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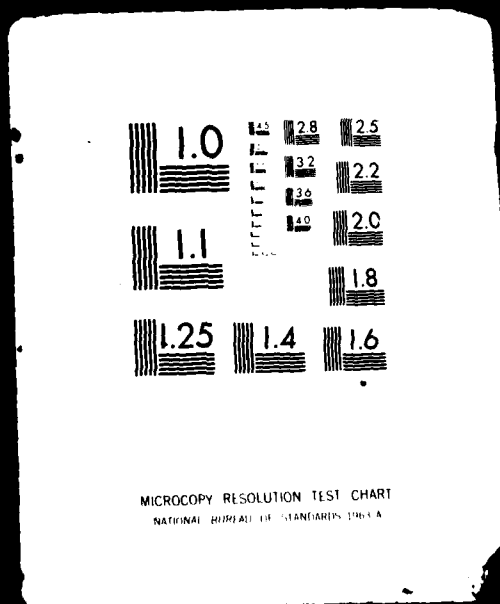
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A FURTHER COMPILATION OF COMPRESSIBLE BOUNDARY LAYER DATA
WITH A SURVEY OF TURBULENCE DATA



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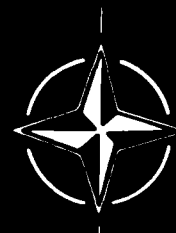
A Further Compilation of Compressible Boundary Layer Data with a Survey of Turbulence Data

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
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AGARDograph No.263

A FURTHER COMPILATION OF COMPRESSIBLE BOUNDARY LAYER DATA
WITH A SURVEY OF TURBULENCE DATA

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The Microfiche in the pocket part of this report may be obtained from: Advisory Group for Aerospace Research and Development, 7 Rue Ancelle 92200 Neuilly Sur Seine, France

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1. PREFACE - THE AGARD-EUROVISC CATALOGUE

With the publication of this volume, the third in a series, the EUROVISC working group on compressible turbulent boundary layer data has come to the end of its programme of data collection and presentation. Throughout our aim has been to describe experiments and present data to a common standard, and to separate, so far as possible, opinion from information received by us as, in essence, factual. The data presented are of course subject to error, whether of a gross nature perhaps best described as mistakes, or, inevitably, as a result of inaccuracies both systematic and random which can not be avoided in an experimental field as taxing as this. We have been able, on occasion, to detect mistakes in published sources, and by checks on internal consistency and correspondence with the authors incorporate appropriate corrections. We hope we have not made serious mistakes ourselves. We have not made any attempt to assess the level of experimental accuracy, presenting the data available to us if we found it functionally complete and if we could make sense of it. There is a large measure of uncertainty in all high Mach number data while in most cases turbulence data are perhaps best regarded as possibly indicating trends rather than establishing values.

The three volumes, AGARDograph 223, 253 and 263 provide the data from 77 experimental studies and a commentary on the results. The experiments are described in ENTRIES of which 59 will be found in the first volume, AG 223. These are referred to in all three volumes by a reference number such as CAT 7201, while a further 18 studies described in this volume, AG 263, are distinguished by a final S, as for example CAT 7501 S. CAT I, AG 223, also contains introductory material designed to assist users of the collection which should be consulted by anyone proposing to use CAT III, AG 263. The second volume, CAT II, AG 253, contains a discussion of the mean flow data from CAT I and some, but not all, of the supplementary data collected for and presented in CAT III. In consequence, some discussion of the mean flow data in CAT III will be found in the individual entries describing the experiments. This volume also contains a presentation and discussion of the available turbulence data.

It has not been possible to print all the profile data in "hard copy" form, so the ENTRIES contain only a selection. The full profile listings are however enclosed on microfiche in pockets attached to the back cover, and on the magnetic tapes deposited with AGARD holding instructions listed below.

The very large quantity of data presented in this collection represents an enormous collective effort by the original authors who obtained it. Ours has been the secondary and less taxing task of collecting, ordering and criticising it. For the first editor this has now continued for more than ten years. Our feelings were admirably expressed 200 years ago by Edward Gibbon:

"I will not dissemble the first emotions of joy on the recovery of my freedom.....".

11. ACKNOWLEDGEMENTS

Once more we are unable to express, in any adequate manner, our thanks to Frau C. Mohr. In a very real sense it is she who has had to put together the data collection which is the main purpose of this project. She has uncomplainingly and repeatedly rearranged all the numerical information to suit the editors' wishes, however ill advised, on occasion, our requests might be.

We also thank Frau C. King for preparing the typescript, Frau H. Berger for typing the tables and references, and Frau I. Gereke for making all our drawings.

We must again thank the DFG and TUB for funding the research work, and the Hermann-Föttinger-Institut for continued hospitality to the second author. The publication is once more funded by AGARD and we thank R.H. Rollins, executive of the Fluid Dynamics Panel, for his help and encouragement.

We are specially indebted to Dr. V. Mikulla who has at our request prepared chapter 2 of this volume. We have benefitted from the help and advice of Professor K. Gersten (Ruhr Universität Bochum) as AGARD editor. Among the many colleagues who have assisted by general discussion and detailed comments on various parts of the text, we would single out L.C. Squire (Cambridge and Professor P. Bradshaw, Imperial College).

Finally we must thank our wives and families for tolerating frequent absences of mind and body, not only in the past two years covering the preparation of this volume, but also throughout the course of the catalogue project.

iii. GRAPHICAL PRESENTATION OF PROFILE DATA

Selected profile data from the sources below may be found in the figures listed.

(a) Mean flow profiles may be found either in the main text (three number reference) or in the ENTRY (single number).

<u>SOURCE</u>	<u>Temperature</u>	<u>Profiles</u>	
		<u>Velocity</u>	
		<u>"Inner"</u>	<u>"Outer"</u>
5701s Richmond	-	5.1.1,5.1.3,5.1.4	5.1.5
6801 Perry & East	-	5.2.8	5.2.9
7205 Horstman & Owen	-	4.4.1	-
7306s Rose	2 (Entry)	3	4
7405s Peterson	5.2.1	5.2.7	5.2.9
7501s Kussoy & Horstman	5.2.2	5.2.3,5.2.5	5.2.4,5.2.6
7703s Berg	-	1, 3, 4	2
7801s Collins et al.	-	1	2
7802s Kussoy et al.	-	1, 2 and 4.4.1	3
7803s Laderman	-	1	2
7804s Watson	-	1, 3	2
7901s Voisinnet	-	2, 4, 5	3
7902s Chew & Squire	-	1, 3, 5	2, 4
7903s Bartlett et al.	-	1	2
Klebanoff (1955)	-	4.4.1	-
Willmarth et al. (1976)	-	5.1.2, 5.1.3	-

(b) Turbulence profiles are plotted in the main text only, for

5803 Kistler	3.1.1-5,3.4.2-3
7101 Sturek & Danberg	3.4.1-3
7205 Horstman & Owen	3.1.1-5,3.1.6-9,3.4.1,4.4.2-3
7306s Rose	3.1.6-9,3.2.6-7,3.3.3,4.4.2-3,4.5.5,4.6.1,4.6.3,4.7.1
7501s Kussoy & Horstman	3.1.6-9,3.2.8,4.4.2-3
7802s Kussoy et al.	3.1.1-5,3.1.6-9,3.2.1-5,3.3.1-2,4.4.2-3,4.5.1-4,4.6.1-2
8001s Mateer & Viegas	4.5.6
Klebanoff (1955)	4.4.2-3
Rose & Johnson (1975)	4.4.4

iv. CLASSIFIED LIST OF SUPPLEMENTARY ENTRIES

The ENTRIES are listed in numerical order, otherwise following the conventions of § 7 of AGARDograph 223. The pressure gradient classification is given both as an abbreviation and as in AG223 § 7.1.

	M_0	R THETA $\times 10^{-3}$	TW/TR	PG ²	TO	CF ³	NX	TURB ⁴
5701 RICHMOND	<1,5.8	1-9	1.0	ZPG,IB	-	F/V	1(3)	-
5806 MORKOVIN & PHINNEY	1.77	16	1.0	ZPG,IB2	-	(V)	1	CC HWP
6002 DANBERG	5.1	3-4	0.8,0.9	ZPG,IA1	P	V	2	-
7306 ROSE	4	3.4	1.0	SBLI,(IIA4)	P	V	12	CT HWP
7404 VOISINET et al.	4.9	6-26	0.8,1.0	ZPG,IB1	P	-	2	-
7405 PETERSON	14	6-11	0.25	FPG,IIB5	P	V	2	-
7501 KUSSOY & HORSTMAN	7	8.5	0.5	SBLI,(IIA4)	P	F	18,19	CT HWP
7701 MABEY	2.5-4.5	1-8	1.0	ZPG,IA1	P	F	3	-
7702 LADERMAN & DEMETRIADES	3.0	3-4	0.6-1.0	ZPG,IB1	P	(P)	3	CC HWP
7703 BERG	6	14-20	0.9	ZPG,IB1R	P	V(F)	17	CC HWP
7801 COLLINS et al.	0.1-2.2	6,23,40	1.0	ZPG,(IA1),IB2	-	F,P,V	4-8	LDV
7802 KUSSOY et al.	2.3	30	1.0	APG,IIA4	(P)	P,surface	13,14	CT HWP
7803 LADERMAN	3.0	3-5	1.0	APG,IIB2	P	V(P)	10,14	-
7804 WATSON	10-12	3-20	0.4-1.1	ZPG,IA1	P	F	7	-
7901 VOISINET	2.9	3-60	1.0	ZPG,IB1R	P	F	1	-
7902 CHEW & SQUIRE	2.5	24	1.0	RELAXATION	-	P	7	-
7903 BARTLETT et al.	9.3	3-12	0.3	ZPG,IA1	P	P	3	(Electron)
8001 MATEER & VIEGAS	1.45	40-100	1.0	SBLI,(IIA4)	P	surface	7	CT HWP

NOTES: (1) Numerical values are nominal, not precise.

(2) SBLI: Shock boundary layer interaction.

(3) CF: F-Floating element balance, P-Preston tube, V-deduced from profile. "surface"-embedded hot wire gauge.

(4) TURB: Turbulent measurements - see tables 3.1 and 4.3.1 in the main text.

v. DATA ON MAGNETIC TAPE

For the first volume, AG 223, all the mean flow profile data and the "Kopfdaten" (Section B of each entry) were made available on magnetic tape. The format was prepared by Prof. P. Bradshaw (Imperial College) as more suitable for possible FORTRAN users than the printed format in the microfiche and hard copies. The supplementary data described in the ENTRIES of this volume have been prepared in the same tape format, with the addition of all tabular turbulence data available to us. These are added as the final files on the tape, in a different format.

Arrangements have been made with the following organizations in NATO countries to hold master copies of the data tape. These organizations will prepare copies on request; enquiries as to terms should be directed to the organization concerned.

FRANCE

O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92 Chatillon sous Bagneux

GERMANY

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7514 Eggenstein	AVA
Leopoldshafen 2	3400 Göttingen
	Bunsenstr. 10

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Delft

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Orpington, Kent BR5 3 RE

UNITED STATES

COSMIC (Computer Software Management and Information Centre,
University of Georgia)
Suite 112
Barrow Hall
Athens
Georgia 30602

vi. CORRIGENDA

AGARDograph 223

For ENTRY 7305 (Watson et al.) in the tables of sections B and C the wall temperature TW was set at the recovery temperature. The proper nominal operating conditions correspond to the TW value given in section D. Thus $TW = 283 \text{ K}$ and $TW/TR = 1.05$. Other corrections include:

- page vi - Abbreviations: STP - stagnation temperature probe.
- page 13 - § 3.6, para. 2, last line: ρ' not p' .
- page 25 - eqn. 5.13: $\delta_i = -R_z[1 - (1 + 2\delta_n/R_z)^{1/2}]$.
- page 27 - 5.6, para. 2, line 4: "---, so that p_{or} was set equal to -----".
- 5503-A-1: § DATA 55030101 - 0113.
- 7006-A-1, lines 3 & 6: Roughness values in μm .
- 7006-B-2: First profile numbered 70060406 should be 70060405.
- 7105-A-3, Table 1: Table heading; P INF at $X = 2.083 \text{ m}$.
: Last line, $X = 2.083$, $-RZ = 197.5$.
- 7209-A-1, para. 2; line 3: "--- at $X = 25 \text{ mm}$ ---".
- 7303-A-1, footnote: "--- values about 10% lower".
- 7305-A-1, Identification panel: $9 < RE/m \times 10^{-6} < 50$.
- 7401-A-1, para 2: "--- here. The plates were 0.1 m wide ---".
para 4: Reference to Smith et al. should be "1962".
- 7402-B-4, run 1702: $X = 0.623$.
- R-3 References: Fenter (1960) DRL 468 should be Fenter (1959) DRL 437.

AGARDograph 253

- page v - 7404s: Fig 2.5.20 describes inner velocity profile.
- page 13 - eqn (2.2.10): Bar on last term.
- page 39 - Fig 2.5.11, left: Ordinate should be $\bar{T}/T_\delta$.
- page 41 - Last para, line 6: ---- and T^* , ----.
- page 117 - Fig 4.2.18 and 4.2.17 (caption): Delete.
- page 165 - para 1, last word: ---quantities.
- § 6.1, line 1: --- § 6.3, no distinction ---.
- page 171 - After eqn (6.1.16): --- at which $M = 1$.
- page 176 - line 4: --- as for a zero normal pressure ---.
- page 191 - eqn (7.1.2), RH: first term numerator should be $2\gamma(2M^2 - 1)dM$.
- eqn (7.1.3), RH: first & second term denominators should be $M^2[2\gamma M^2 - (\gamma - 1)]$.
- page 196 - eqn (7.2.1): Integral dy .
- page 202 - eqn (7.5.5): fourth last term should be $\delta_z^2/2R_z$.

AGARDograph 263

- page 11 - Fig (2.1), legend: Interchange "single tungsten wire" and "ceramic supported platinum hot wire". "Commercial platinum hot wire" should be "--- hot film".
- page 55 - para 3, line 10: Add "--- equal values of Re_{δ_2} may be seen in Fig (5.1.3)."
- page 63 - Fig (5.2.7), legend: second profile, 0104, should be 0202.

1. INTRODUCTION

In preparing the first volume of this series, AGARDograph 223, we imposed certain restrictions on those flows considered as candidates for an entry. These were that the flow should be nominally two-dimensional, that the Mach number be high enough for the effects of compressibility to be significant, that the Reynolds number be high enough for at least some part of the flow to be recognisably turbulent, that there be no flow through the surface on which the boundary layer was formed, and that there be no discontinuities in the mean flow property profiles. We also required, as a general principle, that the information supplied must include profiles normal to the surface, in addition to data measured on the wall, and that the principal part of the data be presented in tabular form.

This third volume contains 18 further entries and the mean flow data presentation follows the same pattern as for AG 223. We have however included some cases in which shock waves impinge on and interact with a boundary layer, and inevitably many of the profiles in such flows incorporate what should be discontinuities in the flow properties concerned. There is also one case, Morkovin & Phinney (1958) which we include because of its historical interest in relation to the development of turbulence measuring techniques although we had to take the data from a graph.

The principal novel feature of this volume in relation to its forbears, AG 223 and AG 253, is that a great part of the main text preceeding the entries is devoted to a survey of turbulence measurements. We have, inevitably, found it necessary to be slightly less strict in insisting on tabular data in discussing this area, but have, whenever possible, used tables obtained in private correspondence in addition to the sparse published data. These tabulated data have been prepared in a standard form, and samples appear in some cases as part of the entries. Tabular data for all cases considered have been gathered together and provided as part of the microfiche collection which accompanies this volume. The collection includes data for entries in AG 223, indicated by a four number serial such as CAT 7205, as well as those associated with the supplementary entries which appear below and are distinguished by a final S, such as CAT 7501S.

1.1. The entries

There is a full discussion of the planning and layout of an entry in AG 223, so that we only repeat the main points here.

An entry is composed of four sections, A - D:

Section A. This provides a description of the experiment in a standard format, and predominantly in a standard sequence. The description is keyed to a fixed set of topics indicated by numbers in the left hand margin. These may appear in any order, or be repeated if a topic recurs. The topics are

1. Description of test section
2. Flow quality
3. Observations of transition and tripping devices (trips)
4. Upstream history of the test boundary layer
5. Measures taken to test for, or ensure, two-dimensional flow
6. Measurements at the test-surface (wall measurements)
7. Probes used for boundary-layer traverses
8. Relative positions of measurement stations
9. Author's interpolation procedures and assumptions
10. Corrections to the profile data
11. Viscosity law assumed by authors
12. Editors' assumptions and interpolation procedures. Selection of data
13. Profiles presented
14. Wall data presented
- § Data summary
15. Editors' comments.

Topics 1 - 11 provide a description in which, so far as possible, we have restricted ourselves to statements which we could verify either in the published reports or by correspondence with the authors. At various

points, however, we have filled out the verifiable facts by an estimate or interpretation. Where this has happened we have inserted a marker (E). The end of the description, marked 12 - 14, describes the measures we found necessary in processing the data and is followed by (§ DATA) a brief data summary which states what was in fact measured, in contrast to data which are deduced from the measurements.

Up to this point we have tried to avoid statements of opinion, but in § 15 "Editors' comments" we have introduced much which must be considered our own interpretation and comment. In AG 223 we usually kept § 15 fairly short as the data were to be discussed at length in AG 253. Some of the entries in this volume are also discussed there, when, in the entries below, section and figure number references to AG 253 will be given. Where, however, an entry is not discussed in AG 253 or in connection with the turbulence data in chapters 3 and 4 or one of the special features of mean flow in chapter 5 of the main text of this volume, the treatment in § 15 is more extended, usually including at least a graphical treatment of the mean flow profiles.

Section B, the "Kopfdaten," contains tables of the principal boundary conditions and various derived quantities such as integral thicknesses. The table heading for a typical entry is shown here:

RUN	MD	TW/TR	RED2W	CF	H12	H12K	PW	PD
X	POD	PW/PD	RED2D	CQ	H32	H32K	TW	TD
RZ	TOD	TAUW	D2	PI2	H42	D2K	UD	TR

The list is reproduced in part at the start of this volume. There is one change: TAUW the wall shear stress replaces the simple wave indicator SW, which proved less useful than was hoped. Those quantities marked by a star (*) represent the data used as input. In many cases these data would be entered directly, but the values shown often represent the results of preliminary calculations. In particular the D-state quantities (see AG 253 § 7.1) are often derived indirectly from the profile data. The stars indicate therefore the quantities which are, functionally, the independent variables rather than those which were directly available as numbers for processing. A good example is the wall shear stress TAUW. Data are usually presented in the form of a skin friction coefficient CF. This quantity depends, in addition to the shear stress, on the reference values used in its formation, the D-state density and velocity. Many of the flows considered here have strong normal pressure gradients, so that the possible D-state properties are quite rapidly varying functions of the Y-value chosen to specify the boundary layer edge. We have adopted the practice, therefore, of reducing authors' CF input data to TAUW values for use as programme input, since we are then free to try various different D-states if we think it proper without having to consciously correct the normalisation of CF. For this reason a CF value in our tables may well differ from that given by the original author. In this, and in many other features, our selection of a D-state, however carefully considered, may be ill advised. We hope however that it is self-consistent, so that the essential data may be recovered, and, at need, represented in a form better suited to the user's prejudices.

Section C, mean profile tables, provides a selection from the available profile data. In an attempt to reduce the number of printed pages, the amount of space allotted to this section in this volume is significantly less than in AG 223. Readers will therefore need to have recourse to the full tabulation in the microfilm presentation which accompanies this volume, or the computer tape data base (see § 1.2 below and the address list at the start of this volume).

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	RHO/RHOD*U/UD
---	---	-------	------	--------	------	------	------	---------------

The presentation is as in AG 223 save that for layout reasons the last column of data RHO*U/RHOD*UD has been relabelled R*U/RD*UD. At the foot of each profile is a statement of the input used to construct the profile. As for the "Kopfdaten" tables of section B, quite often the data available to us did not directly fit our scheme of presentation. The input information at the foot of a profile table is again indicative of the functional input rather than the numerical information as such. Not infrequently, a notice follows describing an averaging procedure when several sets of data were supplied for a given value of Y. The boundary layer edge state chosen or accepted by the editors is marked by the letter D. We have made clear in § 7 of AG 253 that this selection is essentially arbitrary. In using the information it is important to recognise that the scaled dimensionless information offered, while in principle more universal, is in fact critically dependent on the choice of scaling quantity used. Thus it is the pressure, velocity, or shear stress rather than the pressure ratio, velocity ratio or shear stress coefficient which represents the data entered to the catalogue. The dimensionless quantities are convenient, but coloured by the scaling process.

Section D supplies a miscellany of supplementary data. Of its very nature this does not fit the standard profile-based scheme. Typically, in AG 223, and this volume, we present such information as wall-shear stress, temperature, or pressure distributions which have not been interpolated to the profile stations. Often far more detail is available, in terms of a streamwise distribution, for these quantities than for profile-derived data. We also present, at times, a selection of turbulence data.

Turbulence data notionally form a part of section D. We have, so far, encountered tabular data for 15 distinct turbulence quantities. The greatest number presented by a single author is 10, Rose (CAT 7306S), followed by Kussoy & Horstman (CAT 7501S) and Kussoy et al. (CAT 7802S) with 6. Other authors give only a single quantity. We have not therefore attempted to adopt a standard layout for turbulence data tables. We have however adopted a standard scaling, choosing as reference quantities appropriate groupings of the local wall data, ρ_w , u_τ and T_w . The values of these may be obtained from the data in the tables of section B, and we felt it more helpful to refer the fluctuation quantities to a fixed, stated, base rather than give quantities such as local intensities $\overline{u'^2}/u^2$ etc. The scaling values ρ_w , u_τ and T_w are given with the turbulence data. In addition, for zero pressure gradient-cases we give our calculated value of the transformed outer law defect thickness Δ^* . For the reasons stated in § 7.1 of AG 253, and discussed further at various points in chapters 3 and 4 below, we consider this to be the only proper outer region scaling length. For any family of flows which have self-similar outer region velocity profiles, the ratio (Δ^*/δ) is fixed, so long as a consistent definition for δ is used, even if it does not lend itself to measurement, since

$$(\Delta^*/\delta) = \int_0^{y>\delta} \frac{u^*(\delta) - \bar{u}^*}{u_\tau} d(y/\delta) .$$

We do not give a value for pressure gradient-cases since the flows are not similar to each other, and since in many cases there are strong normal pressure gradients which make Δ^* dependent on the choice of D-point .

Y	U'	V'	W'	RHO*U'V'	RHO*U'W'	RHO*U'	RHO'V'	RHO'W'	RHO*U'T'	RHO*V'T'
UT	UT	UT	UT	RHOW*UT2	RHOW*UT2	RHOW*UT	RHOW*UT	RHOW*UT	RHOW*UT*TW	RHOW*UT*TW

We then give the profiles. For 'single component' terms these are the root mean square values of the quantity in question. For two component or correlation terms they are the time means. Thus:

$$\begin{array}{llll} U' = \left[\frac{\overline{u'^2}}{u_\tau^2} \right]^{\frac{1}{2}} & T' = \left[\frac{\overline{T'^2}}{T_w^2} \right]^{\frac{1}{2}} & RHO \ U' = \left[\frac{(\overline{\rho u})^2}{\rho_w^2 u_\tau^2} \right]^{\frac{1}{2}} & RHO*U'V' = \left[\frac{\overline{\rho u'v'}}{\rho_w u_\tau^2} \right] \\ UT & TW & RHO*UT & RHO*UT*TW = \left[\frac{(\overline{\rho u})'T_0'}{\rho_w u_\tau TW} \right] \end{array}$$

The total amount of turbulence data is large, (see Tables 3.1 and 4.3.1), but the very large collections are generally either accessibly published, or of less interest than might at first seem apparent. We have therefore only given a small selection in the entries. The full listing is in the microfiche collection and the tape data base.

Order of sections. While an entry will usually consist of sections in the order A-B-C-D, we have mixed sections freely when it was possible to save space by doing so. The page numbers include an indication of the section - e.g., CAT 7204 A2/B1 which is the second page of section A for entry 7204, and also carries some or all of section B.

1.2. The data collection

The entries in this volume describe experiments which provided 420 mean flow profiles. To print these as tables would have required about 300 pages, so that only a very small proportion could actually be provided as part of the entries. The mean flow profiles for the supplementary entries are however listed in full in two forms, a set of microfiche to be found in pockets at the rear of this volume, and on magnetic tape, copies of which may be obtained from the institutions listed at the start of this volume.

Both the microfiche collection and the magnetic tape also contain a listing of all the tabular turbulence data we have processed, including a limited amount associated with the experiments described in AG 223. We have also included certain cases not described in the catalogue (Rose & Johnson, 7502S and Klebanoff, 5504S, subsonic), where we have processed graphical data in the same way as for the entries proper. In some cases we had data which we have not processed. The data collection does not include the turbulence profiles listed in AG 223 with CAT 7403. The authors have since reprocessed the data to obtain a very different answer

(Laderman & Demetriades, 1979). We have also not listed the very large amount of mass flow fluctuation data - $\overline{(\rho u)^2}$ - sent to us by Berg (CAI 7703S) as this quantity alone, in a hypersonic flow, cannot serve as more than a form of flow visualisation allowing a comparison of general turbulence levels.

Other than turbulence information, data listed as part of section D in an entry have not been reproduced in the microfiche or the data tape.

1.3 Background for the survey of turbulence measurements

Our purpose in chapters 3 and 4 of the main text of this volume is to survey the available data - experimental results - from turbulence measurements. We have not at any point in the survey considered the experimental difficulties and likely accuracy or relevance of the data, taking instead the position that these are the data reported, and that the level of uncertainty is that as given by the authors.

Measurements of the turbulence flow field are required partly for their own sake (in environmental studies at low speed, for example) but principally, as an aid to the modelling of turbulent effects for calculation methods. It is difficult to discuss possible measurements apart from the technique used to make them, but certain generalities serve to set the scene.

The aim is to provide sufficient information to 'close' the time-mean boundary layer approximation to the Navier-Stokes equations. This requires a means of predicting the various components of the Reynolds stress tensor, τ_{ij} , and in particular the shear stress ($-\bar{\rho} \overline{u'v'}$), with the normal stresses $\bar{\rho} \overline{u'^2}$, $\bar{\rho} \overline{v'^2}$ usually considered of lesser importance. The difficulty is apparent, as not only it is necessary to make measurements, usually with fragile sensors, in the hostile environment of a supersonic flow, but for the stress component of most interest it is in principle necessary to measure two components at the same time and place. There is therefore much to be gained by developing any means of relating the shear stress to the most simply measured single component, $\overline{u'^2}$. Unfortunately, while this may be done for lack of an alternative in simple models, there is no general simple inter-relationship. The development of turbulence in a flow is a complex process, and no proper description can be made unless a field equation is introduced for the significant terms of the Reynolds stress itself. This in turn requires information about the gradients of the stress terms which implies further knowledge or modelling of triple correlation terms.

It is proper then to look briefly at the possible measurements. There are three techniques of significance, here mentioned in ascending order of current success.

- a) The electron beam fluorescence technique relies on measurements of the mean and fluctuating intensity of light emitted by fluorescent gas molecules in the boundary layer which have been illuminated by a powerful electron beam. In principle the equipment can be calibrated to give values for the mean density $\bar{\rho}$ and r.m.s and spectral distribution of the density fluctuations, ρ' . The principal limitations lie in obtaining a sufficiently powerful beam without losing spatial resolution. There are very considerable problems in bringing the beam to bear on a region of interest unless the whole experiment is designed round the beam equipment. Unless the density is very low the beam spreads substantially even if the original cross section was small so that spatial resolution is lost. Despite great efforts by a number of experiments (Wallace, 1967, 1968, 1969; McDonald, 1975; Bartlett, 1981) no significant data has yet been obtained. For a general description of the technique see Bütetisch and Vennemann (1974).
- b) The laser-doppler velocimeter relies on the frequency shift of light scattered from small particles in the test gas. With modern techniques it is no longer necessary to 'seed' the flow with particles, and with a suitable arrangement of sensors it is possible to make simultaneous measurements of mean and fluctuating velocity components in any direction, given the free light paths required. The shear stress correlation may then be made electronically. Spatial resolution is good, and spectral distributions of the fluctuating terms can be obtained within certain limits of frequency. The technique is probably approaching maturity for low speed flows, and has achieved some success in compressible flow up to about $M = 3$ (see for instance Johnson & Rose, 1975; Rose & Johnson, 1975.) There remain problems of interpretation particularly near the wall, see Schairer (1980) and § 4.3 below, and it is very difficult to get accurate results (Dimotakis et al., 1979) at the high frequencies characteristic

of fluctuation in supersonic flows. A great advantage is that the technique is non-intrusive so that the life of sensors does not have to be considered, and, in comparison with the electron beam, a laser beam is relatively easily introduced into the test section. For a recent review of the technique see Durst et al. (1976).

- c) The hot-wire anemometer has provided the bulk of the available data, and all that considered at any length below. Hot wires, or analogous devices in suitable combinations can in principle provide, with the aid of modal analysis, almost any turbulent quantity desired (see for instance the ten quantities listed by Rose, 1973, CAT 7306S). The interpretation of the measurements and the extent to which the derived turbulence quantities can be said to be measured with any accuracy provide however an extensive field for controversy.

Since hot-wire anemometry has provided nearly all the useful data, and since the editors are only too conscious of their lack of expertise in this field, we have asked Dr. V. Mikulla (MBB, formerly NASA Ames) to prepare and account (chapter 2 below) of the technique and the interpretation of the results. His account of the conventional modal analysis technique is relatively brief, indicating only key features since the procedures are relatively well covered in the literature. Much of his chapter describes a technique designed to circumvent the inherent ambiguities of modal analysis, and so offer a greater measure of certainty in the determination of turbulence quantities for the future. The technique is relatively novel, and readers should not assume that it is to be regarded as an established standard one. Data obtained using it will be found in CAT 7205 (new data), 7501S 7802S and 80001S.

The electron beam can only provide one single component fluctuation quantity, $\overline{u'^2}$, and that probably not of very great importance in turbulence modelling. It is probably fair to say that the interest in the results of these investigations is mainly due to a desire by modellers to satisfy themselves that, for many purposes, they can ignore ρ' . The LDV can provide three velocity components and correlations between them. These are the most important data for an understanding of momentum transfer, but do not help directly with heat transfer problems. The hot wire can provide some form of data for all one or two component quantities, including the thermal terms, though in reducing the data it is necessary to assume various forms of linkage between the possible terms, so introducing a fundamental uncertainty.

All three techniques potentially provide spectral distributions. We do not present any of these here, as the data are essentially imprecise and so adequately assessed from graphical presentation in the original papers.

No significant triple correlation measurements have been made at supersonic mean velocities.

2. HOT WIRE ANEMOMETRY IN COMPRESSIBLE TURBULENT BOUNDARY LAYERS

by V. Mikulla

2.1 Basis of hot-wire anemometry in a compressible turbulent boundary layer

The brief summary below outlines the underlying principles of compressible hot-wire anemometry as described by Kovaszny (1950, 1953), Morkovin (1956) and Morkovin & Phinney (1958).

A hot-wire anemometer senses those changes in the kinematic and thermodynamic variables of the surrounding flow which modify the rate of heat transfer between the wire and the fluid. For instance changes in the mass flow rate per unit area flowing past the wire and changes in the temperature of this fluid affect the cooling and therefore the resistance of the wire which can be sensed as a measurable electric signal. Correct interpretation of the signal depends on understanding of the nature of the fluctuations in the fluid and an adequate knowledge of the heat transfer laws and appropriate calibration processes.

The nature of the fluctuations in compressible flow was first investigated by Kovaszny (1950, 1953) who showed that a viscous compressible heat conducting fluid can have three different kinds of small perturbation fields obeying three independent differential equations (the linearized equations for the conservation of momentum, energy and mass). The three independent modes are the vorticity mode τ' , the sound-wave mode Π' with the pressure as its principle variable and the entropy mode σ' . If the different modes are not sufficiently weak then linearisation is no longer possible and the modes are coupled in a non-linear manner.

The hot wire heated by an electric current unfortunately does not respond directly to any one of the fluctuation modes discussed above but to a linear combination of mass-flow fluctuations $m'(t)$ and stagnation temperature fluctuations θ'_T .

The equation for the change of enthalpy $E(\approx cT_w)$ of the wire reads

$$\frac{dE}{dt} = W - H \quad (2.1.1)$$

where W stands for the thermal energy $I_w^2 R_w$ generated per unit time and H for the rate of energy loss to the fluid. Since the present discussion and the suggested new measuring technique concentrate on constant temperature operation, it is this operation which is mainly described. If the wire is correctly compensated for constant temperature operation so that there is an instantaneous response to a change of T_w , then $\frac{dE}{dt} = 0$. Differentiating the equation for W logarithmically yields

$$d \ln W = 2 d \ln I_w + d \ln R_w = d \ln H \quad (2.1.2a)$$

Another form of this equation contains the wire response parameter $K^* = (d \ln R_w) / (d \ln T_w)$; (see e.g., Rose 1973) so that

$$d \ln W = 2 d \ln I_w + K d \ln T_w \quad (2.1.2b)$$

Introducing a nonlinear resistance-temperature relationship

$$R_w = R_r [1 + \{\alpha_r (T_w - T_r)\} + \gamma_r \{\alpha_r (T_w - T_r)^2\}] \quad (2.1.3)$$

and linearizing the ensuing equation Morkovin (1956, appendix) gives

$$K = \frac{1}{1 + \alpha'_w} \{ \alpha_r T_r + \alpha'_w [1 + \gamma_r (\alpha'_w + 2\alpha_r T_r)] \} \quad (2.1.4)$$

where

$$\alpha'_w = \frac{I_w^2 - R_r}{R_r} \quad (\text{the overheating parameter}), \quad (2.1.5)$$

α_r = the temperature resistivity coefficient,

γ_r = the ratio of resistivity coefficients and

index r refers to 'recovery', i.e., the condition of the unheated wire.

* The perturbation in R due to T_w (averaged over the wire length) is described by this parameter.

The energy loss H to the fluid for a hot wire which has a yaw angle ϕ to the direction of the flow can be written as

$$H = Nu_t(M, Re_t, \theta, \phi) \cdot \pi \cdot l \cdot K_t (T_w - T_t), \quad (2.1.6)$$

where M = Mach number,

$$Re_t = \frac{\rho u d}{\mu_t} = \text{Reynolds number},$$

$$\theta = T_w/T_t; \quad \eta = T_r/T_t,$$

l = the length of the wire; d = the diameter of the wire,

K = the thermal conductivity and

the suffix t denotes stagnation conditions.

The small sensitivity to Prandtl number in most gases is absorbed in the dependence on T_r .

Perturbations of W and H are expressed in terms of perturbations in the flow variables to be measured ρ, u, T_t , in the yaw angle ϕ and in the wire temperature which is viewed as a temporary independent variable of the perturbation process (T_w is constant for $dE/dt = 0$).

Now "the forbidding algebraic manipulations are made tractable by the use of logarithmic derivatives" (Morkovin 1956) and the logarithmic differential of H is developed as:

$$\begin{aligned} d \ln H = & \left[n_t - m_t \frac{\partial \ln Nu_t}{\partial \ln Re_t} - \left\{ \frac{\partial \ln Nu_t}{\partial \ln \theta} + \frac{\theta}{\theta - \eta} \right\} + 1 - \frac{1}{\tau_{wr}} \left\{ \frac{1}{2\alpha} \frac{\partial \ln \eta}{\partial \ln M} - m_t \frac{\partial \ln \eta}{\partial \ln Re_t} \right\} - \frac{1}{2\alpha} \frac{\partial \ln Nu_t}{\partial \ln M} \right] d \ln T_t \\ & + \left[\frac{\partial \ln Nu_t}{\partial \ln Re_t} + \frac{1}{\alpha} \frac{\partial \ln Nu_t}{\partial \ln M} - \frac{1}{\tau_{wr}} \left\{ \frac{1}{\alpha} \frac{\partial \ln \eta}{\partial \ln M} + \frac{\partial \ln \eta}{\partial \ln Re_t} \right\} \right] d \ln \eta + \left[\frac{\partial \ln Nu_t}{\partial \ln Re_t} - \frac{1}{\tau_{wr}} \frac{\partial \ln \eta}{\partial \ln Re_t} \right] d \ln \rho \\ & + \left[\frac{\partial \ln Nu_t}{\partial \ln \theta} + \frac{\theta}{\theta - \eta} \right] d \ln T_w + \left[\frac{1}{\tau_{wr}} \frac{\partial \ln \eta}{\partial \phi} - \frac{\partial \ln Nu_t}{\partial \phi} \right] d \phi, \end{aligned} \quad (2.1.7)$$

where $m_t = \partial \ln \nu_t / \partial \ln T_t$; $n_t = \partial \ln K_t / \partial \ln T_t$,

$$\tau_{wr} = \frac{T_w - T_r}{T_r}; \quad \alpha = \left(1 + \frac{\gamma - 1}{2} M^2 \right)^{-1} \quad \text{and}$$

$$d\phi = \frac{v'}{u}$$

The term in square brackets multiplied by $d \ln T_t$ is sometimes given in a slightly different form (Morkovin, 1956).

$$\left[n_t - m_t \frac{\partial \ln Nu_t}{\partial \ln Re_t} - \frac{\partial \ln Nu_t}{\partial \ln \theta} - \frac{1}{\tau_{wr}} \left\{ 1 - \frac{1}{2\alpha} \frac{\partial \ln \eta}{\partial \ln M} - m_t \frac{\partial \ln \eta}{\partial \ln Re_t} \right\} - \frac{1}{2\alpha} \frac{\partial \ln Nu_t}{\partial \ln M} \right] d \ln T_t. \quad (2.1.8)$$

The plus sign in the last term of eqn.(2.1.7) is associated with a v' that increases the heat loss from the wire.

The response of the system - combining eqn.(2.1.3) and (2.1.7) - to variations in ρ, u, T_t and ϕ then consists of the coupled variations in I and R_w which are usually detected as fluctuations in voltage across the wire

$$E_w = I_w \cdot R_w \quad (2.1.9)$$

or

$$d \ln E_w = d \ln I_w + d \ln R_w = d \ln I_w + K d \ln T_w \quad (2.1.10)$$

Rose (1973) has shown that $d \ln E_w = d \ln E$ where E is the bridge voltage. This relationship holds since $E = E_w [(R_w + R_s)/R_w]$ and $d \ln R_w$ is assumed to be zero (R_s is the resistance in series with the anemometer bridge circuit including the probe cable).

Combining eqn.(2.1.2), (2.1.10) and (2.1.7) yields $d \ln H = d \ln W = 2 d \ln E - d \ln R_w$ and with $d \ln R_w = 0$

$$\frac{dE}{E} = \frac{E'}{E} = \left[\frac{1}{200} \left(100 \frac{T_t'}{T_t} \right) + \left[\frac{1}{200} \left(100 \frac{u'}{u} \right) + \left[\frac{1}{200} \left(100 \frac{\rho'}{\rho} \right) + \left[\frac{1}{200} \left(100 \frac{v'}{v} \right) \right] \right] \right] \quad (2.1.11)$$

where the contents of the square brackets are the same as for eqn(2.1.7).

Introducing the fluctuation sensitivities S for the respective variables leads to the equation which relates the fluctuation of the bridge voltage to the fluctuations of the flow variables

$$E' = S_{T_t} T_t' + S_u u' + S_\rho \rho' + S_v v' \quad (2.1.12)$$

where ()' denotes fluctuations as percentages of the mean values.

The fluctuation sensitivities S apply to the entire compressible flow regime from subsonic to supersonic flow for arbitrary Reynolds numbers and for yawed and normal ($S_v=0$) hot wires. The relationships for the fluctuation sensitivities are presented here in the form given by Rose (1973):

$$S_{T_t} = \frac{1}{2} \left[n_t + 1 - m_t \frac{\partial \ln Nu_t}{\partial \ln Re_t} - \left(\frac{\partial \ln Nu_t}{\partial \ln \theta} + \frac{\theta}{\theta - \eta} \right) + \frac{1}{\tau_{wr}} \left(\frac{1}{2\alpha} \frac{\partial \ln \eta}{\partial \ln M} + m_t \frac{\partial \ln \eta}{\partial \ln Re_t} \right) - \frac{1}{2\alpha} \frac{\partial \ln Nu_t}{\partial \ln M} \right] \quad (2.1.13)$$

$$S_u = \frac{1}{2} \left[\frac{\partial \ln Nu_t}{\partial \ln Re_t} + \frac{1}{\alpha} \frac{\partial \ln Nu_t}{\partial \ln M} - \frac{1}{\tau_{wr}} \left(\frac{1}{\alpha} \frac{\partial \ln \eta}{\partial \ln M} + \frac{\partial \ln \eta}{\partial \ln Re_t} \right) \right] \quad (2.1.14)$$

$$S_\rho = \frac{1}{2} \left[\frac{\partial \ln Nu_t}{\partial \ln Re_t} - \frac{1}{\tau_{wr}} \frac{\partial \ln \eta}{\partial \ln Re_t} \right] \quad (2.1.15)$$

$$S_v = \frac{1}{2} \left[\frac{1}{\tau_{wr}} \frac{\partial \ln \eta}{\partial \phi} - \frac{\partial \ln Nu_t}{\partial \phi} \right] \quad (2.1.16)$$

The basic practical technique for extracting quantitative information from the fluctuating signal of a hot wire in compressible flow was the original Kovaszny observation that the values of the sensitivity coefficients vary with operating conditions, especially with the temperature of the wire. When the wire is barely heated it responds mainly to stagnation temperature fluctuations whereas at high overheats the values of the sensitivity coefficients S_u , S_ρ and S_v dominate those of S_{T_t} .

In the general form above, the expressions for the sensitivities are complicated and calibration techniques designed to determine them accurately would be very difficult. Even if the three sensitivities S_{T_t} , S_u and S_ρ for a normal wire for instance could be determined, it would still not be possible to determine the fluctuating quantities T_t' , u' and ρ' using the squared RMS signal of a properly compensated anemometer at six different overheat ratios mainly because the variation of S_u and S_ρ with wire temperature is small and the resulting matrix of the six linear equations is nearly singular. A solution to this problem for supersonic flow has been given by Morkovin (1956) who showed that for $M > 1.2$ for a normal wire and $M \sin \phi > 1.2$ for a yawed wire the terms $\partial \ln Nu_t / \partial \ln M$ and $\partial \ln \eta / \partial \ln M$ are negligibly small at all wire operating temperatures yielding for the sensitivities:

$$S_u = S_\rho = S_{\rho u} = \frac{1}{2} \left[\frac{\partial \ln Nu_t}{\partial \ln Re_t} - \frac{1}{\tau_{wr}} \cdot \frac{\partial \ln \eta}{\partial \ln Re_t} \right] \quad (2.1.17)$$

$$S_{T_t} = \frac{1}{2} \left[n_t + 1 - m_t \frac{\partial \ln Nu_t}{\partial \ln Re_t} - \left(\frac{\partial \ln Nu_t}{\partial \ln \theta} + \frac{\theta}{\theta - \eta} \right) + \frac{m_t}{\tau_{wr}} \cdot \frac{\partial \ln \eta}{\partial \ln Re_t} \right] \quad (2.1.18)$$

$$S_r = \frac{1}{2} \left[\frac{1}{\tau_{wr}} \cdot \frac{\partial \ln \eta}{\partial \phi} - \frac{\partial \ln Nu_t}{\partial \phi} \right] \quad (2.1.19)$$

Under these conditions eqn.(2.1.12) reduces to

$$E^{*'} = S_{T_t} T_t^{*'} + S_{\rho_u} (\rho_u)^{*'} + S_v v^{*'} \quad (2.1.20)$$

For a normal wire when $S_v = 0$, this equation links the fluctuating output voltage with small fluctuations in total temperature and mass flow in the direction of the mean motion.

For a determination of $T_t^{*'}$ and $(\rho_u)^{*'}$ the Kovaszny (1953) technique is usually applied. This uses measurements of the mean square of $E^{*'}$

$$\frac{\overline{E^{*'^2}}}{(S_{T_t})^2} = F^2 \overline{(\rho_u)^{*'^2}} + \overline{T_t^{*'^2}} - 2F \overline{(\rho_u)^{*'}} \overline{T_t^{*'}} = S \quad (2.1.21)$$

where $F = -S_{\rho_u}/S_{T_t}$ is a function of the overheat ratio .

Taking three readings at three overheat ratios one obtains three different sets of corresponding values of $\overline{E^{*'^2}}$, S_{T_t} and S_{ρ_u} and can solve three linear equations for the three unknown quantities $\overline{T_t^{*'^2}}$, $\overline{(\rho_u)^{*'^2}}$ and $\overline{T_t^{*'}} \overline{(\rho_u)^{*'}}$. The sensitivities S_{T_t} , S_{ρ_u} and S_v are usually determined by direct calibration of the wire using for instance the definition given by Rose (1973)

$$S_{T_t} = \left(\frac{\partial \ln E}{\partial \ln T_t} \right)_{\rho_u, \phi} ; S_{\rho_u} = \left(\frac{\partial \ln E}{\partial \ln \rho_u} \right)_{T_t, \phi} ; S_v = \left(\frac{\partial \ln E}{\partial \phi} \right)_{\rho_u, T_t} \quad (2.1.22)$$

Despite the fact that this now classic mode-diagram method was developed over twenty years ago, it is surprising to find that the amount of actual fluctuating data in high speed flow based on this method is rather scarce. There are several reasons for this, one of the most important ones probably being the fact that the variation of the overheat is a lengthy and difficult procedure requiring long wire life times and long tunnel running times (continuous tunnels). Nevertheless there have been extensive investigations based on the classic approach, for example those of Demetriades (1972) and Laderman (1979).

2.2. Sensors with very high overheat ratios

Since the following description is based on experience with CTA-operation the classic modal analysis is not pursued any further here. This alternate approach is suggested as it promises a more direct, faster and more accurate method of obtaining quantitative fluctuating data in compressible flows. It makes use of the advantages of hot films at high speeds and the slowly emerging significance of extreme sensor operating temperature in the easier interpretation of the sensor fluctuating signal. The time constants of hot films are not well defined and no compensating amplifiers for constant current anemometers exist that will properly restore the response of a hot film. Therefore a decision to use hot films or hot wires mounted on ceramic substrates automatically limits the experimenter to the use of constant temperature anemometry if quantitative information about fluctuating flow variables is to be obtained.

In this connection some remarks about CTA and CCA seem appropriate. It is neither useful nor possible to judge one technique as being useless and the other excellent in the high speed laboratory. The fact is that the CCA was available to the pioneers (Kovaszny, Morkovin etc.) at the time they did their work, whereas the CTA is much more common in the fluid dynamics laboratory nowadays. Which of the two instruments to use should be a question of what you want to measure with which sensor in the fastest time with the least effort (i.e., without studying the anemometer and its response for months).

If quantitative measurements of stagnation temperature fluctuations are intended, then the CCA with compensating amplifiers and single cold wires should be used.

If mass flux fluctuations are to be measured it is quicker and easier to use CTA with either wires or films at temperature loadings near the maximum possible values. The same is true for transverse velocity fluctuations and Reynolds shear stress measurements.

While Owen et al. (1975) have shown some of the problems of the standard CTA at low overheat ratios, there have also been papers that show that the CTA can have sufficient frequency response at low wire temperatures under certain conditions and with special bridge circuits (Bonnet et al. 1980).

2.2.1 Supported high temperature sensors

The approach to high speed anemometers suggested here avoids any controversy as to possible CTA frequency response problems by using the sensors at very high overheat ratios only. It is the author's opinion that this technique so simplifies the analysis of fluctuation measurements that high temperature hot-film anemometry will become a routine measurement procedure in the future. We first discuss the significance of high values of the temperature loading

$$(T_w - T_r)/T_r (= \tau_{wr}) .$$

The objective is to virtually eliminate the response of the hot film or supported hot wire to stagnation temperature fluctuations, thus avoiding any modal analysis techniques. Although this means that no information is obtained about the stagnation temperature fluctuations, it should be kept in mind that the fluctuating stagnation temperature - being a combination of u' and T' - is generally of secondary importance for turbulence research and modelling.*)

Horstman & Rose (1975) have shown for transonic flow that the ratio of stagnation temperature fluctuation sensitivity to mass-flow fluctuation sensitivity $S_{T_t}/S_{\rho u}$ approaches zero if τ_{wr} approaches the value of 1.5. Since this result is essentially independent of sensor material, sensor Reynolds number, Mach number and length to diameter ratio, it means that if a sensor can be operated at a high temperature such that $\tau_{wr} \geq 1.5$, then it will only respond to mass-flow fluctuations over the entire compressible flow region from transonic to hypersonic regardless of the magnitude of the stagnation temperature fluctuations. This observation opens new possibilities for high speed turbulence measurements with thermal sensors. While it is a consequence of the original Kovasznay observation of the variation of the sensitivities $S_{\rho u}$ and S_{T_t} with wire temperature, its potential can only now be fully exploited with the development of sputtered nickel films on quartz or pyrex and new platinum wire ceramic wedges that retain their full strength at maximum possible temperature loading.

Figure (2.1) shows the importance of the requirement $\tau_{wr} \geq 1.5$ in relation to the operating temperature of various existing hot-wire and hot-film probes. The sensitivity ratio is plotted against the sensor operating temperature for four different recovery temperatures T_r . Notice that even for non-heated flows (T_r near room temperature) with the usual operating temperature range of tungsten wires ($300K < T_w < 600K$) it is not possible to achieve a condition in which $S_{T_t}/S_{\rho u} \approx 0$. For these sensors it is therefore always necessary to use modal analysis techniques to separate T_t' and $(\rho u)'$. There are also commercial film probes that cannot be operated much higher than $T_w \approx 600K$. With these films it would also be necessary to use mode diagrams to separate the fluctuations with the additional difficulty of carefully analysing the frequency response of the CTA-operated hot films at a range of different overheat ratios.

As a typical example of the importance of the wire operating temperature we take the hot wire turbulence data obtained in a shock wave boundary layer interaction by Ardonceau et al. (1979). In this study the hot wire was only heated up to a maximum value of $\tau_{wr} \approx 0.7$; $a_w = (R_w - RT_t)/RT_t \approx 0.8$, $T_w \approx 500K$ so that it was still sensitive to both T_t' and $(\rho u)'$. The required operating temperature for virtual removal of the stagnation temperature sensitivity in this particular flow would have to be about 750K. The significance of being able to increase the sensor temperature from $T_w \approx 600K$ to $T_w \approx 750K$ in a compressible flow at recovery temperatures around 300K is seen in Fig. (2.1). The ratio of sensitivities $S_{T_t}/S_{\rho u}$ decreases from 1.0 to approximately 0.2. Commercial film probes are available that can be operated at maximum temperatures around 750K and those sensors would be perfectly adequate for non-heated high speed flows being effectively sensitive to mass-flow fluctuations only. For higher recovery temperatures ($T_r \geq 400K$) there are no commercial film probes available

*) The correlation $T_t'v'$ has been mostly needed in the past to deduce the important Reynolds shear stress $\rho u'v'$ from hot-wire measurements (equation 2.3.4). It will be shown below how an alternate assumption can replace the measurement of $T_t'v'$ in deducing $\rho u'v'$ so that there is no major disadvantage in removing the response of the probe-anemometer system to T_t' .

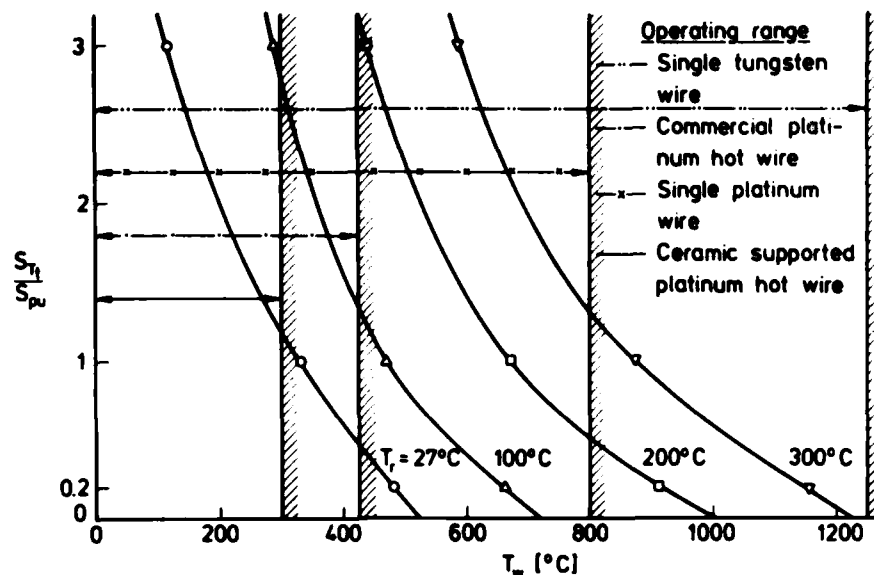


Fig. 2.1 Ratio of total temperature sensitivity to mass-flux sensitivity vs. operating sensor temperature for various recovery temperatures.

that could eliminate the response to stagnation temperature fluctuations. Only platinum and platinum-alloy wires can be operated at high enough temperatures. Figure (2.2) shows the more general diagram of the ratio of the two sensitivities S_{T_t} and S_{ρ_u} plotted against the temperature loading factor τ_{wr} .

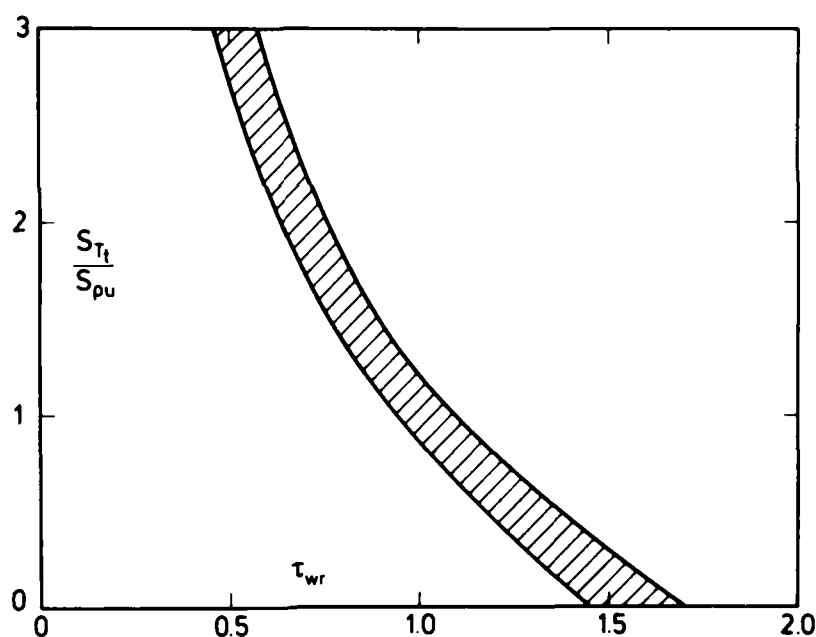


Fig. 2.2 Ratio of total temperature sensitivity to mass-flux sensitivity vs. temperature loading factor τ_{wr} .

The general problem with single wires at their maximum possible operating temperature in high speed flows is that their strength is also reduced considerably and this is particularly true for single platinum wires. One solution to this problem lies in a probe design with a platinum wire mounted on the tip edge of a high temperature very thin ceramic wedge (Mikulla & Horstman 1975). It turned out that the wires could be operated safely on such a wedge-shaped body at wire temperatures well over 1250K making them virtually solely mass flux sensitive in the whole recovery temperature range considered from $T_r = 300K$ to $T_r = 600K$ (Figure 2.1). This important characteristic was in fact the main reason for their success when used in the hypersonic boundary layer with recovery temperatures well in excess of 500K (Mikulla and Horstman 1975). The ability of wedge-shaped sensors to retain their geometry and strength while the sensing film or wire is operated just

below the oxidizing temperature has important advantages for the accuracy and interpretation of high speed turbulence measurements. In addition to eliminating the response to total temperature fluctuations the high operating temperature provides in general - just as in incompressible flow - optimum frequency response with fewer contamination problems for the probe/CTA system. It is easy to see why a ceramic hot wire wedge probe operating at $T_w = 1500K$ is less affected by dust, oil or grease particles in the flow than a tungsten wire operating at $T_w = 600K$. In the former case most of the oncoming particles are burnt away.

Figure (2.3) shows another advantage of wedge-shaped sensors compared to single hot wires. At the maximum operating temperatures considered, slanted wires and films needed for the measurement of transverse velocity

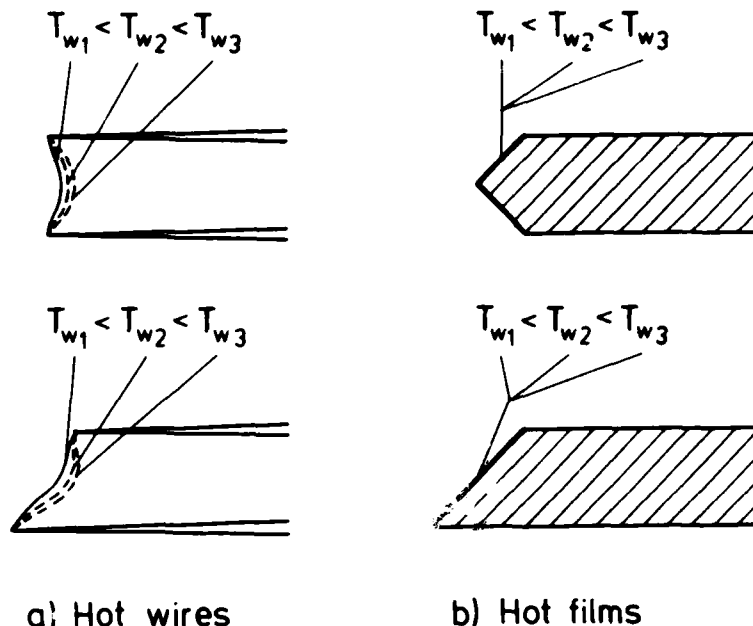


Fig. 2.3 Comparison of the geometry of single hot wires and wedge type sensors at high operating temperatures and dynamic loading.

fluctuations and Reynolds shear stresses have not only maximum sensitivity to mass flow fluctuations $(\rho u)'$ but also to the transverse velocity fluctuations v' or w' . While for the inclined single or dual films ($\phi = 45^\circ$) this increased sensitivity at high overheats is approximately the same for mass flux fluctuations and transverse velocity fluctuations, the increase of S_v or S_w with increasing wire operating temperature for the single slanted wire is significantly less than the increase of $S_{\rho u}$, firstly because of the natural slack given to most wires in high speed flow to avoid strain gauging and secondly because of the additional slack caused by elongation of the wire near the maximum operating temperatures (Figure 2.3). This elongation is particularly pronounced for platinum and platinum alloy wires. As a consequence, the single slanted wire or X-probe in compressible flow has the disadvantage that time consuming individual yaw calibration is absolutely necessary and that even with this calibration the accuracy of v' and w' measurements and consequently also of $(\rho u)'v'$ will be less than the accuracy of $(\rho u)'$ measurements.

For the slanted single and dual hot films and supported hot wires at very high temperature loading τ_{wp} and yaw angles at 45° it can be assumed that $S_v = S_w = S_{\rho u}$ thus making separate yaw calibrations unnecessary. In addition, because of the factors discussed above, the achievable accuracy of v' , w' and $(\rho u)'v'$ is of the same order as that for $(\rho u)'$ -measurements.

While it is difficult to assess the upper limits of the expected errors with the new sensors accurately, a comparison with the error estimates of the single tungsten wire measurements of Rose (1973) would not show an increasing error in the transverse fluctuations and cross correlation compared to $(\rho u)'$

Rose (1973)		Mikulla and Horstman (1975)	
$(\rho u)'$	$\pm 8\%$	$(\rho u)'$	$\pm 8\%$
$(\rho u)'v'$	$\pm 15\%$	$(\rho u)'v'$	$\pm 8\%$
v'	$\pm 25\%$	v'	$\pm 8\%$
w'	$\pm 25\%$	w'	$\pm 8\%$

2.2.2 Calibration of highly heated sensors

The main problem with these very highly heated hot-film probes and supported hot-wire probes is the accurate determination of the sensitivity $S_{\rho u} = \frac{\partial \ln E}{\partial \ln \rho u}$ over the entire Reynolds number range encountered in the actual turbulence measurements. There have been doubts about the validity of quantitative turbulence measurements with wedge-shaped hot films in gases because of thermal feedback problems which cause the probe sensitivities to be functions of frequency (Bellhouse and Schultz 1967). This is a particularly serious problem for multiple wires or films mounted on the same substrate. It is part of the general problem area of dynamic calibration of thermal sensors which has received considerable attention among hot-wire researchers in recent years.

In order to avoid uncertainties introduced by the static calibration technique of these wedge-shaped sensors, it is suggested that a different method be used to determine $S_{\rho u}$. The wedge-shaped single or dual wire sensor is calibrated against the $(\rho u)'$ -measurement obtained with a single normal wire which might well be operated in the modal analysis method. The advantage of this method is that it is exactly the $(\rho u)'$ -measurement which is probably the most accurately measurable of all the turbulence quantities using a hot wire in high speed flow (wire slackness and elongation at high overheat are in this case the least critical). Figure (2.4) shows a typical calibration curve for a dual hot wire ceramic wedge probe. The mass flux sensitivity of this probe $S_{\rho u}$ is obtained by dividing half of the RMS-value of the instantaneous sum of the fluctuating voltages

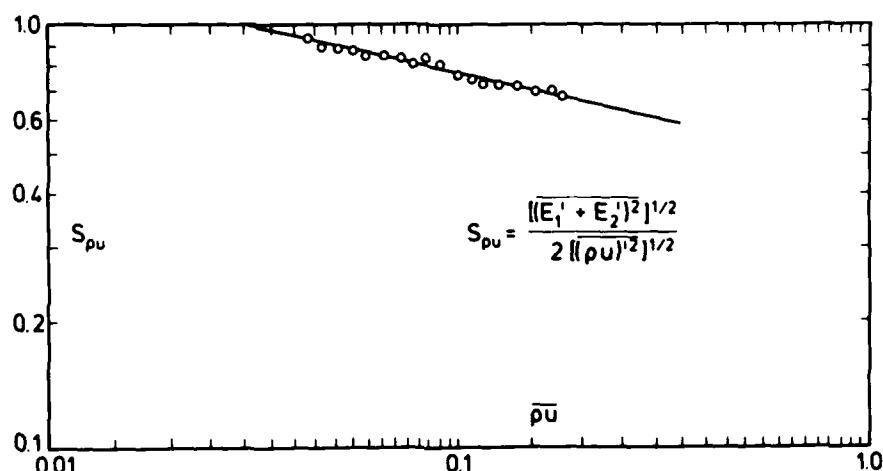


Fig. 2.4 Typical calibration curve of dual platinum wire ceramic wedge probe.

of the two supported platinum wires by the RMS-value of the measured mass-flow fluctuations obtained with the single wire. For this case:

$$S_{\rho u} = \frac{[(E_1' + E_2')^2]^{1/2}}{2[(\rho u)']^{1/2}} \quad (2.2.1a)$$

and for a single film or hot wire wedge probe correspondingly

$$S_{\rho u} = \frac{[E']^{1/2}}{[(\rho u)']^{1/2}} \quad (2.2.1b)$$

Equation (2.2.1a) in fact assumes identical or matched wires with equal sensitivities. While this is hardly ever achievable in practice it seemed a reasonable approximation in the case of the very highly heated platinum alloy wires of the ceramic dual wedge probe. Having obtained the sensitivity of a dual wedge probe in this way, it is then a straightforward matter to measure $\frac{(\rho u)'}{\rho u}$, $\frac{v'}{u}$, $\frac{(\rho u)'v'}{\rho u u}$ and by rotating the probe 90° around its axis also $\frac{w'}{u}$ and $\frac{(\rho u)'w'}{\rho u u}$.

As stated above there are already commercial hot-film probes available that can be operated near $T_w = 700K$ and for most non-heated compressible flows this sensor temperature can assure that τ_{wr} is near 1.5 thus virtually eliminating the response of the probe to T_t' . A check on the response of the sensor to $(\rho u)'$ alone can always be made by operating the sensor at two different overheat ratios near the maximum value and evaluating the mass-flux fluctuations deduced at each overheat. If the two values agree, then the assumption that

$$\frac{S_{T_t}}{S_{\rho u}} = 0 \quad \text{is correct.}$$

In practice it appears that for most compressible adiabatic flows at lower Mach numbers (subsonic to transonic) the stagnation temperature fluctuations are much smaller than the mass-flux fluctuations. In this case it may be sufficient to operate the sensors at temperatures such that τ_{wr} is about 1.0 ensuring that $S_{\rho u} (\rho u)^{1/2} \gg S_{T_t} (T_t)^{1/2}$. For the platinum or platinum alloy hot-wire ceramic wedge probe the condition $\frac{S_{T_t}}{S_{\rho u}} = 0$ can be virtually ensured in most high speed wind tunnels due to their potential for very high operating temperatures ($T_w = 1250\text{K}$ to $T_w = 1500\text{K}$). The thermal sensor industry should respond to the challenge of making high temperature probes based on the combination of platinum or platinum alloy wires (diameter 5μ to 10μ) and high temperature ceramic backing material as off-the-shelf items.

2.2.3 Advantages and disadvantages of highly heated sensors

The advantages of such sensors compared to standard hot-wire probes for measurements in compressible flow are quite clear:

- No mode diagram is required and therefore no variation of overheat ratios is necessary.
- CTA-operation is implied with all the corresponding advantages of availability and ease of operation.
- No yaw calibration for 45° -slanted sensors is necessary if the probe axis is aligned parallel to the flow.
- The determination of fluctuating quantities is not dependent on squared RMS readings. (This generally results in a loss of information and of accuracy in the turbulent quantities.)
- Accurate direct determination of v' and w' fluctuations at high Mach numbers may be obtained without any assumptions concerning the physics of turbulence.
- Short running times (characteristic of most high speed wind tunnels) are sufficient to measure $(\rho u)'$, v' , $(\rho u)'v'$ with previously calibrated sensors.

The main disadvantage of these sensors is the general disadvantage of all wedge-shaped hot-film sensors in boundary layers near the wall. They are more affected by large mean-flux gradients and turbulence properties than single wires or fibre-film probes. In particular the dual wedge probe is not a good sensor for the wall region since the two sensors are exposed to quite different gradients. Although miniaturization of the probes would reduce this problem these sensors cannot provide accurate measurements in the very important wall region of high speed turbulent boundary layers. They have, however, one further important advantage which concerns their use in transonic flow.

2.3. Special features in measurement

2.3.1 Transonic flow

Although transonic flow is currently of major interest in aerodynamic research the use of the hot wire in this field has been hampered by the calibration difficulties described by Morkovin (1956). In a recent review and evaluation of transonic hot-wire anemometry Horstman and Rose (1977) have shown, however, that the use of thermal sensors can lead to meaningful fluctuating data in transonic turbulent boundary layers if certain conditions are met. Morkovin (1956) had observed that the terms $\partial \ln Nu_t / \partial \ln M$ and $\partial \ln \eta / \partial \ln M$ in the expressions for the sensitivities S_{T_t} and S_u (eqn. 2.1.13 and 2.1.14) were not negligible in the transonic flow regime at all wire overheats for a wide range of Reynolds numbers. Thus $S_\rho \neq S_u$ and since neither varies much with wire operating temperature it was not possible to use modal analysis techniques to determine the fluctuations. The significant result of the investigation of Horstman and Rose was that if the sensor operating temperature and the sensor Reynolds number were high enough, then $S_\rho = S_u$ just as in supersonic and hypersonic flow.

The conditions which ensure this can be summarized as follows:

$$\left. \begin{array}{l} \text{If } Re_t > 20 \\ \tau_{wr} > 0.5 \end{array} \right\} \quad \text{for } 0.4 < M < 1.2$$

then

$$S_p = S_u = S_{\rho u} = \frac{1}{2} \left[\frac{\partial \ln H u_t}{\partial \ln Re_t} - \frac{1}{\tau_{wr}} \frac{\partial \ln n}{\partial \ln Re_t} \right] \quad (2.3.1)$$

The first condition, $Re_t > 20$, is usually fulfilled in most transonic flows. The second condition, $\tau_{wr} > 0.5$, is automatically satisfied if the hot wire or hot film is operated at temperature loadings near $\tau_{wr} = 1.5$ or higher, as suggested for $M > 1.2$ above. This technique therefore makes possible an extension of turbulence measurements to transonic flow. For most transonic flows in unheated wind tunnels commercial hot-film wedge sensors with maximum operating temperatures up to 700K will give a high enough value of τ_{wr} . If ceramic supported platinum wires are used, however, it becomes possible to cover the entire Mach number range with a single probe. A dual wire probe which has had its sensitivity $S_{\rho u}$ measured over a sufficiently wide Reynolds number range may therefore be used straightforwardly to measure $(\rho u)'$, v' , w' and $(\rho u)'v'$ for any Mach number. The only restriction is that Re_t must be greater than 20.

2.3.2 Shear stress measurements

The Reynolds shear stress $\bar{\rho} \overline{u'v'}$ can be obtained from the directly measured quantities $(\rho u)'$, v' , w' and $(\rho u)'v'$ with assumptions relating to the fluctuating pressure field. Before discussing this, however, it should again be emphasized that the measurement of v' and w' is a direct measurement without requiring any assumptions concerning the magnitude of the pressure fluctuations and therefore not dependent on the Mach number. These transverse velocity fluctuations, because of the inherent properties of the measurement technique, have an accuracy which cannot be achieved for those quantities measured with single hot wires at high speeds.

If the traditional hot-wire mode diagram method is used and $(\rho u)'$, v' , T_t' and their correlations $(\rho u)'v'$, $T_t'v'$ and $(\rho u)'T_t'$ are measured with X-type wire probes or single slanted wires, then in principle all the important turbulence quantities such as u' , v' and $\bar{\rho} \overline{u'v'}$ can be deduced if the assumption is made that p' is negligible. This assumption has been used and discussed extensively in the literature (see, e.g., Horstman and Rose 1977). It does seem a reasonable assumption for non-hypersonic flows. The necessary relations are given below: From the definition of stagnation temperature

$$c_p T_t = \frac{u^2}{2} + \frac{\gamma}{\gamma-1} \frac{p}{\rho}$$

it can be shown either by logarithmic differentiation or by Reynolds time averaging and neglecting all higher order terms that

$$\left(1 + \frac{\gamma-1}{2} M^2\right) \frac{T_t'}{T_t} = (\gamma-1) M^2 \frac{u'}{u} + \frac{p'}{p} - \frac{\rho'}{\rho}.$$

With $\frac{p'}{p} = 0$; $\frac{(\rho u)'}{\bar{\rho} u} = \frac{u'}{u} + \frac{\rho'}{\bar{\rho}}$ it follows that (Kistler 1954 and Rose 1973):

$$\frac{\overline{u'^2}}{\bar{u}^2} = (\alpha + \beta)^{-2} \cdot \overline{T_t'^{**2}} + 2\alpha(\alpha + \beta)^{-2} \cdot \overline{(\rho u)^{**} T_t'^{**}} + \alpha^2(\alpha + \beta)^{-2} \cdot \overline{(\rho u)^{**2}} \quad (2.3.2)$$

$$\frac{\overline{\rho'^2}}{\bar{\rho}^2} = (\alpha + \beta)^{-2} \cdot \overline{T_t'^{**2}} - 2\beta(\alpha + \beta)^{-2} \cdot \overline{(\rho u)^{**} T_t'^{**}} + \beta^2(\alpha + \beta)^{-2} \cdot \overline{(\rho u)^{**2}} \quad \text{and} \quad (2.3.3)$$

$$\frac{\overline{u'v'}}{\bar{u}^2} = (\alpha + \beta)^{-1} \cdot \overline{T_t'^{**} v'^{**}} + \alpha(\alpha + \beta)^{-1} \cdot \overline{(\rho u)^{**} v'^{**}} \quad (2.3.4)$$

where

$$\alpha = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1}, \quad \beta = \alpha(\gamma-1)M^2.$$

Although the equation for the Reynolds shear stress (eqn. 2.3.4) is here derived with the assumption $p' = 0$ it can be shown (Mikulla and Horstman 1975) that the assumption $\overline{p'v'} = 0$ is sufficient to yield $\bar{\rho} \overline{u'v'}$ from the measured hot-wire cross-correlations $(\rho u)'v'$ and $T_t'v'$.

While this classical approach to the interpretation of the hot wire fluctuating signal is necessarily dependent upon the mode diagram method, it should once more be pointed out that, although it is possible in theory, in practice it is extremely difficult if not impossible to obtain accurate values of all the necessary correlation terms with single hot wires. This is especially true for all measurements involving v' and w' fluctuations. The method, using squared RMS-values of the fluctuating voltage within a 180°-rotation of a single yawed wire, gives a result which requires the difference between two large numbers. This difficulty is added to the above mentioned difficulty of reduced yaw sensitivity resulting from wire slackness and elongation at high sensor temperature.

Since with the measurement technique suggested here no information is obtained about the stagnation temperature fluctuations, it is not possible in general to deduce the velocity fluctuation u' and the density fluctuation ρ' from the measurement of $(\rho u)'^2$ alone. This can only be achieved for the trivial case that stagnation temperature fluctuations in the flow are so low as to be negligible. In this case equations (2.3.2) and (2.3.4) reduce to

$$\frac{\overline{u'^2}}{\bar{u}^2} = \alpha^2(\alpha+\beta)^{-2} \cdot \overline{(\rho u)'^2} \quad (2.3.5)$$

and

$$\frac{\overline{\rho'^2}}{\bar{\rho}^2} = \beta^2(\alpha+\beta)^{-2} \overline{(\rho u)'^2} \quad (2.3.6)$$

It is, however, possible to derive the very important Reynolds shear stress $\bar{\rho} \overline{u'v'}$ by an alternative route. This approach requires the assumption of a value for the turbulent Prandtl number Pr_t in addition to assuming $\overline{p'v'} = 0$. It is then possible to obtain $\bar{\rho} \overline{u'v'}$ from an accurate measurement of $\overline{(\rho u)'^2}$ alone.

If triple correlations are neglected it follows from the expression of the cross-correlation $\overline{(\rho u)'^2}$

$$\overline{(\rho u)'^2} = \bar{\rho} \overline{u'^2} + \bar{u} \overline{\rho'^2} \quad (2.3.7)$$

and from the equation of state with the assumption $\overline{p'v'} = 0$ that

$$\bar{\rho} \overline{v'^2} + \bar{T} \overline{\rho'^2} = 0 \quad (2.3.8)$$

The turbulent Prandtl number is defined as

$$Pr_t = \frac{\overline{u'v'}}{\overline{T'v'}} \frac{dT/dy}{d\bar{u}/dy} \quad (2.3.9)$$

Expanding the energy equation

$$dT_t/dy = dT/dy + \frac{\bar{u}}{c_p} d\bar{u}/dy \quad (2.3.10)$$

using

$$\bar{u}^2/c_p \bar{T} = (\gamma-1)M^2 \quad ,$$

and combining equation (2.3.8-2.3.10), the following relation is obtained

$$\bar{u} \overline{\rho'v'} = \bar{\rho} \overline{u'v'} \frac{(\gamma-1)M^2}{Pr_t} \left(1 - \frac{c_p}{\bar{u}} \frac{dT_t/dy}{d\bar{u}/dy} \right) \quad (2.3.11)$$

Substituting equation (2.3.11) into equation (2.3.7) the expression for Reynolds shear stress becomes

$$\bar{\rho} \overline{u'v'} = \left[1 + \frac{(\gamma-1)M^2}{Pr_t} \left(1 - \frac{c_p}{\bar{u}} \frac{dT_t/dy}{d\bar{u}/dy} \right) \right]^{-1} \overline{(\rho u)'^2} \quad (2.3.12)$$

and for isoenergetic flow

$$\bar{\rho} \overline{u'v'} = \left[1 + \frac{(\gamma-1)M^2}{Pr_t} \right]^{-1} \overline{(\rho u)'^2} \quad (2.3.13)$$

It has been pointed out by Fernholz (private communication) that the expression for shear stress (equation 2.3.12) assumes that the gradient of the turbulent intensity $\frac{\partial \bar{u}^2}{\partial y}$ is also negligible since equation (2.3.10) is more properly expanded as

$$d\bar{T}_t/dy = d\bar{T}/dy + \frac{1}{2c_p} \left[2 \bar{u} \frac{d\bar{u}}{dy} + \frac{d\bar{u}^2}{dy} \right]$$

Since present measuring techniques and hot-wire sensors in general are not very suitable for accurate measurements very close to the viscous sublayer the assumption of a constant turbulent Prandtl number and the neglect of the gradient $\frac{d\bar{u}^2}{dy}$ should be quite reasonable.

It is not suggested that the new approach to the hot-wire measurement problem put forward here is the only and exclusive way of obtaining accurate measurements in high speed flows. On the contrary the author would suggest that for a problem as difficult as accurate turbulence measurements at high Mach numbers all available instruments, methods and sensors should be used, aiming at an optimal solution which combines if possible their several specific advantages. The very high temperature technique suggested here provides an addition to the available range of probes. While it is highly desirable to use as many different sensors as possible in a given flow, this coverage should be combined with the use of a chosen single sensor in as many different experiments as possible in different tunnels over the full range of Mach number. It should then, finally, become possible to distinguish the influence of Mach number on turbulent flow properties from the potentially spurious influences introduced by differing data reduction techniques.

2.4 Conclusions

This review and summary of hot-wire anemometry in compressible flow describes novel techniques for the measurement of turbulence in compressible flows with thermal sensors. While the original classical papers of Kovasznay and Morkovin remain as the basis it is shown that extreme overheating of a supported sensor leads to advantages in simplicity and accuracy of measurements of turbulent fluctuations over the full Mach number range.

The greatest amount of information about fluctuating flow variables will generally be achieved using the newly developed sensors and techniques in combination with the classical hot-wire mode diagram method.

It thus becomes apparent that the hot wire has no fundamental handicap for accurate high speed turbulence measurements in non-separated boundary layers outside the immediate wall region and that it will therefore be a complementary instrument to the LDV in this field for a long time to come.

3. TURBULENCE DATA - SINGLE COMPONENTS

When measuring fluctuating velocities in turbulent boundary layers, single component quantities such as $\overline{u'^2}$, $\overline{v'^2}$ and $\overline{w'^2}$ are measured first since the measuring technique required is straight-forward ($\overline{u'^2}$) and relatively easy ($\overline{v'^2}$, $\overline{w'^2}$), at least in subsonic flows. When multiplied by the local mean density $\bar{\rho}$ the three quantities $\bar{\rho} \overline{u'^2}$, $\bar{\rho} \overline{v'^2}$ and $\bar{\rho} \overline{w'^2}$ are the Reynolds normal stresses in a boundary layer. The ratio $(\overline{u'^2}/\bar{u}^2)^{1/2}$ is often used to characterize the local turbulence level of a flow where $\bar{u}$ is the mean velocity, but of even much greater theoretical importance are the terms $\overline{v'^2}$ and the sum of the three components $\overline{q'^2} = (\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$ which is twice the specific kinetic energy of the fluctuating motion. For both $\overline{v'^2}$ and $\overline{q'^2}$, so-called transport equations can be derived which play an important role in turbulence modelling. The transport equation for the kinetic energy of the fluctuating motion is part of almost every higher order turbulence model whereas a transport equation for $\overline{v'^2}$ has been used successfully for example by Wilcox and Traci (1976) and Wilcox and Rubesin (1980).

It has been interesting to find during this investigation how few measurements of all three normal stress distributions in tabular form are available both in subsonic and supersonic boundary layers and that the standard reference measurement remains the zero pressure-gradient subsonic boundary layer investigated by Klebanoff (1955).

As well as the velocity fluctuations, density, temperature and mass flux fluctuations are of interest in compressible boundary layers. Here we have even fewer data. Before we set out to discuss single component measurements it is appropriate to recall the conclusions drawn by Sandborn (1974) in his earlier study of the same topic: "Hot-wire measurements of the longitudinal component of the turbulent velocity in super- and hypersonic flow were found to agree with the incompressible data in the outer regions of the layers. Measurements of the vertical component of the turbulent velocity and the Reynolds shear stress with yawed hot wires appear questionable. Mass flux and temperature fluctuation measurements show considerable scatter from one boundary layer to another. Neither mass flux or temperature data could be correlated with the degree of similarity observed for the turbulent stress terms."

Since we still know very little about the turbulence structure of subsonic boundary layers, statements about the structure of supersonic boundary layers should be even more modest.

What we would like to investigate in the first place is whether the turbulence structure changes as a result of effects of compressibility, in boundary layers both with and without heat transfer, and secondly how pressure gradient effects and shock interactions affect the turbulence. Does similarity of the turbulence profiles exist if Reynolds number, Mach number or heat transfer change? What is the order of magnitude relationship between normal and tangential shear stresses and between the kinetic energy of the fluctuating motion? Finally, how does the shape and range of the energy spectrum compare as between the subsonic and supersonic boundary layer.

We begin our survey with Table (3.1) listing investigations in which measurements of single components of fluctuating quantities were performed. Their number is rather impressive but if one undertakes a closer inspection many data have to be excluded from our discussion, mainly because they are no longer available in tabular form. It has been our principle to compare tabulated data only and to use measurements in graphical form at most for qualitative comparisons.

Comparing the graphical presentations we find that the fluctuating velocities were made dimensionless with one of three velocities, u_δ the velocity at the outer edge of the boundary layer, u_τ the skin friction velocity $(\tau_w/\rho_w)^{1/2}$ or $\bar{u}$ the local mean velocity, and they were invariably plotted against y/δ where δ is the boundary layer thickness. In a few cases u_∞ , the "undisturbed" upstream velocity, has been used and δ was exchanged for the momentum defect thickness δ_2 .

After our discussion of δ as a "dangerous" scaling length in compressible turbulent boundary layers in section 7 of AGARDograph 253, there is little need for a further explanation here. This rigid exclusion of δ leaves us however with the problem of determining a scaling length for the outer-region properties of a boundary layer.

Table 3.1

Author	M_0	Heat transfer	PG	Number of profiles						Anemometer wall geometry
				$\langle u' \rangle$	$\langle v' \rangle$	$\langle w' \rangle$	$\langle T' \rangle$ $\langle T_0' \rangle$	$\langle p' \rangle$	$\langle \rho u' \rangle$	
Morkovin & Phinney (1958)	1.8	AW	Z	-	-	-	-	-	1	CCHWA
Kistler (1958/59) CAT 5803	1.7-4.7	AW	Z	3	-	-	3	-	3	CCHWA tunnel wall
Wallace (1968, 1969)	8	Cooled	Z	-	-	-	-	5	-	Electron beam nozzle wall
Waltrup & Schetz (1971), CAT 7104	1.9-2.4	AW	A	2	-	-	-	-	-	CTHWA tunnel wall
Sturek & Danberg (1972a/b) CAT 7101	3.5	AW	Z	1	1	-	1	-	1	CTHWA ramp
Yanta & Smith (1973)	0	AW	Z	1	1	-	-	-	-	LDV, channel
Yanta & Lee (1974)	3	AW	Z	8	8	-	-	-	-	LDV nozzle wall
Yanta & Crapo (1976)	3	AW	Z	4	-	-	-	-	-	LDV nozzle wall
Rose (1973, 1974) CAT 7306 S	3.9	AW	A SBLI	12	12	12	2 5	-	-	CTHWA nozzle wall
Johnson & Rose (1973, 1975)	2.9	AW	Z	1	1	-	-	-	-	CTHWA & LDV nozzle wall
Johnson (1974)	2.9	AW	Z	1	-	-	-	-	-	LDV nozzle wall
Rose & Johnson (1975)	2.9	AW	A SBLI	2	2	-	-	-	-	LDV, CTHWA nozzle wall
Johnson & Rose (1976)	0.8	AW	Z	1	1	-	-	-	-	LDV, CTHWA flat plate
Rose & McDaid (1977)	0.8	AW	Z	2	-	-	-	1	-	CTHWA, flat plate
Horstman & Rose (1977)	0.8	AW	Z	2	1	1	-	2	-	CTHWA, flat plate, tunnel wall
Mikulla (private com.)										
Owen & Horstman (1974)	6.7	Cooled	Z	1	-	-	- 1	1	1	CCHWA cone-ogive cylinder
Mikulla & Horstman (1975)	6.9	Cooled	Z	-	1	1	-	-	1	CTHWA cone-ogive cylinder
Owen, Horstman, Kusoy (1975)	6.7	Cooled	Z	1	-	-	- 1	1	1	CCHWA cone-ogive cylinder
Mikulla & Horstman (1976)	6.9	Cooled	A	-	8	-	-	-	8	CTHWA cone-ogive cylinder
Kusoy & Horstman (1975) CAT 7501 S	6.7		SBLI Z							
Kusoy et al. (1978) CAT 7802 S	2.3	AW	A Z	25	25	25	-	-	-	CTHWA, axisym. tunnel wall
Acharya et al. (1978) CAT 7802 S			F							
Mateer et al. (1976)	1.4	AW	A	-	7	-	-	-	-	-
Mateer & Viegas (1979)										axisym. tunnel wall
Coakley & Viegas (1977) CAT 8001										
Gootzait & Childs (1974, 1976, 1977)	3.9	AW	A Z	8 2	5 2	- -	- 1	- -	- -	CTHWA, axisym. nozzle wall
Demetriades & Laderman (1973b) and L & D (1974) CAT 7403	9.4	Cooled	Z	1	1	-	1	-	-	CCHWA tunnel wall

Table 3.1 cont.

Author	M_δ	Heat transfer	PG	Number of profiles						Anemometer wall geometry
				$\langle u' \rangle$	$\langle v' \rangle$	$\langle w' \rangle$	$\langle T' \rangle$ $\langle T_0' \rangle$	$\langle \rho' \rangle$	$\langle (\rho u)' \rangle$	
Laderman (1976, 1978b) Fluctuation data corrected in Laderman & Demetriades (1979)	7.1	AW Cooled	Z	1 1	1 1	- -	3 4	- -	- -	CCHWA cone
Laderman (1978a) Laderman & Demetriades (1979)	3	AW Cooled	Z	1	1	-	1	-	-	CCHWA flat plate
Dimotakis et al. (1979)	0.1-2.2	AW	Z	10	4	-	-	-	-	LDV, flat plate, tunnel wall
Ardonceanu et al. (1979)	2.2	AW	A	24	24	-	-	-	23	LDV
Lee (1979)			Ramp				4			
Berg (1977); Kubota & Berg (1977), CAT 7703S	6	Cooled	Z	-	-	-	- 12	-	12	CCHWA Tunnel wall

If fluctuation measurements are available, a boundary layer edge or characteristic thickness may be defined in relation to these. Definition 'by approach to the free stream fluctuation level' cannot be very precise, as the fluctuation level measurements can never be very accurate. The availability of conditional sampling techniques however makes possible a definition in terms of the 50% intermittency point, as suggested and initially applied by Laderman & Demetriades (CAT 7403). This proposal is attractive as it provides a well conditioned intersection and should be universally applicable. It should also relate properly to the physical process of turbulent mixing in the boundary layer. The 50% intermittency point lies well within the δ -value as defined by most other criteria, but this is not of itself a disadvantage if the δ -value is defined as a suitable multiple of the y -value at 50% intermittency. Unfortunately, the 50% intermittency point is not available in most investigations yet and can thus not serve as a universal scaling length. The problems of choosing an edge criterion may be avoided by using a suitable integral thickness. If there is in fact any universal similarity in the inner and outer regions of the transformed velocity profiles of zero pressure gradient boundary layers, then the defect-integral thickness Δ^* defined in eqn. (3.3.16 of AG 253) should bear a nearly fixed proportion to the physical boundary layer thickness δ , however that may be defined. As can be seen from the definition of the defect thickness Δ^* the skin friction velocity u_τ must be available, and the van Driest transformation must hold. This may not always be the case. Another well defined integral thickness which is not restricted in this way is the momentum defect thickness δ_2 . It provides (at least in flows without normal pressure gradients) a convenient way of describing the accumulated friction effect of the boundary layer. δ_2 appears in the momentum integral equation in just this way - the integral equation itself being a convenient short-hand for a control surface momentum balance. If only because of its importance in the momentum integral equation, the momentum defect thickness is also, conventionally, the most favoured reference length for the formation of Reynolds numbers intended to correlate experimental data (for definitions and further discussion see section 7 of AG 253).

The customary use of δ_2 as a scaling length for Reynolds numbers and the fact that as an integral thickness it is precisely defined independently of a wall shear stress value, provide, with convenience, the only reasons for using it as a reference length in scaling outer region profiles. The "physical" thickness δ is ill defined, but in principle is, in any self similar flow, a fixed fraction of the outer law defect thickness Δ^* , which again, as an integral thickness is well defined though dependent on a value of the skin friction velocity u_τ . If outer region turbulence quantities are presumed to display a similar dependence on y/δ then they must be plotted using a well defined δ which is difficult to quantify, or the defect thickness Δ^* which in principle amounts to the same thing. This is very successful when done for mean flow profiles. δ_2 (or δ_1) as a fraction of Δ^* will vary with Reynolds number and so cannot serve as a proper reference length over a wide Reynolds number range.

For the inner region of a boundary layer the obvious scaling length, well known from mean flow measurements, is the ratio of the kinematic viscosity at the wall ν_w and the skin friction velocity u_τ . If we may expect any lead from mean flow behaviour, we should see similarity when data are plotted against $y^+ = (u_\tau y / \nu_w)$ for the inner region and against (y/Δ^*) for the outer region. Similarity in plots against (y/δ_2) should appear only for data covering a limited Reynolds number range.

As for the scaling velocity we find little to be gained by using the mean velocity $\bar{u}$ since it depends on both independent variables x and y , and the outer edge velocity u_δ has definite disadvantages in all cases where an edge state - or as we usually call it a D-state - is hard to define. This is the case in all compressible boundary layers with severe pressure gradients. It may well be reasonable in many cases to use the "undisturbed" upstream velocity U_∞ when showing the development of some fluctuating quantity in the downstream direction.

3.1 Normal components of the Reynolds stress/zero pressure-gradient

Of the fluctuating velocities it is $\overline{u'^2}$ which has been measured most often. Nevertheless we know of only 8 tabulated profiles (2 in Rose 1973, 1975), all measured by hot-wire anemometry, that satisfy the boundary conditions of zero pressure-gradient and adiabatic or isothermal wall. They cover a Mach number range $1.7 \leq M_\delta \leq 7.2$ and a range of the heat transfer parameter $0.5 \leq T_w/T_r \leq 1$. We have plotted both the Reynolds normal stress $\bar{\rho} \overline{u'^2}$ and the mean square $\overline{u'^2}$ of the fluctuating velocity component u' , in order to separate out the influence of the mean density $\bar{\rho}$ on the distribution, against the inner region coordinate y^+ , and against y/Δ^* and y/δ_2 as characteristic coordinates of the outer region. We have extracted experimental data from the following investigations: Kistler (1958, CAT 5803), Horstman & Owen (1972, CAT 7205), Kussoy & Horstman (1975, CAT 7501S) and Kussoy et al. (1978, CAT 7802S). From the latter two experiments we have used the first one or two profiles of each series which were not affected by the downstream pressure rise. Unfortunately all distributions of the turbulent fluctuations had an "undocumented" upstream history which could have had an influence unknown to us, though the mean flow profiles plotted in Fig. (4.4.1) appear to conform well to the incompressible norm. Figures (3.1.1) and (3.1.2) give the inner region plots for the fluctuating velocity component u' and show no sign of profile similarity in the given Mach and Reynolds number range. When plotted against the appropriate outer region coordinate y/Δ^* in Figs. (3.1.3) and (3.1.4) there is at least a recognisable common trend. The differences in level between the various sets of data are so great, however, that it is not possible to consider any form of similarity as established. No Mach or Reynolds number effect on the normal stress $\bar{\rho} \overline{u'^2}$ can be observed but there appears to exist a Mach number effect on $\overline{u'^2}$ as can be seen from Figs. (3.1.2) and (3.1.4) where the level of the intensity decreases with increasing Mach number.

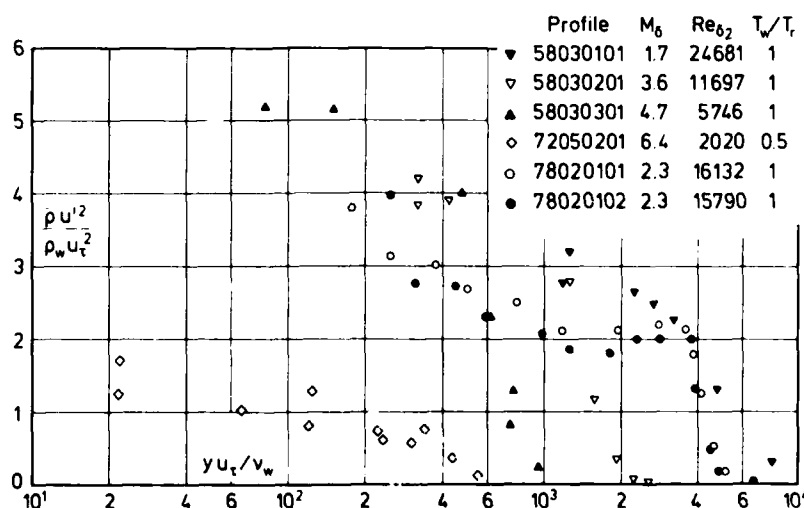


Fig. 3.1.1 Reynolds normal stress distributions in a compressible turbulent boundary layer with zero pressure-gradient (adiabatic and isothermal wall).

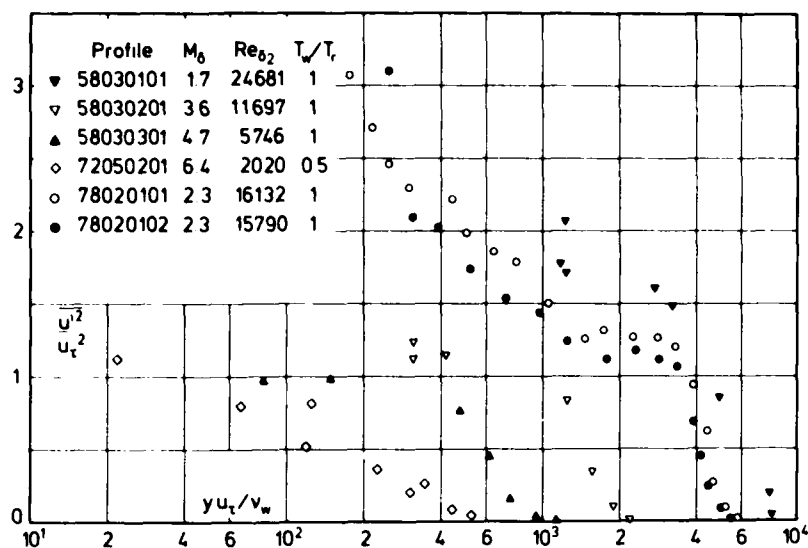


Fig. 3.1.2 Distributions of the mean square of the fluctuating velocity u' in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

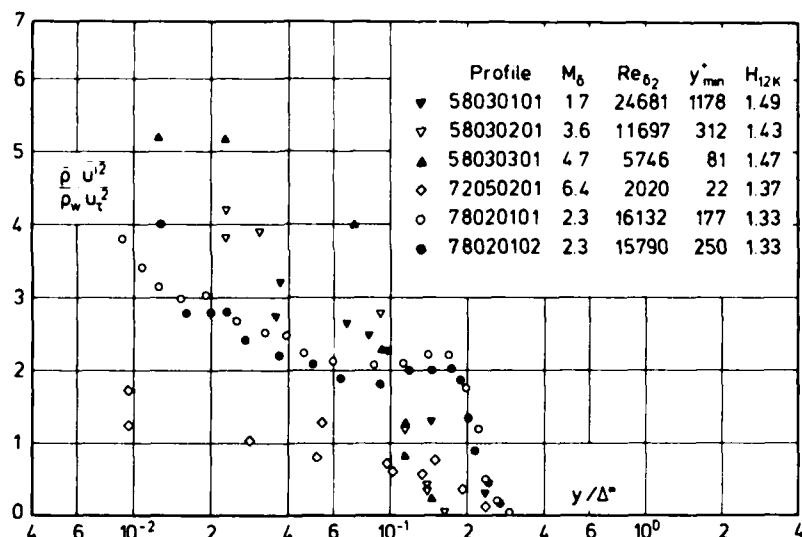


Fig. 3.1.3 Reynolds normal stress distributions in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

We are well aware however that the sample of measurements available to us is very small and it is only too possible that new and systematic measurements over the whole parameter range may show a different pattern.

In the captions of Figs. (3.1.3) and (3.1.4) we have given the minimum value of y^+ as an indication of the proximity to the wall of the innermost measurements and also H_{12K} which serves as a good indicator of how far the profiles are fully developed and conform to the zero pressure gradient norm. Except for profile 72050201 the closest measurement of u' lies at the outer end of the log-law region or even beyond it. H_{12K} lies well within the range given for example by Rotta (1962, Fig. 13.6) for subsonic zero pressure-gradient boundary layers.

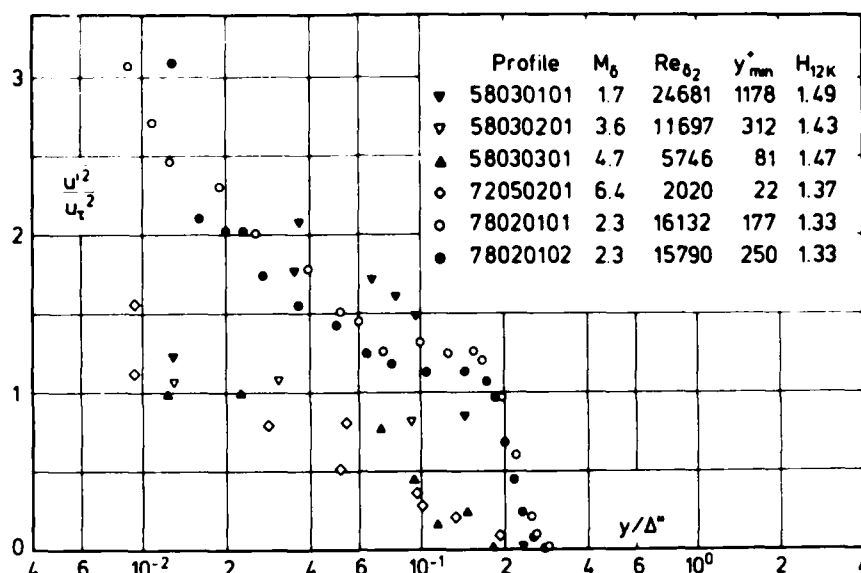


Fig. 3.1.4 Distributions of the mean square of the fluctuating velocity u' in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

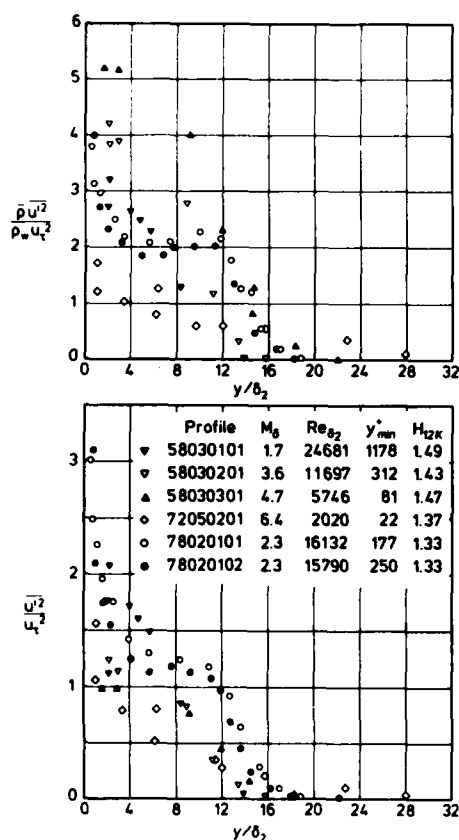


Fig. 3.1.5 a/b Reynolds normal stress and distributions in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

Fig. (3.1.5 a/b) shows the normal stress $\bar{\rho} u'^2$ and the mean square $\bar{u'^2}$ plotted against y/δ_2 in order to show the above distributions in a manner more familiar to all those who have been plotting their turbulence data against y/δ . The disadvantage of such a plot should be obvious from a comparison with the above figures. Though there exists a recognisable common trend comparable to that in Fig. (3.1.4) the distribution in the wall region is so compressed that it is almost impossible to draw any valid conclusions from such a graph.

Laser-doppler and hot-wire measurements of a single u' -distribution (Johnson & Rose 1975, graphical presentation) at $M_\delta = 2.9$ show a monotonic increase towards the wall. The data agree well with each other. Closer to the wall than $y/\delta = 0.30$ their results lie up to 50% above the Kistler distributions for the most nearly matched Mach numbers (1.7 and 3.6) plotted above. The Johnson and Rose data agree well on the other hand with LDV measurements by Yanta & Crapo (1976) at a Mach number of 2.9. Yanta & Lee (1974) compared their measurements at $M_\delta = 3$ with the u' -distribution of Klebanoff (1955) and found satisfactory agreement ($\pm 10\%$). All the latter measurements were plotted against y/δ in the original reports.

The picture becomes even more confusing when we look at the distributions of the other two normal stresses, $\bar{\rho} v'^2$ and $\bar{\rho} w'^2$, plotted against y^+ in Fig. (3.1.6 a and b). On the whole $\bar{\rho} w'^2$ is approximately of the same magnitude as $\bar{\rho} v'^2$. We would expect $\bar{\rho} w'^2$ to be larger than $\bar{\rho} v'^2$ from our knowledge of subsonic boundary layers, and such behaviour has been established for distributions of the normalized fluctuation velocities in transonic boundary

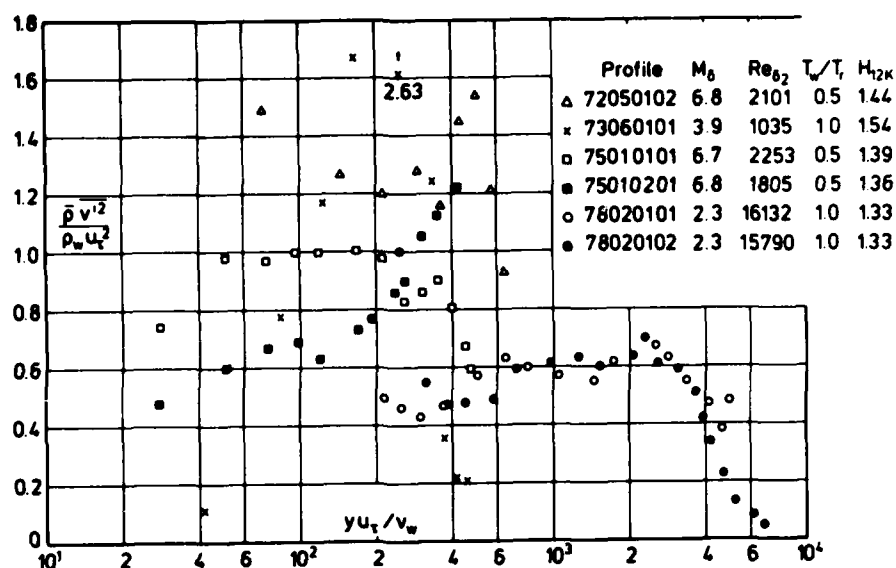


Fig. 3.1.6a Reynolds normal stress distributions in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

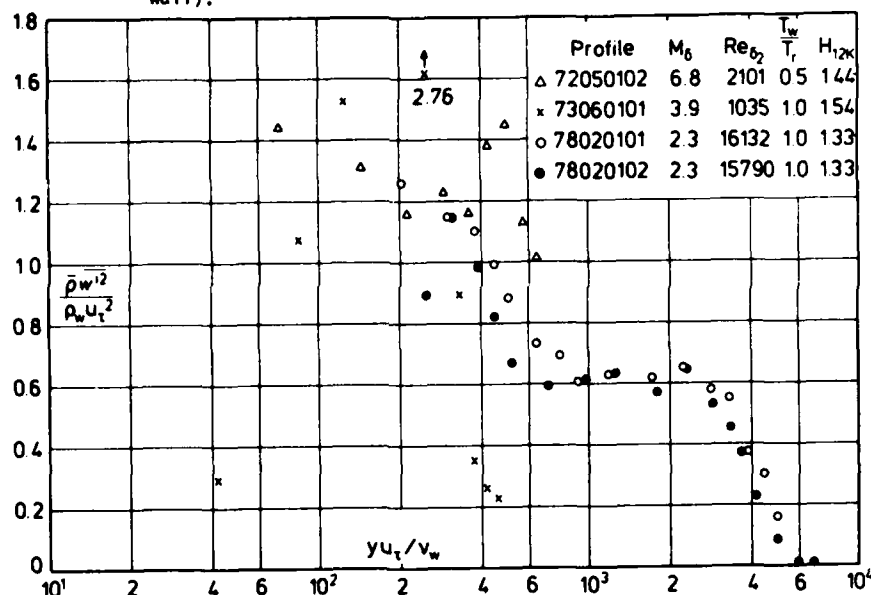


Fig. 3.1.6b Reynolds normal stress distributions in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

layers (Horstman & Rose 1977), with the longitudinal velocity component u' being larger than w' and v' .

As for the distributions of $\bar{\rho} v'^2$ and $\bar{\rho} w'^2$ one finds a general pattern of behaviour in that the profiles rise from the wall, reach a peak and fall again towards the edge of the boundary layer. This is true here with two exceptions. We have no explanation for the peculiar behaviour of profile 72050102 (Horstman & Owen 1972) which shows a second peak in the outer region both in the $\bar{\rho} v'^2$ and in the $\bar{\rho} w'^2$ distribution. As can be seen in Fig. (3.1.8) this second peak is apparently due to the density distribution and not a feature of the turbulence as such.

The second exception is profile 75010201 (Kussoy & Horstman 1975) which shows an increase towards the outer edge of the boundary layer. This again is due to the influence of the density as is evident from a comparison with the respective $\bar{v}^2$ profile in Figs. (3.1.8) and (3.1.9a). The comparatively high peak in profile 73060101 could have been caused by the effect of the incoming shock wave (see Fig. 7306S-1). It is clearly visible also in Fig. (3.1.8) and thus apparently an effect of the turbulence structure.

Fig. (3.1.7) shows the normal stress component $\bar{\rho} \overline{v'^2}$ plotted against the outer region coordinate y/Δ^* . As in Fig. (3.1.6) where no similarity could be found for the inner region, the same absence of similarity is demonstrated here for the outer region of the boundary layer. Again, as for $\bar{\rho} \overline{u'^2}$, no influence of the Mach number can be observed on either $\bar{\rho} \overline{v'^2}$ or $\bar{\rho} \overline{w'^2}$.

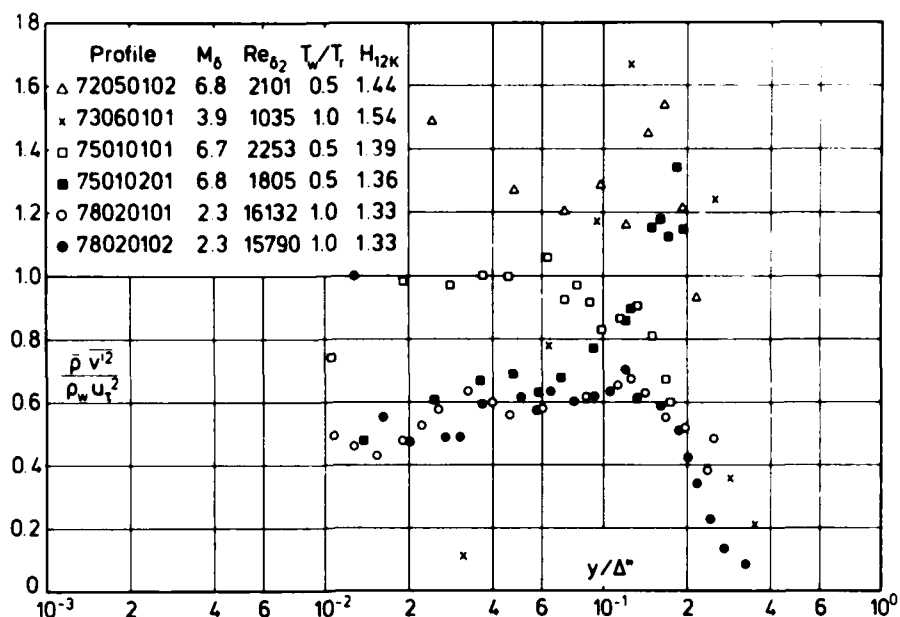


Fig. 3.1.7 Reynolds normal stress distributions in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

Investigating the turbulence quantities v' and w' without the density profile, we find a common trend in all profiles in that they show a maximum and decrease both towards the wall and towards the outer edge (Figs. 3.1.8 and 3.1.9). Whereas no similarity can be established for $\overline{v'^2}$ when plotted against y^+ (Fig. 3.1.8), a similarity pattern appears to emerge in the outer region if $\overline{v'^2}$ and $\overline{w'^2}$ are plotted versus y/Δ^* (Fig. 3.1.9 a/b). The latter figure shows a Mach number effect - if such an effect can be deduced from such a small sample of data - but for $\overline{v'^2}$ and $\overline{w'^2}$ in the opposite direction to that for $\overline{u'^2}$, i.e., the fluctuation level increases with increasing Mach number.

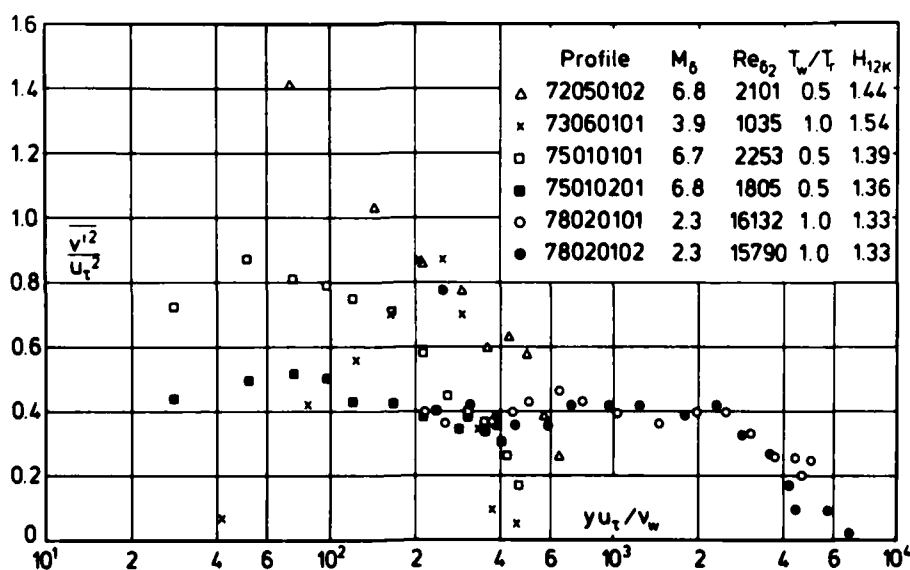


Fig. 3.1.8 Distributions of the mean square of the fluctuating velocity v' in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

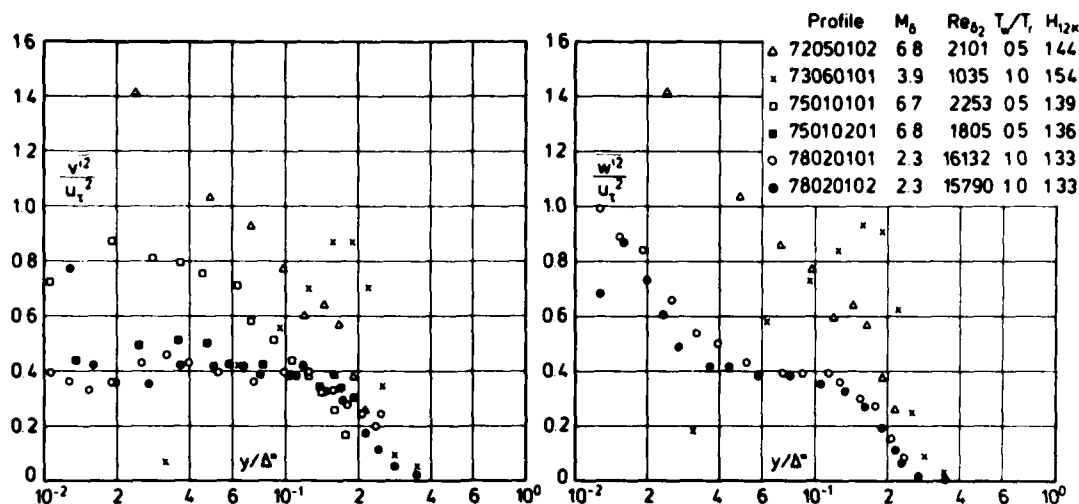


Fig. 3.1.9 a/b Distributions of the mean square of the fluctuating velocities v' and w' in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall).

Examining the $(\overline{v'^2})^{1/2}/u_\infty$ turbulence intensity distributions presented by Yanta & Lee (1974) we find no similarity between the individual profiles even if they are plotted against " y/δ^* ". Close to the wall, profiles at the same Mach number and approximately the same Reynolds number differ by 300%. We were therefore very surprised to find a statement by the authors that "the various turbulence parameters bear a remarkable similarity to incompressible data not only in trends but also in magnitude thus indicating a Mach number independence."

Laser-doppler and hot-wire measurements performed by Johnson & Rose (1975) show a monotonic increase of $\bar{\rho} \overline{v'^2}$ towards the wall and agreement between the two measuring techniques within a band of about $\pm 20\%$. Johnson and Rose draw no conclusions from the comparison with the incompressible data which are, in any case, themselves inconsistent.

Conclusions from a small sample of measurements

After a rather exhaustive but useless attempt to find common trends or similarity in distributions of Reynolds normal stress components in compressible turbulent boundary layers with zero pressure gradient we arrive at the following conclusions:

- (1) No systematic effect of Mach number, Reynolds number or heat transfer parameter could be observed for the Reynolds normal stresses.
- (2) The Reynolds normal stress components $\bar{\rho} \overline{u'^2}$, $\bar{\rho} \overline{v'^2}$ and $\bar{\rho} \overline{w'^2}$ do not show a similar behaviour, whether in the inner or in the outer region of the boundary layer.
- (3) A trend towards similarity can be observed for the mean square fluctuating velocities $\overline{v'^2}$ and $\overline{w'^2}$ (Fig. 3.1.9).
- (4) Little can as yet be said about the behaviour of the fluctuating velocities or normal stresses in the inner region of a compressible boundary layer since no measurements have been performed close enough to the wall.
- (5) Systematic investigations of fluctuating velocities even in zero pressure-gradient compressible boundary layers are called for which cover a wide range of the above three parameters before reliable turbulence models can be established.

3.2 Normal components of the Reynolds stress - various pressure gradients

A discussion of the behaviour of normal stress components in compressible turbulent boundary layers in an adverse pressure gradient can only be a discussion of case studies at present. The two reasons for this are the scarcity of data and the lack of a suitable pressure gradient parameter which could be used to compare data from different experiments. Such a pressure gradient parameter would have to take account of boundary layer flows with both streamwise and normal pressure gradients, and of flows where both pressure gradients are present. The pressure gradient parameters which have been used most often in investigations of subsonic boundary layers are defined as

$$\Pi_1 = (\delta_1/\tau_w)dp/dx \quad \text{or} \quad \Pi_2 = (\delta_2/\tau_w)dp/dx \quad (3.2)$$

where (see also section 2.3.3 of AG 253) δ_1 is the displacement and δ_2 the momentum defect thickness. Sometimes $(v_w/\rho_w u_t^2) dp/dx$ has also been used but all three parameters have relevance only in boundary layers with no normal pressure gradient and all three tend to infinity as τ_w tends to zero at separation. When we could we have given Π_2 in all entries of AG 223 where normal pressure gradients were absent or at least small. The experimental investigations discussed below have both streamwise and normal pressure gradients and so none of the above pressure gradient parameters has any meaning.

We begin our discussion with the reflected wave case of Kussoy et al. (1978, CAT 7802S). Here the boundary layer was generated along a straight adiabatic wall and the wave structure (see figures 6.2.2 and 6.2.3 of AG 253), produced in each case by a centre body, consisted of a compression wave followed by an expansion. For series 02 the compression wave was stronger than for series 01, and was followed more rapidly by a stronger expansion wave. Figs. (3.2.1) and (3.2.2) show the distributions of the three normal stresses $\bar{\rho} u'^2$, $\bar{\rho} v'^2$ and $\bar{\rho} w'^2$ plotted against y^+ . Since no separation was observed in either of the two boundary layers this is a plausible scaling length. δ_2 is excluded as a result of the presence of the normal pressure gradient.

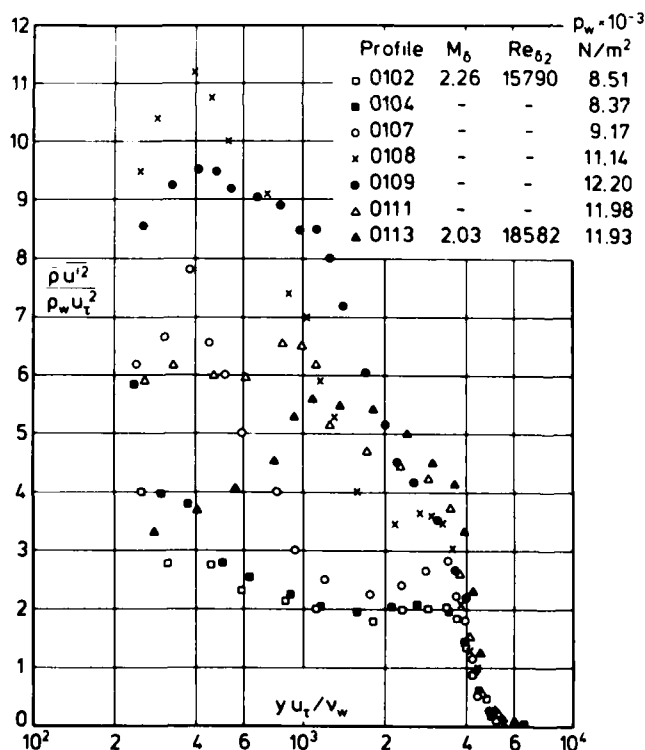


Fig. 3.2.1 Reynolds normal stress distributions in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

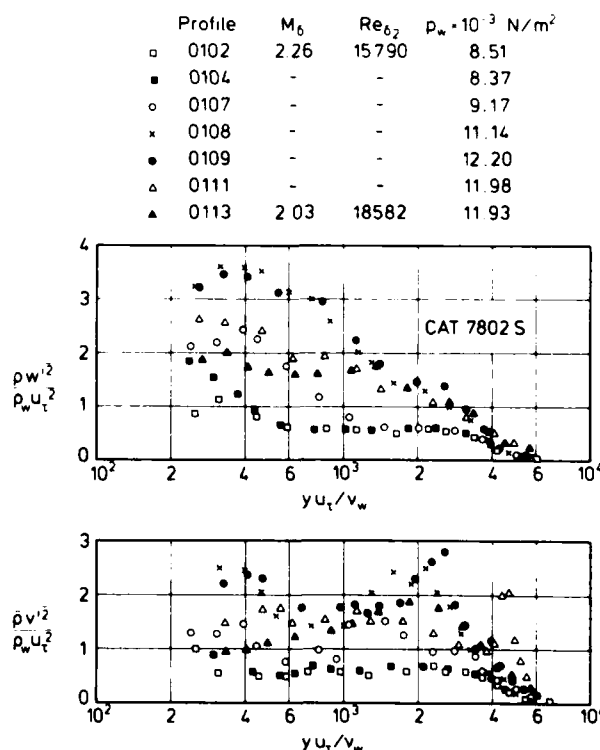


Fig. 3.2.2 Reynolds normal stress distributions in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

As can be seen from the pressure distribution (Fig. 6.2.2 of AG 253) the profiles are not affected by the incoming compression wave up to profile 0104 with the result that the turbulence structure does not change at all. We then observe a sharp increase in the level of all three normal stresses reaching a maximum for profile 0108. For the $\bar{\rho} \overline{u'^2}$ -distributions the maximum moves out into the boundary layer all the way down to profile 0113, though decreasing in relative magnitude, whereas there is only a small shift of the maximum of $\bar{\rho} \overline{w'^2}$. The $\bar{\rho} \overline{v'^2}$ distribution presents a picture in contrast to the other normal stresses in that one observes two peaks for profiles 0108 to 0111. Whether this is an effect of the outgoing expansion wave on the turbulence structure, here v' , or on the hot-wire sensor is not clear and should be investigated experimentally in more detail.

As for the differences in level of magnitude between the three normal stresses, the order is $\bar{\rho} \overline{u'^2}$, $\bar{\rho} \overline{w'^2}$ and $\bar{\rho} \overline{v'^2}$ as is observed in measurements in subsonic boundary layers. The differences are clearly more distinct than shown in the distributions of $\bar{\rho} \overline{w'^2}$ and $\bar{\rho} \overline{v'^2}$ in the zero pressure gradient flows discussed in section 3.1. above.

Fig. (3.2.3) shows the normal stress distribution ($\bar{\rho} \overline{u'^2}$) plotted versus y/Δ^* . Though the definition of the outer edge velocity u_δ , necessary for the determination of Δ^* , is problematical, the normal stress-distributions

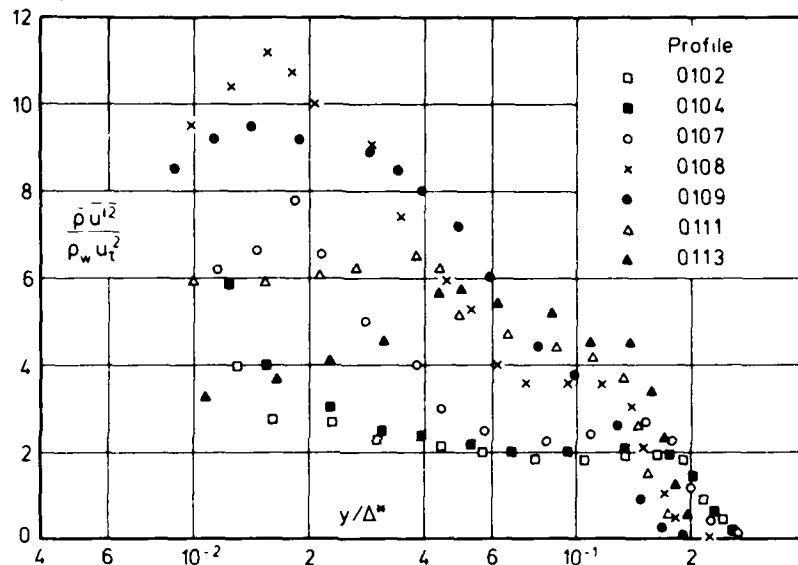


Fig. 3.2.3 Reynolds normal stress distributions in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

are qualitatively similar to those presented in Fig. (3.2.1). It is not very clear, with this reservation, why the normal stress distributions show a similar behaviour when plotted against y^+ and much less so against y/Δ^* .

The pressure distribution which generates the profiles of series 02 increases, reaches a plateau and then decreases again. The pressure rise, steeper than in series 01, leads to a higher level for the maxima of the normal stresses (Fig. 3.2.4) whereas the subsequent drop in pressure reduces the turbulence level so that it approaches the level upstream of the pressure rise in the outer region and even falls below this level in the inner region. This shows that the turbulence is more affected by pressure gradient effects in the inner region than in the outer region. Qualitatively the normal stress distributions $\bar{\rho} \overline{w'^2}$ and $\bar{\rho} \overline{v'^2}$ (Fig. 3.2.5) behave as those of series 01 (Fig. 3.2.2), and we observe again the distinct second peak of the $\bar{\rho} \overline{v'^2}$ distribution in the outer region of the boundary layer (profiles 0207 to 0211). Again the magnitude of the normal stresses follows the order $\bar{\rho} \overline{u'^2}$, $\bar{\rho} \overline{w'^2}$ and $\bar{\rho} \overline{v'^2}$.

The next two investigations were performed in boundary layers with shock interaction, and we deal with the adiabatic wall case first. The boundary layer ($M_\delta \approx 3.9$) developed on the axisymmetric nozzle and test section wall and was subjected to an adverse pressure gradient induced by the incident and reflected shock-wave system generated by a cone on the centre line (Rose 1973, CAT 7306S). The pressure distribution and the wave structure of the flow are shown in Fig. 7306S-1 of this report.

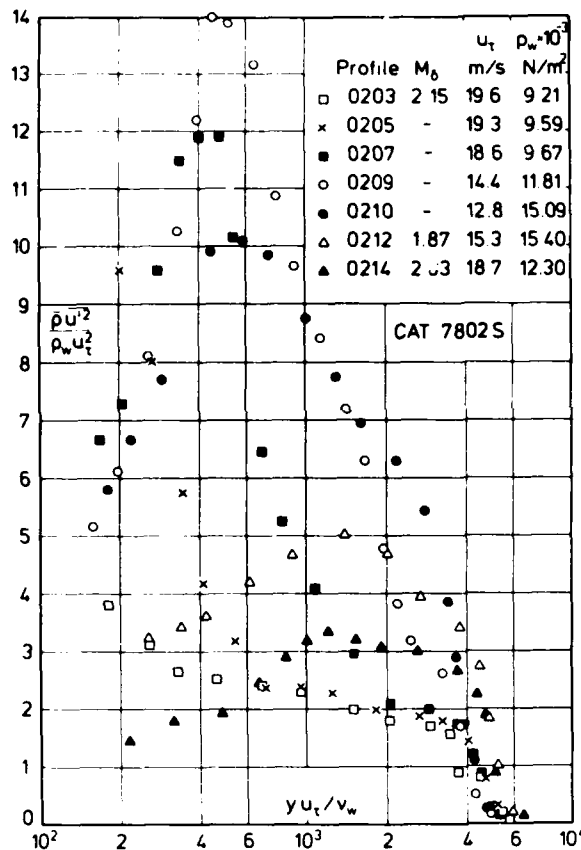


Fig. 3.2.4 Reynolds normal stress distributions in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

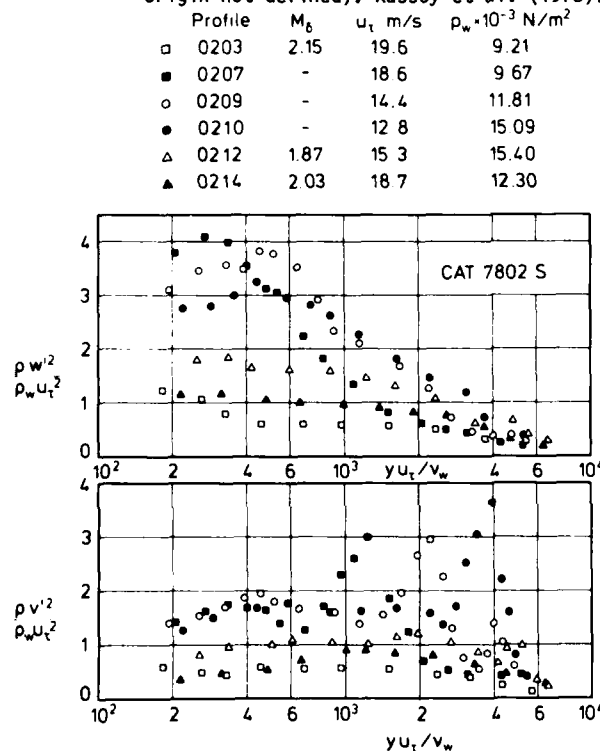


Fig. 3.2.5 Reynolds normal stress distributions in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

Again all three normal stress components were measured and are presented in Figs. (3.2.6) and (3.2.7). The turbulence levels of the three components differ greatly from those of the two previous cases. The most obvious difference lies in that $\bar{\rho} \bar{u}^2$ is smaller than both $\bar{\rho} \bar{v}^2$ and $\bar{\rho} \bar{w}^2$, reaching only about one third of the maxima of the other two normal stresses. The rise in pressure causes the turbulence structure to deviate from that of the first three profiles at profile 0104 with changes in $\bar{\rho} \bar{v}^2$ and $\bar{\rho} \bar{w}^2$ greater than in $\bar{\rho} \bar{u}^2$. Since the wall-pressure gradient increases monotonically in the region investigated in this experiment the maximum of the normal stress moves outwards into the boundary layer with the maximum decreasing only slightly in magnitude. This behaviour is observed for all three normal stresses. In contrast to the previous experiment however no double peak occurs in the $\bar{\rho} \bar{v}^2$ distributions.

The last two cases to be discussed in this section (CAT 7501S) are again boundary layers with shock interaction. Unfortunately they are less well documented than the other experiments and of the normal stresses only $\bar{\rho} \bar{v}^2$ is given. Fig. (3.2.8) shows the $\bar{\rho} \bar{v}^2$ distributions for the two boundary layer flows examined. The information about the boundary layer with pressure distribution II (series 02) is however relatively so scarce that we can only express our astonishment at the fast relaxation of profiles 0209 and 0212 to the $\bar{\rho} \bar{v}^2$ level upstream of the shock. For series 01 $\bar{\rho} \bar{v}^2$ starts at the low level upstream of the shock, increases by a factor of about 20 just downstream of the shock (profile 0105) and then decreases again in magnitude without however reaching the original level of profile 0101, even at profile 0115.

No general conclusions can be drawn from the few cases presented above and more data are needed before any useful attempt at a turbulence model for the normal stresses can be made.

Beginning with Newman's (1951) early normal stress measurements in an incompressible adverse pressure gradient boundary layer one discussion has never ended (e.g., Rotta 1962). The question is whether or not at least near separation, the convection term $\partial(\bar{\rho} \bar{u}^2)/\partial x$ must be retained in a first order boundary-layer theory, since it approaches an order of magnitude which is no longer negligible. Rose (1973) and Rose & Johnson (1975) have discussed this question for compressible boundary layers. They compared the values of the average pressure gradient $\partial \bar{p}/\partial x$ (approximately $5 \times 10^5 \text{ N/m}^3$) with the maximum normal stress gradient (about $4 \times 10^4 \text{ N/m}^3$). They also found the term $\partial(\bar{\rho} \bar{u}^2)/\partial x$ everywhere less than

Profile	u_t m/s	$p_w \cdot 10^{-3}$ N/m ²	y_{min} mm
○ 0101	39.1	2.92	0.5
● 0103	35.8	2.91	0.5
● 0104	27.1	2.98	0.5
□ 0105	24.0	4.89	0.5
■ 0107	25.6	6.82	0.5
△ 0110	27.1	8.31	0.5
▲ 0112	27.7	9.28	0.5

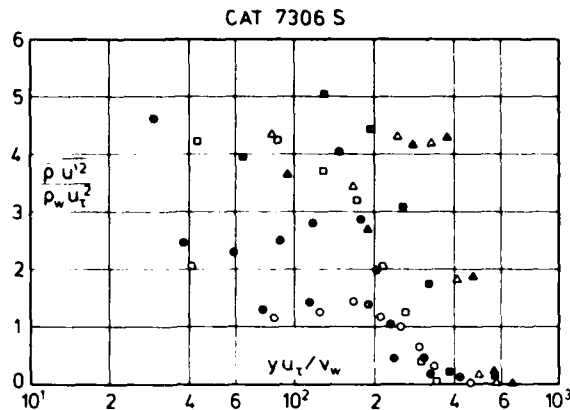


Fig. 3.2.6 Reynolds normal stress distributions in a compressible turbulent boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

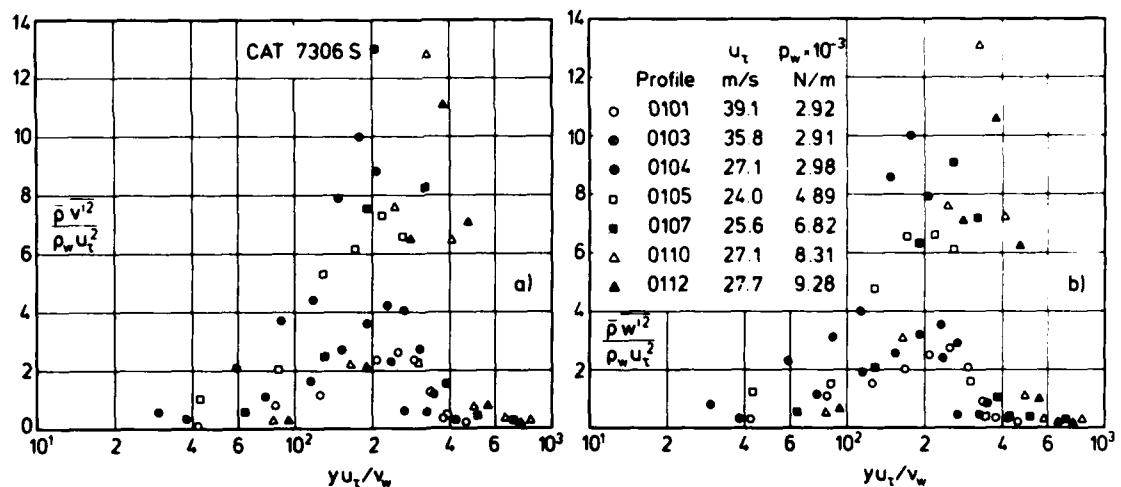


Fig. 3.2.7 a/b Reynolds normal stress distribution in a compressible turbulent boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

8×10^4 N/m³ and concluded that "within engineering accuracy, the term $\partial(\bar{\rho} \overline{u'^2})/\partial x$ may be neglected throughout the entire flow upstream, within and downstream of the shock-wave interaction region. Within the interaction itself, the pressure gradient term $\partial \bar{p}/\partial x$ is an order of magnitude larger than the Reynolds stress gradient."

Rose (1973) had come to a similar but not quite the same conclusion from his evaluation of the above gradients, stating "that the flow within and just downstream of the interaction is definitely not boundary-layer-like in that $\partial(\bar{\rho} \overline{u'^2})/\partial x$ is not negligible; and, further, that the value of $\partial \bar{p}/\partial x$ varies substantially across the boundary layer" (see CAT 7306S).

The only other boundary layer flow with separation was investigated by Kussoy & Horstman (1975, CAT 7501S). Unfortunately, $\bar{\rho} \overline{u'^2}$ was not measured, and an estimate of the order of magnitude of individual terms in the momentum equation must therefore remain incomplete.

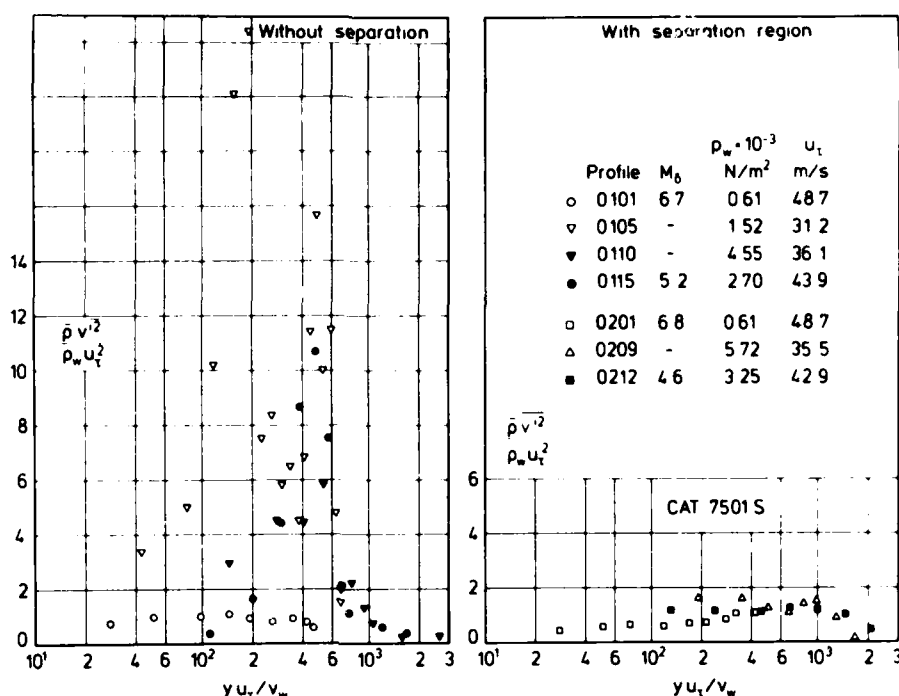


Fig. 3.2.8 Reynolds normal stress distributions in a shock/boundary-layer interaction flow (isothermal wall $T_w/T_r = 0.47$, defined origin). Kussoy & Horstman (1975).

3.3 Kinetic energy of the fluctuating motion

A discussion of the kinetic energy distribution of the fluctuating motion across compressible turbulent boundary layers is confined to three cases, two provided by Kussoy et al. (1978), CAT 7802S) and one by Rose (1973, CAT 7306S). Since there are hardly any measurements in subsonic flow which might be compared to the experiments presented here, we can only hope that more measurements will appear eventually so that a discussion about the behaviour of this important quantity gains more meaning. As is evident from the single fluctuation components discussed above, the locally scaled turbulence level increases with the increasing pressure (Fig. 3.3.1) and then decreases again as the pressure gradient falls. In contrast to the second pressure

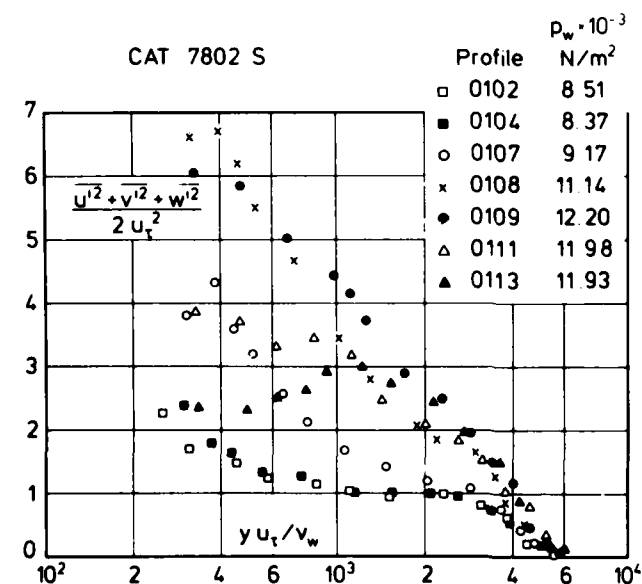


Fig. 3.3.1 Specific kinetic energy of the fluctuating motion in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

distribution where the turbulence level returns to its initial level (Fig. 3.3.2 - profiles 0203 and 0214) for series 01 the level remains higher than for the starting profile. Scaling with such a quantity as u_t (which decreases down to profile 0210 - see legend of Fig. 3.2.4) exaggerates the rise of the overall level so that in absolute terms the maxima of profiles 0207 and 0210 are about equal.

In interpreting the distributions of turbulent energy - or of any other turbulence or mean flow quantity - in flows with strong pressure gradients it is necessary to take account of the change in the scaling quantities as well as the variation of the dimensionless value. In relation to the local friction velocity the distributions of the fluctuating kinetic energy of series 02 have higher peak values than those of series 01 as a result of either the higher pressure level or the steeper pressure gradient.

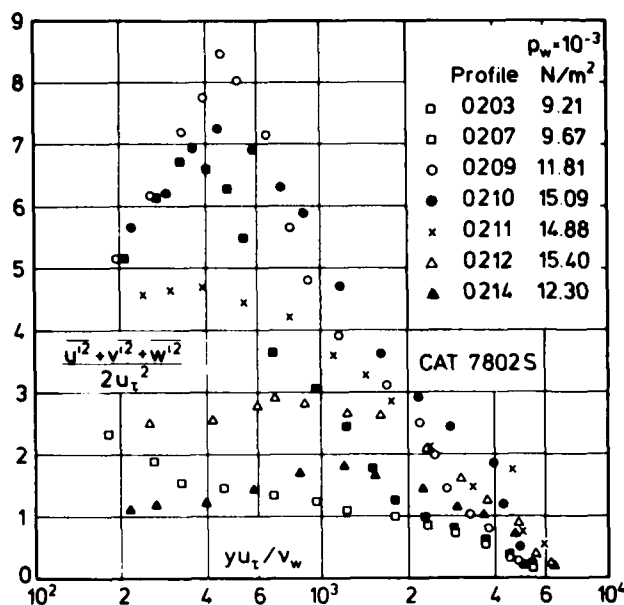


Fig. 3.3.2 Specific kinetic energy of the fluctuating motion in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

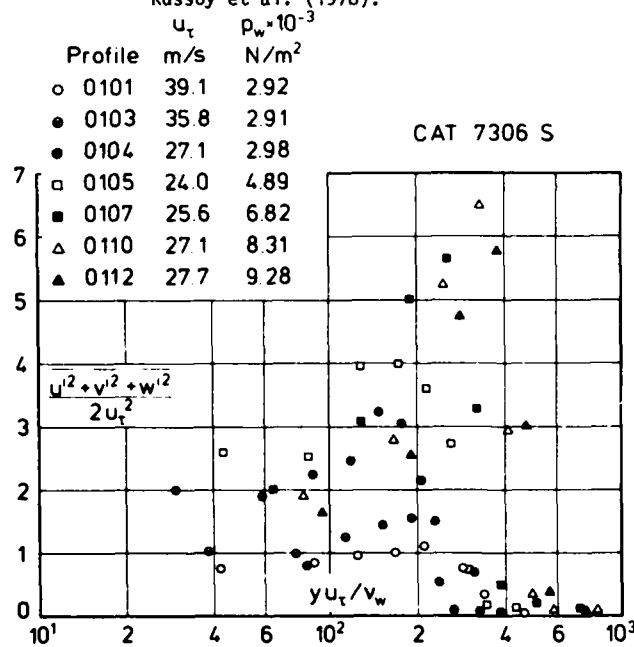


Fig. 3.3.3 Specific kinetic energy of the fluctuating motion in a compressible turbulent boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

adiabatic wall, is, of course, identical to the recovery temperature T_r . The latter is again close to the total temperature.

The influence of the temperature fluctuations in comparison with other fluctuating quantities of the flow field has been investigated by Morkovin who arrived at the following equation

$$\frac{(T_0')^2}{T_0^2} = \frac{(T')^2}{T^2} \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} + \frac{(u')^2}{\bar{u}^2} \frac{(\gamma-1) M^2}{1 + \frac{\gamma-1}{2} M^2} \quad (3.4.1)$$

(for details see Morkovin 1962 or section 2.4 of AG 253). Morkovin now assumed that $(T_0')^2 / T_0^2$ is an order smaller than the two remaining terms and based this assumption on measurements by Kistler (1959) who showed

Which of the two is more important calls for further investigation. It is interesting to note, however, that the scaled peak of $(u'^2 + v'^2 + w'^2)$ is reached before the maximum of the wall pressure (see the legend of Figs. 3.3.1 and 3.3.2), an observation which points to a greater importance of the pressure gradient. One may finally note that the peak of the fluctuating kinetic energy lies still in the log-law region of the boundary layer as long as the pressure is rising in the streamwise direction.

This is not the case for the profiles in the boundary layer with shock interaction presented in Fig.(3.3.3) where, in a pressure distribution which increases monotonically, the peak of the specific kinetic energy moves out almost to the edge of the boundary layer. This behaviour may be connected with the wave pattern downstream of the shock interaction but we would like to see other experiments under similar conditions confirm such a pattern before it can be discussed any further, or taken as a general rule.

If one is interested in the development of the fluctuating kinetic energy in varied pressure distributions, $(u'^2 + v'^2 + w'^2)$ would, of course, have to be referred to a fixed, upstream, scaling level such as u_t^2 for profile 01.

3.4. Temperature fluctuations

Measurements of temperature fluctuations have been reported for some investigations in compressible turbulent boundary layers but the number of data in tabular form is hardly larger than in 1974 when Sandborn reported the available results in his figure 15. He then weighted the static temperature fluctuation intensities by a representative mean static difference across the boundary layer. This coordinate was based on the concept that the temperature fluctuation level should be proportional to the mean temperature gradient across the boundary layer, which was originally proposed by Kovasznay (1953). Here we propose to nondimensionalize the static and the total temperature fluctuations by the wall temperature T_w which, in the case of an

that at a Mach number of 4.67 $(T_0^{\overline{T^2}})^{1/2} / T_0$ reached at most a value of 0.048 and about 0.02 for a Mach number 1.72.

In Fig. (3.4.1) we have plotted against y^+ and y/Δ^* the only tabulated data available to us (Sturek 1971, CAT 7101) and Owen et al. (1975, CAT 7205, Horstman & Owen 1972) and find the same order of magnitude as Kistler. If the latter data (CAT 7205) which were measured on an isothermal wall had been nondimensionalized

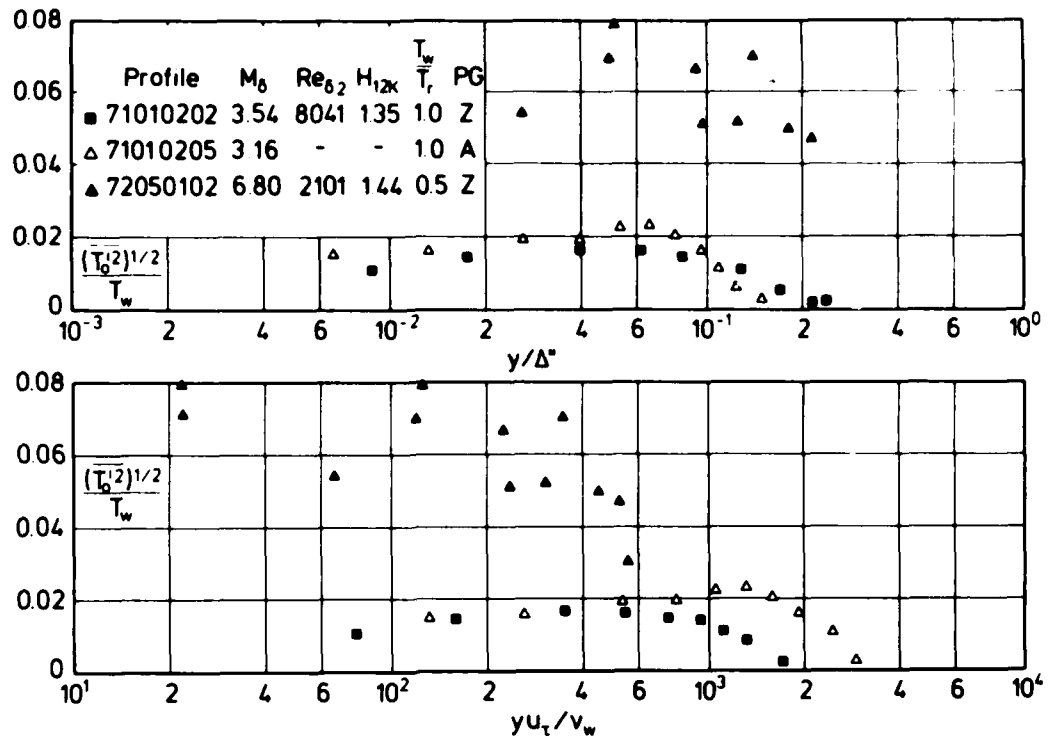


Fig. 3.4.1 Total temperature fluctuations in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined).

by T_0 they would have to be divided by two and would have had about the same maximum level for $(T_0^{\overline{T^2}})^{1/2}$ as Sturek's data at about half the free-stream Mach number. It is therefore at least doubtful whether Kistler's measurements above suffice to allow the conclusion that the level of the total temperature fluctuations increases with Mach number.

With the assumption that $(T_0^{\overline{T^2}})^{1/2} / T_0$ is an order smaller than the two remaining terms in eqn.(3.4.1) one can write

$$\frac{(T_0^{\overline{T^2}})^{1/2}}{T} = -(\gamma-1)\bar{M}^2 \frac{(\overline{u'^2})^{1/2}}{\bar{u}} \quad (3.4.2)$$

and, neglecting pressure fluctuations and second order terms, such as $\bar{\rho'^2 T}$, eqn.(3.4.2) yields

$$\frac{(T_0^{\overline{T^2}})^{1/2}}{T} = -\frac{(\overline{\rho'^2})^{1/2}}{\bar{\rho}} = -(\gamma-1)\bar{M}^2 \frac{(\overline{u'^2})^{1/2}}{\bar{u}} \quad (3.4.3)$$

Eqn.(3.4.3) was given by Morkovin (1960 eqn.8) and was later called Morkovin's hypothesis by Bradshaw & Ferriss (1971) who deduced from this equation that if $(\overline{\rho'^2})^{1/2} / \bar{\rho}$ is small the turbulence structure is not affected by compressibility effects.

Though the Mach number distribution reaches its maximum in the outer region of a compressible boundary layer, velocity fluctuations^{*)} become small there and therefore the static temperature fluctuations also remain small.

^{*)} Fig. (3.1.2) shows that the fluctuating velocity component u' becomes small if one considers that $u_t/u_\delta = 0.035$ and 0.046 for profiles 58030101 and 58030301 respectively.

This means that nowhere in the boundary layer should the fluctuations of the static temperature become larger than about 0.1.

The static temperature-fluctuation distributions are plotted against y^+ and y/Δ^* in Fig. (3.4.2) and confirm the reasoning which we have just made, at least in the parameter range available to us. Profile 71010205 was measured in an adverse pressure gradient boundary layer but it does not show a marked difference to the zero

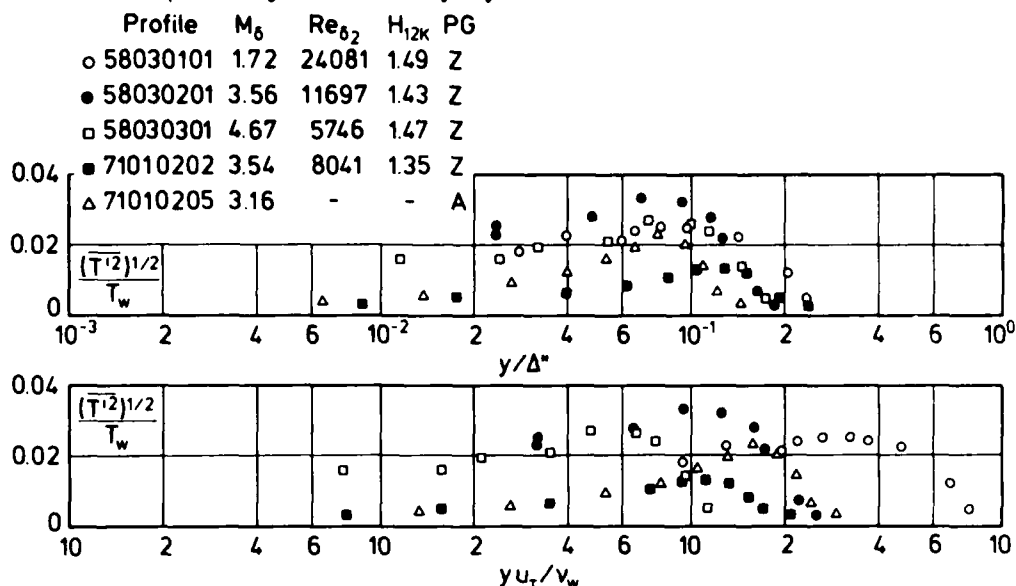


Fig. 3.4.2 Fluctuations of static temperature in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined).

pressure gradient cases. No Mach or Reynolds number effects can be recognized and we do not claim a similarity behaviour, not even in the y/Δ^* plot.

Fig. (3.4.3) finally gives the local "temperature turbulence level" which shows a certain influence of the Mach number on the peak level of the fluctuation distribution. Again the temperature fluctuations lie within the order of magnitude discussed above.

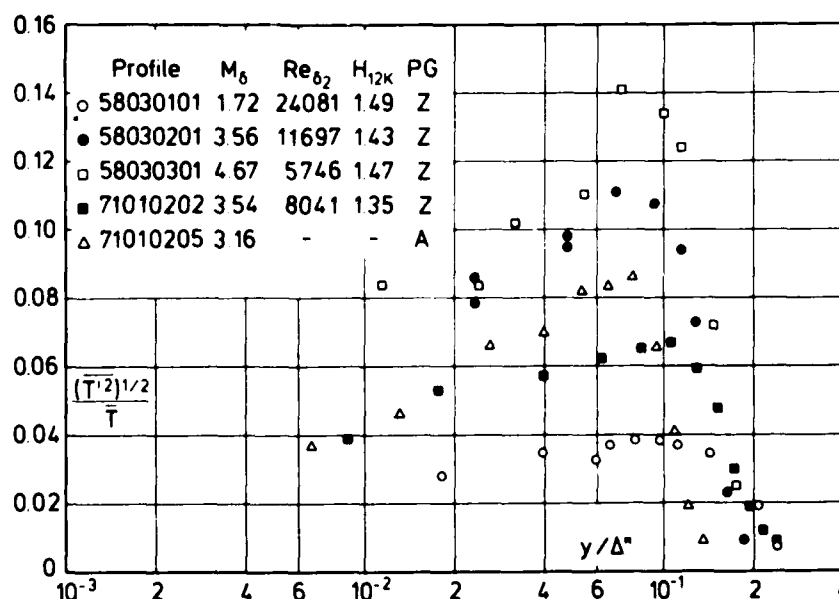


Fig. 3.4.3 Static temperature fluctuation distribution in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined).

4. TURBULENCE DATA - TWO COMPONENT TERMS

The system of conservation equations for compressible turbulent boundary layers can be closed if relationships for the shear-stress component $\bar{\rho} \overline{u'v'}$ and for either the heat-flux term $\bar{\rho} \overline{v'H'}$ - see eqns. (2.2.3) and (2.2.8) in AGARDograph 253 - or the turbulent Prandtl number Pr_t are known. Therefore the main aim in turbulence modelling consists of establishing such relationships, be it in the form of relatively unsophisticated Boussinesq or mixing length models or by using the transport equations for correlations of the various turbulence quantities. Comparisons with mean flow measurements have been made for various turbulence models used in numerical solution programmes by Marvin (1977), Rubesin et al. (1977), Horstman et al. (1978) and Viegas & Horstman (1979) for example.

These investigations show that our knowledge of the behaviour of the "two-component" correlations mentioned above is still incomplete and that we know little about the influence of such important parameters as Mach number, pressure gradient, heat transfer, Reynolds number, free-stream turbulence, wall roughness and wall curvature on the turbulence structure and especially on the shear stress distribution of compressible boundary layers. In this section we shall discuss the relatively few two-component correlation measurements with the main emphasis on the Reynolds shear stress component $-\bar{\rho} \overline{u'v'}$.

4.1 Distribution of Reynolds shear stress ($-\bar{\rho} \overline{u'v'}$) in a compressible two-dimensional boundary layer

Three main avenues have been explored so far so as to gain some insight into the shear stress distribution of a compressible turbulent boundary layer.

Two methods for the determination of the Reynolds shear stress distribution use the mean momentum equation for compressible boundary layers and evaluate the individual terms by either inserting semi-empirical relationships for the mean velocity and density or mean flow measurements of these two quantities. The third method attempts to measure the shear-stress distribution directly by means of hot-wire or laser-Doppler anemometry. These measurements are very difficult to perform - both as far as the design and lifetime of the probes is concerned and in consequence of uncertainties in how the probe signals should be interpreted (e.g., Laderman, 1978c). The meaning of some of these measurements is still highly controversial. We will therefore confine our discussion to those measurements which we think we understand leaving many others to a later critical review.

The qualitative behaviour of the total shear stress

$$\tau = \mu(\partial \bar{u}/\partial y) - \bar{\rho} \overline{u'v'} \quad * \quad (4.1.1)$$

across the boundary layer can be predicted from knowledge of the shear stress and its slope at the wall and at the outer edge of the boundary layer. At the wall the shear stress is equal to the skin friction τ_w , and its slope is determined by

$$(\partial \tau / \partial y)_w = dp/dx \quad (4.1.3)$$

Equation (4.1.3) follows from the momentum equation if the boundary conditions at the wall are inserted. At the outer edge of the boundary layer both the magnitude and the slope of the shear stress are zero.

In Fig. (4.1.1) we have presented the three qualitative shear stress distributions for zero, positive and negative pressure gradients and their slope at the wall. The total shear stress τ as defined by eq. (4.1.1) contains two terms, the molecular shear stress which dominates close to the wall (viscous sublayer) and then decays rapidly, and the Reynolds shear stress τ_t which is zero at the wall, increases to a maximum value in the log-law region and then decreases to zero at the outer edge of the boundary layer.

The reader should keep this qualitative behaviour of the shear stress distribution in mind in order to make it easier to follow the subsequent discussion, which will begin with zero-pressure gradient boundary layers and continue with flows in an adverse pressure gradient.

* The complete expression for the total shear stress containing smaller order terms was given by van Driest (1951) and reads

$$\tau = \mu(\partial \bar{u}/\partial y) - \bar{\rho} \overline{u'v'} - \bar{v} \overline{\rho'u'} - \bar{\rho}' \overline{u'v'} \quad (4.1.2)$$

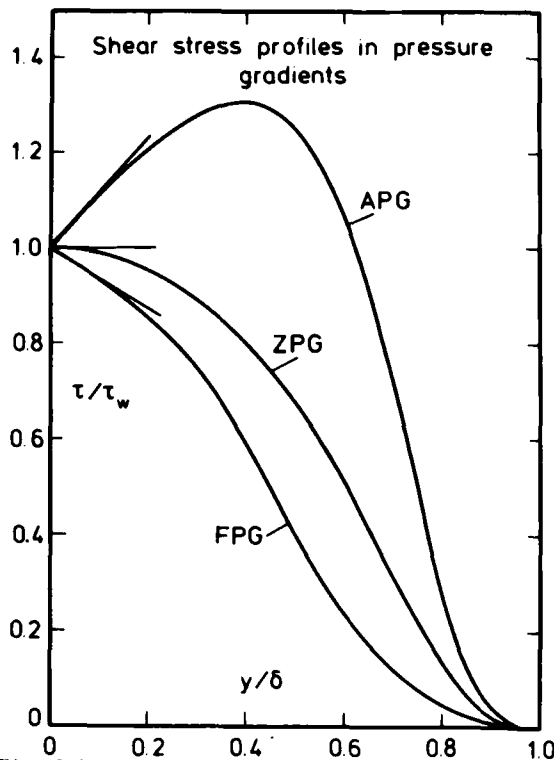


Fig. 4.1.1 Sketch to show the variation of shear stress profiles in a boundary layer in favourable (FPG), zero (ZPG) and adverse (APG) pressure gradients (shock free flow).

relatively thick and may even occupy the greater part of the boundary layer.

We first consider the influence of Mach number, Reynolds number and heat transfer on the shear-stress distribution.

Maise & McDonald (1967) calculated the shear-stress distributions for Mach and Reynolds numbers in the range $0 \leq M_\delta < 5$ and $10^3 \leq Re_\delta < 10^5$ by assuming a semi-empirical relationship for the velocity distribution and the Crocco relationship for the density-velocity distribution. The shear-stress distribution of Maise & McDonald, however, has a small disadvantage in that it approaches zero at $y/\delta = 1$ with a finite slope and thus does not fulfill the boundary layer conditions correctly. The main result of this early investigation was that it showed little effect of either the Mach or the Reynolds number on the total shear stress distribution in turbulent boundary layers along adiabatic walls. Other evaluations of eqn. (4.2.2) which include also cases with heat transfer along isothermal walls have used an assumption of similarity. This means for example that the velocity profiles $\bar{u}/u_\infty$ collapse on to a single curve when plotted as $\bar{u}/u_\infty$ against y/δ_2 (Squire 1971). Meier & Rotta (1970, 1971) assume that $\bar{u}/u_\delta$ and $\bar{\rho}/\rho_\delta$ are functions of the dimensionless wall distance y/δ only, i.e., that the velocity and temperature profiles are self-similar in the x direction.* They introduce $(\bar{\rho}\bar{u}/\rho_\delta u_\delta)$ as a function $F(\xi)$ with $\xi = y/\delta$ and obtain from eqn. (4.2.3)

$$\frac{\tau}{\rho_\infty u_\infty^2} = - \left[\frac{c_f}{2\delta_2} \frac{\bar{u}}{u_\infty} \int_0^y \frac{\bar{\rho}\bar{u}}{\rho_\infty u_\infty} dy - \int_0^y \frac{\bar{\rho}\bar{u}^2}{\rho_\infty u_\infty^2} dy \right] + C_1 \quad (4.2.4)$$

where C_1 is determined by the boundary conditions at the outer edge $y = \delta$ and $\tau_t = 0$. No reason is given for the choice of these unusual boundary conditions (Rotta 1964 has also used it for temperature distributions). The derivation of eqn. (4.2.4) can be understood more easily if one remembers that

$$\frac{d}{dx} \left(\frac{\delta_2}{\delta} \delta \right) = \frac{\delta_2}{\delta} \frac{d\delta}{dx} + \delta \frac{d(\delta_2/\delta)}{dx} \quad \text{and, with the second term zero for the locally selfsimilar flow } (\delta_2/\delta \text{ is}$$

assumed independent of x),

* It should be noted that, strictly, none of these forms of self-similarity can apply to even the zero pressure gradient case as such quantities as δ_2/δ are functions of Reynolds number.

4.2 Indirect determination of shear stress

4.2.1 Zero pressure gradient cases

The total shear stress distribution in a steady compressible constant pressure boundary layer can be calculated from the equation of motion (e.g., Sandborn, 1974) yielding

$$\tau = \tau_w + \int_0^y \left[\frac{\partial}{\partial x} (\bar{\rho} \bar{u}^2) - \frac{\partial}{\partial y} (\bar{\rho} \bar{u} \bar{v}) \right] dy \quad (4.2.1)$$

or, if the continuity equation is substituted into (4.2.1)

$$\tau = \tau_w + \int_0^y \frac{\partial}{\partial x} (\bar{\rho} \bar{u}^2) dy - \bar{u} \int_0^y \frac{\partial}{\partial x} (\bar{\rho} \bar{u}) dy \quad (4.2.2)$$

with the equivalent form

$$\frac{\tau}{\tau_w} = 1 + \frac{2}{c_f \rho_\delta u_\delta^2} \left[\int_0^y \frac{\partial}{\partial x} (\bar{\rho} \bar{u}^2) dy - \bar{u} \int_0^y \frac{\partial}{\partial x} (\bar{\rho} \bar{u}) dy \right]. \quad (4.2.3)$$

In eqn. (4.2.3) c_f is sometimes substituted by $2 d\delta_2/dx$ with δ_2 as the momentum defect thickness.

As mentioned above the molecular part of the shear stress, $\mu(\partial\bar{u}/\partial y)$ plays a role only in the immediate vicinity of the wall. It is therefore often neglected outside the viscous sublayer and τ is set equal to τ_t . Such a simplification may however lead to substantial errors in boundary layers at high Mach numbers and small Reynolds numbers where the viscous sublayer can become

$$\frac{d\delta_2}{dx} = \frac{\delta_2}{\delta} \frac{d\delta}{dx} = \frac{c_f}{2} \quad \text{and}$$

$$\delta^{-1} \frac{d\delta}{dx} = (c_f/2\delta_2) \quad (4.2.5)$$

The following relationship is also used

$$\int_0^y \frac{\partial F}{\partial x} dy = -\delta^{-1} \frac{d\delta}{dx} \int_0^y \frac{\partial F}{\partial y} y dy = -\delta^{-1} \frac{d\delta}{dx} \left[Fy \Big|_0^y - \int_0^y F dy \right] \quad (*) \quad (4.2.6)$$

The evaluation of Meier's (1970) measurements along an adiabatic wall resulted in a spreading of the shear-stress profiles in the wall region - $\tau/\rho_\delta u_\delta^2$ against y/δ - i.e., showed a decrease of the shear stress maximum ($\tau_w/\rho_\delta u_\delta^2$) with increasing Mach number in the range $2.25 \leq M_\delta \leq 4.50$, and a collapse of the profiles onto each other in the outer region. Such a decrease in $c_f/2$ with Mach number is well known from theoretical considerations, and the collapse of the profiles in the outer region is probably no more than a consequence of the similarity assumption.

Bushnell & Morris (1971 a and b) have extended the above parameter range to boundary layers with heat transfer, small pressure gradients and small transverse curvature effects. For this purpose an extended evaluation equation was derived - eqn. 4 of the original paper - assuming local similarity in y/δ coordinates with δ taken at the value of y for which $\bar{\rho}/\rho_\delta = 0.995$. The shear-stress distributions which they calculated are shown in Fig. (4.2.1) from the data presented in AGARDograph 223. In no case had skin friction been measured, and in two cases at least (Jones & Feller, 1970, Lee et al., 1969) it is doubtful whether the assumption of local similarity holds. For this latter reason we have excluded the measurements by Perry (1968, see also Perry & East 1968). Additionally we may notice from table 4.2.1 that the distances between profiles - given as $\Delta x/\delta_0$ - are rather large for a calculation of derivatives and not spaced as closely together as those used by Meier & Rotta (1971). Therefore we must wonder how Bushnell & Morris arrived at such smooth curves with such small discrepancies at the outer edge (c.f. Laderman, 1979 and 1980, and the authors' own experience, which confirms Laderman's findings).

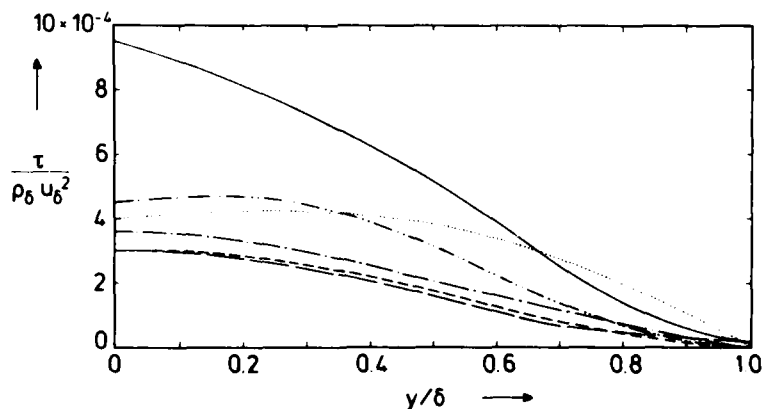


Fig. 4.2.1 Calculated shear-stress distributions in compressible turbulent boundary layers from Bushnell & Morris (1971) (zero pressure gradient, adiabatic and isothermal wall).

---- Adcock et al. (1965), — Danberg (1967), - · - · - Jones & Feller (1970),
- - - Lee et al. (1969), - - - Samuels (1969).

$$*) \quad \frac{\partial F}{\partial x} = \frac{dF}{d\xi} \left(\frac{\partial \xi}{\partial x} \right)_y \quad \frac{d\delta}{dx} = \frac{dF}{d\xi} \left(-\frac{y}{\delta^2} \right) \frac{d\delta}{dx} = \frac{dF}{d\xi} \left(-\frac{y}{\delta} \right) \frac{\partial \xi}{\partial y} \frac{d\delta}{dx} = -\frac{y}{\delta} \frac{d\delta}{dx} \frac{dF}{d\xi} \frac{\partial \xi}{\partial y} = -\delta^{-1} \frac{d\delta}{dx} \frac{\partial F}{\partial y} y \quad \text{and}$$

$$(Fy)' = \frac{\partial F}{\partial y} y + 1 \cdot F \quad \text{or} \quad Fy \Big|_{y_1}^{y_2} = \int_{y_1}^{y_2} \frac{\partial F}{\partial y} y dy + \int_{y_1}^{y_2} F dy$$

Table 4.2.1

Author	profile	M_δ	Re_δ	T_w/T_r	$\Delta x/\delta_0$	c_f
Adcock et al. --- (CAT 6501)	6501-0107	6.02	13341	≈ 1	7	NM
Danberg (CAT 6702)	6702-0103	6.54	2574	0.52	3	NM
Jones & Feller ---- (CAT 7002)	7702-0102	5.76	9718	0.81	≈ 20	NM
.	7002-0303	5.75	46425	0.77	-	NM
Lee et al. (1969) — . —	-	4.67	57000	-	-	-
Samuels et al. — (CAT 6701)	6701-0103 or 0104	5.98	10863	0.49	≈ 9	NM

Data reconstruction for Bushnell & Morris' (1971a) shear-stress calculations.

These observations should be borne in mind if one considers Sandborn's conclusion of the existence of a "best estimate." In his survey paper on compressible turbulent boundary layers Sandborn (1974) plotted the above shear-stress distributions as τ/τ_w versus y/δ , added data at a Mach number 7.2 obtained by Horstman & Owen (1972) at intervals of $\Delta x/\delta_0 \approx 20$ and data measured and evaluated by Meier & Rotta (1971). Sandborn found only small variations between the calculated shear stress profiles and was thus able to construct a "best estimate" for the shear distribution. He states: "Between the different sets of measurements it was not possible to identify consistent Mach number or Reynolds number variations... This survey suggests that the general magnitude of the shear-stress distribution across a supersonic, adiabatic zero pressure gradient turbulent boundary layer can be estimated from mean flow data to within approximately $\pm 15\%$. The general observation of Morkovin (1962, 1964) that compressibility effects on the turbulence are 'passive' appears to be valid for the shear-stress distribution. It is possible that the incompressible, zero pressure gradient, shear-stress distribution is an adequate model for the super- and hypersonic flows, at least up to Mach number 7" (cf. Fig. 4.2.2 taken from Sandborn). Sandborn further ventures an explanation for this behaviour: "The probability exists that since all the evaluations employ a similarity approximation, the resulting distribution must be locked to a similarity shape. Obviously, the fixing of the distribution to $\tau/\tau_w = 1$ at $y/\delta = 0$ and $\tau/\tau_w = 0$ at $y/\delta = 1$, together with a zero slope at $y/\delta = 0$ makes large variations unlikely."

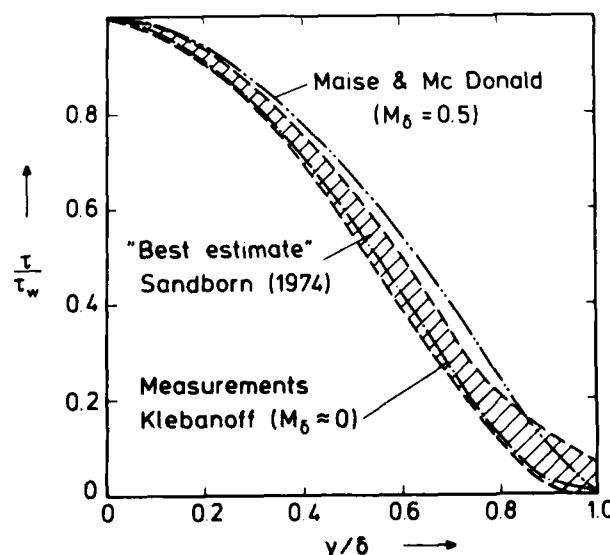


Fig. 4.2.2 Comparison of "estimated" supersonic shear stress with measurements in incompressible flow and the empirical prediction of Maise & McDonald (1967). (Figure from Sandborn 1974).

In the meantime further evaluations of shear-stress distributions from mean flow data have been published. Watson (1978) showed that shear-stress distribution at a Mach number 11, a heat transfer parameter in the range $0.38 \leq T_w/T_r \leq 1$, and at Reynolds numbers Re_{δ_2} below 2000 were above the subsonic flow data of Klebanoff (1955) - see the curve in Fig. (4.2.2) - but in general agreed with the body of data presented by Sandborn (1974). The boundary layer thickness used as the characteristic length scale was determined in this case as lying between the velocity and the pitot thickness and appeared to have played an important role in the calculation procedure. Other indirect shear-stress evaluations which again agree approximately with the "best estimate" or with Klebanoff's distribution are those by Mikulla & Horstman (1975) and by Collins et al. (1978), the former measurements at $M_\delta = 6.9$ along a cooled wall, the latter in a range $0.1 \leq M_\delta \leq 2.2$ along an adiabatic wall (see Dimotakis et al. 1979).

4.2.2 Adverse pressure gradient cases

In section 4.1 we described, in general terms, the constraints on the total shear-stress profile in a boundary layer. In a shock free flow these lead to shear-stress profiles similar to those found in incompressible flow, as sketched in Fig. (4.1.1). As we pointed out in section 5.1 of AG 253, there are features of compressible flows with pressure gradients which do not always have an equivalent in incompressible flow. For instance a boundary layer in a strong adverse pressure gradient becomes thinner and exerts an increased shear stress on the wall as a result of bulk compression. It is advisable to entertain some caution in comparing shear-stress distributions and we will distinguish between the three types of flows for which shear-stress distributions have become available. Of those for which mean-flow derived profiles have been published, the flows on curved ramps (Sturek & Danberg, 1971b, CAT 7101; Laderman, 1978b, CAT 7803S) are simple wave flows with pronounced streamline curvature and normal pressure gradients. The straight-wall flows of Zwarts (1970, CAT 7007), Peake et al. (1971, CAT 7102) and Lewis et al. (1972, CAT 7201) are reflected wave cases in which much of the flow should be free of pronounced curvature or normal pressure gradients. Shock-boundary layer interaction cases do not lend themselves to mean flow analysis.

The shear-stress distribution across a compressible adverse pressure-gradient boundary layer can be determined from the equation of motion and from closely spaced mean flow measurements of velocity and density. Such an evaluation is however more difficult than for a ZPG boundary layer, and it is difficult to ensure that the calculated shear-stress distributions meet the boundary conditions on both edges of the boundary layer (Sturek 1973a and Laderman 1978b).

Sturek (1973a, 1974) has derived a relationship for the turbulent shear stress τ_t in which he also considered effects of longitudinal wall curvature

$$\frac{\tau_t}{\tau_w} = \frac{1}{\tau_w} \left\{ \tau_w + \int_0^y \beta \frac{\partial}{\partial x} (\bar{\rho} \bar{u}^2) dy - \bar{u} \beta \int_0^y \frac{\partial}{\partial x} (\bar{\rho} \bar{u}) dy - 2 \int_0^y \left[\int_0^y \frac{\partial}{\partial x} (\bar{\rho} \bar{u}) dy \right] \bar{u} \beta^2 R^{-1} dy + \frac{dp}{dx} \int_0^y \beta dy \right\} \quad (4.2.7)$$

by using the equations for continuity and momentum in the form

$$\frac{\partial}{\partial x} (\bar{\rho} \bar{u}) + \frac{\partial}{\partial y} \beta^{-1} (\bar{\rho} \bar{v} + \bar{\rho}' \bar{v}') = 0 \quad (4.2.8)$$

$$\beta \bar{\rho} \bar{u} \frac{\partial \bar{u}}{\partial x} + (\bar{\rho} \bar{v} + \bar{\rho}' \bar{v}') \left(\frac{\partial \bar{u}}{\partial y} + \bar{u} \beta R^{-1} \right) = -\beta \frac{dp}{dx} + \frac{\partial}{\partial y} \left(\mu \frac{\partial \bar{u}}{\partial y} - \bar{\rho} \bar{u}' \bar{v}' \right) \quad (4.2.9)$$

where $\beta = (1+y/R)^{-1}$.

We discuss first the two simple-wave ramp-flow cases, for which no directly measured Reynolds shear stresses are available. Sturek (1973a, 1974) calculated three shear-stress distributions as shown in Fig.(4.2.3). Values of the partial derivatives have been determined along lines of constant mass flux using a least square technique which fits a parabola to the data. Since initial efforts to calculate the shear-stress distribution resulted in profiles with a large (about $6 \tau_w$) negative value in the vicinity of the boundary layer outer edge it was found that the partial derivatives at the outer edge could be in error by as much as +30%. The partial derivative of mass flux was therefore corrected in an "empirical but consistent manner." These profiles then fulfill the boundary condition at the wall, $\partial \tau / \partial y = dp/dx$, and at the outer edge with a slope tending towards zero. The trend of the three shear-stress distributions agrees qualitatively with that observed in the early stages of subsonic adverse pressure-gradient boundary layers in that the maximum of the shear stress increases and moves away from the wall into the boundary layer.

An experiment similar to that of Sturek was performed by Laderman (1978b and 1979) who investigated two adiabatic boundary layers growing over curved walls (ramps) at a nominal Mach number of 3. Laderman calculated 17 shear stress profiles using eqn.(4.2.7) but did not correct his profiles to make τ_t tend to zero for $y \rightarrow \delta$. One might agree with him that there is "no rationale for changing only one of the derivative terms, $(\partial(\bar{\rho} \bar{u})/\partial x)$, to the exclusion of others."

The effect of pressure gradient on the turbulent shear stress was summarized by Laderman as follows. "The stress distribution is extremely sensitive to dp/dx with the peak value of τ_t/τ_w rising from 60 to 300% above the wall value for the weak-to-moderate pressure gradients used in the present tests. It should be emphasized that, while τ_t/τ_w versus y is invariant with x location, the absolute magnitude of τ_w increases with x ."

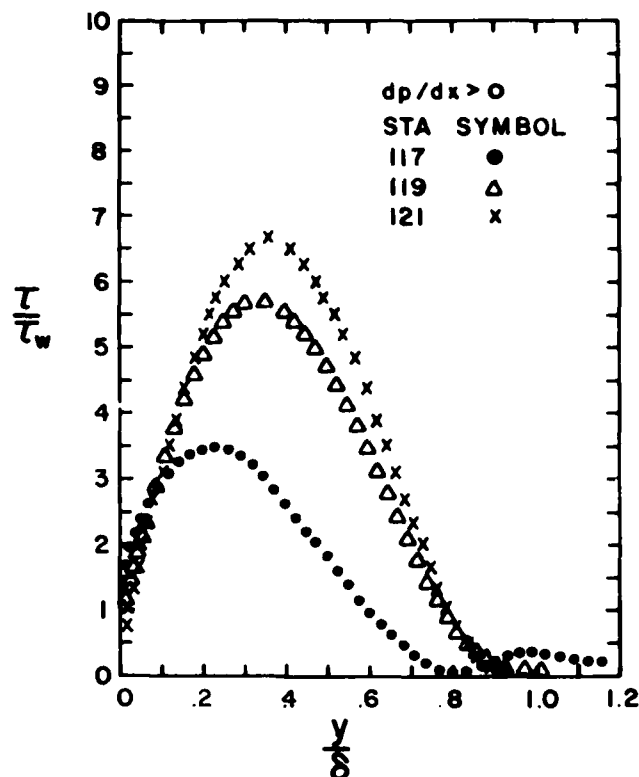


Fig. 4.2.3 Shear-stress distributions calculated from mean flow measurements (adiabatic wall, ramp flow). Taken from Sturek (1973a).

From among the reflected wave cases the experimental investigation by Lewis et al. (1972, CAT 7201) includes mean flow profiles in zero, adverse and favourable pressure gradients. Wilcox & Rubesin (1980) calculated the respective shear stress distributions from the mean flow data and found qualitative agreement with the sketched curves shown in Fig. (4.1.1) which are characteristic of the three types of pressure gradients.

The latter authors have also compared various semi-empirical relationships with the evaluated shear-stress profiles and found "no good agreement" between theory and experiment. They state that the error introduced by the evaluation methods permits assessment of the turbulence models to about $\pm 15\%$ which is fairly close to the $\pm 20\%$ estimated as the uncertainty for local shear-stress measurements by Acharya et al. (1978).

A comparison between the results of several boundary layer calculation methods and shear-stress distributions across compressible turbulent boundary layers evaluated from the mean flow measurements of Zwartz (1970, CAT 7007), Peake et al. (1971, CAT 7102), Sturek & Danberg (1971b, CAT 7101) and Lewis et al. (1972, CAT 7201) can be found in a paper by Rubesin et al. (1977).

4.3. Direct measurements of the Reynolds shear stress ($-\bar{\rho} \overline{u'v'}$) - available data

Table (4.3.1) gives a survey of measurements of Reynolds shear stress ($-\bar{\rho} \overline{u'v'}$) in compressible turbulent boundary layers by means of hot-wire anemometers and laser-Doppler velocimetry. The investigations are listed in order of date for identifiable groups of investigators. We have not separated zero and adverse pressure-gradient flows from each other since some of the important investigations contain data in both types of flow. Unfortunately few investigators have provided tabulated data so that we had to take a few essential measurements from figures in publications. This is against our stated principle (cf. AGARDograph 223) but appears to be permissible here since the experimental uncertainties in the fluctuating flow-field quantities due to the various assumptions employed and calibration errors are $\pm 20\%$ for the turbulent shear stress (Acharya et al. 1978). A closer look at some of the subsequent investigations makes this appear a conservative estimate.

A comparison of the investigations presented in Table (4.3.1) with those used by Sandborn (1974) in his earlier survey shows that the majority of measurements in the table were performed after 1974 so that a new discussion is certainly appropriate.

Table 4.3.1

Author	M_δ	Heat transfer	Re number	No of $\overline{u'v'}$ profiles	Probe	Anemometer, wall geometry, pressure gradient
Demetriades & Laderman (1973b) Mean flow data in Laderman & Demetriades (1971) $\overline{u'v'}$ data corrected in Laderman & Demetriades (1979)	9.4	Cooled	37×10^3 Re_θ	1	X-wire	CCHWA. Nozzle wall, ZPG
Laderman (1976) and (1978a) $\overline{u'v'}$ data corrected in Laderman & Demetriades (1979)	7.1	AW Cooled	$1.4 - 2 \times 10^3$ Re_θ	2	X-wire	CCHWA, Cone, ZPG
Laderman (1978a) and Laderman & Demetriades (1979) Mean flow data in Laderman (1978a)	3	AW Cooled	6.57×10^6 Re/m	2	X-wire	CCHWA, flat plate ZPG
Rose (1973, 1974) CAT 7306 S	3.9	AW	17×10^6 Re/m	12	-	CTHWA axisym. nozzle wall. APG
Rose & Murphy (1973) Mean flow data in Rose (1973, 1974)	3.9	AW	8.7×10^4 Re_δ	5	No information	CTHWA, nozzle wall, shock/ boundary layer interaction. APG
Johnson & Rose (1973 and 1975)	2.9	AW	5.7×10^7 Re/m	1	Yawed wire, normal wire	CTHWA, LDV nozzle wall
Johnson (1974) ⁺ ⁺ Measurement is superceded by Johnson & Rose (1975) Mean flow data in Reda & Murphy (1973)	2.9	AW	5.7×10^7 Re/m	1	-	LDV(dual scatter) nozzle wall Nominally ZPG
Rose & Johnson (1975)	2.9	AW	1.4×10^6 Re_δ	2	X-wire	CTHWA and LDV Nozzle wall. ZPG, APG. Shock/boundary layer interaction
Yanta & Lee (1974) and Yanta & Crapo (1976) Mean flow data in report (see also Lee & Smith 1974)	3	AW	14×10^3 Re_θ	8	-	LDV (dual scatter) flat nozzle wall nominally ZPG
Mikulla & Horstman (1975) Mean flow data in Horstman & Owen (1972, CAT 7205). See also Owen & Horstman (1974)	6.9	Cooled	2×10^5 Re_δ	1	Ceramic wedge probes	CTHWA, cone-ogive cylinder ZPG
Mikulla & Horstman (1976)	6.9 6.7	Cooled	9×10^3 Re_θ	8	Ceramic wedge probe	CTHWA cone-ogive cylinder
Mikulla (private communication) Mean flow data in Marvin et al. (1975) and in Kussoy & Horstman (1975, CAT 7501 S)	"	"	"	tabulated data		ZPG, APG, shock boundary-layer interaction
Horstman & Rose (1977)	0.78	AW	4×10^5 Re_δ	1	Dual film sensor	CTHWA. Tunnel side wall. ZPG.
Kussoy et al. (1978, CAT 7802 S) Acharya et al. (1978) Mean flow data in the same report	2.3	AW	$4 - 106 \times 10^6$ Re/m	26	Ceramic wedge probe (single and dual wire probes)	CTHWA, axisymmetric constant diameter tube, ZPG, APG, FPG.
Gootzait & Childs (1977) Mean flow data in the same report and in Gootzait (1976)	3.9	AW	-	2 ZPG 6 APG	Single wire	CTHWA, axisym. wind tunnel wall APG, ZPG
Mateer, Brosh, Viegas (1976) and	1.4	AW	3.7×10^7 Re_x	7	Ceramic wedge probe	CTHWA, axisym. pipe flow. APG. Shock boundary layer interaction.

Table 4.3.1 (cont.)

Author and	M_δ	Heat transfer	Re number	No. of $u'v'$ profiles	Probe	Anemometer, wall geometry, pressure gradient
Mateer & Viegas (1979) Mean flow data in (1976) report and private communication (see CAT 8001 S)						
Dimotakis, Collins Lang (1979)	0.1-2.2	AW	23-40 $\times 10$ Re_0	10	-	LDV flat plate and ceiling boundary layer
Mean flow data in Collins et al. (1978, CAT 7801 S) For a critique of data see Schairer (1980)						

An anomaly exhibited especially by some of the earlier shear-stress measurements is that the maximum value of $-\bar{\rho} \overline{u'v'}$ occurs much further away from the wall than is expected for flows at constant pressure (as compared with Klebanoff's measurement in subsonic flow) and some authors suggest (see Sandborn 1974) that density fluctuations may contribute substantially to the turbulent shear stresses near the wall. This suggestion is based on an inspection of the complete expression for the turbulent shear stress (Hinze 1956):

$$\tau_t = -\left[\bar{\rho} \overline{u'v'} + \bar{u} \overline{\rho'v'} + \bar{v} \overline{\rho'u'} + \bar{\rho}' \overline{u'v'}\right] \quad (4.3.1)$$

As Dimotakis et al. (1979) note correctly such a conjecture is in direct opposition to the conclusion by Morkovin (1962) that effects of density fluctuations should be small compared to effects of variation in mean density for Mach numbers up to 5. The same authors have carefully analyzed their own LDV shear stress measurements and arrive at the conclusion that the departure of the Reynolds stress from the expected value near the wall is independent of Mach number ($0.1 \leq M_\delta \leq 2.2$) and is a consequence of particle depletion near the wall which is unique to boundary layers in air.

It is interesting to set against these findings recent results published by Schairer (1980), who performed measurements in a subsonic boundary layer almost identical to that of Klebanoff, using laser-Doppler velocimetry. His turbulent shear stress measurements do not decrease close to the wall, some values being even higher than those of Klebanoff. Schairer gives the scatter of the shear stress measurements near the wall as being roughly 20% of the mean shear stress at the wall and states that conclusions based on these data are highly speculative. He offers, however, an explanation for the discrepancies found with earlier LDV measurements: "Unlike the measurements of those reporting dropoff in shear stress near the wall, the measurements reported here were made with a laser velocimeter that produced moving interference fringes (Bragg cell). An argument is presented suggesting that, if $\overline{u'v'}$ is negative and the turbulence intensities are high enough, measurements of shear stress near the wall made with stationary fringes will be lower than the actual shear stress."

If Schairer's explanation proves to be correct for supersonic flows also, then the sharp decrease in $-\bar{\rho} \overline{u'v'}$ which can be noted in the shear stress measurements of Yanta & Lee (1974) is due to the same effect. In the latter experiment, in a compressible boundary layer along a straight adiabatic nozzle wall, the shear stress profiles begin to decrease from their maximum value towards the wall at y/δ values of 0.4 which is much too far out in a zero pressure-gradient boundary layer.

As for measurements of Reynolds shear stress by hot-wire anemometry, Mikulla & Horstman (1975) have emphasized two main problems which arise: "First, it is necessary to obtain accurate measurements of the cross correlations $\overline{(\rho u)'v'}$ and $\overline{T'_t v'}$. Indirect determination via the mode-diagram approach (cf. section 2) needs very accurate measurements which are difficult to obtain in part due to problems associated with wire strain gauging and vibration. These problems become more severe the higher the Mach number. Secondly, additional assumptions regarding the fluctuating flow field are required to deduce the Reynolds shear stress $-\bar{\rho} \overline{u'v'}$ from the above cross correlations." These specific problems appear to have been solved by Mikulla & Horstman, and their "post 1975" measurements should be free of these effects. It is questionable, however, whether this can be said of all other measurements. An instructive example of evaluation problems occurring in hot-wire anemometry when applied to supersonic flows may be seen by comparing Laderman & Demetriades (1973) and (1979).

We hope to have drawn the attention of those who intend to model turbulence quantities to some of the experimental problems which have to be surmounted and to the larger than usual uncertainty range for measurements of fluctuating quantities in supersonic boundary layers.

According to Morkovin (1960) the simplest conceivable statement of the supersonic - subsonic similarity for zero pressure gradient at high Reynolds numbers takes the form

$$\tau_t/\tau_w = -\bar{\rho} \overline{u'v'}/(\rho_w u_\tau^2) = -\bar{\rho} \overline{u'v'}/\tau_w = f(\eta) \quad (4.3.2)$$

$f(\eta)$ would represent a universal shear-stress distribution function obtainable, say, from Klebanoff's measurements (1955) at low speeds. Usually η is assumed to be y/δ but in compressible boundary layers the boundary layer thickness δ has been shown to be an ill-defined length scale (cf. section 7 of AG 253) and thus η is ill-defined. For zero pressure-gradient boundary layers any other integral thickness would be a better choice in terms of precision and Morkovin suggested for example the displacement thickness δ_{1K} at constant density. Other well defined length scales would be the momentum thickness δ_2 , the defect thickness Δ^* or the characteristic length of the inner region of the boundary layer v_w/u_τ .

It is also attractive to plot the specific shear stress as $-\overline{u'v'}/u_\tau^2$ which gives the distribution of the correlation $-\overline{u'v'}$ itself, independent of the density which may change considerably across the boundary layer. Finally some authors make the shear stress dimensionless by $\rho_\infty u_\infty^2$ where the index ∞ denotes some undisturbed state upstream of the region of investigation. Such a form lacks connection to local flow quantities but may be useful if the development of $-\overline{u'v'}$ is to be shown in the downstream direction, for example. We have chosen to present dimensionless "shear stress" in the forms $(-\bar{\rho} \overline{u'v'}/\rho_w u_\tau^2)$ and $(-\overline{u'v'}/u_\tau^2)$ in order to show possible similarities between measurements at different Reynolds number, Mach number and heat transfer parameter. As in the case of the normal stress components discussed in the previous chapter, we will test the measurements for inner and outer layer similarity by plotting these dimensionless quantities against $y^+ = y u_\tau/v_w$, y/Δ^* . The full treatment will only be given to zero pressure-gradient boundary layers, since we cannot expect similarity in flows with adverse or favourable pressure gradients unless the pressure gradient in the profiles considered is constant in properly scaled dimensionless form.

Our reservations as to the use of y/δ_2 as an appropriate scaling have been adequately expressed in the previous chapter.

4.4 Direct measurements of the Reynolds shear stress $(-\bar{\rho} \overline{u'v'})$ - zero pressure gradient boundary layers

From among the 95 Reynolds shear stress profiles listed in Table (4.3.1) there were only 7 profiles in a zero pressure gradient boundary layer where data were available in tabular form. Their parameter range is as follows: $2.3 \leq M_\delta \leq 6.8$, $1000 \leq Re_{\delta_2} \leq 16100$, and $0.5 \leq T_w/T_r \leq 1$. Five of these profiles were taken as probably free from severe upstream pressure-gradients effects in the tests by Rose (1973, CAT 7306S), Kussoy & Horstman (1975, CAT 7501S) and Kussoy et al. (1978, CAT 7802S) on the wall of an axisymmetric wind tunnel and one profile from the zero pressure-gradient region on a circular cylinder aligned with the flow (Horstman & Owen 1972, CAT 7205). The shear stress profiles given in CAT 7501S were provided by V. Mikulla & C.C. Horstman as a private communication and profile 72050102 was taken from Fig.8 of Mikulla & Horstman (1975). The mean flow profiles are those of CAT 7205 so we have classified these later turbulence data with the earlier entry. Since the Reynolds shear-stress profile measured in subsonic flow by Klebanoff (1955) is used so often for a comparison with supersonic flow data we have also included this profile. Again, the data had to be taken from Fig.(5) of the Klebanoff report.

The mean flow profiles which belong to the respective shear-stress profiles are plotted in Fig. (4.4.1). The shape parameter H_{12K} is typical for velocity profiles in a zero pressure gradient boundary layer, and the wake strength $\Delta(\bar{u}^*/u_\tau)$ is within the range of other measurements plotted in Fig. (3.3.5) or AG 253, except for profiles 72050201 and 75010101 which are too high by about 30%. The c_f values also seem to be almost 12% low.

Fig. (4.4.2b) shows the shear stress distribution plotted against $y u_\tau/v_w$, and no pattern of similarity can be observed except that the data with cooling which happen to have Reynolds number of approximately 2000 and a Mach number of about 7 form a group which is different from the adiabatic wall measurements at a much higher Reynolds number but lower Mach number. Only Klebanoff's measurements approach the expected limiting value of one for $|\bar{\rho} \overline{u'v'}/\rho_w u_\tau^2|$ in the wall region. The "left hand side" decrease of the shear stress profiles 78020101/0102 in the outer region and that of profiles 72050102, 73060101 and 75020302 in the inner region of the boundary layer apparently has no physical explanation at a point so far out in the boundary layer and must be caused by deficiencies in the measuring techniques. The trends which we have just described are confirmed by the distributions of the correlation $-\overline{u'v'}$ shown in Fig. (4.2.2a). Fig. (4.4.3) shows the same shear stress data plotted against y/Δ^* . A trend towards a similarity pattern can be observed in the outer region for

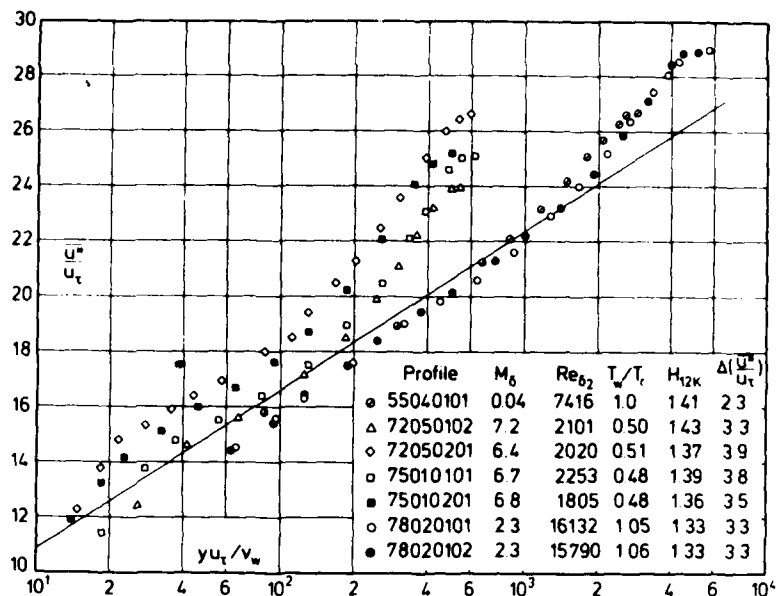


Fig. 4.4.1 Law of the wall for a compressible turbulent boundary layer with zero pressure gradient (origin not defined, adiabatic and isothermal wall).

Profile	M_δ	Re_{δ_2}	T_w/T_r	H_{12K}	
○ 55040101	0.04	7416	1.0	140	(Klebanoff 1955)
△ 72050102	6.8	2101	0.5	144	
x 73060101	3.9	1035	1.0	154	
□ 75010101	6.7	2253	0.5	139	
■ 75010201	6.8	1805	0.5	136	
○ 78020101	2.3	16132	1.0	133	
● 78020102	2.3	15790	1.0	133	

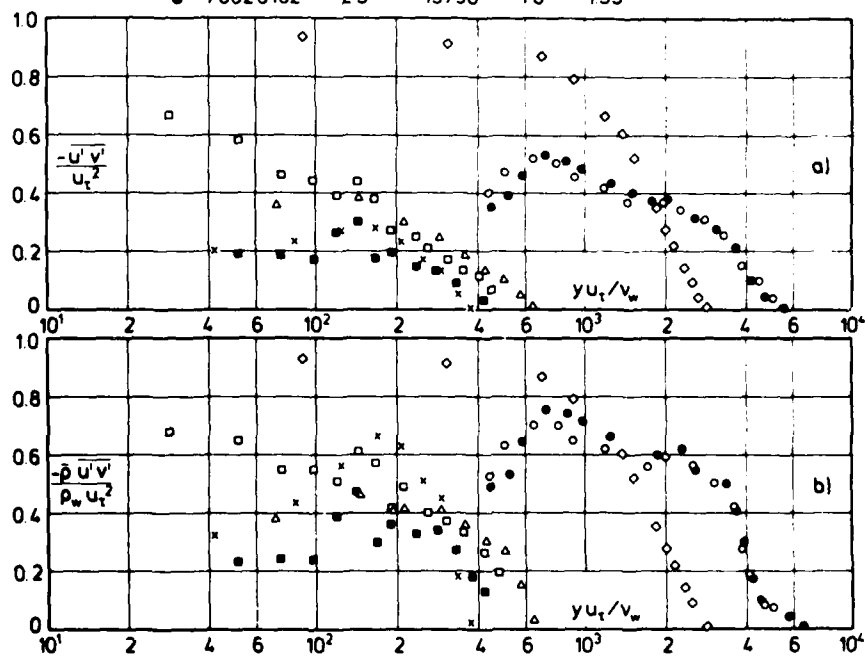


Fig. 4.4.2 a/b Reynolds shear stress distributions in a compressible turbulent boundary layer with zero pressure gradients (adiabatic and isothermal wall, origin not defined).

$-\bar{\rho} \overline{u'v'}$ (Fig. 4.4.3b) and less so for $-\overline{u'v'}$ in Fig. (4.4.3a). As in Fig. (4.4.2) we cannot discern systematic differences in the level of the individual profiles which might be caused by Mach number, Reynolds number or heat-transfer parameter effects.

Profile	M_0	Re_{δ_0}	T_w/T_t	H_{12K}
◇ 55040101	0.04	7416	1.0	140
△ 72050102	6.8	2101	0.5	144
× 73060101	3.9	1035	1.0	154
□ 75010101	6.7	2253	0.5	139
■ 75010201	6.8	1805	0.5	136
○ 78020101	2.3	16132	1.0	133
● 78020102	2.3	15790	1.0	133

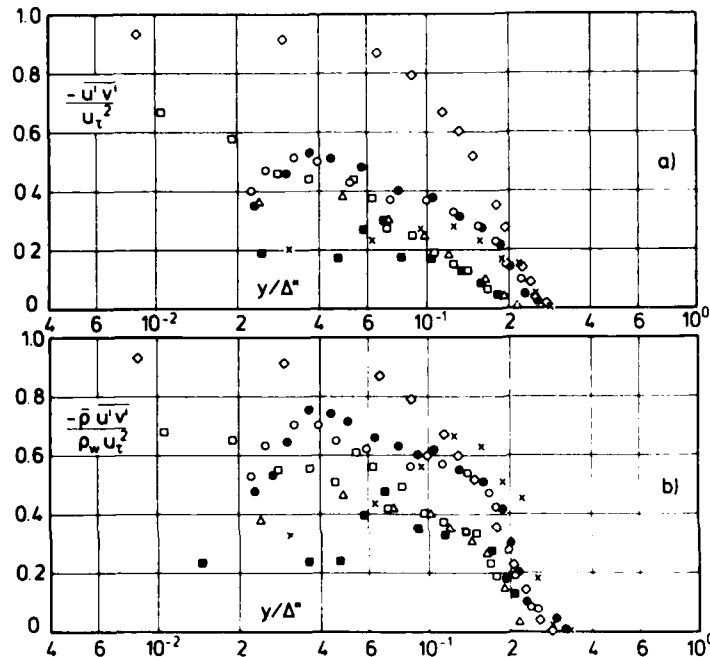


Fig. 4.4.3 a/b Reynolds shear stress distributions in a compressible turbulent boundary layer with zero pressure gradient (adiabatic and isothermal wall, origin not defined).

Demetriades (1979) - they cannot be considered here. Finally, Laderman & Demetriades (1979) have performed shear-stress measurements in an adiabatic and a cooled flat plate boundary layer at a Mach number 3. The cooled wall data in the "restored state" give fair agreement with the "best estimate" whereas the adiabatic wall data show considerable discrepancies. It is conceivable - though certainly not satisfactory - that error bands of $\pm 30\%$ are what we will have to live with using the measuring techniques at present available to us, but it seems important to make this quite clear to all those who seek to establish turbulence models based on turbulence measurements in compressible boundary layers.

We finally show a comparison between Reynolds shear-stress profiles measured by means of CT hot-wire and laser-Doppler anemometry (Fig. 4.4.4) and presented by Rose & Johnson (1975, Fig. 8). It is astonishing and encouraging at the same time to notice how small the differences are in the results obtained by both techniques. Here the turbulent boundary layer developed on the adiabatic wall of a planar wind-tunnel nozzle and test section. The incident shock wave was produced by a full-span generator set at 7° angle of incidence to the freestream flow, producing approximately a 2.5 to 1 pressure rise across the interaction. The profiles with zero pressure gradient which are of interest here were taken under conditions upstream of the incident shock wave of $M_\infty = 2.9$ and $Re_{\delta_0} = 1.4 \times 10^6$ at $x = 137$ mm.

Plotted against the outer-region coordinate y/Δ^* Klebanoff's profile taken in a subsonic boundary layer conforms well with the supersonic shear stress profiles.

We now attempt briefly to discuss those Reynolds shear stress measurements which were not available in tabulated form. A comparison with the data presented in figures (4.4.2) and (4.4.3) is difficult, however, since those data which are given in graphical form were all plotted against y/δ .

Extensive measurements of fluctuating quantities were carried out by Demetriades & Laderman (1973b, CAT 7403) and by Laderman (1976, 1978a). A revised version of these data was subsequently published by Laderman (1978c) and by Laderman & Demetriades (1979). A comparison of the revised data performed by the above authors with Sandborn's "best estimate" shows fair agreement but the range of the maximum and minimum values denoted by a vertical bar lies within $\pm 30\%$ which is unacceptably large (Laderman 1976, adiabatic cone boundary layer). The shear-stress data across the cooled cone boundary layer lie however considerably below the "best estimate", with uncertainties of the same magnitude as the above measurements. Next, there are shear-stress-measurements in a Mach 9.4 tunnel-wall boundary layer (Demetriades & Laderman 1973b). Because of their uncertainty range - even after the correction reported in Laderman &

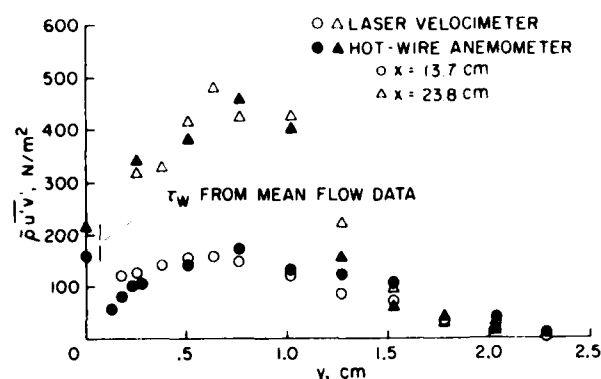


Fig. 4.4.4 Reynolds shear-stress distributions in a compressible boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Taken from Rose & Johnson (1975).

4.5 Direct measurements of Reynolds shear stress ($-\rho \overline{u'v'}$) - adverse pressure gradient boundary layers

At the start of section 4.2.2 we remarked that certain features of compressible flow did not have an equivalent in low speed flow. The most marked of these is the possibility of very concentrated streamwise pressure changes in centred expansions and, as an extreme, in shock waves. The discussion of cases for which direct shear stresses have been measured will begin with adverse pressure gradient reflected wave, straight wall cases without shocks before considering shock boundary layer interactions of increasing severity. There are no measurements in curved wall flows.

Gootzait & Childs (1977) measured the Reynolds shear stress in the boundary layer on the adiabatic wall of a cylindrical extension to an axisymmetric nozzle, where the pressure gradients were induced by contoured centre bodies mounted on the wind-tunnel centreline. Though the tunnel diameter was only 53 mm (as used by Rose, CAT 7306) and the boundary layer approximately 5 mm thick, shear stress profiles were measured at 8 positions with measurements as close as 0.5 mm to the wall. Since data are not available in tabular form it is difficult to compare them with other data under similar boundary conditions. The authors found reasonably good agreement between their fluctuation measurements and shear-stress distributions calculated by means of an integration of the mean flow equations using the semi-empirical relationship of Sun & Childs (1975). Qualitatively the turbulent shear stress increases with distance downstream from the beginning of the pressure rise, and the most marked increase in $-\rho \overline{u'v'}$ occurs near the middle of the boundary layer.

The following six case studies can be discussed in more detail since mean and fluctuating flow data are available in tabular form. In five boundary layer flows with varied pressure gradients, Reynolds normal stresses were measured besides the Reynolds shear stresses. The data already presented in section 3.2 should also, therefore, be borne in mind in the following discussion.

We begin again with the reflected wave case of Kussoy et al. (1978, CAT 7802S) where two centre bodies, sting mounted on the tunnel axis, were designed to impose shock-free compressions on the boundary layer (pressure distribution I, series 01, and pressure distribution II, series 02), followed where geometry allowed, by firstly a constant pressure region and finally an expansion (series 02). Measurements of the Reynolds shear stress $-\rho \overline{u'v'}$ were performed by means of dual ceramic wedge probes operated in the constant temperature mode. A discussion of the flow field and of the mean flow data can be found in AG 253 (Figs. 6.2.2 and 6.2.3) and in section 6 (CAT 7802S) where we give a corrected version of the inner and outer law plots. The experimental data were also compared with the results of four calculation methods in an investigation by Acharya et al. (1978).

The distributions of the Reynolds shear stress $-\rho \overline{u'v'}$ and the double correlation $\overline{u'v'}$ are plotted versus $y u_\tau / \nu_w$ in Fig. (4.5.1). The legend gives the Mach number at the beginning and the end of the pressure rise, the pressure distribution on the wall and the respective values of the skin friction velocity. The shear stress profiles react to the pressure increase downstream of 0104 by a sharp increase in level reaching a maximum value for profile 0111 (the maximum for $\overline{u'v'}$ was reached at 0108 and for $\overline{v'^2}$ with a double peak at 0109, Fig. 3.2.2), and with peaks of almost the same height for profiles 0108, 0109 and 0113. All shear stress distributions are typical of those in an adverse pressure gradient boundary layer in subsonic flow. What is less distinctly marked than in subsonic flow is the shift of the maxima towards the outer edge of the boundary layer.

In contrast to the distributions in zero pressure-gradient boundary layers both the $\overline{u'v'}$ and $\overline{u'^2}$ profiles show a similarity behaviour in the outer region which was quite unexpected. This is partly understandable since the Reynolds number hardly changes in the region investigated but we would have expected the large

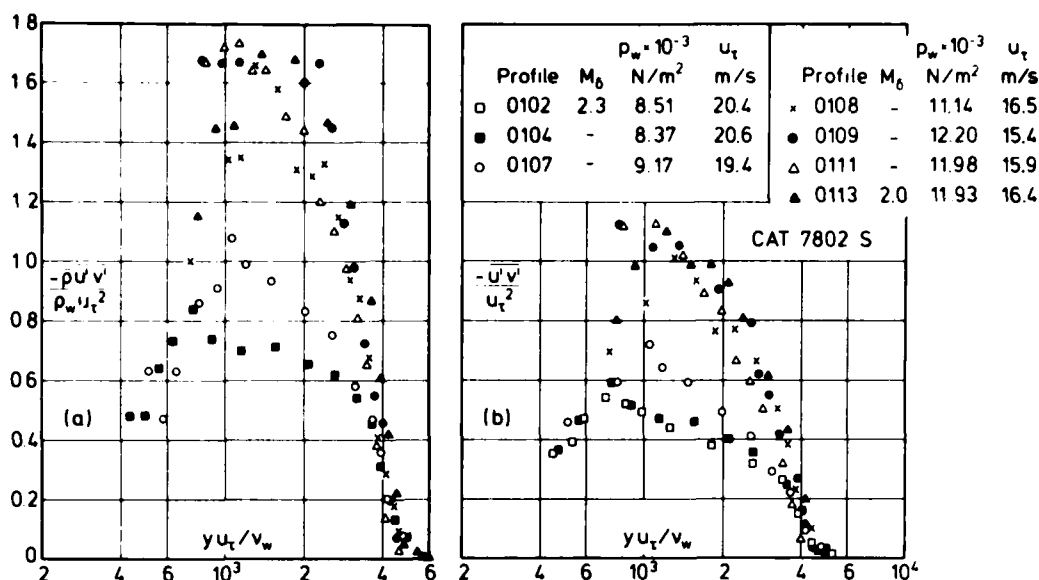


Fig. 4.5.1 Reynolds shear-stress distributions in a compressible turbulent boundary layer with varied, mainly adverse pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978). Pressure distribution I.

eddies in the outer region and with them the Reynolds shear stress to be severely influenced by the pressure gradients and thus show no similarity at all. This behaviour might be fortuitous were it not for a similar tendency in Fig. (4.5.2a) where we have plotted the same shear-stress distributions against the outer region coordinate y/Δ^* . Here the similarity is confined to those profiles (0102, 0104, 0107) where the pressure gradient is small or even negligible but it is obvious that the "disturbed" profiles tend towards the similar ones in the downstream direction where the pressure gradient decreases again (profile 0113).

The shear stress profiles of pressure distribution II (series 02) show a similar trend to those of series 01 Figs.(4.5.2b,4.5.3) but relaxation after the severe adverse pressure gradient occurs much faster (Fig.4.5.2b, profile 0214), probably due to the favourable pressure gradient further downstream. Profile 0214 lies however

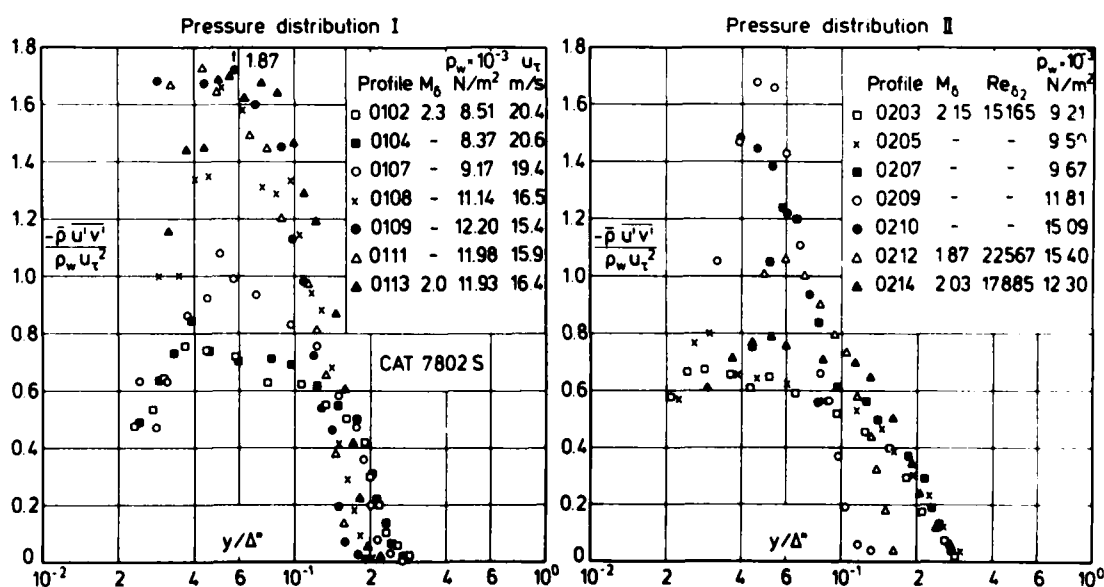


Fig. 4.5.2 Reynolds shear-stress distributions in a compressible turbulent boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

	Profile	M_0	Re_{02}	$p_w \cdot 10^{-3} \text{ N/m}^2$
□	0203	2.15	15165	9.21
■	0207	-	-	9.67
○	0209	-	-	11.81
●	0210	-	-	15.09
△	0212	1.87	22567	15.40
▲	0214	2.03	17885	12.30

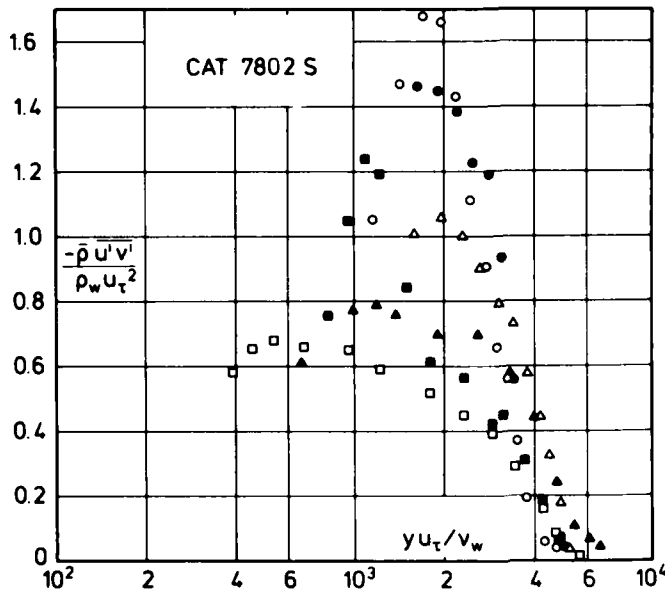


Fig. 4.5.3 Reynolds shear-stress distributions in a compressible turbulent boundary layer with zero pressure gradient (origin not defined, adiabatic wall). Kussoy et al. (1978).

stress profiles are plotted in Fig. (4.5.4), side by side for the two pressure distributions. Profiles 0101 and 0201 are, for both flows, in the region of nominally zero pressure gradient with the level of $-\bar{\rho} u'v'$ differing by roughly a factor 2. Profile 0105 was measured in the middle of the shock interaction and shows a peak value of the dimensionless shear stress which is about 20 times the value in the ZPG region upstream. The corresponding profile in series 02 is not available but is stated as being similar by Mikulla & Horstman (1976). Shear stress profiles 0110 and 0209 respectively were taken at the pressure peak or just downstream in a slightly favourable pressure-gradient region. As in Fig. (3.2.8), where we have plotted the two normal stress distributions $\bar{\rho} \overline{v'^2}$, the documentation of series 01 is much more complete. For this attached flow case one can agree with the authors who state "that it displays large turbulent memory effects in that it is still typical of an adverse pressure-gradient flow although the surface pressure gradient is zero at this location." In this respect profile 0209 has reached a higher state of relaxation but its peak level is still about five times above the ZPG profile 0201. Though the last profile 0212 has a lower u_τ value than profile 0201 (see legend of Fig. 4.5.4), the overall shear-stress level is below that of the ZPG profile and must therefore be severely affected by the downstream pressure history. Kussoy & Horstman (1975) have also compared their measured shear stress distributions with those obtained from the integration of the mean momentum equation using the measured mean flow profiles. The agreement is reasonable. This experiment is remarkable in that it presents Reynolds normal and shear stresses in boundary layers with and without shock induced separation and in the flow downstream. Being well aware of the difficulty of measurements in such a complex flow we would nevertheless like to see another and more fully documented experimental investigation of this type providing all normal stresses, different devices to measure skin friction and shear-stress measurements by laser and hot-wire anemometry.

The forerunner of the above experiment (series 01) is that of Rose (1973, CAT 7306S) which is also discussed in section 3.2 (normal stresses) and section 6 of this AGARDograph. Here the adverse pressure gradient was again induced by a shock but the boundary layer was adiabatic and not cooled. The Reynolds shear stress distributions are plotted in Fig. (4.5.5), and the legend gives the distributions of the skin friction velocity

still slightly above the "undisturbed" shear-stress distribution 0203. As can be seen from the legend of Fig. (3.2.5) the values for u_τ of profiles 0203 and 0214 differ only by 5%, so our statement holds both for the scaled and unscaled profiles. There are 3 investigations with 4 test cases (cf. Table 4.2.1) where Reynolds shear stresses have been measured upstream and downstream of a shock/boundary layer interaction (Rose 1973, CAT 7306S; Mateer & Viegas 1980, CAT 8001S; Kussoy & Horstman 1975, CAT 7501S).

For the last investigation tabular data were not available other than seven profiles given by Mikulla & Horstman (1976), and mean flow data were published by Kussoy & Horstman (1975, see also chapter 5 and CAT 7501S). The test boundary layer was formed on a cone-ogive-cylinder mounted on the centre line of the wind tunnel. An annular shock generator was mounted coaxially with the model and could be traversed in the axial direction. Two deflection angles, 7.5° and 15° (series 01 and 02) were used, and the shock waves produced were followed closely by an expansion. The turbulence measurements were performed with two $10 \mu\text{m}$ diameter platinum-rhodium wires mounted on ceramic wedges which were operated using CT anemometers. Both boundary layer flows ($M_0 \approx 6.8$) were nonadiabatic, with and without separation. The shear

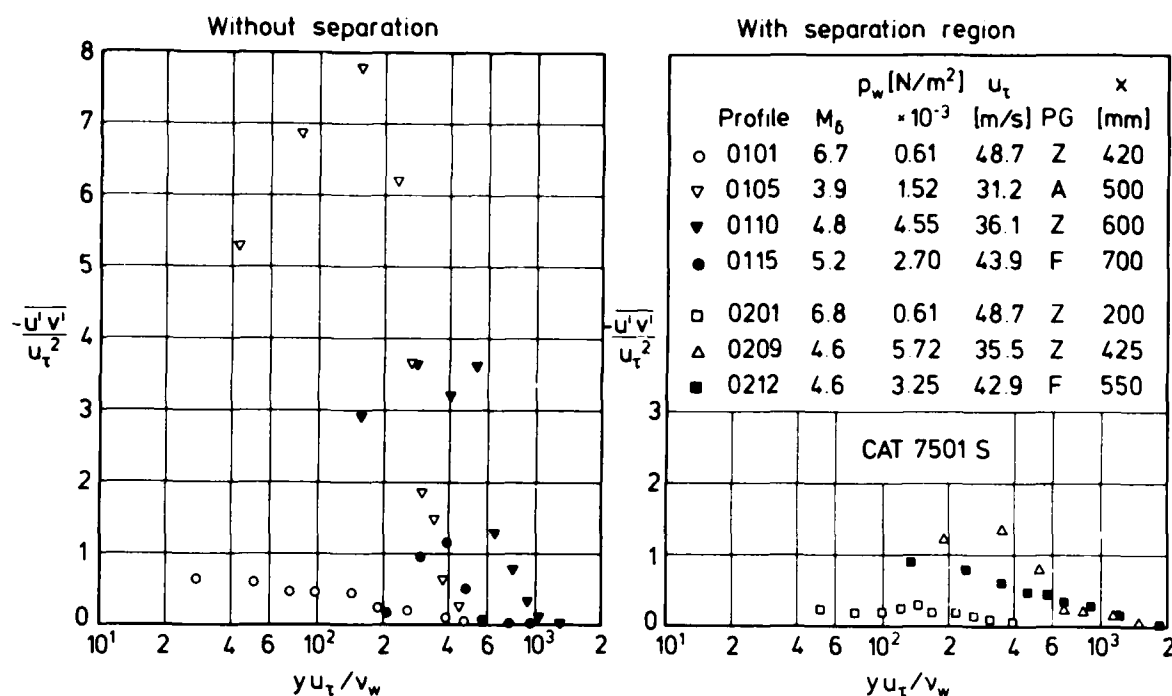


Fig. 4.5.4 Reynolds shear-stress distributions in a shock/boundary-layer interaction flow (isothermal wall, $T_w/T_r = 0.47$, defined origin). Kussoy et al. (1975).

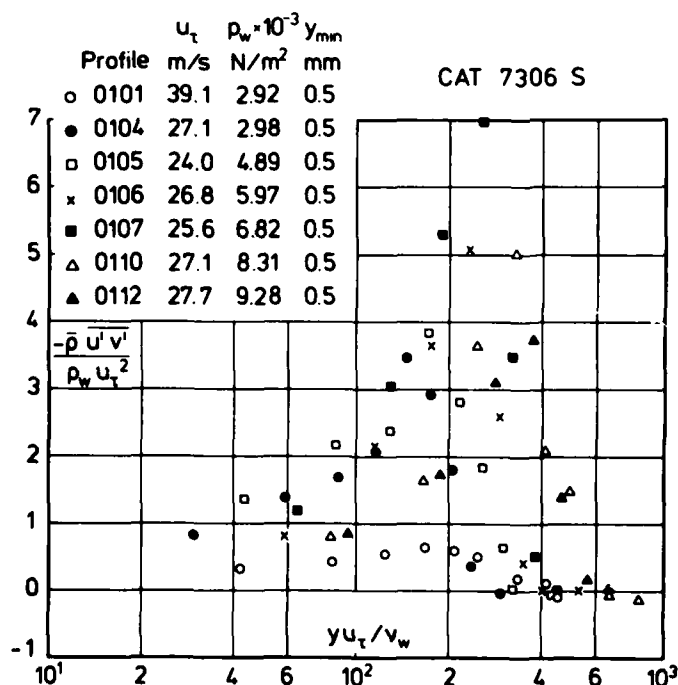


Fig. 4.5.5 Reynolds shear-stress distributions in a compressible boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

u_t - taken from Rubesin et al. (1974) - and of the wall static pressure which increases monotonically whereas u_t has a distinct minimum at station 0105. The shear-stress distributions show the typical behaviour of those in an adverse pressure gradient, increasing in level with the increasing pressure and with the peak moving out towards the edge of the boundary layer. Profile 0112 may already be influenced by the levelling off of the pressure gradient showing a lower peak value than the upstream distributions.

Rose (1973) has also measured $\bar{\rho} \overline{v'w'}$. This turbulence term represents a circumferential shear stress which should in principle be zero. The values recorded therefore may be interpreted either as a sign of asymmetry or as an indication of the level of accuracy of the hot-wire measurements.

The experience of this first extensive investigation of the turbulence structure downstream of a shock/boundary layer interaction was apparently transferred to a similar study by Rose & Johnson (1975) who measured a shear-stress profile downstream from a shock ($x = 23.8$ cm) using an X-wire and a laser under the same flow conditions. Fig. (4.4.4) above shows both the comparison between the two undisturbed profiles and that between the two profiles downstream

from the shock. The two measuring techniques give good agreement in the zero and the adverse pressure gradient regions. Further, somewhat earlier, measurements by Rose & Murphy (1973) in a shock/boundary layer interaction region along an adiabatic wall are not available either in graphical or in tabular form. These profiles are given indirectly only as the ratio a_1 of the Reynolds shear stress $-\bar{\rho} \overline{u'v'}$ and the kinetic energy of the fluctuating flow $\bar{\rho}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$. They are discussed in section 4.6 below. The last series of shear-stress distributions for which tabular data are available are those performed by Mateer & Viegas (1980, CAT 8001S) in the boundary layer on the inner surface of a cylindrical duct of constant diameter. At the rear end of the duct a hollow cylindrical choke of varying cross section was inserted and its position adjusted to give a suitable position for a normal shock in the test section. The shear-stress profile 8001S 0101 (Fig.4.5.6) was measured upstream of the shock interaction and was virtually unaffected by it. The next profile for which the skin friction velocity u_τ was available, 8001S 0103, shows an increase of

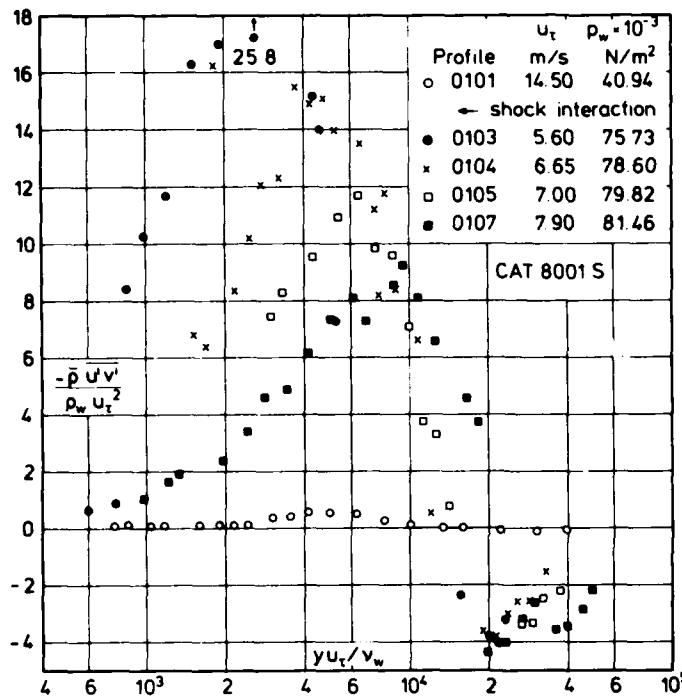


Fig. 4.5.6 Reynolds shear-stress distributions in a transonic turbulent boundary layer with shock interaction (adiabatic wall, origin not defined, $0.9 \leq M_0 \leq 1.44$). Mateer & Viegas (1980).

the peak level of $-(\bar{\rho} \overline{u'v'})/(\rho_w u_\tau^2)$ by a factor of about 50. τ_w has fallen by a factor of two or three so that the absolute increase is also very great. The maxima in the scaled profiles fall downstream, without however recovering the upstream distribution of profile 0101. The absolute turbulence level has fallen below the upstream value at the last measuring station (0107).

The mean flow structure, discussed in the entry describing this experiment (CAT 8001S) is such that the shear stress outside the boundary layer does not fall to zero, but reverses sign as measurements continue through a high total pressure region originating in the bifurcated foot of the shock structure into a low total pressure region containing the core flow which has traversed a normal shock. An experiment of this nature is inevitably "bedevilled" by a high level of mean flow fluctuation, so that it would be unwise to build too much on the precise numerical values. The trends shown should however be valid, and the order of magnitude of the reversed stresses is much greater than any likely error range, except for profile 01 where the change in sign indicates the level of error likely to be present.

4.6 Ratio a_1 of the Reynolds shear stress $-\bar{\rho} \overline{u'v'}$ and the kinetic energy of the fluctuating flow $\bar{\rho}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$

In his investigation of the turbulence structure of an incompressible turbulent boundary layer with zero pressure gradient Klebanoff (1955) introduced the ratio of the Reynolds shear stress $-\bar{\rho} \overline{u'v'}$ to the kinetic energy of the turbulent velocity fluctuations $\overline{q^2} = (\bar{\rho}/2)(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$. The ratio $-\overline{u'v'}/(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$ was denoted a_1 by Bradshaw & Ferriss (1971) and used as one of the semi-empirical inputs ($a_1 = 0.15$) of their calculation method for compressible turbulent boundary layers along adiabatic walls. Rose & Murphy (1973) were apparently the first to compare this assumption with measurements in compressible boundary layers and found that the streamwise variation of this ratio is small compared with that normal to the wall and that its values range nominally from 0.08 to 0.22. The other two sets of fluctuation measurements which are complete enough for a_1 to be evaluated are those by Rose (1973, CAT 7306S) and by Kussoy et al. (1978, CAT 7802S). Since Klebanoff found a_1 to be constant in the range $0.1 \leq y/\delta \leq 0.8$ in an incompressible zero pressure-gradient boundary layer, we have plotted the available data for a compressible boundary layer in Fig. (4.6.1) and note that a_1 is by no means constant in the two boundary layers from which the measurements were taken. There appears to be a slight dependence on Reynolds number but the discrepancies between the distributions could also well be due to uncertainties of the measurements. The shape of the a_1 distribution suggests that

	Profile	M_6	Re_{δ_2}	H_{12K}
x	73060101	3.9	1035	154
o	78020101	2.3	16132	133
•	78020102	2.3	15790	133

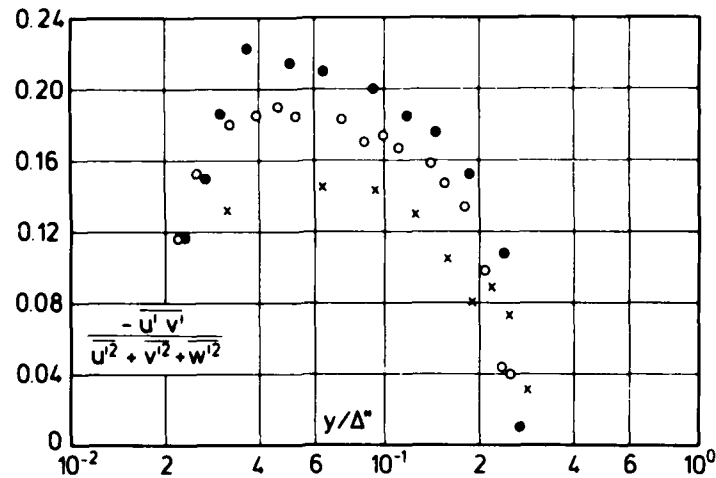


Fig. 4.6.1 Ratio of the Reynolds shear stress to turbulent energy in a compressible boundary layer with zero pressure gradient (adiabatic wall, origin not defined).

it decreases towards zero faster than the turbulent kinetic energy both towards the wall and towards the outer edge of the boundary layer.

Fig. (4.6.2) shows a_1 -distributions in the reflected wave region of an adverse pressure-gradient boundary layer for the two pressure distributions (series 01 and series 02) discussed above. The profiles show a surprisingly high degree of similarity in the outer region if plotted against yu_t/v_w . The influence of the various parameters appears to play a role only in the inner region which is however not completely covered by measurements. This similar behaviour in inner region coordinates is most probably due to the relatively small changes of Reynolds number in these two boundary layer flows, since the low and medium high Reynolds number cases in Fig. (4.6.1) do not show this similarity when plotted against y^+ .

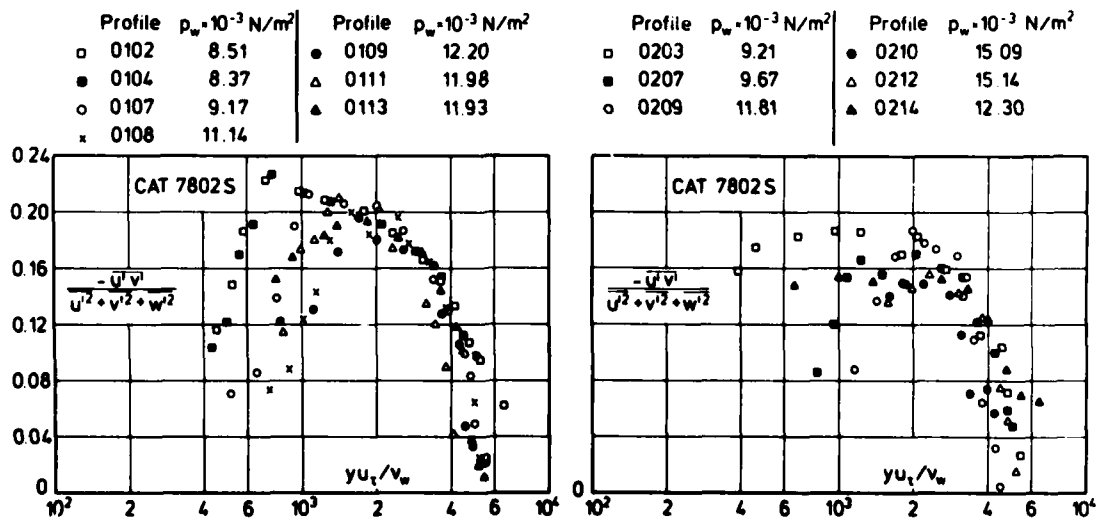


Fig. 4.6.2 Ratio of Reynolds shear stress to turbulent energy in a compressible boundary layer with varied pressure gradient (adiabatic wall, origin not defined). Kussoy et al. (1978).

In Fig. (4.6.3) we present a_1 distributions as evaluated from a shock/boundary layer experiment performed by Rose (1973). The profiles are highly disturbed by the shock, showing a wide spread in peak level and no similarity at all in the outer region.

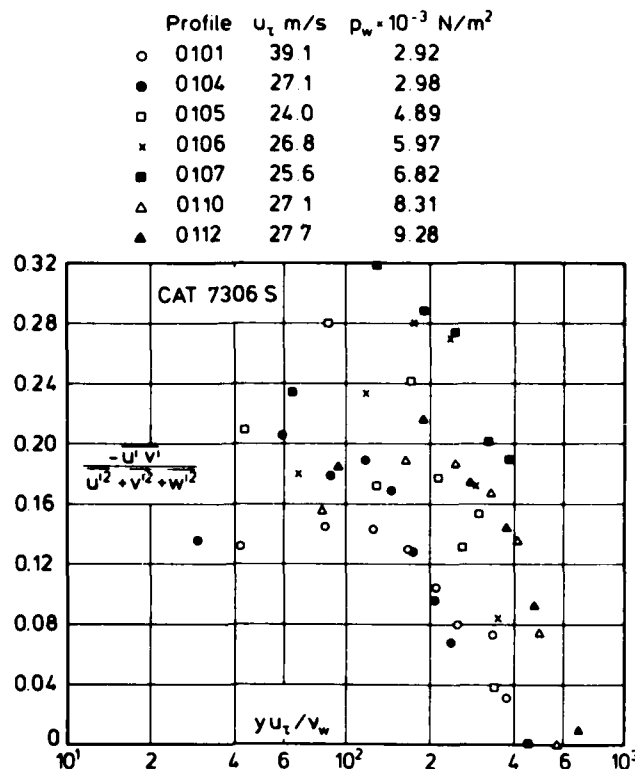


Fig. 4.6.3 Ratio of Reynolds shear stress to turbulent energy in a compressible boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

It should be clear from the experiments presented here that a_1 is not a constant, not even to a first approximation. The data we have is not yet sufficient for us to suggest any general model for the variation of a_1 . Problems which occur with calculation methods of the Bradshaw type may be partly due to the assumption of a constant value for a_1 across the boundary layer.

4.7 Other correlation terms

After the Reynolds shear stress $-\bar{\rho} \overline{u'v'}$ the most important quantity of the fluctuating motion is the turbulent heat flux. Sandborn (1974) gives the full expression as

$$q_t = -c_p(\bar{\rho} \overline{v'T'} + \bar{v} \overline{\rho'T'} + \overline{\rho'v'T'}) \quad (4.7.1)$$

which can be derived from the energy equation. In the case of a turbulent boundary layer one usually retains only the first term $-c_p \bar{\rho} \overline{v'T'}$, assuming that the other two terms are at least one order of magnitude smaller. This appears plausible, certainly as long as Morkovin's hypothesis holds.

The turbulent heat flux term q_t can be obtained in much the same way as the shear stress term (Eqn. 4.1.2). Meier & Rotta (1970) have done this for the ZPG boundary layer along an adiabatic wall and Horstman & Owen (1972) for a ZPG boundary layer along an isothermal wall ($T_w/T_r = 0.5$). Sandborn (1974) compared these two evaluations in his Fig.(9) and found the heat flux to increase with increasing Mach number ($2.5 \leq M_\delta \leq 4.5$) and to decrease with increasing Reynolds number (for a constant Mach number $M_\delta = 6.8$ the Reynolds number Re_θ was varied in the range between 4900 and 9700). The only turbulence measurements from which $\overline{v'T'}$ can be deduced are those of Rose (1973) in a boundary layer with shock interaction, and they are shown in Fig.(4.7.1). We have plotted $-\bar{\rho} \overline{v'T'}$ nondimensionalized with $\rho_w u_\tau T_w$ against y^+ and find a behaviour which is similar to

that of the Reynolds shear stress in Fig. (4.5.5). The maximum peak value for $-\bar{\rho} \overline{v'T'}$ occurs at the same position, profile 0107, as for $-\bar{\rho} \overline{u'v'}$ in Fig. (4.5.5). The turbulent heat flux is strongly increased by the adverse pressure gradient, finally decreasing towards the initial low level distribution upstream of the shock interaction.

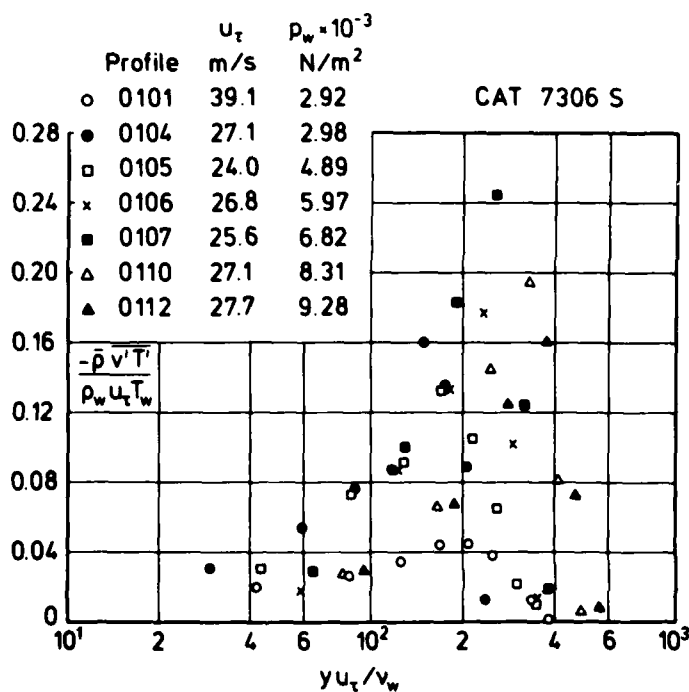


Fig. 4.7.1 Turbulent heat-transfer distributions in a compressible boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

5. MEAN FLOW TOPICS

We have, in the preceding chapters, discussed turbulence data at some length. Many of the data have only become available to us since the completion of AGARDograph 223, and the new entries in this volume have also provided data which throw light on certain special features of the mean flow. In AG 223 we frequently remarked, of axisymmetric flows, that the boundary layer thickness was a substantial proportion of the transverse radius of curvature characteristic of the flow. We were not in a position to say just what the effects of large transverse curvature might be, nor at what point they might become significant. We have since obtained the data of Richmond (1957, CAT 5701S) which, with the low speed results of Willmarth et al. (1976) provide the basis of the discussion in §5.1 below.

The availability of data for strongly cooled flows with large pressure gradients at reasonably high Reynolds numbers, in particular that of Peterson (1974, CAT 7406S), Kussoy & Horstman (1975 - CAT 7501S), has made it possible to start on a proper practical assessment of the breakdown conditions for the van Driest temperature/velocity correlation and the associated transformation procedures. This is discussed in §5.2, while the flow field for one of these key cases (Kussoy & Horstman, 1975, CAT 7501S) is examined in some detail in §5.3.

5.1 Transverse curvature effects

Dealing with the effect of wall curvature on compressible turbulent boundary layers one must distinguish between curvature in the transverse (cross-sectional) and in the longitudinal (camber) direction (cf. Thomann 1968, CAT 6800). The flow along a waisted body of revolution as investigated by Winter et al. (1970, CAT 7004) contains both effects (cf. AG 253, figures 5.3.18 to 5.3.21).

If for a body of constant radius the boundary layer thickness is small compared with the body radius, then the boundary layer can be treated as if it were planar. This assumption does not hold for long slender bodies of revolution, and the boundary layer equations and turbulence models must contain terms which take into account the transverse curvature.

Very few experimental investigations are available which could serve as a basis for an order of magnitude estimate of the curvature terms in the equations or for a comparison with the results of calculation methods. We know of only three experiments, two (Richmond 1957, Willmarth et al. 1976) in a subsonic and one (Richmond 1957, CAT 5701S) in a supersonic boundary layer, and begin with a description of Richmond's investigation.

The boundary layer was formed on the outer surface of one of a number of slender cylinders aligned with the flow. For the subsonic tests two models were used. The first (series 01) consisted of an aluminium tube 3.65 m long and 25.4 mm in diameter. The front end was mounted on the tunnel settling chamber screens so that it extended along the contraction centre line into the working section. The second model (series 02) consisted of a steel wire under tension passing through the screens.

For the hypersonic test cases, results are presented for two wires ($d = 0.61, 1.63$ mm diameter, series 05 and 04) and for a composite wire-cylinder model. It consisted of a wire passing through the throat on which was mounted a 3° half-angle cone-ogive nosed cylinder to reach the 6.35 mm diameter. For the hypersonic tests, the author obtained mean velocity profiles assuming isoenergetic flow. Skin friction values were measured by means of a floating element balance for series 03 and calculated for the other series by matching the velocity profiles to the Coles' wake-and-wall profile at low speeds (Coles 1955) and by matching a transformed profile at high speeds (series 04 and 05). Fig. (5.1.1) shows 4 velocity profiles plotted in log-law coordinates with the characteristic length scale δ_1/R in the range 1.2 to 1.9. Profiles 0301 and 0302 which are denoted laminar by the author show large discrepancies from the standard log-law. Whereas profile 0301 shows a low Reynolds number, Re_{δ_2} , laminar-like velocity distribution (cf. profiles 7305/0301 and 0302 in Fig. 4.4.4 of AG 253), 0302 lies much below the log-law. This is probably a consequence of the faulty - too high - value of the skin friction. The two "turbulent" velocity profiles behave typically like velocity distributions in a moderately favourable pressure gradient (cf. profile 72010119 in Fig. 5.1.2 of AG 253), showing a "negative" wake component. The similarity between a favourable pressure gradient profile and one with large transverse curvature (suggested first by Patel 1973) is also evident from the skin-friction values which are considerably higher for the curved wall profiles than for a plane wall boundary layer at the same Mach and Reynolds number, Re_{δ_2} (for profile 0303 the values for the skin friction coefficient would be 1.94×10^3 and 1.23×10^3 respectively, with c_f (plane wall) determined according to Fernholz (1971), for example. This is a further

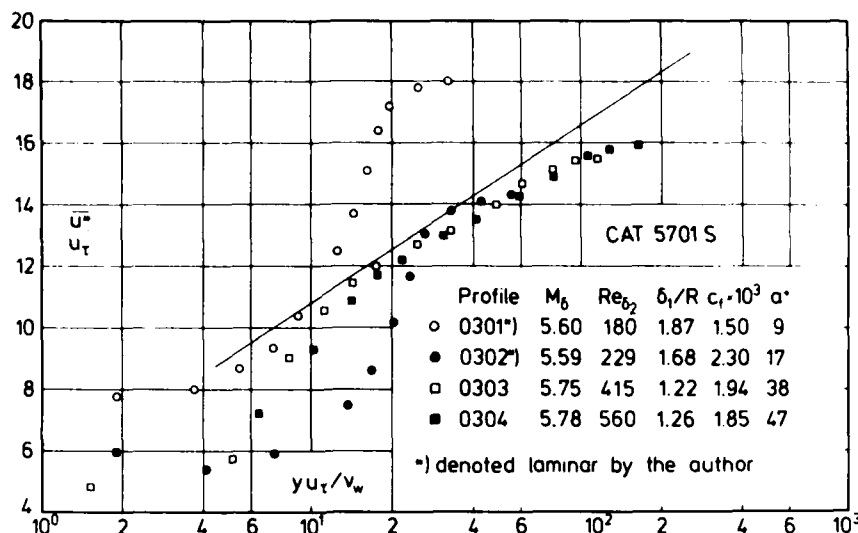


Fig. 5.1.1 Log-law for a compressible boundary layer with transverse curvature (adiabatic wall, origin not defined, ZPG, c_f from FEB). Richmond (1957).

indication that the boundary layer profiles on a cylinder are very full. The full shape is a result of the cylindrical geometry of the flow (Willmarth et al. 1976) and not of the acceleration of the stream which produces a full velocity profile on a plane wall. As for the turbulence structure, Willmarth & Yang (1970) have found in subsonic flow that the effect of transverse curvature is to reduce the spatial scale of the turbulence.

Another problem which arises in flows with transverse curvature is the choice of a suitable dimensionless length scale. Exact solutions of the equation of motion for laminar boundary layers along walls with transverse curvature have shown that $a^+ = u_\tau R / \nu_w$ may represent such a length scale besides δ_1/R . Here δ_1 denotes the displacement thickness, δ_2 the momentum loss thickness and R the body radius. We have calculated at least two of these length scales and given their values in the legends of the subsequent figures but prefer δ_1/R to a^+ since increasing values of this dimensionless length coincide with an increasing departure of the profiles from the standard log-law.

In order to compare supersonic and subsonic velocity profiles with marked transverse curvature effects we have plotted velocity profiles obtained by Willmarth et al. (1976) in subsonic flow. The test boundary layer was generated on circular cylinders, with a diameter range $0.5 \leq d \leq 51$ mm, mounted on the centre line of an octagonal vertical wind tunnel. The authors took great care to achieve flow symmetry about the cylinders and found that a cylinder must be straight to within a small fraction of its diameter for reasonably axially symmetric flow on it to be obtained. Fig. (5.1.2) shows a selection of the measured profiles, covering a range of $0.3 \leq \delta_1/R \leq 5.8$ at a considerably higher Reynolds number range than the supersonic flow profiles. The plot shows clearly that the higher δ_1/R the greater the departure from the standard log law. The shape parameter H_{12K} (ρ constant) becomes unusually small indicating that the profile is very full (with the limit of $H_{12K} = 1$ for a rectangular velocity profile). The similarity of velocity profiles with approximately equal δ_1/R where we have plotted two supersonic turbulent profiles together with equivalent subsonic ones (Willmarth et al. 1976). If the range for δ_1/R is increased further than about 6, the form of the profiles changes dramatically as can be seen in Fig. (5.1.4) where we present some of the subsonic profiles measured by Richmond. Velocity profiles with low values of δ_1/R behave like plane wall ZPG profiles whereas those with δ_1/R larger than 8 resemble profiles measured by Patel (1965) in a highly favourable pressure gradient (with profile 0502 as an exception). Following a suggestion by Rao (1967) we have plotted these latter velocity profiles against a stretched coordinate Y^+ where $Y^+ = (Ru_\tau / \nu_w) \ln[1 + (y/R)]$. They are, however, not shown here, since the pattern of the velocity profiles is not changed in such a way that the universal law is recovered. We therefore have to accept that the standard universal log-law does not hold any longer if δ_1/R exceeds, say, 0.8 (cf. Fig. 5.1.2).

Since the above velocity profiles are similar to those in favourable pressure gradient flow we do not expect agreement with the standard outer law curve which holds only for zero pressure-gradient boundary layers.

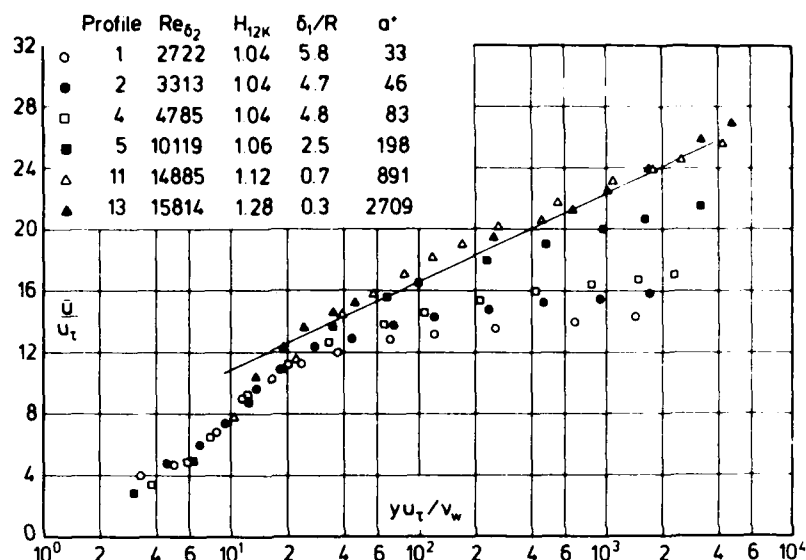


Fig. 5.1.2 Law of the wall for a subsonic turbulent boundary layer with transverse curvature (adiabatic wall, origin not defined, ZPG). Willmarth et al. (1976).

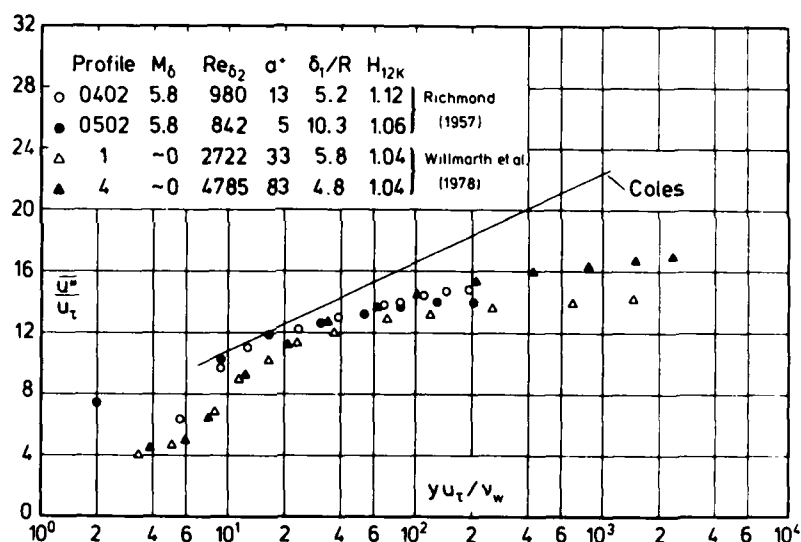


Fig. 5.1.3 Comparison of subsonic and supersonic turbulent boundary layers with strong transverse curvature effects (adiabatic wall, ZPG).

Fig. (5.1.5) shows a selection of Richmond's profiles plotted in outer law coordinates. Some systematic tendency appears to exist in that the slope of the velocity distributions becomes smaller with increasing δ_1/R which is equivalent to an increase in the pressure gradient parameter for an accelerated flow. Such a behaviour is confirmed by the FPG profiles measured by Lewis et al. (1972) - compare Figs. (5.2.1 and 5.2.2 of AG 253), for example. We should note, however, that the outer-law distribution calculated from Willmarth's data does not show such a consistent pattern as presented in Fig. (5.1.5). Finally readers should be warned not to attach too much significance to outer law plots, since the difference $u_0^* - \bar{u}^*$ will be very sensitive to small changes in the flow properties at large y -values.

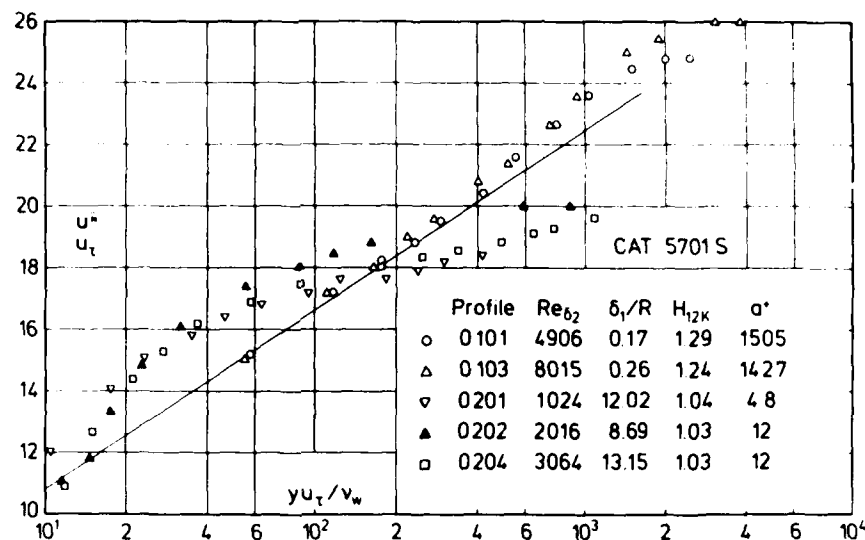


Fig. 5.1.4 Law of the wall for a subsonic turbulent boundary layer with transverse curvature (adiabatic wall, origin not defined, ZPG). Richmond (1957).

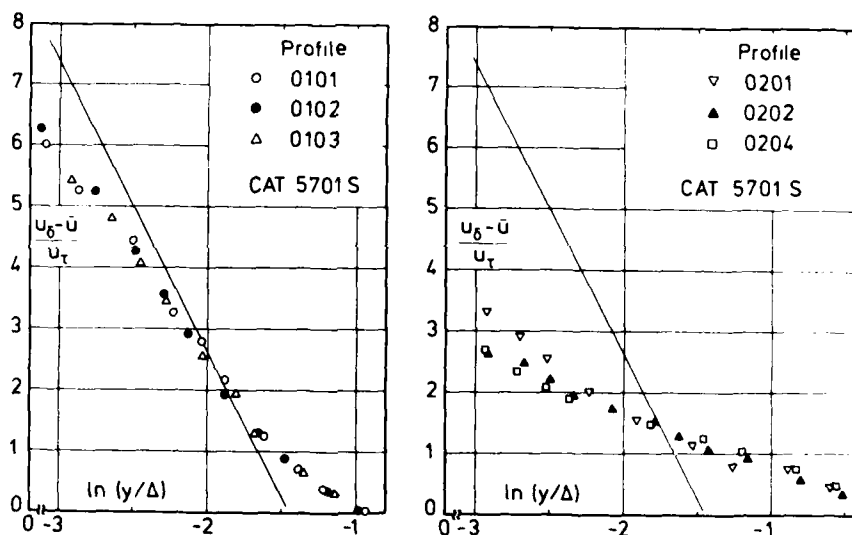


Fig. 5.1.5 Outer law for a subsonic turbulent boundary layer with transverse curvature (adiabatic wall, origin not defined, ZPG). Richmond (1957).

5.2 Validity of the van Driest temperature-velocity transformation

Throughout our discussion of mean velocity profiles in AG 253 we presumed that it was proper to make comparisons between "transformed" compressible flow profiles and the "incompressible norm" consisting of an inner region semi-logarithmic profile with an outer region wake profile. Departures from the "norm" could then be explained, at least qualitatively, in terms of the influence of the streamwise pressure gradient on the outer region and on the extent of the semi-logarithmic profile and of Reynolds number on the size of the wake component. This discussion was essentially in the same terms as for incompressible flows without heat transfer, and the vast majority of experiments studied fitted quite comfortably into this framework.

The validity of this discussion is, however, wholly dependent on the validity of the transformation used which in our specific case holds (a) for a boundary layer with a variable pressure gradient in streamwise direction dp/dx along an adiabatic wall or (b) for a boundary layer with zero pressure gradient along an isothermal wall. These restrictions enter the transformation via the temperature-velocity relationship. No other close examination of the validity of the transformation was made as for nearly all cases a sufficient justification was found in that the procedure appeared to work. In particular, no theoretical reasons were put forward for

expecting success in outer region correlations based on the transformed velocities, other than justification by good works. We therefore here summarize the assumptions which are brought together in the transformation without the details of derivation to be found in sections 3.3.1 and 2.5.4 of AG 253. The greater part of what follows is concerned with the semi-logarithmic law portion of the profile.

For incompressible flow there are many ways of deriving the semi-logarithmic velocity profile. These decline in elegance from Millikan's (1938) dimensional and functional deduction of its necessary existence to ever-increasingly complex derivations based on more and more complicated turbulence models. Since the log-law is known to exist, no turbulence model qualifies unless it can be shown to produce it. The differing models are all essentially descriptions of what happens subject to the same dimensional constraints. There is little to be gained therefore by using a complex model when a simple one satisfying the constraints will work, even though some of the assumptions of the model are demonstrably incorrect.

In AG 253 the turbulence model used was the Prandtl mixing length model, which for those flows which display a semi-logarithmic region in incompressible flows achieves a high degree of success. This yields, assuming the sublayer thin enough, the static pressure not to vary significantly with y and the total shear stress to remain constant with y and equal to wall shear stress

$$\tau_w = \rho_w u_\tau^2 = -\bar{\rho} \bar{u}^* \bar{v}^* = \ell^2 \bar{\rho} (\partial \bar{u} / \partial y)^2 \quad (5.2.1)$$

Using $\ell = \kappa y$ one obtains

$$\frac{\partial \bar{u}}{\partial y} = \frac{1}{\kappa y} u_\tau \left(\frac{\bar{\rho}_w}{\bar{\rho}} \right)^{1/2} = \frac{1}{\kappa y} u_\tau \left(\frac{\bar{T}}{\bar{T}_w} \right)^{1/2} \quad (5.2.2)$$

The assumptions so far are all either reasonable in physical terms or justified by working well over a wide range in subsonic flows, with recognisable faults which would not be expected to have any particularly different effect in a compressible flow. If the density is constant, eqn.(5.2.2) integrates directly to give the semi-logarithmic law. If however the density varies, eqn.(5.2.2) is not soluble in closed form unless $(\bar{\rho}/\rho_w)$ or $(\bar{T}/T_w)$ can be expressed as functions of either y or $\bar{u}$. No mean flow profile is a universal function of (y/δ) , but, subject to various restrictions, the van Driest temperature-velocity correlation derived in section 2.5.4 of AG 253 relates $(\bar{u}/u_\delta)$ to $(\bar{T}/T_\delta)$. The relationship (eqn. 2.5.37 of AG 253) may then be inserted into eqn.(5.2.2) and integrated to give the modified velocity transformation (see section 3.3 of AG 253) which in transformed coordinates again yields the low speed semi-log law for a transformed velocity $(\bar{u}^*/u_\tau)$, eqn.(3.3.10, AG 253) as a function of $(y u_\tau / \nu_w)$.

The transformation in the outer layer has received much less attention (e.g., Fernholz 1969, 1972) than in the inner layer. Here there are many data of importance and interest but we have no simple applicable model and so have arbitrarily extended the application of the log-law region transformation into the outer region. For the "base case", the zero pressure gradient boundary layer, the succession of profiles displayed in section 4 of AG 253 shows that the transformation correlates the data, with a few exceptions, onto the curve for incompressible flow. We have then taken this as an encouragement to apply it in other cases where there is a logarithmic law.

As mentioned above in applying the transformation we have added to the assumptions which lead to a log law those assumptions and limitations implicit in the van Driest temperature-velocity correlation. In a real flow the assumptions of the exact form that both laminar and turbulent Prandtl numbers are one, cannot be satisfied. The approximate form (Walz 1966) assumes that the mixed Prandtl number is constant and near one. The results of numerical calculations show that the velocity profile is not very sensitive to minor changes in the Prandtl number, so that this is probably not a critical assumption. The correlation can only be derived however subject to further sufficient conditions. These are that either (a) there be no heat transfer at the wall (AW) or (b) the wall temperature be constant and there be no streamwise pressure gradient (isothermal ZPG). Given these conditions the temperature-velocity correlation should be described by the various forms of eqn.(2.5.37 of AG 253). Section 2.5.6 of AG 253 was devoted to showing how well the correlation fits the experimental data and proved that for flows which, within the limits of experiment, satisfy the conditions the correlation is found to be accurate within a few percent in nearly all cases. This statement is based on the correlation of $\bar{T}/T_\delta$ with $\bar{u}/u_\delta$ and not on the variation of the Crocco parameter which is oversensitive to small errors.

The correlation should, however, be expected to break down when both pressure gradient and heat transfer are present together. We find good agreement in strong pressure gradients on adiabatic walls (e.g., Sturek & Danberg, Fig. 5.1.5 AG 253 and Rose 7306S-2) but when pressure gradients are combined with heat transfer (e.g., Hill CAT 5901, Fig. 5.1.7; Perry & East CAT 6807, Fig. 5.1.8; Kemp & Owen CAT 7206, Fig. 5.1.10 of AG 253) the correlation breaks down and so must throw the transformation into doubt.

The interaction of the restrictions on the correlation and the application of the transformation could not, at the time of preparation for AG 253, be displayed clearly, since the Reynolds number Re_{δ_2} for the appropriate data was in most cases relatively low so that a comparison with the logarithmic law could not lead to a clear conclusion, since, for instance, transition effects in particular could not be excluded as a cause for the departure. The one exception, the data of Perry & East, then caused us some perplexity (see AG 253, p.143), but has now been joined by three other cases (Peterson 1974, CAT 7405S, and Kussoy & Horstman 1975, CAT 7501S) with pressure gradient, strong heat transfer, and relatively high Reynolds number.

The first of the new cases was reported by Peterson (1974) who performed pressure and temperature measurements in a cold wall, favourable pressure gradient turbulent boundary layer at a maximum free stream Mach number of about 13 and a heat transfer parameter $(T_w/T_r) = 0.24$. The measurements describe a simple wave expansion flow of the same general type as those studied by Fischer et al. (CAT 7001) and Beckwith et al. (CAT 7105 and Fig. 5.1.9 of AG 253). The flow at the upstream station is in the nozzle expansion field while that at the downstream station is not. Normal pressure gradients are however apparent at both stations.

The measured temperature distributions are compared with our standard, eqn.(2.5.37 of AG 253), in Fig. (5.2.1) and show large discrepancies - the measured data are much lower -, in fact larger than expected since the longitudinal pressure gradient was considered relatively modest (cf. the Mach number increase from station 01 to 02 is from 13.4 to 13.9 only). Though the "Mach number level" is much lower and the Reynolds number range

considerably higher than in the case investigated by Beckwith et al. (see Fig. 5.1.9 of AG 253) the discrepancies between measured and calculated temperatures are much larger in Peterson's boundary layer.

	Profile	M_δ	T_w/T_r	Re_{δ_2}	$x[m]$
---	o 0101	13.4	0.24	960	1.92
---	• 0102	13.9	0.24	965	2.66
---	□ 0202	14.2	0.24	1451	2.66
	theory van Driest				

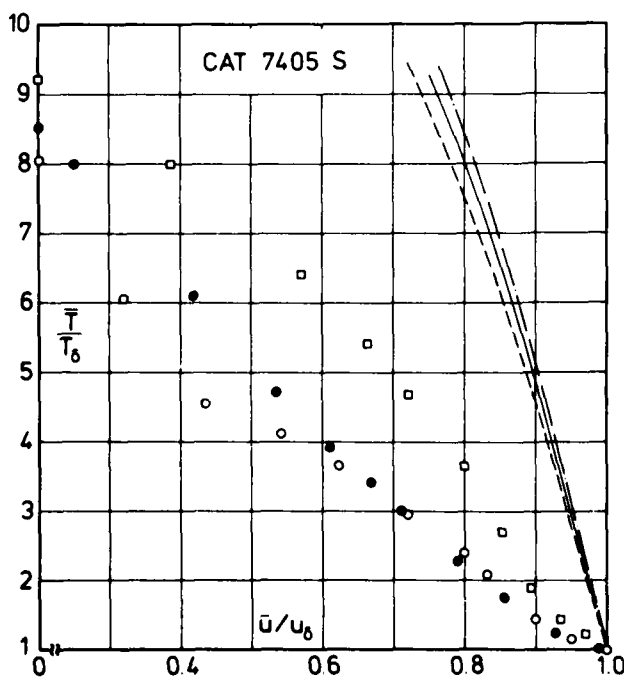


Fig. 5.2.1 Comparison between measured and theoretical temperature profiles (favourable pressure gradient, isothermal wall, origin not defined). Peterson (1974).

Two further sets of measurements were taken in a boundary layer with a shock boundary layer interaction and a varied pressure gradient downstream. They are remarkable in that the cooled boundary layer passes through regions of zero pressure gradient, adverse pressure gradient and finally favourable pressure gradient (for a description see Kussoy & Horstman 1975, CAT 7501S and section 5.3 below. The turbulence data is discussed in sections 3.2 and 4.5 above). This makes possible a particularly clear illustration of the influence of the combination of pressure gradient and heat transfer on the temperature/velocity correlation. Fig. (5.2.2) shows the temperature-velocity relationship for the second series (see Fig. 5.3.2 and the associated discussion). For the upstream profile 0201 agreement with theory is good. Profile 0203 is also, except in the inner region, upstream of the interaction. Agreement in the outer region is good, but the data lie high in relation to theory in the inner region. This trend becomes more marked in the downstream adverse pressure-gradient profiles shown, 0204, 0205 for which no part of the data is in agreement with theory. The data in this APG region lie up to 20% above the curves in contrast to the favourable pressure-gradient data in Fig. (5.2.1) which lie below the van Driest prediction. It is therefore

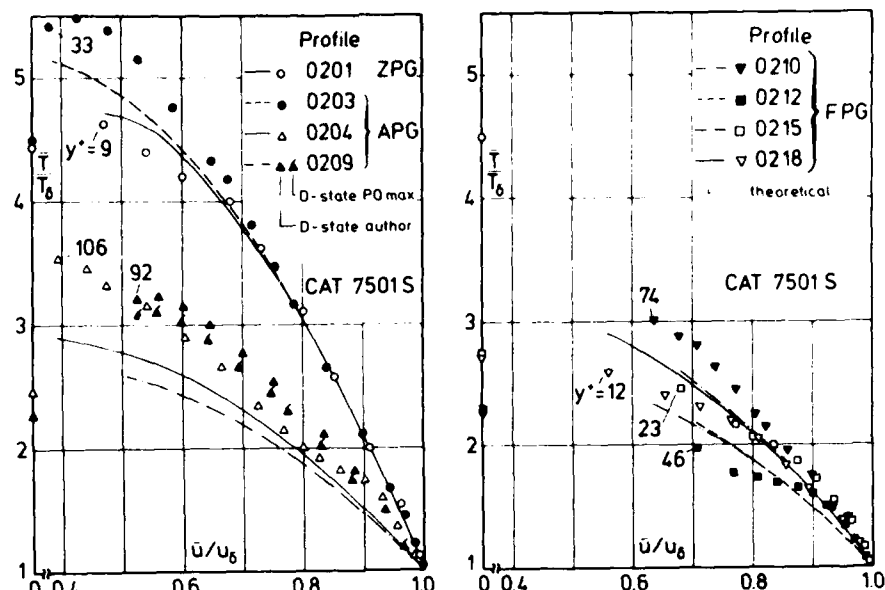


Fig. 5.2.2 Comparison between measured and theoretical temperature profiles (shock boundary-layer interaction, isothermal wall, $T_w/T_r = 0.47$, defined origin). Kussoy & Horstman (1975).

specially interesting to see the data further downstream, in a relatively modest favourable pressure-gradient region move back across the theoretical curve. In the right hand half of Fig. (5.2.2) the first profile, 0210, is locally in a favourable pressure gradient except for $15 < y < 20$, but still lies above the curve. The next profile, 0212, is entirely in a reflected wave favourable pressure gradient and lies below its curve, while as the flow relaxes (profiles 0215, 0218 - out of the field of view for Fig. 5.3.2) the data once more come into agreement with van Driest's relationship. The data for series 01 were obtained under less severe conditions (section 5.3) without shock induced boundary-layer separation and so are not discussed in detail here. They show the same general trends.

With this behaviour of the experimental temperature-velocity correlation in mind, we can now examine the velocity transformation for the semi-logarithmic law. We begin with those profiles which show only small departures from the calculated temperature distribution, that is profiles 75010201/03/15 and 18 (Fig. 5.2.3). For the ZPG profile 0201 the skin friction is apparently too low giving measurements above Coles' log-law but the wake strength is typical for a ZPG boundary layer. Profile 0203 shows the effect of the adverse pressure gradient near the wall, which shortens the log-law region. The two downstream profiles present the typical behaviour of velocity distributions in a favourable pressure gradient (e.g., Fig. 5.2.1 of AG 253). In Fig. (5.2.4) agreement with the outer law is good for the ZPG velocity distributions and the other profiles show the departures expected for the respective local pressure gradient (e.g., section 5.2 of AG 253). As for the profiles which are affected severely by the streamwise pressure gradient they show no agreement at all with the standard log-law (Fig. 5.2.5). Since we knew that the temperature-velocity correlation used so far should not hold in this case we have redefined the transformed velocity as $\bar{u}_p^*$ where

$$\frac{\bar{u}_p^*}{u_\tau} = \frac{u_\delta}{u_\tau} \int_0^{u_\delta/u_\tau} \left(\frac{\bar{\rho}}{\rho_w} \right)^{1/2} d \left(\frac{\bar{u}}{u_\delta} \right) \quad (5.2.3)$$

This definition springs from the same general derivation with all the weaknesses mentioned above but does not rely on the temperature-velocity correlation (eqn. 2.5.37 of AG 253). The measured density distribution is used instead. Profiles transformed in this way are shown in Fig. (5.2.5) together with those using the conventional transformation for $\bar{u}^*$ but neither of the two brings the profiles in and downstream of the shock interaction onto the "incompressible norm" (Coles). The effect of the change in transformation is quite large, but small compared with that which would be required to give the profiles a satisfactory log-law. No particular pattern can be seen, and were it not for the comparison with the standard outer law (Fig. 5.2.6) a

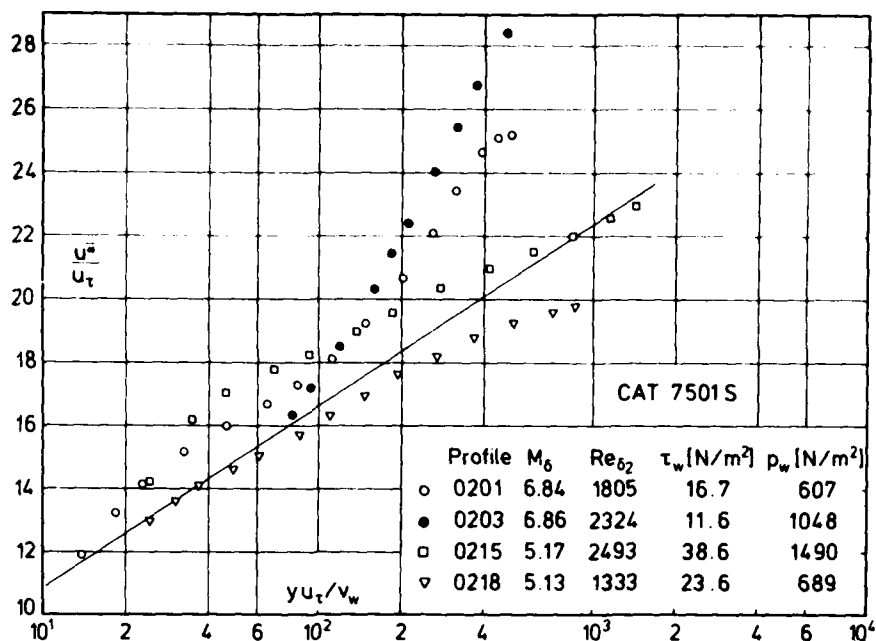


Fig. 5.2.3 Law of the wall for a compressible boundary layer with shock interaction (isothermal wall, $T_w/T_r = 0.47$, defined origin, varied pressure gradient). Kussoy & Horstman (1975).

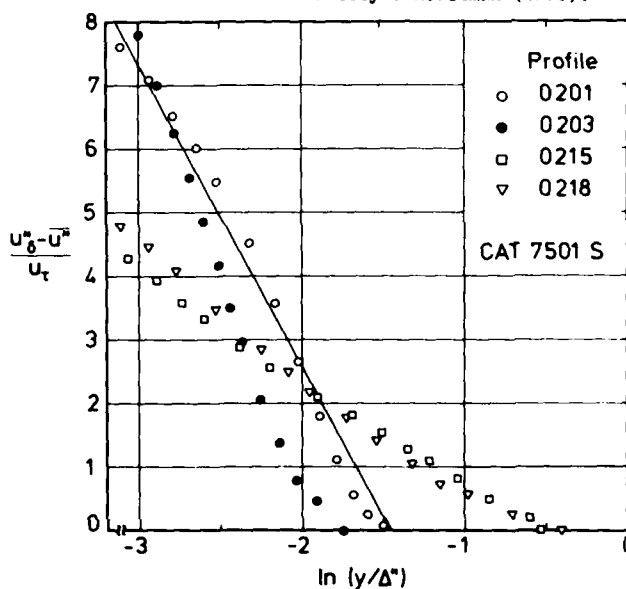


Fig. 5.2.4 Outer law for a compressible boundary layer with shock interaction (isothermal wall, $T_w/T_r = 0.47$, defined origin, varied pressure gradient). Kussoy & Horstman (1975).

physical explanation would be difficult.

Beginning with profiles 0204 and 0206, one finds the typical behaviour of a velocity distribution in a severe pressure gradient (cf. Rose CAT 7306S, Kussoy et al. CAT 7802S and in a more moderate pressure gradient Sturek & Danberg and Zwarts in Figs. 5.3.17 and 5.3.14 of AG 253) with the measurements below the outer law norm. Profiles 0208 and 0210 are already in a transitional phase and having passed through both compression and expansion waves (see Fig. 5.3.2) happen to lie quite close to the standard zero pressure gradient profile. Finally profile 0212 represents a favourable pressure gradient profile such as those in Figs. (5.2.2) and (5.2.3) of AG 253 where again the pressure gradient is much more moderate. Since we have used both transformations in Fig. (5.2.6), it is easy to observe that the differences in the outer law plot are very small. As a next step we have investigated how the transformations influence a cooled boundary layer with a favourable pressure gradient and we

find again that the measurements do not agree at all with the standard law of the wall (Fig. 5.2.7, Peterson CAT 7405S).

The figure also shows the effect of the different transformations. The profiles using measured density values are very different from those using the van Driest correlation. We also show profiles using measured temperatures as differences between these and the density based profiles show the sensitivity of the process to normal pressure gradients. Differences arising from the pressure variation seem to be relatively small. We have also plotted three profiles from Perry & East (1968, CAT 6801) in Fig. (5.2.8). They show a similar trend to those of Peterson in Fig. (5.2.7) though at a higher level in relation to the standard log law. In Fig. (5.2.6) the outer law profiles behaved on the whole in a manner explicable in terms of local, or upstream, pressure gradients. The favourable pressure-gradient profiles shown in Fig. (5.2.9) on the other hand resemble, if anything, adverse pressure-gradient profiles. We have no explanation for this behaviour,

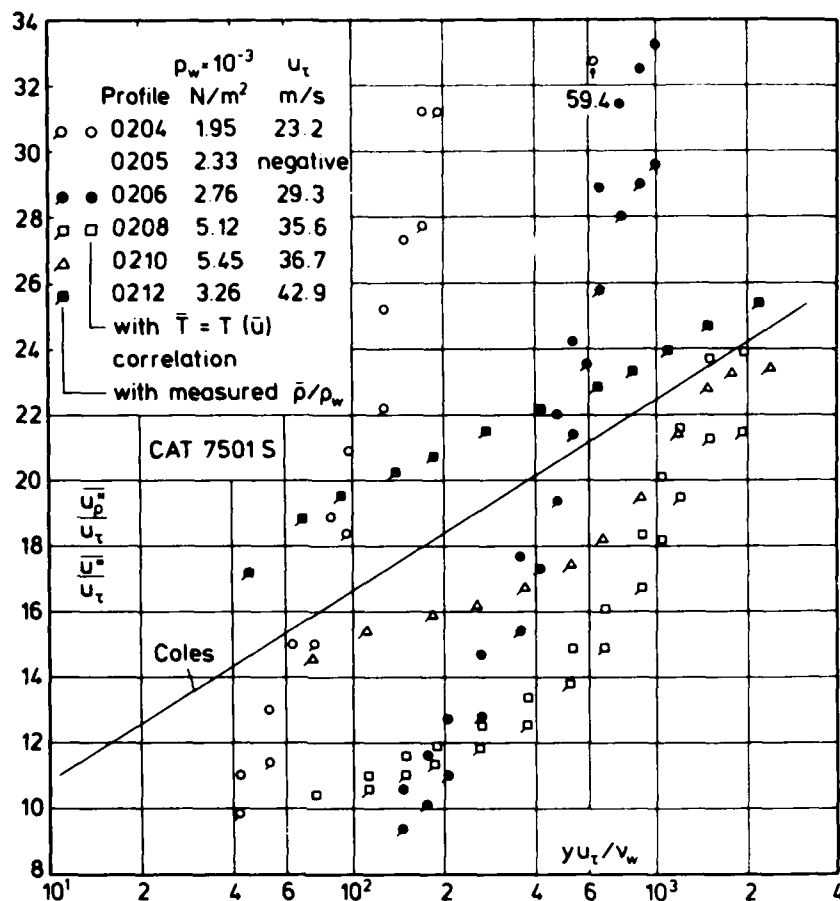


Fig. 5.2.5 Law of the wall for a compressible boundary layer with cooling and varied pressure gradient (isothermal wall, $T_w/T_r = 0.47$, defined origin). Kussoy & Horstman (1975).

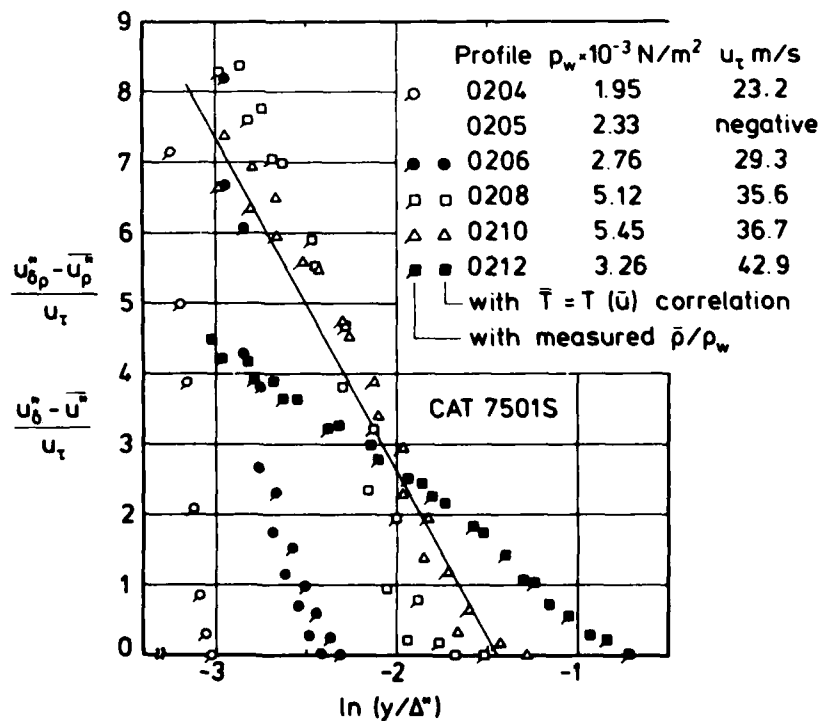


Fig. 5.2.6 Outer law for a compressible boundary layer with cooling and varied pressure gradient (isothermal wall, $T_w/T_r = 0.47$, defined origin). Kussoy & Horstman (1975).

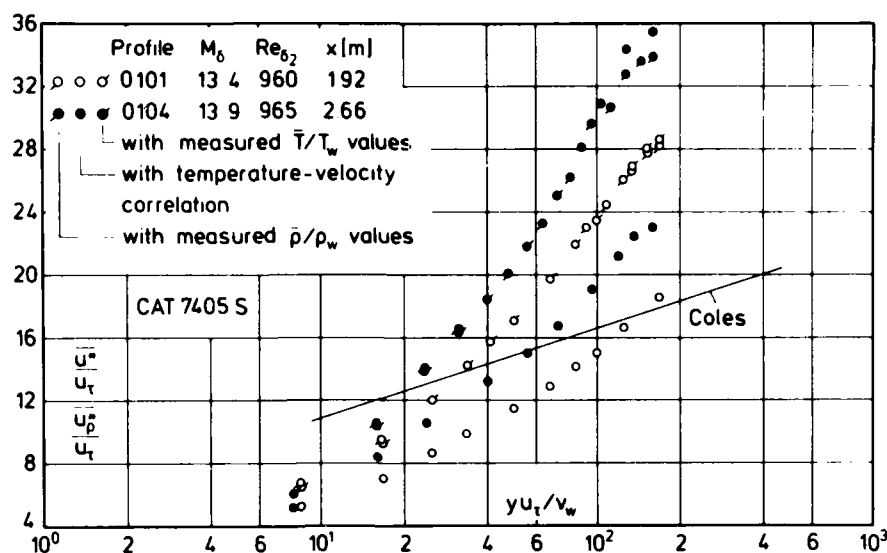


Fig. 5.2.7 Law of the wall for a compressible boundary layer with cooling and favourable pressure gradient (isothermal wall, $T_w/T_r = 0.24$, origin not defined). Peterson (1974).

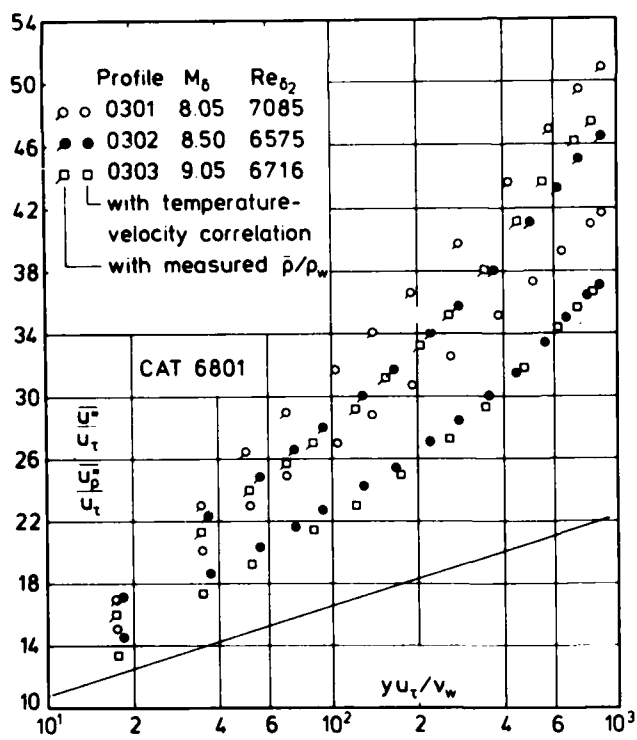


Fig. 5.2.8 Law of the wall for a compressible boundary layer with cooling and favourable pressure gradient (isothermal wall, $T_w/T_r = 0.35$, origin not defined). Perry & East (1968).

and can only refer to the similar profiles measured by Hill (CAT 5901, Fig. 5.2.12 of AG 253) and say that in certain respects they all appear to show laminar characteristics. The effect of changing to a transformation based on measured density is large for these profiles, and more marked than for CAT 7501S (Fig. 5.2.6), as would be expected because of the much greater departure of the temperature-velocity data from the van Driest relationship. As a conclusion we can only state that there are boundary conditions - such as severe wall cooling accompanied by a severe pressure gradient - which can lead to a breakdown of the standard temperature-velocity correlation (eqn. 2.5.37 of AG 253) and of the standard semi-logarithmic law. The first breakdown is to be expected since the correlation was derived under assumptions which do not cover the above boundary conditions. The departures from the law of the wall are less easy to explain, and we can only warn the reader to look out for these special boundary conditions which apparently lead to such an abrupt breakdown of the law of the wall. It is, however, comforting to note that the disturbed velocity distributions return to the semi-logarithmic law very rapidly after the pressure gradient has been relaxed (Figs. 5.2.3 and 5.2.6).

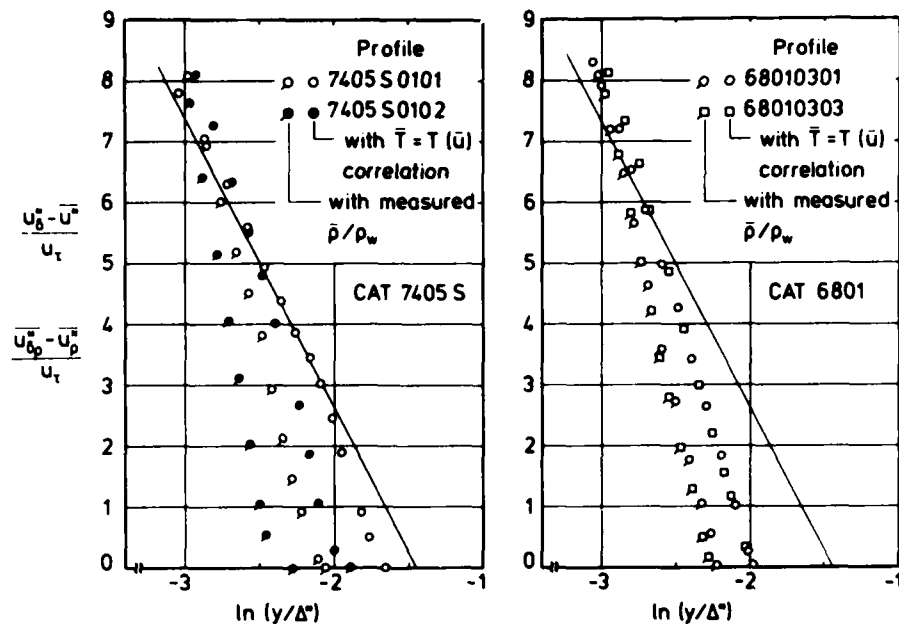


Fig. 5.2.9 Outer law for a compressible boundary layer with cooling and favourable pressure gradient (isothermal wall, origin not defined). Perry & East (1968), Peterson (1974).

5.3 Discussion of the wave structure of the shock/boundary-layer interaction (Kussoy & Horstman (1975))

Since the experiment of Kussoy & Horstman (1975, CAT 7501S) is of primary importance for the discussion of mean flow and turbulence data in this volume and one of the building blocks for turbulence modelling we thought it to be of advantage if the wave pattern of their two experimental configurations were discussed in more detail. This is a procedure in line with that followed in sections 6.1 and 6.2 of AG 253. The test boundary layer was formed on a 10° semi-apex angle cone-ogive cylinder mounted on the centre line of the tunnel. An annular shock generator was mounted coaxially with the model and could be traversed in the axial direction. Two deflection angles, 7.5° and 15° (series 01 and 02) were used, and the shock waves produced were followed closely by an expansion. Measurements were made at different stations in relation to the wave structure by traversing the shock generator, so moving the wave pattern over instruments at fixed stations in the rear part of the model.

Figure (5.3.1) shows the static pressure field for series 01, in which the boundary layer remains attached. A very small amount of upstream influence is shown by the small pressure rise in profile 0104 near the wall,

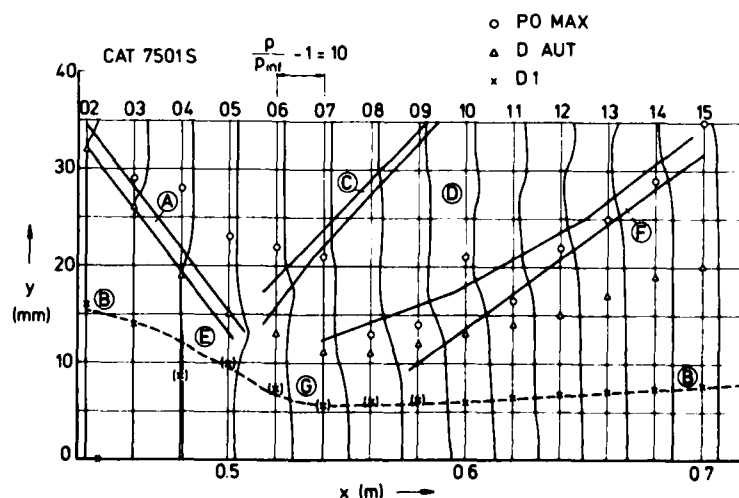


Fig. 5.3.1 Attached shock/boundary-layer interaction. Kussoy & Horstman (1975). Pressure Distribution I.

but this has negligible effect on the development of the wave structure as a whole. This is dominated by the incoming shock A and its reflection by, and deformation of, the displacement surface B - B'. For profiles 0104 to 0110 there are normal static pressure gradients large enough for the calculation of D1 to be invalid, so that in this region the form of the displacement surface as shown is speculative. There is a relatively weak reflected shock C springing from the intersection of the incoming shock and the displacement surface. Its presence implies a locally concave region - caused by the upstream influence. This is followed by a relatively weak expansion region D coming from the convex part of the displacement surface E, the incoming compression A being almost completely cancelled by the curvature of the flow. A strong compression F, initially fairly widely distributed, is then formed as the flow is turned back to the original direction by the concave portion of the displacement surface G. The whole flow field behind the incoming shock is immersed in an expansion originating from the corner at the end of the 7.5° shock generating wedge. This is relatively weak as can be seen by the slow streamwise fall in static pressure at $y = 35$ mm from profile 0103 to 0108.

In the second series (02) the pressure rise of the incoming shock A is nearly twice as large (Fig. 5.3.2). This causes the boundary layer to separate at B forming a separation bubble hatched in the figure. The bubble

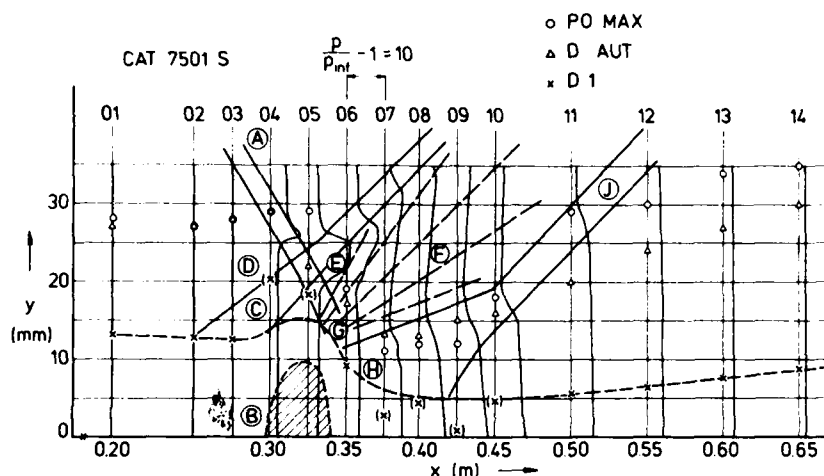


Fig. 5.3.2 Separated shock/boundary-layer interaction. Kussoy & Horstman (1975). Pressure Distribution II.

distorts the displacement surface causing a strong upstream influence. The displacement surface upstream of the bubble becomes concave C and an outgoing shock D is generated upstream of the incoming shock A. The two shocks cross, giving rise to the local pressure hump E to be seen in profile 0205 - the form and position of the hump in profile 0204 suggests that the probe was perhaps responding to an upstream influence of the shocks intersecting it downstream of the tip. The pressure rise E is then eroded by a strong expansion F springing from the convex portion of the displacement surface G. Again the exact form and position is not known as it cannot be calculated because of normal pressure gradient effects. The concave portion H of the displacement surface which follows in turn generates a compression which coalesces to form the second outgoing shock J. As in case one, the whole flow is in an expansion field spreading from the rear of the shock generator, and this is best seen in the steady fall of static pressure behind the final shock (profiles 0211 to 0214). This region is in a gentle reflected wave expansion and so shows little normal pressure gradient.

SECTION 6

THE ENTRIES

The entries are arranged in the sequence given in the table below.

Note: Boundary conditions and evaluated data are given for all profiles as section B of each entry. This data is also printed on the microfiche, which gives complete data for all profiles. The tables of section C of each entry provide only a selection of the profile data. Only selected turbulence data are given in the entry. The complete tables are printed on the microfiche.

CLASSIFIED LIST OF SUPPLEMENTARY ENTRIES

The ENTRIES are listed in numerical order, otherwise following the conventions of § 7 of AGARDograph 223. The pressure gradient classification is given both as an abbreviation and as in AG223 § 7.1.

	M_0	R THETA $\times 10^{-3}$	TW/TR	PG ²	TO	CF ³	NX	TURB ⁴
5701 RICHMOND	<1,5.8	1-9	1.0	ZPG,IB	-	F/V	1(3)	-
5806 MORKOVIN & PHINNEY	1.77	16	1.0	ZPG,IB2	-	(V)	1	CC HWC
6002 DANBERG	5.1	3-4	0.8,0.9	ZPG,IA1	P	V	2	-
7306 ROSE	4	3.4	1.0	SBLI,(IIA4)	P	V	12	CT HWP
7404 VOISINET et al.	4.9	6-26	0.8,1.0	ZPG,IB1	P	-	2	-
7405 PETERSON	14	6-11	0.25	FPG,IIB5	P	V	2	-
7501 KUSSOY & HORSTMAN	7	8.5	0.5	SBLI,(IIA4)	P	F	18,19	CT HWP
7701 MABEY	2.5-4.5	1-8	1.0	ZPG,IA1	P	F	3	-
7702 LADERMAN & DEMETRIADES	3.0	3-4	0.6-1.0	ZPG,IB1	P	(P)	3	CC HWP
7703 BERG	6	14-20	0.9	ZPG,IB1R	P	V(F)	17	CC HWP
7801 COLLINS et al.	0.1-2.2	6,23,40	1.0	ZPG,(IA1),IB2	-	F,P,V	4-8	LDV
7802 KUSSOY et al.	2.3	30	1.0	APG,IIA4	(P)	P,surface	13,14	CT HWP
7803 LADERMAN	3.0	3-5	1.0	APG,IIB2	P	V(P)	10,14	-
7804 WATSON	10-12	3-20	0.4-1.1	ZPG,IA1	P	F	7	-
7901 VOISINET	2.9	3-60	1.0	ZPG,IB1R	P	F	1	-
7902 CHEW & SQUIRE	2.5	24	1.0	RELAXATION	-	P	7	-
7903 BARTLETT et al.	9.3	3-12	0.3	ZPG,IA1	P	P	3	(Electron)
8001 MATEER & VIEGAS	1.45	40-100	1.0	SBLI,(IIA4)	P	surface	7	CT HWP

NOTES: (1) Numerical values are nominal, not precise.

(2) SBLI: Shock boundary layer interaction.

(3) CF: F-Floating element balance, P-Preston tube, V-deduced from profile. "surface"-embedded hot wire gauge.

(4) TURB: Turbulent measurements - see tables 3.1 and 4.3.1 in the main text.

axisymmetric 	M: subsonic, 5.8 $R \text{ THETA} \times 10^{-3}: 1 - 8.5$ TW/TR: 1.0	5701 ZPG - AW
Two low speed tunnels, probably (E) $W = H = 0.60 \text{ m}$ and 0.90 m. $0.8 < Re/m \times 10^{-6} < 3$ Hypersonic tunnel with symmetrical nozzle. $W = H = 0.127 \text{ m}$. $0.1 < P_0 < 0.6 \text{ MN/m}^2$. $T_0: 380\text{K}$. Air. $1.5 < Re/m \times 10^{-6} < 7.5$.		
RICHMOND R.L., 1957. Experimental investigation of thick axially symmetric boundary layers on cylinders at subsonic and hypersonic speeds. GALCIT Hyp. Res. Proj. Memo 39, CALTECH, Pasadena, CA.		

- 1 The test boundary layer was formed on the outer surface of one of a number of slender cylinders aligned with the flow. For the subsonic tests two models were used. The first (series 01) consisted of an aluminium tube 3.65 m long and 25.4 mm in diameter. The front end of this ($X = 0$) was mounted on the tunnel settling chamber screens so that it extended along the contraction centre line into the working section ($W = H = 0.9 \text{ m}$) which started at about $X = 1.8 \text{ m}$. The test zone extended from $X = 2.4 \text{ m}$ to $X = 3.1 \text{ m}$. The second model consisted of a steel wire under tension ($d = 0.61 \text{ mm}$) passing through the honeycomb and screens ($X = 0$) and secured at the downstream end of the test section ($W = H = 0.6 \text{ m}$, $X \approx 6 \text{ m}$). Measurements were made at a single station ($X = 4.9 \text{ m}$). The results presented here (series 02) were obtained with a "stovepipe" ($d = 0.2 \text{ m}$) mounted surrounding the model in the test section. For the hypersonic tests, results are presented for two wires ($d = 0.61, 1.63 \text{ mm}$, series 05, 04) and for a composite wire-cylinder model. This last (series 03) consisted of a wire ($d = 1.59 \text{ mm}$) passing through the throat ($X = 0$) on which was mounted a 3° half-angle cone-ogive nosed cylinder of final diameter 6.35 mm. The change in section began at the start of the test rhombus ($X = 0.24 \text{ m} - E$) and was complete by $X = 0.3 \text{ m} (E)$. The models continued with constant diameter to the point at which they were anchored at the rear of the test section ($X = 0.89 \text{ m} - E$).
- 3 On the larger (25.4 mm - series 01) subsonic model, the boundary layer was found to be turbulent at the lowest practical tunnel speed. At the relatively high speeds used for the tests the flow was therefore presumed to be fully turbulent. For the subsonic tests on the smaller wire model, a variety of tripping devices were tried, the results being little affected by which was used. The results presented here are probably obtained (E) using a 'clay centre-body trip' of unspecified nature. For the hypersonic tests 'laminar and naturally turbulent boundary layers were found on all
- 4 models tested.' We therefore suppose that no trip was used. Since either the test model itself, or a support wire, passed upstream into a low speed region for all tests described, all the test layers had at one point passed through a favourable pressure gradient region.
- 5 No measurements of axial symmetry were made for the larger subsonic cylinder (series 01). For the subsonic tests on a wire (series 02) a strut attached to the model behind the test section could be used to displace it in any direction in the Y-Z plane. The flow at a survey station, as assessed by a "double Pitot sliding on and rotating about the wire model," "was forced to be symmetrical" by adjustment of this strut and the use of the "stovepipe" referred to above. Originally, without these precautions, "the boundary layer axial non-symmetry was found to be continually changing in an unpredictable manner."

In the hypersonic tests, the rear end of the model could be moved vertically to impose axisymmetry, but the principal source of asymmetry was the planar nature of the nozzle expansion field, which caused the side boundary layer thicknesses to be less than the top and bottom thicknesses for all models. This was most pronounced at $X = 0.25 - 0.30 \text{ m}$, the axial symmetry steadily improving to

- 2 $X = 0.61$ m. However, due to the presence of weak waves in the free stream, measurements were taken slightly upstream of this point at $X = 0.508$ m. Asymmetry would seem to have been considerable as "a correction factor of from 0.842 to 0.866, depending on the free-stream Reynolds number per inch, was applied to momentum and displacement thickness as computed from the thicker boundary layer on top of the models."
- 6 No wall pressure or temperature measurements are mentioned. Skin friction measurements were made at $M = 5.8$ on the composite (1.59/6.35 mm - series 03) model with an FEB. The element consisted of a 12.7 mm long section of the outer surface of the cylinder, bounded by two 63 μ m gaps.
- 7 No details are given for the Pitot tubes used to give the profiles of series 01. For series 02, a HWP ($d = 0.25$ mm, $l = 0.38$ mm) was used to give velocity profiles. The hot wire was calibrated for mean flow by observing the shedding frequency of vortices in flow normal to a standardized cylinder. The probe was mounted on a support hinged to the strut used to align the model wire so as to reduce error in the relative positioning of the model and the probe.

- In the hypersonic tests a 12-tube Pitot rake was used, with three tubes located in each of 4 planes 90° apart round the models. Since up to 26 data points are given in one profile and the values of Y for a given model do not remain constant in successive runs, it seems that there must have been
- 8 provision for altering the geometry of the rake in some way. For series 01 profiles were measured at $X = 2.44$, 2.74 and 3.05 m from the screens ahead of the tunnel contraction. For series 02, all measurements were made 4.88 m from the tunnel screens. In the hypersonic tests, all measurements were made 0.508 m from the tunnel throat.
 - 9 For the hypersonic tests, the author obtained mean velocity profiles assuming isoenergetic flow. Wall values were calculated assuming recovery factors of 0.9 for turbulent and 0.86 for laminar flow respectively. In addition to the skin friction values measured at $M = 5.8$, the author gives values obtained by matching profiles to the Coles wake-and-wall profile at low speeds, using Coles' (1955) streamline hypothesis, and by matching a transformed profile at high speeds for the 'wire' results of
 - 11 series 4 and 5. The Sutherland viscosity law was used.
 - 12 We have presented all profiles tabulated by the author, replacing the isoenergetic total temperature assumption by the Crocco-van Driest temperature/velocity correlation with recovery factor 0.896 for all profiles, whether referred to by the author as 'laminar' (0301, 0302, 0401, 0501) or as 'turbulent'. For profile 0301 we found it necessary to interpolate a D-state point to match the author's stated edge conditions. The subsonic profiles comprise one set of measurements at three
 - 13 successive situations for fixed free stream conditions (01), and one set of profiles at a single station for increasing unit Reynolds number (02). The three $M = 5.8$ sets consist of single station measurements for a range of unit Reynolds number on each of three models. Skin friction values are
 - 14 'measured' for series 03 and as estimated by the author from the velocity profile in the other cases.
 - 5 DATA: 5701 0101-0502. Pitot profiles. $NX = 1(3)$. Skin friction from FEB (series 03) or velocity profiles.
 - 15 Editors' comments. The interest of this study lies in the exceptionally large ratios of representative boundary layer thicknesses to transverse body radius (Table 1). The profiles will not be discussed in detail here as the effects of transverse curvature are considered in §5 of the main text. Some comment is justified, however, in the assessment of the experiment.

The subsonic data are useful here as they provide an indication of the effect of transverse curvature independent of the complications of high Mach number and the associated Reynolds number effects. Representative inner and outer law profiles for low and high values of δ_1/R_z are shown below. For all except series 01, marked differences from the behaviour of a normal ZPG planar boundary layer are visible. The profiles for the high Mach number cases should not be considered accurate as we do not

know whether they come from the top/bottom of the model, or from the sides where the boundary layers are thinner. As remarked in §2 above, the author applied a correction factor of about 15%, implying a substantial degree of asymmetry.

For all profiles except series 01 the measurement extended within the peak of the momentum deficit integrand, so that on this count the integral values are reliable. For all cases involving very large values of Y/R_z , however, it should be noted that the integrals will be very sensitive to small changes in the flow properties at large Y -values. We found large discrepancies between our integral values and the author's in the subsonic case. There are no comparable experiments compressible flow, but the low speed results may be compared to those of Willmarth et al. (1976). For these, δ/R_z ranged from 1.8 to 42.5, and δ_1/R_z from 0.26 to 5.8. The general tendency of the profiles is the same. The profiles are discussed further in §5.1 of the main text. The Reynolds numbers for the hypersonic measurements are relatively low, the author describing profiles 0301, 0302, 0401 and 0501 as laminar.

Table 1 Transverse curvature for profiles measured on slender cylinders

CAT 5701	R_z (m)	δ_1/R_z	Approx. δ/R_z	$Re_\theta \times 10^{-3}$	$Re_{\delta_2} \times 10^{-3}$	M_δ	
0101	1.27×10^{-2}	0.17	1.7	4.9	$=Re_\theta$	0.14	successive
0102	"	0.22	2.2	6.6	"	"	stations on
0103	"	0.26	2.9	8.0	"	"	cylinder
0201	3.048×10^{-4}	12	76	1.0	"	0.036	single station
0202	"	8.7	89	2.0	"	"	on stretched
0203	"	12	90	2.8	"	"	wire
0204	"	13	90	3.1	"	"	"
0301	3.175×10^{-3}	1.87	4.0	1.0	0.180	5.6	single station
0302	"	1.68	3.5	1.3	0.229	"	on composite
0303	"	1.22	3.1	2.4	0.415	"	wire/cylinder
0304	"	1.26	3.5	3.3	0.559	"	"
0401	8.128×10^{-4}	4.42	8.7	1.2	0.214	"	single station
0402	"	5.22	10	5.7	0.978	"	on stretched
0501	3.048×10^{-4}	13.2	27	2.2	0.398	"	wire
0502	"	10.3	42	5.0	0.842	5.8	"

CAT 5701S

BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS

RUN X * RZ *	MD POD* TOD*	YU/TR* PW/PD* TAUM	RED2W RED2D D2	CF * CQ PI2*	H12 H32 H42	H12K H32K D2K	PW TW UD*	PD TD TR
5701S0101 2.4384**00 1.2700**-02	0.1354 1.0132**05 3.0000**02	1.0000 1.0000 4.1474**+00	4.9057**+03 4.9181**+03 1.6601**-03	3.2300**-03 NM 0.0000**+00	1.3004 1.7535 0.0007	1.2937 1.7534 1.6616**-03	1.0004**+05 2.9989**02 4.6939**01	1.0004**+05 2.9890**02 2.9989**02
5701S0102 2.7432**00 1.2700**-02	0.1354 1.0132**05 3.0000**02	1.0000 1.0000 3.9162**+00	6.5658**+03 6.5824**+03 2.2219**-03	3.0500**-03 NM 0.0000**+00	1.2707 1.7348 0.0008	1.2642 1.7347 2.2238**-03	1.0004**+05 2.9989**02 4.6939**01	1.0004**+05 2.9890**02 2.9989**02
5701S0103 3.0480**00 1.2700**-02	0.1354 1.0132**05 3.0000**02	1.0000 1.0000 3.7236**+00	8.0150**+03 8.0353**+03 2.7123**-03	2.9000**-03 NM 0.0000**+00	1.2388 1.7270 0.0008	1.2325 1.7268 2.7145**-03	1.0004**+05 2.9989**02 4.6939**01	1.0004**+05 2.9890**02 2.9989**02
5701S0201 4.8768**00 3.0480**-04	0.0132 1.0132**05 3.0000**02	1.0000 1.0000 7.3347**-02	1.0248**+03 1.0249**+03 3.5156**-03	5.9200**-03 NM 0.0000**+00	1.0421 1.4242 0.0000	1.0421 1.4242 3.5156**-03	1.0131**05 3.0000**02 4.5900**00	1.0131**05 2.9999**02 3.0000**02
5701S0202 4.8768**00 3.0480**-04	0.0357 1.0132**05 3.0000**02	1.0000 1.0000 4.4663**-01	2.0155**+03 2.0158**+03 2.5627**-03	4.9500**-03 NM 0.0000**+00	1.0331 1.4408 0.0003	1.0328 1.4408 2.5627**-03	1.0123**05 2.9999**02 1.2390**01	1.0123**05 2.9999**02 2.9999**02
5701S0203 4.8768**00 3.0480**-04	0.0351 1.0132**05 3.0000**02	1.0000 1.0000 4.5242**-01	2.7822**+03 2.7827**+03 3.5956**-03	5.1800**-03 NM 0.0000**+00	1.0310 1.4293 0.0003	1.0307 1.4293 3.5956**-03	1.0124**05 2.9999**02 1.2190**01	1.0124**05 2.9993**02 2.9999**02
5701S0204 4.8768**00 3.0480**-04	0.0357 1.0132**05 3.0000**02	1.0000 1.0000 4.6813**-01	3.0637**+03 3.0643**+03 3.8924**-03	5.1800**-03 NM 0.0000**+00	1.0297 1.4265 0.0004	1.0295 1.4265 3.8924**-03	1.0123**05 2.9999**02 1.2400**01	1.0123**05 2.9992**02 2.9999**02
5701S0301 5.0800**-01 3.1750**-03	5.6000 9.9629**04 3.6742**02	1.0000 1.0000 3.1635**+00	1.8024**+02 1.0025**+03 6.8609**-04	1.5000**-03 NM 0.0000**+00	8.4782 1.6628 0.1727	1.3770 1.5251 1.8552**-03	9.6072**01 3.3446**02 7.9809**02	9.6072**01 5.0255**02 3.3446**02
5701S0302 5.0800**-01 3.1750**-03	5.5900 1.6858**05 3.8020**02	1.0000 1.0000 8.2671**+00	2.2947**02 1.2611**+03 5.3474**-04	2.3000**-03 NM 0.0000**+00	9.2556 1.6593 0.1672	1.4943 1.5106 1.5434**-03	1.6432**02 3.4611**02 8.1165**02	1.6432**02 5.2444**01 3.4611**02
5701S0303 5.0800**-01 3.1750**-03	5.7500 4.4437**05 3.8020**02	1.0000 1.0000 1.6392**+01	4.1488**+02 2.3939**+03 4.1262**-04	1.9400**-03 NM 0.0000**+00	9.3563 1.8017 0.1797	1.3258 1.6857 8.2801**-04	3.6509**02 3.4585**02 8.1474**02	3.6509**02 4.9944**01 3.4585**02
5701S0304 5.0800**-01 3.1750**-03	5.7800 5.8192**05 3.8020**02	1.0000 1.0000 2.0040**+01	5.5973**02 3.2589**03 4.3447**-04	1.8500**-03 NM 0.0000**+00	9.2223 1.8038 0.1811	1.2611 1.6977 8.5678**-04	4.6320**02 3.4581**02 8.1530**02	4.6320**02 4.9494**01 3.4581**02
5701S0401 5.0800**-01 8.1280**-04	5.7500 1.6823**05 3.8020**02	1.0000 1.0000 NM	2.1459**02 1.2382**03 5.6373**-04	NM NM 0.0000**+00	6.3822 1.5738 0.2052	1.3648 1.4326 1.2356**-03	1.3822**02 3.4585**02 8.1474**02	1.3822**02 4.9944**01 3.4585**02
5701S0402 5.0800**-01 8.1280**-04	5.7900 5.8192**05 3.8020**02	1.0000 1.0000 2.2910**+01	9.7971**+02 5.7212**03 7.6601**-04	2.1300**-03 NM 0.0000**+00	5.5380 1.6205 0.2330	1.1218 1.5553 1.0967**-03	4.5835**02 3.4579**02 8.1548**02	4.5835**02 4.9346**01 3.4579**02
5701S0501 5.0800**-01 3.0480**-04	5.5800 1.6823**05 3.8020**							

5701S0201		RICHMOND		PROFILE TABULATION		22 POINTS, DELTA AT POINT 21		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	1.00000	0.00000	0.00000	1.00003	0.00000
2	2.2860"-04	1.0000"+00	NM	1.00000	0.32461	0.32462	1.00003	0.32461
3	3.0480"-04	1.0000"+00	NM	1.00000	0.37472	0.37473	1.00003	0.37472
4	3.8100"-04	1.0000"+00	NM	1.00000	0.43572	0.43573	1.00003	0.43572
5	4.5720"-04	1.0000"+00	NM	1.00000	0.51416	0.51416	1.00002	0.51415
6	5.3340"-04	1.0000"+00	NM	1.00000	0.57080	0.57081	1.00002	0.57079
7	6.0960"-04	1.0000"+00	NM	1.00000	0.59912	0.59913	1.00002	0.59912
8	6.8580"-04	1.0001"+00	NM	1.00000	0.65359	0.65359	1.00002	0.65358
9	7.6200"-04	1.0001"+00	NM	1.00000	0.68191	0.68192	1.00002	0.68191
10	1.1430"-03	1.0001"+00	NM	1.00000	0.76470	0.76471	1.00001	0.76470
11	1.5240"-03	1.0001"+00	NM	1.00000	0.81917	0.81917	1.00001	0.81916
12	1.9050"-03	1.0001"+00	NM	1.00000	0.84095	0.84096	1.00001	0.84095
13	2.2860"-03	1.0001"+00	NM	1.00000	0.86056	0.86057	1.00001	0.86056
14	3.0480"-03	1.0001"+00	NM	1.00000	0.89106	0.89107	1.00001	0.89106
15	4.1910"-03	1.0001"+00	NM	1.00000	0.91503	0.91503	1.00001	0.91503
16	6.0960"-03	1.0001"+00	NM	1.00000	0.93682	0.93682	1.00000	0.93682
17	8.0010"-03	1.0001"+00	NM	1.00000	0.95643	0.95643	1.00000	0.95642
18	1.1811"-02	1.0001"+00	NM	1.00000	0.95860	0.95861	1.00000	0.95860
19	1.5621"-02	1.0001"+00	NM	1.00000	0.97603	0.97603	1.00000	0.97603
20	1.9431"-02	1.0001"+00	NM	1.00000	0.99129	0.99129	1.00000	0.99128
D 21	2.3241"-02	1.0001"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000
22	2.7051"-02	1.0001"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,U ASSUME P=PD AND VAN DRIEST - TURBULENT

5701S0202		RICHMOND		PROFILE TABULATION		21 POINTS, DELTA AT POINT 21		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.99997	0.00000	0.00000	1.00023	0.00000
2	3.0480"-04	1.0003"+00	NM	0.99998	0.55201	0.55206	1.00016	0.55197
3	3.8100"-04	1.0003"+00	NM	0.99998	0.58914	0.58918	1.00015	0.58910
4	4.5720"-04	1.0004"+00	NM	0.99999	0.66340	0.66344	1.00013	0.66335
5	5.3340"-04	1.0005"+00	NM	0.99999	0.71182	0.71186	1.00011	0.71178
6	6.0960"-04	1.0005"+00	NM	0.99999	0.74007	0.74011	1.00010	0.74004
7	6.8580"-04	1.0005"+00	NM	0.99999	0.77075	0.77078	1.00009	0.77071
8	8.3820"-04	1.0006"+00	NM	0.99999	0.80223	0.80226	1.00008	0.80219
9	1.0668"-03	1.0006"+00	NM	0.99999	0.83290	0.83293	1.00007	0.83287
10	1.4478"-03	1.0007"+00	NM	0.99999	0.86761	0.86764	1.00006	0.86759
11	1.8288"-03	1.0007"+00	NM	0.99999	0.88456	0.88458	1.00005	0.88454
12	2.2098"-03	1.0007"+00	NM	1.00000	0.90151	0.90153	1.00004	0.90149
13	2.7118"-03	1.0008"+00	NM	1.00000	0.91927	0.91929	1.00004	0.91926
14	4.1148"-03	1.0008"+00	NM	1.00000	0.93784	0.93785	1.00003	0.93783
15	6.0198"-03	1.0008"+00	NM	1.00000	0.95479	0.95480	1.00002	0.95478
16	7.9248"-03	1.0008"+00	NM	1.00000	0.96932	0.96933	1.00001	0.96932
17	1.1735"-02	1.0009"+00	NM	1.00000	0.98385	0.98386	1.00001	0.98385
18	1.5545"-02	1.0009"+00	NM	1.00000	0.99273	0.99274	1.00000	0.99273
19	1.9355"-02	1.0009"+00	NM	1.00000	0.99435	0.99435	1.00000	0.99435
20	2.3165"-02	1.0009"+00	NM	1.00000	0.99919	0.99919	1.00000	0.99919
D 21	2.6975"-02	1.0009"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,U ASSUME P=PD AND VAN DRIEST - TURBULENT

5701S0204		RICHMOND		PROFILE TABULATION		24 POINTS, DELTA AT POINT 24		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.99997	0.00000	0.00000	1.00023	0.00000
2	1.5240"-04	1.0001"+00	NM	0.99998	0.39512	0.39516	1.00019	0.39509
3	2.2860"-04	1.0002"+00	NM	0.99998	0.45964	0.45968	1.00018	0.45959
4	3.0480"-04	1.0003"+00	NM	0.99998	0.55641	0.55645	1.00016	0.55636
5	3.8100"-04	1.0004"+00	NM	0.99998	0.64915	0.64919	1.00013	0.64911
6	4.5720"-04	1.0004"+00	NM	0.99999	0.69673	0.69677	1.00012	0.69669
7	5.3340"-04	1.0005"+00	NM	0.99999	0.73383	0.73387	1.00011	0.73379
8	6.0960"-04	1.0005"+00	NM	0.99999	0.76206	0.76210	1.00010	0.76202
9	6.8580"-04	1.0005"+00	NM	0.99999	0.78222	0.78226	1.00009	0.78219
10	7.6200"-04	1.0006"+00	NM	0.99999	0.79674	0.79677	1.00008	0.79671
11	9.1440"-04	1.0006"+00	NM	0.99999	0.82497	0.82500	1.00007	0.82494
12	1.0668"-03	1.0006"+00	NM	0.99999	0.84029	0.84032	1.00007	0.84027
13	1.4478"-03	1.0007"+00	NM	0.99999	0.86288	0.86290	1.00006	0.86285
14	1.8288"-03	1.0007"+00	NM	0.99999	0.87982	0.87984	1.00005	0.87979
15	2.2098"-03	1.0007"+00	NM	0.99999	0.89272	0.89274	1.00005	0.89270
16	2.5908"-03	1.0007"+00	NM	1.00000	0.90240	0.90242	1.00004	0.90238
17	4.4958"-03	1.0008"+00	NM	1.00000	0.92337	0.92339	1.00003	0.92336
18	6.4008"-03	1.0008"+00	NM	1.00000	0.93547	0.93548	1.00003	0.93546
19	8.3058"-03	1.0008"+00	NM	1.00000	0.94596	0.94597	1.00002	0.94595
20	1.2116"-02	1.0008"+00	NM	1.00000	0.96048	0.96048	1.00002	0.96047
21	1.5926"-02	1.0008"+00	NM	1.00000	0.97499	0.97500	1.00001	0.97499
22	1.9736"-02	1.0009"+00	NM	1.00000	0.98387	0.98387	1.00001	0.98386
23	2.3546"-02	1.0009"+00	NM	1.00000	0.99193	0.99194	1.00000	0.99193
D 24	2.7356"-02	1.0009"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,U ASSUME P=PD AND VAN DRIEST - TURBULENT

5701S0402		RICHMOND		PROFILE TABULATION		22 POINTS, DELTA AT POINT 20		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.90950	0.00000	0.00000	7.00752	0.00000
2	1.2700"-04	1.7287"+00	NM	0.92340	0.15889	0.39195	6.08463	0.06442
3	3.5560"-04	2.7459"+00	NM	0.93433	0.22625	0.52378	5.35938	0.09773
4	5.8420"-04	7.3528"+00	NM	0.96110	0.39896	0.75510	3.58216	0.21080
5	8.1280"-04	1.1154"+01	NM	0.97261	0.49741	0.83505	2.81839	0.29629
6	1.0414"-03	1.3574"+01	NM	0.97768	0.55095	0.86795	2.48181	0.34973
7	1.5240"-03	1.6332"+01	NM	0.98216	0.60622	0.89600	2.18455	0.41015
8	1.9812"-03	1.8963"+01	NM	0.98553	0.65458	0.91656	1.96067	0.46748
9	2.4384"-03	2.1171"+01	NM	0.98787	0.69257	0.93056	1.80534	0.51545
10	3.3528"-03	2.4942"+01	NM	0.99111	0.75302	0.94960	1.59026	0.59714
11	4.2926"-03	2.8425"+01	NM	0.99348	0.80484	0.96332	1.43261	0.67242
12	5.2070"-03	3.1632"+01	NM	0.99529	0.84974	0.97362	1.31281	0.74163
13	6.1468"-03	3.4481"+01	NM	0.99666	0.88774	0.98135	1.22202	0.80306
14	7.0612"-03	3.6905"+01	NM	0.99768	0.91883	0.98709	1.15411	0.85528
15	7.6962"-03	3.8148"+01	NM	0.99816	0.93437	0.98978	1.12213	0.88206
16	8.3058"-03	3.9412"+01	NM	0.99862	0.94991	0.99237	1.09138	0.90928
17	9.2456"-03	4.1275"+01	NM	0.99926	0.97237	0.99591	1.04902	0.94938
18	1.0160"-02	4.2885"+01	NM	0.99977	0.99136	0.99875	1.01496	0.98403
19	1.1074"-02	4.3479"+01	NM	0.99996	0.99827	0.99975	1.00297	0.99679
D 20	1.2014"-02	4.3628"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
21	1.2929"-02	4.3628"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
22	1.3386"-02	4.3628"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

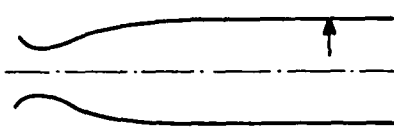
INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST - TURBULENT

5701S0501		RICHMOND		PROFILE TABULATION		20 POINTS, DELTA AT POINT 19		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.91039	0.00000	0.00000	6.57964	0.00000
2	1.2700"-04	3.3382"+00	NM	0.94018	0.26523	0.57654	4.72499	0.12202
3	5.8420"-04	4.7155"+00	NM	0.94948	0.32437	0.66046	4.14576	0.15931
4	1.0414"-03	6.9442"+00	NM	0.96042	0.40143	0.74720	3.46451	0.21567
5	1.5240"-03	8.6551"+00	NM	0.96664	0.45161	0.79225	3.07749	0.25744
6	1.9812"-03	1.0283"+01	NM	0.97138	0.49462	0.82500	2.78200	0.29655
7	2.4384"-03	1.2216"+01	NM	0.97595	0.54122	0.85533	2.49761	0.34246
8	2.8956"-03	1.3738"+01	NM	0.97894	0.57527	0.87461	2.31149	0.37838
9	3.3528"-03	1.6332"+01	NM	0.98312	0.62903	0.90089	2.05116	0.43921
10	3.8354"-03	1.8865"+01	NM	0.98638	0.67742	0.92088	1.84796	0.49832
11	4.2926"-03	2.2216"+01	NM	0.98982	0.73656	0.94149	1.63386	0.57624
12	4.7498"-03	2.6192"+01	NM	0.99299	0.80108	0.96010	1.43642	0.66839
13	5.2070"-03	3.0254"+01	NM	0.99553	0.86201	0.97471	1.27860	0.76233
14	5.6642"-03	3.3954"+01	NM	0.99739	0.91398	0.98535	1.16228	0.84778
15	6.1468"-03	3.6768"+01	NM	0.99860	0.95161	0.99217	1.08705	0.91272
16	6.6040"-03	3.8427"+01	NM	0.99924	0.97312	0.99577	1.04710	0.95098
17	7.0612"-03	3.9554"+01	NM	0.99965	0.98746	0.99806	1.02160	0.97696
18	7.5184"-03	3.9981"+01	NM	0.99980	0.99283	0.99890	1.01226	0.98680
D 19	8.1534"-03	4.0554"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
20	8.7630"-03	3.7042"+01	NM	0.99871	0.95520	0.99278	1.08025	0.91903

INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST - LAMINAR

5701S0502		RICHMOND		PROFILE TABULATION		20 POINTS, DELTA AT POINT 18		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.90934	0.00000	0.00000	7.09081	0.00000
2	1.2700"-04	4.3108"+00	NM	0.94591	0.29503	0.63510	4.63408	0.13705
3	5.8420"-04	1.0498"+01	NM	0.97081	0.47856	0.82345	2.96078	0.27812
4	1.0414"-03	1.8286"+01	NM	0.98455	0.63808	0.91084	2.03768	0.44700
5	1.5240"-03	2.1482"+01	NM	0.98799	0.69297	0.93143	1.80665	0.51556
6	1.9812"-03	2.3942"+01	NM	0.99015	0.73242	0.94412	1.66165	0.56819
7	2.4384"-03	2.6423"+01	NM	0.99200	0.77015	0.95488	1.53724	0.62116
8	3.3528"-03	3.0627"+01	NM	0.99458	0.83019	0.96964	1.36418	0.71079
9	4.2672"-03	3.4481"+01	NM	0.99648	0.88165	0.98039	1.23654	0.79285
10	5.2070"-03	3.8148"+01	NM	0.99798	0.92796	0.98882	1.13547	0.87085
11	6.1468"-03	4.1130"+01	NM	0.99904	0.96398	0.99467	1.06470	0.93423
12	7.0612"-03	4.2738"+01	NM	0.99955	0.98285	0.99753	1.03009	0.96838
13	8.1026"-03	4.3479"+01	NM	0.99978	0.99142	0.99878	1.01489	0.98412
14	9.1440"-03	4.3628"+01	NM	0.99982	0.99314	0.99902	1.01189	0.98729
15	1.0058"-02	4.3777"+01	NM	0.99987	0.99485	0.99927	1.00890	0.99046
16	1.0998"-02	4.4076"+01	NM	0.99996	0.99828	0.99976	1.00295	0.99681
17	1.1913"-02	4.4076"+01	NM	0.99996	0.99828	0.99976	1.00295	0.99681
D 18	1.2827"-02	4.4226"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
19	1.3767"-02	4.4226"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
20	1.4224"-02	4.4226"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST - TURBULENT

	M: 1.77 R THETA $\times 10^{-3}$: 16 TW/TR: 1	5806 ZPG - AW
Continuous tunnel with symmetric nozzle. W = 0.19, H = 0.28 m. PO = 93 KN/m ² . TO = 295K. Air: RE/m $\times 10^{-6}$ = 12.7		
MORKOVIN M.V., PHINNEY R.E., 1958. Extended applications of hot wire anemometry to high speed turbulent boundary layers. Dept. Aeronaut. The Johns Hopkins Univ. ASTIA AD-158-279.		

- 1 The test boundary layer was formed on the upper nozzle wall and flat roof of the tunnel test section.
- 3 The measuring station was 0.43 m downstream of the end of the nozzle. "Screening" was glued to the last 0.13 m of the nozzle wall so as to thicken the boundary layer. The profile station was 33 boundary layer thicknesses downstream. "It is therefore likely that the layer represents very nearly a fully developed equilibrium turbulent boundary layer." The test station is some way downstream of "the disequilibrating nozzle pressure gradient." Pressure disturbances from the screening were reflected back to the wall 0.09 m downstream of the profile station.
- 6 No wall measurements are reported, but it is suggested that since the test surface was separated from the tunnel structure by an air gap from 0.05 to 0.09 m deep, it is a "plausible hypothesis" that the flow was effectively adiabatic.
- 7 "Primary" mean flow measurements were made using an FPP ($h_1 = 0.1$, $h_2 = 0.05$, $b_1 = 0.9$ mm). Fluctuation measurements were made with a large number of HWP operating in the constant current mode. Normal wires were made from Tungsten ($d = 3.8$ μ m) with and without copper "sleeves" ($d = 13$ μ m), and of Platinum -10% Rhodium ($d = 2.5$ μ m) with and without silver "sleeves" ($d = 63$ μ m), the nominal l/d ratios of the sensing element ranging from 198 to 667. Exploratory investigations were also made using a number of X-wire probes.
- 9 The authors reduced the Pitot profile data assuming isoenergetic flow. A skin friction value was obtained by comparison with measurements by Coles (CAT 5301) and Shutts et al. (CAT 5501) and a fit to Coles' wall law (assuming $\rho_T/\rho_W = 1.1$ as did Kistler in CAT 5803).
- 12 The editors have, exceptionally, prepared this entry from the authors' graphical data, and so implicitly accepted their interpolations and smoothing procedures. We have replaced the assumption of isoenergetic flow by the Crocco/van Driest temperature/velocity correlation. We present therefore the authors' single profile, with their estimated CF value. The fluctuation data are presented graphically below.
- 14
- § DATA: 5806 0101. Pitot profile. CC HWP measurements, NX = 1.
- 15 Editors' comments. As remarked above, we have prepared these data from a graphical original, in contravention of our own "ground rules". We would justify this in view of the continuing relative paucity of fluctuation data, and the relative inaccessibility of the original report.

The mean flow data are completely normal, agreeing well with both inner and outer laws, using the authors' CF estimate. The importance of the study lies in the very detailed treatment of the hot-wire results. A large number of wires was used, so that the original results display both scatter and systematic differences between wires. Below, we show reproductions of Figs. 12, 13 of the source paper from which readers may make their own assessment of the authors' selection of a best fit curve.

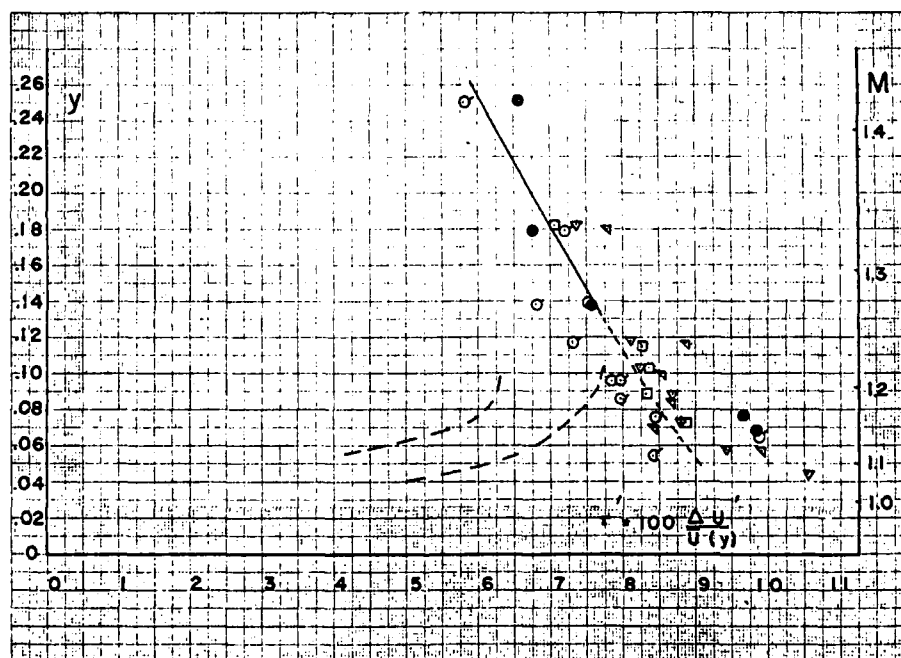
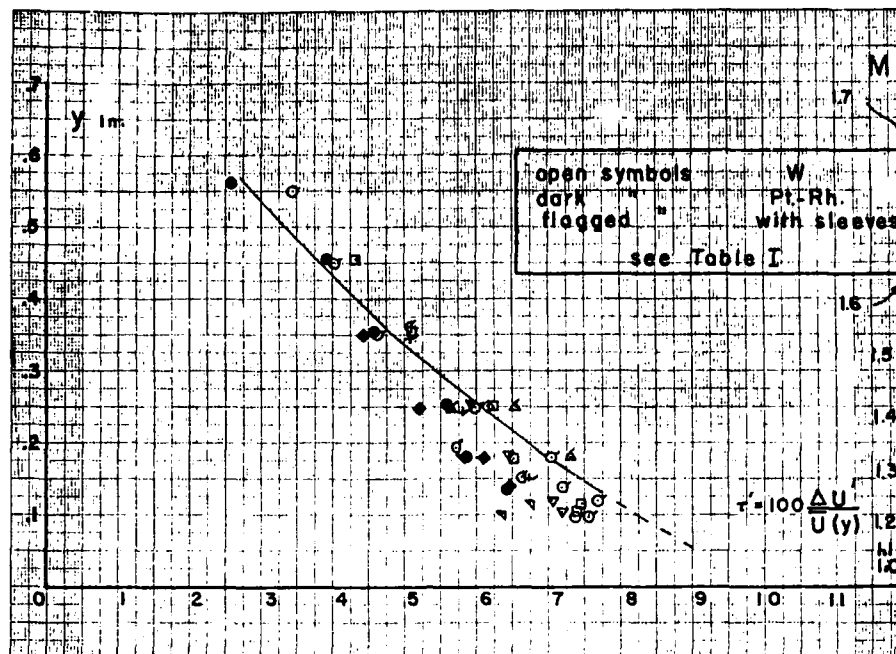


Fig. 1. (Source figure 12A/13A). Distribution of rms x-component fluctuation velocity $\Delta u'$.

Upper figure: Data for $Y > 0.1$ inch as obtained from modal analysis without correction for upstream influence in the transonic region. ("Process calibration" - Authors' APP.III).

Lower figure: Data for $Y < 0.25$ inch after correction. The two broken lines represent the envelope of the uncorrected data at low Y -values.

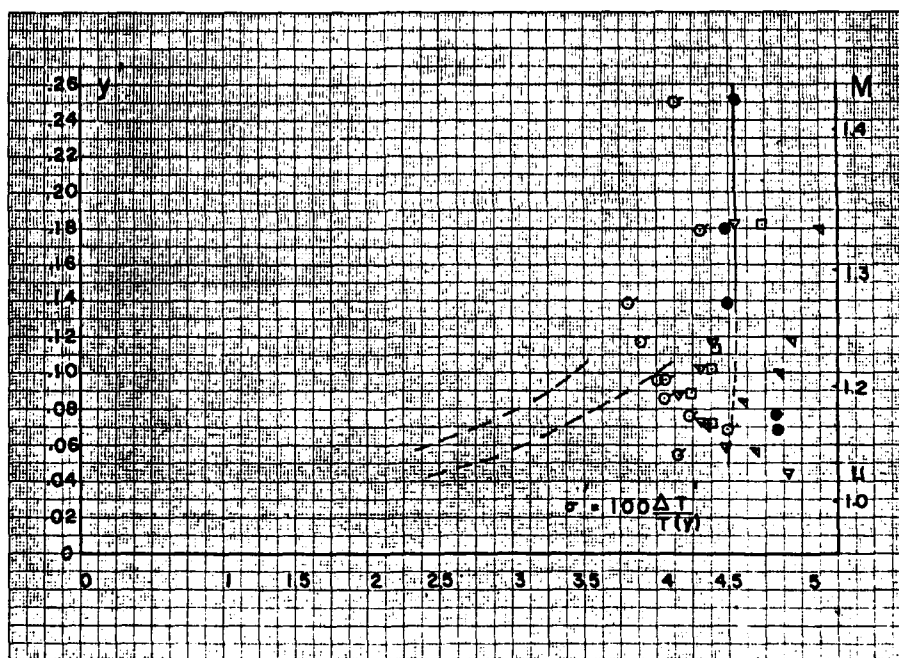
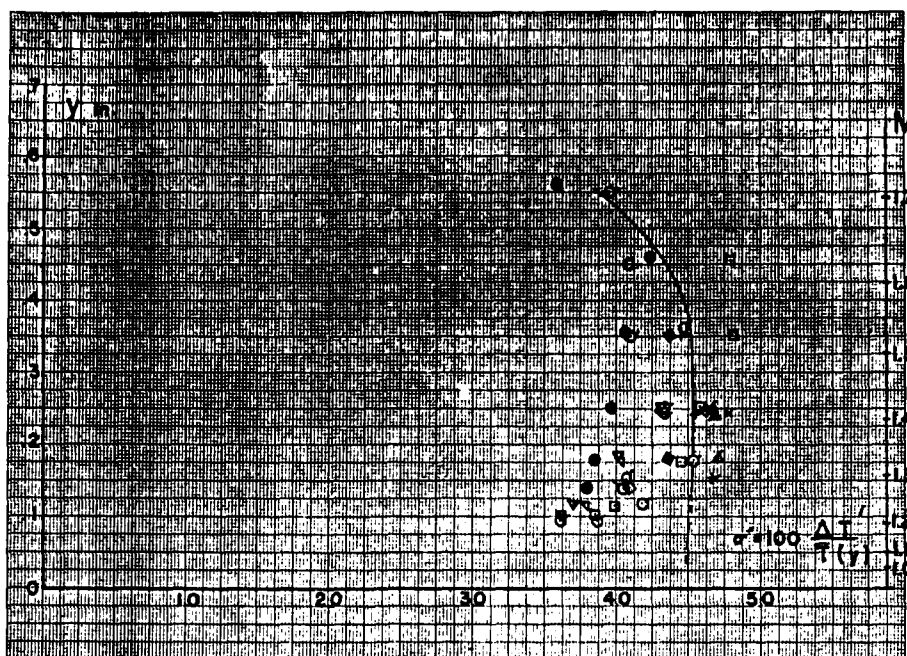


Fig. 2. (Source figures 12B/13B). Distribution of rms temperature fluctuations $\Delta T'$. Upper and lower as for Fig. 1.

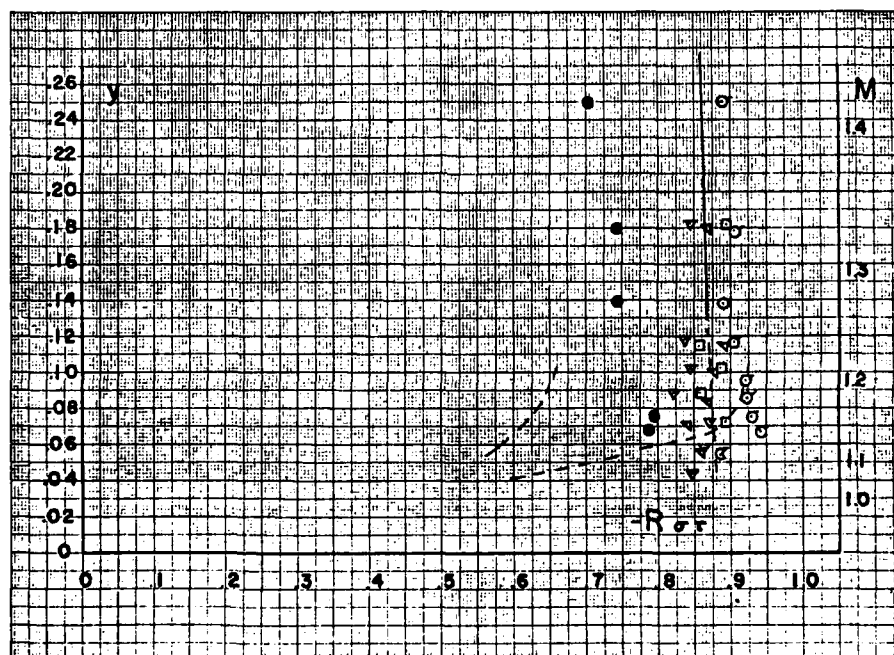
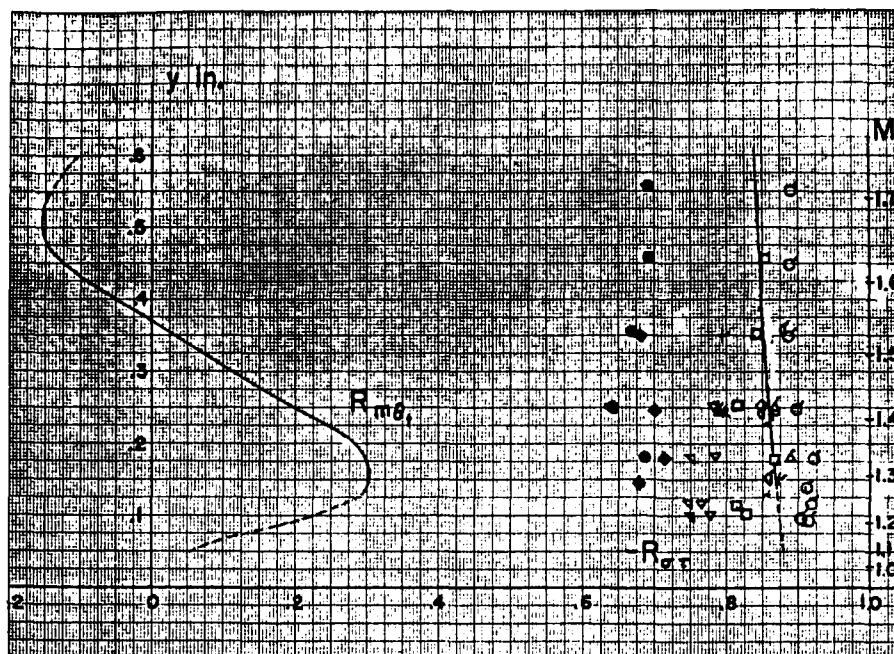


Fig. 3. (Source figure 12C/13C). Distribution of entropy-velocity fluctuation correlation function $R_{\sigma\tau}$. Upper and lower as for Fig. 1. The mass flux/total temperature correlation $R_{m\theta_t}$ is calculated from the authors' best-estimate smoothed curves as shown for the other turbulence quantities.

CAT 5806S		MORKOVIN		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS						
RUN	MD *	TW/TR*	RED2W	CF	H12	H12K	PW	PD		
X	POD*	PW/POD*	RED2D	CQ	H32	H32K	TW	TD		
RZ	TOO*	TAUW *	DZ	PI2*	H42	D2*	UD	TR		
5806S0101	1.7700	1.0000	1.2254"+04	1.8500"-03	2.5434	1.2884	1.6967"+04	1.6967"+04		
NM	9.3126"+04	1.0000	1.7672"+04	NM	1.8132	1.8049	2.8318"+02	1.8136"+02		
INFINITE	2.9500"+02	6.8837"+01	1.3937"-03	0.0000"+00	0.0726	1.6500"-03	4.7792"+02	2.8318"+02		

5806S0101		MORKOVIN		PROFILE TABULATION		34 POINTS, DELTA AT POINT 34				
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD		
1	0.0000"+00	1.0000"+00	NM	0.95994	0.00000	0.00000	1.56142	0.00000		
2	1.2497"-04	1.4976"+00	NM	0.97094	0.44181	0.52410	1.40721	0.37244		
3	1.5621"-04	1.5319"+00	NM	0.97153	0.45480	0.53793	1.39896	0.38452		
4	2.1869"-04	1.6224"+00	NM	0.97300	0.48644	0.57109	1.37831	0.41434		
5	2.9680"-04	1.6624"+00	NM	0.97362	0.49944	0.58449	1.36962	0.42676		
6	4.0615"-04	1.7325"+00	NM	0.97467	0.52090	0.60636	1.35500	0.44749		
7	4.6863"-04	1.7734"+00	NM	0.97525	0.53277	0.61829	1.34680	0.45908		
8	5.3111"-04	1.8078"+00	NM	0.97573	0.54237	0.62786	1.34010	0.46852		
9	6.2484"-04	1.8560"+00	NM	0.97638	0.55537	0.64071	1.33095	0.48139		
10	7.3419"-04	1.8974"+00	NM	0.97693	0.56610	0.65122	1.32333	0.49211		
11	8.1229"-04	1.9379"+00	NM	0.97745	0.57627	0.66109	1.31605	0.50233		
12	9.3726"-04	1.9939"+00	NM	0.97814	0.58983	0.67413	1.30628	0.51607		
13	1.0935"-03	2.0496"+00	NM	0.97882	0.60282	0.68649	1.29684	0.52936		
14	1.4059"-03	2.1641"+00	NM	0.98015	0.62825	0.71028	1.27818	0.55569		
15	1.7183"-03	2.2606"+00	NM	0.98122	0.64859	0.72894	1.26311	0.57710		
16	2.1869"-03	2.3901"+00	NM	0.98261	0.67458	0.75229	1.24369	0.60489		
17	2.6556"-03	2.4931"+00	NM	0.98367	0.69435	0.76970	1.22881	0.62638		
18	3.1242"-03	2.5844"+00	NM	0.98459	0.71130	0.78437	1.21601	0.64504		
19	3.7490"-03	2.7040"+00	NM	0.98575	0.73277	0.80262	1.19975	0.66899		
20	4.3739"-03	2.8047"+00	NM	0.98669	0.75028	0.81724	1.18646	0.68881		
21	4.9987"-03	2.9048"+00	NM	0.98761	0.76723	0.83116	1.17358	0.70822		
22	5.6236"-03	3.0109"+00	NM	0.98856	0.78475	0.84530	1.16027	0.72853		
23	6.2484"-03	3.1127"+00	NM	0.98945	0.80113	0.85830	1.14783	0.74776		
24	7.4981"-03	3.3271"+00	NM	0.99125	0.83446	0.88413	1.12257	0.78759		
25	8.7478"-03	3.5240"+00	NM	0.99283	0.86384	0.90617	1.10041	0.82349		
26	9.6850"-03	3.6687"+00	NM	0.99395	0.88475	0.92146	1.08472	0.84949		
27	1.0935"-02	3.8416"+00	NM	0.99525	0.90904	0.93882	1.06659	0.88020		
28	1.2184"-02	4.0194"+00	NM	0.99653	0.93333	0.95574	1.04859	0.91145		
29	1.3434"-02	4.1893"+00	NM	0.99772	0.95593	0.97110	1.03198	0.94100		
30	1.4684"-02	4.3371"+00	NM	0.99872	0.97514	0.98386	1.01797	0.96650		
31	1.5621"-02	4.4211"+00	NM	0.99927	0.98588	0.99089	1.01019	0.98089		
32	1.6402"-02	4.4701"+00	NM	0.99959	0.99209	0.99491	1.00570	0.98928		
33	1.7183"-02	4.5060"+00	NM	0.99983	0.99661	0.99783	1.00244	0.99540		
D 34	1.8745"-02	4.5330"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000		

INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST

	M: 5.1 $R_{\theta} \times 10^{-3}$: 2.9-4.3 TW/TR: 0.79-0.92	6002 ZPG · MHT (ROUGH)
Continuous tunnel with fixed contoured nozzle. $W = 0.15$; $L = 0.6$ m. $0.75 < P_0 < 1.0$ MN/m ² . T_0 : 380K. Air, $RE/m \times 10^{-6} = 15$.		
DANBERG J.E., 1960. Measurements of the characteristics of the compressible turbulent boundary layer with air injection. NAVORD Rep. 6683.		

- 1 The test boundary layer was formed on a flat plate model 0.6 m long mounted with the test surface on the tunnel centreline and spanning the tunnel. Tunnel wall boundary layers were compensated for by increasing the working section and plate widths from 0.1364 m at the leading edge ($X = 0$) to 0.1545 m at the trailing edge. The leading edge was chamfered at 10° on the underside. Up to $X = 0.0698$ m the test surface was smooth. From this point to $X = 0.5334$ m the surface consisted of a "sintered woven stainless steel wire mesh insert." "The exposed surface consisted of 0.127 mm wire and was flat to within a few tenths of a millimetre." This value refers to the long-wave flatness of the surface, which had a short-wave roughness of the same order as the wire diameter. The surface was probably, however, hydrodynamically smooth. The insert, constructed to allow of tests with air injection, was 0.127 m wide. The test surface was actively cooled. There were two traverse stations at $X = 0.2925$, 0.3685 m. Transition was "expected" at $X = 0.216$ m, on the basis of the tests made by Winkler and Cha (CAT 5902). Provision was made to check the uniformity of wall temperature across the plate.
- 2 Wall temperature was measured at 6 points on the centreline and 12.7, 38.1 mm off the centreline at $X = 0.344$ m. Pitot and T_0 profiles were measured, both probes being constructed from flattened tubing with $h_2 = 0.304$ mm. The sensor for the STP was a 0.127 mm iron-constantan thermocouple bead. The general construction was as for Winkler and Cha (CAT 5902), and as described by Winkler (1954).
- 3 The author has deduced CF values from the limiting slope of the velocity profiles. A small amount of slip at the nominal surface was permitted. The static pressure was assumed constant through the layer.
- 4 We present here the four profiles measured with no wall mass transfer. They form two pairs taken at the profile station, each pair corresponding to a given nominal TW/TR value. The original report also gives data for four injection rates. The editors have accepted the author's assumptions and data reduction procedures, and present the profile-derived CF values. The D-state was assumed to be the last measured data point.
- 5 § DATA: 60020101-0202. Pitot and T_0 profiles. $NX = 2$.
- 6 Editors' comments. This experiment adds further data in the transitional range to that from its sister experiments, Winkler and Cha (CAT 5902) and Danberg (CAT 5702). The profiles are plotted as figures (2.5.21), and (4.4.8-10) in AGARDograph 253 where the skin friction data are discussed at length.

CAT 6002S DANBERG

BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS

RUN X *	MD *	TW/TR PW/PD*	RED2W RED2D O2	CF *	M12 H32 H42	H12K H32K D2K	PW TW* UD	PD TD* TR
RZ	TOD*	TAUW		CO PI2*				
6002S0101	5.0500	0.9129	7.5070**+02	9.3600**-04	10.5303	1.6011	1.3371**+03	1.3371**+03
2.9250**-01	7.4980**+05	1.0000	3.2523**+03	NM	1.8386	1.7626	3.1380**+02	6.1710**+01
INFINITE	3.7650**+02	2.2342**+01	2.3975**-04	0.0000**+00	0.3664	5.0724**-04	7.9539**+02	3.4373**+02
6002S0102	5.1800	0.8970	9.7485**+02	1.2900**-03	11.3930	1.3585	1.5011**+03	1.5011**+03
3.6850**-01	9.7738**+05	1.0000	4.3394**+03	NM	1.8508	1.8123	3.1036**+02	5.9570**+01
INFINITE	3.7900**+02	3.6372**+01	2.6341**-04	0.0000**+00	0.2324	5.7011**-04	8.0159**+02	3.4600**+02
6002S0201	5.0860	0.8154	7.2578**+02	7.8300**-04	10.9210	1.6059	1.2999**+03	1.2999**+03
2.9250**-01	7.5994**+05	1.0000	2.9269**+03	NM	1.8683	1.8232	2.7538**+02	5.9930**+01
INFINITE	3.6930**+02	1.8430**+01	2.1086**-04	0.0000**+00	0.3182	4.2277**-04	7.8942**+02	3.3773**+02
6002S0202	5.2000	0.7895	9.1559**+02	1.0680**-03	10.7583	1.3799	1.2763**+03	1.2763**+03
3.6850**-01	8.5012**+05	1.0000	3.7066**+03	NM	1.8465	1.8051	2.7602**+02	5.9810**+01
INFINITE	3.8314**+02	2.5800**+01	2.6521**-04	0.0000**+00	0.3308	5.5589**-04	8.0631**+02	3.4962**+02

CF FROM VELOCITY PROFILE TABLE 20
 TRAPEZOIDAL RULE FOR 0201

6002S0201 DANBERG

PROFILE TABULATION

31 POINTS, DELTA AT POINT 31

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000**+00	1.0000**+00	NM	0.74431	0.00000	0.00000	4.59500	0.00000
2	2.9500**-04	2.7454**+00	NM	0.92836	0.25754	0.53200	4.26700	0.12468
3	3.2000**-04	2.7745**+00	NM	0.92942	0.25930	0.53500	4.25700	0.12568
4	3.4500**-04	3.4624**+00	NM	0.93841	0.29747	0.59300	3.97400	0.14922
5	3.9600**-04	4.3155**+00	NM	0.94588	0.33839	0.64800	3.66700	0.17671
6	4.7200**-04	5.2431**+00	NM	0.95064	0.37765	0.69400	3.37700	0.20551
7	5.9900**-04	6.9043**+00	NM	0.95667	0.43906	0.75500	2.95700	0.25533
8	7.2600**-04	8.3789**+00	NM	0.95887	0.48702	0.79400	2.65800	0.29872
9	8.5300**-04	9.7145**+00	NM	0.96083	0.52666	0.82200	2.43600	0.33744
10	9.8000**-04	1.0471**+01	NM	0.96057	0.54785	0.83500	2.32300	0.35945
11	1.1070**-03	1.1641**+01	NM	0.96125	0.57905	0.85300	2.17000	0.39309
12	1.2340**-03	1.3195**+01	NM	0.96183	0.61808	0.87300	1.99500	0.43759
13	1.3610**-03	1.3679**+01	NM	0.96091	0.62972	0.87800	1.94400	0.45165
14	1.4880**-03	1.4182**+01	NM	0.96019	0.64161	0.88300	1.89400	0.46621
15	1.6150**-03	1.4309**+01	NM	0.96169	0.64460	0.88500	1.88500	0.46950
16	1.7420**-03	1.4513**+01	NM	0.96159	0.64933	0.88700	1.86600	0.47535
17	1.8690**-03	1.4769**+01	NM	0.96265	0.65523	0.89000	1.84500	0.48238
18	1.9960**-03	1.5153**+01	NM	0.96345	0.66395	0.89400	1.81300	0.49311
19	2.1230**-03	1.5500**+01	NM	0.96524	0.67176	0.89800	1.78700	0.50252
20	2.2500**-03	1.6499**+01	NM	0.96839	0.69376	0.90800	1.71300	0.53006
21	2.3770**-03	1.6812**+01	NM	0.97158	0.70050	0.91200	1.69500	0.53805
22	2.5040**-03	1.7629**+01	NM	0.96904	0.71781	0.91700	1.63200	0.56189
23	2.7580**-03	1.9009**+01	NM	0.97227	0.74611	0.92800	1.54700	0.59987
24	3.0120**-03	2.0348**+01	NM	0.97609	0.77260	0.93800	1.47400	0.63636
25	3.2660**-03	2.1651**+01	NM	0.97787	0.79752	0.94600	1.40700	0.67235
26	3.6470**-03	2.3658**+01	NM	0.98260	0.83446	0.95800	1.31800	0.72686
27	4.2820**-03	2.6884**+01	NM	0.98874	0.89062	0.97400	1.19600	0.81438
28	4.9170**-03	3.0095**+01	NM	0.99374	0.94321	0.98700	1.09500	0.90137
29	5.5520**-03	3.2231**+01	NM	0.99780	0.97662	0.99500	1.03800	0.95857
30	6.1870**-03	3.3309**+01	NM	1.00027	0.99306	0.99900	1.01200	0.98715
D 31	8.7270**-03	3.3770**+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,U/UD,T/TD ASSUME P=PD

	M: 3.9 (Free stream) $R \text{ THETA} \times 10^{-3}$: 3.4 (Upstream) TW/TR: 1.0	7306 APG-SBLI AW
Axially symmetric blow-down tunnel. Continuous flow. $D = 53$, $L = 165$ mm. P_0: 0.37 MN/m². T_0: 300 K. Dried and filtered air. $RE/m \times 10^{-6}$: 17 (Free stream).		
ROSE W.C., 1973. The behaviour of a compressible turbulent boundary layer in a shock-wave-induced adverse pressure gradient. NASA TN D-7092. And Rose, W.C. private communications.		

- 1 The test boundary layer was formed on the nozzle and wall of a small axisymmetric wind tunnel. The nozzle section was about 0.15 m long and fed into the cylindrical test section ($D = 52.8$, $L = 165$ mm). The adverse pressure gradient was produced by a 9° semi-apex angle cone (base diameter 33 mm) which could be traversed longitudinally. Initial measurements were made, with the cone retracted, at distances of 66, 71.1 and 76.2 mm from the start of the test section. The main body of tests was made by traversing the cone, and its associated pressure field, past a single traversing assembly mounted at the last of these three stations. It was assumed that the resulting slight changes in the state of the "undisturbed" boundary layer entering the pressure field had negligible effect. The zero for X was taken at the tip of the cone. No trips were used either on
- 2 the tunnel wall or the cone.
- 3 The Mach number in the empty test zone was 3.88 ± 0.02 . No trips were used either on the tunnel wall or the cone. The test boundary layer had passed through the predominantly simple wave favourable
- 4 pressure gradient field of the nozzle (coordinates given in table 3 of the source paper) which resulted in slight overexpansion. This was followed by a weak recompression wave, causing a static pressure rise at the wall of about 10% about 40 mm from the start of the test section. (For a comment on the role of the upstream history see §15). The axial history and transverse disposition
- 2 of non-uniformities were checked by Pitot traverses both on and off the tunnel axis. Axisymmetry
- 5 was checked by static holes at 90° intervals round the test section wall at axial intervals of 25.4 mm.
- 6 Wall pressure measurements were made at 33 positions along the test section at intervals of 2.54 mm with tappings of diameter 0.34 mm. An additional 9 tappings were used to check symmetry. Wall temperature was not measured. The values of TW given in the report were calculated by assuming $r = 0.90$. An initial series of tests designed to detect incipient separation, and so to guide the choice of cone-angle, used an orifice dam, consisting of two 0.34 mm diameter static tappings drilled at 0.75 mm centres on either side of a rectangular fence ($h = 0.13$, $\Delta X = 0.25$ mm). The dam was constructed in a plug of diameter 12.7 mm and the surface of the plug was machined to conform with the radius of the test section, with the central fence of constant height to give a width/height ratio of about 100. (A discussion of the interpretation of orifice dam results, in conjunction with observations of the behaviour of small quantities of alcohol injected as a surface flow visualisation tracer, is given in App. B of the source paper.)
- 7 The TTP used was a FWP of essentially the same construction as the normal HWP used for turbulence measurement (see below), but employed as an unheated resistance probe. A calibration of resistance against wire temperature was made in the empty tunnel for a range of total pressures and temperatures. This was used in conjunction with recovery factors suggested by Laurence and Sandborn (1962) to provide a calibration function over the range of Mach number and wire Reynolds number encountered in the test layer. Pitot pressures were measured with a FPP for which $h_1 = 0.25$, $h_2 = 0.1$, $b_2 = 0.38$ mm. The diameter of the basic tube used increased from 0.63 mm at the tip to 1.65 mm 13 mm back from the tip. The diameter then remained constant to the support approximately 40 mm back.

Two HWP were used, operated in the CT mode at five overheat ratios. All the measurements finally reported were made with two wires, one normal to the flow and the other oblique. During the 30-46 hours that the probes operated, the cold wire resistance changed by 3%. The wires were etched tungsten wires of 5 μm diameter mounted on jewellers broaches tapering from about 50 μm at the tip to about 200 μm 6.3 mm back from the tip. About 3.2 mm of the prongs extended from the end of the 1 mm diameter holder in which they were mounted. The wires were mounted fairly slackly to the prongs which were laterally separated by 0.61 and 0.66 mm for the normal and the oblique wire respectively. The effective l/d ratios were about 100. A DISA model 55D01 constant temperature system was used. Each wire was individually calibrated for each run, and the square wave response was adjusted for each experimental point (1 case for the normal wire, 4 cases for the oblique wire, two each aligned with and perpendicular to the profile normal). The signal interpretation techniques used followed those of Morkovin and Phinney (1958), Morkovin (1956) and Kovaszny (1950, 1953) and give values for the turbulent mass and heat flux, and complete Reynolds stress tensor.

- 8 As remarked above, the main body of data was obtained at a single station in the tunnel, but over a range of positions relative to the tip of the movable cone centre body. Mean flow and fluctuation profiles were obtained at 12 X values from X = 61.0 to 116.8 mm. For the mean flow profiles, constant Y-intervals of 0.254 mm were used, while turbulence measurements were made at Y-intervals
- 9 of 0.508 mm. No interpolation was required for the Pitot and T0 data, but auxiliary assumptions were required for the third necessary state variable, here the static pressure. The pressure field was a consequence of the incident conical shock wave and its associated, distributed, reflected wave system. The author assumed that, outside the boundary layer, the total pressure loss in the incident shock, 0.4%, could be ignored, and that the distributed reflected compression waves were effectively isentropic. Thus, outside the boundary layer, P could be computed from the Rayleigh Pitot formula. The static pressures in this region, and also in the boundary layer, were additionally calculated by the two layer method of Rose (1970). Good agreement was found with the Pitot derived values, and as a cross-check, Pitot profiles within the boundary layer were also calculated and compared with those measured. A graphical comparison (Fig. 9 of the source paper) is given for the input (01) and for the downstream computed profiles 04, 05, and 07, when the wave system has left the boundary layer. Discrepancies are generally less than 5%, reaching a maximum of about 10% near the D-point for profile 07. The authors have selected the D-points on the basis of the total temperature profile which showed a marked "overshoot". No Pitot corrections are reported. Y(min) was
- 11 $2 h_1$. Viscosity values were computed from Sutherland's relation.
- 12 The editors have presented all the mean flow data as tabulated by the author. Integral values for profiles with substantial discontinuities (03, 04 and to a lesser extent 05, 06) should be ignored. The author's fluctuation data are tabulated in the source paper, which is readily accessible. We therefore have not given tables here, but the data are presented with our normalisation in the
- 13 microfiche tables. The single profile sequence consists of two profiles (01, 02) in which the boundary layer is undisturbed, four profiles (03-06) describing the interaction proper, and six
- 14 profiles downstream of the interaction in which the boundary layer relaxes towards a linear APG condition. Values for the wall shear stress are given, taken from the graphical presentation in Rubesin et al., (1974), assuming that they used the author's D-state in defining CF.
- § DATA: 73060101-0112. Pitot and T0 profiles obtained separately. NX = 12. Hot-wire measurements with both normal and oblique wires.
- 15 Editors' comments. This experiment is fully and accessibly reported. We suggest that recourse should be had to the original paper, particularly for discussions of the data reduction (a great deal more calculated information is presented) and of the turbulence measurements, which are barely discussed here.

Much similar work has been performed at the University of Washington (see for instance Sun and Childs 1977) (NASA CR 2872), but this is the first of this series of experiments to become available

with tabulated data including an estimation of the static pressure. Further similar data may become available from Gootzait and Childs (1977).

The boundary layer studied develops through a shock-boundary layer interaction without separation. The shock structure induces discontinuities in the flow (e.g., 0104), and very large changes in static pressure normal to the wall. We have reduced the data following our standard scheme, using the author's estimate of the static pressure (see §9 above) so that velocity, density and temperature profiles should be accurate within the limitations of that estimate. The large static pressure variations imply that the selection of a 'free stream state' is virtually pointless save for providing scaling quantities, and that no conventional integral thickness has any meaning. The only possible boundary layer length scale to which it would be possible to give an unambiguous definition is the displacement thickness as defined in § 7.3 of AGARDograph 253. The calculated integral thicknesses in this entry should therefore be disregarded.

Since the van Driest transformation of the velocity profile is based on a temperature - velocity relationship which holds for APG flows on adiabatic walls but whose validity range for shock-boundary-layer interaction is not known, it is advisable, as the next step, to compare measurements with the theoretical relationship. For this purpose we need a free-stream state and have retained the author's values as they appear very reasonable in relation to the static pressure field (Fig. 1). The temperature profile normalized by T_δ and plotted versus $\bar{u}/u_\delta$ is then compared with eqn.(2.5.37) of AGARDograph 253. Agreement between measurements and theory is good, the values differing at most by about 4% downstream of the interaction (Fig. 2). This contradicts the author's statement that the departure of the temperature from the Crocco relationship is substantial. This latter conclusion was drawn on the basis of a plot $(T_t - T_w)/(T_{tD} - T_w)$ which we have shown to be extremely sensitive to small uncertainties in the measurements (cf. § 2.5.6 in AGARDograph 253) and which we consider therefore as an unreliable check. Nevertheless it is the temperature-distribution measurements here which are used to justify Chew & Squire's assumption (1979) of the validity of the van Driest temperature-velocity relationship in a shock-boundary-layer interaction.

Some selected velocity profiles in transformed coordinates are shown in Figs. 3 and 4. It is apparent that the upstream (0101, 0102 - the shock has not yet reached the log-law region) and downstream profiles (0110 and 0111) have a distinct log-law region. A comparison of the wake strength $\Delta(\bar{u}^*/u_t)$ with that of profiles in the same Reynolds number range (Fig. 3.3.6 of AG 253) shows that profiles 0101 to 0103 have a wake strength of approximately 3.2 against about 2. This excess wake strength may well be due to the upstream history of the flow which the author describes as "a history of the favourable pressure gradient in the expansion section and of the slight adverse gradient induced by a recompression wave." Profiles 0104 to 0108 apparently suffer severely from the normal pressure gradient and show no log-law region, with profile 0109 (not in figure) relaxing towards the more typical profile 0110. However, profiles 0110 and 0111 are still far from an "equilibrium" ZPG velocity profile.

The behaviour of the velocity profiles in the boundary layer is reflected similarly in the outer-law plot (Fig. 4) where they are compared with the "standard" ZPG profile. The deviation is largest for profile 0105 and becomes smaller as the profile moves downstream (0111). The shock strength and the subsequent disturbance is much weaker than that in series 05 of Chew & Squire's experiment (CAT 7902). We should note here that all profiles were scaled by using u_t as given in Rubesin et al. (1974), whose data reduction relies heavily on information close to the wall, when the minimum y_t/ν values here are from 14 to 30. These u_t values would seem to be too high by about 10%. Reynolds numbers Re_{δ_2} were rather small, 1035 for 0101 and 1759 for 0110, but little emphasis should be placed on the numerical values for profiles between 02 and 08 because of the strong normal pressure gradient effects.

The Reynolds stresses are tabulated in full in the source paper. All components of the stress tensor are assumed to become zero at the wall except T_{rx} , for which a wall shear stress value was

found by curve fitting to the law of the wall. This wall value appears, in general, not inconsistent with the hot-wire derived values in the boundary layer in the graphical presentation of the source paper.

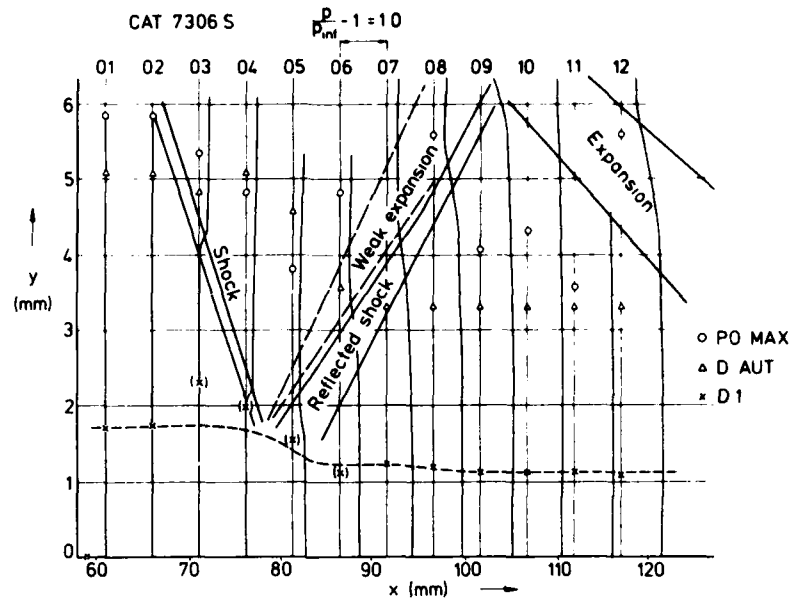


Fig. 1 Static pressure profiles and wave structure for an attached shock boundary-layer interaction. Rose (1973). PO max. Δ Authors' boundary layer edge. X values of D1 calculated without taking account of normal pressure gradient. (X) D1 values which for this reason should be discarded.

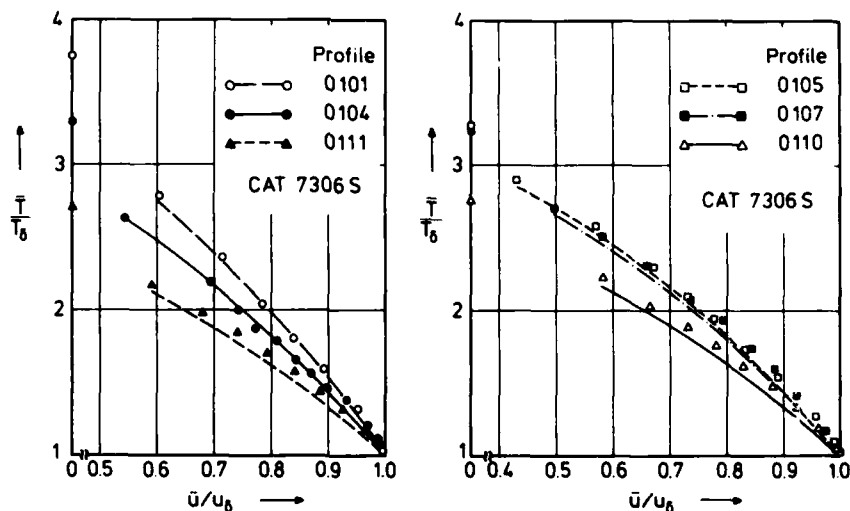


Fig. 2 Comparison between measured and theoretical temperature profiles in a compressible boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

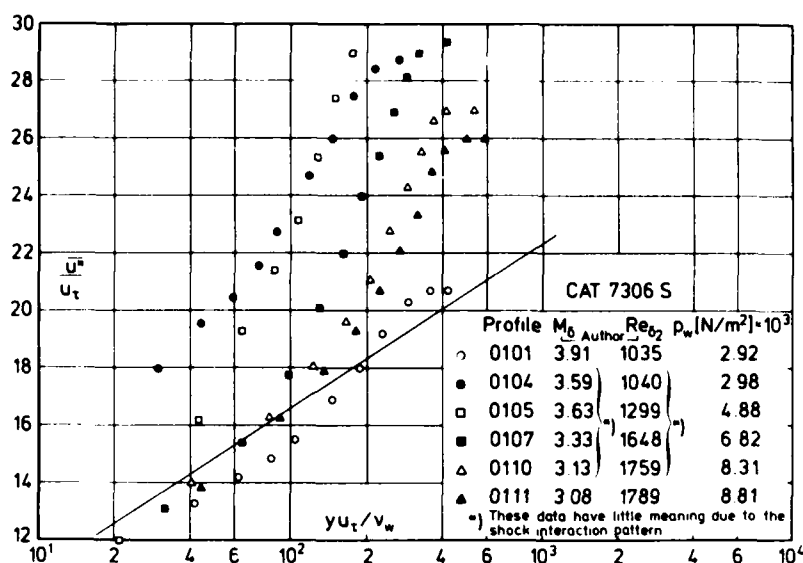


Fig. 3 Law of the wall for a compressible boundary layer with shock interaction (adiabatic wall, origin not defined, D-state author). Rose (1973).

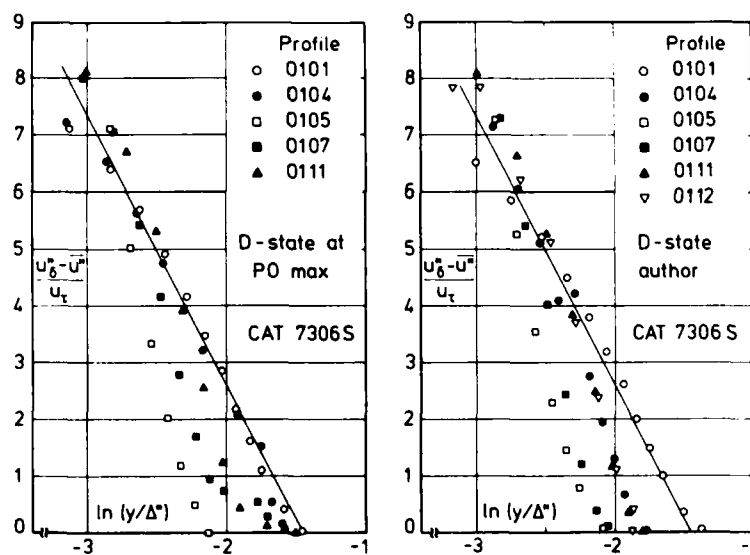


Fig. 4 Outer law for a compressible boundary layer with shock interaction (adiabatic wall, origin not defined). Rose (1973).

CAT 73065		ROSE								BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS									
RUN	X *	MD *	TW/TR	RED2W	CF *	M12	M12K	PW*	PD*										
RZ *		POD	PW/PO	RED2D	CQ	M32	M32K	TW*	TD										
		TOD*	TAUW	DZ	PI2	M42	D2K	UD	TR										
7306S0101		3.9100	1.0037	1.0351**+03	1.7959*-03	8.8333	1.5396	2.9200**+03	2.9200**+03										
6.1000*-02		3.9295**+05	1.0000	3.4031**+03	NM	1.8121	1.7923	2.7750**+02	7.3935**+01										
-2.1567*-02		3.0000**+02	5.6120**+01	1.9460*-04	NC	-0.0007	3.8226*-04	6.7408**+02	2.7649**+02										
7306S0102		3.9100	1.0037	1.0640**+03	1.7551*-03	8.8215	1.5378	2.9200**+03	2.9200**+03										
6.6000*-02		3.9295**+05	1.0000	3.4981**+03	NM	1.8097	1.7895	2.7750**+02	7.3935**+01										
-2.2244*-02		3.0000**+02	5.4845**+01	2.0003*-04	NC	0.0040	3.9556*-04	6.7408**+02	2.7649**+02										
7306S0103		3.6400	1.0016	9.0527**+02	1.7347*-03	17.0575	1.5936	2.9130**+03	4.1947**+03										
7.1100*-02		3.8967**+05	0.6944	2.6824**+03	NM	1.7875	1.7701	2.7780**+02	8.2194**+01										
-2.2898*-02		3.0000**+02	6.7488**+01	1.3429*-04	NC	0.0513	3.6571*-04	6.6165**+02	2.7735**+02										
7306S0104		3.5900	1.0010	1.0405**+03	1.0204*-03	13.1583	1.5895	2.9780**+03	4.3777**+03										
7.6200*-02		3.7916**+05	0.6803	3.0229**+03	NM	1.7992	1.7692	2.7780**+02	8.3855**+01										
-2.3390*-02		3.0000**+02	4.0300**+01	1.5146*-04	NC	0.0045	3.9140*-04	6.5913**+02	2.7752**+02										
7306S0105		3.6300	1.0015	1.2989**+03	7.8571*-04	8.1688	1.8195	4.8880**+03	4.2526**+03										
8.1300*-02		3.8956**+05	1.1494	3.8337**+03	NM	1.7148	1.6868	2.7780**+02	8.2522**+01										
-2.3882*-02		3.0000**+02	3.0820**+01	1.9097*-04	NC	-0.0284	3.7457*-04	6.6115**+02	2.7738**+02										
7306S0106		3.5900	1.0010	1.7354**+03	1.0000*-03	4.2021	1.7378	5.9690**+03	4.3574**+03										
8.6400*-02		3.7740**+05	1.3699	5.0418**+03	NM	1.7441	1.7088	2.7780**+02	8.3855**+01										
-2.4313*-02		3.0000**+02	3.9311**+01	2.5380*-04	NC	-0.0494	3.8669*-04	6.5913**+02	2.7752**+02										
7306S0107		3.3300	0.9975	1.6485**+03	1.0612*-03	6.4939	1.7614	6.8170**+03	6.2716**+03										
9.1400*-02		3.7482**+05	1.0870	4.3183**+03	NM	1.7282	1.7014	2.7780**+02	9.3232**+01										
-2.4658*-02		3.0000**+02	5.1662**+01	1.9041*-04	NC	-0.0599	3.4750*-04	6.4467**+02	2.7850**+02										
7306S0108		3.2400	0.9962	1.7077**+03	1.1837*-03	6.5374	1.7356	7.4490**+03	7.0765**+03										
9.6500*-02		3.7098**+05	1.0526	4.3143**+03	NM	1.7362	1.7128	2.7780**+02	9.6789**+01										
-2.5019*-02		3.0000**+02	6.1552**+01	1.8307*-04	NC	-0.0595	3.3295*-04	6.3910**+02	2.7887**+02										
7306S0109		3.1800	0.9953	1.7240**+03	1.3265*-03	6.7018	1.7088	7.8800**+03	7.7224**+03										
1.0160*-02		3.7070**+05	1.0204	4.2509**+03	NM	1.7462	1.7262	2.7780**+02	9.9256**+01										
-2.5300*-02		3.0000**+02	7.2514**+01	1.7473*-04	NC	-0.0684	3.1809*-04	6.3521**+02	2.7912**+02										
7306S0110		3.1300	0.9956	1.7587**+03	1.3367*-03	6.7759	1.6866	8.3140**+03	8.3140**+03										
1.0670*-01		3.7069**+05	1.0000	4.2531**+03	NM	1.7562	1.7385	2.7810**+02	1.0137**+02										
-2.5551*-02		3.0000**+02	7.6215**+01	1.7014*-04	NC	-0.0633	3.0725*-04	6.3185**+02	2.7934**+02										
7306S0111		3.0800	0.9937	1.7888**+03	1.4694*-03	6.6149	1.6773	8.8130**+03	8.8130**+03										
1.1180*-01		3.6483**+05	1.0000	4.2354**+03	NM	1.7638	1.7473	2.7780**+02	1.0355**+02										
-2.5762*-02		3.0000**+02	8.5992**+01	1.6753*-04	NC	-0.0742	2.9555*-04	6.2839**+02	2.7957**+02										
7306S0112		3.0400	0.9930	1.8410**+03	1.4898*-03	6.4623	1.6639	9.2800**+03	9.2800**+03										
1.1680*-01		3.6192**+05	1.0000	4.2885**+03	NM	1.7712	1.7558	2.7780**+02	1.0533**+02										
-2.5928*-02		3.0000**+02	8.9438**+01	1.6732*-04	NC	-0.0784	2.8919*-04	6.2553**+02	2.7975**+02										

TAUW CALCULATED FROM CF (RUBESIN ET AL) WITH D-STATE DATA ROSE

7306S0101		ROSE		PROFILE TABULATION		24 POINTS, DELTA AT POINT 21			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD	
1	0.0000**+00	1.0000**+00	1.00000	0.92500	0.00000	0.00000	3.75330	0.00000	
2	2.5000*-04	3.1198**+00	1.00000	0.96200	0.36317	0.60571	2.78165	0.21775	
3	5.1000*-04	4.7618**+00	1.00000	0.97000	0.46547	0.71621	2.36748	0.30252	
4	7.6000*-04	5.6918**+00	1.00000	0.96700	0.51407	0.75730	2.17017	0.34896	
5	1.0200*-03	6.4377**+00	1.00000	0.96800	0.54987	0.78555	2.04093	0.38490	
6	1.2700*-03	7.2348**+00	1.00000	0.97200	0.58568	0.81260	1.92501	0.42213	
7	1.5200*-03	8.2083**+00	1.00000	0.97800	0.62660	0.84146	1.80339	0.46660	
8	1.7800*-03	9.2483**+00	1.00000	0.98600	0.66752	0.86868	1.69352	0.51294	
9	2.0300*-03	1.0355**+01	1.00000	0.99200	0.70844	0.89277	1.58810	0.56217	
10	2.2900*-03	1.1452**+01	1.00000	0.99800	0.74680	0.91369	1.49689	0.61040	
11	2.5400*-03	1.2766**+01	1.00000	1.00500	0.79028	0.93558	1.40153	0.66755	
12	2.7900*-03	1.3987**+01	1.00000	1.01000	0.82864	0.95283	1.32220	0.72064	
13	3.0500*-03	1.5180**+01	1.00000	1.01500	0.86445	0.96794	1.25377	0.77202	
14	3.3000*-03	1.6513**+01	1.00000	1.01800	0.90281	0.98188	1.18283	0.83011	
15	3.5600*-03	1.7435**+01	1.00000	1.01700	0.92839	0.98912	1.13512	0.87138	
16	3.8100*-03	1.8382**+01	1.00000	1.01400	0.95396	0.99493	1.08773	0.91468	
17	4.0600*-03	1.9158**+01	1.00000	1.01000	0.97442	0.99847	1.04995	0.95096	
18	4.3200*-03	1.9652**+01	1.00000	1.00800	0.98721	1.00078	1.02768	0.97383	
19	4.5700*-03	1.9951**+01	1.00000	1.00500	0.99488	1.00123	1.01279	0.98858	
20	4.8300*-03	2.0051**+01	1.00000	1.00200	0.99744	1.00037	1.00587	0.99453	
21	5.0800*-03	2.0152**+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	
22	5.3300*-03	2.0152**+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	
23	5.5900*-03	2.0152**+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	
24	5.8400*-03	2.0152**+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	

INPUT VARIABLES Y, TO/TOD, P/PW, M

7306S0104 ROSE		PROFILE TABULATION 25 POINTS, DELTA AT POINT 19						
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000*+00	1.0000*+00	0.68027	0.92507	0.00000	0.00000	3.30957	0.00000
2	2.5000*-04	2.4075*+00	0.68027	0.94905	0.33426	0.54271	2.63614	0.14005
3	5.1000*-04	4.1379*+00	0.67347	0.96004	0.46797	0.69338	2.19540	0.21270
4	7.6000*-04	5.0934*+00	0.67347	0.96204	0.52646	0.74594	2.00756	0.25024
5	1.0200*-03	5.7952*+00	0.67347	0.95504	0.56546	0.77389	1.87305	0.27826
6	1.2700*-03	6.6042*+00	0.67347	0.96903	0.60724	0.80958	1.77742	0.30675
7	1.5200*-03	7.5920*+00	0.67347	0.97502	0.65460	0.84276	1.65753	0.34242
8	1.7800*-03	8.5261*+00	0.67347	0.98202	0.69638	0.87018	1.56146	0.37532
9	2.0300*-03	9.6554*+00	0.67347	0.98901	0.74373	0.89823	1.45863	0.41473
10	2.2900*-03	9.1813*+00	0.89116	1.00200	0.72423	0.89411	1.52414	0.52278
11	2.5400*-03	1.0933*+01	0.90476	1.01399	0.79387	0.93334	1.38223	0.61093
12	2.7900*-03	1.2138*+01	0.91837	1.01698	0.83844	0.95371	1.29387	0.67693
13	3.0500*-03	1.3329*+01	0.93197	1.01698	0.88022	0.96983	1.21396	0.74455
14	3.3000*-03	1.4662*+01	0.94558	1.01598	0.92479	0.98493	1.13429	0.82107
15	3.5600*-03	1.5884*+01	0.95238	1.01199	0.96379	0.99538	1.06664	0.88876
16	3.8100*-03	1.6696*+01	0.95918	1.00799	0.98886	1.00082	1.02435	0.93716
17	4.0600*-03	1.7156*+01	0.97279	1.00500	1.00279	1.00327	1.00097	0.97503
18	4.3200*-03	1.7156*+01	0.98639	1.00200	1.00279	1.00178	0.99799	0.99014
19	4.5700*-03	1.7063*+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
20	4.8300*-03	1.7063*+01	1.00680	1.00000	1.00000	1.00000	1.00000	1.00680
21	5.0800*-03	1.6879*+01	1.02041	0.99900	0.99443	0.99793	1.00706	1.01116
22	5.3300*-03	1.6787*+01	1.03401	0.99900	0.99164	0.99714	1.01113	1.01972
23	5.5900*-03	1.6787*+01	1.04082	0.99900	0.99164	0.99714	1.01113	1.02642
24	5.8400*-03	1.6696*+01	1.04762	0.99900	0.98886	0.99635	1.01521	1.02816
25	6.1000*-03	1.6696*+01	1.05442	0.99900	0.98886	0.99635	1.01521	1.03483

INPUT VARIABLES Y, TO/TOD, P/PW, M

7306S0105 ROSE		PROFILE TABULATION 22 POINTS, DELTA AT POINT 17						
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000*+00	1.0000*+00	1.14943	0.92507	0.00000	0.00000	3.36300	0.00000
2	2.5000*-04	1.6913*+00	1.14943	0.95405	0.24793	0.42834	2.98478	0.16495
3	5.1000*-04	2.5875*+00	1.14943	0.96404	0.34711	0.56612	2.66003	0.24463
4	7.6000*-04	3.6846*+00	1.14943	0.97003	0.43251	0.66471	2.36201	0.32347
5	1.0200*-03	4.6237*+00	1.13793	0.97602	0.49311	0.72514	2.16247	0.38158
6	1.2700*-03	5.5386*+00	1.11494	0.98701	0.54545	0.77355	2.01121	0.42883
7	1.5200*-03	7.0597*+00	1.06897	0.99500	0.62259	0.83282	1.78936	0.49753
8	1.7800*-03	8.7851*+00	1.02299	1.00500	0.69972	0.88376	1.59521	0.56675
9	2.0300*-03	1.0569*+01	0.97701	1.01299	0.77135	0.92370	1.43403	0.62932
10	2.2900*-03	1.2216*+01	0.93103	1.01698	0.83196	0.95190	1.30914	0.67698
11	2.5400*-03	1.3574*+01	0.91954	1.01698	0.87879	0.96989	1.21807	0.73218
12	2.7900*-03	1.4920*+01	0.93103	1.01499	0.92287	0.98417	1.13726	0.80570
13	3.0500*-03	1.6062*+01	0.94253	1.01299	0.95868	0.99450	1.07613	0.87103
14	3.3000*-03	1.7156*+01	0.95402	1.00799	0.99174	1.00168	1.02017	0.93674
15	3.5600*-03	1.7622*+01	0.96552	1.00500	1.00551	1.00400	0.99701	0.97229
16	3.8100*-03	1.7716*+01	0.97701	1.00200	1.00826	1.00325	0.99009	0.99001
17	4.0600*-03	1.7435*+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
18	4.3200*-03	1.7248*+01	1.02299	1.00000	0.99449	0.99848	1.00803	1.01329
19	4.5700*-03	1.6971*+01	1.04598	0.99900	0.98623	0.99566	1.01921	1.02180
20	4.8300*-03	1.6879*+01	1.05747	0.99900	0.98347	0.99487	1.02332	1.02807
21	5.0800*-03	1.6787*+01	1.06897	0.99900	0.98072	0.99409	1.02745	1.03425
22	5.3300*-03	1.6696*+01	1.08046	0.99900	0.97796	0.99329	1.03160	1.04034

INPUT VARIABLES Y, TO/TOD, P/PW, M

7306S0107 ROSE		PROFILE TABULATION 27 POINTS, DELTA AT POINT 14						
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000*+00	1.0000*+00	1.08696	0.92600	0.00000	0.00000	2.97966	0.00000
2	2.5000*-04	2.0325*+00	1.08696	0.96000	0.31832	0.50554	2.52227	0.21786
3	5.1000*-04	2.6500*+00	1.08696	0.96800	0.38438	0.58876	2.34606	0.27278
4	7.6000*-04	3.4894*+00	1.08696	0.97800	0.45646	0.66967	2.15241	0.33818
5	1.0200*-03	4.5330*+00	1.08696	0.99100	0.53153	0.74423	1.96044	0.41263
6	1.2700*-03	5.6404*+00	1.08696	1.00600	0.60060	0.80543	1.79838	0.48681
7	1.5200*-03	7.0018*+00	1.08696	1.01300	0.67568	0.85991	1.61968	0.57708
8	1.7800*-03	8.2713*+00	1.08696	1.01800	0.73874	0.89932	1.48200	0.65960
9	2.0300*-03	1.0002*+01	1.07609	1.02100	0.81682	0.94019	1.32491	0.76362
10	2.2900*-03	1.1754*+01	1.06522	1.02100	0.88099	0.97116	1.19367	0.86665
11	2.5400*-03	1.3329*+01	1.04348	1.01600	0.94895	0.99110	1.09080	0.94810
12	2.7900*-03	1.4155*+01	1.03261	1.00700	0.97898	0.99679	1.03672	0.99284
13	3.0500*-03	1.4662*+01	1.01087	1.00300	0.99700	1.00056	1.00716	1.00424
14	3.3000*-03	1.4748*+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
15	3.5600*-03	1.4920*+01	0.95652	1.00000	1.00601	1.00185	0.99176	0.96625
16	3.8100*-03	1.5442*+01	0.88043	1.00000	1.02402	1.00728	0.96757	0.91657
17	4.0600*-03	1.5530*+01	0.84783	1.00000	1.02703	1.00817	0.96361	0.88703
18	4.3200*-03	1.6152*+01	0.78261	1.00000	1.04805	1.01422	0.93648	0.84757
19	4.5700*-03	1.6604*+01	0.71739	1.00000	1.06306	1.01838	0.91771	0.79609
20	4.8300*-03	1.6879*+01	0.70652	1.00000	1.07207	1.02082	0.90668	0.79547
21	5.0800*-03	1.6787*+01	0.71739	1.00000	1.06907	1.02001	0.91034	0.80382
22	5.3300*-03	1.6696*+01	0.72826	1.00000	1.06607	1.01920	0.91401	0.81207
23	5.5900*-03	1.6604*+01	0.73913	1.00000	1.06306	1.01838	0.91771	0.82022
24	5.8400*-03	1.6423*+01	0.75000	1.00000	1.05706	1.01673	0.92516	0.82424
25	6.1000*-03	1.6332*+01	0.76087	1.00000	1.05405	1.01590	0.92891	0.83212
26	6.3500*-03	1.6423*+01	0.76087	1.00000	1.05706	1.01673	0.92516	0.83618
27	6.6000*-03	1.6332*+01	0.77174	1.00000	1.05405	1.01590	0.92891	0.84401

INPUT VARIABLES Y, TO/TOD, P/PW, M

7306S0110 ROSE		PROFILE TABULATION		27 POINTS, DELTA AT POINT 14				
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	1.00000	0.92515	0.00000	0.00000	2.73787	0.00000
2	2.5000-04	2.4663+00	1.00000	0.96806	0.38978	0.57914	2.20749	0.26733
3	5.1000-04	3.2643+00	1.00000	0.97804	0.46645	0.66448	2.02928	0.32744
4	7.6000-04	4.0531+00	1.00000	0.99102	0.53035	0.72926	1.89076	0.38570
5	1.0200-03	4.8552+00	1.00000	0.99800	0.58786	0.78011	1.76104	0.44299
6	1.2700-03	5.7952+00	1.00000	1.00599	0.64856	0.82772	1.62878	0.50818
7	1.5200-03	7.1178+00	1.00000	1.01198	0.72524	0.88076	1.47486	0.59718
8	1.7800-03	8.5905+00	1.00000	1.01597	0.80192	0.92494	1.33036	0.69526
9	2.0300-03	1.0283+01	1.00000	1.01896	0.88179	0.96392	1.19496	0.80666
10	2.2900-03	1.1678+01	1.00000	1.01896	0.94249	0.98865	1.10035	0.89849
11	2.5400-03	1.2529+01	1.00000	1.01198	0.97764	0.99820	1.04250	0.95750
12	2.7900-03	1.2925+01	1.00000	1.00399	0.99361	0.99982	1.01253	0.98744
13	3.0500-03	1.3006+01	1.00000	1.00100	0.99681	0.99942	1.00524	0.99420
14	3.3000-03	1.3086+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
15	3.5600-03	1.3086+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
16	3.8100-03	1.3086+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
17	4.0600-03	1.3086+01	0.99000	1.00000	1.00000	1.00000	1.00000	0.99000
18	4.3200-03	1.3247+01	0.98000	1.00000	1.00639	1.00215	0.99158	0.99044
19	4.5700-03	1.3247+01	0.97000	1.00000	1.00639	1.00215	0.99158	0.98033
20	4.8300-03	1.3329+01	0.96000	1.00000	1.00958	1.00321	0.98741	0.97536
21	5.0800-03	1.3329+01	0.96000	1.00000	1.00958	1.00321	0.98741	0.97536
22	5.3300-03	1.3329+01	0.95000	1.00000	1.00958	1.00321	0.98741	0.96520
23	5.5900-03	1.3410+01	0.94000	1.00000	1.01278	1.00426	0.98325	0.96009
24	5.8400-03	1.3410+01	0.93000	1.00000	1.01278	1.00426	0.98325	0.94987
25	6.1000-03	1.3574+01	0.91000	1.00000	1.01917	1.00636	0.97501	0.93925
26	6.3500-03	1.3821+01	0.89000	1.00000	1.02875	1.00944	0.96281	0.93310
27	6.6000-03	1.3904+01	0.87000	1.00000	1.03195	1.01046	0.95879	0.91689

INPUT VARIABLES Y, TO/TOD, P/PW, M

7306S0111 ROSE		PROFILE TABULATION		19 POINTS, DELTA AT POINT 14				
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	1.00000	0.92600	0.00000	0.00000	2.68288	0.00000
2	2.5000-04	2.5263+00	1.00000	0.97300	0.40260	0.59115	2.15603	0.27418
3	5.1000-04	3.4133+00	1.00000	0.98300	0.48701	0.68254	1.96416	0.34750
4	7.6000-04	4.1807+00	1.00000	0.99400	0.54870	0.74286	1.83290	0.40529
5	1.0200-03	5.0452+00	1.00000	0.99700	0.61039	0.79405	1.69232	0.46921
6	1.2700-03	6.0051+00	1.00000	1.00300	0.67208	0.84074	1.56489	0.53725
7	1.5200-03	7.1762+00	1.00000	1.01000	0.74026	0.88666	1.43466	0.61803
8	1.7800-03	8.5261+00	1.00000	1.01600	0.81169	0.92841	1.30828	0.70964
9	2.0300-03	1.0142+01	1.00000	1.02100	0.88961	0.96740	1.18253	0.81808
10	2.2900-03	1.1452+01	1.00000	1.01800	0.94805	0.98991	1.09025	0.90797
11	2.5400-03	1.2216+01	1.00000	1.01200	0.98052	0.99909	1.03823	0.96230
12	2.7900-03	1.2607+01	1.00000	1.00600	0.99675	1.00187	1.01029	0.99166
13	3.0500-03	1.2687+01	1.00000	1.00300	1.00000	1.00150	1.00300	0.99850
14	3.3000-03	1.2687+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
15	3.5600-03	1.2846+01	0.99000	1.00000	1.00649	1.00223	0.99154	1.00067
16	3.8100-03	1.2846+01	0.99000	1.00000	1.00649	1.00223	0.99154	1.00067
17	4.0600-03	1.2766+01	0.99000	1.00000	1.00325	1.00112	0.99576	0.99533
18	4.3200-03	1.2846+01	0.98000	1.00000	1.00649	1.00223	0.99154	0.99056
19	4.5700-03	1.2925+01	0.97000	1.00000	1.00974	1.00333	0.98734	0.98571

INPUT VARIABLES Y, TO/TOD, P/PW, M

7306S0112 ROSE		PROFILE TABULATION		27 POINTS, DELTA AT POINT 14				
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	1.00000	0.92600	0.00000	0.00000	2.63754	0.00000
2	2.5000-04	2.6186+00	1.00000	0.97600	0.41776	0.60567	2.10192	0.28815
3	5.1000-04	3.5279+00	1.00000	0.98700	0.50329	0.69644	1.91481	0.36371
4	7.6000-04	4.2672+00	1.00000	0.99400	0.56250	0.75183	1.78647	0.42085
5	1.0200-03	5.0934+00	1.00000	0.99700	0.62171	0.80015	1.65641	0.48306
6	1.2700-03	6.0051+00	1.00000	1.00300	0.68092	0.84457	1.53845	0.54898
7	1.5200-03	7.1762+00	1.00000	1.01100	0.75000	0.89115	1.41182	0.63121
8	1.7800-03	8.4620+00	1.00000	1.01800	0.81908	0.93190	1.29445	0.71992
9	2.0300-03	1.0002+01	1.00000	1.02000	0.89474	0.96848	1.17164	0.82661
10	2.2900-03	1.1228+01	1.00000	1.01800	0.95066	0.99061	1.08582	0.91232
11	2.5400-03	1.1984+01	1.00000	1.01200	0.98355	1.00008	1.03389	0.96730
12	2.7900-03	1.2216+01	1.00000	1.00600	0.99342	1.00066	1.01463	0.98623
13	3.0500-03	1.2372+01	1.00000	1.00200	1.00000	1.00100	1.00200	0.99900
14	3.3000-03	1.2372+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
15	3.5600-03	1.2450+01	0.99000	1.00000	1.00329	1.00115	0.99574	0.99538
16	3.8100-03	1.2529+01	0.98000	1.00000	1.00658	1.00230	0.99151	0.99066
17	4.0600-03	1.2607+01	0.97000	1.00000	1.00987	1.00343	0.98729	0.98586
18	4.3200-03	1.2607+01	0.95000	1.00000	1.00987	1.00343	0.98729	0.96553
19	4.5700-03	1.3167+01	0.89000	1.00000	1.03289	1.01119	0.95841	0.93901
20	4.8300-03	1.3410+01	0.84000	1.00000	1.04276	1.01441	0.94635	0.90041
21	5.0800-03	1.3904+01	0.78000	1.00000	1.06250	1.02067	0.92281	0.86272
22	5.3300-03	1.4407+01	0.72000	1.00000	1.08224	1.02670	0.89999	0.82136
23	5.5900-03	1.4834+01	0.67000	1.00000	1.09868	1.03155	0.88153	0.78402
24	5.8400-03	1.5267+01	0.62000	1.00000	1.11513	1.03626	0.86354	0.74401
25	6.1000-03	1.5706+01	0.57000	1.00000	1.13158	1.04082	0.84602	0.70124
26	6.3500-03	1.4920+01	0.57000	1.00000	1.10197	1.03250	0.87789	0.67039
27	6.6000-03	1.8095+01	0.45000	1.00000	1.21711	1.06244	0.76199	0.62743

INPUT VARIABLES Y, TO/TOD, P/PW, M

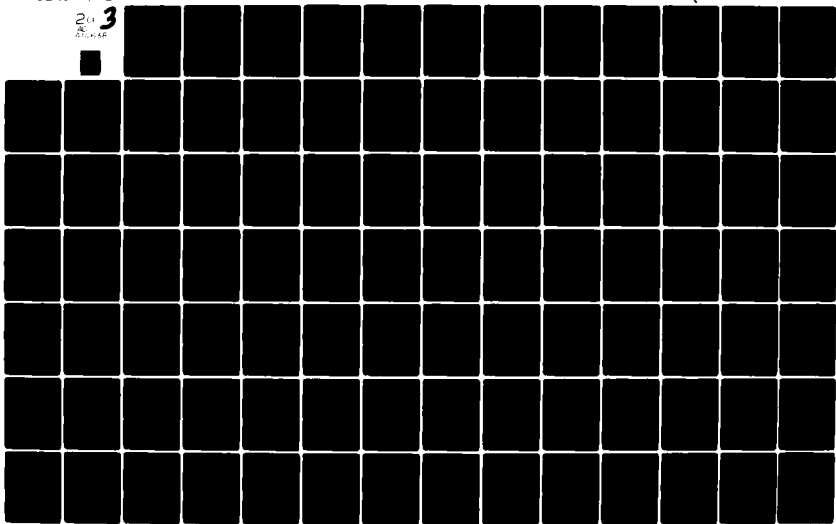
AD-A111 638

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/6 20/4
A FURTHER COMPILATION OF COMPRESSIBLE BOUNDARY LAYER DATA WITH --ETC(U)
NOV 81 H H FERNHOLZ, P J FINLEY, V MIKULLA
AGARD-A6-263

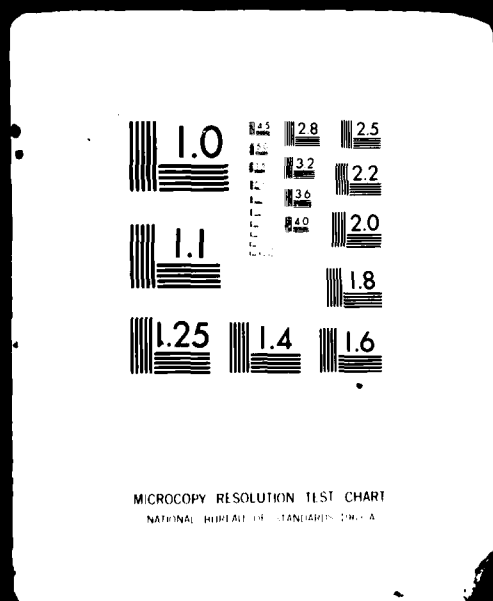
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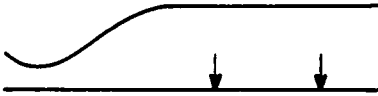
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2 3
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2 OF 3
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	M: 4.9 R THETA $\times 10^{-3}$: 6-26 TW/TR: 0.8, 1.0	7404 ZPG AW - MHT
Boundary layer channel. Effectively continuous. $W = 0.33$, $H = 0.272$ m. $0.1 < P_0 < 1$. MN/m ² . T_0 : 340, 420K. Air, dewpoint 215-233K. $2 < RE/m \times 10^{-6} < 23$.		
VOISINET R.L.P., LEE R.E., MEIER H.U., 1974. Comparative measurements of total temperature in a supersonic turbulent boundary layer using a conical equilibrium and combined temperature-pressure probe. NOLTR 74-10.		

- 1 The general arrangement of this experiment is as for Voisinnet and Lee, CAT 7202, and only differences will be described here. The purpose was to compare the temperature distributions obtained using the
- 7 ECP (Danberg 1961), for which the cone semi-angle was 5° , the support diameter 1.5 mm and the length before increase in support diameter about 25 mm (E) with those using a combined Pitot-temperature probe. The combined probe was as designed by Meier (1967, 1970, CAT 7003), consisting of a Pitot tube with a circular front-face ($d = 0.5$ mm), followed by a conical section with half angle about 6° (E), and containing a thermocouple bead just behind the opening. The tube can be vented in a controlled manner outside the windtunnel, and so can operate either as a Pitot tube, with the vents closed, or
- 8 as a STP when vented. The probes were mounted on a common holder, the tip of the ECP 0.75 mm higher than the centre of the combined probe. There are two values of X , 1.702 and 2.057 m.
- 12 The editors have presented all the tabulated profile data, incorporating the authors' assumptions and
- 13 reduction procedures. The profiles are divided into an 'A' set, using the ECP, and a 'B' set using the combined probe. Profiles 0101-0301 are for a near adiabatic wall case, 0401-0602 for TW/TR=0.8. There are three unit Reynolds numbers in each group.
- § DATA: 74040101-0602 A and B. Pitot profiles and two T_0 profiles obtained simultaneously.
- 15 Editors' comments. These data are among the most carefully considered total temperature surveys in published form. Agreement between the two probe types was good. For the AW case, the combined probe gave values up to about 2% lower near the wall, and within 1% further out. For TW/TR = 0.8, the combined probe read up to 2.5% higher near the wall, within 1% further out. A discussion of possible error sources in the combined probe may be found in Mabey and Sawyer (1976). Sample profiles are shown as figures (2.5.19) and (2.5.20) in AGARDograph 253. The skin friction value was not measured, so that the Fernholz (1971) correlation was used in order to compare the velocity profiles with the standard logarithmic and outer law. Agreement of the measured velocity distribution with the "standard" logarithmic laws was good (AG 253, Fig. 2.5.20), whereas for the outer law data points fell slightly above and below the standard curve in the middle of the boundary layer and towards the edge respectively. This behaviour was found also in Voisinnet's experiment CAT 7901S, and the earlier NOL studies such as CAT 7202. A comparison between the measured temperature and the standard temperature-velocity relationship, eqn.(2.5.37) of AGARDograph 253 (Fig. 2.5.19), showed that the measured profiles were between 5 and 15% lower for profiles 0401A to 0602A and 0402B to 0602B. Most of the velocity profiles extended into the viscous sublayer.

CAT 7404S

VOISINET

BOUNDARY CONDITIONS AND EVALUATED DATA, SI UNITS

RUN X * RZ	MD * POD TOD	TW/TR PW/PD* TAUW	RED2W RED2O O2	CF CQ PIZ*	H12 H32 H42	H12K H32K H2K	PW TW* UD	PD* TD* TR
7404S0101A 1.7020**+00 INFINITE	4.7852 1.0016**+05 3.3818**+02	0.9641 1.0000 NM	1.4570**+03 6.1810**+03 2.5636**+03	NM NM 0.0000**+00	10.0602 1.8200 0.2654	1.4530 1.7652 5.6573**+03	2.4410**+02 2.9820**+02 7.4693**+02	2.4410**+02 6.0610**+01 3.0931**+02
7404S0102A 2.0570**+00 INFINITE	4.7557 9.7695**+04 3.3897**+02	0.9749 1.0000 NM	1.5103**+03 6.3943**+03 2.6905**+03	NM NM 0.0000**+00	10.6881 1.8028 0.1637	1.4692 1.7510 6.2951**+03	2.4670**+02 3.0230**+02 7.4697**+02	2.4670**+02 6.1370**+01 3.1010**+02
7404S0201A 1.7020**+00 INFINITE	4.8305 5.1765**+05 3.3808**+02	0.9556 1.0000 NM	5.9667**+03 2.5531**+04 2.0924**+03	NM NM 0.0000**+00	10.0512 1.8301 0.2652	1.4020 1.7794 4.4970**+03	1.1950**+03 2.9540**+02 7.4607**+02	1.1950**+03 5.9660**+01 3.0912**+02
7404S0202A 2.0570**+00 INFINITE	4.9071 5.3705**+05 3.3878**+02	0.9677 1.0000 NM	5.7754**+03 2.5593**+04 2.1024**+03	NM NM 0.0000**+00	10.8266 1.8216 0.1912	1.3893 1.7748 4.7907**+03	1.1320**+03 2.9960**+02 7.5090**+02	1.1320**+03 5.8250**+01 3.0960**+02
7404S0301A 1.7020**+00 INFINITE	4.7883 9.7319**+05 3.3809**+02	0.9569 1.0000 NM	9.7003**+03 4.0960**+04 1.7503**+03	NM NM 0.0000**+00	10.0437 1.8269 0.2443	1.4185 1.7746 3.7396**+03	2.3630**+03 2.9590**+02 7.4692**+02	2.3630**+03 6.0530**+01 3.0923**+02
7404S0401A 1.7020**+00 INFINITE	4.7871 1.0002**+05 4.2098**+02	0.7765 1.0000 NM	2.0524**+03 7.0129**+03 4.0496**+03	NM NM 0.0000**+00	6.0282 1.8175 0.8712	1.4418 1.7620 7.1965**+03	2.4320**+02 2.9900**+02 8.3343**+02	2.4320**+02 7.5400**+01 3.8904**+02
7404S0402A 2.0570**+00 INFINITE	4.8060 1.0214**+05 4.1871**+02	0.7926 1.0000 NM	2.2245**+03 7.7798**+03 4.4033**+03	NM NM 0.0000**+00	6.1586 1.8086 0.8609	1.4484 1.7552 8.0310**+03	2.4280**+02 3.0350**+02 8.3177**+02	2.4280**+02 7.4510**+01 3.8291**+02
7404S0501A 1.7020**+00 INFINITE	4.8754 5.1864**+05 4.2303**+02	0.7769 1.0000 NM	6.6365**+03 2.3336**+04 2.7302**+03	NM NM 0.0000**+00	7.1800 1.8322 0.7072	1.3709 1.7849 5.0556**+03	1.1350**+03 3.0040**+02 8.3815**+02	1.1350**+03 7.3520**+01 3.8668**+02
7404S0502A 2.0570**+00 INFINITE	4.8637 5.2095**+05 4.2198**+02	0.7829 1.0000 NM	7.4641**+03 2.6315**+04 3.0368**+03	NM NM 0.0000**+00	7.0417 1.9228 0.7251	1.3730 1.7766 5.6913**+03	1.1560**+03 3.0200**+02 8.3677**+02	1.1560**+03 7.3630**+01 3.8575**+02
7404S0601A 1.7020**+00 INFINITE	4.9139 1.0981**+06 4.2548**+02	0.7793 1.0000 NM	1.2138**+04 4.3274**+04 2.4564**+03	NM NM 0.0000**+00	7.5119 1.8486 0.6645	1.3590 1.8041 4.4425**+03	2.2960**+03 3.0300**+02 8.4172**+02	2.2960**+03 7.2990**+01 3.8882**+02
7404S0602A 2.0570**+00 INFINITE	4.9719 1.1494**+06 4.2357**+02	0.7841 1.0000 NM	1.3007**+04 4.7545**+04 2.6318**+03	NM NM 0.0000**+00	7.6763 1.8393 0.6637	1.3460 1.7945 4.9426**+03	2.2450**+03 3.0340**+02 8.4150**+02	2.2450**+03 7.1260**+01 3.8693**+02
7404S0101B 1.7020**+00 INFINITE	4.7852 1.0016**+05 3.3958**+02	0.9582 1.0000 NM	1.4967**+03 6.3131**+03 2.6347**+03	NM NM 0.0000**+00	9.7628 1.8144 0.3044	1.4361 1.7578 5.7833**+03	2.4410**+02 2.9760**+02 7.4847**+02	2.4410**+02 6.0860**+01 3.1059**+02
7404S0102B 2.0570**+00 INFINITE	4.7557 9.7695**+04 3.3941**+02	0.9736 1.0000 NM	1.5345**+03 6.4880**+03 2.7353**+03	NM NM 0.0000**+00	10.4966 1.7996 0.1901	1.4629 1.7478 6.3693**+03	2.4670**+02 3.0230**+02 7.4746**+02	2.4670**+02 6.1450**+01 3.1050**+02
7404S0201B 1.7020**+00 INFINITE	4.8305 5.1765**+05 3.3893**+02	0.9551 1.0000 NM	5.9457**+03 2.5417**+04 2.0909**+03	NM NM 0.0000**+00	10.0636 1.8241 0.2588	1.3919 1.7699 4.5325**+03	1.1950**+03 2.9600**+02 7.4901**+02	1.1950**+03 5.9810**+01 3.0990**+02
7404S0202B 2.0570**+00 INFINITE	4.9071 5.3705**+05 3.3715**+02	0.9668 1.0000 NM	6.0385**+03 2.6771**+04 2.1833**+03	NM NM 0.0000**+00	10.3873 1.8210 0.2520	1.3671 1.7717 4.9236**+03	1.1320**+03 2.9790**+02 7.4909**+02	1.1320**+03 5.7970**+01 3.0811**+02
7404S0301B 1.7020**+00 INFINITE	4.7883 9.7319**+05 3.3742**+02	0.9562 1.0000 NM	9.9743**+03 4.2113**+04 1.7942**+03	NM NM 0.0000**+00	9.7644 1.8252 0.2775	1.3841 1.7737 3.8175**+03	2.3630**+03 2.9510**+02 7.4618**+02	2.3630**+03 6.0410**+01 3.0861**+02
7404S0401B 1.7020**+00 INFINITE	4.7872 1.0003**+05 4.2110**+02	0.7768 1.0000 NM	2.0436**+03 6.9844**+03 4.0347**+03	NM NM 0.0000**+00	6.0538 1.8139 0.8646	1.4391 1.7583 7.1985**+03	2.4320**+02 2.9920**+02 8.3356**+02	2.4320**+02 7.5420**+01 3.8915**+02
7404S0402B 2.0570**+00 INFINITE	4.8060 1.0214**+05 4.1736**+02	0.7954 1.0000 NM	2.1987**+03 7.7162**+03 4.3464**+03	NM NM 0.0000**+00	6.2526 1.8053 0.8439	1.4426 1.7515 7.9990**+03	2.4280**+02 3.0360**+02 8.3042**+02	2.4280**+02 7.4270**+01 3.8168**+02
7404S0501B 1.7020**+00 INFINITE	4.8755 5.1870**+05 4.2091**+02	0.7797 1.0000 NM	6.6232**+03 2.3383**+04 2.7150**+03	NM NM 0.0000**+00	7.2297 1.8312 0.6978	1.3614 1.7806 5.0638**+03	1.1350**+03 3.0000**+02 8.3606**+02	1.1350**+03 7.3150**+01 3.8475**+02
7404S0502B 2.0570**+00 INFINITE	4.8638 5.2101**+05 4.2102**+02	0.7870 1.0000 NM	7.3972**+03 2.6198**+04 3.0129**+03	NM NM 0.0000**+00	7.1084 1.8215 0.7128	1.3633 1.7735 5.6931**+03	1.1560**+03 3.0290**+02 8.3582**+02	1.1560**+03 7.3460**+01 3.8468**+02
7404S0601B 1.7020**+00 INFINITE	4.9140 1.0982**+06 4.2666**+02	0.7794 1.0000 NM	1.2262**+04 4.3700**+04 2.4907**+03	NM NM 0.0000**+00	7.3922 1.8449 0.6713	1.3162 1.7980 4.5327**+03	2.2960**+03 3.0390**+02 8.4289**+02	2.2960**+03 7.3190**+01 3.8990**+02
7404S0602B 2.0570**+00 INFINITE	4.9718 1.1498**+06 4.2432**+02	0.7848 1.0000 NM	1.3241**+04 4.8409**+04 2.6898**+03	NM NM 0.0000**+00	7.5014 1.8371 0.6846	1.3262 1.7901 5.0386**+03	2.2460**+03 3.0420**+02 8.4225**+02	2.2460**+03 7.1390**+01 3.8762**+02

7404S0101A		VOISINET	PROFILE TABULATION		18 POINTS, DELTA AT POINT 18			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.88180	0.00000	0.00000	4.92012	0.00000
2	1.3210 ⁻ 03	1.7458 ⁺ 00	NM	0.91750	0.19412	0.40561	4.36588	0.09290
3	2.4890 ⁻ 03	2.9078 ⁺ 00	NM	0.94020	0.28398	0.55584	3.83107	0.14509
4	3.8100 ⁻ 03	3.7501 ⁺ 00	NM	0.94480	0.33152	0.62081	3.50663	0.17704
5	5.3090 ⁻ 03	4.3495 ⁺ 00	NM	0.94490	0.36128	0.65627	3.29976	0.19889
6	6.8830 ⁻ 03	5.0697 ⁺ 00	NM	0.94560	0.39394	0.69183	3.08414	0.22432
7	1.0719 ⁻ 02	6.2882 ⁺ 00	NM	0.94240	0.44360	0.73773	2.76579	0.26673
8	1.6002 ⁻ 02	8.6228 ⁺ 00	NM	0.95620	0.52558	0.80663	2.35547	0.34245
9	2.0930 ⁻ 02	1.1208 ⁺ 01	NM	0.96540	0.60340	0.85747	2.01940	0.42462
10	2.6848 ⁻ 02	1.4748 ⁺ 01	NM	0.97430	0.69590	0.90451	1.68944	0.53539
11	3.1928 ⁻ 02	1.8008 ⁺ 01	NM	0.98030	0.77129	0.93470	1.46861	0.63645
12	3.8532 ⁻ 02	2.2084 ⁺ 01	NM	0.98830	0.85629	0.96322	1.26537	0.76122
13	4.3536 ⁻ 02	2.4316 ⁺ 01	NM	0.99050	0.89942	0.97482	1.17470	0.82985
14	5.0775 ⁻ 02	2.6528 ⁺ 01	NM	0.99300	0.94021	0.98498	1.09749	0.89748
15	6.1595 ⁻ 02	2.8661 ⁺ 01	NM	0.99600	0.97793	0.99394	1.03301	0.96218
16	7.1755 ⁻ 02	2.9307 ⁺ 01	NM	0.99840	0.98907	0.99722	1.01654	0.98099
17	8.1382 ⁻ 02	2.9567 ⁺ 01	NM	0.99900	0.99352	0.99833	1.00970	0.98874
D 18	9.0449 ⁻ 02	2.9948 ⁺ 01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

7404S0201A		VOISINET	PROFILE TABULATION		16 POINTS, DELTA AT POINT 16			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.87370	0.00000	0.00000	4.95104	0.00000
2	9.9100 ⁻ 04	2.6541 ⁺ 00	NM	0.92100	0.26525	0.52577	3.92900	0.13382
3	2.1340 ⁻ 03	3.2453 ⁺ 00	NM	0.92120	0.30117	0.57678	3.66771	0.15726
4	3.2770 ⁻ 03	4.1119 ⁺ 00	NM	0.92450	0.34653	0.63495	3.35744	0.18912
5	7.2140 ⁻ 03	5.9586 ⁺ 00	NM	0.93130	0.42671	0.72076	2.85312	0.25262
6	1.2802 ⁻ 02	9.0973 ⁺ 00	NM	0.95440	0.53564	0.81451	2.31232	0.35225
7	1.9406 ⁻ 02	1.3824 ⁺ 01	NM	0.97260	0.66668	0.89266	1.79282	0.49791
8	2.5425 ⁻ 02	1.8720 ⁺ 01	NM	0.98490	0.77944	0.94027	1.45525	0.64612
9	3.1877 ⁻ 02	2.2846 ⁺ 01	NM	0.99070	0.86308	0.96656	1.25418	0.77067
10	3.6957 ⁻ 02	2.5535 ⁺ 01	NM	0.99560	0.91347	0.98077	1.15279	0.85078
11	4.4425 ⁻ 02	2.7656 ⁺ 01	NM	0.99690	0.95133	0.98933	1.08148	0.91479
12	5.1105 ⁻ 02	2.8855 ⁺ 01	NM	0.99890	0.97209	0.99435	1.04632	0.95033
13	5.6464 ⁻ 02	2.9462 ⁺ 01	NM	0.99750	0.98242	0.99558	1.02697	0.96944
14	6.4872 ⁻ 02	2.9745 ⁺ 01	NM	0.99790	0.98721	0.99666	1.01924	0.97784
15	7.6860 ⁻ 02	3.0049 ⁺ 01	NM	0.99830	0.99232	0.99778	1.01104	0.98689
D 16	8.8773 ⁻ 02	3.0508 ⁺ 01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

7404S0501A		VOISINET	PROFILE TABULATION		26 POINTS, DELTA AT POINT 25			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.71020	0.00000	0.00000	5.42	0.00000
2	9.1400 ⁻ 04	3.0408 ⁺ 00	NM	0.80730	0.28666	0.52392	3.124	0.15685
3	1.3720 ⁻ 03	3.5163 ⁺ 00	NM	0.81890	0.31321	0.56145	3.1734	0.17472
4	2.1840 ⁻ 03	4.0320 ⁺ 00	NM	0.82330	0.33946	0.59387	3.06059	0.19404
5	2.9460 ⁻ 03	4.4038 ⁺ 00	NM	0.82640	0.35712	0.61444	2.96026	0.20756
6	4.3180 ⁻ 03	5.1156 ⁺ 00	NM	0.83570	0.38860	0.65015	2.79908	0.23227
7	5.7660 ⁻ 03	5.8504 ⁺ 00	NM	0.84420	0.41855	0.68139	2.65027	0.25710
8	7.3150 ⁻ 03	6.6608 ⁺ 00	NM	0.85460	0.44921	0.71165	2.50971	0.28356
9	8.9150 ⁻ 03	7.5475 ⁺ 00	NM	0.86450	0.48049	0.73994	2.37145	0.31202
10	1.0871 ⁻ 02	8.7623 ⁺ 00	NM	0.87630	0.52027	0.77254	2.20492	0.35037
11	1.2675 ⁻ 02	9.9682 ⁺ 00	NM	0.88720	0.55692	0.79991	2.06302	0.38774
12	1.4707 ⁻ 02	1.1382 ⁺ 01	NM	0.89830	0.59702	0.82689	1.91830	0.43105
13	1.6967 ⁻ 02	1.3073 ⁺ 01	NM	0.90970	0.64167	0.85367	1.76992	0.48232
14	1.8339 ⁻ 02	1.4097 ⁺ 01	NM	0.91440	0.66725	0.86696	1.68821	0.51354
15	2.0879 ⁻ 02	1.6045 ⁺ 01	NM	0.92740	0.71340	0.89119	1.56054	0.57108
16	2.3597 ⁻ 02	1.8243 ⁺ 01	NM	0.93670	0.76209	0.91230	1.43305	0.63661
17	2.7026 ⁻ 02	2.0732 ⁺ 01	NM	0.94560	0.81372	0.93197	1.31177	0.71047
18	3.1801 ⁻ 02	2.3722 ⁺ 01	NM	0.95620	0.87170	0.95206	1.19286	0.79813
19	3.9624 ⁻ 02	2.6877 ⁺ 01	NM	0.96970	0.92897	0.97142	1.09349	0.88837
20	4.4704 ⁻ 02	2.8100 ⁺ 01	NM	0.97620	0.95024	0.97893	1.06129	0.92239
21	5.1308 ⁻ 02	2.9280 ⁺ 01	NM	0.98400	0.97032	0.98666	1.03396	0.95425
22	5.7531 ⁻ 02	2.9886 ⁺ 01	NM	0.98880	0.98047	0.99093	1.02144	0.97013
23	6.3957 ⁻ 02	3.0265 ⁺ 01	NM	0.99380	0.98677	0.99456	1.01586	0.97904
24	6.8834 ⁻ 02	3.0546 ⁺ 01	NM	0.99610	0.99141	0.99654	1.01039	0.98630
D 25	8.1382 ⁻ 02	3.1069 ⁺ 01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
26	9.1745 ⁻ 02	3.1599 ⁺ 01	NM	1.00330	1.00861	1.00313	0.98916	1.01413

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

7404S01018		VOISINET	PROFILE TABULATION		20 POINTS, DELTA AT POINT 20			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	NM	0.87630	0.00000	0.00000	4.88943	0.00000
2	3.0500-04	1.1830+00	NM	0.88900	0.10363	0.22533	4.72776	0.04766
3	4.5700-04	1.1954+00	NM	0.89320	0.10689	0.23262	4.73591	0.04912
4	1.3210-03	1.7456+00	NM	0.91470	0.19410	0.40495	4.35270	0.09303
5	2.4890-03	2.9075+00	NM	0.92610	0.28396	0.55162	3.77376	0.14617
6	3.8100-03	3.7501+00	NM	0.93190	0.33152	0.61656	3.45875	0.17826
7	5.3090-03	4.3490+00	NM	0.92990	0.36126	0.65102	3.24752	0.20047
8	6.8830-03	5.0697+00	NM	0.92840	0.39394	0.68551	3.02804	0.22639
9	1.0791-02	6.2882+00	NM	0.93230	0.44360	0.73377	2.73615	0.26818
10	1.6002-02	8.6221+00	NM	0.94620	0.52556	0.80239	2.33094	0.34424
11	2.0930-02	1.1208+01	NM	0.95690	0.60340	0.85368	2.00162	0.42650
12	2.6848-02	1.4748+01	NM	0.96780	0.69590	0.90149	1.67816	0.53719
13	3.1928-02	1.8009+01	NM	0.97500	0.77132	0.93218	1.46062	0.63821
14	3.8532-02	2.2084+01	NM	0.98360	0.85629	0.96093	1.25935	0.76304
15	4.3536-02	2.4316+01	NM	0.98980	0.89942	0.97448	1.17387	0.83014
16	5.0775-02	2.6528+01	NM	0.99400	0.94021	0.98547	1.09860	0.89703
17	6.1595-02	2.8661+01	NM	0.99770	0.97793	0.99479	1.03477	0.96136
18	7.1755-02	2.9307+01	NM	0.99790	0.98907	0.99697	1.01603	0.98124
19	8.1382-02	2.9567+01	NM	0.99900	0.99352	0.99833	1.00970	0.98874
D 20	9.0449-02	2.9948+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

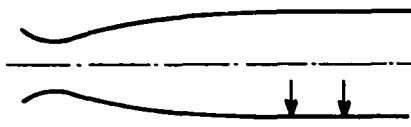
INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

7404S02018		VOISINET	PROFILE TABULATION		18 POINTS, DELTA AT POINT 18			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	NM	0.87340	0.00000	0.00000	4.94934	0.00000
2	3.0500-04	1.2968+00	NM	0.89650	0.12852	0.27911	4.71668	0.05918
3	4.8300-04	1.7141+00	NM	0.91050	0.18886	0.39721	4.42328	0.08980
4	9.9100-04	2.6541+00	NM	0.91600	0.26525	0.52435	3.90767	0.13418
5	2.1340-03	3.2449+00	NM	0.91470	0.30115	0.57471	3.64198	0.15780
6	3.2770-03	4.1119+00	NM	0.91990	0.34653	0.63337	3.34073	0.18959
7	7.2140-03	5.9586+00	NM	0.93000	0.42671	0.72025	2.84914	0.25280
8	1.2802-02	9.0973+00	NM	0.95080	0.53564	0.81297	2.30359	0.35291
9	1.9406-02	1.3824+01	NM	0.97000	0.66668	0.89147	1.78803	0.49858
10	2.5425-02	1.8720+01	NM	0.98060	0.77942	0.93821	1.44896	0.64751
11	3.1877-02	2.2847+01	NM	0.99190	0.86310	0.96715	1.25565	0.77024
12	3.6957-02	2.5535+01	NM	0.99620	0.91347	0.98107	1.15349	0.85052
13	4.4425-02	2.7656+01	NM	0.99820	0.95133	0.98998	1.08290	0.91419
14	5.1105-02	2.8855+01	NM	0.99830	0.97209	0.99405	1.04569	0.95062
15	5.6464-02	2.9463+01	NM	0.99790	0.98244	0.99579	1.02734	0.96928
16	6.4872-02	2.9746+01	NM	0.99880	0.98723	0.99711	1.02012	0.97744
17	7.6860-02	3.0049+01	NM	0.99950	0.99232	0.99838	1.01226	0.98629
D 18	8.8773-02	3.0508+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

7404S05018		VOISINET	PROFILE TABULATION		29 POINTS, DELTA AT POINT 28			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	NM	0.71280	0.00000	0.00000	4.10152	0.00000
2	3.0500-04	1.5518+00	NM	0.78300	0.16774	0.33438	3.97391	0.08414
3	3.5600-04	1.8222+00	NM	0.79320	0.19834	0.38892	3.84506	0.10115
4	5.3300-04	2.3491+00	NM	0.80710	0.24196	0.46119	3.63295	0.12695
5	9.1400-04	3.0408+00	NM	0.81720	0.28666	0.52712	3.38132	0.15589
6	1.3720-03	3.5163+00	NM	0.82210	0.31320	0.56254	3.22601	0.17438
7	2.1840-03	4.0320+00	NM	0.82760	0.33945	0.59541	3.07668	0.19353
8	2.9460-03	4.4038+00	NM	0.83340	0.35711	0.61703	2.98544	0.20668
9	4.3180-03	5.1156+00	NM	0.84240	0.38860	0.65275	2.82161	0.23134
10	5.7660-03	5.8504+00	NM	0.85180	0.41854	0.68444	2.67422	0.25594
11	7.3150-03	6.6608+00	NM	0.86080	0.44921	0.71422	2.52800	0.28252
12	8.9150-03	7.5475+00	NM	0.87030	0.48048	0.74241	2.38744	0.31097
13	1.0871-02	8.7623+00	NM	0.88070	0.52025	0.77448	2.21607	0.34948
14	1.2675-02	9.9682+00	NM	0.89030	0.55691	0.80131	2.07030	0.38705
15	1.4707-02	1.1382+01	NM	0.89820	0.59701	0.82684	1.91815	0.43106
16	1.6967-02	1.3072+01	NM	0.91040	0.64164	0.85398	1.77142	0.48209
17	1.8339-02	1.4097+01	NM	0.91570	0.66723	0.86758	1.69067	0.51316
18	2.0879-02	1.6044+01	NM	0.92490	0.71336	0.88998	1.55645	0.57180
19	2.3597-02	1.8243+01	NM	0.93450	0.76208	0.91122	1.42973	0.63734
20	2.7026-02	2.0732+01	NM	0.94630	0.81370	0.93231	1.31279	0.71018
21	3.1801-02	2.3722+01	NM	0.95880	0.87168	0.95335	1.19615	0.79702
22	3.9624-02	2.6878+01	NM	0.96980	0.92897	0.97147	1.09360	0.88833
23	4.4704-02	2.8100+01	NM	0.97690	0.95022	0.97928	1.06209	0.92203
24	5.1308-02	2.9280+01	NM	0.98520	0.97030	0.98725	1.03525	0.95364
25	5.7531-02	2.9885+01	NM	0.99010	0.98043	0.99157	1.02285	0.96942
26	6.3957-02	3.0265+01	NM	0.99330	0.98675	0.99431	1.01538	0.97925
27	6.8834-02	3.0546+01	NM	0.99590	0.99139	0.99644	1.01022	0.98636
D 28	8.1382-02	3.1071+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
29	9.1745-02	3.1599+01	NM	1.00000	1.00859	1.00148	0.98594	1.01576

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

axisymmetric 	M: 14 R THETA $\times 10^{-3}$: 6-11 TW/TR: 0.25	7405 FPG-SHT
Blowdown tunnel with axisymmetric contoured nozzle. Running time 55 sec. D = 0.47 m. $8 < P_0 < 20 \text{ MN/m}^2$. T_0: 1300K. Nitrogen. $1.4 < RE/m \cdot 10^{-6} < 3.8$.		
PETERSON C.W. 1974. Pressure and temperature measurements in a cold-wall hypersonic turbulent boundary layer. Proc. 1974 Heat Transfer and Fluid Mechanics Institute. <u>And</u> Peterson, C.W., private communications. <u>Also</u> Peterson and George, 1974, 1975 a,b.		

- 1 The test boundary layer was formed on the nozzle wall of an axisymmetric M = 14 wind tunnel. Wall
- 8 temperature and pressure measurements were made at 10 stations ranging from X = 0.74 m to 2.74 m, where X is the axial distance from the throat (X = 0). Profiles were measured at two stations,
- 2 X = 1.92 and 2.66 m. The "smooth monotonic decrease in wall pressure along the nozzle indicates that
- 3 no imbedded shocks or boundary layer separation are present." No boundary layer trips were used, but a comparison of the measured velocity profiles with a calculated laminar profile indicated that the
- 4 profiles were fully turbulent. The nozzle wall was not actively cooled downstream of the nozzle region (X > 0.56 m), and as a result of the short running time wall temperatures in this region "show only a weak dependence upon axial station and test conditions." "However, the estimated heat transfer rates were high enough near the throat to cause substantial temperature rises in wall temperature in this region." The cooling water flow rate was the same throughout, so that the throat-wall temperature would have been significantly higher in the higher Reynolds number cases. The boundary layer passed through a strong simple wave expansion in the throat region, but in the test zone the longitudinal pressure gradient was considered relatively modest.
- 6 Wall pressure was measured with tappings of 3.18 mm in diameter, while the wall temperature was found from thermocouples buried approximately 2 mm below the surface. Pitot, total temperature and static
- 7 pressure profiles were measured separately at two stations, one nominally in the expansion field of the nozzle, the other nominally downstream of the nozzle wave structure, though in fact still in a region with pressure gradients. Pitot surveys were made using a twin-probe rake which was traversed at right angles to the wall of the nozzle. An FPP with a rectangular face 1.27 mm high and 4.06 mm wide was used for surveys between the wall (Y = 0) and (Y = 65 mm). To generate Pitot pressure corrections for viscous and rarefaction effects, other rectangular FPP with h_1 ranging from 0.19 to 1.04 mm and b_1/h_1 from 2.38 to 14.67 were used in a separate calibration experiment (see Peterson and George: 1974, 1975a and ,more briefly, 1975b.) The T_0 profile was measured with a singly shielded STP for which $d_1 = 2.2$ mm. In the initial surveys, reported in Peterson (1974) the static pressure profile was obtained using a 'cone-static' probe. This consisted of a 10° half angle cone-cylinder probe with static tappings on the conical face of the probe, essentially probe 2 of the calibration studies reported by Peterson and George cited above. The probe diameter was 3.18 mm, with the centre of the tapping (d = 0.15 mm) 3.18 mm from the tip and 5.72 mm from the shoulder of the cone. For the later tests reported here (private communication) a CCP was used for which $\alpha = 10^\circ$ (half angle), d = 2.13 mm, with tappings (d = 0.41 mm) 34.1 mm downstream of the shoulder.
- 9 The author has interpolated all profile data to a set of fixed y/ δ values, with the D point chosen by inspection of the total temperature profile. Pressure readings were normalised by the instantaneous tunnel reservoir pressure values to give fixed nominal reservoir conditions. Total temperatures were normalised to allow for reservoir and wall temperature variations using the relationship

$$T_0 = 1 + \left[\frac{1-r}{r} \frac{T_0(m) - T_W}{T_{0D} - T_W} \right] T_0(\text{measured})$$

where r is the measured probe recovery factor. The author allowed for real gas effects by using the Beattie - Bridgeman equation of state (see Kestin, 1979, Vol. II, p. 228) and allowing for the variation of specific heats. The probe correction procedure is described in the papers by Peterson and George cited above, allowing for viscous interactions and thermal transpiration effects. Viscosities were calculated from Sutherland's formula for $T > 100K$. For $T < 100K$ a linear variation was assumed (Boudreau 1969).

The editors have accepted the corrected data as interpolated by the author, incorporating his assumptions and data reduction procedures. The boundary layer edge stagnation conditions are however calculated from the author's static state values assuming perfect gas relationships, and viscosity values were calculated according to Keyes (1952). The static pressures are those measured using a CCP. These values are discussed below. The profiles form two sets, a low Reynolds number case (series 01) and a "higher" Reynolds number case (series 02). Skin friction and wall heat transfer were not measured but the author's values deduced from a linear approximation to the inner profile are given for convenience, and were used in deducing the hypothetical static pressure profiles. The wall pressure values used were taken from the table in Peterson (1974).

§ DATA: 7405 0101 - 0202. Pitot, T_0 and static pressure profiles. $NX = 2$.

Editors' comments. The measurements presented here describe a simple wave expansion flow of the same general type as those studied by Fischer et al. (CAT 7001) and Beckwith et al. (CAT 7105). The Reynolds numbers are slightly greater - $Re_0 \times 10^{-3}$ from 6 to 12 as compared to about 10 and 4 respectively. In principle, the flow at the upstream stations is in the nozzle expansion field while that at the downstream station is not - the free stream Pitot reading is stated to be constant. Normal pressure gradients are however apparent at both stations in the boundary layer. The streamwise wall pressure gradients are consistent with the pressure differences across the boundary layer if a simple wave structure is assumed, except for profile 0102 for which the streamwise wall pressure gradient is relatively low.

A special effort was made to obtain full and appropriate calibration data for the probes used (Peterson and George, 1974, 1975). The Pitot and total temperature probes presented no special problems, but some difficulty was found with the static probes (cf. Beckwith et al., CAT 7105). Initial measurements (Peterson, 1974) were made with the cone-static probe as "it is less sensitive to gradients in the flow, causes less flow field interference near solid boundaries, is free from over expansion phenomena and usually has a faster response time..." However, it was found that probe heating effects caused large errors when $M > 8$, so the measurements for $(y/\delta) > 0.5$ were not considered trustworthy. This finding prompted the use of the conventional cone-cylinder probe for the revised tests described here. Both probes probably suffer from errors due to high turbulence, with the effects likely to be greater on the CCP. The profiles show a range of values for which $P(\text{measured}) > P_W$ at low values of Y . It seems probable that these are the result of wall interference effects, and that the CCP would be the more strongly affected because of the greater length from tip to sensing hole.

In an attempt to assess the various measurements we have calculated the static pressure following the procedure of § 6.3 of AGARDograph 253. This assumes that the overall pressure difference across the boundary layer is a result of streamwise curvature, whether caused by the wall or by displacement effects, and for convenience, that the radius of curvature of the streamlines may be considered constant. The normal stress acting is then calculated by integrating the momentum flux (Fig. 1) across the layer and matching the stress to the wall pressure and the boundary layer edge pressure (Fig. 2). The Reynolds stress contribution is then subtracted, the distribution being assumed the same as that deduced (Fig. 3) from the measurements of Beckwith et al. (1971) and Fischer et al. (1979). Since the

specific momentum flux rises quite rapidly at low values of Y (Fig. 1) this distribution was applied over the full width of the layer, though, as seen below, the Reynolds stress may not rise so rapidly. Figure 4, for profile 0202, shows a typical result. With allowance for probable wall proximity effects on the pressure measurements, the profile agrees in shape and magnitude with the measurements, though it seems that the start of significant Reynolds stress effects should be taken at about $y/\delta = 0.20$ rather than 0.05 as here. Profiles 0102, 0201 are similar. Profile 0101 however shows a large disagreement between the deduced static pressure profile and that measured (Fig. 5). To obtain agreement, it would be necessary not only to shift the Reynolds stress distribution, but to substantially change its magnitude. The intensity is assumed proportional to the wall shear stress (AGARDograph 253, eqn. 6.3.3), so that this may be a consequence of an inappropriately deduced CF value. Two values are given, depending on a linear and a parabolic fit to the profile data, and the 'linear' value was chosen for all flow profiles here because it was the lower of the two. The relevant values are given in Table 1.

The temperature and velocity profiles are discussed in detail in § 5.2 of the main text and so are not presented here. The principal feature is that in this flow with strong heat transfer and pressure gradient, the conditions required for the van Driest temperature-velocity correlation are violated. The experimental values diverge widely from eqn. 2.5.37 of AG 253, so that the validity of the transformation must also be questioned. It is therefore to be expected that, although the Reynolds numbers are relatively high for a nozzle wall study, the wall law profiles do not agree with the 'standard' semilog law. The outer region profiles also depart noticeably from the 'standard' semi-empirical outer law.

Table 1 Static pressure profiles deduced from the analysis of Finley (1977).

y/δ	$\frac{\Delta p}{\gamma M_\delta^2 P_\delta C_f}$	P/P_δ			
		0101	0102	0201	0202
0	0	1.37	1.34	1.45	1.35
0.05	0.1	1.353	1.329	1.436	1.340
0.10	0.4	1.300	1.294	1.396	1.311
0.15	1.1	1.176	1.215	1.306	1.244
0.20	1.7	1.063	1.144	1.227	1.185
0.25	2.1	0.987	1.095	1.170	1.143
0.30	2.5	0.909	1.044	1.112	1.100
0.35	2.7	0.864	1.014	1.075	1.055
0.40	2.9	0.817	0.981	1.037	1.045
0.45	3.0	0.786	0.958	1.008	1.023
0.50	2.9	0.786	0.955	1.001	1.016
0.55	2.6	0.819	0.971	1.014	1.026
0.60	2.3	0.849	0.984	1.024	1.033
0.65	1.9	0.895	1.006	1.043	1.045
0.70	1.6	0.920	1.013	1.047	1.046
0.75	1.3	0.942	1.018	1.047	1.046
0.80	1.0	0.963	1.021	1.045	1.042
0.85	0.7	0.983	1.022	1.041	1.038
0.90	0.4	1.001	1.022	1.035	1.032
0.95	0.2	1.000	1.011	1.018	1.016
1.00	0	1.000	1.000	1.000	1.000
CF(linear) $\times 10^3$		0.691	0.420	0.463	0.326
CF(parabolic) $\times 10^3$		0.913	0.492	0.599	0.411
(Author's values deduced from profile data)					
$\delta(\text{mm})$ (Author)		85.09	127.0	71.12	111.76

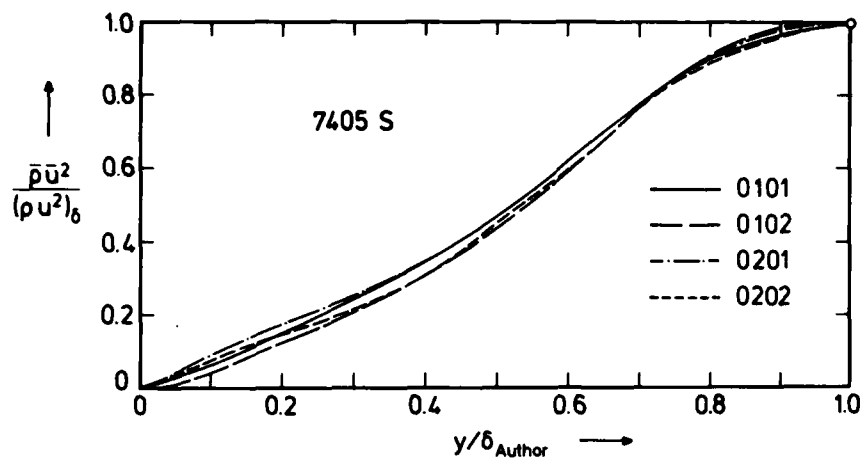


Fig. 1 Profiles of specific momentum flux through the boundary layer.

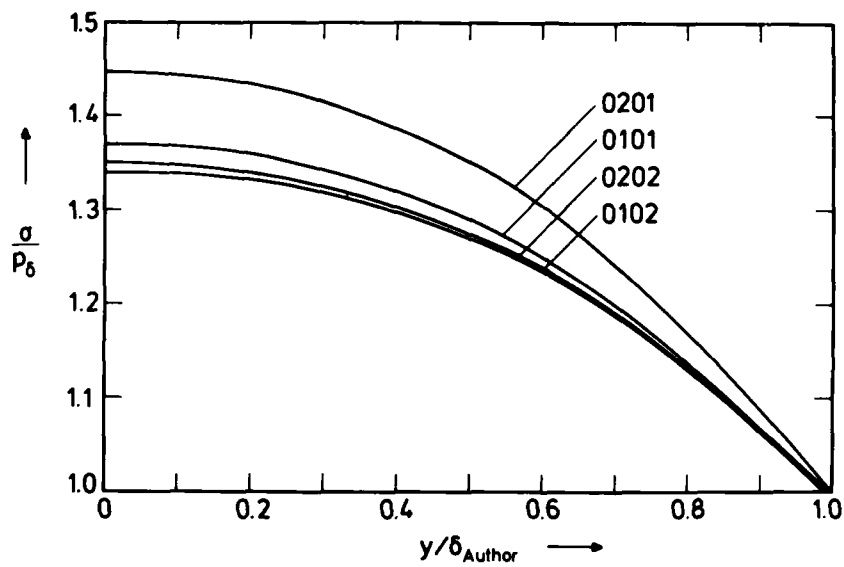


Fig. 2 Total normal stress profiles.

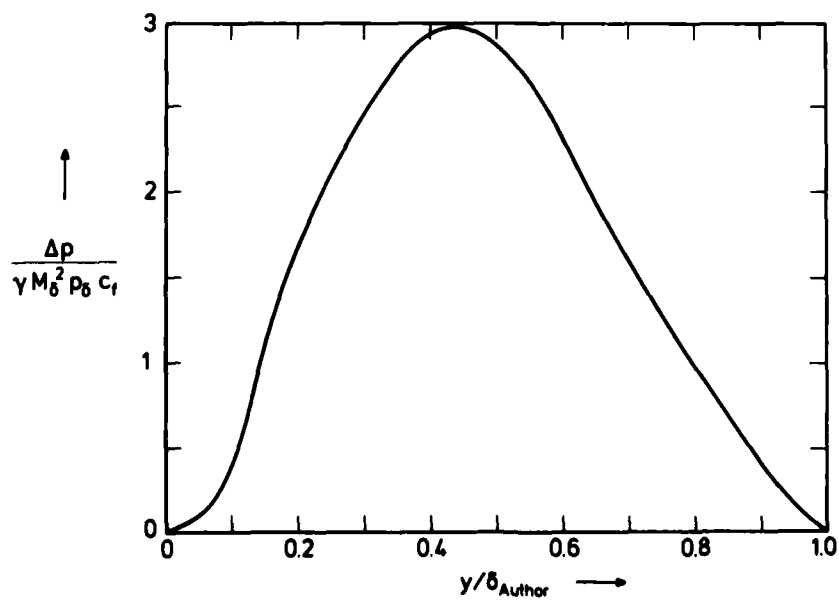


Fig. 3 Contribution of Reynolds normal stress to total normal stress.

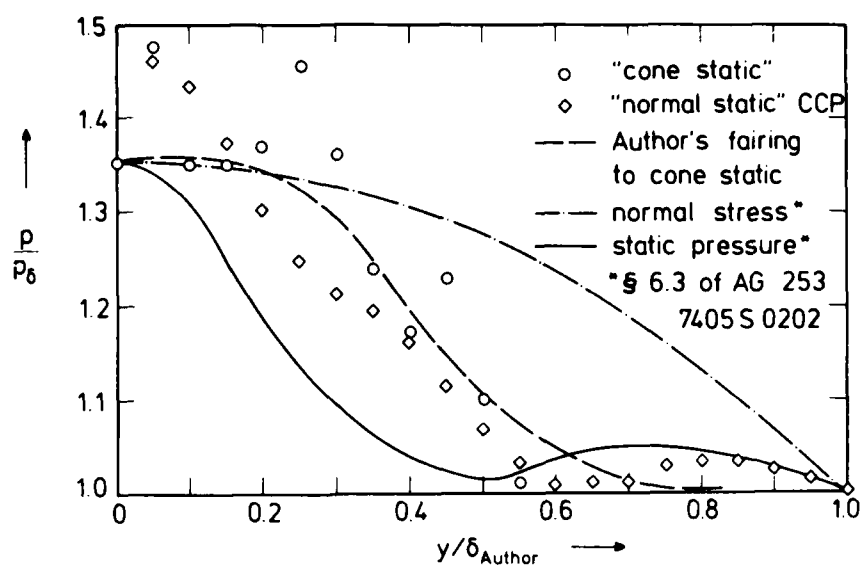


Fig. 4 Normal stress and static pressure profile 7405 S 0202. Experimental results from a "cone-static" probe (static holes on conical nose) and "normal" static probe (static holes on cylindrical surface behind nose).

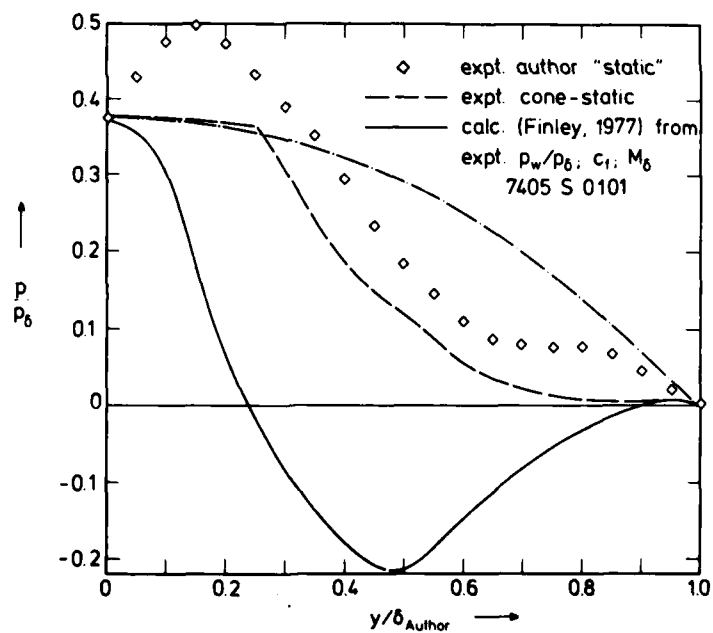


Fig. 5 Normal stress and static pressure profiles for profile 7405 S 0101.

CAT 7405S PETERSON

BOUNDARY CONDITIONS AND EVALUATED DATA, SI UNITS

RUN X *	MO * POD	TW/TR PW/PD	REDZW REDZO	CF * CQ	H12 H32	H12K H32K	PW TW*	PD*
RZ *	TOD	TAUM	DZ	PI2	H42	D2K	UD	TD*
7405S0101	13.3160	0.2406	9.6035"+02	6.9120"-04	8.1006	1.8954	3.5465"+01	2.5807"+01
1.9185"+00	7.9498"+06	1.3742	6.5038"+03	NM	1.7404	1.6651	2.9830"+02	3.7277"+01
-2.0240"-01	1.3792"+03	2.2475"+00	4.3884"-03	NM	1.5233	9.2537"-03	1.6689"+03	1.2396"+03
7405S0102	13.8800	0.2386	9.6514"+02	4.1990"-04	11.0708	2.0593	2.8000"+01	2.1078"+01
2.6603"+00	8.1868"+06	1.3284	6.9179"+03	NM	1.7359	1.6698	2.9780"+02	3.5129"+01
-2.3110"-01	1.3887"+03	1.1936"+00	5.0603"-03	NM	1.5325	1.2786"-02	1.6761"+03	1.2479"+03
7405S0201	13.6777	0.2410	1.4388"+03	4.6270"-04	10.7875	1.6957	8.2967"+01	5.7520"+01
1.9185"+00	2.0212"+07	1.4424	1.0125"+04	NM	1.7818	1.7344	2.9830"+02	3.5847"+01
-2.0240"-01	1.3771"+03	3.4853"+00	2.8375"-03	NM	1.5234	6.9525"-03	1.6685"+03	1.2376"+03
7405S0202	14.2247	0.2434	1.4508"+03	3.2630"-04	14.8048	1.7666	6.0219"+01	4.4358"+01
2.6603"+00	2.0370"+07	1.3576	1.1101"+04	NM	1.7871	1.7324	2.9780"+02	3.2837"+01
-2.3110"-01	1.3617"+03	2.0501"+00	3.4098"-03	NM	1.4739	1.0013"-02	1.6608"+03	1.2235"+03

CF: LINEAR PROFILE SKIN FRICTION ESTIMATE

7405S0101

PETERSON

PROFILE TABULATION

23 POINTS, DELTA AT POINT 21

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.37423	0.21629	0.00000	0.00000	8.00220	0.00000
2	4.2545"-03	4.4495"+00	1.42702	0.26374	0.13054	0.32104	6.04773	0.07575
3	8.5090"-03	1.0160"+01	1.47892	0.30791	0.20442	0.43600	4.54903	0.14175
4	1.2763"-02	1.7136"+01	1.49404	0.39804	0.26818	0.54324	4.10323	0.19780
5	1.7018"-02	2.5042"+01	1.47506	0.47683	0.32565	0.62317	3.66200	0.25101
6	2.1272"-02	3.3006"+01	1.43681	0.53144	0.37472	0.67527	3.24741	0.29877
7	2.5527"-02	4.1323"+01	1.39117	0.58421	0.41989	0.72021	2.94202	0.34056
8	2.9782"-02	5.0643"+01	1.34699	0.63453	0.46533	0.76026	2.66939	0.38363
9	3.4036"-02	6.2227"+01	1.29663	0.68531	0.51625	0.79866	2.39333	0.43269
10	3.8290"-02	7.7056"+01	1.23400	0.72872	0.57490	0.83120	2.09040	0.49067
11	4.2545"-02	9.2976"+01	1.18469	0.76548	0.63183	0.85765	1.84255	0.55144
12	4.6799"-02	1.1086"+02	1.14317	0.79697	0.69021	0.87976	1.62466	0.61903
13	5.1054"-02	1.3081"+02	1.10967	0.82142	0.74497	0.89694	1.43035	0.69585
14	5.5308"-02	1.4878"+02	1.08943	0.84777	0.80000	0.91382	1.30480	0.76299
15	5.9563"-02	1.6542"+02	1.08159	0.88266	0.84369	0.93440	1.22660	0.82394
16	6.3817"-02	1.8312"+02	1.07697	0.91460	0.88779	0.95289	1.15203	0.89081
17	6.8072"-02	1.9303"+02	1.07416	0.94166	0.91157	0.96774	1.12702	0.92234
18	7.2826"-02	2.0228"+02	1.06417	0.96444	0.93321	0.98010	1.10302	0.94558
19	7.6581"-02	2.1529"+02	1.04357	0.98233	0.96280	0.99007	1.05745	0.97707
20	8.0836"-02	2.2559"+02	1.02222	0.99439	0.98563	0.99679	1.02278	0.99624
21	8.5090"-02	2.3221"+02	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
22	8.9344"-02	2.3503"+02	0.97901	1.00414	1.00608	1.00223	0.99237	0.98873
23	9.3599"-02	2.3385"+02	0.96482	1.00961	1.00354	1.00489	1.00268	0.96695

INPUT VARIABLES Y,T/TD,M/MD,P/PD

7405S0102

PETERSON

PROFILE TABULATION

22 POINTS, DELTA AT POINT 21

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.32837	0.21445	0.00000	0.00000	8.47725	0.00000
2	6.3500"-03	2.5199"+00	1.34112	0.26446	0.08918	0.25228	8.00189	0.04228
3	1.2700"-02	7.5523"+00	1.39552	0.32482	0.16883	0.41765	6.11942	0.09524
4	1.9050"-02	1.5465"+01	1.36792	0.39788	0.24587	0.53440	4.72439	0.15473
5	2.5400"-02	2.4013"+01	1.30260	0.46387	0.30810	0.61134	3.93711	0.20226
6	3.1750"-02	3.2871"+01	1.23256	0.52032	0.36144	0.66734	3.40890	0.24129
7	3.8100"-02	4.3237"+01	1.18974	0.57416	0.41525	0.71554	2.96924	0.28671
8	4.4450"-02	5.4608"+01	1.16723	0.61764	0.46721	0.75255	2.59452	0.33856
9	5.0800"-02	6.8455"+01	1.13101	0.66510	0.52355	0.78952	2.27412	0.39266
10	5.7150"-02	8.4505"+01	1.09034	0.71427	0.58207	0.82503	2.00900	0.44777
11	6.3500"-02	1.0437"+02	1.04644	0.75811	0.64721	0.85581	1.74847	0.51219
12	6.9850"-02	1.2663"+02	1.00851	0.79659	0.71319	0.88181	1.52876	0.58173
13	7.6200"-02	1.4975"+02	0.98281	0.83706	0.77579	0.90735	1.36792	0.65190
14	8.2550"-02	1.7343"+02	0.96154	0.87170	0.83505	0.92856	1.23652	0.72207
15	8.8900"-02	2.0504"+02	0.93135	0.89940	0.90814	0.94583	1.08471	0.81210
16	9.5250"-02	2.2427"+02	0.93230	0.93417	0.94988	0.96521	1.03254	0.87151
17	1.0160"-01	2.3440"+02	0.96696	0.96614	0.97112	0.98217	1.02289	0.92847
18	1.0795"-01	2.3890"+02	0.96698	0.98799	0.98043	0.99070	1.02106	0.96734
19	1.1430"-01	2.4515"+02	1.01187	0.99142	0.99319	0.99548	1.00461	0.99276
20	1.2065"-01	2.4908"+02	0.96698	0.96614	1.00115	0.99826	0.99425	1.00137
21	1.2700"-01	2.4852"+02	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
22	1.3335"-01	2.4119"+02	1.02606	1.00217	0.98513	1.00070	1.03185	0.99508

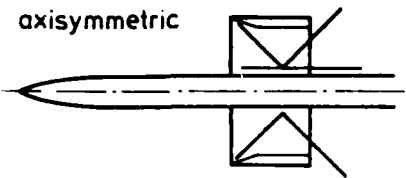
INPUT VARIABLES Y,T/TD,M/MD,P/PD

7405S0201		PETERSON		PROFILE TABULATION		26 POINTS, DELTA AT POINT 21		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	1.44242	0.21662	0.00000	0.00000	8.32158	0.00000
2	3.5560 ⁻ 03	6.8737 ⁺ 00	1.41029	0.33906	0.16287	0.41642	6.53703	0.08984
3	7.1120 ⁻ 03	1.7857 ⁺ 01	1.35402	0.46104	0.26868	0.58776	4.78560	0.16630
4	1.0668 ⁻ 02	2.6238 ⁺ 01	1.30621	0.53718	0.32710	0.66430	4.12452	0.21038
5	1.4224 ⁻ 02	3.3804 ⁺ 01	1.26338	0.58033	0.37203	0.70669	3.60820	0.24744
6	1.7780 ⁻ 02	4.1713 ⁺ 01	1.22276	0.62794	0.41382	0.74678	3.25661	0.28039
7	2.1336 ⁻ 02	5.1301 ⁺ 01	1.18397	0.67066	0.45941	0.78178	2.89585	0.31963
8	2.4892 ⁻ 02	6.1555 ⁺ 01	1.15267	0.70915	0.50361	0.81160	2.59712	0.36021
9	2.6448 ⁻ 02	7.3645 ⁺ 01	1.12568	0.74342	0.55120	0.83760	2.30918	0.40831
10	3.2004 ⁻ 02	8.7963 ⁺ 01	1.10408	0.77493	0.60271	0.86088	2.04017	0.46588
11	3.5560 ⁻ 02	1.0383 ⁺ 02	1.08870	0.80577	0.65509	0.88290	1.81479	0.52942
12	3.9116 ⁻ 02	1.2108 ⁺ 02	1.07597	0.83506	0.70763	0.90219	1.52546	0.59720
13	4.2672 ⁻ 02	1.3955 ⁺ 02	1.06391	0.86290	0.75988	0.92020	1.46646	0.66760
14	4.6228 ⁻ 02	1.5969 ⁺ 02	1.04706	0.89229	0.81305	0.93837	1.33204	0.73761
15	4.9784 ⁻ 02	1.8052 ⁺ 02	1.02867	0.92290	0.86458	0.95648	1.22389	0.80391
16	5.3340 ⁻ 02	1.9963 ⁺ 02	1.01856	0.95028	0.90931	0.97218	1.14305	0.86630
17	5.6896 ⁻ 02	2.1402 ⁺ 02	1.01877	0.97234	0.94159	0.98443	1.09308	0.91752
18	6.0452 ⁻ 02	2.2430 ⁺ 02	1.02085	0.98819	0.96399	0.99310	1.06130	0.95524
19	6.4008 ⁻ 02	2.3296 ⁺ 02	1.01819	0.99637	0.98246	0.99771	1.03130	0.98503
20	6.7564 ⁻ 02	2.3832 ⁺ 02	1.01001	0.99965	0.99372	0.99966	1.01199	0.99771
D 21	7.1120 ⁻ 02	2.4134 ⁺ 02	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
22	7.4676 ⁻ 02	2.4231 ⁺ 02	0.99973	0.99774	1.00201	0.99892	0.99383	1.00485
23	7.8232 ⁻ 02	2.4072 ⁺ 02	0.98391	0.99475	0.99872	0.99734	0.99723	0.98401
24	8.1788 ⁻ 02	2.3839 ⁺ 02	0.97246	0.99197	0.99387	0.99582	1.00393	0.96460
25	8.5344 ⁻ 02	2.3562 ⁺ 02	0.96069	0.98845	0.98806	0.99390	1.01186	0.94364
26	8.8900 ⁻ 02	2.3286 ⁺ 02	0.95093	0.98407	0.98224	0.99153	1.01901	0.92529

INPUT VARIABLES Y,T/TD,M/MD,P/PD

7405S0202		PETERSON		PROFILE TABULATION		21 POINTS, DELTA AT POINT 21		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	1.35757	0.21869	0.00000	0.00000	9.06896	0.00000
2	5.5880 ⁻ 03	5.3734 ⁺ 00	1.46134	0.33955	0.13688	0.38736	8.00838	0.07068
3	1.1176 ⁻ 02	1.3761 ⁺ 01	1.43604	0.47500	0.22585	0.57262	6.42818	0.12792
4	1.6764 ⁻ 02	2.1619 ⁺ 01	1.37258	0.56068	0.28494	0.66368	5.42530	0.16791
5	2.2352 ⁻ 02	2.9491 ⁺ 01	1.30226	0.62129	0.33379	0.72186	4.67698	0.20099
6	2.7940 ⁻ 02	3.6316 ⁺ 01	1.24487	0.67493	0.37096	0.76572	4.26062	0.22373
7	3.3528 ⁻ 02	4.5996 ⁺ 01	1.21507	0.70971	0.41805	0.79822	3.64572	0.26604
8	3.9116 ⁻ 02	5.6524 ⁺ 01	1.19506	0.74231	0.46388	0.82601	3.17079	0.31132
9	4.4704 ⁻ 02	7.0750 ⁺ 01	1.16107	0.77526	0.51941	0.85309	2.69750	0.36719
10	5.0292 ⁻ 02	8.9392 ⁺ 01	1.11353	0.80051	0.58425	0.87460	2.24090	0.43460
11	5.5880 ⁻ 02	1.0982 ⁺ 02	1.06611	0.82335	0.64790	0.89263	1.89815	0.50135
12	6.1468 ⁻ 02	1.3138 ⁺ 02	1.03167	0.85585	0.70889	0.91427	1.66339	0.56705
13	6.7056 ⁻ 02	1.5606 ⁺ 02	1.00620	0.89030	0.77282	0.93598	1.46682	0.64206
14	7.2644 ⁻ 02	1.7686 ⁺ 02	1.00601	0.91601	0.82284	0.95163	1.33752	0.71576
15	7.8232 ⁻ 02	1.9766 ⁺ 02	1.01068	0.94430	0.87000	0.96801	1.23800	0.79027
16	8.3820 ⁻ 02	2.0968 ⁺ 02	1.02680	0.96152	0.89614	0.97768	1.19028	0.84340
17	8.9408 ⁻ 02	2.2312 ⁺ 02	1.03609	0.97228	0.92447	0.98402	1.13299	0.89986
18	9.4996 ⁻ 02	2.3627 ⁺ 02	1.03380	0.97918	0.95137	0.98829	1.07911	0.94679
19	1.0058 ⁻ 01	2.4796 ⁺ 02	1.02570	0.98535	0.97467	0.99202	1.03590	0.98225
20	1.0617 ⁻ 01	2.5603 ⁺ 02	1.01521	0.99294	0.99043	0.99623	1.01175	0.99965
D 21	1.1176 ⁻ 01	2.6099 ⁺ 02	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,T/TD,M/MD,P/PD

	M: 7.2 (Free-stream) R THETA $\times 10^{-3}$: 8.5 (Initially) TW/TR: 0.5	7501
		VPG-SBLI SHT
Blowdown axisymmetric wind tunnel. Useful running time 3 minutes, D = 1.07 m. PO: 3.5 MN/m ² TO: 695K. Air, dew point 205K. RE/m $\times 10^{-6}$: 11 (Free-stream).		
KUSSOY M.I., HORSTMAN C.C., 1975. An experimental documentation of a hypersonic shock-wave turbulent boundary layer interaction flow - with and without separation. NASA TMX 62,412. And: Horstman, C.C., private communications, Mikulla, V., private communications, Mikulla and Horstman (1976), Marvin et al. (1975).		

- 1 The test boundary layer was formed on a 10° semi-apex angle cone-ogive-cylinder 3.30 m long and 203 mm in diameter with a shoulder fairing radius of 810 mm. The model was mounted on the centreline of the tunnel, and is generally similar to that used by Horstman and Owen (CAT 7205) save that provision was made for active cooling, which would maintain a constant surface temperature of 300K $\pm$ 5K during a run. An annular shock generator, outside diameter 0.51, inside diameter 0.46 m, was mounted coaxially with the model and could be traversed in the axial direction. Two deflection angles, 7.5° and 15° (series 01 and 02) were used, and the shock waves produced were followed closely by an expansion. Measurements were made at different stations in relation to the wave structure by traversing the shock generator, so moving the wave pattern over instruments at fixed stations in the rear part of the model. The undisturbed boundary layer thickness at shock impingement point increased by about 10% as the shock structure was moved from the foremost to the rear-most position used. The X-coordinate is measured from the leading edge of the shock generator. The test region extended from X = 0.42 to 0.95 m for series 01 and X = 0.20 to 0.95 m for series 02.
- 2 The empty-tunnel inviscid flow test-core was 0.7 m in diameter and in this region small disturbances were less than ± 0.05 in Mach number and $\pm 3\%$ in total temperature. There was an axial Mach number gradient less than 0.12/m, while free-stream turbulence fluctuations were less than 0.83% in TO and 2.7% in specific mass flow. For the stronger shock case, in which there was a small separation region, some unsteadiness of the flow was observed. Run to run variations in reservoir pressure were less than 0.5%, but TO varied by 50K during a run and from run to run. Natural transition occurred between 0.4 and 0.8 m from the model nose. The results of Horstman and Owen (CAT 7205) suggest that the initial test layer is a fully relaxed equilibrium constant pressure turbulent boundary layer. (AGARDograph 253, Figs. 4.3.5/6). Variations in surface pressure and wall shear stress around the model were measured at selected axial positions, and were less than the accuracy of measurement. Oil flow observations were also completely symmetrical.
- 6 Static pressure tappings (D = 1.6 mm) were located along the surface as well as in several instrumentation ports. TW was measured by thermocouples attached to the inside of the model skin every 50 mm. Heat transfer at the wall was determined in runs for which the cooling system was disconnected, using the thin wall transient technique with specially constructed instrumentation ports. Skin friction was measured using a Kistler FEB with the element (d = 9.5 mm) machined to the outside contour of the model. Buoyancy corrections were applied for forces induced by the longitudinal pressure gradients. Static calibrations, and electrical self-calibrations before and after each run, were repeatable to within 5%.
- 7 Pitot, static pressure and TO profiles were measured using a traverse gear with a Y-resolution of 3 μ m. The Pitot probes were FPP. The first type was used for measurements outside the separation region, a full size version in the outer part of the layer and a half size version near the wall. For the full size FPP, $h_1 = 0.46$, $h_2 = 0.26$, $b_1 = 2.0$, $b_2 = 1.8$ mm. Over a length of 10 mm the section changed to a circular tube ($d_1 = 1.6$, $d_2 = 1.3$ mm). This section continued to a point about 35 mm back from the

tip, when the tube was by stages faired into a body 6 mm in diameter, mounted on a triangular strut 70 mm back from the tip. The tube was cranked about 10 mm towards the test surface. The second type had the same tip structure save that the change of section from tip to circular tube took place in 2 mm and it was attached to a 3 mm strut 5 mm back from the tip. This probe was used facing both ways in the separated zone.

Two static pressure tubes were used, both CCP with 10° half angle tips geometrically similar to those of Behrens (1963). The larger was made from 1.07 mm tube with 3 orifices ($d = 0.36$ mm) at 120° intervals 13.7 mm from the tip. The tube continued to a point 28.9 mm from the tip before increasing section to enter the same type of support as the Pitot tube, the strut being 80 mm back from the tip. A small tube was used in the separation region, facing both ways. For this the tube diameter was 0.71 mm, with 3 0.23 mm orifices 9.1 mm back from the tip. The support was of 3 mm diameter 26 mm back from the tip.

Two TTP were used, both FWP following Vas (1972). In these the sensor was a chromel-alumel thermocouple formed as a butt weld in a wire 70 μ m in diameter. An auxiliary junction is formed at one end of the wire to allow for temperature correction due to conduction along the support prongs, 10 mm long and 0.51 mm in diameter. For the longer probe, the prongs were predominantly in the stream direction and mounted on a streamwise tube 4 mm in diameter and 53 mm long. The cross section then increased gradually to a 8 mm diameter body mounted on a 20° , 6 mm wide wedge about 85 mm back from the tip. For the small probe used in the separated region, the sensor, again on prongs 10 mm long, was mounted vertically on a tube 4 mm in diameter.

- 8 Measurements were made at ports 1.6, 1.85, 2.1 and 2.35 m from the model tip. All other positions are stated relative to the leading edge of the shock generator.
- 9 The data presented are the mean of many runs, with in many cases more than one survey for each type of measurement. The data have been interpolated to chosen X and Y values by the authors, who show, graphically, the scatter in selected wall data. The reservoir total temperature variations both during a run and from run to run were eliminated by a normalisation procedure in which for every relevant datum it was assumed that $(T_0 - T_W)/(T_{0D} - T_W)$ was a function of position only. Run to run variations in
- 10 normalised data were less than 5%. Wall heat transfer data errors due to longitudinal conduction were calculated to be less than 5% and no corrections were applied. The Pitot tubes were calibrated in a free jet, matching Mach number, velocity and density and the correction factors indicated were below 1% and so ignored. The static probes were also calibrated for viscous interaction effects, the correction factors agreeing with those of Behrens (1963). The greatest corrections applied were 6% in the low pressure (upstream) region and 2% downstream of the shock interaction. The total temperature probe readings were corrected following the method of Vas (1972). Radiation corrections were found to be negligible, while an independent calibration indicated a maximum corrected T_0 error of 1.5%. All data reduction procedures took account of the caloric imperfections of air.
- 7 Turbulence measurements were made at four X values for each wave structure by Mikulla and Horstman (1976). The probes consisted of 10 μ m wires mounted on the leading edge of slender wedges made from a refractory ceramic. The probes used correspond to two 45° inclined wires running back from a common apex with an overall width of 3.5 mm. A description is given in Mikulla and Horstman (1975). The probes are operated in the constant temperature mode and yield values for both the turbulent intensities and the Reynolds shear stress.
- 12 The authors note that "the choice of a boundary layer thickness for these types of interaction flows is rather arbitrary" and the editors agree (see AGARDograph 253 §7.1). The authors have set their 'D' point to the maximum PT2 reading where possible, and in the downstream region where PT2 continually increases, when the local Mach number profile no longer showed curvature. We have accepted the data as presented by the authors. There are two sets of profiles, at 19 stations for
- 13 the weaker shock (01) and 18 stations for the strong shock (02). The fluctuation profiles (V. Mikulla,

- 14 private communication) are tabulated in section D, as are the complete wall measurement data. The profile tables use CF values as corrected for buoyancy effects. The uncorrected values are also given in section D. The balance was not cooled so it may be that further correction is called for. (See Voisinnet, 1977.)
- § DATA: 75010101-0213. Pitot, static pressure and TO profiles. NX = 19, 18. CQ by thin wall technique. CF from FEB. Fluctuation profiles (NX = 4).
- 15 Editors' comments. These flows are reported in great detail with exceptionally complete instrumentation, and provide obvious test cases for advanced calculation methods. Turbulence levels are very high, and further unsteadiness in the strong shock case (series 02) arises from the "large excursions" of the separation and reattachment points. The authors estimate the range of movement to have a length scale of about 15 mm, and report that the frequency of the unsteadiness was confined to a narrow band around 15 kHz (Horstman and Owen, 1974). Some question therefore arises as to whether a calculation method should lump together fluctuations from this cause and more random conventional turbulence. (The power spectra obtained by Mikulla and Horstman, 1976, show pronounced peaks at 10, 15, 25 kHz.) We must also express some reservations as to the accuracy of the static pressure profiles. While it is possible to calibrate a probe in steady flow with the appropriate mean flow conditions, the response of such probes to flows with a large fluctuating component is largely unknown. A static probe is also very likely to give dubious readings when any part of it is intersected by a shock wave. We would therefore feel that the measurements, which are very welcome, do not necessarily present a picture of the static pressure field which is accurate to the calibration accuracy of the probes, and would not be surprised if discrepancies were to be found in comparisons with calculations - the defect may lie in the measurements rather than the calculations.

The boundary layer is fairly thick compared to the body (δ/R_z up to 0.2) but such information as we have from extreme cases (Richmond, CAT 5701S) suggests that the effect of transverse curvature here will be negligible. As remarked above, the large variations of pressure in the Y direction make it very difficult to decide upon a value for δ . By the same token (see §§6,7, of AGARDograph 253) it is difficult to choose a D-state with any relevance, the D-state values here being arbitrary scaling quantities. Though it would be possible to calculate a proper displacement thickness, it would be very difficult. The conventionally defined D1, D2 etc. presented here and by the authors have no meaning, are critically dependent on the choice of D-point, and should be disregarded.

Comparisons should be made with the undisturbed flow on the same body, Horstman and Owen (CAT 7205) and with the APG and SBLI cases of Kussoy et al. (CAT 7802S) and Rose (CAT 7306S). Neither experiment is on the same large scale as this one (Rose working with a very small rig). In both cases the test layer is on the inner surface of a cylindrical test section, with the wave pattern produced by a centre-body.

CAT 75015

KUSSQY/HORSTMAN

BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS

RUN X * RZ *	MD * POD TOD*	TW/TR PW/PO TAUM *	RED2W RED2D DZ	CF CQ * PIZ	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD* TD TR
750150101	6.7020	0.4762	2.2530**+03	8.7503**+04	13.1371	1.3904	6.0700**+02	6.0700**+02
4.2000**+01	1.9083**+06	1.0000	8.3567**+03	2.6241**+04	1.8119	1.7577	3.0000**+02	6.9616**+01
1.0150**+01	6.9500**+02	1.6700**+01	1.2256**+03	NC	0.6038	3.2540**+03	1.1212**+03	6.2996**+02
750150102	6.7150	0.4762	2.2954**+03	8.7164**+04	12.9841	1.3733	6.0700**+02	6.0700**+02
4.4000**+01	1.9318**+06	1.0000	8.5435**+03	2.6647**+04	1.8182	1.7653	3.0000**+02	6.9373**+01
1.0150**+01	6.9500**+02	1.6700**+01	1.2440**+03	NC	0.6145	3.2073**+03	1.1214**+03	6.2993**+02
750150103	5.7380	0.4769	1.9401**+03	1.1422**+03	11.0585	1.3978	6.2096**+02	6.7620**+02
4.6000**+01	8.1265**+05	0.9183	5.5139**+03	3.5701**+04	1.8041	1.7571	3.0000**+02	9.1171**+01
1.0150**+01	6.9153**+02	1.7800**+01	1.2663**+03	NC	0.6919	3.0329**+03	1.0985**+03	6.2909**+02
750150104	4.5590	0.4712	1.9088**+03	9.0744**+04	5.9104	1.7579	7.5875**+02	6.9684**+02
4.8000**+01	2.1702**+05	1.0889	2.9630**+03	6.8033**+04	1.7102	1.6573	3.0000**+02	1.3477**+02
1.0150**+01	6.9500**+02	9.2000**+00	1.4623**+03	NC	0.6083	2.5105**+03	1.0612**+03	6.3674**+02
750150105	3.8980	0.4749	2.5612**+03	6.6604**+04	10.5079	2.1091	1.5175**+03	2.4280**+03
5.0000**+01	3.2149**+05	0.6250	4.0927**+03	4.7223**+04	1.6554	1.5639	3.0000**+02	1.6967**+02
1.0150**+01	6.8527**+02	1.7200**+01	9.3489**+04	NC	0.4384	2.5993**+03	1.0180**+02	6.3165**+02
750150106	4.0960	0.4740	2.9117**+03	2.0187**+03	6.4282	2.0143	2.8280**+03	2.0626**+03
5.2000**+01	3.5565**+05	1.3711	4.9550**+03	8.3193**+04	1.6156	1.5777	3.0000**+02	1.5797**+02
1.0150**+01	6.8805**+02	4.8900**+01	1.1489**+03	NC	0.3663	2.1320**+03	1.0322**+03	6.3292**+02
750150107	4.8280	0.4721	3.9313**+03	1.6594**+03	5.8255	1.6994	4.0353**+03	2.4486**+03
5.4000**+01	1.0575**+06	1.6480	8.4158**+03	6.6871**+04	1.6711	1.6387	3.0000**+02	1.2275**+02
1.0150**+01	6.9500**+02	6.6300**+01	9.7716**+04	NC	0.2855	1.7997**+03	1.0725**+03	6.3549**+02
750150108	4.7130	0.4717	4.6423**+03	1.2373**+03	7.5157	1.6240	4.7455**+03	3.6906**+03
5.6000**+01	1.3880**+06	1.2859	9.5799**+03	5.2619**+04	1.6963	1.6638	3.0000**+02	1.2770**+02
1.0150**+01	6.9500**+02	7.1000**+01	7.9991**+04	NC	0.2826	1.7073**+03	1.0678**+03	6.3600**+02
750150109	4.7910	0.4720	4.8616**+03	1.1160**+03	8.1679	1.5883	4.8700**+03	3.9315**+03
5.8000**+01	1.6244**+06	1.2387	1.0286**+04	4.8912**+04	1.7162	1.6806	3.0000**+02	1.2431**+02
1.0150**+01	6.9500**+02	7.0500**+01	7.6323**+04	NC	0.2924	1.6952**+03	1.0710**+03	6.3565**+02
750150110	4.8380	0.4721	4.6335**+03	1.2193**+03	7.2766	1.5350	4.5525**+03	3.4490**+03
6.0000**+01	1.5075**+06	1.3200	9.9505**+03	5.2869**+04	1.7384	1.7043	3.0000**+02	1.2233**+02
1.0150**+01	6.9500**+02	6.8900**+01	8.1458**+04	NC	0.3344	1.6626**+03	1.0729**+03	6.3544**+02
750150111	4.9750	0.4725	4.4209**+03	1.1882**+03	8.4340	1.4851	4.0699**+03	3.3179**+03
6.2000**+01	1.7049**+06	1.2267	9.9133**+03	4.9404**+04	1.7627	1.7282	3.0000**+02	1.1680**+02
1.0150**+01	6.9500**+02	6.8300**+01	7.6771**+04	NC	0.3304	1.6424**+03	1.0780**+03	6.3487**+02
750150112	5.0640	0.4728	4.1428**+03	1.1781**+03	9.3733	1.4159	3.6420**+03	3.1728**+03
6.4000**+01	1.8083**+06	1.1479	9.5518**+03	4.6476**+04	1.7952	1.7628	3.0000**+02	1.1340**+02
1.0150**+01	6.9500**+02	6.7100**+01	7.2823**+04	NC	0.2923	1.5742**+03	1.0812**+03	6.3451**+02
750150113	5.2890	0.4734	4.3060**+03	1.1792**+03	9.0691	1.3840	3.2766**+03	2.8280**+03
6.6000**+01	2.0829**+06	1.1586	1.0643**+04	4.4751**+04	1.8087	1.7768	3.0000**+02	1.0539**+02
1.0150**+01	6.9500**+02	6.5300**+01	7.8384**+04	NC	0.4036	1.6353**+03	1.0886**+03	6.3368**+02
750150114	5.1860	0.4731	4.1721**+03	1.1980**+03	9.1732	1.3399	2.9798**+03	2.7934**+03
6.8000**+01	1.8313**+06	1.0667	9.9905**+03	4.3582**+04	1.8278	1.8001	3.0000**+02	1.0895**+02
1.0150**+01	6.9500**+02	6.3000**+01	7.9728**+04	NC	0.3989	1.6065**+03	1.0853**+03	6.3405**+02
750150115	5.2400	0.4733	4.0886**+03	1.2271**+03	9.2379	1.3166	2.6969**+03	2.5524**+03
7.0000**+01	1.7790**+06	1.0566	9.9546**+03	4.3780**+04	1.8403	1.8128	3.0000**+02	1.0706**+02
1.0150**+01	6.9500**+02	6.0200**+01	8.3890**+04	NC	0.3917	1.6512**+03	1.0871**+03	6.3385**+02
750150116	5.3950	0.4737	4.3805**+03	1.2129**+03	8.6321	1.2993	2.3108**+03	2.1731**+03
7.4000**+01	1.8013**+06	1.0634	1.1182**+04	4.1310**+04	1.8453	1.8173	3.0000**+02	1.0189**+02
1.0150**+01	6.9500**+02	5.3700**+01	1.0003**+03	NC	0.5346	1.8720**+03	1.0919**+03	6.3332**+02
750150117	5.5310	0.4740	4.1840**+03	1.1752**+03	9.2110	1.2927	1.9454**+03	1.8556**+03
7.8000**+01	1.7858**+06	1.0484	1.1128**+04	3.9875**+04	1.8551	1.8236	3.0000**+02	9.7634**+01
1.0150**+01	6.9500**+02	4.6700**+01	1.0683**+03	NC	0.5359	1.9833**+03	1.0958**+03	6.3287**+02
750150118	5.6830	0.4744	3.9713**+03	NM	9.9948	1.2608	1.6626**+03	1.5794**+03
8.2000**+01	1.7904**+06	1.0527	1.1051**+04	3.8808**+04	1.8655	1.8371	3.0000**+02	9.3172**+01
1.0150**+01	6.9500**+02	NM	1.1327**+03	NC	0.4630	2.0965**+03	1.0998**+03	6.3241**+02
750150119	5.8220	0.4747	3.6746**+03	NM	10.5825	1.2664	1.3864**+03	1.3451**+03
8.6000**+01	1.7661**+06	1.0307	1.0652**+04	3.7369**+04	1.8731	1.8382	3.0000**+02	8.9342**+01
1.0150**+01	6.9500**+02	NM	1.1763**+03	NC	0.4898	2.1875**+03	1.1033**+03	6.3201**+02

CAT 75015 KUSSOY/HORSTMAN BOUNDARY CONDITIONS AND EVALUATED DATA, SI UNITS									
RUN X * RZ *	MD * POD TOD*	TW/TR PW/PO TAUM *	RED2W RED2D DZ	CF CQ * PIZ	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD* TD TR	
7501S0201	6.8420	0.4764	1.8052**03	8.3958**04	13.8716	1.3581	6.0700**02	6.0700**02	
2.0000**01	2.1743**06	1.0000	6.9499**03	2.5229**04	1.8228	1.7746	3.0000**02	6.7068**01	
1.0150**01	6.9500**02	1.6700**01	9.4408**04	NC	0.5880	2.5057**03	1.1234**03	6.2970**02	
7501S0202	6.8450	0.4764	2.0261**03	8.7401**04	12.2146	1.3576	6.2096**02	6.0700**02	
2.5500**01	2.1804**06	1.0230	7.8069**03	2.8440**04	1.8229	1.7759	3.0000**02	6.7015**01	
1.0150**01	6.9500**02	1.7400**01	1.0588**03	NC	0.7306	2.6115**03	1.1235**03	6.2969**02	
7501S0203	6.8580	0.4764	2.3236**03	5.8047**04	10.3829	1.6101	1.0483**03	6.0700**02	
2.8000**01	2.2067**06	1.7270	8.9836**03	3.6549**04	1.7571	1.7080	3.0000**02	6.6786**01	
1.0150**01	6.9500**02	1.1600**01	1.2098**03	NC	0.5868	2.6647**03	1.1237**03	6.2967**02	
7501S0204	4.8470	0.4721	5.6237**03	2.1727**04	20.3135	2.1519	1.9454**03	3.4144**03	
3.0500**01	1.5084**06	0.5698	1.2111**04	1.7650**04	1.7000	1.6085	3.0000**02	1.2196**02	
1.0150**01	6.9500**02	1.2200**01	9.9529**04	NC	0.4018	4.0501**03	1.0732**03	6.3540**02	
7501S0205	4.0130	0.4689	3.3293**03	NM	44.8998	4.0966	2.3315**03	6.8979**03	
3.3000**01	1.0656**06	0.3380	5.4618**03	2.3192**04	1.4831	1.4129	3.0000**02	1.6466**02	
1.0150**01	6.9500**02	NM	4.0932**04	NC	0.5818	2.8673**03	1.0325**03	6.3984**02	
7501S0206	5.2030	0.4732	3.9812**03	7.1324**04	8.8031	2.1581	2.7588**03	2.0347**03	
3.5500**01	1.3599**06	1.3559	9.5834**03	8.0442**04	1.6393	1.5612	3.0000**02	1.0835**02	
1.0150**01	6.9500**02	2.7500**01	1.0382**03	NC	0.3051	2.4345**03	1.0859**03	6.3399**02	
7501S0207	5.0990	0.4734	4.3133**03	1.6753**03	2.3293	1.6541	3.4764**03	1.9120**03	
3.8000**01	1.1346**06	1.8181	1.0063**04	1.1317**03	1.7129	1.6568	3.0000**02	1.1199**02	
1.0150**01	6.9430**02	5.8300**01	1.2417**03	NC	0.6884	1.8119**03	1.0819**03	6.3374**02	
7501S0208	4.9920	0.4712	4.4114**03	1.4535**03	5.2666	1.6100	5.1182**03	2.9658**03	
4.0000**01	1.5546**06	1.7257	9.9170**03	8.1071**04	1.7052	1.6731	3.0000**02	1.1649**02	
1.0150**01	6.9708**02	7.5200**01	8.5293**04	NC	0.1845	1.5796**03	1.0803**03	6.3670**02	
7501S0209	4.6410	0.4686	4.5410**03	2.0611**03	0.7294	1.5711	5.7252**03	2.6902**03	
4.2500**01	9.2679**05	2.1282	9.1066**03	1.0211**03	1.7073	1.6876	3.0000**02	1.3173**02	
1.0150**01	6.9917**02	8.3600**01	1.1071**03	NC	0.1049	1.4984**03	1.0680**03	6.4016**02	
7501S0210	4.6210	0.4714	4.7591**03	1.4661**03	5.8190	1.3952	5.4490**03	3.8969**03	
4.5000**01	1.3100**06	1.3983	9.5351**03	6.8904**04	1.7997	1.7756	3.0000**02	1.3186**02	
1.0150**01	6.9500**02	8.5400**01	8.0488**04	NC	0.0973	1.4004**03	1.0637**03	6.3643**02	
7501S0211	4.5570	0.4711	4.6063**03	1.5014**03	6.7441	1.2741	4.3042**03	3.7525**03	
5.0000**01	1.1657**06	1.1470	9.0402**03	6.3219**04	1.8704	1.8557	3.0000**02	1.3487**02	
1.0150**01	6.9500**02	8.1900**01	8.2969**04	NC	0.2586	1.3064**03	1.0611**03	6.3675**02	
7501S0212	4.6490	0.4715	4.2820**03	1.5642**03	6.7359	1.2488	3.2559**03	2.9452**03	
5.5000**01	1.0246**06	1.1055	8.6570**03	6.1774**04	1.8848	1.8719	3.0000**02	1.3057**02	
1.0150**01	6.9500**02	6.9700**01	9.4780**04	NC	0.3806	1.3803**03	1.0651**03	6.3630**02	
7501S0213	4.9040	0.4723	3.8810**03	1.4843**03	7.1190	1.2411	2.4832**03	2.1731**03	
6.0000**01	1.0272**06	1.1427	8.5104**03	5.8502**04	1.8818	1.8654	3.0000**02	1.1962**02	
1.0150**01	6.9500**02	5.4300**01	1.0564**03	NC	0.2991	1.6012**03	1.0754**03	6.3516**02	
7501S0214	5.1400	0.4730	3.2202**03	1.4257**03	8.7740	1.2318	1.8556**03	1.7105**03	
6.5000**01	1.0640**06	1.0848	7.6021**03	5.3711**04	1.8918	1.8725	3.0000**02	1.1060**02	
1.0150**01	6.9500**02	4.5100**01	1.0216**03	NC	0.2796	1.6263**03	1.0838**03	6.3422**02	
7501S0215	5.1700	0.4731	2.4934**03	1.5032**03	8.8218	1.2306	1.4902**03	1.3724**03	
7.0000**01	8.8346**05	1.0858	5.9412**03	5.4133**04	1.9011	1.8817	3.0000**02	1.0952**02	
1.0150**01	6.9500**02	3.8600**01	9.7536**04	NC	0.2865	1.4882**03	1.0848**03	6.3411**02	
7501S0216	5.2300	0.4733	2.0822**03	1.5949**03	8.4965	1.2451	1.2140**03	1.1035**03	
7.5000**01	7.6047**05	1.1001	5.0541**03	5.5597**04	1.9013	1.8755	3.0000**02	1.0741**02	
1.0150**01	6.9500**02	3.3700**01	9.9167**04	NC	0.2616	1.4916**03	1.0868**03	6.3389**02	
7501S0217	5.1420	0.4730	1.6293**03	1.7597**03	9.2792	1.2580	8.3462**02	8.4130**02	
8.5000**01	5.2451**05	0.9921	3.8489**03	5.2819**04	1.8859	1.8574	3.0000**02	1.1053**02	
1.0150**01	6.9500**02	2.7400**01	1.0502**03	NC	0.4675	1.7054**03	1.0839**03	6.3421**02	
7501S0218	5.1250	0.4730	1.3330**03	2.0451**03	7.6163	1.2755	6.8955**02	6.2764**02	
9.5000**01	3.8375**05	1.0986	3.1324**03	5.7188**04	1.8754	1.8464	3.0000**02	1.1114**02	
1.0150**01	6.9500**02	2.3600**01	1.1587**03	NC	0.4430	1.7756**03	1.0833**03	6.3428**02	

TAUM(C), TABLE 3.4 - TAUM(0205) NOT USED (NEGATIVE)

7501S0201		KUSSOY/HORSTMAN		PROFILE TABULATION		44 POINTS, DELTA AT POINT 36		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	1.00000	0.43200	0.00000	0.00000	4.47664	0.00000
2	5.0000-04	3.4246+00	1.00000	0.64800	0.21967	0.47244	4.62326	0.10214
3	7.5000-04	4.5646+00	1.00000	0.69300	0.25972	0.54489	4.40152	0.12380
4	1.0000-03	5.7072+00	1.00000	0.73300	0.29421	0.60264	4.19556	0.14364
5	1.2500-03	6.3937+00	1.00000	0.77800	0.31307	0.64192	4.20419	0.15268
6	1.5000-03	7.0771+00	1.00000	0.79600	0.33075	0.66767	4.07494	0.16385
7	1.7500-03	7.5319+00	1.00000	0.80700	0.34201	0.68328	3.99147	0.17119
8	2.0000-03	8.1079+00	1.00000	0.81300	0.35574	0.69856	3.85597	0.18116
9	2.5000-03	8.7916+00	1.00000	0.82400	0.37138	0.71693	3.72655	0.19238
10	3.0000-03	9.3626+00	1.00000	0.83200	0.38395	0.73074	3.62221	0.20174
11	3.5000-03	1.0044+01	1.00000	0.83800	0.39842	0.74461	3.49280	0.21318
12	4.0000-03	1.0620+01	1.00000	0.84700	0.41026	0.75731	3.40746	0.22225
13	4.5000-03	1.0962+01	1.00000	0.85500	0.41713	0.76575	3.37003	0.22722
14	5.0000-03	1.1754+01	1.00000	0.86100	0.43262	0.77892	3.24170	0.24028
15	6.0000-03	1.2782+01	1.00000	0.87500	0.45191	0.79743	3.11366	0.25611
16	7.0000-03	1.4272+01	1.00000	0.88400	0.47852	0.81682	2.91383	0.28033
17	8.0000-03	1.5866+01	1.00000	0.89500	0.50541	0.83577	2.73459	0.30563
18	9.0000-03	1.7472+01	1.00000	0.90600	0.53113	0.85286	2.57842	0.33077
19	1.0000-02	1.9178+01	1.00000	0.91600	0.55715	0.86850	2.42997	0.35741
20	1.1000-02	2.1006+01	1.00000	0.92600	0.58375	0.88336	2.28994	0.38576
21	1.2000-02	2.3060+01	1.00000	0.93500	0.61225	0.89743	2.14856	0.41769
22	1.3000-02	2.5348+01	1.00000	0.94400	0.64250	0.91108	2.01076	0.45310
23	1.4000-02	2.7746+01	1.00000	0.95500	0.67276	0.92476	1.88950	0.48942
24	1.5000-02	3.0366+01	1.00000	0.96500	0.70433	0.93747	1.77160	0.52916
25	1.6000-02	3.3106+01	1.00000	0.97500	0.73590	0.94940	1.66443	0.57040
26	1.7000-02	3.6536+01	1.00000	0.98000	0.77360	0.95938	1.53795	0.62380
27	1.8000-02	3.9497+01	1.00000	0.98600	0.80474	0.96789	1.44658	0.66909
28	1.9000-02	4.2811+01	1.00000	0.99100	0.83821	0.97576	1.35514	0.72004
29	2.0000-02	4.6584+01	1.00000	0.99400	0.87474	0.98255	1.26168	0.77876
30	2.1000-02	4.9765+01	1.00000	0.99700	0.90441	0.98795	1.19325	0.82794
31	2.2000-02	5.2511+01	1.00000	0.99900	0.92926	0.99196	1.13951	0.87052
32	2.3000-02	5.5248+01	1.00000	1.00000	0.95338	0.99520	1.08966	0.91331
33	2.4000-02	5.7077+01	1.00000	1.00000	0.96916	0.99689	1.05805	0.94220
34	2.5000-02	5.8676+01	1.00000	1.00000	0.98275	0.99830	1.03188	0.96745
35	2.6000-02	5.9807+01	1.00000	1.00000	0.99225	0.99924	1.01414	0.98531
D 36	2.7000-02	6.0737+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
37	2.8000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
38	2.9000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
39	3.0000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
40	3.1000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
41	3.2000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
42	3.3000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
43	3.4000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529
44	3.5000-02	6.1072+01	1.00000	1.00000	1.00278	1.00027	0.99500	1.00529

INPUT VARIABLES Y,M,P/PINF,TO/TOINF

7501S0203		KUSSOY/HDRSTMAN		PROFILE TABULATION		44 POINTS, DELTA AT POINT 37		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	1.72700	0.43200	0.00000	0.00000	4.49558	0.00000
2	5.0000-04	1.3250+00	1.71600	0.54000	0.09434	0.21483	5.18535	0.07109
3	7.5000-04	1.5335+00	1.70500	0.58000	0.11753	0.27163	5.34170	0.08670
4	1.0000-03	1.8667+00	1.70500	0.61700	0.14407	0.33391	5.37200	0.10598
5	1.2500-03	2.2145+00	1.69300	0.65400	0.16492	0.38392	5.41936	0.11994
6	1.5000-03	2.5690+00	1.68200	0.69300	0.18285	0.42829	5.48622	0.13131
7	1.7500-03	3.1305+00	1.67000	0.72700	0.20749	0.48149	5.38474	0.14933
8	2.0000-03	3.7686+00	1.65900	0.74700	0.23199	0.52703	5.16088	0.16942
9	2.5000-03	4.8271+00	1.64800	0.76700	0.26742	0.58417	4.77173	0.20175
10	3.0000-03	5.5945+00	1.62500	0.78200	0.29032	0.61853	4.53913	0.22143
11	3.5000-03	6.3827+00	1.60200	0.79600	0.31204	0.64884	4.32352	0.24041
12	4.0000-03	6.9788+00	1.58000	0.80700	0.32750	0.66961	4.18039	0.25308
13	4.5000-03	7.7376+00	1.55700	0.81800	0.34617	0.69248	4.00177	0.26943
14	5.0000-03	8.5905+00	1.53400	0.82800	0.36600	0.71464	3.81259	0.28754
15	6.0000-03	1.0383+01	1.47700	0.84700	0.40449	0.75365	3.47152	0.32065
16	7.0000-03	1.2317+01	1.42000	0.86400	0.44226	0.78693	3.16610	0.35294
17	8.0000-03	1.4416+01	1.36400	0.88000	0.47988	0.81613	2.89238	0.38487
18	9.0000-03	1.6604+01	1.30700	0.89400	0.51619	0.84081	2.65331	0.41418
19	1.0000-02	1.8817+01	1.25000	0.90700	0.55045	0.86186	2.45151	0.43945
20	1.1000-02	2.1140+01	1.19300	0.92000	0.58428	0.88097	2.27344	0.46230
21	1.2000-02	2.3603+01	1.13600	0.93200	0.61811	0.89813	2.11127	0.48325
22	1.3000-02	2.6423+01	1.08000	0.94300	0.65471	0.91429	1.95016	0.50633
23	1.4000-02	2.9785+01	1.02300	0.95400	0.69583	0.93027	1.78737	0.53244
24	1.5000-02	3.2384+01	1.00000	0.96400	0.72601	0.94206	1.68373	0.55951
25	1.6000-02	3.4653+01	1.00000	0.97400	0.75139	0.95226	1.60614	0.59288
26	1.7000-02	3.7042+01	1.00000	0.98200	0.77719	0.96115	1.52940	0.62845
27	1.8000-02	3.9554+01	1.00000	0.98700	0.80344	0.96826	1.45236	0.66668
28	1.9000-02	4.2047+01	1.00000	0.99200	0.82867	0.97485	1.38393	0.70440
29	2.0000-02	4.5116+01	1.00000	0.99400	0.85871	0.98036	1.30342	0.75215
30	2.1000-02	4.8295+01	1.00000	0.99700	0.88874	0.98598	1.23078	0.80110
31	2.2000-02	5.1258+01	1.00000	0.99800	0.91586	0.98990	1.16821	0.84737
32	2.3000-02	5.3979+01	1.00000	1.00000	0.94007	0.99374	1.11744	0.88930
33	2.4000-02	5.6481+01	1.00000	1.00000	0.96180	0.99613	1.07267	0.92865
34	2.5000-02	5.8295+01	1.00000	1.00000	0.97725	0.99774	1.04238	0.95718
35	2.6000-02	5.9667+01	1.00000	1.00000	0.98877	0.99890	1.02060	0.97874
36	2.7000-02	6.0578+01	1.00000	1.00000	0.99635	0.99965	1.00662	0.99307
D 37	2.8000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
38	2.9000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
39	3.0000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
40	3.1000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
41	3.2000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
42	3.3000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
43	3.4000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
44	3.5000-02	6.1019+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M,P/PINF,TO/TOINF

750150206		KUSOY/HORSTMAN		PROFILE TABULATION		44 POINTS, DELTA AT POINT 26			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD	
1	0.0000+00	1.0000+00	1.35591	0.43200	0.00000	0.00000	2.77095	0.00000	
2	5.0000-04	1.1252+00	1.35591	0.75000	0.07957	0.17161	4.65124	0.05003	
3	7.5000-04	1.1498+00	1.35591	0.76700	0.08668	0.18847	4.72741	0.05406	
4	1.0000-03	1.1753+00	1.35591	0.77800	0.09341	0.20390	4.76518	0.05802	
5	1.2500-03	1.2125+00	1.35591	0.79000	0.10225	0.22392	4.79579	0.06331	
6	1.5000-03	1.2745+00	1.35591	0.79600	0.11513	0.25128	4.76388	0.07152	
7	1.7500-03	1.3499+00	1.35591	0.80100	0.12858	0.27922	4.71570	0.08028	
8	2.0000-03	1.4619+00	1.35591	0.80700	0.14549	0.31354	4.64404	0.09154	
9	2.5000-03	1.6258+00	1.35591	0.81700	0.16587	0.35423	4.56105	0.10531	
10	3.0000-03	1.7996+00	1.35591	0.82400	0.18374	0.38841	4.46854	0.11786	
11	3.5000-03	2.0252+00	1.35591	0.83100	0.20315	0.42403	4.35673	0.13197	
12	4.0000-03	2.2497+00	1.35591	0.83800	0.21987	0.45382	4.26007	0.14444	
13	4.5000-03	2.5999+00	1.35591	0.84400	0.24294	0.49207	4.10266	0.16263	
14	5.0000-03	2.9251+00	1.35591	0.85100	0.26216	0.52288	3.97823	0.17822	
15	6.0000-03	3.8253+00	1.35591	0.86400	0.30848	0.58995	3.65753	0.21870	
16	7.0000-03	5.0260+00	1.35591	0.88100	0.36056	0.65663	3.31653	0.26845	
17	8.0000-03	6.7504+00	1.35591	0.89000	0.42399	0.72438	2.91898	0.33649	
18	9.0000-03	9.0019+00	1.35591	0.92000	0.49452	0.78800	2.53913	0.42080	
19	1.0000-02	1.2255+01	1.35591	0.94200	0.58140	0.84951	2.13496	0.53952	
20	1.1000-02	1.7146+01	1.30519	0.96600	0.69172	0.90867	1.72568	0.68726	
21	1.2000-02	2.1058+01	1.24761	0.99100	0.76860	0.94573	1.51403	0.77931	
22	1.3000-02	2.4218+01	1.18317	0.99900	0.82549	0.96495	1.36645	0.83553	
23	1.4000-02	2.7274+01	1.11874	1.00000	0.87699	0.97739	1.24206	0.88034	
24	1.5000-02	3.0093+01	1.06444	1.00000	0.92197	0.98652	1.14494	0.91716	
25	1.6000-02	3.3002+01	1.01700	1.00000	0.96617	0.99449	1.05948	0.95462	
D 26	1.7000-02	3.5320+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	
27	1.8000-02	3.6659+01	1.01700	1.00000	1.01903	1.00290	0.96859	1.05303	
28	1.9000-02	3.6250+01	1.08473	1.00000	1.01326	1.00203	0.97796	1.11143	
29	2.0000-02	3.1949+01	1.30519	1.00000	0.95041	0.99176	1.08889	1.18676	
30	2.1000-02	2.9113+01	1.52566	1.00000	0.90659	0.98353	1.17692	1.27496	
31	2.2000-02	2.6922+01	1.76283	1.00000	0.87123	0.97614	1.25533	1.37077	
32	2.3000-02	2.4584+01	2.06802	1.00000	0.83183	0.96700	1.35141	1.47977	
33	2.4000-02	2.2942+01	2.30519	1.00000	0.80300	0.95964	1.42820	1.54891	
34	2.5000-02	2.1607+01	2.52566	1.00000	0.77878	0.95296	1.49735	1.60742	
35	2.6000-02	2.0883+01	2.67810	1.00000	0.76533	0.94904	1.53772	1.65286	
36	2.7000-02	2.0873+01	2.71211	1.00000	0.76514	0.94899	1.53831	1.67311	
37	2.8000-02	2.1399+01	2.67810	1.00000	0.77494	0.95186	1.50873	1.68961	
38	2.9000-02	2.5438+01	1.93228	1.00000	0.84643	0.97051	1.31465	1.42645	
39	3.0000-02	2.8234+01	1.44093	1.00000	0.89256	0.98068	1.20719	1.17056	
40	3.1000-02	2.8114+01	1.25447	1.00000	0.89064	0.98028	1.21142	1.01512	
41	3.2000-02	2.8738+01	1.20346	1.00000	0.90063	0.98233	1.18965	0.99374	
42	3.3000-02	2.8859+01	1.18646	1.00000	0.90256	0.98272	1.18552	0.98349	
43	3.4000-02	2.8980+01	1.16945	1.00000	0.90448	0.98310	1.18142	0.97315	
44	3.5000-02	2.9126+01	1.15274	1.00000	0.90678	0.98356	1.17651	0.96369	

INPUT VARIABLES Y,M,P/PINF,TO/TOINF

750150208		KUSOY/HORSTMAN		PROFILE TABULATION		44 POINTS, DELTA AT POINT 22			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD	
1	0.0000+00	1.0000+00	1.72575	0.43071	0.00000	0.00000	2.57736	0.00000	
2	5.0000-04	2.4991+00	1.67458	0.82752	0.24659	0.48071	3.80015	0.21183	
3	7.5000-04	2.7459+00	1.65125	0.84945	0.26242	0.51049	3.78429	0.22275	
4	1.0000-03	3.0005+00	1.62812	0.85643	0.27764	0.53423	3.70242	0.23493	
5	1.2500-03	3.1663+00	1.61646	0.86441	0.28706	0.54968	3.66671	0.24232	
6	1.5000-03	3.3345+00	1.60479	0.87139	0.29627	0.56428	3.62743	0.24964	
7	1.7500-03	3.5048+00	1.59312	0.87537	0.30529	0.57737	3.57678	0.25717	
8	2.0000-03	3.6767+00	1.58146	0.87936	0.31410	0.58994	3.52754	0.26448	
9	2.5000-03	4.0278+00	1.55833	0.88734	0.33133	0.61381	3.43203	0.27871	
10	3.0000-03	4.5466+00	1.53500	0.89432	0.35517	0.64381	3.28580	0.30076	
11	3.5000-03	5.2689+00	1.52333	0.90030	0.38582	0.67852	3.09284	0.33419	
12	4.0000-03	5.9206+00	1.51167	0.90927	0.41146	0.70683	2.95105	0.36207	
13	4.5000-03	6.5874+00	1.50020	0.91725	0.43610	0.73206	2.81787	0.38974	
14	5.0000-03	7.5019+00	1.48854	0.92921	0.46775	0.76286	2.65992	0.42691	
15	6.0000-03	9.6828+00	1.46521	0.94915	0.53566	0.81892	2.33729	0.51337	
16	7.0000-03	1.3386+01	1.44187	0.97009	0.63442	0.88162	1.93116	0.65825	
17	8.0000-03	1.7688+01	1.40708	0.99202	0.73257	0.93110	1.61543	0.81101	
18	9.0000-03	2.3385+01	1.37229	1.01097	0.84515	0.97346	1.32668	1.00693	
19	1.0000-02	2.7368+01	1.32562	1.01994	0.91567	0.99404	1.17852	1.11812	
20	1.1000-02	2.9908+01	1.24437	1.01994	0.95793	1.00243	1.09506	1.13911	
21	1.2000-02	3.2039+01	1.13958	1.01196	0.99199	1.00460	1.02560	1.11625	
22	1.3000-02	3.2551+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	
23	1.4000-02	3.3235+01	0.82562	0.99701	1.01062	1.00025	0.97959	0.84304	
24	1.5000-02	3.5817+01	0.65596	0.99701	1.04968	1.00630	0.91906	0.71822	
25	1.6000-02	3.6919+01	0.60479	0.99701	1.06591	1.00865	0.89546	0.68124	
26	1.7000-02	3.6155+01	0.60479	0.99701	1.05469	1.00704	0.91169	0.66804	
27	1.8000-02	3.6468+01	0.59312	0.99701	1.05929	1.00771	0.90497	0.66046	
28	1.9000-02	3.6659+01	0.59312	0.99701	1.06210	1.00811	0.90092	0.66369	
29	2.0000-02	3.5844+01	0.61625	0.99701	1.05008	1.00636	0.91847	0.67522	
30	2.1000-02	3.4468+01	0.65125	0.99701	1.02945	1.00324	0.94974	0.68794	
31	2.2000-02	3.3391+01	0.68604	0.99701	1.01302	1.00064	0.97571	0.70357	
32	2.3000-02	3.2422+01	0.72104	0.99701	0.99800	0.99817	1.00034	0.71947	
33	2.4000-02	3.1064+01	0.76750	0.99701	0.97656	0.99448	1.03702	0.73601	
34	2.5000-02	2.9859+01	0.81396	0.99701	0.95713	0.99095	1.07191	0.75248	
35	2.6000-02	2.9077+01	0.85591	0.99701	0.94431	0.98852	1.09583	0.77210	
36	2.7000-02	2.8365+01	0.89767	0.99701	0.93249	0.98622	1.11855	0.79147	
37	2.8000-02	2.7651+01	0.94187	0.99701	0.92047	0.98380	1.14232	0.81117	
38	2.9000-02	2.7016+01	0.98138	0.99701	0.90966	0.98155	1.16432	0.82733	
39	3.0000-02	2.6365+01	1.02333	0.99701	0.89844	0.97915	1.18775	0.84361	
40	3.1000-02	2.5814+01	1.06263	0.99701	0.88882	0.97704	1.20835	0.85938	
41	3.2000-02	2.5156+01	1.10479	0.99701	0.87720	0.97441	1.23391	0.87244	
42	3.3000-02	2.5212+01	1.11646	0.99701	0.87821	0.97464	1.23168	0.88346	
43	3.4000-02	2.5518+01	1.11646	0.99701	0.88361	0.97587	1.21972	0.89325	
44	3.5000-02	2.7274+01	1.02333	0.99701	0.91406	0.98247	1.15528	0.87026	

INPUT VARIABLES Y,M,P/PINF,TO/TOINF

7501S0215 KUSSOY/HORSTMAN PROFILE TABULATION 44 POINTS, DELTA AT POINT 40								
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TO	R/RD*U/UD
1	0.0000+00	1.0000+00	1.08580	0.43200	0.00000	0.00000	2.74138	0.00000
2	5.0000-04	6.9442+00	1.08580	0.77800	0.43327	0.68013	2.46417	0.29969
3	7.5000-04	9.7241+00	1.08580	0.83500	0.51838	0.76445	2.17475	0.38167
4	1.0000-03	1.1109+01	1.08580	0.86400	0.55590	0.79930	2.06742	0.41979
5	1.2500-03	1.1572+01	1.08580	0.88600	0.56789	0.81587	2.06399	0.42920
6	1.5000-03	1.2038+01	1.08580	0.89800	0.57969	0.82752	2.03780	0.44093
7	1.7500-03	1.2364+01	1.08580	0.90600	0.58781	0.83530	2.01934	0.44914
8	2.0000-03	1.2965+01	1.08580	0.91500	0.60251	0.84664	1.97453	0.46557
9	2.5000-03	1.3755+01	1.08580	0.92700	0.62128	0.86093	1.92027	0.48680
10	3.0000-03	1.4535+01	1.08580	0.93800	0.63926	0.87397	1.86910	0.50771
11	3.5000-03	1.5372+01	1.08580	0.94600	0.65803	0.88554	1.81104	0.53092
12	4.0000-03	1.6107+01	1.08580	0.95300	0.67408	0.89519	1.76362	0.55114
13	4.5000-03	1.6833+01	1.08050	0.96000	0.68956	0.90434	1.71999	0.56810
14	5.0000-03	1.7388+01	1.07563	0.96400	0.70116	0.91045	1.68609	0.58082
15	6.0000-03	1.8401+01	1.06546	0.97200	0.72186	0.92143	1.62937	0.60253
16	7.0000-03	1.9188+01	1.05529	0.97700	0.73752	0.92897	1.58653	0.61791
17	8.0000-03	1.9901+01	1.04556	0.98300	0.75145	0.93622	1.55224	0.63062
18	9.0000-03	2.0435+01	1.04025	0.98600	0.76170	0.94079	1.52550	0.64153
19	1.0000-02	2.1017+01	1.03538	0.99000	0.77273	0.94597	1.49864	0.65355
20	1.1000-02	2.1607+01	1.03538	0.99300	0.78375	0.95037	1.47099	0.66907
21	1.2000-02	2.2237+01	1.03538	0.99500	0.79536	0.95476	1.44100	0.68601
22	1.3000-02	2.2813+01	1.03538	0.99700	0.80580	0.95854	1.41503	0.70137
23	1.4000-02	2.3559+01	1.03052	0.99800	0.81915	0.96251	1.38065	0.71842
24	1.5000-02	2.4151+01	1.03052	0.99900	0.82959	0.96563	1.35484	0.73447
25	1.6000-02	2.4729+01	1.03052	0.99900	0.83965	0.96809	1.32934	0.75048
26	1.7000-02	2.5484+01	1.02521	1.00000	0.85261	0.97166	1.29874	0.76701
27	1.8000-02	2.6123+01	1.02521	1.00000	0.86344	0.97414	1.27286	0.78461
28	1.9000-02	2.6817+01	1.02521	1.00000	0.87505	0.97673	1.24590	0.80372
29	2.0000-02	2.7545+01	1.02034	1.00000	0.88704	0.97931	1.21887	0.81981
30	2.1000-02	2.8186+01	1.02034	1.00000	0.89749	0.98150	1.19598	0.83736
31	2.2000-02	2.8823+01	1.02034	1.00000	0.90774	0.98358	1.17409	0.85478
32	2.3000-02	2.9601+01	1.01504	1.00000	0.92012	0.98602	1.14839	0.87153
33	2.4000-02	3.0291+01	1.01504	1.00000	0.93095	0.98809	1.12654	0.89030
34	2.5000-02	3.0939+01	1.01504	1.00000	0.94101	0.98996	1.10676	0.90792
35	2.6000-02	3.1746+01	1.01017	1.00000	0.95338	0.99220	1.08308	0.92541
36	2.7000-02	3.2435+01	1.01017	1.00000	0.96383	0.99403	1.06365	0.94405
37	2.8000-02	3.3145+01	1.00531	1.00000	0.97447	0.99584	1.04435	0.95861
38	2.9000-02	3.3705+01	1.00531	1.00000	0.98279	0.99723	1.02961	0.97369
39	3.0000-02	3.4204+01	1.00531	1.00000	0.99014	0.99843	1.01682	0.98713
40	3.1000-02	3.4879+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
41	3.2000-02	3.5320+01	1.00000	1.00000	1.00638	1.00100	0.98933	1.01180
42	3.3000-02	3.5858+01	0.99513	1.00000	1.01412	1.00219	0.97660	1.02120
43	3.4000-02	3.6305+01	0.99513	1.00000	1.02050	1.00315	0.96628	1.03311
44	3.5000-02	3.6713+01	0.99513	1.00000	1.02631	1.00401	0.95703	1.04399

INPUT VARIABLES Y,M,P/PINF,TO/TOINF

7501S0218 KUSSOY/HORSTMAN PROFILE TABULATION 44 POINTS, DELTA AT POINT 44								
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TO	R/RD*U/UD
1	0.0000+00	1.0000+00	1.09865	0.43200	0.00000	0.00000	2.70135	0.00000
2	5.0000-04	4.6010+00	1.09865	0.67600	0.34829	0.55964	2.58184	0.23814
3	7.5000-04	6.4984+00	1.09865	0.74400	0.42166	0.65399	2.40557	0.29868
4	1.0000-03	7.8969+00	1.09865	0.79600	0.46829	0.71220	2.31296	0.33829
5	1.2500-03	8.7005+00	1.09865	0.82400	0.49307	0.74170	2.26273	0.36012
6	1.5000-03	9.4982+00	1.09865	0.84400	0.51649	0.76569	2.19781	0.38276
7	1.7500-03	1.0002+01	1.09865	0.85800	0.53073	0.78067	2.16366	0.39640
8	2.0000-03	1.0548+01	1.09865	0.86800	0.54576	0.79395	2.11636	0.41216
9	2.5000-03	1.1340+01	1.08801	0.88300	0.56683	0.81242	2.05428	0.43028
10	3.0000-03	1.2123+01	1.08801	0.89400	0.58693	0.82790	1.98970	0.45271
11	3.5000-03	1.3062+01	1.07737	0.90400	0.61015	0.84380	1.91256	0.47532
12	4.0000-03	1.4021+01	1.06576	0.91200	0.63298	0.85787	1.83684	0.49775
13	4.5000-03	1.4894+01	1.05513	0.91900	0.65307	0.86969	1.77339	0.51745
14	5.0000-03	1.5627+01	1.05513	0.92600	0.66946	0.87958	1.72623	0.53763
15	6.0000-03	1.6980+01	1.05513	0.93800	0.69873	0.89629	1.64542	0.57475
16	7.0000-03	1.8229+01	1.05513	0.94900	0.72468	0.91056	1.57877	0.60855
17	8.0000-03	1.9375+01	1.05513	0.95900	0.74771	0.92282	1.52324	0.63922
18	9.0000-03	2.0313+01	1.05513	0.96600	0.76605	0.93179	1.47954	0.66450
19	1.0000-02	2.1047+01	1.05513	0.97200	0.78010	0.93880	1.44825	0.68396
20	1.1000-02	2.1670+01	1.05513	0.97700	0.79180	0.94452	1.42293	0.70038
21	1.2000-02	2.2599+01	1.05513	0.98200	0.80898	0.95160	1.38368	0.72564
22	1.3000-02	2.3233+01	1.05513	0.98600	0.82049	0.95654	1.35913	0.74258
23	1.4000-02	2.3953+01	1.05513	0.98900	0.83337	0.96125	1.33046	0.76232
24	1.5000-02	2.4584+01	1.05513	0.99100	0.84449	0.96494	1.30561	0.77981
25	1.6000-02	2.5235+01	1.04932	0.99300	0.85580	0.96860	1.28097	0.79344
26	1.7000-02	2.5894+01	1.04449	0.99400	0.86712	0.97169	1.25572	0.80823
27	1.8000-02	2.6319+01	1.04449	0.99600	0.87434	0.97429	1.24168	0.81956
28	1.9000-02	2.6771+01	1.03868	0.99800	0.88195	0.97694	1.22700	0.82700
29	2.0000-02	2.7450+01	1.03288	0.99900	0.89327	0.97986	1.20326	0.84111
30	2.1000-02	2.7876+01	1.03288	0.99900	0.90029	0.98133	1.18812	0.85311
31	2.2000-02	2.8341+01	1.02708	1.00000	0.90790	0.98338	1.17318	0.86092
32	2.3000-02	2.8823+01	1.02224	1.00000	0.91571	0.98495	1.15695	0.87027
33	2.4000-02	2.9247+01	1.02224	1.00000	0.92254	0.98630	1.14300	0.88209
34	2.5000-02	2.9564+01	1.02224	1.00000	0.92761	0.98728	1.13279	0.89093
35	2.6000-02	3.0056+01	1.01644	1.00000	0.93541	0.98877	1.11733	0.89949
36	2.7000-02	3.0490+01	1.01644	1.00000	0.94224	0.99005	1.10404	0.91149
37	2.8000-02	3.1089+01	1.01074	1.00000	0.95161	0.99176	1.08617	0.92279
38	2.9000-02	3.1417+01	1.01064	1.00000	0.95868	0.99268	1.07666	0.93180
39	3.0000-02	3.2026+01	1.00580	1.00000	0.96605	0.99433	1.05941	0.94402
40	3.1000-02	3.2461+01	1.00580	1.00000	0.97268	0.99548	1.04742	0.95593
41	3.2000-02	3.2795+01	1.00580	1.00000	0.97776	0.99634	1.03838	0.96509
42	3.3000-02	3.3404+01	1.00000	1.00000	0.98693	0.99787	1.02231	0.97610
43	3.4000-02	3.3849+01	1.00000	1.00000	0.99356	0.99896	1.01090	0.98819
44	3.5000-02	3.4283+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M,P/PINF,TO/TOINF

SECTION D: SUPPLEMENTARY DATA

D1 - WALL MEASUREMENTS FOR SERIES 01. FACSIMILE OF AUTHORS' TABLE 3

AUTHORS' SYMBOLS AND UNITS

τ_{wm} - wall shear stress reading from balance

τ_{wc} - wall shear stress reading corrected for buoyancy
(pressure gradient) effects

7.5 DEGREE SHOCK WAVE GENERATOR

IDENT CAT	x	P_w	τ_{wm}	τ_{wc}	ρ_w
7501	(cm)	(N/m ²)	(N/m ²)	(N/m ²)	(N/m ²)
0101 -	42.0	607.	16.7	16.7	6240.
	42.5	607.	16.7	16.7	6240.
	43.0	607.	16.7	16.7	6240.
	43.5	607.	16.7	16.7	6240.
0102 -	44.0	607.	16.7	16.7	6240.
	44.5	607.	16.7	16.7	6240.
	45.0	607.	16.7	17.1	6580.
	45.5	614.	16.7	17.4	6810.
0103 -	46.0	621.	16.7	17.8	7040.
	46.5	634.	16.7	18.5	7380.
	47.0	655.	16.7	19.5	7720.
	47.5	689.	10.8	15.0	8280.
0104 -	48.0	759.	4.1	9.2	9080.
	48.5	862.	1.0	7.4	10800.
	49.0	1010.	0.1	7.9	12500.
	49.5	1240.	1.6	11.4	14400.
0105 -	50.0	1520.	5.4	17.2	16500.
	50.5	1790.	11.3	25.2	19300.
	51.0	2070.	18.8	34.0	22100.
	51.5	2480.	26.5	42.2	24400.
0106 -	52.0	2830.	33.0	48.9	27000.
	52.5	3170.	39.2	55.0	28900.
	53.0	3520.	44.6	60.3	31200.
	53.5	3790.	49.5	64.0	32900.
0107 -	54.0	4010.	53.5	66.3	34800.
	54.5	4270.	57.3	68.3	36500.
	55.0	4490.	60.2	69.6	37800.
	55.5	4620.	62.8	70.5	38800.
0108 -	56.0	4740.	64.9	71.0	39500.
	56.5	4810.	66.7	71.1	40100.
	57.0	4860.	68.1	71.1	40300.
	57.5	4900.	69.1	70.7	40300.
0109 -	58.0	4870.	70.1	70.5	40300.
	58.5	4810.	70.7	70.0	40200.
	59.0	4750.	71.4	69.7	39900.
	59.5	4650.	71.8	69.3	39500.
0110 -	60.0	4540.	72.1	68.9	38900.
	60.5	4470.	72.3	68.8	38400.
	61.0	4370.	72.6	68.6	37900.
	61.5	4190.	72.3	68.5	37300.
0111 -	62.0	4070.	72.2	68.3	36800.
	62.5	3960.	72.1	68.1	36200.

IDENT CAT	x	P_w	τ_{wm}	τ_{wc}	ρ_w
7501	(cm)	(N/m ²)	(N/m ²)	(N/m ²)	(N/m ²)
	63.0	3860.	71.8	67.8	35500.
	63.5	3740.	71.6	67.6	34800.
0112 -	64.0	3640.	71.1	67.1	34200.
	64.5	3540.	70.6	66.7	33500.
	65.0	3450.	70.1	66.3	32900.
	65.5	3360.	69.6	65.9	32400.
0113 -	66.0	3280.	69.0	65.3	31800.
	66.5	3190.	68.4	64.7	31200.
	67.0	3100.	67.7	64.1	30600.
	67.5	3050.	67.1	63.6	30100.
0114 -	68.0	2980.	66.3	63.0	29500.
	68.5	2900.	65.7	62.4	29100.
	69.0	2810.	64.8	61.6	28600.
	69.5	2740.	64.1	60.9	28100.
0115 -	70.0	2700.	63.4	60.2	27400.
	71.0	2610.	61.8	58.7	26400.
	72.0	2490.	59.8	56.9	25400.
	73.0	2410.	58.1	55.5	24300.
0116 -	74.0	2310.	56.4	53.7	23400.
	75.0	2210.	54.4	52.0	22500.
	76.0	2100.	52.5	50.1	21800.
	77.0	2030.	50.5	48.2	21000.
0117 -	78.0	1940.	48.8	46.7	20200.
	79.0	1900.	47.6	45.5	19400.
	80.0	1810.	45.8	43.8	18700.
	81.0	1720.			18000.
0118 -	82.0	1660.			17600.
	83.0	1590.			16900.
	84.0	1520.			16200.
	85.0	1460.			15700.
0119 -	86.0	1390.			15100.
	87.0	1330.			14600.
	88.0	1270.			14100.
	89.0	1250.			13500.
	90.0	1210.			13100.
	91.0	1210.			12700.
	92.0	1180.			12400.
	93.0	1160.			11400.
	94.0	1130.			11600.
	95.0	1100.			11200.

SECTION D: SUPPLEMENTARY DATA
D2 - WALL MEASUREMENTS FOR SERIES 02. FACSIMILE OF AUTHORS' TABLE 4
AUTHORS' SYMBOLS AND UNITS

τ_{wm} - wall shear stress reading from balance

τ_{wc} - wall shear stress reading corrected for buoyancy
(pressure gradient) effects

15 DEGREE SHOCK WAVE GENERATOR

IDENT CAT	x (cm)	P_w (N/m ²)	τ_{wm} (N/m ²)	τ_{wc} (N/m ²)	ρ_w (N/m ³)	IDENT CAT	x (cm)	P_w (N/m ²)	τ_{wm} (N/m ²)	τ_{wc} (N/m ²)	ρ_w (N/m ³)
7501						7501					
0201 -	20.0	607.	16.7	16.7	4240.	0209 -	42.0	5690.	78.9	82.2	54600.
	21.0	607.	16.7	16.7	4240.		47.4	5720.	81.9	82.6	54500.
	22.0	607.	16.7	16.7	4240.		49.0	5720.	84.3	83.3	54400.
	23.0	607.	16.7	16.7	4240.		49.5	5680.	86.3	84.7	54100.
	24.0	607.	16.7	16.7	4240.		49.5	5680.	88.3	86.7	53700.
	25.0	607.	16.7	16.7	4240.		49.5	5680.	88.3	86.7	53700.
0202 -	26.0	621.	16.3	17.4	7040.	0210 -	49.5	5450.	90.7	85.3	52700.
	27.0	689.	15.2	17.4	7260.		49.5	5450.	91.7	86.1	52700.
	28.0	758.	12.3	15.8	7600.		49.5	5450.	92.2	86.3	51900.
	29.0	821.	9.3	14.3	7940.		49.5	5450.	92.7	86.5	50900.
0203 -	30.0	891.	5.4	11.6	8400.		49.5	5450.	92.7	86.5	50900.
	31.0	951.	3.9	11.6	9080.		49.5	5450.	91.9	85.3	49500.
	32.0	1010.	2.9	11.6	9650.		49.5	5450.	91.4	84.6	48400.
	33.0	1070.	2.9	11.6	10200.		49.5	5450.	90.7	83.9	47900.
	34.0	1130.	2.9	11.6	10700.		49.5	5450.	90.7	83.9	47900.
0204 -	35.0	1190.	2.9	11.6	11200.	0211 -	49.5	5450.	90.7	83.9	47900.
	36.0	1250.	2.9	11.6	11700.		49.5	5450.	90.7	83.9	47900.
	37.0	1310.	2.9	11.6	12200.		49.5	5450.	90.7	83.9	47900.
	38.0	1370.	2.9	11.6	12700.		49.5	5450.	90.7	83.9	47900.
0205 -	39.0	1430.	2.9	11.6	13200.	0212 -	49.5	5450.	90.7	83.9	47900.
	40.0	1490.	2.9	11.6	13700.		49.5	5450.	90.7	83.9	47900.
	41.0	1550.	2.9	11.6	14200.		49.5	5450.	90.7	83.9	47900.
	42.0	1610.	2.9	11.6	14700.		49.5	5450.	90.7	83.9	47900.
0206 -	43.0	1670.	2.9	11.6	15200.	0213 -	49.5	5450.	90.7	83.9	47900.
	44.0	1730.	2.9	11.6	15700.		49.5	5450.	90.7	83.9	47900.
	45.0	1790.	2.9	11.6	16200.		49.5	5450.	90.7	83.9	47900.
	46.0	1850.	2.9	11.6	16700.		49.5	5450.	90.7	83.9	47900.
	47.0	1910.	2.9	11.6	17200.		49.5	5450.	90.7	83.9	47900.
	48.0	1970.	2.9	11.6	17700.		49.5	5450.	90.7	83.9	47900.
	49.0	2030.	2.9	11.6	18200.		49.5	5450.	90.7	83.9	47900.
	50.0	2090.	2.9	11.6	18700.		49.5	5450.	90.7	83.9	47900.
	51.0	2150.	2.9	11.6	19200.		49.5	5450.	90.7	83.9	47900.
	52.0	2210.	2.9	11.6	19700.		49.5	5450.	90.7	83.9	47900.
	53.0	2270.	2.9	11.6	20200.		49.5	5450.	90.7	83.9	47900.
	54.0	2330.	2.9	11.6	20700.		49.5	5450.	90.7	83.9	47900.
	55.0	2390.	2.9	11.6	21200.		49.5	5450.	90.7	83.9	47900.
	56.0	2450.	2.9	11.6	21700.		49.5	5450.	90.7	83.9	47900.
	57.0	2510.	2.9	11.6	22200.		49.5	5450.	90.7	83.9	47900.
	58.0	2570.	2.9	11.6	22700.		49.5	5450.	90.7	83.9	47900.
	59.0	2630.	2.9	11.6	23200.		49.5	5450.	90.7	83.9	47900.
	60.0	2690.	2.9	11.6	23700.		49.5	5450.	90.7	83.9	47900.
	61.0	2750.	2.9	11.6	24200.		49.5	5450.	90.7	83.9	47900.
	62.0	2810.	2.9	11.6	24700.		49.5	5450.	90.7	83.9	47900.
	63.0	2870.	2.9	11.6	25200.		49.5	5450.	90.7	83.9	47900.
	64.0	2930.	2.9	11.6	25700.		49.5	5450.	90.7	83.9	47900.
	65.0	2990.	2.9	11.6	26200.		49.5	5450.	90.7	83.9	47900.
	66.0	3050.	2.9	11.6	26700.		49.5	5450.	90.7	83.9	47900.
	67.0	3110.	2.9	11.6	27200.		49.5	5450.	90.7	83.9	47900.
	68.0	3170.	2.9	11.6	27700.		49.5	5450.	90.7	83.9	47900.
	69.0	3230.	2.9	11.6	28200.		49.5	5450.	90.7	83.9	47900.
	70.0	3290.	2.9	11.6	28700.		49.5	5450.	90.7	83.9	47900.
	71.0	3350.	2.9	11.6	29200.		49.5	5450.	90.7	83.9	47900.
	72.0	3410.	2.9	11.6	29700.		49.5	5450.	90.7	83.9	47900.
	73.0	3470.	2.9	11.6	30200.		49.5	5450.	90.7	83.9	47900.
	74.0	3530.	2.9	11.6	30700.		49.5	5450.	90.7	83.9	47900.
	75.0	3590.	2.9	11.6	31200.		49.5	5450.	90.7	83.9	47900.
	76.0	3650.	2.9	11.6	31700.		49.5	5450.	90.7	83.9	47900.
	77.0	3710.	2.9	11.6	32200.		49.5	5450.	90.7	83.9	47900.
	78.0	3770.	2.9	11.6	32700.		49.5	5450.	90.7	83.9	47900.
	79.0	3830.	2.9	11.6	33200.		49.5	5450.	90.7	83.9	47900.
	80.0	3890.	2.9	11.6	33700.		49.5	5450.	90.7	83.9	47900.
	81.0	3950.	2.9	11.6	34200.		49.5	5450.	90.7	83.9	47900.
	82.0	4010.	2.9	11.6	34700.		49.5	5450.	90.7	83.9	47900.
	83.0	4070.	2.9	11.6	35200.		49.5	5450.	90.7	83.9	47900.
	84.0	4130.	2.9	11.6	35700.		49.5	5450.	90.7	83.9	47900.
	85.0	4190.	2.9	11.6	36200.		49.5	5450.	90.7	83.9	47900.
	86.0	4250.	2.9	11.6	36700.		49.5	5450.	90.7	83.9	47900.
	87.0	4310.	2.9	11.6	37200.		49.5	5450.	90.7	83.9	47900.
	88.0	4370.	2.9	11.6	37700.		49.5	5450.	90.7	83.9	47900.
	89.0	4430.	2.9	11.6	38200.		49.5	5450.	90.7	83.9	47900.
	90.0	4490.	2.9	11.6	38700.		49.5	5450.	90.7	83.9	47900.
	91.0	4550.	2.9	11.6	39200.		49.5	5450.	90.7	83.9	47900.
	92.0	4610.	2.9	11.6	39700.		49.5	5450.	90.7	83.9	47900.
	93.0	4670.	2.9	11.6	40200.		49.5	5450.	90.7	83.9	47900.
	94.0	4730.	2.9	11.6	40700.		49.5	5450.	90.7	83.9	47900.
	95.0	4790.	2.9	11.6	41200.		49.5	5450.	90.7	83.9	47900.
	96.0	4850.	2.9	11.6	41700.		49.5	5450.	90.7	83.9	47900.
	97.0	4910.	2.9	11.6	42200.		49.5	5450.	90.7	83.9	47900.
	98.0	4970.	2.9	11.6	42700.		49.5	5450.	90.7	83.9	47900.
	99.0	5030.	2.9	11.6	43200.		49.5	5450.	90.7	83.9	47900.
	100.0	5090.	2.9	11.6	43700.		49.5	5450.	90.7	83.9	47900.

7501S

KUSSOY/MIKULLA

TURBULENCE DATA

7501S0101 UT= 4.8682E+01 RHO= 7.0465E-03 TW= 3.0000E+02 D*= 1.4401E-01

I	Y [M]	V' UT	RHO*U'V' RHO*UT2	(RHO U)' RHO*UT
1	1.5000E-3	8.5184E-1	-6.8118E-1	2.0716E+0
2	2.7500E-3	9.3472E-1	-6.5182E-1	2.5398E+0
3	4.0000E-3	9.0035E-1	-5.5199E-1	2.7501E+0
4	5.2500E-3	8.9044E-1	-5.5786E-1	2.9345E+0
5	6.5000E-3	8.7036E-1	-5.1089E-1	3.0840E+0
6	7.7500E-3	8.7454E-1	-6.1071E-1	3.2427E+0
7	9.0000E-3	8.4552E-1	-5.6374E-1	3.4595E+0
8	1.0250E-2	7.6560E-1	-4.2280E-1	3.6338E+0
9	1.1500E-2	7.6575E-1	-4.9327E-1	3.8651E+0
10	1.2750E-2	7.1901E-1	-4.4629E-1	4.0972E+0
11	1.4000E-2	6.7067E-1	-3.9931E-1	4.2825E+0
12	1.5250E-2	6.6317E-1	-3.8170E-1	4.6798E+0
13	1.6500E-2	6.3393E-1	-3.7582E-1	5.1053E+0
14	1.7750E-2	6.2006E-1	-3.6995E-1	5.5978E+0
15	1.9000E-2	6.0657E-1	-3.3472E-1	5.8557E+0
16	2.0250E-2	5.7105E-1	-3.4646E-1	6.3132E+0
17	2.1500E-2	5.3344E-1	-3.3472E-1	6.5940E+0
18	2.2750E-2	5.1654E-1	-2.6425E-1	6.8947E+0
19	2.4000E-2	4.5342E-1	-2.3489E-1	6.8489E+0
20	2.5250E-2	4.1157E-1	-1.9378E-1	7.0506E+0
21	2.6500E-2	NM	NM	NM
22	2.7750E-2	NM	NM	NM
23	2.9000E-2	NM	NM	NM

7501S0105 UT= 3.1247E+01 RHO= 1.7616E-02 TW= 3.0000E+02 D*= 2.6123E-01

I	Y [M]	V' UT	RHO*U'V' RHO*UT2	(RHO U)' RHO*UT
1	1.5000E-3	2.3167E+0	-3.3069E+0	1.8130E+0
2	2.7500E-3	2.7544E+0	-4.5042E+0	2.5280E+0
3	4.0000E-3	3.7958E+0	-9.8637E+0	4.2042E+0
4	5.2500E-3	5.1569E+0	-1.5508E+1	5.8437E+0
5	6.5000E-3	5.1392E+0	-1.3114E+1	5.9694E+0
6	7.7500E-3	2.8121E+0	-5.8726E+0	5.7837E+0
7	9.0000E-3	2.6366E+0	-4.3902E+0	6.0677E+0
8	1.0250E-2	1.9644E+0	-2.7938E+0	6.1341E+0
9	1.1500E-2	1.8385E+0	-2.8508E+0	8.4610E+0
10	1.2750E-2	1.3932E+0	-1.4824E+0	8.4120E+0
11	1.4000E-2	1.6228E+0	-1.1403E+0	1.0039E+1
12	1.5250E-2	2.0160E+0	-7.4120E-1	9.7426E+0
13	1.6500E-2	2.3150E+0	0.	1.0055E+1
14	1.7750E-2	1.7760E+0	0.	1.0289E+1
15	1.9000E-2	1.6288E+0	NM	1.1728E+1
16	2.0250E-2	1.7773E+0	NM	1.2189E+1
17	2.1500E-2	1.1378E+0	NM	8.8124E+0
18	2.2750E-2	6.4000E-1	NM	4.7792E+0
19	2.4000E-2	NM	NM	3.5844E+0

7501S0110 UT= 3.6107E+01 RHO= 5.2849E-02 TW= 3.0000E+02 D*= 6.9378E-02

I	Y [M]	V' UT	RHO*U'V' RHO*UT2	(RHO U)' RHO*UT
1	1.5000E-3	1.9737E+0	-2.1919E+0	1.9823E+0
2	2.7500E-3	2.4233E+0	-2.7897E+0	2.5302E+0
3	4.0000E-3	2.3230E+0	-2.6474E+0	2.9216E+0
4	5.2500E-3	2.5254E+0	-3.2879E+0	4.1191E+0
5	6.5000E-3	1.3822E+0	-1.3379E+0	4.2244E+0
6	7.7500E-3	1.3626E+0	-9.3939E-1	4.0550E+0
7	9.0000E-3	9.5518E-1	-4.4123E-1	3.9265E+0
8	1.0250E-2	6.7236E-1	-1.5656E-1	3.3641E+0
9	1.1500E-2	5.3486E-1	-4.2699E-2	2.2944E+0
10	1.2750E-2	4.1848E-1	-1.8503E-2	1.5339E+0
11	1.4000E-2	3.6062E-1	-1.1387E-2	1.2519E+0
12	1.5250E-2	3.6214E-1	0.	1.2806E+0
13	1.6500E-2	6.6653E-1	NM	1.5602E+0
14	1.7750E-2	1.3334E+0	NM	2.9358E+0
15	1.9000E-2	1.7418E+0	NM	2.8363E+0
16	2.0250E-2	9.4731E-1	NM	1.5904E+0
17	2.1500E-2	5.1949E-1	NM	1.1789E+0
18	2.2750E-2	NM	NM	NM

7501S KUSSOY/MIKULLA TURBULENCE DATA
 7501S0115 UT= 4.3830E+01 RHDW= 3.1308E-02 TW= 3.0000E+02 D*= 6.5070E-02

I	Y [M]	V' UT	RHD*U*V' RHDW*UT2	(RHD U)' RHDW*UT
1	1.5000E-3	6.0125E-1	NM	1.8230E+0
2	2.7500E-3	1.2153E+0	-1.9548E-1	2.3676E+0
3	4.0000E-3	1.9385E+0	-1.1403E+0	3.0536E+0
4	5.2500E-3	2.6153E+0	-1.4987E+0	3.9746E+0
5	6.5000E-3	2.8012E+0	-7.0047E-1	5.8069E+0
6	7.7500E-3	2.2617E+0	-1.1403E-1	4.2605E+0
7	9.0000E-3	1.1599E+0	-6.5160E-2	2.7344E+0
8	1.0250E-2	8.1305E-1	-4.8870E-2	2.9174E+0
9	1.1500E-2	7.5782E-1	0.	2.9494E+0
10	1.2750E-2	6.0247E-1	8.1451E-2	2.9794E+0
11	1.4000E-2	9.2764E-1	1.6290E-2	3.4807E+0
12	1.5250E-2	5.1746E-1	6.5160E-2	3.2155E+0
13	1.6500E-2	4.9560E-1	8.1451E-2	3.1164E+0
14	1.7750E-2	4.4767E-1	6.5160E-2	3.0396E+0
15	1.9000E-2	4.9880E-1	6.5160E-2	2.7865E+0
16	2.0250E-2	5.4960E-1	NM	2.7424E+0
17	2.1500E-2	4.2492E-1	NM	2.3420E+0
18	2.2750E-2	4.0026E-1	NM	2.0817E+0
19	2.4000E-2	NM	NM	NM
20	2.5250E-2	0.	0.	0.

7501S0201 UT= 4.8682E+01 RHDW= 7.0465E-03 TW= 3.0000E+02 D*= 1.1155E-01

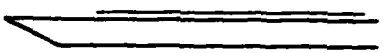
I	Y [M]	V' UT	RHD*U*V' RHDW*UT2	(RHD U)' RHDW*UT
1	1.5000E-3	6.6310E-1	NM	2.3474E+0
2	2.7500E-3	7.0342E-1	-2.3489E-1	2.8669E+0
3	4.0000E-3	7.1825E-1	-2.4076E-1	3.1130E+0
4	5.2500E-3	7.0812E-1	-2.4076E-1	3.3518E+0
5	6.5000E-3	6.5412E-1	-3.9344E-1	3.6008E+0
6	7.7500E-3	6.5352E-1	-4.7565E-1	3.8807E+0
7	9.0000E-3	6.5249E-1	-2.9948E-1	4.1642E+0
8	1.0250E-2	6.4614E-1	-3.5821E-1	4.4694E+0
9	1.1500E-2	6.1984E-1	-3.5233E-1	4.8544E+0
10	1.2750E-2	6.3299E-1	-3.2885E-1	5.2504E+0
11	1.4000E-2	6.2242E-1	-3.2885E-1	5.7030E+0
12	1.5250E-2	5.8828E-1	-3.4059E-1	6.2224E+0
13	1.6500E-2	6.2059E-1	-3.1710E-1	6.7985E+0
14	1.7750E-2	6.2760E-1	-2.7012E-1	7.4598E+0
15	1.9000E-2	5.8961E-1	-2.7600E-1	7.3482E+0
16	2.0250E-2	6.1702E-1	-1.8204E-1	7.2607E+0
17	2.1500E-2	5.5222E-1	-1.8204E-1	6.9304E+0
18	2.2750E-2	5.5448E-1	-1.2919E-1	6.9061E+0
19	2.4000E-2	NM	NM	6.7279E+0
20	2.5250E-2	NM	NM	5.9509E+0
21	2.6500E-2	NM	NM	5.0691E+0

7501S0209 UT= 3.5466E+01 RHDW= 6.6463E-02 TW= 3.0000E+02 D*= 4.8075E-02

I	Y [M]	V' UT	RHD*U*V' RHDW*UT2	(RHD U)' RHDW*UT
1	1.5000E-3	1.5595E+0	-8.4459E-1	2.3456E+0
2	2.7500E-3	1.5231E+0	-9.6190E-1	2.4471E+0
3	4.0000E-3	1.2935E+0	-5.9825E-1	2.4781E+0
4	5.2500E-3	1.1564E+0	-1.9942E-1	2.6088E+0
5	6.5000E-3	1.2239E+0	-1.8769E-1	2.7839E+0
6	7.7500E-3	1.1452E+0	-2.3461E-1	2.8995E+0
7	9.0000E-3	9.7617E-1	-2.3461E-1	3.7032E+0
8	1.0250E-2	7.5198E-1	-2.2288E-1	3.6916E+0
9	1.1500E-2	6.7309E-1	-1.1730E-1	3.5607E+0
10	1.2750E-2	6.1190E-1	NM	3.1516E+0
11	1.4000E-2	8.8327E-1	NM	3.2942E+0
12	1.5250E-2	1.3045E+0	NM	2.4868E+0

7501S0212 UT= 4.2943E+01 RHDW= 3.7797E-02 TW= 3.0000E+02 D*= 4.8830E-02

I	Y [M]	V' UT	RHD*U*V' RHDW*UT2	(RHD U)' RHDW*UT
1	1.5000E-3	9.6010E-1	-1.1678E+0	2.9474E+0
2	2.7500E-3	9.4941E-1	-1.0693E+0	3.0023E+0
3	4.0000E-3	9.0476E-1	-8.4419E-1	3.0018E+0
4	5.2500E-3	9.2105E-1	-6.7335E-1	3.0451E+0
5	6.5000E-3	9.5634E-1	-6.6128E-1	3.2797E+0
6	7.7500E-3	9.6886E-1	-5.3465E-1	3.3282E+0
7	9.0000E-3	9.3323E-1	-5.2058E-1	3.5519E+0
8	1.0250E-2	9.4061E-1	-4.7837E-1	3.6166E+0
9	1.1500E-2	9.0275E-1	-4.0802E-1	3.5867E+0
10	1.2750E-2	8.8766E-1	-3.3768E-1	3.9881E+0
11	1.4000E-2	8.2244E-1	-3.0954E-1	3.5982E+0
12	1.5250E-2	7.7906E-1	-2.6733E-1	3.5561E+0
13	1.6500E-2	7.3527E-1	-1.9698E-1	3.7274E+0
14	1.7750E-2	7.3782E-1	-1.9698E-1	3.8551E+0
15	1.9000E-2	7.1632E-1	-2.1105E-1	3.9539E+0
16	2.0250E-2	6.1929E-1	-1.2663E-1	3.4592E+0
17	2.1500E-2	5.9622E-1	-1.4070E-1	3.8848E+0
18	2.2750E-2	5.4810E-1	-9.8489E-2	3.4460E+0
19	2.4000E-2	4.9969E-1	-9.8489E-2	3.7312E+0
20	2.5250E-2	NM	NM	3.0668E+0

	M: 2.5 - 4.5 R Theta $\times 10^{-3}$: 1-8.2 TW/TR: 1	7701
		ZPG - AW
Continuous wind tunnel with flexible nozzle. W = 0.91, H = 1.22 m. $0.04 < P_0 < 0.2$ MN/m ² . T ₀ : 315K. Air: Dew point, 243K. $3.8 < RE/m \times 10^{-6} < 8.0$.		
MABEY D.G., 1977. Some measurements of transitional and turbulent boundary layers at low Reynolds numbers at supersonic speeds. Appendix E of: Some observations on the wake component of the velocity profiles of turbulent boundary layers at subsonic and supersonic speeds. RAE TR 77-004. <u>And:</u> Mabey et al., CAT 7402, Mabey D.G., private communication. <u>Also:</u> Mabey (1979)		

1 In all respects the equipment and procedures used were as for Mabey et al. (CAT 7402) so that the
11 description for that entry should be consulted.

12 The data presented here are from measurements made at three X stations on the centreline of the flat
14 plate, X = 0.368, 0.623, 0.876 m, and in principle at two unit Reynolds numbers ($4.8 \times 10^6/m$) for
Mach numbers of 2.5, 3.5, 4.0, 4.5. The 18 profiles obtained were classed as 'turbulent' (0101-0502)
and 'transitional' (0601-0901) by the author. The 'series' here divide each group up by Mach number
and for series 01/02, unit Reynolds number.

§ DATA: 70010101-0901. NX up to 3. Pitot and T₀ profiles obtained with same probe. CF obtained
separately with FEB.

15 Editors' comments. These data extend further the very large pool of carefully observed adiabatic flat
plate data presented by Mabey et al. (CAT 7402) and Hastings and Sawyer (CAT 7006). We continue to
regard these experiments for the greater part as the basic source of such data in the range of Mach
number and Reynolds number covered. Sample profiles are plotted as Figs. 4.4.13-17 in AGARDograph 253
and are generally in excellent agreement with the "standard" wall and outer laws, with the
exception of profiles 0601/0701 shown in Fig. (4.4.16) where it appears that some gross error has
occurred. These profiles are so unrepresentative that it is probable that a less meticulous reporter
would have discarded them and possibly been right to do so.

CAT 7701S		MABEY								BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS							
RUN		MD *	TW/TR	RED2W	CF *	M12	M12K	PW	PD								
X *		POD	PW/PD*	RED2D	CO *	M32	M32K	TW*	TD								
RZ		TOD*	TAUM	DZ	P12*	M42	D2K	UD	TR								
7701S0101		2.5000	1.0132	9.5216E+02	2.7400E-03	3.9681	1.5574	2.5445E+03	2.5445E+03								
6.2300E-01		4.3476E+04	1.0000	1.8143E+03	0.0000E+00	1.8293	1.8120	2.9500E+02	1.3733E+02								
INFINITE		3.0900E+02	3.0503E+01	4.5922E-04	0.0000E+00	0.1655	6.0557E-04	5.8741E+02	2.9115E+02								
7701S0102		2.4800	1.0128	1.6961E+03	2.1900E-03	3.8226	1.4486	2.5982E+03	2.5982E+03								
6.7300E-01		4.3033E+04	1.0000	3.2057E+03	0.0000E+00	1.8124	1.7970	2.9500E+02	1.3856E+02								
INFINITE		3.0900E+02	2.4497E+01	8.1117E-04	0.0000E+00	0.1567	1.0879E-03	5.8530E+02	2.9127E+02								
7701S0201		2.4900	1.0130	2.1924E+03	2.1200E-03	4.0263	1.5348	5.0782E+03	5.0782E+03								
3.6800E-01		8.5426E+04	1.0000	4.1605E+03	0.0000E+00	1.8067	1.7930	2.9500E+02	1.3795E+02								
INFINITE		3.0900E+02	4.6724E+01	5.3313E-04	0.0000E+00	0.1343	7.2482E-04	5.8636E+02	2.9121E+02								
7701S0202		2.4900	1.0130	3.1818E+03	2.0100E-03	4.0562	1.4592	5.0782E+03	5.0782E+03								
6.2300E-01		8.5426E+04	1.0000	6.0382E+03	0.0000E+00	1.8042	1.7908	2.9500E+02	1.3795E+02								
INFINITE		3.0900E+02	4.4299E+01	7.7373E-04	0.0000E+00	0.0837	1.0638E-03	5.8636E+02	2.9121E+02								
7701S0203		2.4900	1.0130	4.3256E+03	1.8200E-03	3.9696	1.4168	5.1424E+03	5.1424E+03								
6.7300E-01		8.6507E+04	1.0000	8.2089E+03	0.0000E+00	1.8045	1.7908	2.9500E+02	1.3795E+02								
INFINITE		3.0900E+02	4.0620E+01	1.0387E-03	0.0000E+00	0.0944	1.4249E-03	5.8636E+02	2.9121E+02								
7701S0301		3.4800	1.0174	1.0042E+03	2.2000E-03	5.4647	1.4216	9.7025E+02	9.7025E+02								
8.7600E-01		7.1928E+04	1.0000	2.8084E+03	0.0000E+00	1.8423	1.8149	2.9500E+02	9.1465E+01								
INFINITE		3.1300E+02	1.8095E+01	7.4467E-04	0.0000E+00	0.3440	1.1417E-03	6.6729E+02	2.8996E+02								
7701S0302		3.4900	1.0175	1.2688E+03	2.0700E-03	5.6016	1.4819	1.8981E+03	1.8981E+03								
6.2300E-01		1.4273E+05	1.0000	3.5623E+03	0.0000E+00	1.8479	1.8253	2.9500E+02	9.1094E+01								
INFINITE		3.1300E+02	3.3500E+01	4.7857E-04	0.0000E+00	0.3373	7.2947E-04	6.6785E+02	2.8992E+02								
7701S0303		3.4900	1.0175	1.9373E+03	1.6900E-03	5.8767	1.4236	1.9228E+03	1.9228E+03								
8.7600E-01		1.4459E+05	1.0000	5.4393E+03	0.0000E+00	1.8291	1.8056	2.9500E+02	9.1094E+01								
INFINITE		3.1300E+02	2.7706E+01	7.2136E-04	0.0000E+00	0.2515	1.1579E-03	6.6785E+02	2.8992E+02								
7701S0401		3.9600	1.0199	8.2467E+02	2.0800E-03	6.3925	1.4082	6.3638E+02	6.3638E+02								
8.7600E-01		9.1594E+04	1.0000	2.7699E+03	0.0000E+00	1.8560	1.8224	2.9500E+02	7.5913E+01								
INFINITE		3.1400E+02	1.4530E+01	7.4644E-04	0.0000E+00	0.4146	1.2119E-03	6.9177E+02	2.8924E+02								
7701S0402		3.9900	1.0138	9.2695E+02	2.1000E-03	6.4020	1.4881	1.2208E+03	1.2208E+03								
6.2300E-01		1.8291E+05	1.0000	3.1293E+03	0.0000E+00	1.8543	1.8274	2.9500E+02	7.5525E+01								
INFINITE		3.1600E+02	2.8570E+01	4.3246E-04	0.0000E+00	0.4586	7.0315E-04	6.9523E+02	2.9099E+02								
7701S0403		3.9600	1.0167	1.4886E+03	1.6400E-03	6.9959	1.4146	1.2792E+03	1.2792E+03								
8.7600E-01		1.8412E+05	1.0000	4.9842E+03	0.0000E+00	1.8410	1.8133	2.9500E+02	7.6155E+01								
INFINITE		3.1500E+02	2.3029E+01	6.7136E-04	0.0000E+00	0.2900	1.1492E-03	6.9287E+02	2.9016E+02								
7701S0501		4.4600	1.0279	6.1314E+02	2.0100E-03	7.6357	1.4512	4.1677E+02	4.1677E+02								
8.7600E-01		1.1473E+05	1.0000	2.4862E+03	0.0000E+00	1.8645	1.8197	2.9500E+02	6.2873E+01								
INFINITE		3.1300E+02	1.1664E+01	6.8475E-04	0.0000E+00	0.4646	1.1942E-03	7.0905E+02	2.8699E+02								
7701S0502		4.4700	1.0182	1.0866E+03	1.4400E-03	7.3792	1.4083	7.2139E+02	7.2139E+02								
8.7600E-01		2.0110E+05	1.0000	4.3795E+03	0.0000E+00	1.8559	1.8185	2.9500E+02	6.3248E+01								
INFINITE		3.1600E+02	1.4529E+01	7.0157E-04	0.0000E+00	0.5050	1.2385E-03	7.1276E+02	2.8971E+02								
7701S0601		2.4900	1.0130	5.3784E+02	2.6800E-03	6.6174	2.7917	2.5712E+03	2.5712E+03								
3.6800E-01		4.3253E+04	1.0000	1.0207E+03	0.0000E+00	1.6142	1.5692	2.9500E+02	1.3795E+02								
INFINITE		3.0900E+02	2.9907E+01	2.5831E-04	0.0000E+00	0.0038	4.2788E-04	5.8636E+02	2.9121E+02								
7701S0701		3.5100	1.0145	5.2367E+02	9.9000E-04	9.2292	2.3930	1.8487E+03	1.8487E+03								
3.6800E-01		1.4302E+05	1.0000	1.4774E+03	0.0000E+00	1.6804	1.6173	2.9500E+02	9.0646E+01								
INFINITE		3.1400E+02	1.5784E+01	2.0116E-04	0.0000E+00	0.0174	4.3282E-04	6.7003E+02	2.9077E+02								
7701S0702		3.5100	1.0178	5.1341E+02	1.8900E-03	6.5161	1.6571	9.1978E+02	9.1978E+02								
6.2300E-01		7.1156E+04	1.0000	1.4529E+03	0.0000E+00	1.8032	1.7597	2.9500E+02	9.0357E+01								
INFINITE		3.1300E+02	1.4992E+01	3.9576E-04	0.0000E+00	0.2312	6.8635E-04	6.6896E+02	2.8985E+02								
7701S0801		4.0000	1.0203	4.1032E+02	1.6000E-03	8.5223	1.7763	5.9909E+02	5.9909E+02								
6.2300E-01		9.0964E+04	1.0000	1.3992E+03	0.0000E+00	1.7946	1.7357	2.9500E+02	7.4762E+01								
INFINITE		3.1400E+02	1.0736E+01	3.8759E-04	0.0000E+00	0.1853	7.7628E-04	6.9344E+02	2.8912E+02								
7701S0901		4.5100	1.0186	5.7531E+02	1.6300E-03	8.4900	1.5573	6.8804E+02	6.8804E+02								
6.2300E-01		2.0163E+05	1.0000	2.3524E+03	0.0000E+00	1.8411	1.7946	2.9500E+02	6.2352E+01								
INFINITE		3.1600E+02	1.5968E+01	3.8327E-04	0.0000E+00	0.3936	7.3731E-04	7.1402E+02	2.8962E+02								

PD, POD CALCULATED WITH RED2, D2 (AUTHOR) WITH SUTHERLAND MUE-LAW
 TRAPEZOIDAL RULE FOR ALL INTEGRATIONS

7701S0301		MABEY	PROFILE TABULATION		48 POINTS, DELTA AT POINT 48			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.94099	0.00000	0.00000	3.22014	0.00000
2	3.6300 ⁻ 04	1.9287 ⁺ 00	NM	0.95674	0.29194	0.48094	2.71382	0.17722
3	3.8900 ⁻ 04	2.0370 ⁺ 00	NM	0.95677	0.30513	0.49875	2.67167	0.18668
4	4.1400 ⁻ 04	2.1964 ⁺ 00	NM	0.95856	0.32306	0.52276	2.61837	0.19965
5	4.6500 ⁻ 04	2.4613 ⁺ 00	NM	0.95954	0.35010	0.55708	2.53198	0.22002
6	4.9000 ⁻ 04	2.6403 ⁺ 00	NM	0.95951	0.36693	0.57739	2.47605	0.23319
7	5.1600 ⁻ 04	2.7702 ⁺ 00	NM	0.95575	0.37859	0.58989	2.42784	0.24297
8	5.4100 ⁻ 04	2.9069 ⁺ 00	NM	0.96017	0.39041	0.60480	2.39981	0.25202
9	5.6600 ⁻ 04	3.0398 ⁺ 00	NM	0.96010	0.40153	0.61721	2.36286	0.26121
10	5.9200 ⁻ 04	3.1747 ⁺ 00	NM	0.95998	0.41246	0.62911	2.32649	0.27041
11	6.6800 ⁻ 04	3.5340 ⁺ 00	NM	0.95942	0.44011	0.65793	2.23477	0.29441
12	7.1900 ⁻ 04	3.7414 ⁺ 00	NM	0.95789	0.45524	0.67254	2.18245	0.30816
13	7.7000 ⁻ 04	3.9298 ⁺ 00	NM	0.95573	0.46853	0.68464	2.13527	0.32063
14	8.2000 ⁻ 04	4.1183 ⁺ 00	NM	0.95565	0.48144	0.69675	2.09448	0.33266
15	8.7100 ⁻ 04	4.2525 ⁺ 00	NM	0.95395	0.49040	0.70435	2.06286	0.34144
16	9.9800 ⁻ 04	4.5623 ⁺ 00	NM	0.94971	0.51048	0.72056	1.99241	0.36165
17	1.1250 ⁻ 03	4.8263 ⁺ 00	NM	0.94715	0.52696	0.73357	1.93784	0.37855
18	1.2520 ⁻ 03	5.0369 ⁺ 00	NM	0.94544	0.53973	0.74337	1.89694	0.39188
19	1.3790 ⁻ 03	5.1993 ⁺ 00	NM	0.94445	0.54937	0.75068	1.86712	0.40205
20	1.5060 ⁻ 03	5.3787 ⁺ 00	NM	0.94335	0.55982	0.75838	1.83517	0.41325
21	1.6330 ⁻ 03	5.5826 ⁺ 00	NM	0.94276	0.57146	0.76698	1.80137	0.42578
22	1.8890 ⁻ 03	5.9111 ⁺ 00	NM	0.94304	0.58971	0.78049	1.75171	0.44556
23	2.1410 ⁻ 03	6.2213 ⁺ 00	NM	0.94429	0.60643	0.79280	1.70910	0.46387
24	2.3950 ⁻ 03	6.4861 ⁺ 00	NM	0.94486	0.62034	0.80250	1.67354	0.47952
25	2.6490 ⁻ 03	6.7562 ⁺ 00	NM	0.94642	0.63420	0.81231	1.64052	0.49515
26	2.9030 ⁻ 03	7.0262 ⁺ 00	NM	0.94652	0.64776	0.82101	1.60644	0.51107
27	3.4110 ⁻ 03	7.6083 ⁺ 00	NM	0.94922	0.67606	0.83942	1.54165	0.54450
28	3.9190 ⁻ 03	8.1379 ⁺ 00	NM	0.95154	0.70080	0.85463	1.48718	0.57466
29	4.4270 ⁻ 03	8.6859 ⁺ 00	NM	0.95447	0.72550	0.86933	1.43581	0.60547
30	4.9350 ⁻ 03	9.2001 ⁺ 00	NM	0.95640	0.74794	0.88174	1.38980	0.63444
31	5.4430 ⁻ 03	9.7205 ⁺ 00	NM	0.95845	0.76996	0.89345	1.34647	0.66355
32	6.0780 ⁻ 03	1.0377 ⁺ 01	NM	0.96137	0.79686	0.90725	1.29626	0.69990
33	6.7130 ⁻ 03	1.1078 ⁺ 01	NM	0.96414	0.82466	0.92066	1.24638	0.73867
34	7.3480 ⁻ 03	1.1733 ⁺ 01	NM	0.96853	0.84975	0.93307	1.20570	0.77388
35	7.9830 ⁻ 03	1.2316 ⁺ 01	NM	0.97310	0.87152	0.94377	1.17268	0.80480
36	8.6180 ⁻ 03	1.2881 ⁺ 01	NM	0.97625	0.89209	0.95298	1.14116	0.83510
37	9.2530 ⁻ 03	1.3503 ⁺ 01	NM	0.97937	0.91419	0.96238	1.10820	0.86842
38	9.9880 ⁻ 03	1.3971 ⁺ 01	NM	0.98411	0.93047	0.97029	1.08742	0.89228
39	1.0523 ⁻ 02	1.4363 ⁺ 01	NM	0.98946	0.94390	0.97739	1.07223	0.91155
40	1.1158 ⁻ 02	1.4899 ⁺ 01	NM	0.99066	0.96195	0.98379	1.04592	0.94060
41	1.1793 ⁻ 02	1.5122 ⁺ 01	NM	0.99385	0.96936	0.98769	1.03819	0.95136
42	1.2428 ⁻ 02	1.5379 ⁺ 01	NM	0.99563	0.97784	0.99120	1.02750	0.96467
43	1.3063 ⁻ 02	1.5609 ⁺ 01	NM	0.99709	0.98534	0.99420	1.01806	0.97656
44	1.4333 ⁻ 02	1.5670 ⁺ 01	NM	0.99809	0.98733	0.99530	1.01620	0.97943
45	1.5603 ⁻ 02	1.5988 ⁺ 01	NM	0.99881	0.99760	0.99870	1.00221	0.99650
46	1.6873 ⁻ 02	1.6055 ⁺ 01	NM	0.99995	0.99975	0.99990	1.00030	0.99960
47	1.8143 ⁻ 02	1.6080 ⁺ 01	NM	0.99988	1.00055	1.00010	0.99910	1.00100
D 48	1.9413 ⁻ 02	1.6067 ⁺ 01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,U/UD,RHD/RHOD ASSUME P=PD

7701S0801

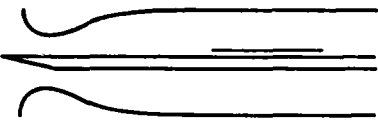
MABEY

PROFILE TABULATION

47 POINTS, DELTA AT POINT 47

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.93904	0.00000	0.00000	3.94396	0.00000
2	3.6500"-04	1.1375"+00	NM	0.95025	0.10825	0.21232	3.84681	0.05519
3	3.8900"-04	1.2144"+00	NM	0.95277	0.13354	0.25983	3.78561	0.06864
4	4.1400"-04	1.2848"+00	NM	0.95521	0.15230	0.29433	3.73468	0.07881
5	4.3900"-04	1.3965"+00	NM	0.95783	0.17688	0.33823	3.65679	0.09249
6	4.6500"-04	1.4852"+00	NM	0.95940	0.19337	0.36684	3.59885	0.10193
7	4.9000"-04	1.5900"+00	NM	0.96199	0.21042	0.39584	3.53895	0.11185
8	5.1600"-04	1.7099"+00	NM	0.96408	0.22751	0.42404	3.47376	0.12207
9	5.4100"-04	1.8094"+00	NM	0.96568	0.24020	0.44444	3.42378	0.12981
10	5.6600"-04	1.8844"+00	NM	0.96702	0.24903	0.45845	3.38895	0.13528
11	5.9200"-04	1.9521"+00	NM	0.96764	0.25654	0.47005	3.35707	0.14002
12	6.1700"-04	2.1336"+00	NM	0.97034	0.27507	0.49825	3.28102	0.15186
13	6.6800"-04	2.3112"+00	NM	0.97170	0.29157	0.52225	3.20835	0.16278
14	7.1900"-04	2.4875"+00	NM	0.97149	0.30678	0.54325	3.13586	0.17324
15	7.7000"-04	2.6988"+00	NM	0.97638	0.32385	0.56746	3.07035	0.18482
16	8.2000"-04	2.9109"+00	NM	0.97825	0.33995	0.58876	2.99940	0.19629
17	8.7100"-04	3.1009"+00	NM	0.97969	0.35367	0.60626	2.93855	0.20631
18	9.9800"-04	3.5017"+00	NM	0.98021	0.38080	0.63856	2.81204	0.22708
19	1.1250"-03	3.9027"+00	NM	0.98125	0.40598	0.66687	2.69816	0.24716
20	1.2520"-03	4.2628"+00	NM	0.98138	0.42725	0.68917	2.60193	0.26487
21	1.3790"-03	4.5693"+00	NM	0.98057	0.44451	0.70607	2.52310	0.27984
22	1.5060"-03	4.8718"+00	NM	0.98060	0.46088	0.72167	2.45191	0.29433
23	1.6330"-03	5.1665"+00	NM	0.97990	0.47627	0.73547	2.38463	0.30842
24	1.8870"-03	5.8237"+00	NM	0.97980	0.50887	0.76338	2.25039	0.33922
25	2.1410"-03	6.4331"+00	NM	0.97919	0.53729	0.78558	2.13775	0.36748
26	2.3950"-03	7.0655"+00	NM	0.97853	0.56525	0.80578	2.03213	0.39652
27	2.6490"-03	7.7178"+00	NM	0.97819	0.59269	0.82428	1.93420	0.42616
28	2.9030"-03	8.3856"+00	NM	0.97856	0.61950	0.84138	1.84459	0.45614
29	3.4110"-03	9.8573"+00	NM	0.97890	0.67482	0.87289	1.67320	0.52169
30	3.9190"-03	1.1588"+01	NM	0.98001	0.73452	0.90249	1.50967	0.59781
31	4.4270"-03	1.3405"+01	NM	0.98124	0.79235	0.92729	1.36960	0.67705
32	4.9350"-03	1.5284"+01	NM	0.98249	0.84799	0.94809	1.25003	0.75846
33	5.4430"-03	1.7183"+01	NM	0.98360	0.90073	0.96540	1.14874	0.84040
34	6.7130"-03	1.9457"+01	NM	0.99023	0.96009	0.98520	1.05300	0.93561
35	7.3480"-03	2.0057"+01	NM	0.99455	0.97515	0.99120	1.03319	0.95936
36	7.9830"-03	2.0400"+01	NM	0.99572	0.98365	0.99390	1.02094	0.97351
37	8.6180"-03	2.0564"+01	NM	0.99874	0.98769	0.99640	1.01772	0.97905
38	9.2530"-03	2.0781"+01	NM	0.99876	0.99300	0.99770	1.00949	0.98832
39	9.8880"-03	2.0807"+01	NM	1.00025	0.99364	0.99860	1.01001	0.98871
40	1.0523"-02	2.0885"+01	NM	1.00053	0.99554	0.99920	1.00736	0.99190
41	1.1158"-02	2.0957"+01	NM	1.00029	0.99730	0.99950	1.00442	0.99510
42	1.1793"-02	2.0871"+01	NM	0.99810	0.99520	0.99790	1.00543	0.99251
43	1.2428"-02	2.1035"+01	NM	0.99539	0.99920	0.99750	0.99661	1.00089
44	1.3063"-02	2.0959"+01	NM	1.00167	0.99734	1.00020	1.00574	0.99450
45	1.4333"-02	2.1000"+01	NM	1.00119	0.99835	1.00020	1.00372	0.99650
46	1.5603"-02	2.1076"+01	NM	1.00091	1.00020	1.00050	1.00060	0.99990
D 47	1.6873"-02	2.1068"+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,U/UD,RHO/RHOD ASSUME P=PD

	M: 3.0 R THETA $\times 10^{-3}$: 3-4 TW/TR: 0.58, 0.77, 1.0	7702
ZPG - M/SHT		
Continuous wind tunnel with fixed symmetrical nozzle. W = 0.079, H = 0.086 m. PO: 0.079 MN/m². TO: 318K. Air, dew point 236K. RE/m $\times 10^{-6}$: 6.6.		
LADERMAN A.J., DEMETRIADES A., 1977. Final technical report. Investigation of the structure of a cooled wall turbulent supersonic boundary layer. Aeronutronic Publication No. U-6370. Newport Beach, CA. And Laderman (1978a), Laderman A.J., private communications.		

- 1 The test boundary layer was formed on the upper surface of an aluminium plate (W = 76.2, L = 660.4, t = 4.75 mm) which was mounted so as to span the tunnel with the test surface on the centreline. The leading edge (X = 0), chamfered at 5° on the underside, was 100 mm upstream of the tunnel throat and measurements were made at X = 350, 388, 425 mm in the nominally constant pressure test zone. Provision was made for cooling of the plate with liquid nitrogen, the cooling system operating for X > 89 mm, and maintaining nominally constant wall temperatures for X > 200 mm. At the lowest temperatures used, a frost layer formed on the plate. Tests were made to determine the possible influence of this frost film. The wall temperature was steadily reduced with the tunnel running and with a thin-film probe mounted at Y = 0.75 mm. The temperature recorded showed no discontinuity as the frost formed. It was concluded that the frost formation had no separate effect on the flow field. Pressure tapings
- 2 were not affected, and the particle size was small enough not to cause any roughness effects. Flow
- 5 uniformity and two-dimensionality were assessed for the main part by Pitot surveys of the volume 250 < x < 480 mm, 0 < Y < 16.5 mm, -16.5 < Z < +16.5 mm. The results obtained, together with sensitive Schlieren studies, suggested that "two-dimensionality of the flow is apparent and it is noted that
- 3 there are no shocks or other wavelets in the surveyed volume." Thermocouples on and off the centreline showed that transverse variation of TW was not significant. The same surveys showed that the profiles
- 4 were "typically turbulent". The test layer has passed through the nozzle pressure gradient growing on the plate in a region without forced cooling. For the cooled wall cases therefore it also passes over a region of rapidly falling wall temperature, with profile measurements commencing about 20 boundary layer thicknesses downstream.
- 6 Wall pressure and temperature were measured by 9 static tapings (d = 0.5 mm) and 14 iron-constantan thermocouples at the positions shown in Table 1. A Preston tube was used in an attempt to determine skin friction.
- 7 Pitot and total temperature probes were carried by a traverse gear mounted in the tunnel roof. The CCP was constructed from 0.1 mm tube and tapered down over the foremost 3.1 mm to give a sharp-lipped orifice (d₁ = d₂ = 0.05 mm). The overall length of the streamwise part of the probe was 6.3 mm. The TTP consisted of an unshielded chromel-alumel thermocouple with the junction between the 0.038 mm wires formed as a 0.127 mm sphere mounted 1.5 mm ahead of the ceramic insulating support (d = 2.4, l = 25.4 mm). A calibration was made in the tunnel freestream which yielded (T(measured) - T)/ (T₀(true) - T) as a function of Reynolds number based on the bead diameter. This "therefore accounts
- 8 for the effects of local Mach number". Traverses were made at X = 350, 388, 425 mm on the centreline.
- 9 The relative positions of static tapings and thermocouples may be seen in Table 1.

The authors assumed that, throughout the layer, P = PD as deduced from freestream PT2 measurements. Differences were observed between measured PW values and PD values. The measured PW values however correspond to a very small fraction of the range of the transducer used, so that they were used for checks on two-dimensionality only. The Preston tube readings were abandoned since "they indicated C_f values considerably higher than implied by the trend of the velocity data. (This is apparently a

consequence of the large scatter inherent in existing Preston tube correlations.)" This discrepancy has since been traced to a numerical error in data reduction. The values finally used were obtained from the correlation of data by Hopkins and Inouye (1971) or from one of a number of variants based on curve fittings to Coles' (1969) wall and wake law. These values and the streamwise variation of the velocity profile data have then been used to calculate the shear stress distribution through the boundary layer. The authors remark that the Pitot data are affected by wall interference at very low values of Y . Since only a very few points close to the wall were affected, no wall proximity correction was applied. "Viscous and rarefaction effects at low Re were examined and concluded to be negligible for $Y > 0.1$ mm" and no corrections made.

The editors have presented the profile data as given by the authors, incorporating therefore their assumptions and data reduction procedures. The Hopkins and Inouye (1971) CF value is given for convenience, the alternative values based on the velocity profiles being given below. The profiles form three sets taken at three successive traverse stations, the sets being distinguished by different TW/TR values.

§ DATA: 7702-0101-0303. Pitot and TO profiles. $NX = 3$. (CF - Preston).

Editors comments. There are relatively few experiments which describe the cooled wall boundary layer in any detail. All such data considered in AGARDograph 223 were obtained at $M = 4.9$ or above so that we have processed no strictly comparable data, the comparatively low Mach number here offering the possibility of assessing the effects of strong cooling independently of the instrumental difficulties associated with high Mach number flows. It is particularly unfortunate therefore that a mistake in data reduction resulted in the Preston tube data being discarded. A correctly processed value would have avoided the requirement for the authors' lengthy and inconclusive discussion of the Preston tube data and provided a valuable addition to the measured cooled wall data.

The profiles are given in very close detail, typically with 80 or more points in a boundary layer thickness of order 10 mm. The profiles extend down into the viscous sublayer, but, as noted by the authors, some aerodynamic interference effects are noticeable in this region. For a general discussion of the data see §§ 2.5 and 4.3 of AGARDograph 253. In Fig. 4.3.3 (AG 253) wall law plots are shown using wall shear values as assessed by the authors (Hopkins & Inouye, 1971) and from Fernholz (1971). We there concluded that the 'Fernholz' value gave the better numerical agreement while the 'Hopkins and Inouye' value have the better correlation. In both inner and outer law plots (Fig. 4.3.4, AG 253) the results conform well to the 'incompressible norm'. The measured temperature profiles also agree well with the theoretical predictions (Fig. 2.5.16, eqn. 2.5.37, AG 253), except for the data closest to the wall in the strongly cooled case (series 03).

A principal aim of the investigation was to document the flow in preparation for fluctuation measurements reported in Laderman & Demetriades (1979). The determination of shear stress from the mean flow profiles then provides an independent comparison value for the Reynolds shear stress $-\bar{\rho} \overline{u'v'}$. This procedure requires a remarkably high standard of accuracy, since it depends on the differentiation of experimentally determined quantities. It is doubtful that this can be achieved with three profiles, at least in such close succession as here, unless it is assumed a priori that the profiles are indeed self-similar. The results obtained do however agree well with the general trend of other data (Sandborn, 1974).

Of the very large number of possible comparison cases for the adiabatic flow, we might suggest Mabey (CAT 7701S) and Mabey et al. (CAT 7402) for flows with defined origin and Stalmach (CAT 5802) for a flow of similar pressure history. The nearest comparisons for the heat transfer case are Voisinnet and Lee (CAT 7202) and Gates (CAT 7301).

Note In AGARDograph 253 this experiment was mistakenly cited as a case with no upstream history. It should therefore be removed from the group listed in Table 4.3.1 and added to those listed in Table 4.3.2 of that volume.

TABLE 1
LOCATION OF PRESSURE TAPS (P) AND
THERMOCOUPLES (TC) ON PLATE SURFACE

SENSOR	X (CM)	Z (CM)
P1	8.9	- 2.03
P2	8.9	0
P3	8.9	2.03
P4	20.3	- 2.03
P5	20.3	2.03
P6	34.3	- 2.03
P7	34.3	2.03
P8	45.7	- 2.03
P9	45.7	2.03
TC1	11.4	-2.03
TC2	11.4	0
TC3	11.4	2.03
TC4	17.8	0
TC5	20.3	-0.25
TC6	27.9	-2.03
TC7	27.9	0.38
TC8	27.9	2.03
TC9	40.6	-2.03
TC10	40.6	-0.38
TC11	40.6	0.38
TC12	40.6	2.03
TC13	54.6	-2.03
TC14	54.6	2.03

SECTION D: SUPPLEMENTARY DATA

D1. PROFILE-DERIVED WALL SHEAR. FACSIMILE OF AUTHORS TABLE 5

AUTHORS SYMBOLS AND UNITS

SUMMARY OF VELOCITY CORRELATION CALCULATIONS

IDENT CAT	x sta cm	T_w/T_{oe}	δ (1) cm	c_f (2)	c_f (3)	π (3)	δ (4) cm	c_f (4)	π (4)
7702									
0101	35.05	.94	.846	.00199	.00196	.54	.765	.00188	.70
0102	38.79		.899	.00196	.00192	.56	.800	.00183	.74
0103	42.52		.960	.00192	.00183	.67	.848	.00176	.84
0201	35.05	.714	.820	.00216	.00208	.55	.721	.00201	.70
0202	38.79		.856	.00215	.00204	.58	.757	.00197	.73
0203	42.52		.899	.00210	.00196	.67	.797	.00191	.80
0301	35.05	.54	.836	.00233	.00228	.42	.721	.00221	.57
0302	38.79		.861	.00227	.00206	.68	.800	.00204	.75
0303	42.52		.876	.00224	.00204	.72	.780	.00199	.84

(1) Determined from pitot profile

(2) Calculated from skin friction correlation (Reference 11) (Hopkins & Inouye, 1971)

(3) Calculated from velocity correlation using δ from pitot profile

(4) Calculated from velocity correlation (Reference 12) (Coles, 1968)

CAT 77025		LADERMAN/D.		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS					
RUN X *	MD *	TW/TR	RED2W	CF *	H12	H12K	PW	PD	
RZ	POD*	PW/PD*	RED2D	CQ	H32	H32K	TW*	TD	
	TOO*	TAUM	OZ	PI2*	H42	D2K	UD	TR	
7702S0101	3.0411	1.0033	1.3626 ⁺ 03	1.9900 ⁻ 03	5.4823	1.4356	2.4912 ⁺ 03	2.4912 ⁺ 03	
3.5052 ⁻ 01	9.7309 ⁺ 04	1.0000	3.1676 ⁺ 03	NM	1.7865	1.7590	2.9833 ⁺ 02	1.1191 ⁺ 02	
INFINITE	3.1889 ⁺ 02	3.2093 ⁺ 01	5.0247 ⁻ 04	0.0000 ⁺ 00	0.0476	9.0975 ⁻ 04	6.4500 ⁺ 02	2.9736 ⁺ 02	
7702S0102	3.0257	1.0029	1.4760 ⁺ 03	1.9600 ⁻ 03	5.4408	1.4237	2.5490 ⁺ 03	2.5490 ⁺ 03	
3.8786 ⁻ 01	9.7309 ⁺ 04	1.0000	3.4108 ⁺ 03	NM	1.7849	1.7586	2.9778 ⁺ 02	1.1245 ⁺ 02	
INFINITE	3.1833 ⁺ 02	3.2017 ⁺ 01	5.3516 ⁻ 04	0.0000 ⁺ 00	0.0431	8.6262 ⁻ 04	6.4329 ⁺ 02	2.9692 ⁺ 02	
7702S0103	3.0008	1.0044	1.6364 ⁺ 03	1.9200 ⁻ 03	5.3797	1.4255	2.6461 ⁺ 03	2.6461 ⁺ 03	
4.2520 ⁻ 01	9.7309 ⁺ 04	1.0000	3.7481 ⁺ 03	NM	1.7794	1.7539	2.9889 ⁺ 02	1.1385 ⁺ 02	
INFINITE	3.1889 ⁺ 02	3.2023 ⁺ 01	5.8155 ⁻ 04	0.0000 ⁺ 00	0.0469	9.4093 ⁻ 04	6.4197 ⁺ 02	2.9757 ⁺ 02	
7702S0201	3.0219	0.7657	1.7773 ⁺ 03	2.1600 ⁻ 03	4.7159	1.4186	2.5637 ⁺ 03	2.5637 ⁺ 03	
3.5052 ⁻ 01	9.7309 ⁺ 04	1.0000	3.3075 ⁺ 03	NM	1.7813	1.7601	2.2778 ⁺ 02	1.1283 ⁺ 02	
INFINITE	3.1889 ⁺ 02	3.5398 ⁺ 01	5.1916 ⁻ 04	0.0000 ⁺ 00	0.2350	7.7833 ⁻ 04	6.4357 ⁺ 02	2.9746 ⁺ 02	
7702S0202	3.0263	0.7671	1.8984 ⁺ 03	2.1500 ⁻ 03	4.6471	1.3983	2.5469 ⁺ 03	2.5469 ⁺ 03	
3.8786 ⁻ 01	9.7309 ⁺ 04	1.0000	3.5450 ⁺ 03	NM	1.7810	1.7609	2.2778 ⁺ 02	1.1242 ⁺ 02	
INFINITE	3.1833 ⁺ 02	3.5105 ⁺ 01	5.5638 ⁻ 04	0.0000 ⁺ 00	0.2507	8.3349 ⁻ 04	6.4334 ⁺ 02	2.9692 ⁺ 02	
7702S0203	2.9974	0.7668	2.0872 ⁺ 03	2.1000 ⁻ 03	4.6319	1.4191	2.6596 ⁺ 03	2.6596 ⁺ 03	
4.2520 ⁻ 01	9.7309 ⁺ 04	1.0000	3.8521 ⁺ 03	NM	1.7742	1.7546	2.2778 ⁺ 02	1.1382 ⁺ 02	
INFINITE	3.1833 ⁺ 02	3.5125 ⁺ 01	5.9508 ⁻ 04	0.0000 ⁺ 00	0.2460	8.9395 ⁻ 04	6.4115 ⁺ 02	2.9706 ⁺ 02	
7702S0301	3.0281	0.5801	2.4791 ⁺ 03	2.3300 ⁻ 03	3.8007	1.3702	2.5400 ⁺ 03	2.5400 ⁺ 03	
3.5052 ⁻ 01	9.7309 ⁺ 04	1.0000	3.6564 ⁺ 03	NM	1.7869	1.7724	1.7222 ⁺ 02	1.1233 ⁺ 02	
INFINITE	3.1833 ⁺ 02	3.7986 ⁺ 01	5.7444 ⁻ 04	0.0000 ⁺ 00	0.4780	7.8744 ⁻ 04	6.4347 ⁺ 02	2.9691 ⁺ 02	
7702S0302	3.0379	0.5801	2.6680 ⁺ 03	2.2700 ⁻ 03	4.1956	1.4092	2.5031 ⁺ 03	2.5031 ⁺ 03	
3.8786 ⁻ 01	9.7309 ⁺ 04	1.0000	3.9507 ⁺ 03	NM	1.7725	1.7563	1.7222 ⁺ 02	1.1186 ⁺ 02	
INFINITE	3.1833 ⁺ 02	3.6706 ⁺ 01	6.2401 ⁻ 04	0.0000 ⁺ 00	0.3831	8.9188 ⁻ 04	6.4420 ⁺ 02	2.9686 ⁺ 02	
7702S0303	2.9856	0.5786	2.8269 ⁺ 03	2.2400 ⁻ 03	3.9801	1.3828	2.7071 ⁺ 03	2.7071 ⁺ 03	
4.2520 ⁻ 01	9.7309 ⁺ 04	1.0000	4.0917 ⁺ 03	NM	1.7695	1.7569	1.7222 ⁺ 02	1.1460 ⁺ 02	
INFINITE	3.1889 ⁺ 02	3.7836 ⁺ 01	6.2960 ⁻ 04	0.0000 ⁺ 00	0.4002	8.8295 ⁻ 04	6.4080 ⁺ 02	2.9764 ⁺ 02	

7702S0301

LADERMAN/D.

PROFILE TABULATION

78 POINTS, DELTA AT POINT 66

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.54101	0.00000	0.00000	1.53315	0.00000
2	5.0800 ⁻ 05	1.4906 ⁺ 00	NM	0.63730	0.25667	0.32581	1.61135	0.20220
3	5.8928 ⁻ 05	1.5379 ⁺ 00	NM	0.64831	0.26713	0.34049	1.62462	0.20958
4	7.9248 ⁻ 05	1.5971 ⁺ 00	NM	0.67058	0.27936	0.36020	1.66240	0.21667
5	9.1440 ⁻ 05	1.6148 ⁺ 00	NM	0.69197	0.28287	0.36990	1.71001	0.21632
6	1.0465 ⁻ 04	1.6621 ⁺ 00	NM	0.71563	0.29189	0.38656	1.75395	0.22040
7	1.1379 ⁻ 04	1.7154 ⁺ 00	NM	0.72141	0.30150	0.39911	1.75227	0.22776
8	1.3208 ⁻ 04	1.8810 ⁺ 00	NM	0.73546	0.32845	0.43325	1.73997	0.24900
9	1.4935 ⁻ 04	2.0949 ⁺ 00	NM	0.74496	0.35836	0.46844	1.70869	0.27415
10	1.5850 ⁻ 04	2.2017 ⁺ 00	NM	0.74794	0.37193	0.48360	1.69066	0.28604
11	1.8593 ⁻ 04	2.4741 ⁺ 00	NM	0.76001	0.40376	0.51991	1.65807	0.31356
12	2.1336 ⁻ 04	2.6986 ⁺ 00	NM	0.77119	0.42777	0.54720	1.63633	0.33441
13	2.3876 ⁻ 04	2.9112 ⁺ 00	NM	0.78080	0.44910	0.57077	1.61523	0.35337
14	2.6924 ⁻ 04	3.0884 ⁺ 00	NM	0.79102	0.46602	0.59005	1.60316	0.36806
15	3.2817 ⁻ 04	3.3447 ⁺ 00	NM	0.80262	0.48933	0.61518	1.58049	0.38923
16	3.8100 ⁻ 04	3.5054 ⁺ 00	NM	0.81170	0.50334	0.63080	1.57053	0.40165
17	4.2469 ⁻ 04	3.6065 ⁺ 00	NM	0.81605	0.51195	0.63981	1.56188	0.40964
18	4.7854 ⁻ 04	3.7492 ⁺ 00	NM	0.82198	0.52382	0.65207	1.54963	0.42079
19	5.2629 ⁻ 04	3.8620 ⁺ 00	NM	0.82562	0.53301	0.66107	1.53825	0.42976
20	5.8115 ⁻ 04	3.9806 ⁺ 00	NM	0.83030	0.54250	0.67063	1.52818	0.43884
21	6.2789 ⁻ 04	4.0541 ⁺ 00	NM	0.83329	0.54829	0.67647	1.52223	0.44439
22	6.9393 ⁻ 04	4.1280 ⁺ 00	NM	0.83726	0.55404	0.68264	1.51809	0.44967
23	7.4879 ⁻ 04	4.1962 ⁺ 00	NM	0.84153	0.55930	0.68852	1.51543	0.45434
24	8.8798 ⁻ 04	4.3950 ⁺ 00	NM	0.84748	0.57433	0.70257	1.49644	0.46950
25	1.0150 ⁻ 03	4.6725 ⁺ 00	NM	0.85459	0.59465	0.72076	1.46910	0.49061
26	1.1379 ⁻ 03	4.7964 ⁺ 00	NM	0.86093	0.60349	0.72990	1.46278	0.49898
27	1.2781 ⁻ 03	4.8612 ⁺ 00	NM	0.86529	0.60807	0.73505	1.46127	0.50302
28	1.3950 ⁻ 03	5.0321 ⁺ 00	NM	0.86879	0.61995	0.74502	1.44416	0.51588
29	1.5443 ⁻ 03	5.2087 ⁺ 00	NM	0.87777	0.63200	0.75729	1.43579	0.52743
30	1.6784 ⁻ 03	5.3793 ⁺ 00	NM	0.88485	0.64341	0.76817	1.42540	0.53892
31	1.8115 ⁻ 03	5.5205 ⁺ 00	NM	0.88922	0.65270	0.77633	1.41469	0.54876
32	2.0655 ⁻ 03	5.8257 ⁺ 00	NM	0.89931	0.67233	0.79364	1.39343	0.56956
33	2.3338 ⁻ 03	6.1507 ⁺ 00	NM	0.90970	0.69261	0.81111	1.37147	0.59142
34	2.5999 ⁻ 03	6.4815 ⁺ 00	NM	0.91863	0.71264	0.82737	1.34790	0.61382
35	2.8732 ⁻ 03	6.8241 ⁺ 00	NM	0.93378	0.73281	0.84614	1.33323	0.63466
36	3.1476 ⁻ 03	7.1668 ⁺ 00	NM	0.93668	0.75243	0.85866	1.30232	0.65933
37	3.4016 ⁻ 03	7.5214 ⁺ 00	NM	0.94559	0.77219	0.87363	1.28000	0.68253
38	3.6759 ⁻ 03	7.8761 ⁺ 00	NM	0.95223	0.79147	0.88695	1.25583	0.70626
39	3.9299 ⁻ 03	8.2429 ⁺ 00	NM	0.95836	0.81091	0.89977	1.23117	0.73082
40	4.2042 ⁻ 03	8.6219 ⁺ 00	NM	0.96374	0.83051	0.91199	1.20583	0.75632
41	4.4785 ⁻ 03	8.9909 ⁺ 00	NM	0.97114	0.84917	0.92440	1.18503	0.78006
42	4.7325 ⁻ 03	9.3768 ⁺ 00	NM	0.97651	0.86824	0.93574	1.16154	0.80561
43	4.9865 ⁻ 03	9.6984 ⁺ 00	NM	0.98125	0.88382	0.94497	1.14317	0.82662
44	5.2710 ⁻ 03	1.0083 ⁺ 01	NM	0.98660	0.90207	0.95544	1.12182	0.85169
45	5.5352 ⁻ 03	1.0470 ⁺ 01	NM	0.98664	0.92011	0.96299	1.09539	0.87913
46	5.6672 ⁻ 03	1.0637 ⁺ 01	NM	0.98783	0.92777	0.96669	1.08565	0.89042
47	5.7892 ⁻ 03	1.0798 ⁺ 01	NM	0.98882	0.93512	0.97012	1.07627	0.90137
48	5.9314 ⁻ 03	1.0977 ⁺ 01	NM	0.99193	0.94321	0.97485	1.06821	0.91260
49	6.0635 ⁻ 03	1.1131 ⁺ 01	NM	0.98987	0.95007	0.97651	1.05643	0.92434
50	6.1956 ⁻ 03	1.1285 ⁺ 01	NM	0.99252	0.95694	0.98046	1.04976	0.93398
51	6.3276 ⁻ 03	1.1428 ⁺ 01	NM	0.99060	0.96324	0.98190	1.03913	0.94493
52	6.4496 ⁻ 03	1.1552 ⁺ 01	NM	0.99144	0.96872	0.98438	1.03259	0.95331
53	6.5816 ⁻ 03	1.1671 ⁺ 01	NM	0.99091	0.97391	0.98605	1.02507	0.96193
54	6.7442 ⁻ 03	1.1808 ⁺ 01	NM	0.99196	0.97985	0.98875	1.01824	0.97104
55	6.8560 ⁻ 03	1.1892 ⁺ 01	NM	0.99145	0.98345	0.98981	1.01296	0.97714
56	6.9779 ⁻ 03	1.1969 ⁺ 01	NM	0.99045	0.98678	0.99051	1.00758	0.98307
57	7.1201 ⁻ 03	1.2040 ⁺ 01	NM	0.99293	0.98985	0.99286	1.00609	0.98685
58	7.2522 ⁻ 03	1.2094 ⁺ 01	NM	0.99303	0.99214	0.99372	1.00320	0.99056
59	7.3843 ⁻ 03	1.2148 ⁺ 01	NM	0.99111	0.99443	0.99358	0.99829	0.99528
60	7.5265 ⁻ 03	1.2165 ⁺ 01	NM	0.99097	0.99519	0.99378	0.99716	0.99660
61	7.6586 ⁻ 03	1.2195 ⁺ 01	NM	0.98993	0.99646	0.99371	0.99448	0.99922
62	7.7907 ⁻ 03	1.2237 ⁺ 01	NM	0.99761	0.99823	0.99818	0.99990	0.99828
63	7.9228 ⁻ 03	1.2267 ⁺ 01	NM	0.99527	0.99949	0.99745	0.99592	1.00154
64	8.0548 ⁻ 03	1.2267 ⁺ 01	NM	0.98572	0.99949	0.99266	0.98636	1.00638
65	8.1869 ⁻ 03	1.2261 ⁺ 01	NM	0.98817	0.99924	0.99380	0.98914	1.00471
D 66	8.3393 ⁻ 03	1.2279 ⁺ 01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
67	8.4714 ⁻ 03	1.2291 ⁺ 01	NM	0.98866	1.00051	0.99449	0.98802	1.00655
68	8.5933 ⁻ 03	1.2291 ⁺ 01	NM	0.98868	1.00051	0.99450	0.98803	1.00655
69	8.7152 ⁻ 03	1.2285 ⁺ 01	NM	0.98786	1.00025	0.99400	0.98754	1.00654
70	8.8575 ⁻ 03	1.2291 ⁺ 01	NM	0.98775	1.00051	0.99403	0.98710	1.00702
71	8.9794 ⁻ 03	1.2291 ⁺ 01	NM	0.98782	1.00051	0.99407	0.98717	1.00698
72	9.1115 ⁻ 03	1.2296 ⁺ 01	NM	0.98774	1.00076	0.99412	0.98677	1.00744
73	9.2334 ⁻ 03	1.2296 ⁺ 01	NM	0.98774	1.00076	0.99412	0.98678	1.00744
74	9.3756 ⁻ 03	1.2285 ⁺ 01	NM	0.98777	1.00025	0.99395	0.98744	1.00659
75	9.4976 ⁻ 03	1.2291 ⁺ 01	NM	0.98785	1.00051	0.99408	0.98721	1.00697
76	9.6398 ⁻ 03	1.2285 ⁺ 01	NM	0.98784	1.00025	0.99399	0.98752	1.00655
77	9.7719 ⁻ 03	1.2296 ⁺ 01	NM	0.98771	1.00076	0.99410	0.98674	1.00746
78	9.8836 ⁻ 03	1.2291 ⁺ 01	NM	0.98773	1.00051	0.99402	0.98708	1.00703

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

7702S0303

LADERMAN/D.

PROFILE TABULATION

65 POINTS, DELTA AT POINT 62

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	NM	0.54007	0.00000	0.00000	1.50287	0.00000
2	5.0800-05	1.9482+00	NM	0.63291	0.34314	0.41400	1.45566	0.28441
3	6.5024-05	1.9370+00	NM	0.64160	0.34151	0.41520	1.47808	0.28090
4	7.8232-05	1.9537+00	NM	0.64894	0.34395	0.42002	1.49132	0.28165
5	8.7376-05	1.9871+00	NM	0.66055	0.34873	0.42861	1.51064	0.28373
6	1.0465-04	2.0651+00	NM	0.69576	0.35948	0.45095	1.57360	0.28657
7	1.2192-04	2.1931+00	NM	0.73356	0.37614	0.48025	1.63013	0.29461
8	1.7069-04	2.4320+00	NM	0.75243	0.40474	0.51524	1.62055	0.31794
9	2.0015-04	2.5541+00	NM	0.76223	0.41838	0.53196	1.61661	0.32906
10	2.2352-04	2.6594+00	NM	0.77201	0.42973	0.54631	1.61622	0.33802
11	2.5095-04	2.7203+00	NM	0.78165	0.43613	0.55584	1.62432	0.34220
12	3.0785-04	2.8422+00	NM	0.79774	0.44861	0.57340	1.63376	0.35097
13	3.3426-04	2.9253+00	NM	0.80139	0.45689	0.58246	1.62524	0.35838
14	3.8710-04	3.0195+00	NM	0.80570	0.46606	0.59251	1.61620	0.36660
15	4.4704-04	3.1580+00	NM	0.81373	0.47920	0.60741	1.60667	0.37806
16	5.1105-04	3.2744+00	NM	0.82060	0.48993	0.61957	1.59919	0.38743
17	5.7912-04	3.3596+00	NM	0.82521	0.49763	0.62809	1.59307	0.39427
18	6.4414-04	3.4712+00	NM	0.83001	0.50752	0.63852	1.58286	0.40340
19	7.1933-04	3.5717+00	NM	0.83413	0.51625	0.64759	1.57355	0.41154
20	7.8232-04	3.6665+00	NM	0.83776	0.52433	0.65583	1.56448	0.41920
21	8.6055-04	3.7501+00	NM	0.84142	0.53136	0.66313	1.55750	0.42577
22	9.1135-04	3.8281+00	NM	0.84417	0.53782	0.66955	1.54989	0.43200
23	1.0384-03	3.9839+00	NM	0.85067	0.55049	0.68245	1.53690	0.44404
24	1.1786-03	4.1438+00	NM	0.85644	0.56316	0.69487	1.52245	0.45642
25	1.3045-03	4.3061+00	NM	0.86324	0.57574	0.70746	1.50991	0.46855
26	1.4366-03	4.4281+00	NM	0.87313	0.58501	0.71864	1.50902	0.47623
27	1.5697-03	4.5888+00	NM	0.87222	0.59698	0.72729	1.48420	0.49002
28	1.7109-03	4.7493+00	NM	0.87785	0.60869	0.73828	1.47113	0.50185
29	1.8278-03	4.8931+00	NM	0.88245	0.61899	0.74768	1.45902	0.51245
30	2.1011-03	5.2025+00	NM	0.89240	0.64057	0.76713	1.43419	0.53489
31	2.3652-03	5.5171+00	NM	0.90309	0.66176	0.78615	1.41126	0.55706
32	2.6294-03	5.8203+00	NM	0.91509	0.68155	0.80439	1.39294	0.57747
33	2.9078-03	6.1417+00	NM	0.92370	0.70191	0.82110	1.36847	0.60002
34	3.1679-03	6.4576+00	NM	0.93619	0.72134	0.83859	1.35149	0.62049
35	3.4381-03	6.7846+00	NM	0.93808	0.74091	0.85102	1.31932	0.64504
36	3.7033-03	7.1060+00	NM	0.94349	0.75965	0.86418	1.29415	0.66776
37	3.9573-03	7.4276+00	NM	0.95405	0.77793	0.87912	1.27708	0.68839
38	4.1097-03	7.6216+00	NM	0.95609	0.78876	0.88589	1.26146	0.70228
39	4.5060-03	8.0932+00	NM	0.96908	0.81446	0.90532	1.23556	0.73272
40	4.7701-03	8.4319+00	NM	0.97154	0.83243	0.91547	1.20946	0.75692
41	5.0343-03	8.7537+00	NM	0.98113	0.84914	0.92810	1.19463	0.77690
42	5.3188-03	9.1236+00	NM	0.98160	0.86795	0.93716	1.16582	0.80386
43	5.5220-03	9.4135+00	NM	0.98823	0.88241	0.94691	1.15153	0.82231
44	5.8166-03	9.7993+00	NM	0.98776	0.90129	0.95501	1.12274	0.85060
45	6.0909-03	1.0170+01	NM	0.99619	0.91905	0.96666	1.10629	0.87379
46	6.3652-03	1.0516+01	NM	0.99909	0.93537	0.97482	1.08613	0.89751
47	6.6192-03	1.0779+01	NM	1.00011	0.94757	0.98022	1.07012	0.91600
48	6.7615-03	1.0953+01	NM	0.99914	0.95553	0.98289	1.05808	0.92894
49	6.8732-03	1.1069+01	NM	1.00326	0.96079	0.98697	1.05523	0.93531
50	7.0256-03	1.1219+01	NM	1.00571	0.96760	0.99080	1.04854	0.94494
51	7.1577-03	1.1286+01	NM	1.00511	0.97061	0.99165	1.04384	0.95001
52	7.2898-03	1.1403+01	NM	1.00409	0.97586	0.99315	1.03575	0.95887
53	7.3304-03	1.1459+01	NM	1.00362	0.97834	0.99385	1.03194	0.96308
54	7.5336-03	1.1604+01	NM	1.00334	0.98479	0.99611	1.02312	0.97360
55	7.8283-03	1.1738+01	NM	1.00294	0.99070	0.99809	1.01497	0.98337
56	7.9604-03	1.1794+01	NM	1.00157	0.99316	0.99831	1.01039	0.98804
57	8.0823-03	1.1838+01	NM	1.00104	0.99512	0.99876	1.00733	0.99149
58	8.2245-03	1.1861+01	NM	1.00173	0.99610	0.99946	1.00676	0.99275
59	8.3566-03	1.1883+01	NM	1.00117	0.99707	0.99953	1.00493	0.99462
60	8.4887-03	1.1928+01	NM	1.00187	0.99903	1.00058	1.00312	0.99747
61	8.6208-03	1.1939+01	NM	1.00189	0.99951	1.00077	1.00252	0.99826
D 62	8.7427-03	1.1950+01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
63	8.8748-03	1.1950+01	NM	0.99909	1.00000	0.99954	0.99909	1.00046
64	9.0068-03	1.1944+01	NM	1.00247	0.99976	1.00115	1.00278	0.99837
65	9.1389-03	1.1916+01	NM	1.00616	0.99854	1.00255	1.00805	0.99454

INPUT VARIABLES Y,M,TO/TOD ASSUME P=PD

rough 	M: 6 $R_{\theta} \times 10^{-3}: 14$ TW/TR: 0.89	7703 ZPG MHT ROUGH
Continuous running tunnel with (here) asymmetric flexible nozzle. $H = 0.071$ m, $W = 0.139$ m increasing to 0.178 m, $L = 1.31$ m. PO: 1.56 MN/m ² . TO: 425K. Air. $Re/m \times 10^{-6}: 15$.		
BERG D.E., 1977. Surface roughness effects on the hypersonic turbulent boundary layer. Ph.D. Thesis GALCIT Pasadena, Calif. (Also as SANDIA Laboratories, SAND 77-0587). Also: Berg (1978, 1979). And: Berg, D.E., private communications.		

- 1 The lower flexible plate of what is normally a symmetric nozzle windtunnel was replaced by a rigid base plate. Four removable surface plates 8.9 mm thick and, in sequence, 0.222, 0.290, 0.330 and 0.330 m long could be mounted on this to give a replaceable test surface extending from $X = 0.131$ to $X = 1.307$ m, with $X = 0$ at the tunnel throat. (There would seem to be small gaps between the plates, giving $X = 0.645$ m at the start of the third plate. Any gaps are closed by the continuous mounting plate - E). The width of the test section increased from 0.139 m at the throat to 0.178 m at $X = 1.31$ m to compensate for boundary layer growth. The start of the third plate was at $X = 0.645$ m so that the replaceable test surface extended from $X = 0.061$ m to $X = 1.229$ m, with $X = 0$ at the tunnel throat.

Measurements were made for $0.62 < X < 1.30$ m. Four sets of plates were made, one of which was smooth while the remainder had transverse square bar roughness distributions machined into them. Three roughness heights were used, 0.32, 0.64 and 1.27 mm. The wavelength of the roughness was four times the height and the top surfaces of the roughness elements were flush with the undisturbed surface of the plate, and so of the smooth surface upstream of the plate. Apart from the smooth wall case (series 01), a step change in roughness always took place at $X = 0.645$ m. For series 02, 03, 04 this was from a smooth surface to roughness heights of 0.32, 0.64, 1.27 mm respectively. For series 05, the sequence was firstly a smooth plate then a 0.292 m plate for which $K = 1.27$ mm and finally, at $X = 0.645$ m, a smooth surface again. It is stated that the earlier tests had shown that in 0.290 m, or about 10 boundary layer thicknesses, the boundary layer would reach an equilibrium state appropriate to the rough surface. Heated air was passed beneath the plate (at low speed) so as to reduce heat transfer to the plate to a minimum.

- 2 The nozzle contour was adjusted to give uniform flow with the smooth surface plates installed. Although between $X = 0.635$ and $X = 1.22$ the centre line Mach number was $6.02 \pm 1\%$, the variation was not random. The Mach number appears to rise and fall, almost periodically. The author attributes this to a pressure disturbance originating in the nozzle which is then reflected to and fro from the top to bottom. The "wavelength" (E) is consistent with this explanation. The test layer will also have experienced a reflected wave expansion in the nozzle, finishing just before the start of the test zone. The outermost points of the first profiles are very nearly in the last part of what would be, here, a simple wave expansion. The wall temperature rises rapidly from about 335K at $X = 0.2$ m to about 345K at $X = 0.65$ m. Crosstream Pitot traverses were made to check two dimensionality, showing about 5% variation in PT2 over the central 2/3 of the tunnel.
- 6 "Direct measurements of wall temperature and pressure were made via instrumentation in the tunnel wall at 15 stations." Static tapings in the smooth surface plates were 0.36 mm in diameter. The wall shear stress could be measured at two positions ($X = 0.709, 1.217$ m), using an FEB mounted to appropriate surface plates. The balance was based on that used by Coles (CAT 5301). The rectangular element ($W = 38.0, L = 4.98$ mm) was placed with its long axis across the flow. When measurements were

being made with rough surfaces, the element was also contoured, and was of a size to accommodate a whole number of roughness element wave lengths (4,2,1 for heights of 0.32, 0.64, 1.27 mm). The element was flush with the surrounding surface to within 2.5 μ m for the smooth plates and 5 μ m for the rough ones. The roughness is that characterised as "D-type" (Perry et al., 1969).

- 7 Pitot, T0 and some static pressure profiles were obtained. The Pitot probe was an FPP made by flattening 1.65 mm tube and filing to give a probe face for which, approximately, $b_1 = 0.25$, $h_1 = 0.20$, $h_2 = 0.10$ mm. It was mounted pitched down at 10°. The T0 probe was a FWP after Behrens (1971) consisting of a 0.127 mm butt-welded chromel-Alumel thermocouple between supports 12.7 mm apart. To minimise conduction corrections, the lead wires within the supports were of 0.025 mm diameter. A further thermocouple on one support monitored support temperature. The static pressure probe (CCP) was of 0.81 mm diameter with a sharpened tip of half angle 8°-10°. Four static holes ($d = 0.18$ mm) were drilled at 90° intervals 9.8 mm downstream of the probe shoulder. Hot wire probes ($d = 0.0025$, $l/d = 180-200$) were used with a "Shapiro-Edwards constant current set with a half power frequency of 320 kHz."
- 9 Free stream static pressure and Mach number were obtained from Pitot readings, and the static pressure assumed constant through the boundary layer in data reduction. The limited (4 profiles) static pressure data in general supported this assumption, but also indicated that a weak pressure wave is reflected from the boundary layer and affects profiles in the vicinity of $X = 1.0$ m. The maximum measured effect was a difference of 7% in static pressure across the boundary layer at $X = 0.85$ m. The authors find that the $dp/dy = 0$ assumption may cause errors in the evaluation of δ_2 of 10% while the pressure wave itself accounts for (real) anomalous behaviour of δ_2 near $X = 0.90$ m. A linear interpolation was used for T0 between the last measured value ($Y > 0.76$ mm) and the wall temperature.

The velocity profile data were reduced to an equivalent incompressible form using the van Driest transformation and an empirical quadratic temperature-velocity correlation. This gave a noticeably better fit (source, Fig. 28) than a 'Crocco' or 'Walz' correlation (e.g., eqns. 2.5.22 or 2.5.37 of AGARDograph 253). The procedure was rather complex but may be summarised (E) as follows. Skin friction was measured using the balance at $X = 0.709$ m for series 03, 04 (smooth to rough) and at $X = 1.217$ m for series 03, 04 and also series 01 (smooth). These values were used as input for a curve fit to the Coles (1968) wall and wake law so as to find values for the wake strength assuming that the small difference in X-value between balance centre and profile (12.7 mm) had negligible effect. (The value for 04, $X = 0.709$ may not have been used on grounds of internal inconsistency). The profiles were required to pass through the δ point of the Coles wall and wake law (source, p. 44). Wake strength values for all profiles of series 01 assuming no roughness effects were also found, with wall shear stress found by the fitting procedure. All other values of the wake strength were estimated following the trend of the smooth wall data and taken as input for subsequent curve fitting used to find wall shear and roughness-induced profile shift. A comparison between profile-derived shear stress values and the five measured values gives good agreement for all cases except at $X = 0.709$ m for series 04. The influence of uncertainty in the determination of the zero for Y on a rough wall was found to be small in a numerical experiment. An extended account of the curve-fitting operation is given in the source paper.

The fluctuation data were reduced by modal analysis following Kovaszny (1953), Morkovin (1956) and others. Some data were discarded as a result of serious errors, but that retained, despite a scatter of 10-20% on a "point-to-point basis", after comparison with other data is such that "the consistency of the observed magnitudes lends considerable credit to their validity."

- 10 The Pitot data were corrected for low Reynolds number effects following Ramaswamy (1971).

- 12 The editors present all the numerical data received from the author (D.E. Berg, private
 13 communication), incorporating their assumptions and data reduction procedures. We have replaced
 the author's selected δ value (based on a curve fit) with a value chosen after inspection of the
 PO profile.

The mean flow profiles consist of five sets:

01: 14 profiles on a smooth surface starting at $X = 0.645$ m and extending to 1.306 m.

02 - 04: 17 profiles on surfaces which change from smooth to rough at $X = 0.645$ m, the profiles being
 measured from $X = 0.620$ to 1.306 m, for roughness heights of 0.32, 0.64 and 1.27 mm respectively.

05: 17 profiles on a surface which changes from rough ($k = 1.27$ mm) to smooth at $X = 0.645$, again
 extending from $X = 0.620$ to 1.306 m.

- 14 The skin friction value given with the profiles is the value deduced by the author from the curve fit
 to the profiles. These and the measured values are given in section D, taken from the author's Table III.
 The fluctuation data are not presented here, see §15 below.

§ DATA: 77030101-0517. Pitot and TO profiles. $NX = 17$. Some CF from FEB ($NX = 2$). Fluctuation data from
 CC HWP.

- 15 Editors' comments. The interest of this study lies in the response of the boundary layer to the changes
 in roughness in series 02 - 05. The high Mach number and modest heat transfer play no significant part
 in this. Since the data reduction procedure relies critically on the wall-and-wake profile fitting we
 first consider this.

The temperature-velocity correlation between profiles is good, but lies systematically about 5% below the
 modified van Driest value of eqn. 2.5.37 in AG 253. In data reduction the author used a quadratic fit
 to his measured values. The disagreement is not sufficient to affect the transformation at a significant
 level. In Fig. 1 we show three representative profiles from the smooth wall series 01 in wall law
 coordinates. The CF value used is the curve-fit value which has been forced to agree with the balance
 value for 0112. For all three profiles there is an extended log law which agrees well with the
 'standard' value. The wake component is within the normal range for profile 0101, but noticeably large
 for the downstream profiles. In Fig. 2 we show the outer law plots and again agreement is fair for
 0101 and 0106, 0112 showing behaviour uncharacteristic of an equilibrium layer. The initial profile
 of one of the smooth-to-rough cases, 0301, is shown for comparison, measured slightly upstream of the
 change and of 0101. The increasing departure of the wake law from the standard form as we move down-
 stream is attributed to the reflecting expansion-compression referred to in §2 above. Figure 2, right,
 shows the last profiles of series 01 - 04. For 01, 03, 04 the wall shear value is constrained to
 agree with the balance value. The profiles are closely similar, and the author has assumed that
 roughness has no effect on the outer profile in the range of his experiment, so that the profile shape
 is assumed to be a function of position only. Further discussion will be confined to the inner law plots.

In Fig. 1 we show log-law plots for the final profiles of series 01 - 04. The negative shift of
 the log law at constant X is seen to increase monotonically with roughness height. In Fig. 3 we show
 representative profiles from series 04. The shift increases monotonically with X , though the rate of
 increase falls off as we move more downstream. The profiles have probably not quite reached their final
 position by station 15. Figure 4 shows the opposite change, from rough to smooth. The first profile,
 0501, is taken about 0.29 m behind the start of the roughness and so corresponds closely to profile
 0410 of the previous figure. On a wall-law plot the two show only small differences. As the flow
 develops downstream over the smooth surface, the profiles move progressively back towards the 'standard'
 wall law, with, apparently, a slight overshoot which however probably lies within the range of
 experimental uncertainty.

The position at which a change in the inner law profile becomes detectable moves upstream as the roughness
 height increases. For series 02 a change occurs at profile 07, but since it is small for 08 and absent
 for 09, the effect probably begins in earnest with profile 10. For series 03, a significant effect is

seen by profile 04, while for series 04, the effect is again seen at profile 04, though more marked.

The author has supplied us with a very great quantity of turbulence data, in the form of profiles of $(\rho u)^{1/2}$ for nearly every mean flow profile. After much deliberation we chose not to present these either here or in the microfiche and magnetic tape profiles. We reasoned that, in this form, they would not assist in the development of turbulence models. Their principal function therefore must be as a description of the spread or decay of higher turbulence levels introduced by roughness. For this purpose the author's graphical presentation of 29 $(\rho u)^{1/2}$ and $T^{1/2}$ profiles in Figs. 38, 39 of the source paper is adequate, and those wishing to pursue the topic are referred there.

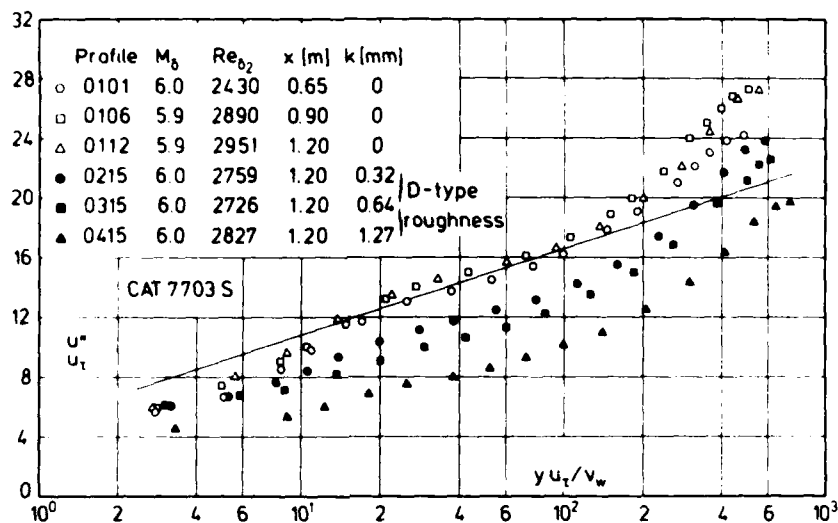


Fig. 1 Law of the wall for a compressible turbulent boundary layer along a smooth/rough wall (isothermal wall $T_w/T_r = 0.90$, origin not defined). Berg (1977).

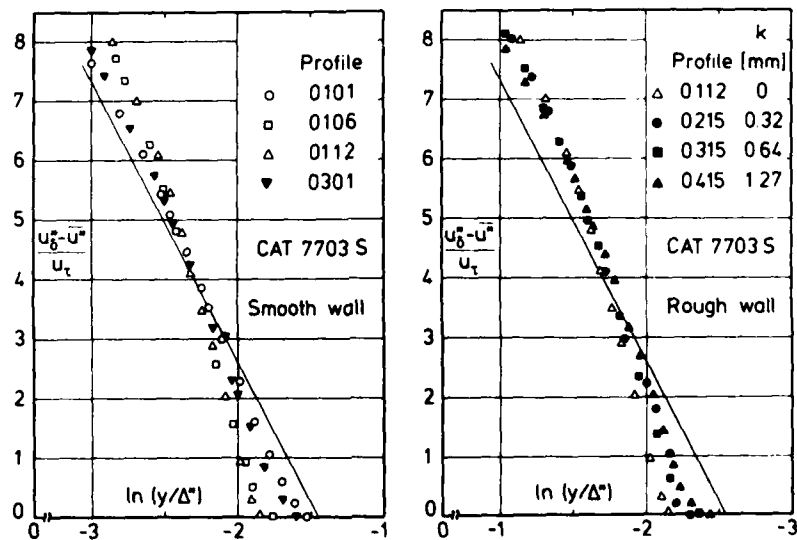


Fig. 2 Outer law for a compressible turbulent boundary layer along a smooth/rough wall (isothermal wall $T_w/T_r = 0.90$, origin not defined). Berg (1977).

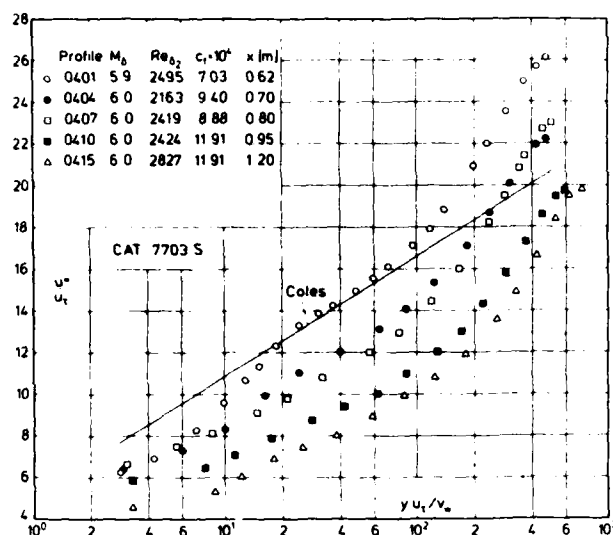


Fig. 3 Law of the wall for a compressible turbulent boundary layer along a rough wall (isothermal wall $T_w/T_\infty = 0.90$, origin not defined, $k = 1.27$ mm, D-type roughness). Berg (1977).

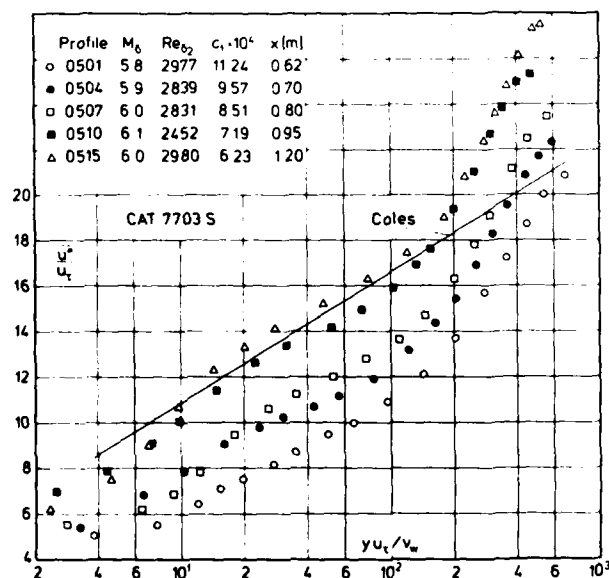


Fig. 4 Law of the wall for a compressible turbulent boundary layer along a rough wall (isothermal wall $T_w/T_\infty = 0.90$, origin not defined, $k = 1.27$ mm, D-type roughness). Berg (1977).

CAT 7703S									BERG									BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS								
RUN	MD *	TW/TR	REDZW	CF	M12	M12K	PW	PD	RUN	MD *	TW/TR	REDZW	CF	M12	M12K	PW	PD	RUN	MD *	TW/TR	REDZW	CF	M12	M12K	PW	PD
X *	P00*	FW/PO	REDZD	CQ	H32	H32K	TW*	TD	X *	P00*	FW/PO	REDZD	CQ	H32	H32K	TW*	TD	X *	P00*	FW/PO	REDZD	CQ	H32	H32K	TW*	TD
RZ	TOD*	TAUW *	DZ	PI2*	H42	D2K	UD	TR	RZ	TOD*	TAUW *	DZ	PI2*	H42	D2K	UD	TR	RZ	TOD*	TAUW *	DZ	PI2*	H42	D2K	UD	TR
7703S0101	5.9940	0.8983	2.4304**+03	8.0170**04	11.0919	1.3873	9.9168**+02	9.9168**+02	7703S0101	5.9940	0.8983	2.4304**+03	8.0170**04	11.0919	1.3873	9.9168**+02	9.9168**+02	7703S0101	5.9940	0.8983	2.4304**+03	8.0170**04	11.0919	1.3873	9.9168**+02	9.9168**+02
6.4516**01	1.5561**+06	1.0000	1.3559**+04	NM	1.8261	1.7713	3.4271**+02	5.1292**+01	6.4516**01	1.5561**+06	1.0000	1.3559**+04	NM	1.8261	1.7713	3.4271**+02	5.1292**+01	6.4516**01	1.5561**+06	1.0000	1.3559**+04	NM	1.8261	1.7713	3.4271**+02	5.1292**+01
INFINITE	4.1986**+02	1.9995**+01	8.5920**04	0.0000**+00	0.6636	2.1075**03	8.6070**+02	3.8153**+02	INFINITE	4.1986**+02	1.9995**+01	8.5920**04	0.0000**+00	0.6636	2.1075**03	8.6070**+02	3.8153**+02	INFINITE	4.1986**+02	1.9995**+01	8.5920**04	0.0000**+00	0.6636	2.1075**03	8.6070**+02	3.8153**+02
7703S0102	6.0411	0.8992	2.2238**+03	7.9960**04	11.4428	1.3871	9.4510**+02	9.4510**+02	7703S0102	6.0411	0.8992	2.2238**+03	7.9960**04	11.4428	1.3871	9.4510**+02	9.4510**+02	7703S0102	6.0411	0.8992	2.2238**+03	7.9960**04	11.4428	1.3871	9.4510**+02	9.4510**+02
6.9596**01	1.5561**+06	1.0000	1.2590**+04	NM	1.8245	1.7675	3.4271**+02	5.0551**+01	6.9596**01	1.5561**+06	1.0000	1.2590**+04	NM	1.8245	1.7675	3.4271**+02	5.0551**+01	6.9596**01	1.5561**+06	1.0000	1.2590**+04	NM	1.8245	1.7675	3.4271**+02	5.0551**+01
INFINITE	4.1952**+02	1.9305**+01	8.1257**04	0.0000**+00	0.6450	2.0376**03	8.6117**+02	3.8114**+02	INFINITE	4.1952**+02	1.9305**+01	8.1257**04	0.0000**+00	0.6450	2.0376**03	8.6117**+02	3.8114**+02	INFINITE	4.1952**+02	1.9305**+01	8.1257**04	0.0000**+00	0.6450	2.0376**03	8.6117**+02	3.8114**+02
7703S0103	6.0050	0.8969	2.3143**+03	7.5209**04	11.8579	1.4079	9.8060**+02	9.8060**+02	7703S0103	6.0050	0.8969	2.3143**+03	7.5209**04	11.8579	1.4079	9.8060**+02	9.8060**+02	7703S0103	6.0050	0.8969	2.3143**+03	7.5209**04	11.8579	1.4079	9.8060**+02	9.8060**+02
7.4676**01	1.5561**+06	1.0000	1.2932**+04	NM	1.8145	1.7590	3.4271**+02	5.1211**+01	7.4676**01	1.5561**+06	1.0000	1.2932**+04	NM	1.8145	1.7590	3.4271**+02	5.1211**+01	7.4676**01	1.5561**+06	1.0000	1.2932**+04	NM	1.8145	1.7590	3.4271**+02	5.1211**+01
INFINITE	4.2054**+02	1.8616**+01	8.2525**04	0.0000**+00	0.5952	2.1451**03	8.6159**+02	3.8213**+02	INFINITE	4.2054**+02	1.8616**+01	8.2525**04	0.0000**+00	0.5952	2.1451**03	8.6159**+02	3.8213**+02	INFINITE	4.2054**+02	1.8616**+01	8.2525**04	0.0000**+00	0.5952	2.1451**03	8.6159**+02	3.8213**+02
7703S0104	5.9615	0.8934	2.5423**+03	7.2978**04	11.8691	1.4083	1.0254**+03	1.0254**+03	7703S0104	5.9615	0.8934	2.5423**+03	7.2978**04	11.8691	1.4083	1.0254**+03	1.0254**+03	7703S0104	5.9615	0.8934	2.5423**+03	7.2978**04	11.8691	1.4083	1.0254**+03	1.0254**+03
7.9756**01	1.5561**+06	1.0000	1.3975**+04	NM	1.8086	1.7549	3.4253**+02	5.2031**+01	7.9756**01	1.5561**+06	1.0000	1.3975**+04	NM	1.8086	1.7549	3.4253**+02	5.2031**+01	7.9756**01	1.5561**+06	1.0000	1.3975**+04	NM	1.8086	1.7549	3.4253**+02	5.2031**+01
INFINITE	4.2185**+02	1.8616**+01	8.7989**04	0.0000**+00	0.5786	2.3148**03	8.6217**+02	3.8339**+02	INFINITE	4.2185**+02	1.8616**+01	8.7989**04	0.0000**+00	0.5786	2.3148**03	8.6217**+02	3.8339**+02	INFINITE	4.2185**+02	1.8616**+01	8.7989**04	0.0000**+00	0.5786	2.3148**03	8.6217**+02	3.8339**+02
7703S0105	5.8732	0.8884	2.8770**+03	6.8625**04	11.5374	1.4150	1.1234**+03	1.1234**+03	7703S0105	5.8732	0.8884	2.8770**+03	6.8625**04	11.5374	1.4150	1.1234**+03	1.1234**+03	7703S0105	5.8732	0.8884	2.8770**+03	6.8625**04	11.5374	1.4150	1.1234**+03	1.1234**+03
8.4836**01	1.5561**+06	1.0000	1.5327**+04	NM	1.8061	1.7529	3.4219**+02	5.3632**+01	8.4836**01	1.5561**+06	1.0000	1.5327**+04	NM	1.8061	1.7529	3.4219**+02	5.3632**+01	8.4836**01	1.5561**+06	1.0000	1.5327**+04	NM	1.8061	1.7529	3.4219**+02	5.3632**+01
INFINITE	4.2364**+02	1.8616**+01	9.3589**04	0.0000**+00	0.5813	2.4268**03	8.6238**+02	3.8516**+02	INFINITE	4.2364**+02	1.8616**+01	9.3589**04	0.0000**+00	0.5813	2.4268**03	8.6238**+02	3.8516**+02	INFINITE	4.2364**+02	1.8616**+01	9.3589**04	0.0000**+00	0.5813	2.4268**03	8.6238**+02	3.8516**+02
7703S0106	5.8996	0.8865	2.8900**+03	6.4721**04	11.9493	1.4153	1.0931**+03	1.0931**+03	7703S0106	5.8996	0.8865	2.8900**+03	6.4721**04	11.9493	1.4153	1.0931**+03	1.0931**+03	7703S0106	5.8996	0.8865	2.8900**+03	6.4721**04	11.9493	1.4153	1.0931**+03	1.0931**+03
8.9916**01	1.5561**+06	1.0000	1.5486**+04	NM	1.8023	1.7508	3.4184**+02	5.3284**+01	8.9916**01	1.5561**+06	1.0000	1.5486**+04	NM	1.8023	1.7508	3.4184**+02	5.3284**+01	8.9916**01	1.5561**+06	1.0000	1.5486**+04	NM	1.8023	1.7508	3.4184**+02	5.3284**+01
INFINITE	4.2419**+02	1.7237**+01	9.5800**04	0.0000**+00	0.5467	2.5476**03	8.6343**+02	3.8562**+02	INFINITE	4.2419**+02	1.7237**+01	9.5800**04	0.0000**+00	0.5467	2.5476**03	8.6343**+02	3.8562**+02	INFINITE	4.2419**+02	1.7237**+01	9.5800**04	0.0000**+00	0.5467	2.5476**03	8.6343**+02	3.8562**+02
7703S0107	6.0349	0.8884	2.5069**+03	7.3933**04	12.1512	1.3792	9.5109**+02	9.5109**+02	7703S0107	6.0349	0.8884	2.5069**+03	7.3933**04	12.1512	1.3792	9.5109**+02	9.5109**+02	7703S0107	6.0349	0.8884	2.5069**+03	7.3933**04	12.1512	1.3792	9.5109**+02	9.5109**+02
9.4996**01	1.5561**+06	1.0000	1.4014**+04	NM	1.8128	1.7651	3.4167**+02	5.1073**+01	9.4996**01	1.5561**+06	1.0000	1.4014**+04	NM	1.8128	1.7651	3.4167**+02	5.1073**+01	9.4996**01	1.5561**+06	1.0000	1.4014**+04	NM	1.8128	1.7651	3.4167**+02	5.1073**+01
INFINITE	4.2309**+02	1.7926**+01	9.1377**04	0.0000**+00	0.5663	2.4104**03	8.6472**+02	3.8440**+02	INFINITE	4.2309**+02	1.7926**+01	9.1377**04	0.0000**+00	0.5663	2.4104**03	8.6472**+02	3.8440**+02	INFINITE	4.2309**+02	1.7926**+01	9.1377**04	0.0000**+00	0.5663	2.4104**03	8.6472**+02	3.8440**+02
7703S0108	6.0076	0.8864	2.5517**+03	7.2558**04	12.0456	1.3733	9.7791**+02	9.7791**+02	7703S0108	6.0076	0.8864	2.5517**+03	7.2558**04	12.0456	1.3733	9.7791**+02	9.7791**+02	7703S0108	6.0076	0.8864	2.5517**+03	7.2558**04	12.0456	1.3733	9.7791**+02	9.7791**+02
1.0008**00	1.5561**+06	1.0000	1.4106**+04	NM	1.8138	1.7670	3.4236**+02	5.1724**+01	1.0008**00	1.5561**+06	1.0000	1.4106**+04	NM	1.8138	1.7670	3.4236**+02	5.1724**+01	1.0008**00	1.5561**+06	1.0000	1.4106**+04	NM	1.8138	1.7670	3.4236**+02	5.1724**+01
INFINITE	4.2509**+02	1.7926**+01	9.1587**04	0.0000**+00	0.5642	2.3938**03	8.6628**+02	3.8626**+02	INFINITE	4.2509**+02	1.7926**+01	9.1587**04	0.0000**+00	0.5642	2.3938**03	8.6628**+02	3.8626**+02	INFINITE	4.2509**+02	1.7926**+01	9.1587**04	0.0000**+00	0.5642	2.3938**03	8.6628**+02	3.8626**+02
7703S0109	6.0509	0.8880	2.4415**+03	7.1878**04	12.5358	1.3842	9.3567**+02	9.3567**+02	7703S0109	6.0509	0.8880	2.4415**+03	7.1878**04	12.5358	1.3842	9.3567**+02	9.3567**+02	7703S0109	6.0509	0.8880	2.4415**+03	7.1878**04	12.5358	1.3842	9.3567**+02	9.3567**+02
1.0516**00	1.5561**+06	1.0000	1.3689**+04	NM	1.8088	1.7619	3.4271**+02	5.1040**+01	1.0516**00	1.5561**+06	1.0000	1.3689**+04	NM	1.8088	1.7619	3.4271**+02	5.1040**+01	1.0516**00	1.5561**+06	1.0000	1.3689**+04	NM	1.8088	1.7619	3.4271**+02	5.1040**+01
INFINITE	4.2479**+02	1.7237**+01	9.0396**04	0.0000**+00	0.5345	2.4417**03	8.6673**+02	3.6592**+02	INFINITE	4.2479**+02	1.7237**+01	9.0396**04	0.0000**+00	0.5345	2.4417**03	8.6673**+02	3.6592**+02	INFINITE	4.2479**+02	1.7237**+01	9.0396**04	0.0000**+00	0.5345	2.4417**03	8.6673**+02	3.6592**+02
7703S0110	6.0089	0.8917	2.5423**+03	6.9827**04	12.9285	1.3907	9.7667**+02	9.7667**+02	7703S0110	6.0089	0.8917	2.5423**+03	6.9827**04	12.9285	1.3907	9.7667**+02	9.7667**+02	7703S0110	6.0089	0.8917	2.5423**+03	6.9827**04	12.9285	1.3907	9.7667**+02	9.7667**+02
1.1024**00	1.5561**+06	1.0000	1.4144**+04	NM	1.8056	1.7591	3.4236**+02	5.1395**+01	1.1024**00	1.5561**+06	1.0000	1.4144**+04	NM	1.8056	1.7591	3.4236**+02	5.1395**+01	1.1024**00	1.5561**+06	1.0000	1.4144**+04	NM	1.8056	1.7591	3.4236**+02	5.1395**+01
INFINITE	4.2253**+02	1.7237**+01	9.1053**04	0.0000**+00	0.4781	2.5013**03	8.6370**+02	3.8394**+02	INFINITE	4.2253**+02	1.7237**+01	9.1053**04	0.0000**+00	0.4781	2.5013**03	8.6370**+02	3.8394**+02	INFINITE	4.2253**+02	1.7237**+01	9.1053**04	0.0000**+00	0.4781	2.5013**03	8.6370**+02	3.8394**+02
7703S0111	6.0191	0.8927	2.5736**+03	7.0323**04	13.3244	1.3888	9.6648**+02	9.6648**+02	7703S0111	6.0191	0.8927	2.5736**+03	7.0323**04	13.3244	1.3888	9.6648**+02	9.6648**+02	7703S0111	6.0191	0.8927	2.5736**+03	7.0323**04	13.3244	1.3888	9.6648**+02	9.6648**+02
1.1532**00	1.5561**+06	1.0000	1.4377**+04	NM	1.8019	1.7577	3.4236**+02	5.1184**+01	1.1532**00	1.5561**+06	1.0000	1.4377**+04	NM	1.8019	1.7577	3.4236**+02	5.1184**+01	1.1532**00	1.5561**+06	1.0000	1.4377**+04	NM	1.8019	1.7577	3.4236**+02	5.1184**+01
INFINITE	4.2207**+02	1.7237**+01	9.2795**04																							

CAT 77035		BERG		BOUNDARY CONDITIONS AND EVALUATED DATA, SI UNITS					
RUN X * RZ	MP * P00* T00*	TW/TR PW/PO TAUW *	RED2W RED2D DZ	CF CQ PI7*	H12 H32 H42	H12W H32W D2K	PW TW* LD	PD TD TR	
770350208 8.4836"-01 INFINITE	6.0013 1.5837"+06 4.2394"+02	0.9014 1.0000 1.8616"+01	2.4088"+03 1.3468"+04 8.5348"-04	7.3714"-04 NM 0.0000"+00	12.9535 1.8030 0.4810	1.4015 1.7510 2.3823"-03	1.0017"+03 3.4722"+02 8.6500"+02	1.0017"+03 5.1679"+01 3.8522"+02	
770350209 8.9915"-01 INFINITE	5.9778 1.5837"+06 4.2360"+02	0.9011 1.0000 1.7926"+01	2.4584"+03 1.3651"+04 8.5559"-04	6.9837"-04 NM 0.0000"+00	13.4285 1.7999 0.4219	1.4048 1.7496 2.4371"-03	1.0262"+03 3.4688"+02 8.6424"+02	1.0262"+03 5.1996"+01 3.8495"+02	
770350210 9.4996"-01 INFINITE	6.0174 1.5837"+06 4.2355"+02	0.9004 1.0000 1.9305"+01	2.3658"+03 1.3282"+04 8.4621"-04	7.7296"-04 NM 0.0000"+00	13.6181 1.6015 0.4159	1.3965 1.7524 2.4236"-03	9.8539"+02 3.4653"+02 8.6489"+02	9.8539"+02 5.1391"+01 3.8485"+02	
770350211 1.0008"+00 INFINITE	5.9732 1.5837"+06 4.2394"+02	0.9008 1.0000 2.0684"+01	2.4771"+03 1.3730"+04 8.5992"-04	8.0324"-04 NM 0.0000"+00	13.7135 1.7972 0.3912	1.4095 1.7470 2.4641"-03	1.0311"+03 3.4705"+02 8.6450"+02	1.0311"+03 5.2108"+01 3.8527"+02	
770350212 1.0516"+00 INFINITE	6.0367 1.5837"+06 4.2428"+02	0.9003 1.0000 1.9305"+01	2.3227"+03 1.3107"+04 8.4394"-04	7.8331"-04 NM 0.0000"+00	14.2522 1.7928 0.3687	1.4208 1.7422 2.5195"-03	9.6615"+02 3.4705"+02 8.6597"+02	9.6615"+02 5.1190"+01 3.8548"+02	
770350213 1.1024"+00 INFINITE	6.0400 1.5837"+06 4.2415"+02	0.9002 1.0000 2.0684"+01	2.3509"+03 1.3278"+04 8.5574"-04	8.4118"-04 NM 0.0000"+00	14.1986 1.7938 0.3714	1.4079 1.7455 2.5479"-03	9.6290"+02 3.4688"+02 8.6589"+02	9.6290"+02 5.1125"+01 3.8536"+02	
770350214 1.1532"+00 INFINITE	6.0212 1.5837"+06 4.2423"+02	0.8990 1.0000 2.0684"+01	2.4451"+03 1.3721"+04 8.7768"-04	8.3036"-04 NM 0.0000"+00	14.3521 1.7871 0.3558	1.4250 1.7379 2.6666"-03	9.8155"+02 3.4653"+02 8.6565"+02	9.8155"+02 5.1416"+01 3.8546"+02	
770350215 1.2040"+00 INFINITE	5.9754 1.5837"+06 4.2389"+02	0.8995 1.0000 2.1374"+01	2.7594"+03 1.5289"+04 9.5832"-04	8.3128"-04 NM 0.0000"+00	14.4383 1.7820 0.3325	1.4415 1.7324 2.9386"-03	1.0287"+03 3.4653"+02 8.6450"+02	1.0287"+03 5.2069"+01 3.8523"+02	
770350216 1.2548"+00 INFINITE	6.1482 1.5837"+06 4.2589"+02	0.8959 1.0000 NM	2.5590"+03 1.4844"+04 1.0065"-03	NM NM 0.0000"+00	14.7327 1.7888 0.3763	1.4294 1.7371 3.1193"-03	8.6300"+02 3.4653"+02 8.6950"+02	8.6300"+02 4.9753"+01 3.8677"+02	
770350217 1.3056"+00 INFINITE	6.1301 1.5837"+06 4.2581"+02	0.8961 1.0000 NM	2.6317"+03 1.5189"+04 1.0219"-03	NM NM 0.0000"+00	14.5789 1.7938 0.3779	1.4180 1.7423 3.1100"-03	8.7887"+02 3.4653"+02 8.6911"+02	8.7887"+02 5.0003"+01 3.8672"+02	
770350301 6.1976"-01 INFINITE	5.9406 1.5865"+06 4.2190"+02	0.9050 1.0000 1.9995"+01	2.1784"+03 1.2016"+04 7.3577"-04	7.5778"-04 NM 0.0000"+00	12.0962 1.8174 0.5453	1.4132 1.7612 1.9070"-03	1.0661"+03 3.4705"+02 8.6164"+02	1.0661"+03 5.2357"+01 3.8347"+02	
770350302 6.4516"-01 INFINITE	5.8942 1.5865"+06 4.2156"+02	0.9060 1.0000 1.9305"+01	2.3193"+03 1.2633"+04 7.5765"-04	7.0835"-04 NM 0.0000"+00	12.1299 1.8097 0.5333	1.4400 1.7504 1.9964"-03	1.1207"+03 3.4722"+02 8.6065"+02	1.1207"+03 5.3038"+01 3.8323"+02	
770350303 6.7056"-01 INFINITE	5.9118 1.5865"+06 4.2300"+02	0.9035 1.0000 1.9995"+01	2.3232"+03 1.2682"+04 7.7023"-04	7.4274"-04 NM 0.0000"+00	12.3480 1.8042 0.5192	1.4380 1.7451 2.0911"-03	1.1004"+03 3.4739"+02 8.6244"+02	1.1004"+03 5.2942"+01 3.8452"+02	
770350304 6.9596"-01 INFINITE	5.9955 1.5865"+06 4.2194"+02	0.9065 1.0000 1.9305"+01	2.0880"+03 1.1719"+04 7.3433"-04	7.6007"-04 NM 0.0000"+00	12.7033 1.8051 0.5135	1.4292 1.7455 2.0197"-03	1.0094"+03 3.4757"+02 8.6286"+02	1.0094"+03 5.1523"+01 3.8342"+02	
770350305 7.2136"-01 INFINITE	5.9403 1.5865"+06 4.2058"+02	0.9097 1.0000 2.0684"+01	2.1579"+03 1.1958"+04 7.2867"-04	7.8377"-04 NM 0.0000"+00	12.7827 1.7981 0.4878	1.4388 1.7388 2.0374"-03	1.0684"+03 3.4774"+02 8.6049"+02	1.0684"+03 5.2197"+01 3.8227"+02	
770350306 7.4676"-01 INFINITE	6.0131 1.5865"+06 4.2347"+02	0.9042 1.0000 2.1374"+01	2.1012"+03 1.1820"+04 7.5017"-04	8.5178"-04 NM 0.0000"+00	12.9562 1.7960 0.5042	1.4494 1.7353 2.1317"-03	9.9142"+02 3.4792"+02 8.6473"+02	9.9142"+02 5.1445"+01 3.8478"+02	
770350307 7.9756"-01 INFINITE	5.9527 1.5865"+06 4.2355"+02	0.9047 1.0000 2.2753"+01	2.3146"+03 1.2796"+04 7.9218"-04	8.5958"-04 NM 0.0000"+00	13.1651 1.7863 0.4666	1.4720 1.7255 2.3029"-03	1.0549"+03 3.4827"+02 8.6375"+02	1.0549"+03 5.2375"+01 3.8495"+02	
770350308 8.4836"-01 INFINITE	5.9465 1.5865"+06 4.2258"+02	0.9050 1.0000 2.3442"+01	2.3976"+03 1.3242"+04 8.1483"-04	8.9210"-04 NM 0.0000"+00	13.4675 1.7816 0.4356	1.4811 1.7211 2.4119"-03	1.0616"+03 3.4757"+02 8.6264"+02	1.0616"+03 5.2350"+01 3.8407"+02	
770350309 8.9916"-01 INFINITE	5.9469 1.5865"+06 4.2292"+02	0.9042 1.0000 2.2063"+01	2.4437"+03 1.3487"+04 8.3104"-04	8.3983"-04 NM 0.0000"+00	13.5578 1.7828 0.4212	1.4712 1.7242 2.4564"-03	1.0612"+03 3.4757"+02 8.6299"+02	1.0612"+03 5.2386"+01 3.8438"+02	
770350310 9.4996"-01 INFINITE	6.0276 1.5865"+06 4.2381"+02	0.9013 1.0000 2.4132"+01	2.2466"+03 1.2658"+04 8.0919"-04	9.7133"-04 NM 0.0000"+00	13.9405 1.7856 0.4104	1.4538 1.7295 2.4260"-03	9.7686"+02 3.4705"+02 8.6533"+02	9.7686"+02 5.1269"+01 3.8507"+02	
770350311 1.0008"+00 INFINITE	6.0164 1.5865"+06 4.2377"+02	0.9022 1.0000 2.4132"+01	2.2947"+03 1.2897"+04 8.2053"-04	9.6386"-04 NM 0.0000"+00	13.8018 1.7859 0.4210	1.4574 1.7290 2.4444"-03	9.8811"+02 3.4739"+02 8.6509"+02	9.8811"+02 5.1432"+01 3.8504"+02	

TW FOR X > 45(IN) SET TO LAST GIVEN VALUE
 TAUW MEASURED: 0112,0304,0315,0404,0415

CAT 77035

BERG

BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS

RUN X * RZ	MD * POD* TOD*	TW/TR PW/PO TAUW *	RED2W RED2D DZ	CF CQ PI2*	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD TD TR
7703S0312	6.0000	0.9023	2.3258**+03	9.5301**+04	13.8389	1.4444	1.0048**+03	1.0048**+03
1.0516**+00	1.5865**+06	1.0000	1.3011**+04	NM	1.7849	1.7313	3.4739**+02	5.1669**+01
INFINITE	4.2368**+02	2.4132**+01	8.2192**+04	0.0000**+00	0.4062	2.4573**+03	8.6472**+02	3.8499**+02
7703S0313	6.0028	0.9022	2.4288**+03	9.5485**+04	14.1037	1.4299	1.0020**+03	1.0020**+03
1.1024**+00	1.5865**+06	1.0000	1.3598**+04	NM	1.7831	1.7335	3.4722**+02	5.1611**+01
INFINITE	4.2355**+02	2.4132**+01	8.5957**+04	0.0000**+00	0.3762	2.6095**+03	8.6464**+02	3.8487**+02
7703S0314	5.9836	0.9014	2.5753**+03	9.4226**+04	14.1732	1.4550	1.0219**+03	1.0219**+03
1.1532**+00	1.5865**+06	1.0000	1.4325**+04	NM	1.7789	1.7263	3.4705**+02	5.1944**+01
INFINITE	4.2389**+02	2.4132**+01	8.9944**+04	0.0000**+00	0.3698	2.7527**+03	8.6465**+02	3.8521**+02
7703S0315	5.9997	0.8999	2.7264**+03	9.2562**+04	14.3345	1.4632	1.0051**+03	1.0051**+03
1.2040**+00	1.5865**+06	1.0000	1.9214**+04	NM	1.7783	1.7242	3.4705**+02	5.1761**+01
INFINITE	4.2440**+02	2.3442**+01	9.6342**+04	0.0000**+00	0.3632	2.9699**+03	8.6545**+02	3.8565**+02
7703S0316	6.0589	0.8995	2.7256**+03	NM	14.4844	1.4487	9.4616**+02	9.4616**+02
1.2548**+00	1.5865**+06	1.0000	1.5466**+04	NM	1.7830	1.7295	3.4705**+02	5.0910**+01
INFINITE	4.2470**+02	NM	1.0048**+03	0.0000**+00	0.3683	3.0972**+03	8.6678**+02	3.8583**+02
7703S0317	6.1157	0.8978	2.6520**+03	NM	14.3116	1.4262	8.9326**+02	8.9326**+02
1.3056**+00	1.5865**+06	1.0000	1.5267**+04	NM	1.7927	1.7396	3.4705**+02	5.0186**+01
INFINITE	4.2559**+02	NM	1.0186**+03	0.0000**+00	0.4003	3.0683**+03	8.6866**+02	3.8655**+02
7703S0401	5.8830	0.9075	2.4954**+03	7.0345**+04	11.9156	1.4042	1.1328**+03	1.1328**+03
6.1970**+01	1.5851**+06	1.0000	1.3570**+04	NM	1.8163	1.7600	3.4705**+02	5.3101**+01
INFINITE	4.2066**+02	1.9305**+01	8.0818**+04	0.0000**+00	0.5395	2.0817**+03	8.5953**+02	3.8244**+02
7703S0402	5.8812	0.9068	2.5828**+03	6.7747**+04	12.1118	1.4207	1.1349**+03	1.1349**+03
6.4516**+01	1.5851**+06	1.0000	1.4026**+04	NM	1.8115	1.7548	3.4722**+02	5.3194**+01
INFINITE	4.2117**+02	1.8616**+01	8.3622**+04	0.0000**+00	0.5231	2.1906**+03	8.6002**+02	3.8290**+02
7703S0403	6.0356	0.9045	2.1657**+03	6.7033**+04	12.7448	1.4162	9.6805**+02	9.6805**+02
6.7056**+01	1.5851**+06	1.0000	1.2271**+04	NM	1.8126	1.7552	3.4739**+02	5.1021**+01
INFINITE	4.2275**+02	1.6547**+01	7.8475**+04	0.0000**+00	0.5181	2.1230**+03	8.6438**+02	3.8409**+02
7703S0404	6.0212	0.9064	2.1627**+03	9.4024**+04	12.6082	1.4018	9.8242**+02	9.8242**+02
6.9596**+01	1.5851**+06	1.0000	1.2228**+04	NM	1.8134	1.7571	3.4757**+02	5.1149**+01
INFINITE	4.2202**+02	2.3442**+01	7.7533**+04	0.0000**+00	0.5221	2.0837**+03	8.6339**+02	3.8345**+02
7703S0405	5.9627	0.9067	2.2096**+03	6.9053**+04	12.5700	1.4357	1.0431**+03	1.0431**+03
7.2136**+01	1.5851**+06	1.0000	1.2285**+04	NM	1.8050	1.7447	3.4774**+02	5.2027**+01
INFINITE	4.2198**+02	1.7926**+01	7.6011**+04	0.0000**+00	0.5160	2.0753**+03	8.6232**+02	3.8351**+02
7703S0406	6.0478	0.9082	2.1113**+03	8.1679**+04	13.1950	1.4405	9.5613**+02	9.5613**+02
7.4676**+01	1.5851**+06	1.0000	1.2049**+04	NM	1.7991	1.7385	3.4792**+02	5.0713**+01
INFINITE	4.2168**+02	1.9995**+01	7.7155**+04	0.0000**+00	0.4890	2.1963**+03	8.6351**+02	3.8310**+02
7703S0407	5.9814	0.9044	2.4185**+03	8.8784**+04	13.1897	1.4551	1.0233**+03	1.0233**+03
7.9756**+01	1.5851**+06	1.0000	1.3479**+04	NM	1.7892	1.7298	3.4827**+02	5.1956**+01
INFINITE	4.2372**+02	2.2753**+01	8.4578**+04	0.0000**+00	0.4695	2.4506**+03	8.6443**+02	3.8508**+02
7703S0408	5.9335	0.9044	2.5192**+03	9.8894**+04	13.2547	1.4515	1.0750**+03	1.0750**+03
8.4836**+01	1.5851**+06	1.0000	1.3852**+04	NM	1.7874	1.7301	3.4757**+02	5.2582**+01
INFINITE	4.2283**+02	2.6200**+01	8.4922**+04	0.0000**+00	0.4415	2.4685**+03	8.6267**+02	3.8433**+02
7703S0409	6.0001	0.9023	2.5032**+03	1.0902**+03	13.5297	1.4701	1.0038**+03	1.0038**+03
8.4916**+01	1.5851**+06	1.0000	1.4001**+04	NM	1.7837	1.7242	3.4757**+02	5.1698**+01
INFINITE	4.2394**+02	2.7579**+01	8.8608**+04	0.0000**+00	0.4482	2.6292**+03	8.6498**+02	3.8522**+02
7703S0410	6.0246	0.9007	2.4240**+03	1.1919**+03	13.6506	1.4555	9.7901**+02	9.7901**+02
9.4996**+01	1.5851**+06	1.0000	1.3637**+04	NM	1.7856	1.7284	3.4705**+02	5.1345**+01
INFINITE	4.2406**+02	2.9647**+01	8.7223**+04	0.0000**+00	0.4404	2.5923**+03	8.6554**+02	3.8530**+02
7703S0411	6.0098	0.9017	2.4326**+03	1.2347**+03	13.9978	1.4847	9.9392**+02	9.9392**+02
1.0008**+00	1.5851**+06	1.0000	1.3639**+04	NM	1.7777	1.7177	3.4739**+02	5.1557**+01
INFINITE	4.2398**+02	3.1026**+01	8.6675**+04	0.0000**+00	0.4092	2.6399**+03	8.6519**+02	3.8525**+02
7703S0412	6.0372	0.9016	2.4132**+03	1.3142**+03	14.5531	1.5097	9.6646**+02	9.6646**+02
1.0516**+00	1.5851**+06	1.0000	1.3636**+04	NM	1.7701	1.7091	3.4739**+02	5.1161**+01
INFINITE	4.2411**+02	3.2405**+01	8.7687**+04	0.0000**+00	0.3756	2.7665**+03	8.6580**+02	3.8532**+02
7703S0413	6.0300	0.9018	2.5240**+03	1.1964**+03	14.6145	1.4960	9.7362**+02	9.7362**+02
1.1024**+00	1.5851**+06	1.0000	1.4237**+04	NM	1.7642	1.7112	3.4722**+02	5.1228**+01
INFINITE	4.2377**+02	2.9647**+01	9.1171**+04	0.0000**+00	0.3617	2.8893**+03	8.6533**+02	3.8502**+02
7703S0414	6.0279	0.9016	2.6473**+03	1.1669**+03	14.6347	1.4825	9.7568**+02	9.7568**+02
1.1532**+00	1.5851**+06	1.0000	1.4921**+04	NM	1.7696	1.7145	3.4722**+02	5.1269**+01
INFINITE	4.2385**+02	2.8958**+01	9.5495**+04	0.0000**+00	0.3544	3.0303**+03	8.6538**+02	3.8510**+02

TW FOR X > 45(IN) SET TO LAST GIVEN VALUE
 TAUW MEASURED: 0112,0304,0315,0404,0415

CAT 77035 BERG BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS									
RUN X * RZ	MD * POD* TOD*	TW/TR PW/PO TAUM *	RED2W RED2D D2	CF CQ PI2*	H12 H32 H42	H12K H32K D2K	PW TW* LD	PD TD TR	
7703S0415 1.2040"+00 INFINITE	6.0240 1.5851"+06 4.2394"+02	0.9010 1.0000 2.9647"+01	2.8270"+03 1.5906"+04 1.0167"-03	1.1914"-03 NM 0.0000"+00	14.9504 1.7633 0.3342	1.5195 1.7053 3.2869"-03	9.7960"+02 3.4705"+02 8.6540"+02	9.7960"+02 5.1338"+01 3.8519"+02	
7703S0416 1.2548"+00 INFINITE	6.0505 1.5851"+06 4.2394"+02	0.9011 1.0000 NM	2.8463"+03 1.6140"+04 1.0430"-03	NM NM 0.0000"+00	15.1342 1.7622 0.3290	1.5215 1.7036 3.4071"-03	9.5349"+02 3.4705"+02 6.6586"+02	9.5349"+02 5.0944"+01 3.8515"+02	
7703S0417 1.3056"+00 INFINITE	6.1258 1.5851"+06 4.2389"+02	0.9014 1.0000 NM	2.6774"+03 1.5521"+04 1.0345"-03	NM NM 0.0000"+00	15.3713 1.7666 0.3314	1.5032 1.7081 3.3939"-03	8.8348"+02 3.4705"+02 6.6709"+02	8.8348"+02 4.9841"+01 3.8499"+02	
7703S0501 6.1976"-01 INFINITE	5.8426 1.5844"+06 4.2368"+02	0.8977 1.0000 3.1716"+01	2.9772"+03 1.5839"+04 9.3778"-04	1.1239"-03 NM 0.0000"+00	12.2700 1.7791 0.5274	1.5105 1.7120 2.6398"-03	1.1810"+03 3.4583"+02 8.6185"+02	1.1810"+03 5.4130"+01 3.8525"+02	
7703S0502 6.4516"-01 INFINITE	5.9580 1.5844"+06 4.2385"+02	0.8969 1.0000 2.8958"+01	2.7725"+03 1.5250"+04 9.4841"-04	1.1123"-03 NM 0.0000"+00	12.2833 1.7826 0.5667	1.4942 1.7158 2.6874"-03	1.0477"+03 3.4549"+02 8.6415"+02	1.0477"+03 5.2330"+01 3.8521"+02	
7703S0503 6.7056"-01 INFINITE	5.8872 1.5844"+06 4.2050"+02	0.9033 1.0000 2.7579"+01	2.8875"+03 1.5670"+04 9.3472"-04	1.0083"-03 NM 0.0000"+00	12.5799 1.7757 0.5165	1.5159 1.7111 2.6935"-03	1.1274"+03 3.4531"+02 6.5943"+02	1.1274"+03 5.3014"+01 3.8228"+02	
7703S0504 6.9596"-01 INFINITE	5.9234 1.5844"+06 4.2211"+02	0.8995 1.0000 2.5511"+01	2.8393"+03 1.5510"+04 9.4483"-04	9.5659"-04 NM 0.0000"+00	12.2142 1.7838 0.5552	1.4700 1.7227 2.6659"-03	1.0858"+03 3.4514"+02 6.6175"+02	1.0858"+03 5.2649"+01 3.8369"+02	
7703S0505 7.2136"-01 INFINITE	5.9847 1.5844"+06 4.2096"+02	0.9018 1.0000 2.3442"+01	2.7368"+03 1.5261"+04 9.4986"-04	9.1721"-04 NM 0.0000"+00	12.6035 1.7843 0.5394	1.4768 1.7227 2.7178"-03	1.0194"+03 3.4497"+02 8.6167"+02	1.0194"+03 5.1568"+01 3.8255"+02	
7703S0506 7.4676"-01 INFINITE	5.8933 1.5844"+06 4.2219"+02	0.8983 1.0000 2.2753"+01	3.0034"+03 1.6244"+04 9.7740"-04	8.3543"-04 NM 0.0000"+00	12.1061 1.7817 0.5582	1.4806 1.7204 2.7496"-03	1.1202"+03 3.4479"+02 6.6128"+02	1.1202"+03 5.3132"+01 3.8381"+02	
7703S0507 7.9756"-01 INFINITE	6.0098 1.5844"+06 4.2466"+02	0.8927 1.0000 2.1374"+01	2.8309"+03 1.5745"+04 1.0035"-03	8.5092"-04 NM 0.0000"+00	12.8713 1.7814 0.5211	1.4715 1.7234 2.9243"-03	9.9352"+02 3.4444"+02 8.6589"+02	9.9352"+02 5.1640"+01 3.8587"+02	
7703S0508 8.4836"-01 INFINITE	5.9487 1.5844"+06 4.2466"+02	0.8924 1.0000 1.9305"+01	2.9835"+03 1.6297"+04 1.0125"-03	7.3673"-04 NM 0.0000"+00	12.8668 1.7789 0.4959	1.4676 1.7237 2.9547"-03	1.0579"+03 3.4444"+02 8.6480"+02	1.0579"+03 5.2574"+01 3.8596"+02	
7703S0509 8.9916"-01 INFINITE	6.0615 1.5844"+06 4.2483"+02	0.8925 1.0000 1.7237"+01	2.5696"+03 1.4505"+04 9.4504"-04	7.1111"-04 NM 0.0000"+00	13.1376 1.7698 0.4995	1.4329 1.7373 2.7408"-03	9.4246"+02 3.4444"+02 8.6696"+02	9.4246"+02 5.0888"+01 3.8594"+02	
7703S0510 9.4996"-01 INFINITE	6.0776 1.5844"+06 4.2462"+02	0.8930 1.0000 1.7237"+01	2.4519"+03 1.3913"+04 9.1182"-04	7.1899"-04 NM 0.0000"+00	13.1104 1.7936 0.5015	1.4116 1.7445 2.6270"-03	9.2721"+02 3.4444"+02 8.6701"+02	9.2721"+02 5.0626"+01 3.8572"+02	
7703S0511 1.0008"+00 INFINITE	6.0282 1.5844"+06 4.2466"+02	0.8936 1.0000 1.8616"+01	2.5503"+03 1.4273"+04 9.1660"-04	7.5060"-04 NM 0.0000"+00	13.3313 1.7900 0.4619	1.4239 1.7410 2.6658"-03	9.7499"+02 3.4479"+02 8.6621"+02	9.7499"+02 5.1363"+01 3.8584"+02	
7703S0512 1.0516"+00 INFINITE	6.0012 1.5844"+06 4.2479"+02	0.8933 1.0000 1.8616"+01	2.6720"+03 1.4931"+04 9.4227"-04	7.3675"-04 NM 0.0000"+00	13.4512 1.7872 0.4409	1.4331 1.7386 2.7582"-03	1.0023"+03 3.4479"+02 8.6587"+02	1.0023"+03 5.1785"+01 3.8600"+02	
7703S0513 1.1024"+00 INFINITE	5.9878 1.5844"+06 4.2475"+02	0.8928 1.0000 1.7926"+01	2.7925"+03 1.5434"+04 9.7496"-04	7.0290"-04 NM 0.0000"+00	13.3946 1.7884 0.4402	1.4319 1.7402 2.8377"-03	1.0162"+03 3.4462"+02 8.6559"+02	1.0162"+03 5.1984"+01 3.8598"+02	
7703S0514 1.1532"+00 INFINITE	5.9995 1.5844"+06 4.2504"+02	0.8918 1.0000 1.6547"+01	2.8268"+03 1.5661"+04 9.9519"-04	6.5414"-04 NM 0.0000"+00	13.4103 1.7950 0.4304	1.3967 1.7513 2.8619"-03	1.0040"+03 3.4444"+02 8.6610"+02	1.0040"+03 5.1842"+01 3.8623"+02	
7703S0515 1.2040"+00 INFINITE	5.9914 1.5844"+06 4.2509"+02	0.8917 1.0000 1.5858"+01	2.9801"+03 1.6469"+04 1.0431"-03	6.2335"-04 NM 0.0000"+00	13.5043 1.7942 0.4186	1.4022 1.7500 3.0108"-03	1.0124"+03 3.4444"+02 8.6600"+02	1.0124"+03 5.1971"+01 3.8628"+02	
7703S0516 1.2548"+00 INFINITE	6.0463 1.5844"+06 4.2581"+02	0.8904 1.0000 NM	2.8531"+03 1.5997"+04 1.0393"-03	NM NM 0.0000"+00	14.4014 1.7971 0.3532	1.4124 1.7497 3.0888"-03	9.5717"+02 3.4444"+02 8.6769"+02	9.5717"+02 5.1231"+01 3.8685"+02	
7703S0517 1.3056"+00 INFINITE	6.1466 1.5844"+06 4.2547"+02	0.8914 1.0000 NM	2.7220"+03 1.5728"+04 1.0636"-03	NM NM 0.0000"+00	14.0951 1.8052 0.4121	1.3730 1.7616 3.0839"-03	8.6473"+02 3.4444"+02 8.6904"+02	8.6473"+02 4.9726"+01 3.8639"+02	

TW FOR X > 45[IN] SET TO LAST GIVEN VALUE
 TAUM MEASURED: 0112,0304,0315,0404,0415

7703S0401		BERG	PROFILE TABULATION			65 POINTS, DELTA AT POINT 50		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.00000	0.82500	0.00000	0.00000	6.53562	0.00000
2	1.2700"-04	1.4093"+00	1.00000	0.82896	0.12198	0.29763	5.95376	0.04999
3	1.8796"-04	1.5159"+00	1.00000	0.83199	0.13503	0.32667	5.85230	0.05582
4	3.1242"-04	1.8164"+00	1.00000	0.84734	0.16390	0.38993	5.66017	0.06889
5	4.3688"-04	2.2290"+00	1.00000	0.85856	0.19317	0.44910	5.40534	0.08308
6	5.6388"-04	2.6645"+00	1.00000	0.86906	0.21836	0.49680	5.17629	0.09598
7	6.7310"-04	2.9860"+00	1.00000	0.87715	0.23488	0.52670	5.02846	0.10474
8	8.2042"-04	3.5002"+00	1.00000	0.88563	0.25885	0.56669	4.79301	0.11823
9	9.7790"-04	3.8473"+00	1.00000	0.88806	0.27374	0.58917	4.63241	0.12718
10	1.0820"-03	4.1559"+00	1.00000	0.88917	0.28628	0.60691	4.49430	0.13504
11	1.3640"-03	4.6037"+00	1.00000	0.88856	0.30352	0.62926	4.29826	0.14640
12	1.6027"-03	4.9611"+00	1.00000	0.88877	0.31657	0.64545	4.15700	0.15527
13	2.1133"-03	5.6425"+00	1.00000	0.88856	0.34003	0.67236	3.90994	0.17196
14	2.6111"-03	6.3312"+00	1.00000	0.88917	0.36216	0.69588	3.69201	0.18848
15	3.1394"-03	6.9949"+00	1.00000	0.89058	0.38225	0.71590	3.50755	0.20410
16	3.6551"-03	7.8416"+00	1.00000	0.89392	0.40643	0.73875	3.30393	0.22360
17	4.1758"-03	8.4161"+00	1.00000	0.89685	0.42203	0.75281	3.18192	0.23659
18	4.6761"-03	9.0124"+00	1.00000	0.89947	0.43763	0.76603	3.06383	0.25002
19	5.1918"-03	9.7462"+00	1.00000	0.90372	0.45609	0.78127	2.93420	0.26626
20	5.7379"-03	1.0554"+01	1.00000	0.90685	0.47557	0.79581	2.80020	0.28420
21	6.2306"-03	1.1485"+01	1.00000	0.91059	0.49709	0.81095	2.66144	0.30471
22	6.7488"-03	1.2472"+01	1.00000	0.91433	0.51892	0.82525	2.52914	0.32630
23	7.2593"-03	1.3477"+01	1.00000	0.91786	0.54023	0.83824	2.40755	0.34817
24	7.7800"-03	1.4569"+01	1.00000	0.92241	0.56247	0.85131	2.29075	0.37163
25	8.2931"-03	1.5763"+01	1.00000	0.92514	0.58582	0.86321	2.17117	0.39758
26	8.8163"-03	1.7089"+01	1.00000	0.92938	0.61071	0.87560	2.05562	0.42595
27	9.3243"-03	1.8418"+01	1.00000	0.93332	0.63468	0.88667	1.95174	0.45430
28	9.8450"-03	1.9703"+01	1.00000	0.93686	0.65701	0.89629	1.86103	0.48161
29	1.0343"-02	2.0885"+01	1.00000	0.94140	0.67690	0.90506	1.78775	0.50626
30	1.0876"-02	2.2401"+01	1.00000	0.94403	0.70158	0.91392	1.69694	0.53857
31	1.1372"-02	2.3806"+01	1.00000	0.94817	0.72371	0.92225	1.62393	0.56791
32	1.1895"-02	2.5153"+01	1.00000	0.95201	0.74431	0.92962	1.55990	0.59595
33	1.2423"-02	2.6748"+01	1.00000	0.95484	0.76798	0.93690	1.48829	0.62951
34	1.2931"-02	2.8320"+01	1.00000	0.95928	0.79062	0.94433	1.42665	0.66192
35	1.3449"-02	2.9643"+01	1.00000	0.96211	0.80918	0.94978	1.37770	0.68939
36	1.3960"-02	3.1125"+01	1.00000	0.96615	0.82947	0.95595	1.32821	0.71973
37	1.4483"-02	3.2520"+01	1.00000	0.96979	0.84814	0.96139	1.28489	0.74823
38	1.4981"-02	3.4001"+01	1.00000	0.97232	0.86752	0.96622	1.24049	0.77890
39	1.5497"-02	3.5605"+01	1.00000	0.97606	0.88802	0.97165	1.19723	0.81158
40	1.6022"-02	3.6941"+01	1.00000	0.97848	0.90474	0.97563	1.16283	0.83901
41	1.6525"-02	3.8276"+01	1.00000	0.98161	0.92116	0.97979	1.13133	0.86605
42	1.7059"-02	3.9449"+01	1.00000	0.98485	0.93534	0.98355	1.10575	0.88949
43	1.7559"-02	4.0536"+01	1.00000	0.98697	0.94829	0.98651	1.08223	0.91155
44	1.8090"-02	4.1551"+01	1.00000	0.98959	0.96022	0.98952	1.06194	0.93180
45	1.8341"-02	4.1962"+01	1.00000	0.99071	0.96502	0.99074	1.05401	0.93997
46	1.8598"-02	4.2376"+01	1.00000	0.99182	0.96981	0.99195	1.04618	0.94817
47	1.9111"-02	4.3199"+01	1.00000	0.99404	0.97930	0.99434	1.03095	0.96448
48	1.9619"-02	4.3789"+01	1.00000	0.99596	0.98603	0.99618	1.02071	0.97597
49	2.0127"-02	4.4301"+01	1.00000	0.99768	0.99184	0.99780	1.01205	0.98592
50	2.0792"-02	4.5025"+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
51	2.1433"-02	4.5591"+01	1.00000	1.00131	1.00632	1.00145	0.99034	1.01122
52	2.2090"-02	4.6095"+01	1.00000	1.00354	1.01193	1.00325	0.98292	1.02069
53	2.2713"-02	4.6417"+01	1.00000	1.00495	1.01550	1.00439	0.97824	1.02673
54	2.3368"-02	4.6982"+01	1.00000	1.00626	1.02172	1.00580	0.96908	1.03790
55	2.4016"-02	4.7466"+01	1.00000	1.00738	1.02703	1.00699	0.96136	1.04747
56	2.4653"-02	4.8028"+01	1.00000	1.00869	1.03315	1.00836	0.95260	1.05854
57	2.5291"-02	4.8480"+01	1.00000	1.01020	1.03804	1.00968	0.94611	1.06720
58	2.5938"-02	4.8773"+01	1.00000	1.01152	1.04120	1.01070	0.94227	1.07262
59	2.6589"-02	4.8953"+01	1.00000	1.01253	1.04314	1.01143	0.94012	1.07585
60	2.7224"-02	4.9086"+01	1.00000	1.01344	1.04457	1.01204	0.93870	1.07814
61	2.7876"-02	4.9342"+01	1.00000	1.01404	1.04732	1.01266	0.93490	1.08317
62	2.8496"-02	4.9581"+01	1.00000	1.01445	1.04987	1.01315	0.93126	1.08793
63	2.9152"-02	4.9886"+01	1.00000	1.01475	1.05314	1.01366	0.92644	1.09415
64	2.9827"-02	5.0155"+01	1.00000	1.01495	1.05599	1.01408	0.92219	1.09964
65	3.0439"-02	5.0203"+01	1.00000	1.01505	1.05650	1.01418	0.92150	1.10059

INPUT VARIABLES Y,M/MD,P/PD,TO/TOD

7703S0415

BERG

PROFILE TABULATION

61 POINTS, DELTA AT POINT 59

I	Y	PT2/P	P/PO	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.00000	0.81863	0.00000	0.00000	6.76005	0.00000
2	1.2700"-04	1.3800"+00	1.00000	0.82526	0.11524	0.28731	6.21570	0.04622
3	3.3528"-04	1.5433"+00	1.00000	0.83218	0.13486	0.33228	6.07060	0.05474
4	4.7244"-04	1.7561"+00	1.00000	0.84451	0.15508	0.37788	5.93739	0.06364
5	6.9088"-04	2.0789"+00	1.00000	0.85484	0.17908	0.42854	5.72617	0.07484
6	9.6774"-04	2.3660"+00	1.00000	0.85965	0.19681	0.46328	5.54100	0.08361
7	1.2090"-03	2.5233"+00	1.00000	0.86035	0.20568	0.47953	5.43565	0.08822
8	1.4630"-03	2.6969"+00	1.00000	0.86165	0.21494	0.49616	5.32861	0.09311
9	1.7247"-03	2.9367"+00	1.00000	0.86336	0.22699	0.51707	5.18893	0.09965
10	1.9888"-03	3.1184"+00	1.00000	0.86456	0.23566	0.53158	5.08841	0.10447
11	2.2403"-03	3.3256"+00	1.00000	0.86607	0.24512	0.54701	4.98006	0.10984
12	2.7381"-03	3.7405"+00	1.00000	0.86997	0.26295	0.57510	4.78356	0.12022
13	3.2563"-03	4.1405"+00	1.00000	0.87499	0.27898	0.59947	4.61721	0.12983
14	3.7846"-03	4.4335"+00	1.00000	0.87980	0.29014	0.61615	4.50981	0.13662
15	4.3155"-03	4.7665"+00	1.00000	0.88381	0.30229	0.63323	4.38805	0.14431
16	4.8108"-03	5.0963"+00	1.00000	0.88692	0.31384	0.64859	4.27082	0.15187
17	5.3137"-03	5.3968"+00	1.00000	0.89083	0.32400	0.66204	4.17514	0.15857
18	5.8090"-03	5.7537"+00	1.00000	0.89534	0.33566	0.67695	4.06748	0.16643
19	6.3221"-03	6.1557"+00	1.00000	0.89975	0.34831	0.69234	3.95103	0.17523
20	6.8428"-03	6.5228"+00	1.00000	0.90366	0.35946	0.70539	3.85086	0.18318
21	7.3660"-03	6.9638"+00	1.00000	0.90727	0.37241	0.71960	3.73372	0.19273
22	7.8638"-03	7.4099"+00	1.00000	0.90967	0.38506	0.73245	3.61823	0.20243
23	8.3795"-03	7.9191"+00	1.00000	0.91258	0.39900	0.74606	3.49616	0.21339
24	8.8875"-03	8.4275"+00	1.00000	0.91579	0.41245	0.75874	3.38413	0.22421
25	9.4056"-03	8.8938"+00	1.00000	0.91830	0.42440	0.76940	3.28662	0.23410
26	9.9593"-03	9.4629"+00	1.00000	0.92301	0.43855	0.78220	3.18134	0.24587
27	1.0429"-02	9.9961"+00	1.00000	0.92652	0.45139	0.79303	3.08652	0.25693
28	1.0945"-02	1.0662"+01	1.00000	0.93093	0.46693	0.80562	2.97685	0.27063
29	1.1455"-02	1.1314"+01	1.00000	0.93524	0.48167	0.81708	2.87755	0.28395
30	1.1956"-02	1.1987"+01	1.00000	0.93845	0.49641	0.82755	2.77907	0.29778
31	1.2466"-02	1.2814"+01	1.00000	0.94185	0.51394	0.83920	2.66625	0.31475
32	1.2987"-02	1.3531"+01	1.00000	0.94416	0.52869	0.84826	2.57434	0.32951
33	1.3492"-02	1.4385"+01	1.00000	0.94667	0.54572	0.85814	2.47273	0.34704
34	1.4018"-02	1.5330"+01	1.00000	0.94957	0.56394	0.86823	2.37027	0.36630
35	1.4521"-02	1.6165"+01	1.00000	0.95158	0.57958	0.87623	2.28561	0.38337
36	1.5034"-02	1.7206"+01	1.00000	0.95559	0.59851	0.88613	2.19207	0.40424
37	1.5557"-02	1.8321"+01	1.00000	0.95970	0.61813	0.89584	2.10041	0.42651
38	1.6060"-02	1.9465"+01	1.00000	0.96391	0.63765	0.90506	2.01462	0.44925
39	1.6579"-02	2.0683"+01	1.00000	0.96802	0.65777	0.91398	1.93077	0.47338
40	1.7089"-02	2.1799"+01	1.00000	0.97123	0.67570	0.92134	1.85925	0.49554
41	1.7617"-02	2.3296"+01	1.00000	0.97404	0.69900	0.92977	1.76925	0.52551
42	1.8095"-02	2.4649"+01	1.00000	0.97624	0.71942	0.93660	1.69489	0.55260
43	1.8628"-02	2.6061"+01	1.00000	0.97845	0.74014	0.94315	1.62380	0.58083
44	1.9147"-02	2.7670"+01	1.00000	0.98065	0.76305	0.94987	1.54962	0.61297
45	1.9639"-02	2.8927"+01	1.00000	0.98276	0.78048	0.95493	1.49701	0.63789
46	2.0152"-02	3.0629"+01	1.00000	0.98536	0.80349	0.96122	1.43116	0.67164
47	2.0668"-02	3.2304"+01	1.00000	0.98807	0.82550	0.96702	1.37228	0.70469
48	2.1201"-02	3.4009"+01	1.00000	0.99098	0.84731	0.97261	1.31763	0.73815
49	2.1704"-02	3.5896"+01	1.00000	0.99378	0.87062	0.97819	1.26181	0.77523
50	2.2225"-02	3.7618"+01	1.00000	0.99639	0.89173	0.98298	1.21513	0.80895
51	2.2730"-02	3.9271"+01	1.00000	0.99910	0.91135	0.98743	1.17391	0.84114
52	2.3233"-02	4.0942"+01	1.00000	1.00050	0.93078	0.99104	1.13367	0.87418
53	2.3762"-02	4.2235"+01	1.00000	1.00040	0.94552	0.99310	1.10317	0.90022
54	2.4265"-02	4.3547"+01	1.00000	1.00000	0.96026	0.99492	1.07350	0.92680
55	2.4775"-02	4.4563"+01	1.00000	1.00010	0.97151	0.99647	1.05203	0.94719
56	2.5291"-02	4.5317"+01	1.00000	1.00010	0.97978	0.99753	1.03657	0.96234
57	2.5941"-02	4.6031"+01	1.00000	1.00020	0.98755	0.99857	1.02244	0.97665
58	2.6548"-02	4.6547"+01	1.00000	1.00020	0.99313	0.99926	1.01239	0.98703
D 59	2.7841"-02	4.7187"+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
60	2.9124"-02	4.7681"+01	1.00000	1.00000	1.00528	1.00063	0.99078	1.00994
61	3.0406"-02	4.7991"+01	1.00000	1.00010	1.00857	1.00108	0.98520	1.01611

INPUT VARIABLES Y,M/MD,P/PO,TO/TOD

7703S0501

BERG

PROFILE TABULATION

63 POINTS, DELTA AT POINT 53

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000*-00	1.0000*-00	1.00000	0.81626	0.00000	0.00000	6.38897	0.00000
2	1.2700*-04	1.4248*-00	1.00000	0.82205	0.12486	0.30110	5.81535	0.05178
3	2.5654*-04	1.5268*-00	1.00000	0.82546	0.13720	0.32829	5.72521	0.05734
4	4.0386*-04	1.7696*-00	1.00000	0.83820	0.16107	0.38027	5.57350	0.06823
5	5.1308*-04	1.9944*-00	1.00000	0.84422	0.17872	0.41626	5.42485	0.07673
6	6.6040*-04	2.1675*-00	1.00000	0.85034	0.19055	0.44007	5.33354	0.08251
7	7.6962*-04	2.3249*-00	1.00000	0.85485	0.20045	0.45932	5.25071	0.08748
8	9.1948*-04	2.4912*-00	1.00000	0.85575	0.21024	0.47690	5.14539	0.09269
9	1.0211*-03	2.6244*-00	1.00000	0.85605	0.21769	0.48980	5.06259	0.09675
10	1.1735*-03	2.8004*-00	1.00000	0.85635	0.22707	0.50560	4.95763	0.10198
11	1.4275*-03	3.0618*-00	1.00000	0.85756	0.24023	0.52715	4.81508	0.10948
12	1.6891*-03	3.3244*-00	1.00000	0.85916	0.25268	0.54682	4.68339	0.11676
13	2.2098*-03	3.7220*-00	1.00000	0.86227	0.27033	0.57362	4.50274	0.12739
14	2.7330*-03	4.1206*-00	1.00000	0.86538	0.28685	0.59739	4.33708	0.13774
15	3.2207*-03	4.5767*-00	1.00000	0.86839	0.30460	0.62136	4.16120	0.14932
16	3.7643*-03	5.0614*-00	1.00000	0.87160	0.32235	0.64397	3.99095	0.16136
17	4.2621*-03	5.5805*-00	1.00000	0.87491	0.34030	0.66550	3.82439	0.17401
18	4.7752*-03	6.0585*-00	1.00000	0.87872	0.35601	0.68363	3.68727	0.18540
19	5.2654*-03	6.5453*-00	1.00000	0.88254	0.37131	0.70043	3.55833	0.19684
20	5.7785*-03	7.1535*-00	1.00000	0.88685	0.38957	0.71931	3.40914	0.21099
21	6.3094*-03	7.7186*-00	1.00000	0.89116	0.40579	0.73534	3.28369	0.22394
22	6.8224*-03	8.4779*-00	1.00000	0.89548	0.42660	0.75421	3.12557	0.24130
23	7.3381*-03	9.2515*-00	1.00000	0.89909	0.44680	0.77107	2.97822	0.25890
24	7.8588*-03	1.0212*-01	1.00000	0.90270	0.47067	0.78930	2.81224	0.28067
25	8.3922*-03	1.1250*-01	1.00000	0.90641	0.49515	0.80656	2.65331	0.30398
26	8.8925*-03	1.2192*-01	1.00000	0.90982	0.51637	0.82052	2.52493	0.32497
27	9.3955*-03	1.3494*-01	1.00000	0.91343	0.54432	0.83713	2.36521	0.35393
28	9.8146*-03	1.4655*-01	1.00000	0.91674	0.56809	0.85025	2.24002	0.37957
29	1.0432*-02	1.5691*-01	1.00000	0.92136	0.58849	0.86159	2.14350	0.40196
30	1.0952*-02	1.6737*-01	1.00000	0.92557	0.60839	0.87194	2.05406	0.42449
31	1.1483*-02	1.7857*-01	1.00000	0.92998	0.62899	0.88211	1.96678	0.44850
32	1.1986*-02	1.9248*-01	1.00000	0.93420	0.65368	0.89309	1.86666	0.47844
33	1.2512*-02	2.0590*-01	1.00000	0.93831	0.67663	0.90277	1.78015	0.50713
34	1.3012*-02	2.1946*-01	1.00000	0.94212	0.69907	0.91161	1.70050	0.53608
35	1.3538*-02	2.3528*-01	1.00000	0.94583	0.72437	0.92072	1.61561	0.56989
36	1.4046*-02	2.5013*-01	1.00000	0.94904	0.74732	0.92843	1.54341	0.60154
37	1.4567*-02	2.6433*-01	1.00000	0.95235	0.76864	0.93538	1.48090	0.63163
38	1.5088*-02	2.7865*-01	1.00000	0.95566	0.78955	0.94191	1.42315	0.66184
39	1.5598*-02	2.9379*-01	1.00000	0.95927	0.81108	0.94842	1.36734	0.69362
40	1.6119*-02	3.0926*-01	1.00000	0.96379	0.83250	0.95508	1.31616	0.72565
41	1.6629*-02	3.2491*-01	1.00000	0.96850	0.85362	0.96152	1.26879	0.75782
42	1.7140*-02	3.3875*-01	1.00000	0.97282	0.87188	0.96702	1.23015	0.78610
43	1.7653*-02	3.5417*-01	1.00000	0.97613	0.89177	0.97213	1.18836	0.81805
44	1.8166*-02	3.6855*-01	1.00000	0.97883	0.90993	0.97648	1.15165	0.84790
45	1.8684*-02	3.8097*-01	1.00000	0.98144	0.92533	0.98022	1.12216	0.87351
46	1.9200*-02	3.9015*-01	1.00000	0.98385	0.93655	0.98313	1.10195	0.89217
47	1.9708*-02	4.0106*-01	1.00000	0.98616	0.94971	0.98623	1.07839	0.91454
48	2.0211*-02	4.0876*-01	1.00000	0.98866	0.95889	0.98880	1.06336	0.92989
49	2.0734*-02	4.1723*-01	1.00000	0.99127	0.96889	0.99150	1.04723	0.94679
50	2.1265*-02	4.2561*-01	1.00000	0.99398	0.97868	0.99419	1.03195	0.96341
51	2.1747*-02	4.3195*-01	1.00000	0.99649	0.98602	0.99643	1.02121	0.97573
52	2.2278*-02	4.3870*-01	1.00000	0.99870	0.99378	0.99855	1.00962	0.98903
53	2.2812*-02	4.4415*-01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
54	2.3310*-02	4.4847*-01	1.00000	1.00090	1.00490	1.00107	0.99241	1.00873
55	2.3838*-02	4.5298*-01	1.00000	1.00130	1.01000	1.00191	0.98406	1.01815
56	2.4465*-02	4.5898*-01	1.00000	1.00171	1.01673	1.00295	0.97307	1.03070
57	2.5095*-02	4.6318*-01	1.00000	1.00251	1.02142	1.00392	0.96602	1.03923
58	2.5723*-02	4.6658*-01	1.00000	1.00391	1.02520	1.00508	0.96113	1.04572
59	2.6363*-02	4.7072*-01	1.00000	1.00572	1.02979	1.00653	0.95534	1.05358
60	2.7026*-02	4.7248*-01	1.00000	1.00772	1.03172	1.00776	0.95408	1.05626
61	2.7694*-02	4.7582*-01	1.00000	1.00963	1.03540	1.00915	0.94993	1.06233
62	2.8339*-02	4.7860*-01	1.00000	1.01103	1.03846	1.01020	0.94633	1.06750
63	2.8974*-02	4.8150*-01	1.00000	1.01174	1.04162	1.01092	0.94192	1.07325

INPUT VARIABLES Y,M/MD,P/PD,TO/TOD

7703S0515

BERG

PROFILE TABULATION

74 POINTS, DELTA AT POINT 62

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.00000	0.81030	0.00000	0.00000	6.62765	0.00000
2	1.1938"-04	1.3640"+00	1.00000	0.81794	0.11365	0.28122	6.12239	0.04593
3	2.3622"-04	1.5808"+00	1.00000	0.82244	0.13953	0.33898	5.90199	0.05743
4	3.5560"-04	1.9213"+00	1.00000	0.83763	0.16902	0.40301	5.68518	0.07089
5	4.9022"-04	2.4951"+00	1.00000	0.84913	0.20524	0.47394	5.33266	0.08888
6	6.2484"-04	2.9485"+00	1.00000	0.85833	0.22881	0.51686	5.10263	0.10129
7	7.2644"-04	3.2527"+00	1.00000	0.86443	0.24315	0.54172	4.96355	0.10914
8	8.7122"-04	3.5401"+00	1.00000	0.86833	0.25589	0.56245	4.83114	0.11642
9	1.0262"-03	3.8533"+00	1.00000	0.87023	0.26903	0.58225	4.68392	0.12431
10	1.1455"-03	4.0327"+00	1.00000	0.87073	0.27626	0.59257	4.60101	0.12879
11	1.2776"-03	4.2352"+00	1.00000	0.87123	0.28418	0.60356	4.51073	0.13380
12	1.4249"-03	4.4144"+00	1.00000	0.87153	0.29100	0.61271	4.43324	0.13821
13	1.9126"-03	4.9302"+00	1.00000	0.87293	0.30976	0.63691	4.22765	0.15065
14	2.4232"-03	5.3114"+00	1.00000	0.87612	0.32290	0.65369	4.09830	0.15950
15	2.9261"-03	5.6843"+00	1.00000	0.87912	0.33524	0.66877	3.97965	0.16805
16	3.4366"-03	5.9123"+00	1.00000	0.88192	0.34256	0.67781	3.91511	0.17313
17	3.9726"-03	6.3375"+00	1.00000	0.88482	0.35580	0.69280	3.79137	0.18273
18	4.4679"-03	6.6537"+00	1.00000	0.88722	0.36533	0.70329	3.70587	0.18978
19	4.9733"-03	6.9992"+00	1.00000	0.88962	0.37546	0.71401	3.61638	0.19744
20	5.4991"-03	7.2726"+00	1.00000	0.89172	0.38329	0.72214	3.54973	0.20344
21	6.0046"-03	7.6861"+00	1.00000	0.89412	0.39482	0.73346	3.45104	0.21253
22	6.5049"-03	8.0857"+00	1.00000	0.89682	0.40566	0.74388	3.36267	0.22122
23	7.0307"-03	8.5542"+00	1.00000	0.90002	0.41800	0.75534	3.26545	0.23131
24	7.5311"-03	8.9772"+00	1.00000	0.90312	0.42883	0.76515	3.18368	0.24034
25	8.0620"-03	9.3909"+00	1.00000	0.90642	0.43916	0.77435	3.10904	0.24906
26	8.5750"-03	9.9271"+00	1.00000	0.90982	0.45220	0.78522	3.01518	0.26042
27	9.1059"-03	1.0402"+01	1.00000	0.91372	0.46344	0.79464	2.94012	0.27028
28	9.5987"-03	1.0937"+01	1.00000	0.91732	0.47577	0.80435	2.85816	0.28142
29	1.0102"-02	1.1490"+01	1.00000	0.92062	0.48821	0.81363	2.77736	0.29295
30	1.0625"-02	1.2100"+01	1.00000	0.92362	0.50155	0.82296	2.69227	0.30567
31	1.1130"-02	1.2754"+01	1.00000	0.92651	0.51550	0.83220	2.60616	0.31932
32	1.1636"-02	1.3427"+01	1.00000	0.92951	0.52944	0.84110	2.52381	0.33326
33	1.2174"-02	1.4133"+01	1.00000	0.93291	0.54369	0.84996	2.44401	0.34777
34	1.2654"-02	1.4909"+01	1.00000	0.93601	0.55893	0.85881	2.36086	0.36377
35	1.3188"-02	1.5659"+01	1.00000	0.93951	0.57328	0.86704	2.28744	0.37904
36	1.3693"-02	1.6549"+01	1.00000	0.94291	0.58983	0.87585	2.20500	0.39721
37	1.4194"-02	1.7441"+01	1.00000	0.94681	0.60598	0.88433	2.12970	0.41524
38	1.4719"-02	1.8403"+01	1.00000	0.95081	0.62293	0.89282	2.05420	0.43463
39	1.5245"-02	1.9487"+01	1.00000	0.95441	0.64149	0.90132	1.97414	0.45656
40	1.5738"-02	2.0517"+01	1.00000	0.95721	0.65864	0.90856	1.90288	0.47747
41	1.6246"-02	2.1757"+01	1.00000	0.96011	0.67870	0.91645	1.82329	0.50264
42	1.6782"-02	2.3021"+01	1.00000	0.96361	0.69857	0.92415	1.75013	0.52805
43	1.7267"-02	2.4308"+01	1.00000	0.96681	0.71823	0.93128	1.68128	0.55391
44	1.7795"-02	2.5658"+01	1.00000	0.97031	0.73829	0.93833	1.61532	0.58089
45	1.8313"-02	2.7123"+01	1.00000	0.97361	0.75945	0.94523	1.54906	0.61019
46	1.8824"-02	2.8709"+01	1.00000	0.97680	0.78172	0.95199	1.48306	0.64191
47	1.9334"-02	3.0252"+01	1.00000	0.98020	0.80279	0.95826	1.42485	0.67254
48	1.9842"-02	3.2026"+01	1.00000	0.98340	0.82636	0.96466	1.36272	0.70789
49	2.0343"-02	3.3554"+01	1.00000	0.98620	0.84612	0.96983	1.31379	0.73819
50	2.0861"-02	3.5254"+01	1.00000	0.98840	0.86759	0.97480	1.26242	0.77217
51	2.1379"-02	3.6939"+01	1.00000	0.99030	0.88835	0.97928	1.21517	0.80587
52	2.1885"-02	3.8621"+01	1.00000	0.99180	0.90862	0.98327	1.17108	0.83963
53	2.2395"-02	4.0118"+01	1.00000	0.99310	0.92627	0.98661	1.13453	0.86962
54	2.2857"-02	4.1496"+01	1.00000	0.99420	0.94222	0.98948	1.10283	0.89722
55	2.3424"-02	4.2657"+01	1.00000	0.99560	0.95546	0.99203	1.07801	0.92024
56	2.3937"-02	4.3772"+01	1.00000	0.99680	0.96800	0.99432	1.05512	0.94238
57	2.4455"-02	4.4647"+01	1.00000	0.99820	0.97773	0.99630	1.03834	0.95951
58	2.4938"-02	4.5283"+01	1.00000	0.99930	0.98475	0.99775	1.02657	0.97193
59	2.5481"-02	4.5860"+01	1.00000	1.00010	0.99107	0.99895	1.01595	0.98326
60	2.5982"-02	4.6155"+01	1.00000	1.00020	0.99428	0.99940	1.01031	0.98920
61	2.6502"-02	4.6478"+01	1.00000	1.00000	0.99779	0.99973	1.00388	0.99586
62	2.7005"-02	4.6682"+01	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
63	2.7640"-02	4.6886"+01	1.00000	0.99990	1.00221	1.00022	0.99604	1.00420
64	2.8296"-02	4.6979"+01	1.00000	1.00000	1.00321	1.00039	0.99439	1.00604
65	2.8913"-02	4.6979"+01	1.00000	1.00000	1.00321	1.00039	0.99439	1.00604
66	2.9591"-02	4.6979"+01	1.00000	1.00010	1.00321	1.00044	0.99449	1.00599
67	3.0223"-02	4.6942"+01	1.00000	1.00010	1.00281	1.00039	0.99519	1.00523
68	3.0866"-02	4.6914"+01	1.00000	1.00020	1.00251	1.00041	0.99581	1.00461
69	3.1504"-02	4.6886"+01	1.00000	1.00020	1.00221	1.00037	0.99634	1.00405
70	3.2139"-02	4.6886"+01	1.00000	1.00010	1.00221	1.00032	0.99624	1.00410
71	3.2758"-02	4.6886"+01	1.00000	1.00000	1.00221	1.00027	0.99614	1.00415
72	3.3431"-02	4.6886"+01	1.00000	0.99990	1.00221	1.00022	0.99604	1.00420
73	3.4066"-02	4.6886"+01	1.00000	0.99990	1.00221	1.00022	0.99604	1.00420
74	3.4709"-02	4.6914"+01	1.00000	0.99990	1.00251	1.00026	0.99551	1.00477

INPUT VARIABLES Y,M/MD,P/PD,TO/TOD

0501

	M: 0.1, 0.6 - 2.2 R THETA $\times 10^{-3}$: 6, 23, 40 TW/TR: 1	7801
(M = 0.1 only). Continuous closed-return low speed tunnel, W = 1.15, H = 0.82 m. Air, RE/m $\times 10^{-6}$: 2.2. (Others) Continuous tunnel with symmetrical flexible nozzle. W = 0.46, H = 0.51 m. 0.067 < PO < 0.18 MN/m ² . TO: 315K. Air. 7 < RE/m $\times 10^{-6}$ < 20.		
COLLINS D.J., COLES D.E., HICKS J.W., 1978. Measurements in the turbulent boundary layer at constant pressure in subsonic and supersonic flow. Part I, Mean flow. AEDC-TR-78-21. And Dimotakis, P.E., Collins, D.J., Lang, D.B., 1979. Title as above. Part II. Laser-doppler velocity measurements. AEDC-TR-79-49.		

- 1 Two experimental arrangements were used. For series 01 (M = 0.1), the test boundary layer was formed on a flat plate (W = 1.15, L = 2.44 m) constructed of formica-faced plywood 19 mm thick. The leading edge (X = 0) was elliptical with a transition strip immediately behind the elliptical section. The test surface was on the lower face of the plate, which completely spanned the conventional low speed tunnel, and was supported from the tunnel roof. Variation in Mach number along the plate was small, the largest excursion for given tunnel operating conditions being less than 2% at X $\approx$ 0.4 m. In the test zone considered here (1.524 x 2.286 m) variations were much less than this, the changes seen in the tables of section B resulting from changes in tunnel operating conditions since in a low speed tunnel M is a function of, inter alia, fan speed rather than tunnel geometry.
- 2 For series 02-11 (M = 0.6-2.2), the test boundary layer was formed on the upper nozzle wall of the wind tunnel, and a flat extension running about 1.5 m downstream from the end of the flexible nozzle. The test zone extended from X = -0.484 to X = +0.076 m, where X = 0 at the balance station which was 0.113 m downstream of the end of the flexible nozzle. A second throat was installed to ensure that the flow remained steady for the transonic cases, and Mach number variations for -1.4 < X < 0.4 were very small, in the worst case (M = 1.32, series 08, 09) being about $\pm 2\%$. (Source Fig.1). There is no mean Mach number gradient. Transition was natural. The boundary layer had passed through the favourable pressure gradient in the tunnel nozzle, but had relaxed in constant pressure conditions for at least 30 boundary layer thicknesses before entering the test zone. (Source Fig.1).
- 6 The flat plate (series 01) was provided with 20 static tapings at at least 7 X-values. A Preston tube ($d_1 = 2.1$ mm, $d_2 = 1.60$ mm) was used for CF determination. The nozzle and extension (series 02-11) had 82 static tapings located throughout the test section and diffuser. At least 28 X-values were covered for -1.4 < X < 0.4. The principal method of CF measurement was by using the FEB originally used by Coles (CAT 5301). The floating element is rectangular, 6.22 mm in the X-direction, 37.85 mm in the Y-direction with gaps of 0.07 mm upstream and downstream, and 0.1 mm at each side. The element was flush with the surface to within 1 μ m. No gap correction was applied. The balance is as described by Coles (1953) save for some small changes made in the method of returning the element to its null position. Additionally, three Preston tubes were used, ($d_1 = 0.82, 1.62, 3.17$ mm, $d_2/d_1 = 0.60$). CF values were calculated using the Hopkins and Keener (1966) T'correlation, and the Bradshaw and Unsworth (1974) correlation revised to take account of the revised CF values of Allen (1977) (see also Bradshaw 1977).
- 7 On the flat plate (series 01) Pitot traverses were made with an FPP ($h_1 = 0.243, h_2 = 0.203$ mm) at six stations. Measurements were also made at three upstream stations using a seven tube rake. Profiles on the nozzle extension (02-11) were also measured with an FPP, made by flattening 1.27 mm tube to an oval and honing the lip thickness to give an opening for which $h_1 = 0.187, h_2 = 0.127$ mm. The

centre of the support stem was 50.8 mm downstream of the probe tip.

Profiles of mean velocity and distributions of fluctuating velocity components were also measured using a dual forward scattering LDV operating in the single particle mode. (Dimotakis et al., 1979). These observations yield values of $\bar{u}$, $\bar{v}$, $\overline{u'^2}$, $\overline{v'^2}$ and $\overline{u'v'}$ with varying degrees of accuracy, generally good for streamwise components and poor for those in the Y-direction.

8 Measurements were made at the stations listed in table 1. All necessary interpolations were made by
9 the authors, who assumed $P = P_W$ throughout the boundary layer and Crocco/van Driest temperature-
10 velocity correlation, using a recovery factor of 0.885, from which T_W was also calculated. No probe
11 corrections were applied, and viscosity was taken from the Sutherland viscosity law. In addition to
9 CF values from the Preston tubes and FRB, values were derived from a fit to the wall and wake law. The
mean flow data were also processed to yield the distribution of τ/τ_{wall} through the boundary layer,
for comparison with the LDV results.

12 The editors have presented all the profiles for which tabular data was supplied. The subsonic profiles
14 for "CIT 1-3", using the Pitot rake, are therefore omitted. The authors' assumptions and data
reduction procedures have been accepted save that we have replaced the authors' recovery factor value
of 0.885 by 0.896. The CF value given in the profile tables of section B is that deduced from a
statistical fit to the law of the wall and wake. The full set of CF values obtained is given as table 1
of section D. The LDV data are not given here as they are not in tabular form, and could not be easily
or very appropriately so presented.

§ DATA: 78010101-1104. Pitot profiles ($NX = 4-8$). CF from FEB, Preston tubes and profile curve fitting.
Mean and fluctuation data from LDV.

15 Editors' comments. The primary purpose of the mean flow measurements was to establish, as accurately as
might be by conventional means, the flow field in which the LDV measurements were to be made. There is
however, one special feature which makes the data set a valuable addition to the general data pool for
ZPG/AW boundary layers, in that the results extended right through the transonic range using the same
instruments (series 02-11, $M = 0.60, 0.80, 0.98, 1.31, 2.16$). (In this they may be compared to Winter
and Gaudet - CAT 7302). The data appear to be of very good quality, and no detectable change is seen
in the transformed velocity profiles through this range, confirming the expectation that there is no
special feature of the transonic turbulent boundary layer (Figs. 1, 2). In Dimotakis et al. (1979)
there is a detailed graphical presentation of the LDV data. The mean values of U agree very well with
the Pitot-derived data at low MD values, but differ by up to 7% at $M = 2.16$. The turbulence intensity
 $\overline{u'^2}$ is compared to the results of Klebanoff (1954/55), and agrees, at all Mach numbers, to within a standard
deviation, the Klebanoff values lying slightly lower. Results involving velocity components normal to
the wall are not so satisfactory. Large discrepancies are found in the values of $\bar{v}$, while the authors
state that agreement between the $\overline{v'^2}$ values and those of Klebanoff (1954/55) is fortuitous, the standard
deviation of the LDV data being about half their absolute values. The values of the Reynolds stress
deduced from the $\overline{u'v'}$ measurements again show quite large departures from mean flow derived results
and the data of Klebanoff, especially in the inner region of the boundary layer ($y/\delta_2 < 3$). These data
are further discussed by Schairer (1980).

The mean velocity profiles do not extend into the viscous sublayer, and the measurements do not reach
further in than the momentum deficit peak in 70% of the cases. For y^+ greater than 100 the data conform
well to the standard law of the wall ($k_1 = 0.40$ and $c = 5.10$). Typical wake strength $\Delta(\bar{u}^*/u_\tau)$ values
given in the legend of Fig. 1 agree in general with the plot shown in Fig. 6 of Collins et al. We have
plotted a few velocity profiles which are characteristic of the Mach and the Reynolds number range covered
by the experiment. Fig. 2 shows the same profiles in outer law form. The profiles follow the standard
norms fairly well, showing a slight curvature for which we have no explanation. This deviation does not
appear in the Winter & Gaudet data (Fig. 4.2.12 of AG 253) which cover almost the same parameter range.

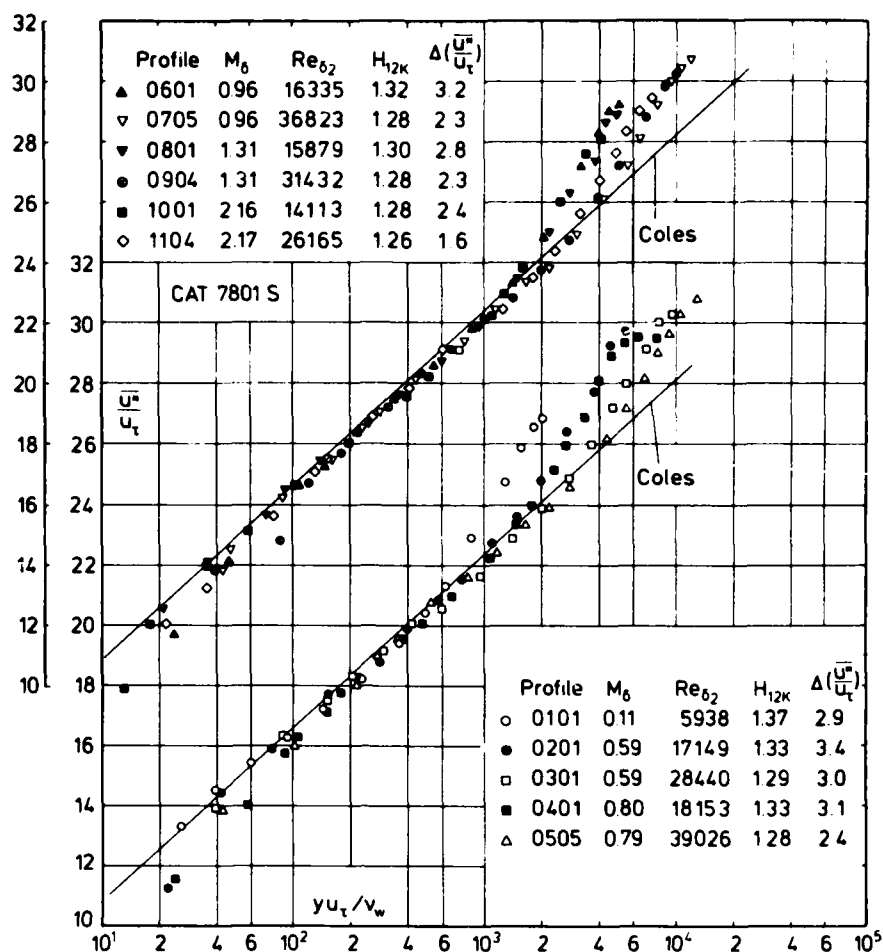


Fig. 1 Law of the wall for a compressible boundary layer (adiabatic wall, zero pressure gradient, defined origin). Collins et al. (1978).

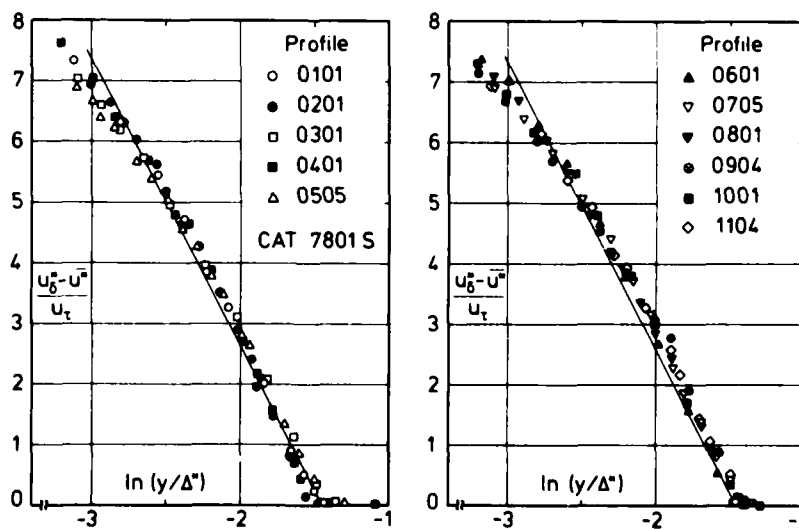


Fig. 2 Outer law for a compressible turbulent boundary layer (adiabatic wall, zero pressure gradient, defined origin). Collins et al. (1978).

Table 1 Measurement stations. (Collins et al. 1978)

SOURCE IDENT	X (m)	Pitot	Preston	Balance	LDV	CAT IDENT
CIT 1	0.304	rake	yes	-	-	-
CIT 2	0.709	rake	yes	-	-	-
CIT 3	0.914	rake	yes	-	-	-
CIT 4	1.524	traverse	yes	-	-	0101
CIT 5	1.676	traverse	yes	-	-	0102
CIT 6	1.828	traverse	yes	-	yes	0103
CIT 7	1.981	traverse	yes	-	-	0104
CIT 8	2.133	traverse	yes	-	-	0105
CIT 9	1.186	traverse	yes	-	-	0106
(Series 01 - Flat plate, X = 0 at leading edge M = 0.1)						
JPL 1	-0.484	traverse	-	-	-	0201-0701
JPL 2	-0.262	traverse	yes	-	yes	0202-0702
		traverse	yes	-	yes	0801-1101
JPL 3	-0.076	traverse	-	-	-	0203-0703
		traverse	-	-	-	0802-1102
JPL 4	0	traverse	yes	yes	yes	0204-0704
		traverse	yes	yes	yes	0803-1103
JPL 5	+0.076	traverse	-	-	-	0205-0705
		traverse	-	-	-	0804-1104

(Series 02 - 11, tunnel wall, X = 0 at balance station.)

(Series 02 - 07, sub/transonic. Series 08 - 11 supersonic.)

CAT 78015		COLLINS/COLES/H		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS				
RUN	MD *	TW/TR*	RED2W	CF *	H12	H12K	PW	PD
X *	POD*	PW/PO*	RED2D	CO *	H32	H32K	TW	TD
RZ	TOD*	TAUW	OZ	P12*	H42	D2K	UD	TR
7801S0101	0.1056	1.0000	5.9384**+03	2.7870**-03	1.3718	1.3672	9.9819**+04	9.9819**+04
1.5240**+00	1.0060**+05	1.0000	5.9475**+03	0.0000**+00	1.7683	1.7682	3.0698**+02	3.0637**+02
INFINITE	3.0705**+02	2.1720**+00	2.6617**-03	0.0000**+00	0.0004	2.6638**-03	3.7062**+01	3.0698**+02
7801S0102	0.1067	1.0000	6.0893**+03	2.7860**-03	1.3971	1.3923	9.9206**+04	9.9206**+04
1.6764**+00	1.0000**+05	1.0000	6.0987**+03	0.0000**+00	1.7641	1.7640	3.1268**+02	3.1204**+02
INFINITE	3.1275**+02	2.2047**+00	2.7807**-03	0.0000**+00	0.0004	2.7830**-03	3.7808**+01	3.1268**+02
7801S0103	0.1028	1.0000	6.8005**+03	2.7560**-03	1.3769	1.3726	1.0671**+05	1.0671**+05
1.8288**+00	1.0750**+05	1.0000	6.8104**+03	0.0000**+00	1.7691	1.7690	3.0368**+02	3.0311**+02
INFINITE	3.0375**+02	2.1769**+00	2.8887**-03	0.0000**+00	0.0004	2.8908**-03	3.5895**+01	3.0368**+02
7801S0104	0.1032	1.0000	7.1854**+03	2.6890**-03	1.3520	1.3476	9.8057**+04	9.8057**+04
1.9812**+00	9.8790**+04	1.0000	7.1960**+03	0.0000**+00	1.7755	1.7755	3.0268**+02	3.0211**+02
INFINITE	3.0275**+02	1.9664**+00	3.2953**-03	0.0000**+00	0.0004	3.2977**-03	3.5970**+01	3.0268**+02
7801S0105	0.1048	1.0000	7.4737**+03	2.6890**-03	1.3514	1.3469	1.0052**+05	1.0052**+05
2.1336**+00	1.0130**+05	1.0000	7.4849**+03	0.0000**+00	1.7764	1.7764	3.1078**+02	3.1017**+02
INFINITE	3.1085**+02	2.0794**+00	3.4036**-03	0.0000**+00	0.0004	3.4062**-03	3.7017**+01	3.1078**+02
7801S0106	0.1066	1.0000	7.8804**+03	2.6760**-03	1.3473	1.3426	9.9309**+04	9.9309**+04
2.2860**+00	1.0010**+05	1.0000	7.8926**+03	0.0000**+00	1.7767	1.7766	3.0998**+02	3.0935**+02
INFINITE	3.1005**+02	2.1119**+00	3.5624**-03	0.0000**+00	0.0004	3.5652**-03	3.7574**+01	3.0998**+02
7801S0201	0.5886	1.0000	1.7149**+04	2.1790**-03	1.4717	1.3300	5.2718**+04	5.2718**+04
-4.8430**-01	6.6650**+04	1.0000	1.7967**+04	0.0000**+00	1.7807	1.7795	3.0369**+02	2.8594**+02
INFINITE	3.0575**+02	2.7860**+01	2.5019**-03	0.0000**+00	0.0120	2.5605**-03	1.9956**+02	3.0369**+02
7801S0202	0.5907	1.0000	1.9242**+04	2.2010**-03	1.4550	1.3132	5.2632**+04	5.2632**+04
-2.6210**-01	6.6650**+04	1.0000	2.0164**+04	0.0000**+00	1.7886	1.7874	3.0800**+02	2.8987**+02
INFINITE	3.1010**+02	2.8299**+01	2.8517**-03	0.0000**+00	0.0121	2.9168**-03	2.0166**+02	3.0800**+02
7801S0203	0.5966	1.0000	2.0674**+04	2.1960**-03	1.4464	1.3022	5.2394**+04	5.2394**+04
-7.6200**-02	6.6650**+04	1.0000	2.1689**+04	0.0000**+00	1.7932	1.7920	3.0121**+02	2.8316**+02
INFINITE	3.0331**+02	2.8664**+01	2.9610**-03	0.0000**+00	0.0124	3.0288**-03	2.0127**+02	3.0121**+02

CAT 78015		COLLINS/COLES/H		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS				
RUN X *	MD *	TW/TR*	RED2W	CF *	H12	H12K	PW	PD
RZ	POD*	PW/PO*	RE02D	CQ *	H32	H32K	TW	TD
	TOD*	TAUW	D2	PI2*	H42	D2K	UD	TR
780150204	0.5997	1.0000	2.1420**04	2.1980**03	1.4389	1.2937	5.2266**04	5.2266**04
0.0000**00	6.6650**04	1.0000	2.2479**04	0.0000**00	1.7978	1.7967	3.0650**02	2.8794**02
INFINITE	3.0865**02	2.8921**01	3.1266**03	0.0000**00	0.0125	3.1975**03	2.0403**02	3.0650**02
780150205	0.5938	1.0000	2.1659**04	2.1950**03	1.4349	1.2925	5.3344**04	5.3344**04
7.6200**02	6.7710**04	1.0000	2.2708**04	0.0000**00	1.7971	1.7960	3.0677**02	2.8854**02
INFINITE	3.0889**02	2.8896**01	3.1341**03	0.0000**00	0.0123	3.2041**03	2.0222**02	3.0677**02
780150301	0.5942	1.0000	2.8440**04	2.0900**03	1.4333	1.2910	9.9469**04	9.9469**04
-4.8430**01	1.2630**05	1.0000	2.9813**04	0.0000**00	1.8008	1.7997	3.1376**02	2.9509**02
INFINITE	3.1593**02	5.1380**01	2.2690**03	0.0000**00	0.0124	2.3189**03	2.0465**02	3.1376**02
780150302	0.5938	1.0000	3.1650**04	2.0570**03	1.4304	1.2884	1.0005**05	1.0005**05
-2.6210**01	1.2700**05	1.0000	3.3166**04	0.0000**00	1.8015	1.8004	3.2196**02	3.0283**02
INFINITE	3.2418**02	5.0793**01	2.5952**03	0.0000**00	0.0123	2.6520**03	2.0717**02	3.2196**02
780150303	0.5934	1.0000	3.4203**04	2.0560**03	1.4230	1.2816	9.9766**04	9.9766**04
-7.6200**02	1.2660**05	1.0000	3.5846**04	0.0000**00	1.8052	1.8041	3.1618**02	2.9741**02
INFINITE	3.1836**02	5.0561**01	2.7510**03	0.0000**00	0.0124	2.8101**03	2.0519**02	3.1618**02
780150304	0.5927	1.0000	3.5067**04	2.0650**03	1.4198	1.2788	1.0006**05	1.0006**05
0.0000**00	1.2690**05	1.0000	3.6741**04	0.0000**00	1.8063	1.8052	3.2149**02	3.0245**02
INFINITE	3.2370**02	5.0807**01	2.8756**03	0.0000**00	0.0123	2.9369**03	2.0666**02	3.2149**02
780150305	0.5917	1.0000	3.5613**04	2.0410**03	1.4171	1.2766	9.9902**04	9.9902**04
7.6200**02	1.2660**05	1.0000	3.7306**04	0.0000**00	1.8057	1.8047	3.2221**02	3.0319**02
INFINITE	3.2442**02	4.9964**01	2.9386**03	0.0000**00	0.0123	3.0013**03	2.0656**02	3.2221**02
780150401	0.7962	1.0000	1.8153**04	2.1360**03	1.5834	1.3250	4.3270**04	4.3270**04
-4.8430**01	6.5710**04	1.0000	1.9736**04	0.0000**00	1.7856	1.7834	3.0528**02	2.7413**02
INFINITE	3.0889**02	4.1014**01	2.3451**03	0.0000**00	0.0209	2.4433**03	2.6431**02	3.0528**02
780150402	0.7835	1.0000	1.9894**04	2.1090**03	1.5616	1.3123	4.4611**04	4.4611**04
-2.6210**01	6.6910**04	1.0000	2.1571**04	0.0000**00	1.7904	1.7884	3.0802**02	2.7749**02
INFINITE	3.1156**02	4.0435**01	2.5659**03	0.0000**00	0.0204	2.6682**03	2.6170**02	3.0802**02
780150403	0.8029	1.0000	2.1588**04	2.1320**03	1.5533	1.2931	4.3769**04	4.3769**04
-7.6200**02	6.6910**04	1.0000	2.3505**04	0.0000**00	1.7988	1.7968	3.0330**02	2.7190**02
INFINITE	3.0695**02	4.2107**01	2.7094**03	0.0000**00	0.0214	2.8190**03	2.6544**02	3.0330**02
780150404	0.7998	1.0000	2.1832**04	2.1200**03	1.5520	1.2939	4.3731**04	4.3731**04
0.0000**00	6.6650**04	1.0000	2.3749**04	0.0000**00	1.7986	1.7966	3.0837**02	2.7665**02
INFINITE	3.1205**02	4.1517**01	2.8123**03	0.0000**00	0.0212	2.9253**03	2.6673**02	3.0837**02
780150405	0.7976	1.0000	2.2763**04	2.1050**03	1.5518	1.2951	4.3651**04	4.3651**04
7.6200**02	6.6380**04	1.0000	2.4751**04	0.0000**00	1.7985	1.7965	3.0767**02	2.7618**02
INFINITE	3.1132**02	4.0916**01	2.9382**03	0.0000**00	0.0211	3.0554**03	2.6576**02	3.0767**02
780150501	0.7947	1.0000	3.0340**04	2.0050**03	1.5517	1.2970	8.7905**04	8.7905**04
-4.8430**01	1.3330**05	1.0000	3.2946**04	0.0000**00	1.8012	1.7993	3.2088**02	2.8826**02
INFINITE	3.2467**02	7.7923**01	2.0589**03	0.0000**00	0.0210	2.1396**03	2.7053**02	3.2088**02
780150502	0.7917	1.0000	3.3617**04	1.9930**03	1.5376	1.2856	8.8236**04	8.8236**04
-2.6210**01	1.3340**05	1.0000	3.6473**04	0.0000**00	1.8049	1.8032	3.2451**02	2.9174**02
INFINITE	3.2831**02	7.7153**01	2.3148**03	0.0000**00	0.0209	2.4036**03	2.7112**02	3.2451**02
780150503	0.7913	1.0000	3.6160**04	1.9870**03	1.5261	1.2753	8.8203**04	8.8203**04
-7.6200**02	1.3330**05	1.0000	3.9238**04	0.0000**00	1.8090	1.8072	3.2091**02	2.8854**02
INFINITE	3.2467**02	7.6818**01	2.4575**03	0.0000**00	0.0209	2.5497**03	2.6950**02	3.2091**02
780150504	0.7888	1.0000	3.7226**04	1.9780**03	1.5226	1.2736	8.8423**04	8.8423**04
0.0000**00	1.3330**05	1.0000	4.0366**04	0.0000**00	1.8101	1.8083	3.2453**02	2.9198**02
INFINITE	3.2831**02	7.6171**01	2.5685**03	0.0000**00	0.0208	2.6638**03	2.7023**02	3.2453**02
780150505	0.7900	1.0000	3.9026**04	1.9530**03	1.5308	1.2803	8.8117**04	8.8117**04
7.6200**02	1.3300**05	1.0000	4.2327**04	0.0000**00	1.8069	1.8051	3.2476**02	2.9209**02
INFINITE	3.2855**02	7.5182**01	2.6998**03	0.0000**00	0.0209	2.8018**03	2.7070**02	3.2476**02
780150601	0.9627	1.0000	1.6335**04	2.1080**03	1.6986	1.3214	3.6457**04	3.6457**04
-4.8430**01	6.6110**04	1.0000	1.8418**04	0.0000**00	1.7889	1.7858	3.0554**02	2.6202**02
INFINITE	3.1059**02	4.9860**01	2.0264**03	0.0000**00	0.0291	2.1491**03	3.1245**02	3.0554**02
780150602	0.9617	1.0000	1.8647**04	2.0650**03	1.6830	1.3079	3.6942**04	3.6942**04
-2.6210**01	6.6910**04	1.0000	2.1017**04	0.0000**00	1.7925	1.7895	3.0698**02	2.6334**02
INFINITE	3.1205**02	4.9386**01	2.2994**03	0.0000**00	0.0291	2.4364**03	3.1290**02	3.0698**02
780150603	0.9680	1.0000	1.9597**04	2.0970**03	1.6681	1.2904	3.6386**04	3.6386**04
-7.6200**02	6.6380**04	1.0000	2.2126**04	0.0000**00	1.8004	1.7976	3.0430**02	2.6055**02
INFINITE	3.0938**02	5.0049**01	2.4081**03	0.0000**00	0.0296	2.5489**03	3.1328**02	3.0430**02
780150604	0.9635	1.0000	2.0075**04	2.0810**03	1.6731	1.2982	3.6721**04	3.6721**04
0.0000**00	6.6650**04	1.0000	2.2635**04	0.0000**00	1.7979	1.7950	3.0768**02	2.6379**02
INFINITE	3.1277**02	4.9661**01	2.4919**03	0.0000**00	0.0293	2.6375**03	3.1376**02	3.0768**02
780150605	0.9604	1.0000	2.0713**04	2.0670**03	1.6701	1.2977	3.6853**04	3.6853**04
7.6200**02	6.6650**04	1.0000	2.3338**04	0.0000**00	1.7981	1.7952	3.0700**02	2.6345**02
INFINITE	3.1205**02	4.9180**01	2.5644**03	0.0000**00	0.0291	2.7131**03	3.1254**02	3.0700**02

CAT 7801S COLLINS/COLES/H BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS									
RUN X * RZ	MD * POD* TOD*	TW/TR* PW/PR* TAUM	RED2W RED2D DZ	CF * CQ * PIZ*	M1Z M3Z M4Z	M12K M32K D2K	PW TW UD	PD TD TR	
7801S0701	0.9606	1.0000	2.8035E+04	1.9700E-03	1.6637	1.2922	7.3857E+04	7.3857E+04	
-4.8430E-01	1.3360E+05	1.0000	3.1548E+04	0.0000E+00	1.8036	1.8009	3.2227E+02	2.7655E+02	
INFINITE	3.2758E+02	9.3972E+01	1.8410E-03	0.0000E+00	0.0292	1.9455E-03	3.2027E+02	3.2227E+02	
7801S0702	0.9592	1.0000	3.1944E+04	1.9400E-03	1.6536	1.2838	7.3470E+04	7.3470E+04	
-2.6210E-01	1.3270E+05	1.0000	3.5929E+04	0.0000E+00	1.8054	1.8028	3.2443E+02	2.7851E+02	
INFINITE	3.2976E+02	9.1802E+01	2.1298E-03	0.0000E+00	0.0292	2.2494E-03	3.2096E+02	3.2443E+02	
7801S0703	0.9577	1.0000	3.4294E+04	1.9530E-03	1.6409	1.2736	7.4204E+04	7.4204E+04	
-7.6200E-02	1.3380E+05	1.0000	3.8565E+04	0.0000E+00	1.8106	1.8081	3.2277E+02	2.7721E+02	
INFINITE	3.2806E+02	9.3052E+01	2.2534E-03	0.0000E+00	0.0292	2.3767E-03	3.1971E+02	3.2277E+02	
7801S0704	0.9608	1.0000	3.5152E+04	1.9250E-03	1.6487	1.2787	7.3504E+04	7.3504E+04	
0.0000E+00	1.3300E+05	1.0000	3.9552E+04	0.0000E+00	1.8092	1.8066	3.2466E+02	2.7858E+02	
INFINITE	3.3001E+02	9.1435E+01	2.3404E-03	0.0000E+00	0.0293	2.4698E-03	3.2153E+02	3.2466E+02	
7801S0705	0.9577	1.0000	3.6823E+04	1.9110E-03	1.6462	1.2785	7.3818E+04	7.3818E+04	
7.6200E-02	1.3310E+05	1.0000	4.1401E+04	0.0000E+00	1.8082	1.8055	3.2516E+02	2.7926E+02	
INFINITE	3.3049E+02	9.0572E+01	2.4550E-03	0.0000E+00	0.0292	2.5904E-03	3.2089E+02	3.2516E+02	
7801S0801	1.3091	1.0000	1.5679E+04	2.0000E-03	1.9952	1.3028	2.3851E+04	2.3851E+04	
-2.6210E-01	6.6910E+04	1.0000	1.9631E+04	0.0000E+00	1.7988	1.7936	3.0423E+02	2.3275E+02	
INFINITE	3.1253E+02	5.7225E+01	2.0800E-03	0.0000E+00	0.0478	2.3035E-03	4.0044E+02	3.0423E+02	
7801S0802	1.3163	1.0000	1.6862E+04	1.9830E-03	2.0028	1.3035	2.3475E+04	2.3475E+04	
-7.6200E-02	6.6510E+04	1.0000	2.0898E+04	0.0000E+00	1.8007	1.7954	3.0228E+02	2.3066E+02	
INFINITE	3.1059E+02	5.6463E+01	2.2108E-03	0.0000E+00	0.0482	2.4486E-03	4.0083E+02	3.0228E+02	
7801S0803	1.3147	1.0000	1.7519E+04	1.9830E-03	1.9893	1.2934	2.3578E+04	2.3578E+04	
0.0000E+00	6.6650E+04	1.0000	2.1702E+04	0.0000E+00	1.8033	1.7982	3.0229E+02	2.3081E+02	
INFINITE	3.1059E+02	5.6568E+01	2.2907E-03	0.0000E+00	0.0482	2.5341E-03	4.0046E+02	3.0229E+02	
7801S0804	1.3108	1.0000	1.8740E+04	1.9590E-03	1.9848	1.2931	2.3751E+04	2.3751E+04	
7.6200E-02	6.6780E+04	1.0000	2.3211E+04	0.0000E+00	1.8035	1.7985	2.9619E+02	2.2646E+02	
INFINITE	3.0428E+02	5.5958E+01	2.3790E-03	0.0000E+00	0.0480	2.6301E-03	3.9549E+02	2.2646E+02	
7801S0901	1.3002	1.0000	2.7331E+04	1.8440E-03	1.9655	1.2871	4.8095E+04	4.8095E+04	
-2.6210E-01	1.3330E+05	1.0000	3.3641E+04	0.0000E+00	1.8090	1.8042	3.1614E+02	2.4263E+02	
INFINITE	3.2467E+02	1.0495E+02	1.8795E-03	0.0000E+00	0.0475	2.0699E-03	4.0607E+02	3.1614E+02	
7801S0902	1.3128	1.0000	2.9314E+04	1.8580E-03	1.9596	1.2714	4.7276E+04	4.7276E+04	
-7.6200E-02	1.3330E+05	1.0000	3.6226E+04	0.0000E+00	1.8156	1.8110	3.1412E+02	2.3981E+02	
INFINITE	3.2272E+02	1.0597E+02	2.0103E-03	0.0000E+00	0.0484	2.2117E-03	4.0777E+02	3.1412E+02	
7801S0903	1.3069	1.0000	2.9900E+04	1.8600E-03	1.9507	1.2691	4.7841E+04	4.7841E+04	
0.0000E+00	1.3380E+05	1.0000	3.6879E+04	0.0000E+00	1.8163	1.8119	3.1513E+02	2.4128E+02	
INFINITE	3.2370E+02	1.0638E+02	2.0459E-03	0.0000E+00	0.0481	2.2485E-03	4.0701E+02	3.1513E+02	
7801S0904	1.3076	1.0000	3.1432E+04	1.8320E-03	1.9588	1.2754	4.7506E+04	4.7506E+04	
7.6200E-02	1.3300E+05	1.0000	3.8801E+04	0.0000E+00	1.8141	1.8094	3.1133E+02	2.3831E+02	
INFINITE	3.1981E+02	1.0417E+02	2.1315E-03	0.0000E+00	0.0481	2.3446E-03	4.0473E+02	3.1133E+02	
7801S1001	2.1633	1.0000	1.4113E+04	1.6560E-03	3.1555	1.2847	9.2424E+03	9.2424E+03	
-2.6210E-01	9.3310E+04	1.0000	2.3400E+04	0.0000E+00	1.8156	1.8039	2.9313E+02	1.5943E+02	
INFINITE	3.0865E+02	5.0139E+01	2.3219E-03	0.0000E+00	0.0913	2.9512E-03	5.4766E+02	2.9313E+02	
7801S1002	2.1540	1.0000	1.4380E+04	1.6490E-03	3.1349	1.2812	9.3772E+03	9.3772E+03	
-7.6200E-02	9.3310E+04	1.0000	2.3739E+04	0.0000E+00	1.8161	1.8047	2.9550E+02	1.6135E+02	
INFINITE	3.1107E+02	5.0223E+01	2.3705E-03	0.0000E+00	0.0909	3.0064E-03	5.4858E+02	2.9550E+02	
7801S1003	2.1564	1.0000	1.5270E+04	1.6330E-03	3.1414	1.2832	9.3425E+03	9.3425E+03	
0.0000E+00	9.3310E+04	1.0000	2.5241E+04	0.0000E+00	1.8159	1.8043	2.9433E+02	1.6055E+02	
INFINITE	3.0986E+02	4.9660E+01	2.5098E-03	0.0000E+00	0.0910	3.1846E-03	5.4783E+02	2.9433E+02	
7801S1004	2.1655	1.0000	1.5331E+04	1.6240E-03	3.1561	1.2824	9.2110E+03	9.2110E+03	
7.6200E-02	9.3310E+04	1.0000	2.5409E+04	0.0000E+00	1.8160	1.8045	2.9634E+02	1.6103E+02	
INFINITE	3.1205E+02	4.9102E+01	2.5624E-03	0.0000E+00	0.0914	3.2571E-03	5.5095E+02	2.9634E+02	
7801S1101	2.1725	1.0000	2.3615E+04	1.5340E-03	3.1351	1.2631	1.7565E+04	1.7565E+04	
-2.6210E-01	1.7990E+05	1.0000	3.9076E+04	0.0000E+00	1.8268	1.8158	3.0781E+02	1.6677E+02	
INFINITE	3.2418E+02	8.9019E+01	2.1618E-03	0.0000E+00	0.0923	2.7215E-03	5.6249E+02	3.0781E+02	
7801S1102	2.1626	1.0000	2.4358E+04	1.5300E-03	3.1194	1.2638	1.7868E+04	1.7868E+04	
-7.6200E-02	1.8020E+05	1.0000	4.0196E+04	0.0000E+00	1.8264	1.8156	3.0512E+02	1.6600E+02	
INFINITE	3.2127E+02	8.9499E+01	2.1822E-03	0.0000E+00	0.0918	2.7432E-03	5.5865E+02	3.0512E+02	
7801S1103	2.1752	1.0000	2.5037E+04	1.5270E-03	3.1300	1.2563	1.7480E+04	1.7480E+04	
0.0000E+00	1.7980E+05	1.0000	4.1513E+04	0.0000E+00	1.8288	1.8183	3.0502E+02	1.6506E+02	
INFINITE	3.2127E+02	8.8406E+01	2.2727E-03	0.0000E+00	0.0925	2.8571E-03	5.6033E+02	3.0502E+02	
7801S1104	2.1736	1.0000	2.6165E+04	1.5070E-03	3.1331	1.2598	1.7563E+04	1.7563E+04	
7.6200E-02	1.8020E+05	1.0000	4.3335E+04	0.0000E+00	1.8268	1.8162	3.0641E+02	1.6593E+02	
INFINITE	3.2272E+02	8.7535E+01	2.3799E-03	0.0000E+00	0.0923	2.9972E-03	5.6137E+02	3.0641E+02	

7801S0301		COLLINS/COLES/H		PROFILE TABULATION		84 POINTS, DELTA AT POINT 69		
I	Y	PT2/P	P/PO	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.99314	0.00000	0.00000	1.06327	0.00000
2	1.0000"-04	1.0515"+00	NM	0.99461	0.45225	0.46335	1.04969	0.44142
3	2.2000"-04	1.0718"+00	NM	0.99517	0.53237	0.54409	1.04454	0.52089
4	3.8000"-04	1.0824"+00	NM	0.99546	0.56926	0.58107	1.04191	0.55769
5	5.2000"-04	1.0903"+00	NM	0.99567	0.59509	0.60687	1.03997	0.58355
6	7.4000"-04	1.0995"+00	NM	0.99591	0.62384	0.63550	1.03772	0.61240
7	9.1000"-04	1.1030"+00	NM	0.99600	0.63420	0.64579	1.03688	0.62282
8	1.0200"-03	1.1096"+00	NM	0.99617	0.65340	0.66483	1.03530	0.64216
9	1.3400"-03	1.1141"+00	NM	0.99629	0.66647	0.67777	1.03421	0.65535
10	1.5100"-03	1.1157"+00	NM	0.99633	0.67079	0.68204	1.03384	0.65972
11	1.6300"-03	1.1224"+00	NM	0.99650	0.68928	0.70031	1.03224	0.67843
12	1.8100"-03	1.1232"+00	NM	0.99652	0.69140	0.70239	1.03206	0.68057
13	1.9400"-03	1.1259"+00	NM	0.99659	0.69863	0.70952	1.03142	0.68791
14	2.1900"-03	1.1307"+00	NM	0.99672	0.71130	0.72199	1.03029	0.70077
15	2.4000"-03	1.1292"+00	NM	0.99668	0.70718	0.71794	1.03066	0.69658
16	2.5500"-03	1.1357"+00	NM	0.99684	0.72407	0.73454	1.02913	0.71374
17	2.8300"-03	1.1366"+00	NM	0.99686	0.72638	0.73681	1.02892	0.71610
18	3.1300"-03	1.1407"+00	NM	0.99697	0.73683	0.74706	1.02796	0.72674
19	3.3100"-03	1.1434"+00	NM	0.99704	0.74347	0.75356	1.02734	0.73351
20	3.5900"-03	1.1457"+00	NM	0.99709	0.74910	0.75907	1.02681	0.73925
21	3.9400"-03	1.1484"+00	NM	0.99716	0.75573	0.76556	1.02619	0.74602
22	4.1400"-03	1.1507"+00	NM	0.99722	0.76136	0.77106	1.02565	0.75178
23	4.4900"-03	1.1538"+00	NM	0.99729	0.76870	0.77823	1.02495	0.75928
24	4.8100"-03	1.1570"+00	NM	0.99737	0.77624	0.78558	1.02422	0.76700
25	5.0900"-03	1.1600"+00	NM	0.99745	0.78317	0.79234	1.02355	0.77411
26	5.4900"-03	1.1628"+00	NM	0.99752	0.78981	0.79880	1.02290	0.78092
27	5.7500"-03	1.1673"+00	NM	0.99763	0.79996	0.80867	1.02189	0.79134
28	6.0500"-03	1.1681"+00	NM	0.99764	0.80167	0.81033	1.02172	0.79310
29	6.4000"-03	1.1696"+00	NM	0.99768	0.80519	0.81375	1.02137	0.79672
30	6.7000"-03	1.1718"+00	NM	0.99774	0.81001	0.81843	1.02089	0.80168
31	7.0600"-03	1.1749"+00	NM	0.99781	0.81695	0.82515	1.02019	0.80882
32	7.3000"-03	1.1777"+00	NM	0.99788	0.82308	0.83109	1.01957	0.81514
33	7.6900"-03	1.1815"+00	NM	0.99797	0.83142	0.83917	1.01872	0.82375
34	8.0200"-03	1.1839"+00	NM	0.99803	0.83645	0.84403	1.01820	0.82894
35	8.3600"-03	1.1851"+00	NM	0.99806	0.83906	0.84655	1.01793	0.83164
36	8.8200"-03	1.1894"+00	NM	0.99816	0.84831	0.85548	1.01697	0.84121
37	9.3000"-03	1.1915"+00	NM	0.99821	0.85253	0.85955	1.01652	0.84558
38	9.7500"-03	1.1973"+00	NM	0.99835	0.86470	0.87126	1.01524	0.85818
39	1.0240"-02	1.2000"+00	NM	0.99841	0.87023	0.87658	1.01465	0.86392
40	1.0650"-02	1.2018"+00	NM	0.99845	0.87394	0.88015	1.01426	0.86778
41	1.1030"-02	1.2066"+00	NM	0.99857	0.88349	0.88932	1.01323	0.87771
42	1.1670"-02	1.2096"+00	NM	0.99864	0.88963	0.89520	1.01257	0.88409
43	1.2050"-02	1.2114"+00	NM	0.99868	0.89314	0.89857	1.01218	0.88775
44	1.2400"-02	1.2158"+00	NM	0.99878	0.90169	0.90675	1.01125	0.89666
45	1.2800"-02	1.2189"+00	NM	0.99885	0.90772	0.91251	1.01059	0.90295
46	1.3240"-02	1.2208"+00	NM	0.99890	0.91144	0.91606	1.01018	0.90684
47	1.3650"-02	1.2236"+00	NM	0.99896	0.91687	0.92125	1.00957	0.91251
48	1.4100"-02	1.2266"+00	NM	0.99903	0.92250	0.92661	1.00895	0.91840
49	1.4370"-02	1.2298"+00	NM	0.99910	0.92863	0.93246	1.00826	0.92482
50	1.4820"-02	1.2301"+00	NM	0.99911	0.92913	0.93293	1.00820	0.92534
51	1.5220"-02	1.2346"+00	NM	0.99921	0.93758	0.94097	1.00725	0.93420
52	1.5810"-02	1.2363"+00	NM	0.99925	0.94059	0.94383	1.00691	0.93736
53	1.6210"-02	1.2395"+00	NM	0.99932	0.94652	0.94947	1.00623	0.94359
54	1.6770"-02	1.2431"+00	NM	0.99941	0.95316	0.95576	1.00547	0.95056
55	1.7380"-02	1.2459"+00	NM	0.99947	0.95818	0.96053	1.00490	0.95585
56	1.7830"-02	1.2475"+00	NM	0.99950	0.96100	0.96319	1.00457	0.95881
57	1.8470"-02	1.2547"+00	NM	0.99967	0.97386	0.97536	1.00308	0.97237
58	1.9110"-02	1.2582"+00	NM	0.99974	0.98000	0.98115	1.00236	0.97884
59	1.9670"-02	1.2587"+00	NM	0.99976	0.98100	0.98210	1.00224	0.97990
60	2.0150"-02	1.2609"+00	NM	0.99980	0.98472	0.98561	1.00181	0.98383
61	2.0700"-02	1.2626"+00	NM	0.99984	0.98774	0.98845	1.00145	0.98702
62	2.1120"-02	1.2639"+00	NM	0.99987	0.99005	0.99063	1.00118	0.98946
63	2.1600"-02	1.2657"+00	NM	0.99991	0.99306	0.99347	1.00082	0.99266
64	2.1950"-02	1.2662"+00	NM	0.99992	0.99397	0.99432	1.00072	0.99361
65	2.2330"-02	1.2672"+00	NM	0.99994	0.99568	0.99593	1.00051	0.99542
66	2.2740"-02	1.2683"+00	NM	0.99997	0.99759	0.99773	1.00029	0.99744
67	2.3200"-02	1.2682"+00	NM	0.99997	0.99729	0.99745	1.00032	0.99713
68	2.3680"-02	1.2707"+00	NM	1.00002	1.00161	1.00151	0.99981	1.00170
D 69	2.4210"-02	1.2697"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000
70	2.4590"-02	1.2715"+00	NM	1.00004	1.00292	1.00274	0.99965	1.00309
71	2.5550"-02	1.2713"+00	NM	1.00003	1.00261	1.00246	0.99969	1.00277
72	2.6470"-02	1.2735"+00	NM	1.00008	1.00643	1.00605	0.99923	1.00682
73	2.7590"-02	1.2739"+00	NM	1.00009	1.00714	1.00671	0.99915	1.00757
74	2.8560"-02	1.2732"+00	NM	1.00008	1.00583	1.00548	0.99930	1.00618
75	2.9540"-02	1.2730"+00	NM	1.00007	1.00553	1.00520	0.99934	1.00586
76	3.0370"-02	1.2735"+00	NM	1.00008	1.00643	1.00605	0.99923	1.00682
77	3.1380"-02	1.2728"+00	NM	1.00007	1.00523	1.00491	0.99938	1.00554
78	3.2190"-02	1.2730"+00	NM	1.00007	1.00553	1.00520	0.99934	1.00586
79	3.2980"-02	1.2738"+00	NM	1.00009	1.00684	1.00642	0.99918	1.00725
80	3.3740"-02	1.2720"+00	NM	1.00005	1.00392	1.00369	0.99953	1.00616
81	3.4550"-02	1.2732"+00	NM	1.00008	1.00583	1.00548	0.99930	1.00618
82	3.5310"-02	1.2726"+00	NM	1.00006	1.00483	1.00454	0.99942	1.00511
83	3.6180"-02	1.2716"+00	NM	1.00004	1.00322	1.00302	0.99962	1.00341
84	3.7090"-02	1.2732"+00	NM	1.00008	1.00583	1.00548	0.99930	1.00618

INPUT VARIABLES Y,M/MD ASSUME P=PD ASSUME VAN DRIEST

7801S0801		COLLINS/COLES/H		PROFILE TABULATION		82 POINTS, DELTA AT POINT 67		
I	Y	PT2/P	P/PO	TO/TOD	M/MO	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	NM	0.97345	0.00000	0.00000	1.30711	0.00000
2	1.0000-04	1.2069+00	NM	0.97878	0.40133	0.44789	1.24550	0.35960
3	1.7000-04	1.2725+00	NM	0.98024	0.45603	0.50548	1.22864	0.41142
4	3.4000-04	1.3440+00	NM	0.98172	0.50713	0.55817	1.21143	0.46075
5	4.3000-04	1.3930+00	NM	0.98269	0.53835	0.58980	1.20028	0.49138
6	6.6000-04	1.4472+00	NM	0.98371	0.57007	0.62147	1.18849	0.52291
7	1.0000-03	1.4940+00	NM	0.98455	0.59546	0.64650	1.17875	0.54846
8	1.1900-03	1.5260+00	NM	0.98511	0.61193	0.66255	1.17230	0.56517
9	1.4800-03	1.5702+00	NM	0.98585	0.63361	0.68349	1.16364	0.58737
10	1.7100-03	1.5903+00	NM	0.98618	0.64304	0.69253	1.15982	0.59710
11	2.1300-03	1.6266+00	NM	0.98677	0.65961	0.70828	1.15304	0.61427
12	2.4500-03	1.6547+00	NM	0.98721	0.67195	0.71994	1.14793	0.62716
13	2.8500-03	1.6892+00	NM	0.98774	0.68661	0.73368	1.14180	0.64256
14	3.2300-03	1.7175+00	NM	0.98817	0.69825	0.74451	1.13688	0.65487
15	3.7000-03	1.7464+00	NM	0.98859	0.70980	0.75518	1.13196	0.66714
16	4.0600-03	1.7816+00	NM	0.98910	0.72345	0.76771	1.12610	0.68174
17	4.3900-03	1.7882+00	NM	0.98919	0.72596	0.77000	1.12507	0.68443
18	4.8600-03	1.8180+00	NM	0.98961	0.73710	0.78014	1.12019	0.69643
19	5.2300-03	1.8502+00	NM	0.99005	0.74885	0.79076	1.11507	0.70915
20	5.6100-03	1.8711+00	NM	0.99033	0.75627	0.79744	1.11182	0.71724
21	5.9300-03	1.8939+00	NM	0.99064	0.76420	0.80453	1.10933	0.72590
22	6.2200-03	1.9221+00	NM	0.99100	0.77384	0.81311	1.10406	0.73647
23	6.7800-03	1.9509+00	NM	0.99137	0.78348	0.82164	1.09978	0.74709
24	7.1500-03	1.9680+00	NM	0.99159	0.78910	0.82659	1.09728	0.75331
25	7.5000-03	1.9956+00	NM	0.99194	0.79803	0.83442	1.09328	0.76323
26	7.8800-03	2.0269+00	NM	0.99232	0.80797	0.84309	1.08882	0.77432
27	8.2800-03	2.0413+00	NM	0.99250	0.81249	0.84701	1.08678	0.77937
28	8.7100-03	2.0680+00	NM	0.99282	0.82072	0.85412	1.08306	0.78862
29	9.0100-03	2.0861+00	NM	0.99304	0.82624	0.85888	1.08056	0.79484
30	9.4100-03	2.1144+00	NM	0.99337	0.83477	0.86619	1.07669	0.80449
31	9.8000-03	2.1390+00	NM	0.99366	0.84210	0.87244	1.07335	0.81282
32	1.0180-02	2.1678+00	NM	0.99399	0.85053	0.87959	1.06950	0.82243
33	1.0590-02	2.1806+00	NM	0.99414	0.85425	0.88273	1.06780	0.82668
34	1.0890-02	2.1991+00	NM	0.99435	0.85957	0.88722	1.06537	0.83278
35	1.1210-02	2.2192+00	NM	0.99458	0.86529	0.89202	1.06274	0.83936
36	1.1580-02	2.2398+00	NM	0.99481	0.87111	0.89689	1.06007	0.84607
37	1.2000-02	2.2664+00	NM	0.99510	0.87854	0.90308	1.05665	0.85467
38	1.2290-02	2.2896+00	NM	0.99536	0.88496	0.90841	1.05368	0.86213
39	1.2590-02	2.3031+00	NM	0.99551	0.88868	0.91148	1.05197	0.86645
40	1.2950-02	2.3241+00	NM	0.99574	0.89440	0.91619	1.04932	0.87313
41	1.3250-02	2.3423+00	NM	0.99593	0.89932	0.92023	1.04704	0.87888
42	1.3630-02	2.3576+00	NM	0.99610	0.90343	0.92360	1.04514	0.88371
43	1.4040-02	2.3833+00	NM	0.99637	0.91026	0.92916	1.04197	0.89174
44	1.4470-02	2.4088+00	NM	0.99664	0.91698	0.93462	1.03884	0.89968
45	1.4930-02	2.4268+00	NM	0.99683	0.92170	0.93844	1.03665	0.90526
46	1.5260-02	2.4554+00	NM	0.99713	0.92913	0.94442	1.03319	0.91409
47	1.5620-02	2.4714+00	NM	0.99730	0.93325	0.94772	1.03127	0.91899
48	1.6000-02	2.4898+00	NM	0.99749	0.93796	0.95150	1.02907	0.92462
49	1.6370-02	2.5044+00	NM	0.99764	0.94168	0.95446	1.02733	0.92907
50	1.6680-02	2.5258+00	NM	0.99786	0.94710	0.95877	1.02480	0.93557
51	1.7090-02	2.5502+00	NM	0.99810	0.95322	0.96362	1.02194	0.94294
52	1.7520-02	2.5676+00	NM	0.99828	0.95754	0.96703	1.01992	0.94814
53	1.7930-02	2.5833+00	NM	0.99844	0.96145	0.97011	1.01804	0.95288
54	1.8330-02	2.6098+00	NM	0.99870	0.96798	0.97522	1.01503	0.96079
55	1.8790-02	2.6238+00	NM	0.99884	0.97139	0.97789	1.01343	0.96493
56	1.9220-02	2.6357+00	NM	0.99896	0.97430	0.98016	1.01206	0.96888
57	1.9730-02	2.6564+00	NM	0.99916	0.97932	0.98406	1.00971	0.97460
58	2.0100-02	2.6722+00	NM	0.99932	0.98314	0.98702	1.00792	0.97927
59	2.0470-02	2.6914+00	NM	0.99950	0.98775	0.99059	1.00575	0.98492
60	2.0980-02	2.6965+00	NM	0.99955	0.98896	0.99152	1.00519	0.98640
61	2.1310-02	2.7099+00	NM	0.99968	0.99217	0.99399	1.00368	0.99035
62	2.1690-02	2.7150+00	NM	0.99973	0.99337	0.99492	1.00311	0.99183
63	2.2000-02	2.7234+00	NM	0.99981	0.99538	0.99646	1.00217	0.99430
64	2.2400-02	2.7285+00	NM	0.99986	0.99659	0.99739	1.00160	0.99579
65	2.2610-02	2.7294+00	NM	0.99987	0.99679	0.99754	1.00151	0.99604
66	2.3020-02	2.7328+00	NM	0.99990	0.99759	0.99816	1.00113	0.99703
67	2.3340-02	2.7430+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000
68	2.3640-02	2.7459+00	NM	1.00003	1.00070	1.00054	0.99967	1.00087
69	2.4330-02	2.7540+00	NM	1.00011	1.00261	1.00199	0.99877	1.00323
70	2.5130-02	2.7579+00	NM	1.00014	1.00351	1.00268	0.99835	1.00434
71	2.5950-02	2.7540+00	NM	1.00011	1.00261	1.00199	0.99877	1.00323
72	2.6720-02	2.7536+00	NM	1.00010	1.00251	1.00192	0.99882	1.00310
73	2.7590-02	2.7575+00	NM	1.00014	1.00341	1.00261	0.99840	1.00422
74	2.8540-02	2.7613+00	NM	1.00018	1.00432	1.00330	0.99797	1.00534
75	2.9360-02	2.7575+00	NM	1.00014	1.00341	1.00261	0.99840	1.00422
76	3.0170-02	2.7622+00	NM	1.00018	1.00452	1.00345	0.99788	1.00559
77	3.1030-02	2.7579+00	NM	1.00014	1.00351	1.00268	0.99835	1.00434
78	3.1830-02	2.7622+00	NM	1.00018	1.00452	1.00345	0.99788	1.00559
79	3.2490-02	2.7566+00	NM	1.00013	1.00321	1.00245	0.99849	1.00397
80	3.3310-02	2.7557+00	NM	1.00012	1.00301	1.00230	0.99858	1.00372
81	3.4150-02	2.7596+00	NM	1.00016	1.00391	1.00299	0.99816	1.00484
82	3.5030-02	2.7596+00	NM	1.00016	1.00391	1.00299	0.99816	1.00484

INPUT VARIABLES Y,M/MO ASSUME P=PO ASSUME VAN DRIEST

780151104		COLLINS/COLES/H		PROFILE TABULATION		97 POINTS, DELTA AT POINT 90			
I	Y	PT2/P	P/PD	TC/TOD	M/MD	U/UD	T/TD	R/RD*U/UD	
1	0.0000+00	1.0000+00	NM	0.94947	0.00000	0.00000	1.84663	0.00000	
2	1.0000+04	1.4431+00	NM	0.95940	0.34196	0.44327	1.68028	0.26380	
3	1.6000+04	1.5518+00	NM	0.96127	0.37625	0.48316	1.64899	0.29300	
4	3.6000+04	1.8612+00	NM	0.96581	0.45337	0.56860	1.57292	0.36149	
5	5.8000+04	2.0947+00	NM	0.96867	0.49920	0.61645	1.52491	0.40425	
6	8.5000+04	2.2926+00	NM	0.97087	0.53349	0.65079	1.48806	0.43734	
7	1.0500+03	2.4035+00	NM	0.97204	0.55144	0.66826	1.46855	0.45505	
8	1.3000+03	2.5337+00	NM	0.97335	0.57160	0.68747	1.44650	0.47526	
9	1.5700+03	2.5912+00	NM	0.97392	0.56022	0.69555	1.43704	0.46402	
10	1.8100+03	2.6919+00	NM	0.97489	0.59497	0.70919	1.42082	0.49914	
11	2.1200+03	2.7671+00	NM	0.97559	0.60570	0.71897	1.40900	0.51027	
12	2.4000+03	2.8388+00	NM	0.97625	0.61572	0.72800	1.39794	0.52077	
13	2.6500+03	2.9201+00	NM	0.97698	0.62686	0.73789	1.38565	0.53253	
14	2.9300+03	2.9812+00	NM	0.97753	0.63508	0.74512	1.37658	0.54129	
15	3.3400+03	3.0447+00	NM	0.97808	0.64350	0.75245	1.36728	0.55033	
16	3.6400+03	3.1232+00	NM	0.97875	0.65373	0.76125	1.35600	0.56139	
17	4.0200+03	3.1762+00	NM	0.97920	0.66055	0.76706	1.34849	0.56883	
18	4.5000+03	3.2538+00	NM	0.97985	0.67038	0.77534	1.33767	0.57962	
19	4.9100+03	3.3148+00	NM	0.98035	0.67800	0.78170	1.32930	0.58805	
20	5.2700+03	3.3660+00	NM	0.98076	0.68432	0.78692	1.32236	0.59504	
21	5.7000+03	3.4358+00	NM	0.98132	0.69284	0.79390	1.31302	0.60464	
22	6.0800+03	3.5083+00	NM	0.98189	0.70156	0.80097	1.30347	0.61449	
23	6.4100+03	3.5442+00	NM	0.98218	0.70608	0.80460	1.29854	0.61962	
24	6.8900+03	3.6048+00	NM	0.98263	0.71300	0.81012	1.29099	0.62752	
25	7.3500+03	3.6821+00	NM	0.98322	0.72202	0.81725	1.28117	0.63789	
26	7.6000+03	3.7021+00	NM	0.98337	0.72433	0.81906	1.27867	0.64056	
27	8.0600+03	3.7834+00	NM	0.98397	0.73365	0.82632	1.26855	0.65138	
28	8.5800+03	3.8471+00	NM	0.98444	0.74087	0.83188	1.26075	0.65983	
29	8.8900+03	3.8855+00	NM	0.98472	0.74519	0.83517	1.25610	0.66490	
30	9.3800+03	3.9512+00	NM	0.98519	0.75251	0.84073	1.24821	0.67354	
31	9.8800+03	4.0276+00	NM	0.98573	0.76093	0.84705	1.23917	0.68356	
32	1.0220+02	4.0643+00	NM	0.98598	0.76494	0.85004	1.23488	0.68836	
33	1.0550+02	4.1003+00	NM	0.98623	0.76885	0.85294	1.23070	0.69305	
34	1.1010+02	4.1468+00	NM	0.98655	0.77387	0.85664	1.22535	0.69909	
35	1.1340+02	4.2029+00	NM	0.98693	0.77988	0.86104	1.21895	0.70638	
36	1.1770+02	4.2661+00	NM	0.98736	0.78660	0.86591	1.21182	0.71456	
37	1.2200+02	4.3338+00	NM	0.98781	0.79372	0.87103	1.20429	0.72327	
38	1.2570+02	4.3808+00	NM	0.98812	0.79864	0.87454	1.19911	0.72932	
39	1.2940+02	4.4311+00	NM	0.98844	0.80385	0.87823	1.19363	0.73577	
40	1.3380+02	4.4690+00	NM	0.98869	0.80776	0.88099	1.18953	0.74062	
41	1.3770+02	4.5346+00	NM	0.98911	0.81448	0.88569	1.18250	0.74900	
42	1.4190+02	4.5988+00	NM	0.98951	0.82100	0.89021	1.17570	0.75717	
43	1.4630+02	4.6465+00	NM	0.98981	0.82581	0.89352	1.17070	0.76324	
44	1.5040+02	4.7146+00	NM	0.99023	0.83263	0.89818	1.16364	0.77187	
45	1.5400+02	4.7661+00	NM	0.99055	0.83775	0.90164	1.15836	0.77838	
46	1.5980+02	4.8373+00	NM	0.99098	0.84477	0.90636	1.15114	0.78736	
47	1.6370+02	4.8701+00	NM	0.99119	0.84797	0.90850	1.14785	0.79148	
48	1.6670+02	4.8803+00	NM	0.99124	0.84898	0.90917	1.14682	0.79277	
49	1.7150+02	4.9670+00	NM	0.99175	0.85740	0.91474	1.13872	0.80355	
50	1.7480+02	4.9961+00	NM	0.99192	0.86021	0.91658	1.13535	0.80730	
51	1.7720+02	5.0525+00	NM	0.99225	0.86562	0.92012	1.12986	0.81436	
52	1.8040+02	5.0882+00	NM	0.99246	0.86903	0.92233	1.12641	0.81892	
53	1.8630+02	5.1462+00	NM	0.99279	0.87455	0.92588	1.12085	0.82606	
54	1.8850+02	5.1887+00	NM	0.99303	0.87856	0.92846	1.11681	0.83135	
55	1.9220+02	5.2100+00	NM	0.99315	0.88057	0.92974	1.11480	0.83400	
56	1.9630+02	5.2817+00	NM	0.99355	0.88728	0.93400	1.10807	0.84291	
57	1.9960+02	5.3367+00	NM	0.99385	0.89240	0.93722	1.10297	0.84972	
58	2.0210+02	5.3497+00	NM	0.99393	0.89360	0.93797	1.10177	0.85133	
59	2.0560+02	5.3865+00	NM	0.99413	0.89701	0.94010	1.09838	0.85590	
60	2.1140+02	5.4585+00	NM	0.99452	0.90363	0.94421	1.09183	0.86479	
61	2.1520+02	5.5200+00	NM	0.99485	0.90925	0.94767	1.08630	0.87238	
62	2.1930+02	5.5510+00	NM	0.99501	0.91205	0.94938	1.08354	0.87619	
63	2.2440+02	5.6465+00	NM	0.99552	0.92068	0.95462	1.07509	0.88794	
64	2.2730+02	5.6700+00	NM	0.99564	0.92278	0.95569	1.07304	0.89082	
65	2.3200+02	5.7193+00	NM	0.99590	0.92720	0.95854	1.06875	0.89688	
66	2.3580+02	5.7768+00	NM	0.99619	0.93231	0.96159	1.06379	0.90392	
67	2.3990+02	5.8131+00	NM	0.99638	0.93552	0.96349	1.06069	0.90836	
68	2.4320+02	5.8665+00	NM	0.99665	0.94023	0.96627	1.05615	0.91490	
69	2.4850+02	5.8962+00	NM	0.99680	0.94284	0.96780	1.05365	0.91852	
70	2.5200+02	5.9341+00	NM	0.99699	0.94615	0.96973	1.05047	0.92314	
71	2.5660+02	6.0136+00	NM	0.99738	0.95307	0.97375	1.04387	0.93283	
72	2.6230+02	6.0541+00	NM	0.99758	0.95658	0.97577	1.04053	0.93776	
73	2.6610+02	6.0993+00	NM	0.99780	0.96039	0.97796	1.03692	0.94314	
74	2.7090+02	6.1661+00	NM	0.99812	0.96621	0.98127	1.03142	0.95137	
75	2.7540+02	6.1861+00	NM	0.99822	0.96791	0.98223	1.02982	0.95380	
76	2.7910+02	6.2190+00	NM	0.99838	0.97072	0.98382	1.02718	0.95779	
77	2.8350+02	6.2769+00	NM	0.99865	0.97563	0.98658	1.02257	0.96490	
78	2.8860+02	6.3137+00	NM	0.99883	0.97874	0.98832	1.01967	0.96926	
79	2.9220+02	6.3423+00	NM	0.99896	0.98115	0.98966	1.01742	0.97271	
80	2.9830+02	6.3876+00	NM	0.99917	0.98496	0.99177	1.01388	0.97819	
81	3.0280+02	6.4080+00	NM	0.99927	0.98666	0.99271	1.01230	0.98065	
82	3.0690+02	6.4332+00	NM	0.99938	0.98877	0.99387	1.01035	0.98369	
83	3.1150+02	6.4548+00	NM	0.99948	0.99057	0.99496	1.00868	0.98630	
84	3.1480+02	6.4861+00	NM	0.99963	0.99318	0.99629	1.00627	0.99008	
85	3.1880+02	6.4994+00	NM	0.99969	0.99428	0.99689	1.00525	0.99168	
86	3.2350+02	6.5127+00	NM	0.99975	0.99539	0.99749	1.00474	0.99328	
87	3.2770+02	6.5333+00	NM	0.99984	0.99709	0.99842	1.00267	0.99576	
88	3.3100+02	6.5478+00	NM	0.99991	0.99830	0.99908	1.00156	0.99752	
89	3.3550+02	6.5624+00	NM	0.99997	0.99950	0.99973	1.00046	0.99927	
90	3.4060+02	6.5684+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000	
91	3.4370+02	6.5745+00	NM	1.00003	1.00050	1.00027	0.99954	1.00073	
92	3.5020+02	6.5855+00	NM	1.00008	1.00140	1.00076	0.99971	1.00205	
93	3.5340+02	6.5928+00	NM	1.00011	1.00201	1.00108	0.99816	1.00293	
94	3.5800+02	6.6001+00	NM	1.00014	1.00261	1.00141	0.99761	1.00381	
95	3.6320+02	6.6013+00	NM	1.00015	1.00271	1.00146	0.99752	1.00395	
96	3.6890+02	6.6086+00	NM	1.00018	1.00331	1.00179	0.99697	1.00483	
97	3.6910+02	6.6061+00	NM	1.00017	1.00311	1.00168	0.99715	1.00454	

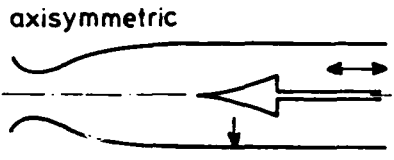
INPUT VARIABLES Y,M/MD ASSUME P=PD ASSUME VAN DRIEST

SECTION D: SUPPLEMENTARY DATA
D.1. SKIN FRICTION DATA. FACSIMILE OF AUTHOR'S TABLE III
AUTHOR'S SYMBOLS AND UNITS

CF FIT - curve fitting, Coles (1968).
CF (H/K) - Preston tube, Hopkins and Keener (1966).
CF (B/U) - Preston tube, Bradshaw and Unsworth (1974).

SKIN FRICTION SUMMARY

IDENT CAT	STATION	ME	RE-TMETHA	2*DTDX	FIT	PRESTON (H/K)	CF PRESTON (B/U)	BALANCE	COMPUTED
7801	CIT-1	.1050	1029.			.004057	.003911		.004410
	CIT-2	.1050	1875.			.003458	.003331		.003703
	CIT-3	.1050	2798.			.003087	.002982		.003321
0101	CIT-4	.1058	5932.		.002787	.002630	.002715		.002826
	CIT-5	.1077	6209.		.002786	.002553	.002637		.002808
	CIT-6	.1031	6604.	.002768	.002756	.002683	.002772		.002782
	CIT-7	.1036	7270.		.002689	.002736	.002825		.002739
	CIT-8	.1052	7475.		.002689	.002611	.002700		.002725
0105	CIT-9	.1070	8068.		.002676	.002493	.002575		.002687
0201	JPL-1	.5927	18870.		.002179				.002249
	JPL-2	.5927	20180.		.002201	.002173	.002169		.002227
	JPL-3	.5986	22190.		.002196				.002194
	JPL-4	.6018	22400.	.002096	.002198	.002109	.002106	.002165	.002190
0205	JPL-5	.5962	22300.		.002195				.002192
0301	JPL-1	.5973	31460.		.002090				.002072
	JPL-2	.5964	34330.		.002057	.002012	.002015		.002048
	JPL-3	.5952	37280.		.002056				.002025
	JPL-4	.5931	36470.	.001992	.002065	.001983	.001985	.001994	.002032
0305	JPL-5	.5935	37930.		.002041				.002020
0401	JPL-1	.7958	19770.		.002136				.002177
	JPL-2	.7882	21850.		.002109	.002139	.002090		.002148
	JPL-3	.8049	23540.		.002132				.002117
	JPL-4	.8014	23710.	.002042	.002120	.002066	.002027	.002086	.002116
0405	JPL-5	.7995	24570.		.002105				.002103
0501	JPL-1	.7980	33940.		.002005				.001998
	JPL-2	.7943	37360.		.001993	.001971	.001935		.001974
	JPL-3	.7940	40190.		.001987				.001953
	JPL-4	.7921	41090.	.001942	.001978	.001920	.001884	.001942	.001947
0505	JPL-5	.7919	42600.		.001953				.001936
0601	JPL-1	.9664	18650.		.002108				.002144
	JPL-2	.9669	20890.		.002065	.002118	.002024		.002103
	JPL-3	.9719	22720.		.002097				.002076
	JPL-4	.9672	22840.	.002054	.002081	.002081	.002008	.002057	.002076
0605	JPL-5	.9651	23850.		.002067				.002062
0701	JPL-1	.9648	32330.		.001970				.001963
	JPL-2	.9626	36250.		.001940	.001932	.001863		.001930
	JPL-3	.9613	38500.		.001953				.001915
	JPL-4	.9637	39900.	.002014	.001925	.001870	.001810	.001947	.001905
0705	JPL-5	.9606	41550.		.001911				.001894
0801	JPL-2	1.3141	19780.		.002000	.001906	.001793		.001994
	JPL-3	1.3215	21880.		.001983				.001958
	JPL-4	1.3197	21900.	.001854	.001983	.001913	.001808	.001867	.001958
0804	JPL-5	1.3151	24190.		.001959				.001931
0901	JPL-2	1.3082	37230.		.001844	.001778	.001701		.001802
	JPL-3	1.3173	37550.		.001858				.001796
	JPL-4	1.3125	37900.	.001750	.001860	.001802	.001697	.001788	.001795
0904	JPL-5	1.3130	40210.		.001832				.001782
1001	JPL-2	2.1722	23070.		.001656	.001740	.001478		.001607
	JPL-3	2.1666	23520.		.001649				.001603
	JPL-4	2.1642	24690.	.001532	.001633	.001683	.001497	.001532	.001590
1004	JPL-5	2.1722	25060.		.001624				.001583
1101	JPL-2	2.1812	38050.		.001534	.001613	.001385		.001476
	JPL-3	2.1737	40570.		.001530				.001462
	JPL-4	2.1820	41600.	.001444	.001527	.001573	.001378	.001445	.001454
1104	JPL-5	2.1797	43060.		.001507				.001447

	M: 2.3 (free stream) RE THETA $\times 10^{-3}$: 30 (upstream) TW/TR: 1	7802
Axisymmetric blowdown tunnel. Running time up to one hour. $D = 0.25$, $L = 2.70$ m. PO: 0.1 (0.03-0.9) MN/m². TO: 280K. Air. RE/m $\times 10^{-6}$: 35 (12-314).		
KUSSOY M.I., HORSTMAN C.C., ACHARYA M., 1978. An experimental documentation of pressure gradient and Reynolds number effects on compressible turbulent boundary layers. NASA TM 78488. <u>And:</u> Horstman C.C., private communications. <u>Also:</u> Acharya et al. (1978)		

- 1 The test boundary layer was formed on the inner surface of a cylindrical test section ($D = 0.2477$, $L = 2.70$ m) attached to the exit of the axisymmetric nozzle. The surface roughness was approximately $0.4 \mu\text{m}$. One of six centre bodies could be stingmounted on the axis of the test section. These were designed to impose a shock free compression on the boundary layer, followed, where geometry allowed, by, firstly, a constant-pressure region and finally an expansion. The centre bodies could be traversed along the centre line so that their associated pressure fields moved past a single, fixed, instrumentation port in the tunnel wall about 2.90 m downstream of the tunnel throat. The position of measuring "stations" is given by their X-position relative to the nose of the centre body.
- 2 Empty-tunnel tests showed that there was an axial Mach number gradient of $-0.05/\text{m}$ as a consequence
- 4 of tunnel wall boundary layer growth. The empty tunnel boundary layer at the instrument port is a
- 3 fully developed equilibrium turbulent boundary layer (see profiles 0101, 0201). The centre bodies traversed by about 0.22 m, and over this distance the thickness of the boundary layer entering the
- 5 interaction varied by about 6%. Pressure variations round the test section measured at selected stations were within experimental error.
- 6 Wall pressure was measured at tappings 0.5 mm in diameter at 50.8 mm intervals along the cylindrical test surface. Careful wall temperature measurements were obtained as part of the shear stress instrumentation. 'Surface shear stress gauges' were made using not-wire sensors embedded in the surface of a plug made from an insulating material and contoured to match the test surface. A platinum -10% rhodium wire $25.4 \mu\text{m}$ in diameter and 6.35 mm long is heated to a predetermined temperature, which is held constant by a constant-temperature hot-wire anemometer. The power required is related to the shear stress. An accurate value for the wall temperature is required for data reduction, and each plug finally contained 6 wires at 5 mm intervals set transversely to the stream. These were, in order, a chromel-constantan thermocouple, a heated wire, two thermocouples, a second heated wire and a final thermocouple. (Note that Fig. 3 of the source paper is incorrect). A Preston tube was also used, for which $d_1 = 1.52$, $d_2 = 0.85$ mm for the first 2.1 mm, the internal diameter then falling to 0.6 mm. The length was 50.8 mm.
- 7 Mean flow Pitot, static pressure and TO profiles were measured. The Pitot was an FPP for which $h_1 = 0.127$, $h_2 = 0.076$, $b_1 = 1.0$ mm. Over a length of 13 mm this section became circular ($d_1 = 1.59$ mm) and then stayed constant to a point 22.9 mm back from the tip. The overall length to the probe support was 50.8 mm, the remainder consisting of 3.2 mm diameter tubing. Two static probes were used, one, after Behrens (1963), a CCP with cone half angle 10° , diameter 1.07 mm, and three 0.36 mm orifices 13.69 mm back from the tip, the other a "Pinckney" (1974) probe with a 10° half angle tip faired into a tube of the same diameter, with four 0.36 mm orifices on the faired portion 5.08 mm back from the tip. The total-temperature probe was an FWP of the design described by Vas (1972). The sensor is a chromel-constantan thermocouple ($d = 76 \mu\text{m}$) mounted on tapered prongs 3.8 mm long.

An auxiliary junction on one of the supports gives the wire-end temperature, required for the elimination of conduction errors. The prongs are mounted on a cylinder 4.4 mm in diameter, the overall length to the probe support being 50.8 mm.

Fluctuation quantities were measured with a single hot wire ($d = 10\mu\text{m}$, $l = 1.5\text{ mm}$, text, figure 1.27) and a similar hot wire which was supported over its whole length by an epoxy film probe ($d = 1.1\text{ mm}$). The probes were operated in the constant temperature mode. The bare hot wire was used for initial measurements in the undisturbed boundary layer, but the design was not sufficiently robust for general use. The film-backed probe was calibrated dynamically for additional thermal inertia effects against a bare wire probe. The calibration of the hot film probe followed the procedures outlined in Horstman and Rose (1977) and Acharya (1977). The authors observe that this probe cannot be used at transonic local Mach numbers so that shear stress values are only measured in positions where $M > 1.2$. Modal analysis showed that total temperature fluctuations were very small, so that - except for this initial study - probes were operated at single, very high overheat ratios so as to respond to mass flow fluctuations only.

- 9 The authors present average PW values for each station relative to the centre body tip, there being very little difference between pressure distributions plotted on this basis for values from three successive (0.1 m apart) static holes. Quite large differences were found in the CF values given by the two surface shear stress gauges, and the values presented are again an average obtained from these devices. In zero pressure gradient conditions the calibration ensured that these values agreed with the profile-fit derived values of CF (the Preston tube value was a little larger). In the regions of strong pressure gradient, the Preston tube and to a lesser degree profile-fit methods are inherently inaccurate. The surface gauge is in principle a sublayer device and so should be relatively little affected by pressure gradients. The total temperature measurements showed that the greatest variation in T_0 was 1/2%, so that T_0 was assumed constant in data reduction. No Pitot corrections were applied, and Sutherland's viscosity law was used.
- 10
- 11
- 12 The editors have presented all the mean flow profile data obtained by the authors, incorporating their assumptions and data reduction procedures. These form two sets, one for each of two centre bodies, of 13 and 14 profiles. The first profile in each set is a representative "undisturbed" profile for which we have arbitrarily set $X = 0$. The skin friction values are those given by the authors, obtained as the average from two surface shear gauges. The fluctuation profiles are given in full in the source paper, and we present sample values in section D. The authors present, in addition, wall pressure and CF values for four other centre bodies, as well as the two for which profiles are available, for four unit Reynolds numbers: 12, 35, 105 and 314×10^6 . These values differ slightly from those presented in the author's profile tables, which have been used here.
- 13
- 14
- § DATA: 78010101-0214. Pitot, static pressure and (T_0) profiles obtained separately. CF from surface shear gauges (embedded hot wire) and (Preston tubes). Fluctuation data from CT HWP and dual wedge probes. NX = 13-14.
- 15 Editors' comments. The experiment provides detailed information for two flow fields which are sufficiently complex to test an advanced calculation method without introducing the complications of shock discontinuities and recirculation regions. The data were discussed at length in AGARDograph 253, but as a result of an unfortunate error in the original evaluation of skin friction from the surface gauges, the criticism of the profiles must be reconsidered. The revised data are used here for figures 1-3 which should be regarded as replacing Figs.(5.3.6a, b; 5.3.7) of AG 253. The presentation of the static pressure field there in Figs.(6.2.2; 6.2.3) is of course unaffected.

The wall law profiles for the milder pressure gradient, series 01, show a semi-log region which agrees with the wall law well within the limits determined by the authors' suggestion of a $\pm 15\%$ uncertainty in the wall shear stress (Fig.1). Series 02 follows the same trend (Fig.2) save that the profile for 0210 suggests that the measured wall stress value is too great by about 20%. Profiles 0101 to 0106 and 0201 to 0207 do not show significant pressure gradient effects and agree well with the

'incompressible norm' (Eqn. 3.3.17 of AG 253), shown as the solid line. The wake strength for profiles 0101-0106 is about 3 which agrees well with other data for this Reynolds number range (Fig. 3.3.4, AG 253). The wake strength in Fig. 1 however shows a marked increase for 0107, at the start of the pressure gradient at the wall but well downstream of the start in the outer region, and this develops to much higher values for profiles 0109 and 0111 respectively at the end of the pressure gradient at the wall and in the outer region. The wake in series 02 similarly increases for 0207 to a maximum around 0209/0210 before decreasing for profiles 0212, 0214 under the influence of the favourable pressure gradient in the outer region.

The outer law plots are much less affected by the change in wall shear value as may be seen by comparing Fig. 3 with Fig. 5.3.7 of AG 253. The earlier discussion therefore remains valid.

The temperature profile shows excellent agreement with the theoretical temperature - velocity relationship (eqn. 2.5.37, AG 253). No velocity profile, however, extends into the sublayer.

Though certain doubts as to the accuracy of the wall shear stress data must remain, these data are unique in providing both mean and fluctuating data at a good number of streamwise stations, so providing a good test case for calculation methods.

Comparable axisymmetric cases, in order of severity of pressure rise, are: Lewis et al. (CAT 7201); the present case; Rose (CAT 7306S), with a shock wave; Kussoy and Horstman (CAT 7501S) with two shock cases, the second of which is strong enough to cause separation.

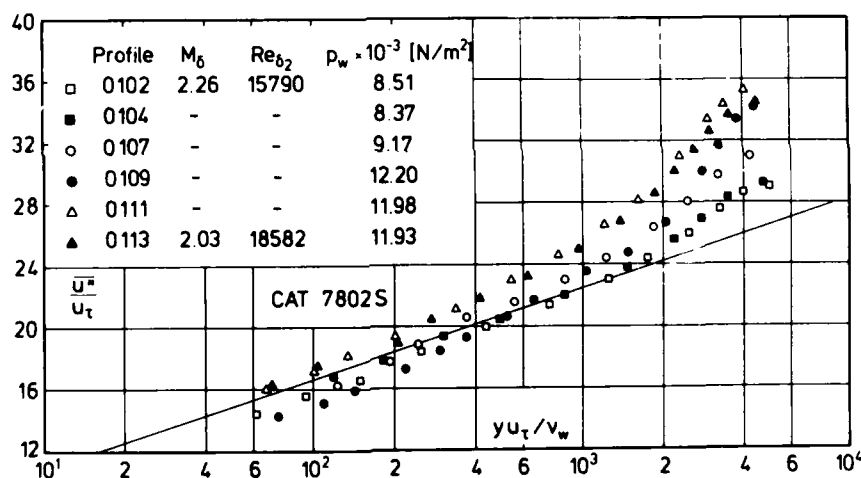


Fig. 1 Law of the wall for an axisymmetric compressible turbulent boundary layer (adiabatic wall, varied pressure gradient, origin not defined, authors' D-state). Kussoy et al. (1978).

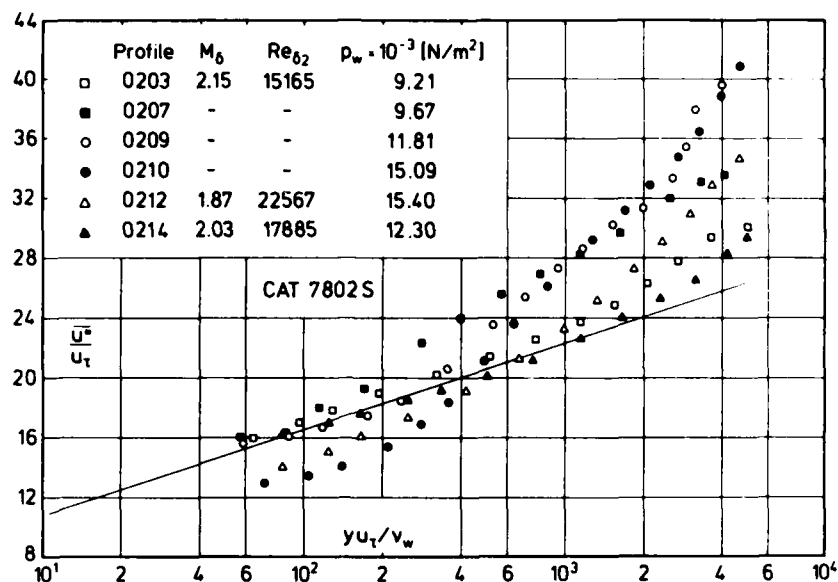


Fig. 2 Law of the wall for an axisymmetric compressible turbulent boundary layer (adiabatic wall, varied pressure gradient, origin not defined, authors' D-state). Kussoy et al. (1978).

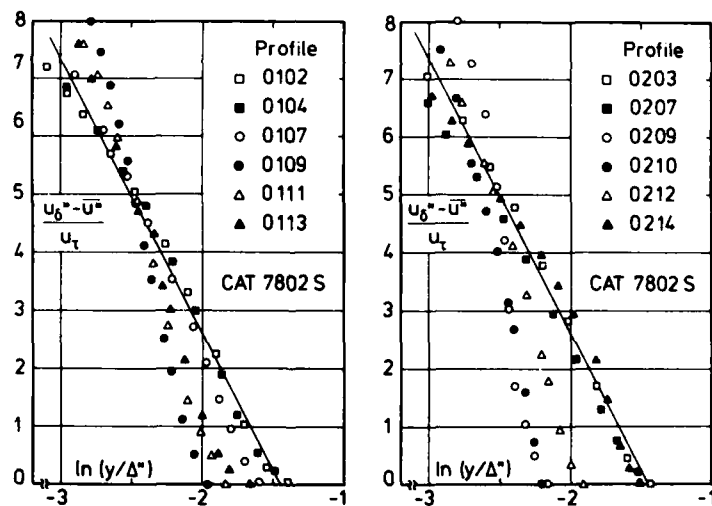


Fig. 3 Outer law for an axisymmetric compressible turbulent boundary layer (adiabatic wall, varied pressure gradient, origin not defined, authors' D-state). Kussoy et al. (1978).

CAT 78025		KUSSDY/HORSTMAN		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS					
RUN X RZ	MD * P00* T00*	TW/TR PW/PO TAUW *	RED2W RED2D DZ	CF CQ *	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD TD TR	
7802S0101	2.2550	1.0553	1.6132 ⁺ 04	1.4390 ⁻ 03	3.7159	1.3342	8.6945 ⁺ 03	8.6945 ⁺ 03	
0.0000 ⁺ 00	1.0132 ⁺ 05	1.0000	2.9254 ⁺ 04	0.0000 ⁺ 00	1.8261	1.8170	2.7800 ⁺ 02	1.3783 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.4147 ⁻ 03	NC	0.0000	3.2368 ⁻ 03	5.3079 ⁺ 02	2.6342 ⁺ 02	
7802S0102	2.2690	1.0557	1.5790 ⁺ 04	1.4528 ⁻ 03	3.7443	1.3323	8.5060 ⁺ 03	8.5060 ⁺ 03	
1.7750 ⁻ 01	1.0132 ⁺ 05	1.0000	2.8797 ⁺ 04	0.0000 ⁺ 00	1.8255	1.8174	2.7800 ⁺ 02	1.3697 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.3934 ⁻ 03	NC	0.0000	3.2219 ⁻ 03	5.3242 ⁺ 02	2.6333 ⁺ 02	
7802S0103	2.2550	1.0553	1.5553 ⁺ 04	1.4390 ⁻ 03	3.9334	1.3305	8.5156 ⁺ 03	8.6945 ⁺ 03	
1.9750 ⁻ 01	1.0132 ⁺ 05	0.9794	2.8204 ⁺ 04	0.0000 ⁺ 00	1.8269	1.8188	2.7800 ⁺ 02	1.3783 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.3280 ⁻ 03	NC	0.0000	3.1776 ⁻ 03	5.3079 ⁺ 02	2.6342 ⁺ 02	
7802S0104	2.2590	1.0554	1.5462 ⁺ 04	1.4430 ⁻ 03	4.0854	1.3299	8.3723 ⁺ 03	8.6402 ⁺ 03	
2.1750 ⁻ 01	1.0132 ⁺ 05	0.9690	2.8085 ⁺ 04	0.0000 ⁺ 00	1.8262	1.8184	2.7800 ⁺ 02	1.3758 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.3228 ⁻ 03	NC	0.0000	3.2120 ⁻ 03	5.3126 ⁺ 02	2.6340 ⁺ 02	
7802S0105	2.2000	1.0539	1.4443 ⁺ 04	1.3872 ⁻ 03	4.8541	1.3284	8.5728 ⁺ 03	9.4761 ⁺ 03	
2.3750 ⁻ 01	1.0132 ⁺ 05	0.9047	2.5612 ⁺ 04	0.0000 ⁺ 00	1.8285	1.8206	2.7800 ⁺ 02	1.4126 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.0584 ⁻ 03	NC	0.0000	2.9906 ⁻ 03	5.2425 ⁺ 02	2.6378 ⁺ 02	
7802S0106	2.1990	1.0539	1.4936 ⁺ 04	1.3863 ⁻ 03	4.6011	1.3374	8.6235 ⁺ 03	9.4909 ⁺ 03	
2.5750 ⁻ 01	1.0132 ⁺ 05	0.9086	2.6475 ⁺ 04	0.0000 ⁺ 00	1.8270	1.8177	2.7800 ⁺ 02	1.4132 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.1267 ⁻ 03	NC	0.0000	3.0696 ⁻ 03	5.2413 ⁺ 02	2.6379 ⁺ 02	
7802S0107	2.1790	1.0534	1.5941 ⁺ 04	1.3244 ⁻ 03	4.1802	1.3780	9.1721 ⁺ 03	9.7927 ⁺ 03	
2.7750 ⁻ 01	1.0132 ⁺ 05	0.9366	2.8029 ⁺ 04	0.0000 ⁺ 00	1.8082	1.7973	2.7800 ⁺ 02	1.4259 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.3106 ⁺ 01	2.2300 ⁻ 03	NC	0.0000	3.1704 ⁻ 03	5.2169 ⁺ 02	2.6392 ⁺ 02	
7802S0108	2.1500	1.0526	2.0653 ⁺ 04	1.1435 ⁻ 03	2.3851	1.4500	1.1139 ⁺ 04	1.0247 ⁺ 04	
2.9750 ⁻ 01	1.0132 ⁺ 05	1.0871	3.5889 ⁺ 04	0.0000 ⁺ 00	1.7737	1.7596	2.7800 ⁺ 02	1.4445 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.7915 ⁺ 01	2.8164 ⁻ 03	NC	0.0000	3.3393 ⁻ 03	5.1810 ⁺ 02	2.6411 ⁺ 02	
7802S0109	2.1480	1.0525	2.3951 ⁺ 04	1.0967 ⁻ 03	1.7376	1.4691	1.2203 ⁺ 04	1.0279 ⁺ 04	
3.1750 ⁻ 01	1.0132 ⁺ 05	1.1872	4.1587 ⁺ 04	0.0000 ⁺ 00	1.7643	1.7493	2.7800 ⁺ 02	1.4458 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.6411 ⁺ 01	3.2604 ⁻ 03	NC	0.0000	3.5697 ⁻ 03	5.1785 ⁺ 02	2.6412 ⁺ 02	
7802S0110	2.0790	1.0507	2.0075 ⁺ 04	1.0750 ⁻ 03	2.9582	1.4646	1.1525 ⁺ 04	1.1450 ⁺ 04	
3.3750 ⁻ 01	1.0132 ⁺ 05	1.0066	3.3903 ⁺ 04	0.0000 ⁺ 00	1.7700	1.7545	2.7800 ⁺ 02	1.4911 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.7238 ⁺ 01	2.5742 ⁻ 03	NC	0.0000	3.3279 ⁻ 03	5.0899 ⁺ 02	2.6460 ⁺ 02	
7802S0111	2.0280	1.0492	1.9315 ⁺ 04	1.0686 ⁻ 03	3.4071	1.4223	1.1980 ⁺ 04	1.2397 ⁺ 04	
3.5750 ⁻ 01	1.0132 ⁺ 05	0.9663	3.1962 ⁺ 04	0.0000 ⁺ 00	1.7820	1.7710	2.7800 ⁺ 02	1.5253 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.8141 ⁺ 01	2.3717 ⁻ 03	NC	0.0000	3.1857 ⁻ 03	5.0218 ⁺ 02	2.6495 ⁺ 02	
7802S0112	2.0320	1.0494	1.8170 ⁺ 04	1.1112 ⁻ 03	3.6342	1.4088	1.1747 ⁺ 04	1.2320 ⁺ 04	
3.7750 ⁻ 01	1.0132 ⁺ 05	0.9534	3.0115 ⁺ 04	0.0000 ⁺ 00	1.7861	1.7760	2.7800 ⁺ 02	1.5226 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.9571 ⁺ 01	2.2387 ⁻ 03	NC	0.0000	3.0536 ⁻ 03	5.0272 ⁺ 02	2.6492 ⁺ 02	
7802S0113	2.0280	1.0492	1.8582 ⁺ 04	1.1213 ⁻ 03	3.5979	1.4036	1.1927 ⁺ 04	1.2397 ⁺ 04	
3.9750 ⁻ 01	1.0132 ⁺ 05	0.9621	3.0750 ⁺ 04	0.0000 ⁺ 00	1.7906	1.7803	2.7800 ⁺ 02	1.5253 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.0022 ⁺ 01	2.2818 ⁻ 03	NC	0.0000	3.0857 ⁻ 03	5.0218 ⁺ 02	2.6495 ⁺ 02	
7802S0202	2.2310	1.0547	1.5666 ⁺ 04	1.4160 ⁻ 03	3.6463	1.3248	9.0273 ⁺ 03	9.0273 ⁺ 03	
1.4400 ⁻ 01	1.0132 ⁺ 05	1.0000	2.8132 ⁺ 04	0.0000 ⁺ 00	1.8275	1.8202	2.7800 ⁺ 02	1.3932 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.2950 ⁻ 03	NC	0.0000	3.0551 ⁻ 03	5.2797 ⁺ 02	2.6392 ⁺ 02	
7802S0203	2.2030	1.0540	1.5165 ⁺ 04	1.3899 ⁻ 03	3.9111	1.3247	9.2106 ⁺ 03	9.4317 ⁺ 03	
1.8400 ⁻ 01	1.0132 ⁺ 05	0.9766	2.6925 ⁺ 04	0.0000 ⁺ 00	1.8272	1.8204	2.7800 ⁺ 02	1.4107 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.1670 ⁻ 03	NC	0.0000	2.9339 ⁻ 03	5.2462 ⁺ 02	2.6376 ⁺ 02	
7802S0204	2.1580	1.0528	1.4692 ⁺ 04	1.3500 ⁻ 03	4.3376	1.3377	9.5021 ⁺ 03	1.0120 ⁺ 04	
2.0400 ⁻ 01	1.0132 ⁺ 05	0.9390	2.5613 ⁺ 04	0.0000 ⁺ 00	1.8266	1.8180	2.7800 ⁺ 02	1.4394 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	2.0176 ⁻ 03	NC	0.0000	2.8048 ⁻ 03	5.1910 ⁺ 02	2.6406 ⁺ 02	
7802S0205	2.1240	1.0519	1.4461 ⁺ 04	1.3214 ⁻ 03	4.6768	1.3121	9.5888 ⁺ 03	1.0672 ⁺ 04	
2.2400 ⁻ 01	1.0132 ⁺ 05	0.8985	2.4868 ⁺ 04	0.0000 ⁺ 00	1.8374	1.8302	2.7800 ⁺ 02	1.4614 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4536 ⁺ 01	1.9279 ⁻ 03	NC	0.0000	2.7347 ⁻ 03	5.1481 ⁺ 02	2.6429 ⁺ 02	
7802S0206	2.1040	1.0513	1.4185 ⁺ 04	1.2946 ⁻ 03	5.1755	1.3390	9.4355 ⁺ 03	1.1011 ⁺ 04	
2.4400 ⁻ 01	1.0132 ⁺ 05	0.8569	2.4197 ⁺ 04	0.0000 ⁺ 00	1.8308	1.8203	2.7800 ⁺ 02	1.4745 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.4175 ⁺ 01	1.8585 ⁻ 03	NC	0.0000	2.7498 ⁻ 03	5.1225 ⁺ 02	2.6442 ⁺ 02	
7802S0207	2.0360	1.0495	1.3617 ⁺ 04	1.1739 ⁻ 03	5.9895	1.3473	9.6728 ⁺ 03	1.2244 ⁺ 04	
2.6400 ⁻ 01	1.0132 ⁺ 05	0.7900	2.2605 ⁺ 04	0.0000 ⁺ 00	1.8300	1.8174	2.7800 ⁺ 02	1.5199 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	4.1707 ⁺ 01	1.6834 ⁻ 03	NC	0.0000	2.6304 ⁻ 03	5.0326 ⁺ 02	2.6490 ⁺ 02	
7802S0208	2.0410	1.0496	1.9462 ⁺ 04	1.0295 ⁻ 03	4.0536	1.4342	1.0085 ⁺ 04	1.2149 ⁺ 04	
2.8400 ⁻ 01	1.0132 ⁺ 05	0.8301	3.2373 ⁺ 04	0.0000 ⁺ 00	1.7860	1.7696	2.7800 ⁺ 02	1.5163 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.6471 ⁺ 01	2.4162 ⁻ 03	NC	0.0000	3.4211 ⁻ 03	5.0394 ⁺ 02	2.6486 ⁺ 02	
7802S0209	2.0120	1.0488	2.8723 ⁺ 04	8.4885 ⁻ 04	2.3751	1.5073	1.1818 ⁺ 04	1.2710 ⁺ 04	
3.0400 ⁻ 01	1.0132 ⁺ 05	0.9298	4.7230 ⁺ 04	0.0000 ⁺ 00	1.7621	1.7386	2.7800 ⁺ 02	1.5362 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.0573 ⁺ 01	3.4800 ⁻ 03	NC	0.0000	4.2228 ⁻ 03	4.9999 ⁺ 02	2.6506 ⁺ 02	
7802S0210	1.9350	1.0466	2.9581 ⁺ 04	8.1912 ⁻ 04	2.2062	1.5729	1.5087 ⁺ 04	1.4325 ⁺ 04	
3.2400 ⁻ 01	1.0132 ⁺ 05	1.0532	4.7184 ⁺ 04	0.0000 ⁺ 00	1.7551	1.7292	2.7800 ⁺ 02	1.5896 ⁺ 02	
-1.2385 ⁻ 01	2.7800 ⁺ 02	3.0754 ⁺ 01	3.3634 ⁻ 03	NC	0.0000	3.9899 ⁻ 03	4.8914 ⁺ 02	2.6562 ⁺ 02	

PROFIL 0201 = PROFIL 0102
TAUW FROM CF (TAB.2, INTERPOLATED)

CAT 78025

KUSSOY/HORSTMAN

BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS

RUN X * RZ *	MO * POO* TOD*	TW/TR PW/PD TAUW *	RED2W RED2D DZ	CF CQ * PIZ	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD TD TR
780250211	1.8520	1.0442	2.3275**+04	9.5445**+04	3.5246	1.5195	1.4875**+04	1.6283**+04
3.4400**+01	1.0132**+05	0.9135	3.5944**+04	0.0000**+00	1.7543	1.7374	2.7800**+02	1.6489**+02
-1.2385**+01	2.7800**+02	3.7314**+01	2.4774**+03	NC	0.0000	3.4166**+03	4.7681**+02	2.6624**+02
780250212	1.8700	1.0447	2.2567**+04	1.1627**+03	3.2261	1.4884	1.5406**+04	1.5838**+04
3.6400**+01	1.0132**+05	0.9727	3.5094**+04	0.0000**+00	1.7595	1.7460	2.7800**+02	1.6359**+02
-1.2385**+01	2.7800**+02	4.5077**+01	2.4361**+03	NC	0.0000	3.2255**+03	4.7954**+02	2.6610**+02
780250213	1.9790	1.0479	2.1440**+04	1.3897**+03	2.9536	1.4062	1.4235**+04	1.3380**+04
3.8400**+01	1.0132**+05	1.0639	3.4796**+04	0.0000**+00	1.7908	1.7809	2.7800**+02	1.5589**+02
-1.2385**+01	2.7800**+02	5.0975**+01	2.5272**+03	NC	0.0000	3.2202**+03	4.9541**+02	2.6530**+02
780250214	2.0390	1.0496	1.7885**+04	1.5238**+03	3.3638	1.3279	1.2300**+04	1.2187**+04
4.0400**+01	1.0132**+05	1.0093	2.9727**+04	0.0000**+00	1.8251	1.8178	2.7800**+02	1.5179**+02
-1.2385**+01	2.7800**+02	5.4045**+01	2.2167**+03	NC	0.0000	2.9115**+03	5.0367**+02	2.6487**+02

PROFIL 0201 = PROFIL 0102

TAUW FROM CF(TAB.2, INTERPOLATED)

780250207

KUSSOY/HORSTMAN

PROFILE TABULATION

55 POINTS, DELTA AT POINT 43

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RO*U/UD
1	0.0000**+00	1.0000**+00	0.79001	1.00000	0.00000	0.00000	1.82906	0.00000
2	5.0000**+04	1.5568**+00	0.79001	1.00000	0.40324	0.51194	1.61178	0.25093
3	7.5000**+04	1.5922**+00	0.79001	1.00000	0.41405	0.52397	1.60145	0.25848
4	1.0000**+03	1.7596**+00	0.79001	1.00000	0.45972	0.57353	1.55636	0.29112
5	1.5000**+03	1.9175**+00	0.79001	1.00000	0.49656	0.61192	1.51862	0.31833
6	2.0000**+03	2.1931**+00	0.79001	1.00000	0.55157	0.66661	1.46065	0.36055
7	2.5000**+03	2.3959**+00	0.79001	1.00000	0.58743	0.70054	1.42219	0.38914
8	3.0000**+03	2.5752**+00	0.79001	1.00000	0.61690	0.72741	1.39038	0.41331
9	3.5000**+03	2.7297**+00	0.79001	1.00000	0.64096	0.74868	1.36435	0.43351
10	4.0000**+03	2.8744**+00	0.79001	1.00000	0.66257	0.76727	1.34099	0.45201
11	4.5000**+03	2.9833**+00	0.79001	1.00000	0.67829	0.78049	1.32403	0.46569
12	5.0000**+03	3.0914**+00	0.79001	1.00000	0.69352	0.79305	1.30764	0.47912
13	6.0000**+03	3.2827**+00	0.79001	1.00000	0.71955	0.81399	1.27974	0.50249
14	7.0000**+03	3.4474**+00	0.79001	1.00000	0.74116	0.83087	1.25673	0.52230
15	8.0000**+03	3.5940**+00	0.79001	1.00000	0.75982	0.84507	1.23699	0.53971
16	9.0000**+03	3.7005**+00	0.79469	1.00000	0.77308	0.85496	1.22305	0.55553
17	1.0000**+02	3.8090**+00	0.79938	1.00000	0.78635	0.86469	1.20918	0.57163
18	1.1000**+02	3.9154**+00	0.80406	1.00000	0.79912	0.87390	1.19591	0.58755
19	1.2000**+02	4.0362**+00	0.80874	1.00000	0.81336	0.88399	1.18121	0.60524
20	1.3000**+02	4.1379**+00	0.81343	1.00000	0.82515	0.89220	1.16912	0.62076
21	1.4000**+02	4.2672**+00	0.81811	1.00000	0.83988	0.90228	1.15411	0.63960
22	1.5000**+02	4.3856**+00	0.82436	1.00000	0.85314	0.91119	1.14071	0.65849
23	1.6000**+02	4.4880**+00	0.83060	1.00000	0.86444	0.91866	1.12938	0.67563
24	1.7000**+02	4.6010**+00	0.83763	1.00000	0.87672	0.92665	1.11716	0.69479
25	1.8000**+02	4.6925**+00	0.84699	1.00000	0.88654	0.93295	1.10744	0.71354
26	1.9000**+02	4.7991**+00	0.85558	1.00000	0.89784	0.94010	1.09635	0.73364
27	2.0000**+02	4.8882**+00	0.86495	1.00000	0.90717	0.94592	1.08725	0.75252
28	2.1000**+02	4.9830**+00	0.87354	1.00000	0.91699	0.95197	1.07773	0.77160
29	2.2000**+02	5.0934**+00	0.88290	1.00000	0.92829	0.95882	1.06687	0.79349
30	2.3000**+02	5.1661**+00	0.89383	1.00000	0.93566	0.96324	1.05983	0.81237
31	2.4000**+02	5.2443**+00	0.90398	1.00000	0.94352	0.96790	1.05236	0.83143
32	2.5000**+02	5.3331**+00	0.91179	1.00000	0.95236	0.97309	1.04402	0.84985
33	2.6000**+02	5.4128**+00	0.92194	1.00000	0.96022	0.97765	1.03664	0.86947
34	2.7000**+02	5.4830**+00	0.93052	1.00000	0.96709	0.98160	1.03023	0.88660
35	2.8000**+02	5.5538**+00	0.93833	1.00000	0.97397	0.98551	1.02385	0.90320
36	2.9000**+02	5.6149**+00	0.94692	1.00000	0.97986	0.98884	1.01840	0.91943
37	3.0000**+02	5.6815**+00	0.95550	1.00000	0.98625	0.99241	1.01254	0.93651
38	3.1000**+02	5.7175**+00	0.96487	1.00000	0.98969	0.99432	1.00939	0.95047
39	3.2000**+02	5.7537**+00	0.97190	1.00000	0.99312	0.99622	1.00625	0.96221
40	3.3000**+02	5.7848**+00	0.97970	1.00000	0.99607	0.99785	1.00357	0.97412
41	3.4000**+02	5.8004**+00	0.98673	1.00000	0.99754	0.99866	1.00223	0.98321
42	3.5000**+02	5.8108**+00	0.99454	1.00000	0.99853	0.99919	1.00134	0.99241
D 43	3.6000**+02	5.8264**+00	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
44	3.7000**+02	5.8420**+00	1.00781	1.00000	1.00147	1.00080	0.99867	1.00997
45	3.8000**+02	5.8629**+00	1.01249	1.00000	1.00344	1.00188	0.99689	1.01756
46	3.9000**+02	5.8629**+00	1.01795	1.00000	1.00344	1.00188	0.99689	1.02305
47	4.0000**+02	5.8734**+00	1.02264	1.00000	1.00442	1.00241	0.99600	1.02922
48	4.2500**+02	5.8891**+00	1.03357	1.00000	1.00589	1.00321	0.99467	1.04244
49	4.5000**+02	5.7744**+00	1.06479	1.00000	0.99509	0.99731	1.00446	1.05721
50	4.7500**+02	5.7020**+00	1.08821	1.00000	0.98821	0.99350	1.01074	1.06966
51	5.0000**+02	5.5843**+00	1.12334	1.00000	0.97692	0.98718	1.02112	1.08600
52	5.2500**+02	5.4881**+00	1.15925	1.00000	0.96758	0.98188	1.02977	1.10534
53	5.5000**+02	5.4881**+00	1.15925	1.00000	0.96758	0.98188	1.02977	1.10534
54	5.7500**+02	5.4679**+00	1.15925	1.00000	0.96562	0.98076	1.03160	1.10212
55	6.0000**+02	5.4529**+00	1.15925	1.00000	0.96415	0.97991	1.03297	1.09970

INPUT VARIABLES Y,M,P/PD,TO=TOD

7802S0209		KUSSOY/HORSTMAN		PROFILE TABULATION		55 POINTS, DELTA AT POINT 41		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000E+00	1.0000E+00	0.92981	1.00000	0.00000	0.00000	1.80963	0.00000
2	5.0000E-04	1.3488E+00	0.92981	1.00000	0.33201	0.42794	1.66136	0.23950
3	7.5000E-04	1.3712E+00	0.93415	1.00000	0.34145	0.43907	1.65354	0.24805
4	1.0000E-03	1.4047E+00	0.93705	1.00000	0.35487	0.45476	1.64219	0.25949
5	1.5000E-03	1.4482E+00	0.94428	1.00000	0.37127	0.47371	1.62795	0.27477
6	2.0000E-03	1.5108E+00	0.95224	1.00000	0.39314	0.49859	1.60836	0.29519
7	2.5000E-03	1.5889E+00	0.96020	1.00000	0.41799	0.52630	1.58537	0.31876
8	3.0000E-03	1.6840E+00	0.96889	1.00000	0.44533	0.55608	1.55927	0.34554
9	3.5000E-03	1.7935E+00	0.97829	1.00000	0.47366	0.58616	1.53145	0.37444
10	4.0000E-03	1.8885E+00	0.98915	1.00000	0.49602	0.60933	1.50903	0.39941
11	4.5000E-03	1.9821E+00	1.00000	1.00000	0.51640	0.62999	1.48830	0.42329
12	5.0000E-03	2.0694E+00	1.01302	1.00000	0.53429	0.64777	1.46990	0.44643
13	6.0000E-03	2.2198E+00	1.03835	1.00000	0.56312	0.67573	1.43994	0.48727
14	7.0000E-03	2.3671E+00	1.06295	1.00000	0.58946	0.70052	1.41232	0.52724
15	8.0000E-03	2.4991E+00	1.08755	1.00000	0.61183	0.72101	1.38874	0.56464
16	9.0000E-03	2.6155E+00	1.11071	1.00000	0.63072	0.73791	1.36878	0.59878
17	1.0000E-02	2.7297E+00	1.13169	1.00000	0.64861	0.75358	1.34986	0.63178
18	1.1000E-02	2.8278E+00	1.15340	1.00000	0.66352	0.76638	1.33410	0.66258
19	1.2000E-02	2.9251E+00	1.17511	1.00000	0.67793	0.77855	1.31888	0.69369
20	1.3000E-02	3.0144E+00	1.19247	1.00000	0.69085	0.78929	1.30525	0.72109
21	1.4000E-02	3.0773E+00	1.21491	1.00000	0.69980	0.79662	1.29584	0.74686
22	1.5000E-02	3.1448E+00	1.23227	1.00000	0.70924	0.80427	1.28592	0.77072
23	1.6000E-02	3.2060E+00	1.24964	1.00000	0.71769	0.81104	1.27706	0.79363
24	1.7000E-02	3.2680E+00	1.26773	1.00000	0.72614	0.81775	1.26822	0.81743
25	1.8000E-02	3.3345E+00	1.28075	1.00000	0.73509	0.82477	1.25888	0.83910
26	1.9000E-02	3.4019E+00	1.29378	1.00000	0.74404	0.83171	1.24957	0.86114
27	2.0000E-02	3.5048E+00	1.29378	1.00000	0.75746	0.84199	1.23565	0.88159
28	2.1000E-02	3.6135E+00	1.29378	1.00000	0.77137	0.85246	1.22129	0.90306
29	2.2000E-02	3.7165E+00	1.29378	1.00000	0.78429	0.86202	1.20802	0.92321
30	2.3000E-02	3.8620E+00	1.27641	1.00000	0.80219	0.87500	1.18976	0.93872
31	2.4000E-02	4.0404E+00	1.24964	1.00000	0.82356	0.89011	1.16816	0.95220
32	2.5000E-02	4.2933E+00	1.20188	1.00000	0.85288	0.91019	1.13890	0.96053
33	2.6000E-02	4.6512E+00	1.13169	1.00000	0.89264	0.93621	1.10000	0.96319
34	2.7000E-02	5.0837E+00	1.05282	1.00000	0.93837	0.96450	1.05647	0.96117
35	2.8000E-02	5.2002E+00	1.04342	1.00000	0.95030	0.97160	1.04533	0.96982
36	2.9000E-02	5.3133E+00	1.03473	1.00000	0.96173	0.97830	1.03476	0.97828
37	3.0000E-02	5.4178E+00	1.02605	1.00000	0.97217	0.98433	1.02518	0.98517
38	3.1000E-02	5.5083E+00	1.01737	1.00000	0.98111	0.98943	1.01703	0.98976
39	3.2000E-02	5.5945E+00	1.00868	1.00000	0.98956	0.99419	1.00938	0.99351
40	3.3000E-02	5.6507E+00	1.00434	1.00000	0.99503	0.99724	1.00446	0.99713
D 41	3.4000E-02	5.7020E+00	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
42	3.5000E-02	5.7537E+00	0.99566	1.00000	1.00497	1.00274	0.99556	1.00284
43	3.6000E-02	5.7952E+00	0.99132	1.00000	1.00895	1.00491	0.99202	1.00420
44	3.7000E-02	5.7640E+00	1.00000	1.00000	1.00596	1.00328	0.99468	1.00865
45	3.8000E-02	5.7227E+00	1.00868	1.00000	1.00199	1.00110	0.99822	1.01159
46	3.9000E-02	5.7330E+00	1.00868	1.00000	1.00298	1.00164	0.99733	1.01304
47	4.0000E-02	5.7382E+00	1.00868	1.00000	1.00348	1.00192	0.99689	1.01377
48	4.2500E-02	5.7485E+00	1.00868	1.00000	1.00447	1.00246	0.99600	1.01523
49	4.5000E-02	5.7382E+00	1.00868	1.00000	1.00348	1.00192	0.99689	1.01377
50	4.7500E-02	5.7330E+00	1.00868	1.00000	1.00298	1.00164	0.99733	1.01304
51	5.0000E-02	5.7124E+00	1.00868	1.00000	1.00099	1.00055	0.99911	1.01013
52	5.2500E-02	5.6969E+00	1.00868	1.00000	0.99950	0.99973	1.00044	1.00796
53	5.5000E-02	5.5741E+00	1.02605	1.00000	0.98757	0.99308	1.01117	1.00769
54	5.7500E-02	5.7175E+00	0.98698	1.00000	1.00149	1.00082	0.99867	0.98911
55	6.0000E-02	5.6815E+00	0.96454	1.00000	0.99801	0.99890	1.00178	0.96177

INPUT VARIABLES Y,M,P/PD,TO=TOD

7802S0214		KUSSOY/HORSTMAN		PROFILE TABULATION		55 POINTS, DELTA AT POINT 37		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.00930	1.00000	0.00000	0.00000	1.83150	0.00000
2	5.0000"-04	1.8222"+00	1.00465	1.00000	0.47425	0.58909	1.54295	0.38357
3	7.5000"-04	1.9220"+00	1.00155	1.00000	0.49681	0.61244	1.51963	0.40364
4	1.0000"-03	2.0325"+00	0.99768	1.00000	0.51986	0.63573	1.49545	0.42412
5	1.5000"-03	2.1904"+00	0.99070	1.00000	0.55027	0.66560	1.46312	0.45069
6	2.0000"-03	2.3189"+00	0.97986	1.00000	0.57332	0.68760	1.43838	0.46841
7	2.5000"-03	2.4192"+00	0.96979	1.00000	0.59049	0.70361	1.41986	0.48058
8	3.0000"-03	2.5082"+00	0.95740	1.00000	0.60520	0.71709	1.40393	0.48901
9	3.5000"-03	2.5937"+00	0.94810	1.00000	0.61893	0.72946	1.38905	0.49790
10	4.0000"-03	2.6880"+00	0.93571	1.00000	0.63364	0.74250	1.37309	0.50598
11	4.5000"-03	2.7882"+00	0.92564	1.00000	0.64885	0.75573	1.35660	0.51565
12	5.0000"-03	2.8778"+00	0.92022	1.00000	0.66209	0.76707	1.34225	0.52588
13	6.0000"-03	3.0248"+00	0.91557	1.00000	0.68318	0.78475	1.31944	0.54454
14	7.0000"-03	3.1807"+00	0.91557	1.00000	0.70476	0.80237	1.29619	0.56676
15	8.0000"-03	3.2974"+00	0.92486	1.00000	0.72045	0.81489	1.27935	0.58910
16	9.0000"-03	3.4171"+00	0.93726	1.00000	0.73615	0.82717	1.26258	0.61403
17	1.0000"-02	3.5318"+00	0.95198	1.00000	0.75086	0.83846	1.24695	0.64012
18	1.1000"-02	3.6450"+00	0.96592	1.00000	0.76508	0.84917	1.23191	0.66582
19	1.2000"-02	3.7767"+00	0.97754	1.00000	0.78127	0.86113	1.21490	0.69288
20	1.3000"-02	3.8784"+00	0.98761	1.00000	0.79353	0.87003	1.20210	0.71478
21	1.4000"-02	3.9943"+00	0.99923	1.00000	0.80726	0.87982	1.18785	0.74011
22	1.5000"-02	4.0784"+00	1.01007	1.00000	0.81707	0.88671	1.17773	0.76048
23	1.6000"-02	4.1721"+00	1.02169	1.00000	0.82786	0.89419	1.16666	0.78307
24	1.7000"-02	4.2672"+00	1.03021	1.00000	0.83865	0.90156	1.15565	0.80369
25	1.8000"-02	4.3635"+00	1.03718	1.00000	0.84944	0.90882	1.14472	0.82345
26	1.9000"-02	4.4612"+00	1.04183	1.00000	0.86023	0.91599	1.13385	0.84165
27	2.0000"-02	4.5556"+00	1.04725	1.00000	0.87052	0.92273	1.12354	0.86008
28	2.1000"-02	4.6833"+00	1.04725	1.00000	0.88426	0.93158	1.10989	0.87900
29	2.2000"-02	4.7991"+00	1.04725	1.00000	0.89652	0.93934	1.09782	0.89608
30	2.3000"-02	4.9544"+00	1.04183	1.00000	0.91270	0.94940	1.08202	0.91413
31	2.4000"-02	5.1127"+00	1.03718	1.00000	0.92889	0.95923	1.06641	0.93294
32	2.5000"-02	5.2837"+00	1.03253	1.00000	0.94605	0.96944	1.05005	0.95327
33	2.6000"-02	5.4629"+00	1.02789	1.00000	0.96371	0.97969	1.03344	0.97442
34	2.7000"-02	5.6353"+00	1.01782	1.00000	0.98038	0.98914	1.01795	0.98901
35	2.8000"-02	5.7433"+00	1.01007	1.00000	0.99068	0.99488	1.00849	0.99644
36	2.9000"-02	5.7952"+00	1.00465	1.00000	0.99559	0.99758	1.00402	0.99821
37	3.0000"-02	5.8420"+00	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
38	3.1000"-02	5.8839"+00	0.99613	1.00000	1.00392	1.00214	0.99644	1.00162
39	3.2000"-02	5.9049"+00	0.99303	1.00000	1.00589	1.00320	0.99467	1.00155
40	3.3000"-02	5.9417"+00	0.99070	1.00000	1.00932	1.00506	0.99157	1.00418
41	3.4000"-02	5.9681"+00	0.98761	1.00000	1.01177	1.00638	0.98936	1.00459
42	3.5000"-02	5.9998"+00	0.98606	1.00000	1.01471	1.00795	0.98672	1.00728
43	3.6000"-02	6.0211"+00	0.98606	1.00000	1.01667	1.00900	0.98496	1.01012
44	3.7000"-02	6.0317"+00	0.98606	1.00000	1.01766	1.00952	0.98408	1.01155
45	3.8000"-02	6.0317"+00	0.98683	1.00000	1.01766	1.00952	0.98408	1.01234
46	3.9000"-02	6.0317"+00	0.98838	1.00000	1.01766	1.00952	0.98408	1.01393
47	4.0000"-02	6.0317"+00	0.99070	1.00000	1.01766	1.00952	0.98408	1.01632
48	4.2500"-02	6.0317"+00	0.99535	1.00000	1.01766	1.00952	0.98408	1.02108
49	4.5000"-02	5.9628"+00	1.01394	1.00000	1.01128	1.00611	0.98980	1.03065
50	4.7500"-02	5.9364"+00	1.02324	1.00000	1.00883	1.00479	0.99201	1.03642
51	5.0000"-02	5.8839"+00	1.03253	1.00000	1.00392	1.00214	0.99644	1.03843
52	5.2500"-02	5.7744"+00	1.05190	1.00000	0.99362	0.99650	1.00580	1.04217
53	5.5000"-02	5.4028"+00	1.16421	1.00000	0.95782	0.97630	1.03895	1.09401
54	5.7500"-02	5.3978"+00	1.17351	1.00000	0.95733	0.97601	1.03941	1.10193
55	6.0000"-02	5.3978"+00	1.17351	1.00000	0.95733	0.97601	1.03941	1.10193

INPUT VARIABLES Y,M,P/PD,TO=TOD

7802S

KUSSOY/H/A

TURBULENCE DATA

7802S0102

UT= 2.0444E+01 RHDW= 1.0656E-01 TW= 2.7800E+02 D** 1.5557E-01

I	Y [M]	U' UT	V' UT	W' UT	RHD*U'V' RHDW*UT2	(RHD U)' RHDW*UT	RHD' RHDW
1	2.0000E-3	1.7602E+0	8.8011E-1	8.2834E-1	NM	3.4977E+0	6.6552E-2
2	2.5000E-3	1.4496E+0	6.4714E-1	9.3189E-1	NM	2.9235E+0	5.6468E-2
3	3.1000E-3	1.4237E+0	5.9537E-1	8.5423E-1	NM	2.9757E+0	5.6468E-2
4	3.6000E-3	1.4237E+0	5.9537E-1	7.7657E-1	-4.7703E-1	3.0279E+0	5.6468E-2
5	4.2000E-3	1.3202E+0	5.9537E-1	6.9891E-1	-5.3378E-1	2.8712E+0	5.4452E-2
6	4.7000E-3	1.2943E+0	5.9537E-1	6.7303E-1	-6.4459E-1	2.8712E+0	5.4452E-2
7	5.7000E-3	1.2425E+0	6.4714E-1	6.4714E-1	-7.5541E-1	2.8712E+0	5.2435E-2
8	6.8000E-3	1.2166E+0	6.4714E-1	6.4714E-1	-7.4054E-1	2.8712E+0	5.2435E-2
9	7.8000E-3	1.1907E+0	6.4714E-1	6.4714E-1	-7.1486E-1	2.8712E+0	5.2435E-2
10	8.9000E-3	1.1649E+0	6.2126E-1	6.2126E-1	-7.1892E-1	2.8712E+0	5.2435E-2
11	1.0000E-2	1.1131E+0	6.4714E-1	6.4714E-1	-6.6081E-1	2.7668E+0	5.2435E-2
12	1.2100E-2	1.0872E+0	6.2126E-1	6.2126E-1	-6.2838E-1	2.8712E+0	5.2435E-2
13	1.4300E-2	1.0613E+0	6.2126E-1	5.9537E-1	-6.0270E-1	2.9235E+0	5.4452E-2
14	1.6400E-2	1.0613E+0	6.2126E-1	5.9537E-1	-6.2297E-1	3.0279E+0	5.6468E-2
15	1.8500E-2	1.0872E+0	6.4714E-1	6.2126E-1	-6.2297E-1	3.1845E+0	5.8485E-2
16	2.0600E-2	1.0613E+0	5.9537E-1	5.6949E-1	-5.5000E-1	3.2367E+0	5.8485E-2
17	2.2800E-2	1.0613E+0	5.6949E-1	5.4360E-1	-5.5135E-1	3.4459E+0	6.2519E-2
18	2.4900E-2	1.0354E+0	5.6949E-1	5.1771E-1	-5.0946E-1	3.4977E+0	6.4535E-2
19	2.7000E-2	1.0354E+0	5.4360E-1	4.9183E-1	-4.9865E-1	3.6021E+0	6.4535E-2
20	2.9100E-2	9.8366E-1	5.1771E-1	4.4006E-1	-4.1892E-1	3.5409E+0	6.4535E-2
21	3.1200E-2	8.2834E-1	4.6594E-1	3.6240E-1	-3.0000E-1	3.0801E+0	5.6468E-2
22	3.3400E-2	6.7303E-1	4.1417E-1	3.3651E-1	-1.9865E-1	2.6102E+0	4.6385E-2
23	3.5500E-2	4.9183E-1	3.1063E-1	2.5886E-1	-1.0270E-1	1.8794E+0	3.4284E-2
24	3.7600E-2	4.9183E-1	3.3651E-1	2.5886E-1	-9.1892E-2	1.8794E+0	3.4284E-2
25	3.9800E-2	3.1063E-1	3.3651E-1	2.0709E-1	-5.9459E-2	1.2007E+0	2.2184E-2
26	4.1900E-2	2.3297E-1	2.5886E-1	1.2943E-1	-2.7027E-2	8.8748E-1	1.6134E-2
27	4.4000E-2	1.5531E-1	2.3297E-1	7.7657E-2	-2.5676E-2	6.7866E-1	1.2100E-2
28	4.6100E-2	1.8120E-1	3.1063E-1	7.7657E-2	-4.5946E-2	6.7866E-1	1.2100E-2
29	4.8200E-2	1.2943E-1	2.3297E-1	5.1771E-2	-1.8919E-2	5.2204E-1	1.0084E-2
30	5.0400E-2	1.2943E-1	2.0709E-1	5.1771E-2	-9.4595E-3	4.6984E-1	8.0669E-3
31	5.2500E-2	1.2943E-1	2.0709E-1	5.1771E-2	-8.1081E-3	4.6984E-1	8.0669E-3
32	5.4600E-2	1.0354E-1	1.5531E-1	5.1771E-2	-6.7568E-3	4.1764E-1	8.0669E-3

7802S

KUSSOY/H/A

TURBULENCE DATA

7802S0109

UT= 1.5433E+01 RHDW= 1.5287E-01 TW= 2.7800E+02 D** 2.1309E-01

I	Y [M]	U' UT	V' UT	W' UT	RHD*U'V' RHDW*UT2	(RHD U)' RHDW*UT	RHD' RHDW
1	1.9000E-3	2.6746E+0	NM	1.6459E+0	NM	4.3865E+0	6.7476E-2
2	2.4000E-3	2.7432E+0	1.3373E+0	1.6802E+0	NM	4.5793E+0	7.0287E-2
3	3.0000E-3	2.7432E+0	1.3716E+0	1.6459E+0	NM	4.8203E+0	7.3099E-2
4	3.5000E-3	2.7089E+0	1.3373E+0	1.6116E+0	NM	4.9167E+0	7.3099E-2
5	4.0000E-3	2.6403E+0	1.2002E+0	1.5431E+0	NM	4.8203E+0	7.0287E-2
6	5.0000E-3	2.5718E+0	1.1316E+0	1.4745E+0	NM	5.0131E+0	7.1693E-2
7	6.1000E-3	2.5032E+0	1.1316E+0	1.4402E+0	-1.6793E+0	5.2059E+0	7.3099E-2
8	7.2000E-3	2.4003E+0	1.0973E+0	1.3716E+0	-1.6612E+0	5.2541E+0	7.4504E-2
9	8.3000E-3	2.3660E+0	1.0973E+0	1.2344E+0	-1.6711E+0	5.2541E+0	7.4504E-2
10	9.3000E-3	2.2631E+0	1.0287E+0	1.1316E+0	-1.6744E+0	5.2059E+0	7.3099E-2
11	1.0400E-2	2.1260E+0	1.0630E+0	1.0630E+0	-1.8612E+0	5.0131E+0	7.1693E-2
12	1.2500E-2	1.9202E+0	1.0630E+0	9.9441E-1	-1.8727E+0	4.7721E+0	6.7476E-2
13	1.4700E-2	1.7488E+0	1.1659E+0	9.2583E-1	-1.6000E+0	4.5793E+0	6.3258E-2
14	1.6800E-2	1.6116E+0	1.2344E+0	9.2583E-1	-1.6760E+0	4.4829E+0	6.1853E-2
15	1.8900E-2	1.5431E+0	1.2687E+0	8.9154E-1	-1.4512E+0	4.3865E+0	6.0447E-2
16	2.1000E-2	1.4745E+0	1.0287E+0	8.2296E-1	-1.1306E+0	4.2901E+0	5.9041E-2
17	2.3100E-2	1.4402E+0	9.2583E-1	7.5438E-1	-9.8182E-1	4.1937E+0	5.6230E-2
18	2.5300E-2	1.3716E+0	7.8867E-1	6.8580E-1	-7.2562E-1	4.0009E+0	5.2013E-2
19	2.7400E-2	1.2687E+0	7.8867E-1	6.1722E-1	-5.4876E-1	3.7116E+0	5.0607E-2
20	2.9600E-2	1.1659E+0	8.5725E-1	5.1435E-1	-4.6116E-1	3.3742E+0	4.6390E-2
21	3.1700E-2	7.5438E-1	6.5151E-1	3.7719E-1	-1.9669E-1	2.1209E+0	2.9521E-2
22	3.3800E-2	5.4864E-1	7.2009E-1	3.0861E-1	-7.1074E-2	1.5907E+0	2.1086E-2
23	3.5900E-2	4.1148E-1	5.1435E-1	2.7432E-1	-2.8099E-2	1.1569E+0	1.6869E-2
24	3.8000E-2	3.0861E-1	5.8293E-1	3.0861E-1	-2.6446E-2	9.6406E-1	1.2652E-2
25	4.0200E-2	2.4003E-1	4.1148E-1	3.0861E-1	-1.3223E-2	6.7484E-1	9.8402E-3
26	4.1500E-2	2.0574E-1	NM	2.7432E-1	NM	5.7844E-1	8.4345E-3

7802S

KUSSOY/H/A

TURBULENCE DATA

7802S0209

UT= 1.4370E+01 RHDW= 1.4805E-01 TW= 2.7800E+02 D*= 2.9842E-01

I	Y [M]	U' UT	V' UT	W' UT	RHO*U'V' RHDW*UT2	(RHO U)' RHDW*UT	RHO' RHDW
1	1.3000E-3	2.2464E+0	NM	NM	NM	3.1538E+0	4.4998E-2
2	1.6000E-3	2.4305E+0	1.1784E+0	1.7308E+0	NM	3.5280E+0	5.0804E-2
3	2.1000E-3	2.7619E+0	1.2153E+0	1.8045E+0	NM	4.1160E+0	5.9513E-2
4	2.7000E-3	3.0934E+0	1.2521E+0	1.8045E+0	NM	4.8109E+0	6.8222E-2
5	3.2000E-3	3.2775E+0	1.2889E+0	1.7676E+0	NM	5.2385E+0	7.4029E-2
6	3.7000E-3	3.4616E+0	1.2889E+0	1.8045E+0	NM	5.7196E+0	8.1286E-2
7	4.2000E-3	3.3880E+0	1.2153E+0	1.7676E+0	NM	5.8265E+0	8.2738E-2
8	5.3000E-3	3.2039E+0	1.1416E+0	1.6572E+0	NM	5.8800E+0	8.2738E-2
9	6.4000E-3	2.8356E+0	1.0680E+0	1.4730E+0	NM	5.6127E+0	7.5480E-2
10	7.4000E-3	2.6146E+0	1.0680E+0	1.2889E+0	NM	5.4523E+0	7.4029E-2
11	8.5000E-3	2.5042E+0	1.0311E+0	1.2521E+0	NM	5.3989E+0	7.2577E-2
12	9.5000E-3	2.3569E+0	9.5747E-1	1.1784E+0	-1.0551E+0	5.2920E+0	6.9674E-2
13	1.1700E-2	2.1359E+0	9.9430E-1	1.1048E+0	-1.4705E+0	5.2385E+0	6.9674E-2
14	1.3800E-2	1.9886E+0	1.1048E+0	1.0311E+0	-1.6811E+0	5.1316E+0	6.8222E-2
15	1.6000E-2	1.7308E+0	1.2889E+0	9.5747E-1	-1.6575E+0	4.8109E+0	6.2416E-2
16	1.8100E-2	1.5467E+0	1.3626E+0	8.8382E-1	-1.4291E+0	4.3833E+0	5.6610E-2
17	2.0200E-2	1.3994E+0	1.1784E+0	7.7334E-1	-1.1181E+0	4.1694E+0	5.3707E-2
18	2.2300E-2	1.2889E+0	8.8382E-1	6.6287E-1	-9.0945E-1	4.0091E+0	5.2255E-2
19	2.4400E-2	1.2521E+0	6.6287E-1	5.1556E-1	-6.5945E-1	4.0091E+0	5.2255E-2
20	2.6600E-2	1.2153E+0	5.5239E-1	5.1556E-1	-5.6496E-1	3.9022E+0	5.0804E-2
21	2.8700E-2	1.1416E+0	5.5239E-1	4.7874E-1	-3.7008E-1	3.6883E+0	4.7901E-2
22	3.0800E-2	9.5747E-1	6.6287E-1	4.7874E-1	-1.9488E-1	3.1003E+0	4.0643E-2
23	3.3000E-2	6.6287E-1	8.4700E-1	4.4191E-1	-1.8307E-1	2.1382E+0	2.7579E-2
24	3.5100E-2	5.1556E-1	7.3652E-1	4.0509E-1	-6.2992E-2	1.6571E+0	2.1773E-2
25	3.7200E-2	3.3143E-1	5.5239E-1	4.4191E-1	-5.1181E-2	1.0691E+0	1.4515E-2
26	3.9300E-2	2.2096E-1	5.5239E-1	4.4191E-1	-4.1339E-2	6.9491E-1	8.7092E-3
27	4.0100E-2	1.8413E-1	NM	NM	NM	6.4145E-1	8.7092E-3

7802S

KUSSOY/H/A

TURBULENCE DATA

7802S0214

UT= 1.8728E+01 RHDW= 1.5409E-01 TW= 2.7800E+02 D*= 1.3784E-01

I	Y [M]	U' UT	V' UT	W' UT	RHO*U'V' RHDW*UT2	(RHO U)' RHDW*UT	RHO' RHDW
1	1.3000E-3	1.0455E+0	5.0863E-1	9.3249E-1	NM	1.6946E+0	3.0682E-2
2	1.6000E-3	1.1020E+0	5.6514E-1	9.3249E-1	NM	1.8128E+0	3.2077E-2
3	1.9000E-3	1.1585E+0	5.9340E-1	9.3249E-1	NM	1.8916E+0	3.3472E-2
4	2.4000E-3	1.1585E+0	5.9340E-1	8.7597E-1	NM	1.9310E+0	3.4866E-2
5	2.9000E-3	1.1868E+0	6.2166E-1	8.7597E-1	NM	2.0099E+0	3.4866E-2
6	3.5000E-3	1.2716E+0	6.7817E-1	8.7597E-1	NM	2.1675E+0	3.7656E-2
7	4.0000E-3	1.3281E+0	7.0643E-1	8.4771E-1	-6.1359E-1	2.2857E+0	3.9050E-2
8	5.1000E-3	1.4411E+0	7.6294E-1	8.4771E-1	-7.1269E-1	2.5222E+0	4.3234E-2
9	6.1000E-3	1.4976E+0	7.9120E-1	8.1946E-1	-7.7506E-1	2.6404E+0	4.4629E-2
10	7.2000E-3	1.5259E+0	7.9120E-1	8.1946E-1	-7.8731E-1	2.7980E+0	4.7418E-2
11	8.3000E-3	1.4976E+0	7.6294E-1	7.9120E-1	-7.6281E-1	2.8375E+0	4.8813E-2
12	9.3000E-3	1.4694E+0	7.6294E-1	7.6294E-1	-7.3274E-1	2.8769E+0	4.8813E-2
13	1.1500E-2	1.4129E+0	7.3469E-1	7.3469E-1	-7.0935E-1	2.9951E+0	5.0208E-2
14	1.3600E-2	1.3846E+0	7.0643E-1	7.0643E-1	-7.3051E-1	3.1133E+0	5.1602E-2
15	1.5700E-2	1.3281E+0	6.7817E-1	6.7817E-1	-7.0156E-1	3.1527E+0	5.2997E-2
16	1.7800E-2	1.2433E+0	6.4991E-1	5.9340E-1	-6.4922E-1	3.1921E+0	5.4392E-2
17	2.0000E-2	1.2151E+0	5.9340E-1	5.6514E-1	-5.7906E-1	3.2709E+0	5.4392E-2
18	2.2100E-2	1.1868E+0	5.9340E-1	5.3689E-1	-5.0668E-1	3.2709E+0	5.4392E-2
19	2.4200E-2	1.1585E+0	5.3689E-1	4.5211E-1	-4.4432E-1	3.2315E+0	5.4392E-2
20	2.6400E-2	1.0738E+0	4.8037E-1	4.8037E-1	-3.4633E-1	3.1133E+0	5.1602E-2
21	2.8500E-2	9.8900E-1	5.0863E-1	4.2386E-1	-2.4276E-1	2.8769E+0	4.7418E-2
22	3.0600E-2	9.0423E-1	5.0863E-1	3.9560E-1	-1.6815E-1	2.5222E+0	4.1840E-2
23	3.2700E-2	7.0643E-1	4.8037E-1	3.9560E-1	-1.1804E-1	1.9310E+0	3.2077E-2
24	3.4800E-2	5.3689E-1	4.5211E-1	3.6734E-1	-8.9087E-2	1.4581E+0	2.3709E-2
25	3.7000E-2	3.9560E-1	4.8037E-1	3.6734E-1	-6.9042E-2	1.0640E+0	1.8131E-2
26	3.9100E-2	2.8257E-1	4.2386E-1	3.3909E-1	-4.4543E-2	7.4877E-1	1.2552E-2
27	4.0100E-2	2.2606E-1	NM	NM	NM	6.3054E-1	1.1157E-2

	M: 3.0 falling to 2.6 or 2.3 R THETA x 10 ⁻³ : 2.7 - 5.4 TW/TR: 1.0	7803
		APG-AW
Continuous wind tunnel with fixed symmetrical nozzle. W = 0.079, H = 0.086 m. PO: 0.097 MN/m ² TO: 317 K. Air, dew-point 236K. RE/m x 10 ⁻⁶ : 6.6.		
LADERMAN A.J., 1978b. Pressure gradient effects on supersonic boundary layer turbulence. Ford Aerospace & Communications Corp., Aeronutronic Division. Rep. No. U-6467. Newport Beach, Calif. <u>And</u> Laderman (1979), A.J. Laderman, private communications.		

- 1 The tests took place on ramps which replaced the tunnel floor block to form a smooth continuation of the nozzle. Two were used. "Ramp 1" (series 01) had a profile in which the start of the curvature ($X = 0$) occurred immediately at the nozzle exit plane. "Ramp 3" (series 02) had an initial straight portion 25.4 mm long before curvature started ($X = 0$). Dimensions are given in Table 1. The ramps were designed to give, without allowance for boundary layer effects, constant pressure gradients corresponding to nominal $\frac{1}{K} = \frac{1}{K_0} = \left[\left(\frac{1}{K} \right) \left(\frac{\tau_w}{\rho} \right) \right] (dp/dx)$ of 0.4 and 1.85 for series 01 and 02 respectively.
- 2 Flow uniformity and two-dimensionality were assessed by Pitot surveys in the volume over the ramp.
- 5 These included continuous Pitot surveys in the cross flow direction (Z) for $-10 < Z < 10$ mm at seven axial stations for about 12 constant Y -values and continuous surveys in the vertical direction were made at the same X stations for, approximately, $Z = 0, \pm 4, \pm 10$ mm. Sample results from these surveys are given graphically and show the flow to be generally free of significant disturbances. The continuous lateral Pitot surveys given show that for "ramp 1" cross-flow variations in the free stream are negligible, but that in the boundary layer there may be variations of up to 10% of the free stream value over this central 20 mm of the 79 mm wide test section. The samples for "ramp 3" show much less variation, one case showing virtually none while the other varies by about 8%. We wonder (E) therefore whether it is entirely proper to say that there are "only marginal cross flow effects." Disturbances originate from the $X = 0$ region in each case, of negligible strength for "ramp 3" but fairly marked for "ramp 1". With the exception of profiles near $X = 0$ which intersect this shock, it should have no significant effect. The "leading edge" disturbances and the running together of the ramp-induced
- 4 compression wave are the only waves shown in schlieren photographs. The test boundary layer developed
- 5 in the favourable pressure gradient on the nozzle wall. Turbulence is fully developed at the start of the test zone.
- 6 Each ramp was provided with static tapings ($d = 0.84$ mm) at 12.7 mm intervals. Preston tubes 1, 1.63 and 2.36 mm in diameter were used, the results from all three agreeing within 5%. For the main investigation all data were obtained using the 1 mm tube and the Bradshaw & Unsworth(1974) correlation.
- 7 Pitot, static pressure and TO profiles were obtained separately, the probe being able to move in both X and the Y directions. Traverses were however made vertically rather than normal to the ramp surface. The Pitot probe was constructed of circular tubing ($d_1 = 0.152, d_2 = 0.076$ mm) which was etched so that the outer surface gradually tapered to an orifice with negligible wall thickness ($d_1 = d_2 = 0.076$ mm). The streamwise length of the probe was 6.3 mm, with the taper extending over the first 3.1 mm. The static pressure probe was an ogive-cylinder probe ($d = 0.51$ mm) with four orifices equally spaced round the circumference 6.3 mm from the tip. The probes were mounted parallel to the ramp surface at the profile station. The TO probe consisted of an unshielded thermocouple junction mounted 1.4 mm ahead of a ceramic insulating support ($d = 2.4, l = 25.4$ mm). The chromel-alumel wired ($d = 0.038$ mm) were welded together to form a disc 0.13 mm in diameter.

8 For "ramp 1" the profile stations, excepting 0101 which was in the nozzle ($X = -12.7$ mm), were approximately midway between the static pressure tapings. For "ramp 3" profiles 0201-0203 are in a nominally zero pressure gradient region, again starting in the nozzle. Profiles 0204 ($X = 0$) 0208/10/12/14/ were approximately over static tapings, the remainder about midway between them. The author has interpolated data where necessary, and also incorporated in the data reduction procedure a programme which interpolates the reduced profile data to give values along the local normals to the ramp surface. It is this interpolated data which is presented. The wall temperature was assumed to be 300K. No corrections were made to Pitot data, rarefaction and viscous effects being negligible. Wall interference effects were observed very near the wall but not corrected for. Wall interference affected the SPP readings for $Y < 1.2$ mm, and in this region near the wall, the static pressure was interpolated to match the wall static pressure.

12 The editors have accepted the data as presented by the author except for moving the D-state point out, for both series, to a position chosen on the basis of the P0 profile. The profiles constitute two series, one for each ramp, at 10 and 14 successive stations for "ramp 1" and "ramp 3" respectively. The wall shear stress values given in the tables are those obtained by the author in a fit to the Coles wall-and-wake law, which were used for consistency with the value of δ used in subsequent data reduction aimed at giving shear stress profiles. The Preston tube values are generally lower than the profile derived values, the maximum difference being 9% at the rear of "ramp 3".

§ DATA: 78030101-0214. Pitot, static pressure and T0 profiles obtained separately. $NX = 10$ and 14. (Supporting Preston tube CF values).

15 Editors' comments. Experiments on curved walls, giving rise to a 'simple wave' structure, are very few in number. These data must be welcomed therefore as providing information at very close intervals in a flow field of a type only really effectively studied by Sturek & Danberg (CAT 7101). In non-dimensional terms (as described by the value of β_1) the pressure gradients are of order one half (02) and one eighth (01) of the flow in CAT 7101. The dimensionless pressure gradient for (02) is about the same as for the straight wall case studied by Lewis et al. (CAT 7201).

A principal aim of the study, as for the ZPG case, CAT 7702, was to document the flow field in preparation for measurements of the turbulence quantities in the flow field. If the accuracy and resolution are sufficiently great, mean flow measurements can also provide an estimate of the shear stress distribution through the boundary layer, and much of the original report is devoted to this aspect.

For a comparison with "standard" - AG 253 - semi-empirical relationships and other measurements we have chosen series 02 which describes the flow with the stronger pressure-gradient distribution. Figure 1 shows 4 velocity profiles, 0203 in the ZPG region and 0206, 0211, 0214 at various stations in the APG region. This experimental data falls below the logarithmic law as given by eqn.(3.3.9) of AG 253, shown as a solid line. This is probably not a true physical effect but rather caused by CF values which are too high by about 20%^{*)}. The measurements extend further into the viscous sublayer than those of Sturek & Danberg (1971), cf. Figs.(5.3.15) to (5.3.17) of AG 253. We cannot understand the behaviour of the profiles in the outer region of the boundary layer (Fig. 2) which apparently show no influence of the pressure gradient since all of them agree well with eqn.(3.3.17) of AG 253, as represented by the solid line, derived for zero-pressure gradient flows. Further

^{*)} This may be a result of the determination of the skin friction via the transformed Coles' velocity profile, a procedure which needs a value for the boundary layer thickness δ . As we have shown in section 7, AG 253, δ is particularly ill defined in compressible boundary layers with normal pressure gradients and therefore afflicted with a large uncertainty.

it is interesting to note that τ_w increases and δ_2 remains almost constant downstream from profiles 0105 and 0207, respectively. In this respect we again see the effect of bulk compression overcoming the fall in τ_w and rise in δ_2 observed in APG incompressible flows. The trend here is suppressed rather than reversed as in the more extreme case as studied by Sturek & Danberg (CAT 7101). However, we would again point out that conventional integral thicknesses in these flows do not have a proper physical meaning (AG 253, §7). Agreement between the temperature-velocity relationship according to van Driest (see AG 253) and the measured data is very good (deviations are below 2%).

Table 1: Model coordinates

Facsimile from source paper. Author's symbols and units.

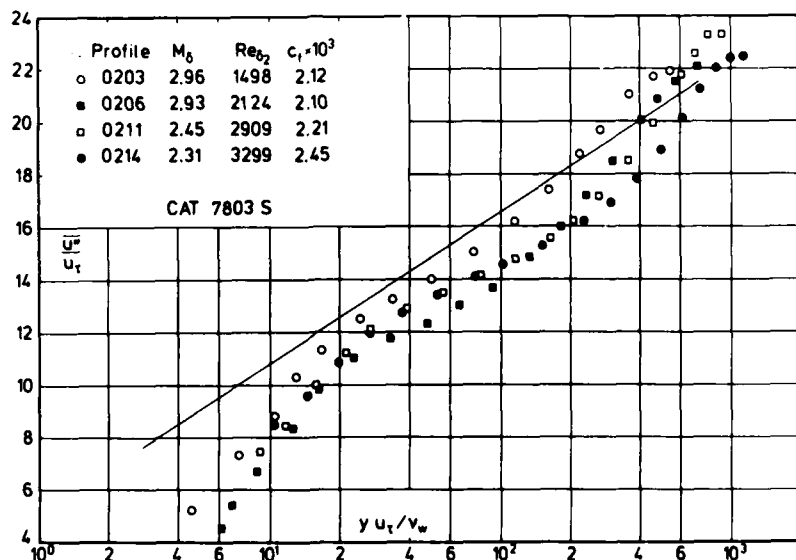
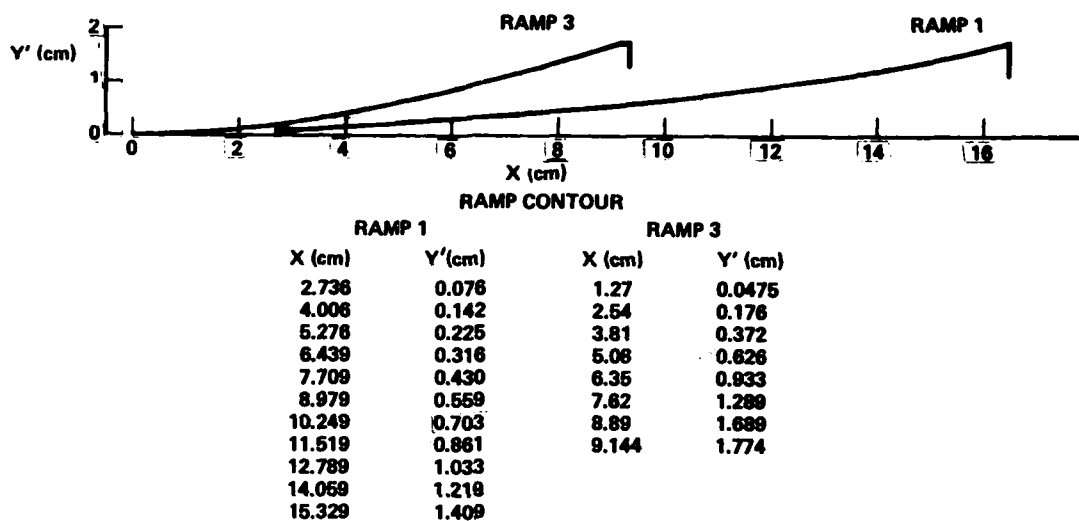
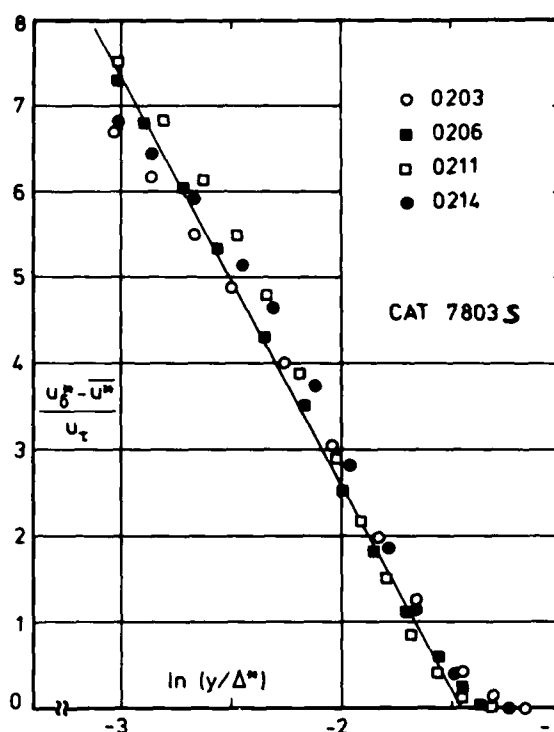


Fig. 1 Law of the wall for a compressible boundary layer in an adverse pressure gradient (adiabatic wall, origin not defined). Laderman (1978).



Outer law for a compressible boundary layer in an adverse pressure gradient (adiabatic wall, origin not defined). Laderman (1978).

CAT 7803S		LADERMAN							BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS						
PUN	MD *	TW/TR	RED2W	CF	H12	H12K	PW	PD*							
X *	POD	PW/PD	RED2D	CQ	H32	H32K	TW*	TD							
RZ	TOD*	TAUW *	OZ	PI2	H42	D2K	UD	TR							
7803S0101	3.0360	1.0137	1.1904"+03	2.1469"-03	5.3391	1.4592	2.5728"+03	2.5051"+03							
-1.2700"-02	9.7111"+04	1.0271	2.7862"+03	NM	1.8003	1.7731	3.0000"+02	1.1161"+02							
INFINITE	3.1735"+02	3.4700"+01	4.3855"-04	NC	0.0608	6.8024"-04	6.4307"+02	2.9595"+02							
7803S0102	2.8571	1.0114	1.4975"+03	2.2001"-03	4.1663	1.4469	3.3805"+03	3.0545"+03							
2.7356"-02	9.0428"+04	1.1067	3.2631"+03	NM	1.7842	1.7594	3.0000"+02	1.2044"+02							
INFINITE	3.1706"+02	3.8400"+01	4.9945"-04	NC	0.0583	7.1472"-04	6.2866"+02	2.9661"+02							
7803S0103	2.8300	1.0144	1.6900"+03	2.1573"-03	4.1305	1.4007	3.5557"+03	3.2496"+03							
4.0056"-02	9.2310"+04	1.0942	3.6540"+03	NM	1.7693	1.7676	3.0000"+02	1.2144"+02							
INFINITE	3.1596"+02	3.9300"+01	5.3711"-04	NC	0.0397	7.6759"-04	6.2528"+02	2.9573"+02							
7803S0104	2.7724	1.0095	1.7077"+03	2.1942"-03	4.3626	1.3597	3.6238"+03	3.4899"+03							
5.2756"-02	9.0801"+04	1.0384	3.5944"+03	NM	1.7991	1.7807	3.0000"+02	1.2500"+02							
INFINITE	3.1717"+02	4.1200"+01	5.2338"-04	NC	0.0677	7.5655"-04	6.2148"+02	2.9718"+02							
7803S0105	2.8311	1.0096	1.8632"+03	2.2188"-03	4.1557	1.3930	3.7307"+03	3.3898"+03							
6.4389"-02	9.6467"+04	1.1006	4.0124"+03	NM	1.7965	1.7752	3.0000"+02	1.2197"+02							
INFINITE	3.1749"+02	4.2200"+01	5.6866"-04	NC	0.0699	8.0457"-04	6.2689"+02	2.9715"+02							
7803S0106	2.7711	1.0100	2.0243"+03	2.2428"-03	3.7170	1.3453	4.0015"+03	3.6165"+03							
7.7089"-02	9.3906"+04	1.1064	4.2606"+03	NM	1.8012	1.7842	3.0000"+02	1.2501"+02							
INFINITE	3.1701"+02	4.3600"+01	5.9900"-04	NC	0.0557	8.2187"-04	6.2121"+02	2.9704"+02							
7803S0107	2.7156	1.0079	2.0706"+03	2.2277"-03	4.0441	1.3849	4.1979"+03	3.9217"+03							
8.9789"-02	9.3531"+04	1.0704	4.2572"+03	NM	1.7968	1.7768	3.0000"+02	1.2821"+02							
INFINITE	3.1732"+02	4.5100"+01	5.8388"-04	NC	0.0623	8.1708"-04	6.1652"+02	2.9765"+02							
7803S0108	2.6230	1.0090	2.0949"+03	2.2769"-03	3.9736	1.3811	4.5190"+03	4.2770"+03							
1.0249"-01	8.8431"+04	1.0566	4.1596"+03	NM	1.7994	1.7803	3.0000"+02	1.3316"+02							
INFINITE	3.1639"+02	4.6900"+01	5.7151"-04	NC	0.0523	7.8927"-04	6.0686"+02	2.9733"+02							
7803S0109	2.5769	1.0058	2.1930"+03	2.3306"-03	3.8427	1.3690	4.7429"+03	4.5506"+03							
1.1519"-01	8.7619"+04	1.0422	4.2655"+03	NM	1.8039	1.7844	3.0000"+02	1.3619"+02							
INFINITE	3.1707"+02	4.9300"+01	5.7881"-04	NC	0.0597	7.9030"-04	6.0296"+02	2.9826"+02							
7803S0110	2.5781	1.0060	2.3248"+03	2.3901"-03	3.5126	1.3270	4.9860"+03	4.5952"+03							
1.2789"-01	8.8633"+04	1.0851	4.5245"+03	NM	1.8104	1.7953	3.0000"+02	1.3611"+02							
INFINITE	3.1703"+02	5.1100"+01	6.0719"-04	NC	0.0579	8.0228"-04	6.0304"+02	2.9821"+02							

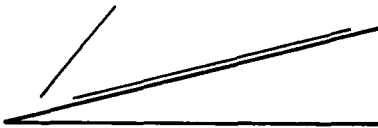
CAT 78035		LADERMAN								BOUNDARY CONDITIONS AND EVALUATED DATA, SI UNITS									
RUN	X *	MD *	TW/TR	RED2W	CF	H12	H12K	PH	PD*										
RZ	POD	POD	PD/PD	RED2D	CO	H32	H32K	TH*	TD										
		TOD*	TAUW *	D2	PI2	H42	D2K	UD	TR										
7803S0201		2.9480	1.0104	1.4666"+03	2.0850"-03	4.7259	1.4231	2.9050"+03	2.7672"+03										
-3.1750"-02		9.4007"+04	1.0498	3.3074"+03	NM	1.7936	1.7677	3.0000"+02	1.1610"+02										
INFINITE		3.1790"+02	3.5100"+01	5.1376"-04	NC	0.0708	7.6738"-04	6.3668"+02	2.9692"+02										
7803S0202		2.9613	1.0096	1.5320"+03	2.1526"-03	4.3434	1.3994	2.9884"+03	2.7404"+03										
-1.9050"-02		9.4970"+04	1.0905	3.4703"+03	NM	1.7914	1.7671	3.0000"+02	1.1556"+02										
INFINITE		3.1822"+02	3.6200"+01	5.3825"-04	NC	0.0814	7.8384"-04	6.3824"+02	2.9714"+02										
7803S0203		2.9571	1.0104	1.4835"+03	2.1268"-03	4.8350	1.4088	2.8949"+03	2.7653"+03										
-6.3500"-03		9.5233"+04	1.0469	3.3575"+03	NM	1.7986	1.7752	3.0000"+02	1.1566"+02										
INFINITE		3.1795"+02	3.6000"+01	5.1747"-04	NC	0.0688	7.7477"-04	6.3764"+02	2.9691"+02										
7803S0204		2.9229	1.0095	1.5040"+03	2.1403"-03	4.7930	1.4204	2.9056"+03	2.7969"+03										
0.0000"+00		9.1482"+04	1.0389	3.3560"+03	NM	1.8041	1.7832	3.0000"+02	1.1742"+02										
INFINITE		3.1805"+02	3.5800"+01	5.2871"-04	NC	0.0869	7.8367"-04	6.3503"+02	2.9718"+02										
7803S0205		2.9194	1.0118	1.5546"+03	2.2925"-03	4.5490	1.4759	3.1255"+03	2.7637"+03										
6.3500"-03		8.9922"+04	1.1309	3.4719"+03	NM	1.7807	1.7551	3.0000"+02	1.1731"+02										
INFINITE		3.1729"+02	3.7800"+01	5.5351"-04	NC	0.0727	8.0345"-04	6.3399"+02	2.9649"+02										
7803S0206		2.9347	1.0103	2.1378"+03	2.0977"-03	1.9081	1.4467	3.8924"+03	2.6570"+03										
1.9050"-02		8.8461"+04	1.4649	4.7955"+03	NM	1.7773	1.7592	3.0000"+02	1.1676"+02										
INFINITE		3.1787"+02	3.3600"+01	7.8571"-04	NC	0.0669	8.9842"-04	6.3579"+02	2.9695"+02										
7803S0207		2.7166	1.0067	2.2074"+03	2.1997"-03	2.9378	1.4783	4.6046"+03	3.6783"+03										
3.1750"-02		8.7858"+04	1.2518	4.5353"+03	NM	1.7635	1.7431	3.0000"+02	1.2831"+02										
INFINITE		3.1770"+02	4.1800"+01	6.6366"-04	NC	0.0634	8.5395"-04	6.1698"+02	2.9800"+02										
7803S0208		2.6319	1.0058	2.3978"+03	2.2052"-03	2.9267	1.4205	5.2167"+03	4.1617"+03										
3.8100"-02		8.7247"+04	1.2535	4.7639"+03	NM	1.7557	1.7405	3.0000"+02	1.1370"+02										
INFINITE		3.1744"+02	4.4500"+01	6.6977"-04	NC	0.0665	8.5719"-04	6.0674"+02	2.9826"+02										
7803S0209		2.6099	1.0055	2.6902"+03	2.3032"-03	2.2019	1.4947	5.7947"+03	4.3069"+03										
4.4450"-02		8.7273"+04	1.3454	5.2983"+03	NM	1.7534	1.7362	3.0000"+02	1.3435"+02										
INFINITE		3.1738"+02	4.7300"+01	7.3573"-04	NC	0.0590	8.6654"-04	6.0654"+02	2.9835"+02										
7803S0210		2.5793	1.0052	3.6627"+03	2.3320"-03	1.9910	1.4382	6.3290"+03	4.7237"+03										
5.0800"-02		9.1286"+04	1.3398	5.9591"+03	NM	1.7558	1.7389	3.0000"+02	1.3614"+02										
INFINITE		3.1729"+02	5.1300"+01	7.7790"-04	NC	0.0536	9.0701"-04	6.0341"+02	2.9845"+02										
7803S0211		2.4447	1.0029	2.8971"+03	2.2048"-03	2.9192	1.3687	6.7134"+03	5.8113"+03										
5.7150"-02		9.1091"+04	1.1552	5.3417"+03	NM	1.7713	1.7594	3.0000"+02	1.4445"+02										
INFINITE		3.1710"+02	5.3600"+01	6.5004"-04	NC	0.0650	8.3321"-04	5.8909"+02	2.9915"+02										
7803S0212		2.3761	1.0013	2.7860"+03	2.3409"-03	3.2335	1.3935	7.0130"+03	6.2692"+03										
6.3500"-02		8.8298"+04	1.1186	4.9974"+03	NM	1.7688	1.7557	3.0000"+02	1.4493"+02										
INFINITE		3.1709"+02	5.8000"+01	6.0533"-04	NC	0.0679	7.9030"-04	5.8138"+02	2.9960"+02										
7803S0213		2.3544	1.0003	3.0826"+03	2.3982"-03	2.7648	1.3982	7.6700"+03	6.5227"+03										
6.9850"-02		8.8810"+04	1.1759	5.4789"+03	NM	1.7695	1.7574	3.0000"+02	1.5046"+02										
INFINITE		3.1727"+02	6.0700"+01	6.5302"-04	NC	0.0741	8.0801"-04	5.7904"+02	2.9992"+02										
7803S0214		2.2889	0.9986	3.2010"+03	2.3380"-03	2.8936	1.3568	8.0542"+03	7.2365"+03										
7.6200"-02		8.8924"+04	1.1130	5.5419"+03	NM	1.7820	1.7712	3.0000"+02	1.5495"+02										
INFINITE		3.1730"+02	6.4700"+01	6.3803"-04	NC	0.0737	8.0250"-04	5.7125"+02	3.0042"+02										

7803S0214		LADERMAN		PROFILE TABULATION		101 POINTS, DELTA AT POINT 87		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	1.11300	0.94547	0.00000	0.00000	1.93611	0.00000
2	7.3040"-05	1.3984"+00	1.11153	0.95082	0.30977	0.41202	1.76919	0.25886
3	8.2969"-05	1.4313"+00	1.11133	0.95377	0.32088	0.42604	1.76292	0.26857
4	1.0283"-04	1.5308"+00	1.11093	0.95570	0.35138	0.46256	1.73288	0.29654
5	1.2269"-04	1.6213"+00	1.11053	0.95742	0.37591	0.49124	1.70774	0.31945
6	1.4056"-04	1.7286"+00	1.11016	0.95920	0.40193	0.52094	1.67988	0.34427
7	1.5049"-04	1.7930"+00	1.10996	0.96008	0.41626	0.53695	1.66394	0.35818
8	1.6042"-04	1.8360"+00	1.10976	0.96055	0.42536	0.54696	1.65354	0.36709
9	1.7034"-04	1.8765"+00	1.10956	0.96098	0.43362	0.55598	1.64399	0.37524
10	1.7829"-04	1.9167"+00	1.10940	0.96139	0.44156	0.56457	1.63476	0.38313
11	1.9219"-04	1.9461"+00	1.10912	0.96169	0.44719	0.57062	1.62817	0.38871
12	2.0410"-04	1.9889"+00	1.10888	0.96211	0.45519	0.57915	1.61875	0.39673
13	2.1602"-04	2.0236"+00	1.10864	0.96245	0.46153	0.58584	1.61127	0.40309
14	2.4183"-04	2.0814"+00	1.10812	0.96299	0.47175	0.59656	1.59911	0.41339
15	2.6566"-04	2.1385"+00	1.10763	0.96352	0.48154	0.60670	1.58740	0.42333
16	2.9148"-04	2.1879"+00	1.10711	0.96396	0.48978	0.61516	1.57748	0.43173
17	3.1531"-04	2.2367"+00	1.10663	0.96439	0.49774	0.62324	1.56786	0.43989
18	3.4113"-04	2.2708"+00	1.10611	0.96470	0.50319	0.62874	1.56129	0.44544
19	3.7489"-04	2.3124"+00	1.10542	0.96526	0.50973	0.63536	1.55366	0.45206
20	3.9872"-04	2.3574"+00	1.10494	0.96579	0.51668	0.64232	1.54544	0.45923
21	4.1460"-04	2.3754"+00	1.10462	0.96603	0.51942	0.64506	1.54225	0.46201
22	4.4042"-04	2.4082"+00	1.10410	0.96647	0.52438	0.64998	1.53645	0.46708
23	4.9602"-04	2.4684"+00	1.10297	0.96731	0.53333	0.65884	1.52604	0.47619
24	5.4368"-04	2.5172"+00	1.10201	0.96801	0.54043	0.66581	1.51779	0.48342
25	5.9531"-04	2.5648"+00	1.10097	0.96872	0.54726	0.67247	1.50991	0.49034

(continued)

7803S0214		LADERMAN	PROFILE TABULATION			101 POINTS, DELTA AT POINT 87			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD	
26	6.5091"-04	2.6110"+00	1.09984	0.96944	0.55379	0.67880	1.50242	0.49691	
27	7.2042"-04	2.6610"+00	1.09844	0.97019	0.56075	0.68549	1.49439	0.50387	
28	7.9389"-04	2.7250"+00	1.09695	0.97071	0.56952	0.69369	1.48359	0.51291	
29	8.6936"-04	2.7784"+00	1.09543	0.97165	0.57670	0.70052	1.47553	0.52007	
30	9.4085"-04	2.8104"+00	1.09398	0.97277	0.58097	0.70476	1.47159	0.52392	
31	1.0084"-03	2.8662"+00	1.09262	0.97330	0.58830	0.71150	1.46268	0.53149	
32	1.0719"-03	2.9059"+00	1.09133	0.97362	0.59346	0.71618	1.45634	0.53668	
33	1.1533"-03	2.9629"+00	1.08969	0.97403	0.60077	0.72274	1.44729	0.54416	
34	1.2189"-03	3.0000"+00	1.08836	0.97431	0.60548	0.72694	1.44148	0.54887	
35	1.2904"-03	3.0345"+00	1.08692	0.97455	0.60982	0.73079	1.43610	0.55310	
36	1.4075"-03	3.1035"+00	1.08456	0.97564	0.61839	0.73855	1.42637	0.56156	
37	1.5287"-03	3.1756"+00	1.08211	0.97626	0.62721	0.74626	1.41565	0.57043	
38	1.6498"-03	3.2608"+00	1.07966	0.97744	0.63746	0.75529	1.40386	0.58087	
39	1.7709"-03	3.3311"+00	1.07722	0.97743	0.64577	0.76215	1.39294	0.58940	
40	1.8841"-03	3.4109"+00	1.07493	0.97788	0.65508	0.76992	1.38138	0.59912	
41	2.0033"-03	3.4804"+00	1.07252	0.97832	0.66305	0.77653	1.37158	0.60722	
42	2.1264"-03	3.5620"+00	1.06983	0.97892	0.67230	0.78413	1.36036	0.61667	
43	2.2475"-03	3.6447"+00	1.06729	0.97940	0.68153	0.79159	1.34905	0.62626	
44	2.3726"-03	3.7360"+00	1.06522	0.97995	0.69156	0.79959	1.33682	0.63714	
45	2.4958"-03	3.8277"+00	1.06389	0.98119	0.70148	0.80769	1.32573	0.64817	
46	2.6169"-03	3.9136"+00	1.06323	0.98181	0.71065	0.81486	1.31481	0.65895	
47	2.7400"-03	3.9939"+00	1.06263	0.98237	0.71909	0.82139	1.30476	0.66896	
48	2.8611"-03	4.0809"+00	1.06257	0.98290	0.72813	0.82827	1.29396	0.68015	
49	2.9862"-03	4.1789"+00	1.06063	0.98416	0.73817	0.83609	1.28290	0.69123	
50	3.1094"-03	4.2674"+00	1.05911	0.98539	0.74711	0.84302	1.27322	0.70126	
51	3.2325"-03	4.3696"+00	1.05767	0.98612	0.75731	0.85054	1.26138	0.71318	
52	3.3556"-03	4.4621"+00	1.05824	0.98740	0.76641	0.85744	1.25165	0.72494	
53	3.4746"-03	4.5685"+00	1.05768	0.98814	0.77674	0.86486	1.23978	0.73783	
54	3.5959"-03	4.6709"+00	1.05570	0.98934	0.78655	0.87203	1.22918	0.74896	
55	3.7170"-03	4.7820"+00	1.05399	0.98997	0.79705	0.87932	1.21710	0.76148	
56	3.8360"-03	4.8894"+00	1.05354	0.99136	0.80707	0.88653	1.20660	0.77407	
57	3.9573"-03	4.9831"+00	1.05395	0.99196	0.81570	0.89240	1.19689	0.78581	
58	4.0785"-03	5.0955"+00	1.05219	0.99326	0.82593	0.89953	1.18617	0.79793	
59	4.2016"-03	5.2028"+00	1.05152	0.99446	0.83558	0.90616	1.17608	0.81019	
60	4.3207"-03	5.3064"+00	1.05019	0.99501	0.84478	0.91214	1.16582	0.82167	
61	4.4419"-03	5.4159"+00	1.04898	0.99571	0.85441	0.91836	1.15530	0.83384	
62	4.5610"-03	5.5108"+00	1.04856	0.99743	0.86266	0.92415	1.14765	0.84436	
63	4.6821"-03	5.6118"+00	1.04816	0.99752	0.87135	0.92939	1.13767	0.85627	
64	4.8053"-03	5.7259"+00	1.04656	0.99865	0.88106	0.93565	1.12775	0.86829	
65	4.9264"-03	5.8346"+00	1.04450	0.99926	0.89021	0.94126	1.11797	0.87940	
66	5.0535"-03	5.9451"+00	1.04302	1.00032	0.89942	0.94704	1.10870	0.89094	
67	5.1726"-03	6.0538"+00	1.04171	1.00087	0.90838	0.95237	1.09921	0.90255	
68	5.2938"-03	6.1387"+00	1.04192	1.00175	0.91532	0.95667	1.09241	0.91247	
69	5.4169"-03	6.2344"+00	1.04079	1.00242	0.92307	0.96129	1.08451	0.92253	
70	5.5420"-03	6.3205"+00	1.03951	1.00266	0.92999	0.96519	1.07712	0.93149	
71	5.6612"-03	6.4030"+00	1.03831	1.00297	0.93658	0.96890	1.07023	0.94001	
72	5.7803"-03	6.4979"+00	1.03646	1.00336	0.94409	0.97312	1.06244	0.94932	
73	5.9014"-03	6.5853"+00	1.03389	1.00320	0.95096	0.97669	1.05484	0.95729	
74	6.0226"-03	6.6554"+00	1.03230	1.00322	0.95643	0.97957	1.04897	0.96400	
75	6.1417"-03	6.7178"+00	1.03140	1.00343	0.96128	0.98220	1.04400	0.97034	
76	6.2629"-03	6.7764"+00	1.02977	1.00317	0.96580	0.98441	1.03890	0.97576	
77	6.3840"-03	6.8455"+00	1.02655	1.00268	0.97111	0.98690	1.03277	0.98095	
78	6.5071"-03	6.9056"+00	1.02368	1.00308	0.97571	0.98943	1.02833	0.98495	
79	6.6263"-03	6.9581"+00	1.02151	1.00264	0.97971	0.99124	1.02369	0.98914	
80	6.7454"-03	7.0071"+00	1.01921	1.00223	0.98342	0.99290	1.01938	0.99274	
81	6.8666"-03	7.0472"+00	1.01680	1.00224	0.98645	0.99443	1.01624	0.99497	
82	6.9878"-03	7.0794"+00	1.01519	1.00176	0.98888	0.99540	1.01323	0.99732	
83	7.1068"-03	7.1111"+00	1.01304	1.00109	0.99126	0.99624	1.01009	0.99916	
84	7.2280"-03	7.1450"+00	1.01015	1.00098	0.99380	0.99745	1.00735	1.00022	
85	7.3531"-03	7.1736"+00	1.00671	1.00046	0.99594	0.99824	1.00463	1.00030	
86	7.4782"-03	7.2033"+00	1.00350	1.00035	0.99816	0.99927	1.00224	1.00053	
D 87	7.6033"-03	7.2281"+00	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	
88	7.7224"-03	7.2477"+00	0.99678	1.00032	1.00145	1.00087	0.99883	0.99882	
89	7.8436"-03	7.2656"+00	0.99425	0.99951	1.00278	1.00111	0.99667	0.99869	
90	7.9667"-03	7.2871"+00	0.99070	0.99927	1.00438	1.00176	0.99480	0.99763	
91	8.0878"-03	7.3063"+00	0.98689	0.99930	1.00580	1.00247	0.99338	0.99591	
92	8.2090"-03	7.3241"+00	0.98317	0.99934	1.00711	1.00313	0.99209	0.99410	
93	8.3321"-03	7.3391"+00	0.97931	0.99916	1.00822	1.00357	0.99079	0.99195	
94	8.4512"-03	7.3517"+00	0.97524	0.99828	1.00915	1.00357	0.98897	0.98964	
95	8.5724"-03	7.3688"+00	0.97190	0.99878	1.01041	1.00443	0.98820	0.98786	
96	8.6935"-03	7.3725"+00	0.96925	0.99895	1.01068	1.00464	0.98808	0.98549	
97	8.8166"-03	7.3828"+00	0.96622	0.99877	1.01144	1.00492	0.98715	0.98362	
98	8.9358"-03	7.3956"+00	0.96228	0.99870	1.01238	1.00533	0.98613	0.98102	
99	9.0549"-03	7.4143"+00	0.95764	0.99858	1.01375	1.00593	0.98463	0.97836	
100	9.1761"-03	7.4287"+00	0.95417	0.99862	1.01481	1.00646	0.98361	0.97633	
101	9.2952"-03	7.4373"+00	0.95092	0.99877	1.01544	1.00683	0.98312	0.97386	

INPUT VARIABLES Y,M,TO/TOD,P/PD - P/PD[1],P/PD[2] LINEAR EXTRAPOLATED
TO/TOD[1]=300/TOD

	M: 10.0 - 11.6 R THETA $\times 10^{-3}$: 2.9 - 19 TW/TR: 0.42 - 1.05	7804
		ZPG AW - SHT
Axially symmetric blow-down tunnel. Running time 5s. D = 1.52 m. M = 18 (Free-stream). $2 < P_0 < 14$ MN/m ² (Reservoir). T ₀ : 305K. Helium, $9 < RE/m \times 10^{-6} < 46$ (Free-stream).		
WATSON R.D., 1978. Characteristics of Mach 10 transitional and turbulent boundary layers. NASA TP 1243 And: Watson R.D., private communications, Watson et al., CAT 7305.		

- The report cited above includes the data for Watson et al., CAT 7305, obtained on "model 1". The details below apply to tests with "model 2" only. The test boundary layer was formed on a flat surface (L = 2.29, W = 0.61 m) inclined at 4° to the free stream. The leading edge (X = 0) had a maximum thickness of 0.1 mm, and was positioned 0.102 m below the tunnel centreline and 0.171 m from the final nozzle plane. The surface was cooled by liquid nitrogen in three streamwise sections, X = 0-0.23, 0.23-1.59, 1.59-2.29 m. Before each run the coolant was cut off, and 5 sec. allowed for the model temperature to stabilise. On the centreline, two chambers for instrumentation with interchangeable
- 2 sections of surface were provided running from X = 0.38-1.41, 1.49-2.29 m. The tunnel test core is
 - 3 about 0.4 m in diameter, with a free-stream Mach number gradient of about 0.125/m. On the basis
 - 5 of the peak in local heat transfer measurements, transition occurred in the range of $0.8 < X < 1.1$ m.
- for the results presented here. End plates were mounted on the model extending up to the position calculated for the shock, assuming inviscid flow. Oil flow studies showed that the flow was effectively two-dimensional over the central instrumented strip. Small corner effects were observed at the junction of the end plates and the test surface.
- 6 Static pressure was measured at 20 stations from X = 0.416 to 2.159 m with tappings of diameter 3.18 mm. Iron-constantan thermocouples were used at about 70 X-stations from X = 0.423 to 2.237 m to give the wall temperature. They were also used to give the local heat-flux with the thin wall transient technique. The skin thickness was approximately 0.51 mm, thermocouple conduction errors were calculated to be insignificant, while errors due to local nonuniformity of thin skin temperature were estimated to be less than 1%. This calculation was not made for every case, and for some cooled wall cases relatively large variations in TW/T₀ were observed. Skin friction was measured with an FEB (Kistler model 322) for which the floating element diameter was 9.4 mm, with a gap of 0.064 mm. The balances were matched to the interchangeable instrumentation plates so that the elements were no more than 0.03 mm below the surface. Errors due to protrusion and gap size are estimated as less than 5%, following Allen (1976). The operation and calibration of several balances were checked in a vacuum chamber at near liquid nitrogen temperatures. Two were found suitable for use under these conditions. The precooling process took 1-2 hrs, during which time the balance temperature became very close to that of the surrounding surface. A haze formed on the model surface at the very low temperatures used (about 77K). The surface near the balance was kept clear by a jet of pure helium, retracted immediately before a run.
 - 7 Pitot, static pressure and T₀ profiles were measured. Different Pitot probes were used. Initial work using the same probe as for CAT 7305 had shown rather large probe-wall interference effects. The probe finally used was a CPP ($d_1 = 0.51$ mm), which tapered to a diameter of 2.3 mm at a point about 12.7 mm downstream of the tip. The static pressure probe used was a CCP (half angle of nose 42.5°, $d_1 = 3.2$ mm, four orifices of 0.8 mm diameter, 12.2 mm downstream of the tip) which gave rise to large interference effects so that measurements with it were abandoned. The STP was a form of semishielded fine wire probe. The sensor was a coil of tungsten wire, wire diameter 10 μ m, coil diameter 100 μ m, mounted in a peripheral shield ($h_1 = 0.61$, $b_1 = 2.0$ mm) on the end of two prongs ($d = 0.4$, $l = 5.6$ mm). The l/d ratio of the wire itself was about 800. The probe and calibration procedures are described by Weinstein (1973).

- 9 The use of interchangeable sections of model skin, each instrumented for a part of the investigation requires a great deal of interpolation and normalisation. The profile data given here are as interpolated and processed by the author (private communication). Pitot profile data were normalised to a constant tunnel reservoir pressure of 13.79 MN/m² (which does not imply a constant POD value). Pitot and T0 profiles in general were taken at slightly different TW/TOD values. The TW values are interpolated to correspond to the TOD values prevailing during the TG profile measurements. C_f values, measured at the profile X-stations, were found to be weak functions of TW/TOD and Re_x so
- 12 that no adjustment was made. Heat transfer data have been interpolated by the editors, firstly, as functions of X, to the profile stations for each experimental temperature condition, and secondly, as functions of interpolated TW/TOD, for each profile station to the authors' TW/TOD value as
- 9 stated for the temperature profile. The static pressure measurements showed unacceptable interference effects, so that the static pressure was assumed constant through the boundary layer at the wall value as interpolated for X. Variation of PW with TW/TOD was found to be small, and PW/P(free stream) was
- 10 assumed to be a function of X only. Probe-wall interference was found to a significant factor with all probes, if assessed by the static pressure change induced at the wall. It was sufficient to eliminate the P-profile data from further consideration. At a given level of induced static pressure, however, Pitot and T0 probes are not so directly affected. No wall proximity correction was applied. Rarefaction corrections were calculated for the Pitot probes and not found significant for the cases presented here (Weinstein, Appendix B of source paper). Real gas correction factors (Erikson, 1960) and ideal gas correction factors (Muehler, 1957) were used in data reduction, while the low temperature viscosity of Helium (Maddalon and Jackson, 1970) was approximated by

$$\mu \text{Ns/m}^2 = 5.023 \left(\frac{T^{1.647}}{T+0.83} \right) \times 10^{-7}$$

at low temperatures (below $T = 8\text{K}$), and the power relation

$$\mu \text{Ns/m}^2 = 5.0277 \times 10^{-7} T^{0.647}$$

- 12 at higher temperatures. The editors present fully interpolated and reduced data as received from the
- 13 author (private communication). These consist of three series of 7 profiles at nominal constant tunnel
- 14 reservoir conditions, each set for a given nominal value of TW/TR (01 - 1.05; 02 - 0.44; 03 - 0.56).
- 12 The PW and C_f values attached to the profile are as presented by the author, the CQ values as interpolated by the editors. The authors' viscosity law has been replaced by that of Neubert (1974). The source paper additionally contains raw data (Pitot and T0 profiles) corresponding to CAT 7305, and a restricted amount of data from an additional upstream station ($X = 0.356 \text{ m}$) corresponding to the general conditions of the data given here. Wall data are also tabulated there for a range of other Reynolds numbers.

- § DATA: 78050101-0307. Pitot and T0 profiles measured separately. C_f from FEB. CQ from thin wall transient technique. $NX = 7$.

- 15 Editors' comments. These results further extend the useful coverage of the transitional range treated by Watson et al. (CAT 7305) from the adiabatic wall case to flows with strong heat transfer. Series 01 should be strictly comparable to CAT 7305 (Fig. 4.4.4 to 4.4.6 of AG 352), at slightly higher Reynolds numbers. The heat transfer cases are not strictly isothermal wall flows. This is a consequence of the fact that the temperature is not maintained constant by the cooling system, the heat transfer loading on the strongly precooled surface building up rapidly at the start of the 5 sec. run. Thus the wall temperature, once flow is fully established, is noticeably higher in the region of greatest heat flux near completion of transition ($X = 0.76 \text{ m}$). (Compare with source, Fig. 11).

At these Mach numbers, there is a strong viscous interaction between the boundary layer and the resulting curved bow shock near the leading edge. In consequence the flow outside the boundary layer is rotational, and the exterior flow states can only be determined if both Pitot and static pressure (or another functionally equivalent pair) are measured (see also Varner & Adams, 1980). It is a pity, therefore, that despite the wall interference problems experienced with the static probe,

values are not available in the outer part of the layer and the exterior flow. Any static pressure variation following on the bow shock curvature will be small, away from the leading edge, but static pressure gradients which result from the changes in rate of displacement thickness growth near transition will be approximately MD times the associated longitudinal variation. This implies a 10% static pressure change in a Y-distance of about 40 mm, about the boundary layer thickness. Corresponding errors in the determination of a local P_0 value from the PT2 value are 15% (eqn. 7.1.3 of AGARDograph 253), so that it is difficult if not impossible to select a δ -value and so D-state on any sensible basis in a flow of this nature. The integral values presented here should not therefore be expected to be very accurate.

The measured longitudinal static pressure variation here is a good example of the type of pressure distribution discussed in § 6.4.2 of AG 253 in connection with the earlier results of CAT 7305. The authors calculated the exterior flow field produced by the experimental displacement surface, as evaluated assuming no normal pressure gradient (source, figure 9) and were then able to calculate back to the longitudinal static pressure variations which are remarkably similar in shape to the experimental values given here. (Source, Figs. 13, 14).

Series 01 (Fig. 1) is a good example of a boundary layer which begins laminar (profile 0101) and, moving through transition (profile 0102), gradually develops the equilibrium wake strength of the "developed" turbulent velocity profile (0106). This is confirmed by the behaviour of the profiles as shown in the outer law plot (Fig. 2a). For a further discussion of the adiabatic compressible boundary layer at high Mach numbers the reader is referred to § 4.4 of AG 253. Series 02 provides the interesting extension of the study to the isothermal case although this last condition is not completely fulfilled. A comparison between the outer law plots of series 01 and 02 - Figs. 2a and 2b - shows little difference. This means that the outer region of the boundary layer is little affected by wall cooling which we would expect to stabilize the laminar boundary layer and delay transition. Such transitional behaviour could be deduced from the plots of profiles 0203 to 0206 in fig. 3 if we assume that the parallel shift of these profiles is not caused by a systematic error in the skin friction measurements (approximately -10%). The low value of τ_w indicates that the mean skin friction has not reached the value appropriate to the turbulent velocity profile (see also Fig. 4.4.5 of AG 253). The rather high data points at the lower end of the log-law region are probably due to aerodynamic interference effects as discussed at length by the author. Agreement between the measured temperature profiles and the "standard" theoretical relationship, eqn.(2.5.37) of AG 253, is good except for profiles 0203 and 0301. Some disagreement is found for most profiles in the near wall region, probably again due to aerodynamic interference effects of the probe.

Further tests on a porous surface (without overall mass-transfer) are reported in Watson (1979). No change in wall shear or boundary layer growth was observed, so that a possible transmission of energy by the fluctuating pressure field into the cavity behind the porous surface was found to have negligible effect.

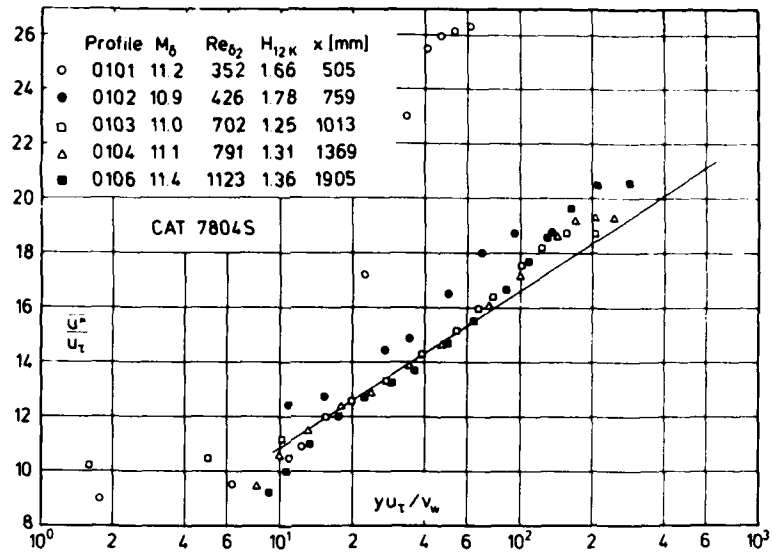


Fig. 1 Law of the wall for a laminar / transitional / turbulent compressible boundary layer (defined origin, adiabatic wall, ZPG, c_f from FEB). Watson (1978).

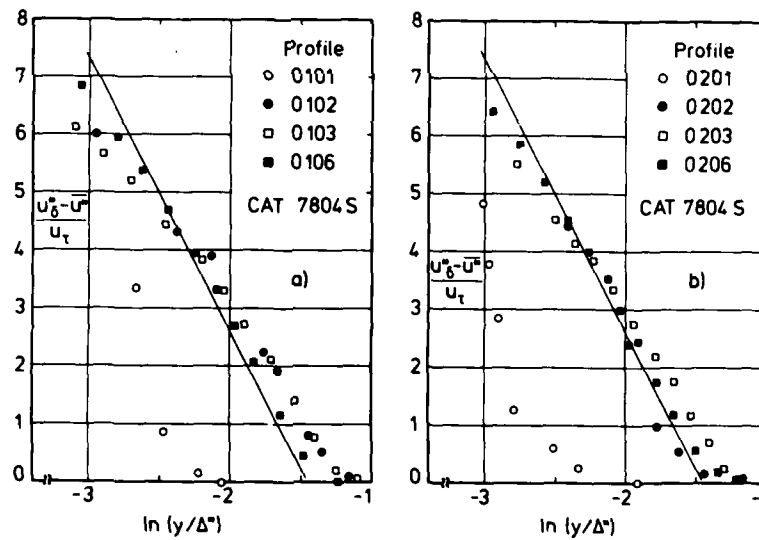


Fig. 2 Outer law for a compressible boundary layer - laminar / transitional / turbulent - (defined origin, isothermal wall, ZPG). Watson (1978).

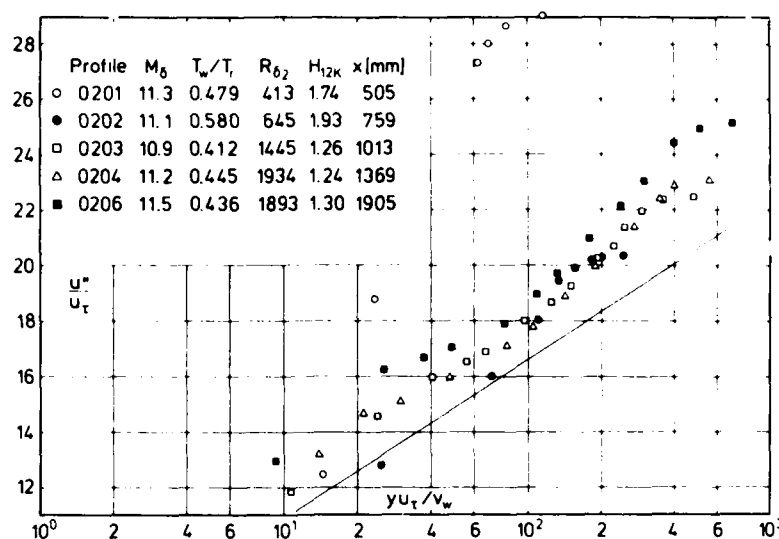


Fig. 3 Law of the wall for a laminar / transitional / turbulent compressible boundary layer (defined origin, isothermal wall, ZPG, c_f from FEB). Watson (1978).

CAT 7804S		WATSON							BOUNDARY CONDITIONS AND EVALUATED DATA, SI UNITS						
RUN	MD *	TW/TR	RED2W	CF	H12	H12K	PW	PD*							
X *	POD	PW/POD*	RED2D	CO *	H32	H32K	TW*	TD							
RZ	TOD*	TAUW *	DZ	PI2	H42	D2K	UD	TR							
7804S0101	11.1750	1.0561	3.5213E+02	1.4817E-04	94.1550	1.6603	6.3570E+02	6.3570E+02							
5.0500E-01	7.5295E+06	1.0000	3.9813E+03	-4.2425E-06	1.7809	1.6834	2.9667E+02	7.3310E+00							
INFINITE	3.1265E+02	9.8040E+00	9.4675E-05	NC	0.1276	1.4499E-03	1.7811E+03	2.8090E+02							
7804S0102	10.9380	1.0527	4.2557E+02	3.0388E-04	64.5007	1.7852	7.2809E+02	7.2809E+02							
7.5900E-01	7.7675E+06	1.0000	4.6392E+03	-1.5992E-05	1.9164	1.8739	2.9944E+02	7.7403E+00							
INFINITE	3.1658E+02	2.2063E+01	1.0551E-04	NC	0.5492	6.2047E-04	1.7913E+03	2.8446E+02							
7804S0103	11.0380	1.0382	7.0193E+02	3.0142E-04	72.9073	1.2538	7.5704E+02	7.5704E+02							
1.0130E+00	8.4430E+06	1.0000	7.6972E+03	-8.3043E-06	1.9044	1.8497	2.9278E+02	7.5388E+00							
INFINITE	3.1386E+02	2.3173E+01	1.6131E-04	NC	0.3119	1.0948E-03	1.7840E+03	2.8200E+02							
7804S0104	11.1020	1.0418	7.9140E+02	2.8258E-04	82.5595	1.3126	7.5360E+02	7.5360E+02							
1.3690E+00	8.6450E+06	1.0000	8.7745E+03	-9.2777E-06	1.8916	1.8092	2.9389E+02	7.4568E+00							
INFINITE	3.1397E+02	2.1877E+01	1.8111E-04	NC	0.1295	1.4150E-03	1.7846E+03	2.8209E+02							
7804S0105	11.2250	1.0298	9.6193E+02	2.5784E-04	80.2262	1.5731	7.3153E+02	7.3153E+02							
1.6510E+00	8.8556E+06	1.0000	1.0737E+04	-7.9363E-06	1.8840	1.7577	2.9611E+02	7.4391E+00							
INFINITE	3.2004E+02	1.9809E+01	2.2511E-04	NC	0.2699	1.8131E-03	1.8022E+03	2.8753E+02							
7804S0106	11.3980	1.0658	1.1233E+03	2.3109E-04	85.1802	1.3642	7.1636E+02	7.1636E+02							
1.9050E+00	9.3445E+06	1.0000	1.3193E+04	-6.2096E-06	1.8933	1.8209	2.9722E+02	7.0031E+00							
INFINITE	3.1042E+02	1.7926E+01	2.5713E-04	NC	0.1835	2.1272E-03	1.7756E+03	2.7887E+02							
7804S0107	11.5100	1.0570	1.6871E+03	2.1477E-04	95.0760	1.2376	7.1085E+02	7.1085E+02							
2.1590E+00	9.7264E+06	1.0000	2.0015E+04	-5.2588E-06	1.9059	1.8908	2.9500E+02	6.8765E+00							
INFINITE	3.1069E+02	1.6858E+01	3.8005E-04	NC	0.0017	3.3613E-03	1.7767E+03	2.7910E+02							
7804S0201	11.2930	0.4790	4.1258E+02	1.8100E-04	93.6376	1.7421	6.3570E+02	6.3570E+02							
5.0500E-01	7.9257E+06	1.0000	2.8468E+03	4.1577E-05	1.7693	1.7437	1.3333E+02	7.1182E+00							
INFINITE	3.0987E+02	1.2231E+01	6.4470E-05	NC	0.1918	9.8941E-04	1.7736E+03	2.7838E+02							
7804S0202	11.1340	0.5800	6.4487E+02	3.4598E-04	74.6694	1.9271	7.2809E+02	7.2809E+02							
7.5900E-01	8.4705E+06	1.0000	4.9224E+03	4.9661E-05	1.8913	1.8391	1.6222E+02	7.3522E+00							
INFINITE	3.1131E+02	2.6028E+01	1.0296E-04	NC	0.4107	7.4115E-04	1.7771E+03	2.7970E+02							
7804S0203	10.9270	0.4124	1.4454E+03	3.4583E-04	46.0738	1.2598	7.5704E+02	7.5704E+02							
1.0130E+00	8.0369E+06	1.0000	8.6016E+03	8.1766E-05	1.8712	1.8388	1.1500E+02	7.6027E+00							
INFINITE	3.1034E+02	2.6055E+01	1.8408E-04	NC	0.8413	8.6287E-04	1.7736E+03	2.7885E+02							
7804S0204	11.1740	0.4455	1.9341E+03	3.0365E-04	45.2493	1.2380	7.5360E+02	7.5360E+02							
1.3690E+00	8.9221E+06	1.0000	1.2486E+04	6.3234E-05	1.8956	1.8447	1.2667E+02	7.4217E+00							
INFINITE	3.1646E+02	2.3814E+01	2.5451E-04	NC	0.9307	1.2343E-03	1.7919E+03	2.8432E+02							
7804S0205	11.0030	0.4319	1.8215E+03	2.8805E-04	52.7118	1.3308	7.3153E+02	7.3153E+02							
1.6510E+00	8.0330E+06	1.0000	1.1286E+04	6.4061E-05	1.8892	1.8257	1.2056E+02	7.5075E+00							
INFINITE	3.1063E+02	2.1263E+01	2.4425E-04	NC	0.7677	1.5052E-03	1.7747E+03	2.7910E+02							
7804S0206	11.4680	0.4364	1.8926E+03	2.4787E-04	67.7031	1.2980	7.1636E+02	7.1636E+02							
1.9050E+00	9.6283E+06	1.0000	1.2539E+04	5.4304E-05	1.8990	1.8529	1.2500E+02	7.1082E+00							
INFINITE	3.1888E+02	1.9464E+01	2.4769E-04	NC	0.5259	1.5275E-03	1.7998E+03	2.8645E+02							
7804S0207	11.4230	0.3808	2.2044E+03	2.4980E-04	65.7860	1.4985	7.1085E+02	7.1085E+02							
2.1590E+00	9.3724E+06	1.0000	1.3264E+04	5.8627E-05	1.9060	1.8666	1.1056E+02	7.2388E+00							
INFINITE	3.2314E+02	1.9312E+01	2.7243E-04	NC	0.5894	1.6510E-03	1.8116E+03	2.9029E+02							

CAT 7804S		WATSON								BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS							
RUN	MD *	TW/TR	RE02W	CF	H12	H12K	PW	PD*									
X *	POD	PW/PD*	RE02D	CO *	H32	H32K	TW*	TD									
PZ	TOO*	TAUW *	D2	P12	H42	D2K	UD	TR									
7804S0301	11.2850	0.6205	4.1001"+02	1.5848"-04	81.6429	2.0756	6.3570"+02	6.3570"+02									
5.0500"-01	7.8983"+06	1.0000	3.3516"+03	2.9673"-05	1.8060	1.6328	1.6944"+02	6.9926"+00									
INFINITE	3.0398"+02	1.0694"+01	7.4204"-05	NC	0.4343	8.5148"-04	1.7566"+03	2.7309"+02									
7804S0302	11.2460	0.6542	6.4960"+02	4.5249"-04	74.6272	1.9813	7.2809"+02	7.2809"+02									
7.5900"-01	8.8946"+06	1.0000	5.4533"+03	3.8144"-05	1.9017	1.8446	1.8111"+02	7.1361"+00									
INFINITE	3.0813"+02	3.4729"+01	1.0864"-04	NC	0.4436	7.4404"-04	1.7684"+03	2.7682"+02									
7804S0303	10.9250	0.5206	1.0227"+03	3.6565"-04	64.0603	1.2730	7.5704"+02	7.5704"+02									
1.0130"+00	8.0297"+06	1.0000	7.0830"+03	6.0152"-05	1.9060	1.8626	1.4389"+02	7.5383"+00									
INFINITE	3.0760"+02	2.7538"+01	1.4996"-04	NC	0.4675	8.5659"-04	1.7657"+03	2.7639"+02									
7804S0304	11.1520	0.5660	1.2279"+03	3.0176"-04	70.4212	1.2805	7.5360"+02	7.5360"+02									
1.3690"+00	8.8367"+06	1.0000	9.2390"+03	4.1698"-05	1.8984	1.8539	1.5944"+02	7.3821"+00									
INFINITE	3.1357"+02	2.3573"+01	1.8739"-04	NC	0.3853	1.1780"-03	1.7836"+03	2.8172"+02									
7804S0305	11.6470	0.5458	1.6447"+03	2.5632"-04	60.4650	1.3015	7.3153"+02	7.3153"+02									
1.6510"+00	1.0606"+07	1.0000	1.2961"+04	4.1868"-05	1.9104	1.9118	1.5278"+02	6.7397"+00									
INFINITE	3.1164"+02	2.1201"+01	2.3012"-04	NC	0.7139	1.2465"-03	1.7799"+03	2.7993"+02									
7804S0306	11.4490	0.5252	1.7854"+03	2.7882"-04	74.2033	1.4315	7.1636"+02	7.1636"+02									
1.9050"+00	9.5506"+06	1.0000	1.3307"+04	4.3096"-05	1.9068	1.8517	1.5000"+02	7.1097"+00									
INFINITE	3.1791"+02	2.1822"+01	2.6338"-04	NC	0.4195	1.7669"-03	1.7970"+03	2.8559"+02									
7804S0307	11.8330	0.5149	2.1329"+03	2.3761"-04	75.5826	1.3254	7.1085"+02	7.1085"+02									
2.1590"+00	1.1136"+07	1.0000	1.6520"+04	3.7567"-05	1.8834	1.8481	1.4833"+02	6.7246"+00									
INFINITE	3.2074"+02	1.9712"+01	2.9622"-04	NC	0.4796	2.3490"-03	1.8063"+03	2.8808"+02									

TRAPEZOIDAL RULE FOR 0207

7804S0201		WATSON								PROFILE TABULATION								18 POINTS, DELTA AT POINT 14	
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD											
1	0.0000"+00	1.0000"+00	NM	0.43026	0.00000	0.00000	18.72988	0.00000											
2	1.0312"-03	2.6364"+00	NM	0.86885	0.10597	0.53614	25.59703	0.02095											
3	1.6764"-03	8.7571"+00	NM	0.89316	0.21043	0.77273	13.48486	0.05730											
4	3.5712"-03	2.8268"+01	NM	0.96931	0.38535	0.92547	5.76767	0.16046											
5	3.7084"-03	3.9983"+01	NM	0.97273	0.45938	0.94647	4.24483	0.22297											
6	3.9675"-03	5.5418"+01	NM	0.97791	0.54169	0.96263	3.15808	0.30481											
7	4.3637"-03	7.9463"+01	NM	0.98478	0.64944	0.97709	2.26360	0.43165											
8	4.9047"-03	1.0652"+02	NM	0.98962	0.75247	0.98616	1.71757	0.57416											
9	5.4077"-03	1.2727"+02	NM	0.99349	0.82276	0.99132	1.45172	0.68286											
10	5.8674"-03	1.3882"+02	NM	0.99575	0.85942	0.99384	1.33729	0.74318											
11	6.9723"-03	1.6263"+02	NM	0.99862	0.93042	0.99753	1.14947	0.86782											
12	8.3464"-03	1.7871"+02	NM	0.99892	0.97544	0.99888	1.04863	0.95256											
13	9.6545"-03	1.8570"+02	NM	1.00050	0.99439	1.00012	1.01155	0.98870											
D 14	1.0638"-02	1.8780"+02	NM	1.00000	1.00000	1.00000	1.00000	1.00000											
15	1.3396"-02	1.9541"+02	NM	1.00222	1.02011	1.00156	0.96397	1.03900											
16	1.5641"-02	1.9776"+02	NM	1.00222	1.02625	1.00169	0.95272	1.05141											
17	1.8329"-02	2.0320"+02	NM	1.00222	1.04031	1.00199	0.92769	1.08009											
18	2.0579"-02	2.0665"+02	NM	1.00222	1.04911	1.00216	0.91250	1.09826											

INPUT VARIABLES Y,M,TO ASSUME P=PD

7804S0202		WATSON								PROFILE TABULATION								13 POINTS, DELTA AT POINT 12	
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD											
1	0.0000"+00	1.0000"+00	NM	0.52106	0.00000	0.00000	22.06297	0.00000											
2	1.4630"-03	7.9999"+00	NM	0.89942	0.20343	0.76248	14.04828	0.05428											
3	4.0513"-03	2.0495"+01	NM	0.94991	0.33178	0.89309	7.24606	0.12325											
4	6.2967"-03	4.3681"+01	NM	0.97992	0.48725	0.95437	3.83653	0.24876											
5	7.6657"-03	8.6372"+01	NM	0.99549	0.68690	0.98481	2.05546	0.47912											
6	8.9662"-03	1.0581"+02	NM	0.99070	0.76064	0.99185	1.70033	0.58333											
7	1.0683"-02	1.5455"+02	NM	1.00014	0.91989	0.99793	1.17689	0.84794											
8	1.1471"-02	1.6327"+02	NM	0.99946	0.94557	0.99834	1.11472	0.89560											
9	1.1671"-02	1.6660"+02	NM	0.99945	0.95518	0.99859	1.09296	0.91366											
10	1.3970"-02	1.7759"+02	NM	0.99850	0.98626	0.99892	1.02584	0.97376											
11	1.6457"-02	1.8102"+02	NM	0.99991	0.99578	0.99986	1.00820	0.99172											
D 12	1.6652"-02	1.8256"+02	NM	1.00000	1.00000	1.00000	1.00000	1.00000											
13	1.8854"-02	1.8269"+02	NM	0.99936	1.00036	0.99969	0.99866	1.00103											

INPUT VARIABLES Y,M,TO ASSUME P=PD

7804S0203

WATSON

PROFILE TABULATION

97 POINTS, DELTA AT POINT 55

I	Y	PT2/P	P/PO	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"+00	1.0000"+00	NM	0.37056	0.00000	0.00000	15.12625	0.00000
2	8.3820"-05	1.2521"+01	NM	0.40706	0.26229	0.55290	4.44361	0.12442
3	4.0132"-04	1.2767"+01	NM	0.54788	0.26494	0.64315	5.89296	0.10914
4	9.1440"-04	1.3491"+01	NM	0.77442	0.27263	0.77031	7.98350	0.0964
5	1.5469"-03	1.4946"+01	NM	0.87111	0.28745	0.82755	8.28814	0.09985
6	2.1285"-03	1.6957"+01	NM	0.88819	0.30676	0.84776	7.63728	0.11100
7	2.5248"-03	1.8528"+01	NM	0.89819	0.32104	0.86044	7.18328	0.11978
8	2.7610"-03	1.8953"+01	NM	0.90353	0.32479	0.86494	7.09187	0.12196
9	2.8575"-03	1.9499"+01	NM	0.90573	0.32955	0.86839	6.94360	0.12506
10	2.9134"-03	2.0225"+01	NM	0.90698	0.33577	0.87200	6.74437	0.12929
11	3.0175"-03	2.1317"+01	NM	0.90933	0.34493	0.87732	6.46947	0.13561
12	3.2385"-03	2.3023"+01	NM	0.91434	0.35874	0.88559	6.09387	0.14532
13	3.6195"-03	2.5505"+01	NM	0.92288	0.37796	0.89700	5.63232	0.15926
14	4.1478"-03	2.8849"+01	NM	0.93174	0.40240	0.90934	5.10669	0.17807
15	4.7041"-03	3.2362"+01	NM	0.93598	0.42656	0.91822	4.63376	0.19816
16	5.1613"-03	3.4973"+01	NM	0.94723	0.44367	0.92798	4.37477	0.21212
17	5.4305"-03	3.6675"+01	NM	0.95039	0.45447	0.93201	4.20563	0.22161
18	5.5626"-03	3.7703"+01	NM	0.95149	0.46088	0.93395	4.10651	0.22743
19	5.6337"-03	3.8551"+01	NM	0.95206	0.46609	0.93533	4.02700	0.23226
20	5.7302"-03	4.0184"+01	NM	0.95285	0.47598	0.93771	3.88122	0.24160
21	5.9233"-03	4.3045"+01	NM	0.95498	0.49282	0.94192	3.65310	0.25784
22	6.2636"-03	4.7225"+01	NM	0.95883	0.51643	0.94780	3.36830	0.28139
23	6.7564"-03	5.2803"+01	NM	0.96391	0.54635	0.95469	3.05337	0.31267
24	7.3609"-03	5.9122"+01	NM	0.96880	0.57838	0.96113	2.76144	0.34806
25	7.8791"-03	6.4282"+01	NM	0.97220	0.60328	0.96555	2.56162	0.37693
26	8.2474"-03	6.7418"+01	NM	0.97379	0.61792	0.96780	2.45308	0.39453
27	8.4430"-03	6.9618"+01	NM	0.97664	0.62799	0.97017	2.38669	0.40649
28	8.5395"-03	7.1915"+01	NM	0.97680	0.63833	0.97118	2.31481	0.41955
29	8.6081"-03	7.4458"+01	NM	0.97692	0.64958	0.97222	2.24004	0.43402
30	8.7605"-03	7.7853"+01	NM	0.97861	0.66432	0.97425	2.15076	0.45298
31	9.0399"-03	8.3321"+01	NM	0.98156	0.68738	0.97746	2.02211	0.48339
32	9.4894"-03	9.2849"+01	NM	0.98428	0.72582	0.98137	1.82815	0.53681
33	1.0071"-02	1.0420"+02	NM	0.98856	0.76910	0.98596	1.64342	0.59994
34	1.0683"-02	1.1444"+02	NM	0.99243	0.80617	0.98970	1.50714	0.65667
35	1.1156"-02	1.2215"+02	NM	0.99590	0.83298	0.99260	1.41996	0.69903
36	1.1445"-02	1.2658"+02	NM	0.99846	0.84799	0.99448	1.37535	0.72308
37	1.1577"-02	1.2791"+02	NM	0.99953	0.85248	0.99519	1.36286	0.73022
38	1.1646"-02	1.2978"+02	NM	0.99884	0.85870	0.99509	1.34289	0.74100
39	1.1758"-02	1.3331"+02	NM	0.99928	0.87032	0.99574	1.30899	0.76070
40	1.1994"-02	1.3847"+02	NM	0.99961	0.88707	0.99650	1.26195	0.78965
41	1.2382"-02	1.4489"+02	NM	0.99955	0.90748	0.99716	1.20743	0.82586
42	1.2951"-02	1.5206"+02	NM	1.00000	0.92972	0.99808	1.15248	0.86603
43	1.3597"-02	1.5873"+02	NM	0.99921	0.94994	0.99828	1.10437	0.90394
44	1.4150"-02	1.6383"+02	NM	0.99916	0.96513	0.99868	1.07073	0.93271
45	1.4506"-02	1.6644"+02	NM	0.99987	0.97282	0.99924	1.05506	0.94709
46	1.4699"-02	1.6766"+02	NM	1.00000	0.97639	0.99940	1.04769	0.95391
47	1.4783"-02	1.6826"+02	NM	1.00005	0.97813	0.99947	1.04412	0.95724
48	1.4872"-02	1.6924"+02	NM	1.00013	0.98096	0.99958	1.03832	0.96269
49	1.5067"-02	1.7024"+02	NM	0.99984	0.98389	0.99952	1.03201	0.96852
50	1.5420"-02	1.7161"+02	NM	0.99936	0.98783	0.99937	1.02351	0.97642
51	1.5961"-02	1.7297"+02	NM	0.99939	0.99176	0.99949	1.01564	0.98410
52	1.6622"-02	1.7364"+02	NM	0.99962	0.99369	0.99966	1.01205	0.98775
53	1.7170"-02	1.7402"+02	NM	1.00032	0.99478	1.00003	1.01058	0.98956
54	1.7640"-02	1.7486"+02	NM	0.99995	0.99716	0.99990	1.00550	0.99443
D 55	1.7892"-02	1.7585"+02	NM	1.00000	1.00000	1.00000	1.00000	1.00000
56	1.8016"-02	1.7640"+02	NM	1.00070	1.00156	1.00039	0.99767	1.00273
57	1.8097"-02	1.7675"+02	NM	1.00070	1.00256	1.00041	0.99571	1.00472
58	1.8273"-02	1.7704"+02	NM	1.00070	1.00339	1.00043	0.99412	1.00635
59	1.8585"-02	1.7749"+02	NM	1.00070	1.00467	1.00046	0.99165	1.00889
60	1.9070"-02	1.7846"+02	NM	1.00070	1.00741	1.00053	0.98638	1.01434
61	1.9688"-02	1.7898"+02	NM	1.00070	1.00888	1.00056	0.98359	1.01726
62	2.0340"-02	1.7937"+02	NM	1.00070	1.00998	1.00059	0.98150	1.01945
63	2.0846"-02	1.7937"+02	NM	1.00070	1.00998	1.00059	0.98150	1.01945
64	2.1171"-02	1.7953"+02	NM	1.00070	1.01043	1.00060	0.98063	1.02036
65	2.1331"-02	1.7972"+02	NM	1.00070	1.01098	1.00061	0.97959	1.02146
66	2.1435"-02	1.7995"+02	NM	1.00070	1.01162	1.00063	0.97838	1.02274
88	2.9337"-02	1.8239"+02	NM	1.00070	1.01849	1.00079	0.96555	1.03650
89	2.9990"-02	1.8190"+02	NM	1.00070	1.01711	1.00076	0.96810	1.03374
90	3.0668"-02	1.8161"+02	NM	1.00070	1.01629	1.00074	0.96963	1.03208
91	3.1209"-02	1.8119"+02	NM	1.00070	1.01510	1.00071	0.97185	1.02970
92	3.1509"-02	1.8135"+02	NM	1.00070	1.01556	1.00072	0.97100	1.03061
93	3.1725"-02	1.8135"+02	NM	1.00070	1.01556	1.00072	0.97100	1.03061
94	3.1801"-02	1.8125"+02	NM	1.00070	1.01528	1.00072	0.97151	1.03006
95	3.1910"-02	1.8083"+02	NM	1.00070	1.01409	1.00069	0.97374	1.02768
96	3.2106"-02	1.8099"+02	NM	1.00070	1.01455	1.00070	0.97288	1.02860
97	3.2438"-02	1.8063"+02	NM	1.00070	1.01354	1.00067	0.97477	1.02658

INPUT VARIABLES Y,M,TO ASSUME P=PD

7804S0206

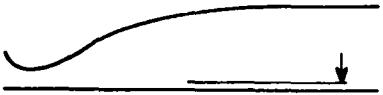
WATSON

PROFILE TABULATION

125 POINTS, DELTA AT POINT 85

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000*-00	1.0000*-00	NM	0.39202	0.00000	0.00000	17.58599	0.00000
2	4.5720*-04	8.5676*-00	NM	0.61594	0.20483	0.63889	9.72874	0.06567
3	1.2548*-03	9.1420*-00	NM	0.88237	0.21198	0.77376	13.32359	0.05807
4	1.8440*-03	1.0093*-01	NM	0.88872	0.22332	0.78981	12.50839	0.06314
5	2.2047*-03	1.0735*-01	NM	0.89278	0.23064	0.79949	12.01573	0.06654
6	2.4003*-03	1.1047*-01	NM	0.89522	0.23413	0.80416	11.79691	0.06817
7	2.5121*-03	1.1174*-01	NM	0.89839	0.23552	0.80698	11.73958	0.06874
8	2.6492*-03	1.1493*-01	NM	0.90022	0.23901	0.81123	11.51988	0.07042
9	2.9261*-03	1.2129*-01	NM	0.90364	0.24581	0.81917	11.10540	0.07376
10	3.3985*-03	1.3342*-01	NM	0.90913	0.25828	0.83247	10.38823	0.08014
11	4.0589*-03	1.4872*-01	NM	0.91632	0.27319	0.84729	9.61884	0.08809
12	4.7523*-03	1.6459*-01	NM	0.92348	0.28784	0.86065	8.93990	0.09627
13	5.3823*-03	1.7794*-01	NM	0.92949	0.29962	0.87071	8.44530	0.10310
14	5.7912*-03	1.8943*-01	NM	0.93310	0.30938	0.87794	8.05261	0.10903
15	6.0503*-03	1.9267*-01	NM	0.93583	0.31209	0.88069	7.96333	0.11059
16	6.1798*-03	1.9648*-01	NM	0.93714	0.31522	0.88296	7.84591	0.11254
17	6.2992*-03	2.0214*-01	NM	0.93834	0.31985	0.88590	7.67167	0.11548
18	6.5126*-03	2.1042*-01	NM	0.94054	0.32647	0.89021	7.43505	0.11973
19	6.9240*-03	2.2314*-01	NM	0.94451	0.33641	0.89669	7.10461	0.12621
20	7.5260*-03	2.4165*-01	NM	0.95031	0.35037	0.90539	6.67769	0.13558
21	8.2550*-03	2.6646*-01	NM	0.95601	0.36824	0.91491	6.17294	0.14821
22	8.9002*-03	2.9329*-01	NM	0.96021	0.38664	0.92311	5.70024	0.16194
23	9.4005*-03	3.1424*-01	NM	0.96265	0.40042	0.92845	5.37634	0.17269
24	9.7333*-03	3.2760*-01	NM	0.96446	0.40896	0.93172	5.19043	0.17951
25	9.9263*-03	3.3078*-01	NM	0.96549	0.41097	0.93276	5.15139	0.18107
26	1.0046*-02	3.3522*-01	NM	0.96620	0.41376	0.93386	5.09405	0.18332
27	1.0239*-02	3.4350*-01	NM	0.96737	0.41890	0.93576	4.99001	0.18753
28	1.0579*-02	3.6079*-01	NM	0.96941	0.42946	0.93937	4.78453	0.19634
29	1.1120*-02	3.9137*-01	NM	0.97185	0.44751	0.94467	4.45619	0.21199
30	1.1814*-02	4.3458*-01	NM	0.97481	0.47183	0.95101	4.06243	0.23410
31	1.2515*-02	4.7724*-01	NM	0.97754	0.49468	0.95636	3.73756	0.25588
32	1.3063*-02	5.1219*-01	NM	0.97970	0.51264	0.96023	3.50850	0.27369
33	1.3457*-02	5.3454*-01	NM	0.98103	0.52381	0.96250	3.37648	0.28506
34	1.3660*-02	5.4786*-01	NM	0.98169	0.53035	0.96373	3.30215	0.29185
35	1.3792*-02	5.5810*-01	NM	0.98209	0.53532	0.96460	3.24694	0.29708
36	1.3937*-02	5.6897*-01	NM	0.98253	0.54055	0.96550	3.19033	0.30263
37	1.4234*-02	5.9569*-01	NM	0.98341	0.55319	0.96752	3.05892	0.31629
38	1.4707*-02	6.4534*-01	NM	0.98483	0.57595	0.97082	2.84126	0.34169
39	1.5392*-02	7.1036*-01	NM	0.98760	0.60446	0.97508	2.60219	0.37471
40	1.6101*-02	7.7960*-01	NM	0.99049	0.63341	0.97908	2.38924	0.40979
41	1.6711*-02	8.3697*-01	NM	0.99192	0.65644	0.98161	2.23609	0.43898
42	1.7163*-02	8.7590*-01	NM	0.99275	0.67161	0.98312	2.14281	0.45880
43	1.7447*-02	9.0833*-01	NM	0.99329	0.68399	0.98424	2.07063	0.47533
44	1.7572*-02	9.2035*-01	NM	0.99352	0.68852	0.98465	2.04516	0.48145
45	1.7716*-02	9.2989*-01	NM	0.99378	0.69210	0.98502	2.02558	0.48629
46	1.7953*-02	9.6306*-01	NM	0.99413	0.70439	0.98596	1.95929	0.50324
47	1.8369*-02	1.0097*-02	NM	0.99477	0.72131	0.98729	1.87345	0.52699
48	1.8979*-02	1.0771*-02	NM	0.99571	0.74512	0.98906	1.76197	0.56134
49	1.9703*-02	1.1618*-02	NM	0.99702	0.77398	0.99114	1.63988	0.60440
50	2.0361*-02	1.2400*-02	NM	0.99812	0.79970	0.99284	1.54135	0.64414
51	2.0881*-02	1.2986*-02	NM	0.99869	0.81845	0.99390	1.47469	0.67397
52	2.1199*-02	1.3401*-02	NM	0.99890	0.83144	0.99451	1.43072	0.69511
53	2.1387*-02	1.3643*-02	NM	0.99904	0.83894	0.99487	1.40625	0.70746
54	2.1526*-02	1.3878*-02	NM	0.99913	0.84618	0.99517	1.38316	0.71949
55	2.1714*-02	1.4145*-02	NM	0.99925	0.85429	0.99553	1.35798	0.73309
56	2.2080*-02	1.4483*-02	NM	0.99927	0.86449	0.99589	1.32709	0.75043
57	2.2636*-02	1.5164*-02	NM	0.99929	0.88464	0.99656	1.26905	0.78528
58	2.3343*-02	1.5833*-02	NM	0.99932	0.90399	0.99718	1.21679	0.81952
59	2.4072*-02	1.6451*-02	NM	0.99932	0.92152	0.99769	1.17214	0.85117
60	2.4628*-02	1.6952*-02	NM	0.99909	0.93547	0.99796	1.13806	0.87690
61	2.5029*-02	1.7240*-02	NM	0.99901	0.94341	0.99813	1.11937	0.89169
62	2.5245*-02	1.7355*-02	NM	0.99901	0.94655	0.99821	1.11214	0.89756
63	2.5397*-02	1.7393*-02	NM	0.99899	0.94759	0.99823	1.10973	0.89952
64	2.5578*-02	1.7476*-02	NM	0.99899	0.94986	0.99829	1.10457	0.90378
65	2.5903*-02	1.7659*-02	NM	0.99897	0.95483	0.99841	1.09336	0.91315
66	2.6396*-02	1.7875*-02	NM	0.99904	0.96067	0.99859	1.08050	0.92419
67	2.7069*-02	1.8132*-02	NM	0.99918	0.96756	0.99883	1.06568	0.93727
68	2.7783*-02	1.8403*-02	NM	0.99857	0.97480	0.99870	1.04964	0.95147
69	2.8407*-02	1.8608*-02	NM	0.99988	0.98021	0.99948	1.03972	0.96130
70	2.8852*-02	1.8737*-02	NM	0.99937	0.98361	0.99931	1.03219	0.96815
71	2.9149*-02	1.8780*-02	NM	0.99944	0.98474	0.99937	1.02994	0.97032
72	2.9329*-02	1.8793*-02	NM	0.99960	0.98509	0.99946	1.02939	0.97092
73	2.9489*-02	1.8800*-02	NM	0.99972	0.98526	0.99952	1.02916	0.97121
74	2.9746*-02	1.8843*-02	NM	0.99995	0.98640	0.99966	1.02708	0.97331
75	3.0183*-02	1.8913*-02	NM	1.00031	0.98823	0.99989	1.02374	0.97670
76	3.0767*-02	1.8966*-02	NM	0.99979	0.98962	0.99966	1.02039	0.97969
77	3.1501*-02	1.9073*-02	NM	0.99916	0.99241	0.99941	1.01415	0.98547
78	3.2154*-02	1.9200*-02	NM	0.99990	0.99573	0.99985	1.00830	0.99162
79	3.2675*-02	1.9298*-02	NM	0.99997	0.99826	0.99994	1.00338	0.99657
80	3.3007*-02	1.9399*-02	NM	1.00002	1.00087	1.00003	0.99831	1.00172
81	3.3216*-02	1.9405*-02	NM	1.00003	1.00105	1.00004	0.99799	1.00205
82	3.3360*-02	1.9361*-02	NM	1.00005	0.99991	1.00002	1.00022	0.99980
83	3.3604*-02	1.9314*-02	NM	1.00009	0.99869	1.00001	1.00265	0.99737
84	3.3972*-02	1.9308*-02	NM	1.00012	0.99852	1.00003	1.00303	0.99701
D 85	3.4519*-02	1.9365*-02	NM	1.00000	1.00000	1.00000	1.00000	1.00000
86	3.5212*-02	1.9449*-02	NM	1.00003	1.00218	1.00007	0.99579	1.00430
124	5.0101*-02	1.9314*-02	NM	1.00003	0.99869	0.99999	1.00260	0.99740
125	5.0615*-02	1.9234*-02	NM	1.00003	0.99660	0.99994	1.00672	0.99327

INPUT VARIABLES Y,M,TO ASSUME P=PD

rough 	M: 2.9 RE THETA $\times 10^{-3}$: 2.7-58 TW/TR: 1	7901 ZPG-AW ROUGH
Boundary layer channel. Effectively continuous. W = 0.33 m. 0.015 < PO < 0.42 MN/m². T0: 320K. Air, dew point 215 - 233K. $1 < RE/m \times 10^{-6} < 30$.		
VOISINET R.L.P., 1979a. Influence of roughness and blowing on compressible turbulent boundary layer flow. NSWC TR 79-153. And: Voisinnet (1979b); Voisinnet R.L.P., private communications; CAT 7202, CAT 7304		

- 1 The test boundary layer was formed on the straight test wall which faces a flexible half-nozzle ($X = 0$ at the throat). The test wall was 2.50 m long, and from $X = 1.22$ the normal smooth surface was replaced by one of a number of interchangeable rough and porous test plate inserts ($W = 0.305$, $L = 1.0$ m). The construction of these surfaces is shown in Fig. 1, details of the roughness screens being given in Table 1. The woven square mesh material was attached so that the mesh grid was at 45° to the flow direction. The layers below the roughness grid were designed to ensure an even
- 2 distribution of the air supply for boundary layer mass addition. Axial Pitot surveys showed that
- 4 the flow in the test region was free of pressure gradients and disturbances. The Mach number distribution for $0 < X < X_T$ was designed to be

$$M = 2.9 - 1.9 \left(1 + 0.55972 \frac{X}{X_T}\right) \left(1 - \frac{X}{X_T}\right)^2$$

where $X_T = 1.143$ m was the nominal start of the test rhombus, just upstream of the start of the porous plate surface. In practice the test section Mach number was slightly higher than 2.9 by an amount depending on the boundary layer growth in the test section. In the test area the wall was at room temperature, while the throat area was slightly heated, so that the tunnel total temperature could be adjusted to give adiabatic wall conditions throughout the boundary layer growth.

- 6 Static pressure tapings were mounted on all test plates. A thermocouple was also attached to each plate to give a value for TW. A floating element balance was used with a rectangular element ($W = 0.127$, $L = 0.254$ m), centred on $X = 1.88$ m. The blowing arrangements and the rough surface were as for the rest of the insert, the roughness screen being cut from and aligned with the piece of wire mesh surrounding it. The surrounding edge gap was less than 0.25 mm with no load applied. The balance was a positive displacement device, the restoring force being supplied by interchangeable leaf springs to give a full deflection (0.25 mm) load range from 50 to 1000 mg.
- 7 Pitot and T0 profile measurements were made in the same general way as for CAT 7202, CAT 7304. The Pitot probe was an FPP ($h_2 = 0.076$, $b_2 = 2.54$ mm). The TTP was a FWP for which the sensing element was a chromel-alumel thermocouple junction at the centre of a traverse fine wire ($d = 0.0254$, $L = 3.56$ mm). The two probes were mounted side by side in a common holder.
- 8 The centre of the balance element was at $X = 1.88$ m, while profiles were measured at $X = 1.98$ m. "The differences in measurement location were accounted for in combining skin friction and boundary layer profile parameters." Static pressure was assumed constant through the layers and evaluated from Pitot measurements in the free stream. At the higher unit Reynolds numbers the FWP proved too
- 10 fragile and the temperature was deduced from the Crocco/Van Driest temperature-velocity correlation.
- 11 No corrections were applied to the Pitot data and (E) Sutherland's viscosity law was used. The
- 12 editors present the profile data for the case of no mass transfer as provided by the author,
- 13 incorporating his assumptions and data reduction procedures. There are four sets of single station profiles. The first set were taken with a smooth wall surface (0101-0112) for $2.7 < Re_\theta \times 10^{-3} < 39$. In

- sets 02-04, four profiles are given for each of the three roughness meshes covering a range
- 14 $7 < Re_\theta \times 10^{-3} < 58$. Skin friction values are given for all profiles. The original report also includes profiles for three blowing rates for each roughness mesh, over the same unit Reynolds number range, and a great deal of fine detail of the skin friction measurements, for all cases whether presented here or not.

§ DATA: 79010101-0404. Pitot and TO profiles measured simultaneously. CF from FEB. NX = 1.

- 15 Editors comments. The experiment provides a usefully wide range of coverage for one type of roughness ($0 \leq k u_\tau / \nu_w \leq 276$) at $M_\theta = 3$, supplemented in the original report by results for three rates of blowing. The balance element is relatively large, so that many of the usual measurement difficulties associated with these instruments are avoided. One selected profile from the smooth wall results is shown in Fig. 2 as a basis for comparison. Except for profiles^{*)} 0109 and 0110 which show discrepancies, the general pattern of the profiles is typical of a fully developed ZPG boundary layer, but as for other NOL/NSWC adiabatic wall data (CAT 7202) the profile lies relatively high in relation to the "standard" wall law. The wake component also is higher than usual (see Figs. 3.3.13, 4.2.19 and the discussion of the wake strength in § 3.3.3 of AGARDograph 253). Agreement with the standard outer law is on the whole better than for the earlier data (AG 253 - Fig. 4.2.20), and examples for the smooth wall and each roughness height are presented in Fig. 3. The slight S-shape of the outer law profile is however characteristic of this experiment and different from the behaviour of the profiles obtained by Shutts & Fenter (1955) or Young (1965) (AG 253 - Fig. 4.6.5).

When the Reynolds number Re_{δ_2} is increased for a given Mach number and roughness height, the dimensionless roughness height $k u_\tau / \nu_w$ increases and the profile as a whole is shifted progressively downwards in relation to the wall law (Fig. 4) while the outer law is unaffected (Fig. 3, profile 0304). For the lowest dimensionless roughness heights (profiles 0201, 0202 and 0301) the surface is aerodynamically smooth, and the profiles are as for the formally smooth surface of series 01. In Fig. 5 we show profiles 0204, 0304 and 0404 which have the highest values $k u_\tau / \nu_w$ of each series, plotted versus $\log y/k$ and compare them with a "standard" log law $\bar{u}^+ = 2.50 \ln(y/k) + 8.50$ (eqn. 4.6.4 of AGARDograph 253). Agreement is satisfactory though this relationship strictly should only hold for velocity profiles with $(k u_\tau / \nu_w) > 70$. The rough-to-smooth skin friction coefficient ratios of the profiles shown in the above figures fall within the band presented by Reda (1974) and reproduced as Fig. (4.6.1). in AG 253. The author states that the transformed velocity profiles agree with low speed behaviour if k_s/k equals 1.2 where k_s is the equivalent sand grain height.

The velocity profiles extend well into the viscous sublayer, and agreement between the measured temperature profiles and the temperature relation, eqn.(2.5.37, AG 253) is good. The author's published values of Re_θ are in error being out by a factor of 2.54.

Comparisons may be made with the experiments by Young (CAT 6506) and Shutts & Fenter (CAT 5502) who all used floating element balances, as did Reda (1974), though tabulated information is not available for this last study. The data given in the legends of figures 2, 4 and 5 were calculated with a D-state at PO max and differ slightly from the "Kopfdaten" printed in the tables below.

^{*)} Not shown here

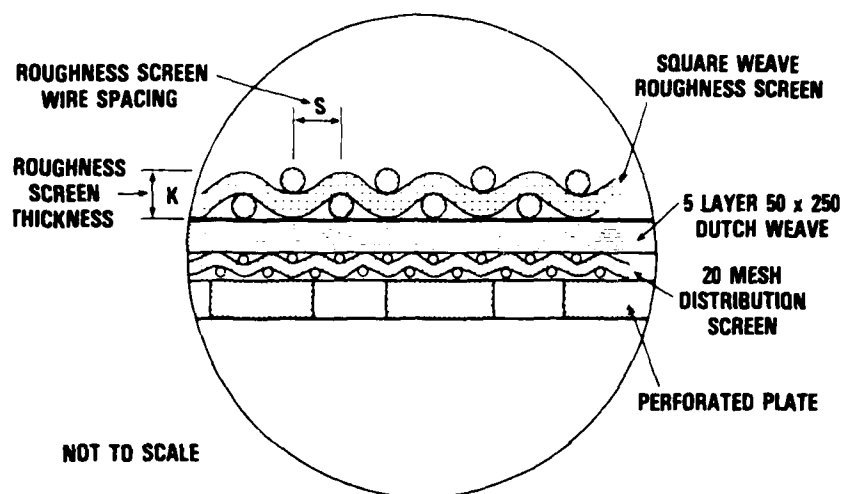


Fig. 1 Test Panel. Cross Section (from Voisinet).

MULTILAYER COMPOSITE	TYPICAL ALL PANELS		
PERFORATED PLATE	22-GAGE 1.58 mm DIA HOLES ON 4.76 mm CENTERS 60° STAGGERED PATTERN 0.782 mm THICKNESS		
DISTRIBUTION MESH	20 MESH, 0.406 mm DIA WIRES 0.584 mm THICKNESS		
FIVE-LAYER DUTCH WEAVE	5 LAYERS 50 x 250 MESH DUTCH WEAVE 0.864 mm THICKNESS		
ROUGHNESS SCREENS	1	2	3
K-(mm/MCH)	0.1/0.004	0.33/0.013	1.25/0.049
d_w -WIRE DIA (mm)	0.05842	0.1905	0.7112
MESH (WRES PER INCH)	200	60	14
S- MESH SPACING (mm)	0.127	0.4233	1.8143
S/d_w	2.174	2.22	2.551
S/K	1.25	1.28	1.48
% CALENDAR	13.0	13.3	12.5

Table 1 Porous roughened test samples (from Voisinet).

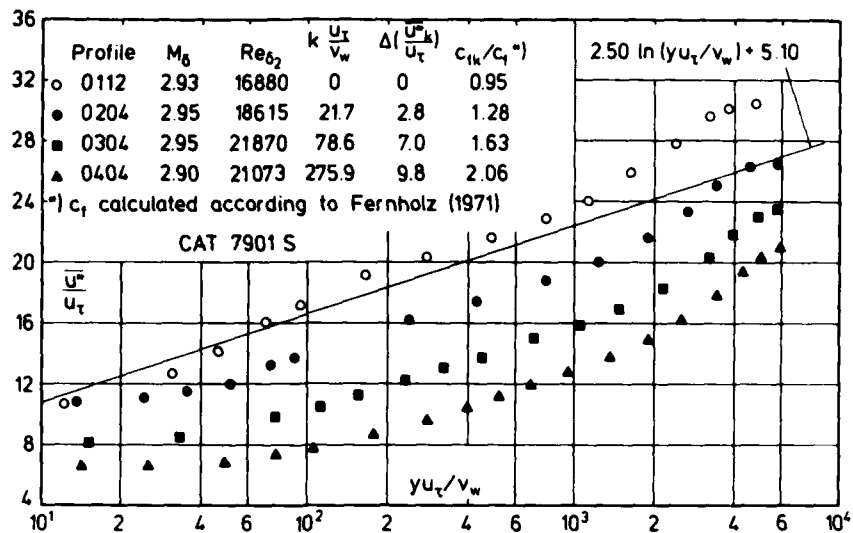


Fig. 2 Law of the wall for compressible turbulent boundary layers over rough walls (adiabatic wall, zero pressure gradient, origin not defined.) Voisinnet (1979).

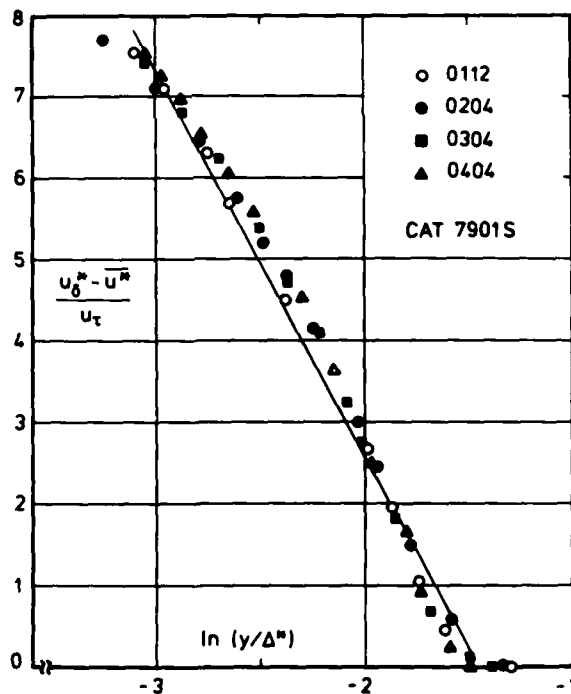


Fig. 3 Outer law for compressible turbulent boundary layers over rough walls (adiabatic wall, zero pressure gradient, origin not defined). Voisinnet (1979).

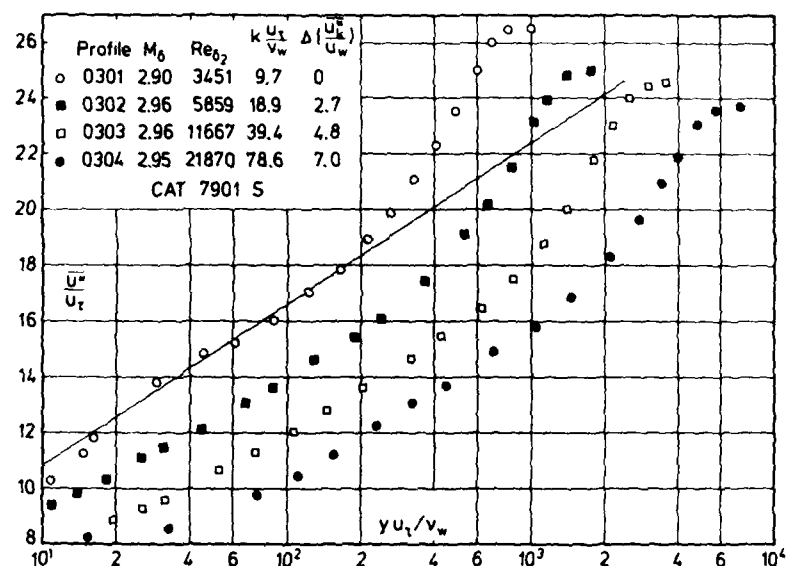


Fig. 4 Law of the wall for compressible turbulent boundary layers over rough walls (adiabatic wall, zero pressure gradient, origin not defined). Voisinet (1979).

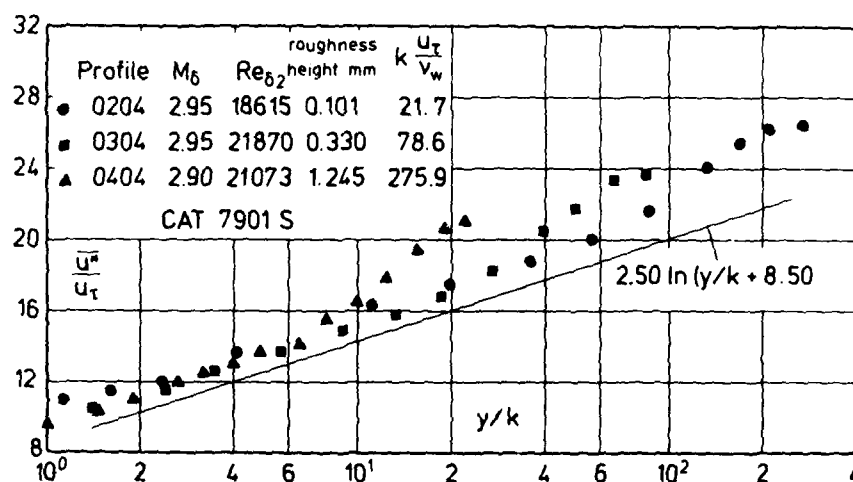


Fig. 5 Law of the wall for compressible turbulent boundary layers over rough walls (adiabatic wall, zero pressure gradient, origin not defined). Voisinet (1979).

CAT 79015 VOISINET BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS								
RUN X * RZ	MD * P00* TOD*	TW/TR PW/P0* TAUW *	RED2W RE020 D2	CF CQ P12*	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD TD TR
7901S0101 1.9810**00 INFINITE	2.8704 1.5440**04 3.2120**02	0.9880 1.0000 5.0550**00	1.2566**03 2.6974**03 2.4813**03	1.7148**03 NM 0.0000**00	4.7971 1.7854 0.1312	1.4407 1.7600 3.7933**03	5.1112**02 2.9680**02 6.3386**02	5.1112**02 1.2131**02 3.0041**02
7901S0102 1.9810**00 INFINITE	2.9282 5.2950**04 3.2080**02	0.9906 1.0000 1.4130**01	3.1374**03 6.9038**03 1.9081**03	1.4659**03 NM 0.0000**00	4.8942 1.7927 0.1086	1.3643 1.7708 2.9577**03	1.6060**03 2.9690**02 6.3819**02	1.6060**03 1.1816**02 2.9973**02
7901S0103 1.9810**00 INFINITE	2.9131 5.1990**04 3.1510**02	0.9923 1.0000 1.4000**01	3.2946**03 7.2378**03 1.9691**03	1.4609**03 NM 0.0000**00	4.9212 1.7738 0.1026	1.4014 1.7535 3.0738**03	1.6133**03 2.9220**02 6.3129**02	1.6133**03 1.1682**02 2.9448**02
7901S0104 1.9810**00 INFINITE	2.9053 1.0560**05 3.2530**02	0.9784 1.0000 2.5390**01	5.7106**03 1.2309**04 1.7185**03	1.2960**03 NM 0.0000**00	4.6457 1.7996 0.1512	1.3354 1.7795 2.5918**03	3.3157**03 2.9750**02 6.4079**02	3.3157**03 1.2101**02 3.0405**02
7901S0105 1.9810**00 INFINITE	2.9360 1.0380**05 3.2020**02	0.9939 1.0000 2.5040**01	5.2504**03 1.1622**04 1.6412**03	1.3337**03 NM 0.0000**00	4.9013 1.8025 0.0940	1.3328 1.7821 2.5242**03	3.1114**03 2.9730**02 6.3822**02	3.1114**03 1.1755**02 2.9912**02
7901S0106 1.9810**00 INFINITE	2.9345 1.0370**05 3.1590**02	0.9955 1.0000 2.4660**01	5.5936**03 1.2418**04 1.7201**03	1.3131**03 NM 0.0000**00	4.9943 1.7893 0.0789	1.3623 1.7685 2.6862**03	3.1155**03 2.9380**02 6.3380**02	3.1155**03 1.1604**02 2.9511**02
7901S0107 1.9810**00 INFINITE	2.9221 2.0480**05 3.1890**02	1.0027 1.0000 4.4250**01	9.7016**03 2.1520**04 1.5196**03	1.1809**03 NM 0.0000**00	4.9922 1.8075 0.0432	1.3173 1.7883 2.3334**03	6.2692**03 2.9880**02 6.3581**02	6.2692**03 1.1777**02 2.9798**02
7901S0108 1.9810**00 INFINITE	2.9252 2.0730**05 3.1920**02	0.9811 1.0000 4.4680**01	1.0322**04 2.2537**04 1.5770**03	1.1810**03 NM 0.0000**00	4.5409 1.8130 0.1773	1.2980 1.7958 2.3317**03	6.3160**03 2.9260**02 6.3636**02	6.3160**03 1.1773**02 2.9825**02
7901S0109 1.9810**00 INFINITE	2.9206 2.1110**05 3.2000**02	0.9728 1.0000 4.5580**01	1.0401**04 2.2511**04 1.5485**03	1.1786**03 NM 0.0000**00	4.5157 1.8144 0.1820	1.2973 1.7958 2.2832**03	6.4767**03 2.9090**02 6.3679**02	6.4767**03 1.1826**02 2.9902**02
7901S0110 1.9810**00 INFINITE	2.9142 3.0920**05 3.1980**02	0.9784 1.0000 6.3350**01	1.3726**04 2.9768**04 1.3919**03	1.1125**03 NM 0.0000**00	4.6106 1.8161 0.1399	1.2960 1.7993 2.0443**03	9.5786**03 2.9240**02 6.3607**02	9.5786**03 1.1851**02 2.9887**02
7901S0111 1.9810**00 INFINITE	2.9390 4.1220**05 3.1850**02	1.0093 1.0000 8.3030**01	1.6332**04 3.6661**04 1.2958**03	1.1164**03 NM 0.0000**00	4.8447 1.8278 0.0772	1.2755 1.8102 1.9279**03	1.2300**04 3.0030**02 6.3676**02	1.2300**04 1.1677**02 2.9752**02
7901S0112 1.9810**00 INFINITE	2.9334 4.1710**05 3.0980**02	1.0276 1.0000 8.3350**01	1.6880**04 3.8513**04 1.2887**03	1.1024**03 NM 0.0000**00	4.8927 1.8295 0.0584	1.2797 1.8111 1.9165**03	1.2552**04 2.9740**02 6.2757**02	1.2552**04 1.1386**02 2.8942**02
7901S0201 1.9810**00 INFINITE	2.9642 5.2060**04 3.1490**02	1.0019 1.0000 1.4190**01	3.1578**03 7.1316**03 1.9908**03	1.5426**03 NM 0.0000**00	5.1293 1.7827 0.0689	1.3773 1.7601 3.1607**03	1.4956**03 2.9460**02 6.3513**02	1.4956**03 1.1421**02 2.9403**02
7901S0202 1.9810**00 INFINITE	2.9438 1.0400**05 3.1370**02	1.0006 1.0000 2.5440**01	5.6706**03 1.2700**04 1.7453**03	1.3612**03 NM 0.0000**00	5.0614 1.7873 0.0672	1.3630 1.7659 2.7494**03	3.0810**03 2.9320**02 6.3233**02	3.0810**03 1.1477**02 2.9301**02
7901S0203 1.9810**00 INFINITE	2.9628 2.0490**05 3.1580**02	0.9964 1.0000 5.0540**01	9.9644**03 2.2383**04 1.5929**03	1.3943**03 NM 0.0000**00	5.1580 1.8008 0.0302	1.3261 1.7801 2.4980**03	5.8988**03 2.9380**02 6.3593**02	5.8988**03 1.1460**02 2.9488**02
7901S0204 1.9810**00 INFINITE	2.9521 4.1340**05 3.1540**02	1.0073 1.0000 1.0810**02	1.8615**04 4.2001**04 1.4701**03	1.4651**03 NM 0.0000**00	4.9568 1.8148 0.0652	1.2948 1.7960 2.2393**03	1.2095**04 2.9670**02 6.3469**02	1.2095**04 1.1498**02 2.9456**02
7901S0301 1.9810**00 INFINITE	2.8870 5.1920**04 3.1880**02	0.9846 1.0000 1.4520**01	3.4151**03 7.3680**03 2.0122**03	1.4849**03 NM 0.0000**00	4.9980 1.7717 0.0595	1.3919 1.7509 3.1851**03	1.6760**03 2.9350**02 6.3286**02	1.6760**03 1.1954**02 2.9808**02
7901S0302 1.9810**00 INFINITE	2.9506 1.0400**05 3.1710**02	0.9975 1.0000 3.0510**01	5.7981**03 1.2965**04 1.8163**03	1.6417**03 NM 0.0000**00	5.2496 1.7706 0.0289	1.3879 1.7497 2.9392**03	3.0496**03 2.9540**02 6.3628**02	3.0496**03 1.1568**02 2.9615**02
7901S0303 1.9810**00 INFINITE	2.9316 2.0900**05 3.1860**02	1.0012 1.0000 6.5490**01	1.1298**04 2.5129**04 1.7455**03	1.7261**03 NM 0.0000**00	5.2817 1.7686 0.0093	1.3938 1.7474 2.8388**03	6.3066**03 2.9800**02 6.3627**02	6.3066**03 1.1718**02 2.9765**02
7901S0304 1.9810**00 INFINITE	2.9371 4.1320**05 3.1380**02	1.0261 1.0000 1.3620**02	2.1668**04 4.9348**04 1.7014**03	1.8241**03 NM 0.0000**00	5.0687 1.7828 0.0727	1.3702 1.7594 2.7209**03	1.2365**04 3.0080**02 6.3190**02	1.2365**04 1.1514**02 2.9314**02

CAT 7901S		VOISINET		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS						
RUN	MD *	TW/TR	RED2W	CF	H12	H12K	PW	PD		
X *	POD*	PW/PD*	RED2D	CQ	H32	H32K	TW*	TD		
RZ	TOD*	TAUW *	D2	PT2*	H42	D2K	UD	TR		
7901S0401	2.8652	0.9905	4.2412 ⁺⁰³	2.0709 ⁻⁰³	5.1613	1.5301	1.7621 ⁺⁰³	1.7621 ⁺⁰³		
1.9810 ⁺⁰⁰	5.2810 ⁺⁰⁴	1.0000	9.1171 ⁺⁰³	NM	1.7245	1.6975	2.9480 ⁺⁰²	1.2044 ⁺⁰²		
INFINITE	3.1820 ⁺⁰²	2.0970 ⁺⁰¹	2.4124 ⁻⁰³	0.0000 ⁺⁰⁰	0.0784	4.0002 ⁻⁰³	6.3046 ⁺⁰²	2.9763 ⁺⁰²		
7901S0402	2.8903	0.9917	7.6375 ⁺⁰³	2.2284 ⁻⁰³	5.2681	1.5422	3.3051 ⁺⁰³	3.3051 ⁺⁰³		
1.9810 ⁺⁰⁰	1.0290 ⁺⁰⁵	1.0000	1.6593 ⁺⁰⁴	NM	1.7219	1.6939	2.9530 ⁺⁰²	1.1925 ⁺⁰²		
INFINITE	3.1850 ⁺⁰²	4.3070 ⁺⁰¹	2.2875 ⁻⁰³	0.0000 ⁺⁰⁰	0.0757	3.8468 ⁻⁰³	6.3283 ⁺⁰²	2.9778 ⁺⁰²		
7901S0403	2.9121	0.9886	1.3450 ⁺⁰⁴	2.3705 ⁻⁰³	5.3703	1.5047	6.2465 ⁺⁰³	6.2465 ⁺⁰³		
1.9810 ⁺⁰⁰	2.0100 ⁺⁰⁵	1.0000	2.9347 ⁺⁰⁴	NM	1.7332	1.7062	2.9740 ⁺⁰²	1.1940 ⁺⁰²		
INFINITE	3.2190 ⁺⁰²	6.7900 ⁺⁰¹	2.1284 ⁻⁰³	0.0000 ⁺⁰⁰	0.0395	3.5890 ⁻⁰³	6.3799 ⁺⁰²	3.0084 ⁺⁰²		
7901S0404	2.8833	0.9935	2.0821 ⁺⁰⁴	2.3792 ⁻⁰³	5.0307	1.4607	1.0054 ⁺⁰⁴	1.0054 ⁺⁰⁴		
1.9810 ⁺⁰⁰	3.0970 ⁺⁰⁵	1.0000	4.5180 ⁺⁰⁴	NM	1.7471	1.7219	2.9580 ⁺⁰²	1.1958 ⁺⁰²		
INFINITE	3.1840 ⁺⁰²	1.3920 ⁺⁰²	2.0607 ⁻⁰³	0.0000 ⁺⁰⁰	0.0954	3.3573 ⁻⁰³	6.3216 ⁺⁰²	2.9772 ⁺⁰²		
7901S0405	2.9096	0.9926	2.6720 ⁺⁰⁴	2.5041 ⁻⁰³	5.0431	1.4545	1.2831 ⁺⁰⁴	1.2831 ⁺⁰⁴		
1.9810 ⁺⁰⁰	4.1130 ⁺⁰⁵	1.0000	5.8380 ⁺⁰⁴	NM	1.7514	1.7250	3.0020 ⁺⁰²	1.2016 ⁺⁰²		
INFINITE	3.2360 ⁺⁰²	1.9040 ⁺⁰²	2.0819 ⁻⁰³	0.0000 ⁺⁰⁰	0.1095	3.3961 ⁻⁰³	6.3947 ⁺⁰²	3.0244 ⁺⁰²		

TRAPEZOIDAL RULE FOR 0112

 ROUGHNESS SCREEN THICKNESS 01: 0.00000 CM 02: 0.01016 CM
 03: 0.03302 CM 04: 0.12450 CM

7901S0204		VOISINET		PROFILE TABULATION		42 POINTS, DELTA AT POINT 30			
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD	
1	0.0000 ⁺⁰⁰	1.0000 ⁺⁰⁰	NM	0.94100	0.00000	0.00000	2.58114	0.00000	
2	6.4000 ⁻⁰⁵	1.7018 ⁺⁰⁰	NM	0.95830	0.30680	0.46103	2.25813	0.20416	
3	1.1400 ⁻⁰⁴	1.7367 ⁺⁰⁰	NM	0.95880	0.31307	0.46921	2.24624	0.20888	
4	1.6500 ⁻⁰⁴	1.8179 ⁺⁰⁰	NM	0.95830	0.32685	0.48656	2.21597	0.21957	
5	2.4100 ⁻⁰⁴	1.9354 ⁺⁰⁰	NM	0.95940	0.34514	0.50950	2.17915	0.23381	
6	2.6700 ⁻⁰⁴	2.0447 ⁺⁰⁰	NM	0.96090	0.36076	0.52878	2.14838	0.24613	
7	3.1800 ⁻⁰⁴	2.1614 ⁺⁰⁰	NM	0.96250	0.37634	0.54763	2.11741	0.25863	
8	3.4300 ⁻⁰⁴	2.1998 ⁺⁰⁰	NM	0.96295	0.38125	0.55347	2.10743	0.26263	
9	4.1900 ⁻⁰⁴	2.3471 ⁺⁰⁰	NM	0.96410	0.39938	0.57450	2.06924	0.27764	
10	1.1300 ⁻⁰³	3.2187 ⁺⁰⁰	NM	0.97130	0.49033	0.67186	1.87749	0.35785	
11	2.0190 ⁻⁰³	3.7256 ⁺⁰⁰	NM	0.97520	0.53531	0.71499	1.78393	0.40079	
12	2.7810 ⁻⁰³	4.0434 ⁺⁰⁰	NM	0.97770	0.56153	0.73872	1.73065	0.42684	
13	3.6450 ⁻⁰³	4.3666 ⁺⁰⁰	NM	0.97950	0.58694	0.76047	1.67875	0.45300	
14	4.6860 ⁻⁰³	4.7031 ⁺⁰⁰	NM	0.98070	0.61221	0.78092	1.62711	0.47994	
15	5.7790 ⁻⁰³	5.0977 ⁺⁰⁰	NM	0.98330	0.64053	0.80324	1.57260	0.51077	
16	6.9220 ⁻⁰³	5.5467 ⁺⁰⁰	NM	0.98540	0.67125	0.82593	1.51395	0.54554	
17	7.8610 ⁻⁰³	5.9380 ⁺⁰⁰	NM	0.98700	0.69689	0.84384	1.46619	0.57553	
18	8.7760 ⁻⁰³	6.2670 ⁺⁰⁰	NM	0.98810	0.71773	0.85771	1.42810	0.60059	
19	1.0020 ⁻⁰²	6.8003 ⁺⁰⁰	NM	0.99020	0.75025	0.87847	1.37103	0.64074	
20	1.0884 ⁻⁰²	7.1896 ⁺⁰⁰	NM	0.99080	0.77311	0.89195	1.33107	0.67010	
21	1.2383 ⁻⁰²	7.8520 ⁺⁰⁰	NM	0.99360	0.81051	0.91361	1.27059	0.71904	
22	1.3526 ⁻⁰²	8.4090 ⁺⁰⁰	NM	0.99640	0.84066	0.93030	1.22464	0.75965	
23	1.4491 ⁻⁰²	8.8806 ⁺⁰⁰	NM	0.99750	0.86535	0.94277	1.18694	0.79429	
24	1.5939 ⁻⁰²	9.5459 ⁺⁰⁰	NM	0.99800	0.89902	0.95841	1.13648	0.84331	
25	1.7310 ⁻⁰²	1.0113 ⁺⁰¹	NM	0.99920	0.92676	0.97095	1.09762	0.88459	
26	1.9317 ⁻⁰²	1.0749 ⁺⁰¹	NM	1.00110	0.95691	0.98417	1.05777	0.93041	
27	2.1628 ⁻⁰²	1.1275 ⁺⁰¹	NM	1.00250	0.98110	0.99422	1.02694	0.96815	
28	2.3406 ⁻⁰²	1.1459 ⁺⁰¹	NM	1.00180	0.98943	0.99700	1.01537	0.98192	
29	2.5870 ⁻⁰²	1.1615 ⁺⁰¹	NM	1.00160	0.99644	0.99950	1.00614	0.99340	
30	2.7394 ⁻⁰²	1.1694 ⁺⁰¹	NM	1.00000	1.00000	1.00000	1.00000	1.00000	
31	2.9731 ⁻⁰²	1.1693 ⁺⁰¹	NM	0.99940	0.99993	0.99968	0.99949	1.00019	
32	3.2271 ⁻⁰²	1.1490 ⁺⁰¹	NM	0.99950	0.99085	0.99639	1.01120	0.98535	
33	3.5319 ⁻⁰²	1.1505 ⁺⁰¹	NM	0.99950	0.99153	0.99664	1.01033	0.98645	
34	3.8799 ⁻⁰²	1.1564 ⁺⁰¹	NM	0.99850	0.99417	0.99712	1.00593	0.99124	
35	4.2939 ⁻⁰²	1.1536 ⁺⁰¹	NM	0.99720	0.99292	0.99600	1.00622	0.98985	
36	4.5555 ⁻⁰²	1.1452 ⁺⁰¹	NM	0.99640	0.98913	0.99420	1.01029	0.98408	
37	4.8628 ⁻⁰²	1.1420 ⁺⁰¹	NM	0.99510	0.98770	0.99302	1.01080	0.98241	
38	5.0381 ⁻⁰²	1.1408 ⁺⁰¹	NM	0.99510	0.98716	0.99282	1.01150	0.98154	
39	5.3353 ⁻⁰²	1.1490 ⁺⁰¹	NM	0.99410	0.99085	0.99369	1.00574	0.98802	
40	5.5817 ⁻⁰²	1.1581 ⁺⁰¹	NM	0.99430	0.99492	0.99529	1.00075	0.99455	
41	5.7341 ⁻⁰²	1.1605 ⁺⁰¹	NM	0.99370	0.99600	0.99539	0.99876	0.99662	
42	5.8661 ⁻⁰²	1.1588 ⁺⁰¹	NM	0.99310	0.99522	0.99480	0.99915	0.99565	

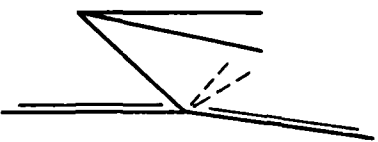
INPUT VARIABLES Y,M,TO/TOD (MODIFIED CROCCO) ASSUME P=PD

MEASURED: PO-PROFILE

AT I= 8 VALUES OF INPUT PROFILES WERE AVERAGED BECAUSE OF SAME Y

7901S0404		VOISINET	PROFILE TABULATION		80 POINTS, DELTA AT POINT 59			
I	Y	PT2/P	P/PO	TO/TCO	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000*-00	1.0000*-00	NM	0.92910	0.00000	0.00000	2.47390	0.00000
2	6.4000*-05	1.3468*-00	NM	0.93730	0.23109	0.34987	2.29221	0.15263
3	1.1400*-04	1.3535*-00	NM	0.93520	0.23310	0.35227	2.28381	0.15425
4	2.1600*-04	1.3857*-00	NM	0.93640	0.24240	0.36532	2.27144	0.16083
5	2.9200*-04	1.4249*-00	NM	0.93880	0.25304	0.38034	2.25921	0.16835
6	3.4300*-04	1.4571*-00	NM	0.94000	0.26133	0.39180	2.24769	0.17431
7	4.1900*-04	1.4835*-00	NM	0.93930	0.26785	0.40039	2.23451	0.17919
8	4.7000*-04	1.5224*-00	NM	0.94000	0.27701	0.41271	2.21972	0.18593
9	5.4600*-04	1.5589*-00	NM	0.94035	0.28521	0.42357	2.20555	0.19205
10	8.0000*-04	1.6926*-00	NM	0.94220	0.31239	0.45896	2.15855	0.21262
11	1.0290*-03	1.8125*-00	NM	0.94450	0.33375	0.48617	2.12192	0.22912
12	1.2570*-03	1.9184*-00	NM	0.94540	0.35078	0.50709	2.08976	0.24265
13	1.5370*-03	2.0496*-00	NM	0.94650	0.37006	0.53021	2.05281	0.25829
14	1.7910*-03	2.1643*-00	NM	0.94780	0.38570	0.54863	2.02324	0.27116
15	2.1210*-03	2.2865*-00	NM	0.94920	0.40142	0.56674	1.99337	0.28432
16	2.3750*-03	2.4162*-00	NM	0.95000	0.41723	0.58438	1.96174	0.29789
17	2.6290*-03	2.4895*-00	NM	0.95020	0.42583	0.59372	1.94398	0.30542
18	2.8830*-03	2.5934*-00	NM	0.95290	0.43766	0.60713	1.92439	0.31549
19	3.0610*-03	2.6654*-00	NM	0.95360	0.44564	0.61569	1.90885	0.32255
20	3.2890*-03	2.7165*-00	NM	0.95360	0.45118	0.62143	1.89705	0.32758
21	3.5430*-03	2.8070*-00	NM	0.95450	0.46083	0.63157	1.87832	0.33624
22	3.7210*-03	2.8691*-00	NM	0.95450	0.46731	0.63810	1.86453	0.34223
23	3.9750*-03	2.9554*-00	NM	0.95470	0.47616	0.64696	1.84613	0.35044
24	4.2290*-03	3.0335*-00	NM	0.95490	0.48399	0.65471	1.82989	0.35779
25	4.5090*-03	3.0918*-00	NM	0.95480	0.48975	0.66026	1.81750	0.36328
26	4.7120*-03	3.1641*-00	NM	0.95540	0.49679	0.66721	1.80375	0.36990
27	4.9660*-03	3.2241*-00	NM	0.95600	0.50255	0.67288	1.79272	0.37534
28	5.4990*-03	3.3876*-00	NM	0.95900	0.51788	0.68821	1.76600	0.38970
29	5.8040*-03	3.4783*-00	NM	0.96210	0.52617	0.69690	1.75425	0.39726
30	6.0580*-03	3.5504*-00	NM	0.96440	0.53265	0.70359	1.74480	0.40325
31	6.3120*-03	3.6163*-00	NM	0.96600	0.53851	0.70941	1.73539	0.40879
32	6.6420*-03	3.7077*-00	NM	0.96790	0.54653	0.71718	1.72201	0.41648
33	6.9220*-03	3.7775*-00	NM	0.96960	0.55256	0.72308	1.71242	0.42226
34	7.2520*-03	3.8624*-00	NM	0.97200	0.55981	0.73023	1.70153	0.42916
35	7.6070*-03	3.9989*-00	NM	0.97590	0.57126	0.74143	1.68452	0.44014
36	7.9880*-03	4.0992*-00	NM	0.97900	0.57951	0.74951	1.67274	0.44807
37	8.4460*-03	4.2113*-00	NM	0.98160	0.58860	0.75799	1.65840	0.45706
38	8.6740*-03	4.2890*-00	NM	0.98210	0.59480	0.76323	1.64649	0.46355
39	9.0550*-03	4.3985*-00	NM	0.98170	0.60344	0.76999	1.62818	0.47292
40	9.3090*-03	4.4894*-00	NM	0.98050	0.61052	0.77510	1.61185	0.48088
41	9.5380*-03	4.5633*-00	NM	0.98100	0.61620	0.77974	1.60120	0.48697
42	9.8170*-03	4.6274*-00	NM	0.98260	0.62109	0.78415	1.59398	0.49194
43	1.0528*-02	4.8849*-00	NM	0.98130	0.64034	0.79816	1.55366	0.51373
44	1.1443*-02	5.1978*-00	NM	0.98260	0.66296	0.81510	1.51167	0.53921
45	1.2306*-02	5.4664*-00	NM	0.98480	0.68175	0.82915	1.47914	0.56056
46	1.3322*-02	5.8598*-00	NM	0.98630	0.70836	0.84758	1.43174	0.59200
47	1.4338*-02	6.2735*-00	NM	0.98840	0.73527	0.86561	1.38597	0.62455
48	1.5354*-02	6.6305*-00	NM	0.99070	0.75771	0.88025	1.34961	0.65223
49	1.6345*-02	7.0765*-00	NM	0.99220	0.78483	0.89663	1.30520	0.68697
50	1.7234*-02	7.5007*-00	NM	0.99280	0.80977	0.91065	1.26468	0.72006
51	1.8148*-02	7.9173*-00	NM	0.99500	0.83352	0.92416	1.22931	0.75177
52	1.9418*-02	8.5750*-00	NM	0.99620	0.86970	0.94271	1.17494	0.80234
53	2.0790*-02	9.2107*-00	NM	0.99780	0.90327	0.95909	1.12741	0.85070
54	2.1704*-02	9.6554*-00	NM	0.99870	0.92602	0.96956	1.09623	0.88444
55	2.2492*-02	9.9801*-00	NM	0.99970	0.94229	0.97696	1.07494	0.90885
56	2.3863*-02	1.0528*-01	NM	1.00060	0.96913	0.98836	1.04008	0.95028
57	2.4829*-02	1.0819*-01	NM	1.00020	0.98304	0.99363	1.02166	0.97257
58	2.5743*-02	1.1030*-01	NM	1.00020	0.99306	0.99748	1.00891	0.98867
59	2.6556*-02	1.1178*-01	NM	1.00000	1.00000	1.00000	1.00000	1.00000
60	2.7648*-02	1.1259*-01	NM	1.00020	1.00378	1.00151	0.99549	1.00605
61	2.8740*-02	1.1292*-01	NM	1.00090	1.00531	1.00243	0.99429	1.00819
62	2.9807*-02	1.1302*-01	NM	0.99910	1.00579	1.00171	0.99190	1.00989
63	3.1179*-02	1.1299*-01	NM	1.00090	1.00565	1.00256	0.99386	1.00875
64	3.4938*-02	1.1255*-01	NM	1.00440	1.00361	1.00355	0.99989	1.00366
65	3.7503*-02	1.1263*-01	NM	1.00560	1.00395	1.00428	1.00065	1.00363
66	4.0729*-02	1.1266*-01	NM	1.00560	1.00413	1.00434	1.00043	1.00391
67	4.3752*-02	1.1298*-01	NM	1.00510	1.00558	1.00464	0.99812	1.00653
68	4.5250*-02	1.1318*-01	NM	1.00580	1.00652	1.00534	0.99765	1.00771
69	4.7079*-02	1.1330*-01	NM	1.00580	1.00708	1.00554	0.99696	1.00861
70	4.9975*-02	1.1337*-01	NM	1.00520	1.00739	1.00536	0.99598	1.00942
71	5.2794*-02	1.1315*-01	NM	1.00330	1.00638	1.00403	0.99534	1.00873
72	5.5258*-02	1.1317*-01	NM	1.00220	1.00649	1.00352	0.99412	1.00946
73	5.8890*-02	1.1273*-01	NM	1.00140	1.00444	1.00236	0.99587	1.00652
74	6.3157*-02	1.1233*-01	NM	1.00070	1.00257	1.00131	0.99750	1.00382
75	6.6485*-02	1.1246*-01	NM	0.99960	1.00316	1.00098	0.99567	1.00534
76	7.0803*-02	1.1216*-01	NM	0.99890	1.00177	1.00011	0.99670	1.00343
77	7.5070*-02	1.1220*-01	NM	0.99890	1.00194	1.00018	0.99648	1.00371
78	7.9108*-02	1.1229*-01	NM	0.99840	1.00239	1.00010	0.99542	1.00470
79	8.3782*-02	1.1177*-01	NM	0.99820	0.99997	0.99909	0.99824	1.00084
80	8.6170*-02	1.1092*-01	NM	0.99740	0.99598	0.99718	1.00243	0.99477

INPUT VARIABLES Y,M,TO/TCO (MODIFIED CROCCO) ASSUME P=PD
 MEASURED: PO=PROFILE
 AT I= 9 VALUES OF INPUT PROFILES WERE AVERAGED BECAUSE OF SAME Y

	M: 2.5 (upstream) R THETA $\times 10^{-3}$: 24 (upstream) TW/TR: 1	7902
		RELAXATION AW
Blowdown tunnel with axisymmetric fixed nozzle. Running time: 60s. W = 0.114 m, H = 0.082 m. PO: 0.5 MN/m ² . TO: 295K. Air.RE/m $\times 10^{-6}$: 50.		
CHEW Y.T., SQUIRE L.C., 1979. The boundary layer development downstream of a shock interaction at an expansion corner. ARC R&M 3839. And: Squire L.C., private communications. Also: Chew Y.T., 1979		

- 1 The test boundary layer was formed on the lower nozzle block of the tunnel 0.114 m wide, facing a fixed contoured upper block. The general arrangement is as for Jeromin, CAT 6602 and Thomas, CAT 7401. The block was straight from a point upstream of the throat to a point ($X = 0$) at which the surface turned down to give a 6° expansion corner. The inclined surface was about (E) 0.15 m long. The block could be traversed so as to move the expansion corner in relation to the throat, which was typically about 0.54 m upstream. A plane shock generator could be mounted in the free stream, and was used to give flow deflections of 4° , 6° and 8° . The relative position of the lower plate was adjusted so that, for the runs with 6° shock deflection, the shock wave impinged on the boundary layer at $X = -20$, 0, or $+20$ mm. For the other shock deflections, the shock met the boundary layer at the corner ($X = 0$).
- 3 The profile data for the flow upstream of the corner (series 01) indicate that the flow is effectively
- 5 a fully developed equilibrium turbulent layer. Three-dimensional effects were assessed by a momentum balance, the greatest discrepancy in a value for D2 being 6% just downstream of the corner. Differences between wall pressure measured on the centreline and at $Z = \pm 19$ mm ranged up to about 16% just downstream of the nominal shock position, as a result of curvature produced in the incident shock by the tunnel side walls, which cause the shock to curve forward off the centreline (Chew, 1979).
- 6 Wall pressure was measured at 186 tappings ($d = 0.3$ mm) drilled normal to the surface in three rows at $Z = -19$, 0, $+19$ mm, (E) except for tappings actually at the corner which were drilled along the bisector of the angle. Wall temperature was measured by 4 thermocouples distributed along the test surface. A Preston tube ($d_1 = 0.419$, $d_2 = 0.21$ mm) was used with the calibration of Allen (1973). Values obtained using the Hopkins and Keener (1966) calibration were about 3% lower, while a change to Allen's revised (1977b) calibration gives changes of at most 2%.

- Static pressure profiles were measured with a CCP ($\alpha = 2.5^\circ$, $d_1 = 1$ mm. Two static holes, $d = 0.4$ mm in the top and bottom 14 mm downstream from the base of the conical tip). For profiles upstream and more than 50 mm downstream of the shock, the maximum variation was 1%. Variations up to 4% were found
- 9 near the shock but in many cases where this maximum was found the tip of the probe intersected the shock so it is not clear whether the variation is genuine. The authors assumed the static pressure for a profile to be constant at the local wall value. No profile extends out so far as to intersect the reflected wave. Initial total temperature measurements using a ECP were not pursued. The temperature profile was deduced from the Crocco/van Driest temperature-velocity correlation, using instantaneous values of stagnation and wall temperature for each Pitot reading. The recovery factor used was 0.89. For the calculation of integral values and for a determination of the local shear stress from a momentum balance, the profile data were interpolated to a fixed Y-grid. Two complete sets of data were obtained at each station since it was only possible to measure 25 profile points

- in a single run, with the data logger used. These were reduced separately, the differences between sets, as shown by the authors' D2 values being at most 2% for the runs without shocks. Differences at the 2%-3% level are common in the flows with shocks, with an untypical peak (E) of about 10%. No profile corrections were applied.
- 12 The editors have presented one of the two complete sets of data incorporating the authors' assumptions and data reduction procedures. This was originally received as a private communication and is the
- 13 alternative to that published in the source paper. The seven series consist of: surveys upstream (01) and downstream (02) of the corner, with no shock; series (03, 04, 05) with shocks giving deflections of 4°, 6° and 8° respectively; and series (06, 07) with a 6° shock displaced to hit the test surface
- 14 at $X = -20$ mm, $+20$ mm respectively. The CF values are those given by the authors using the Allen (1973) calibration.

§ DATA: 7902 0101-0107. Pitot profiles and CF from Preston tubes. $NX = 7$.

- 15 Editors' comments. This entry describes one of a series of experiments made in the same facility with predominantly the same instrumentation. In addition to Jeromin (CAT 6602) and Thomas (CAT 7401), much work has been done on compressible boundary layers with mass addition (for a brief survey see Squire et al., 1977). The present study investigates the influence of an abrupt disturbance on a boundary layer and its recovery downstream. In the constant pressure cases (series 01 and 02) the velocity profiles show the typical scatter ($\pm 5\%$) above and below the logarithmic law (Fig. 1) with wake strength values of $3.30 < \Delta(\bar{u}^*/u_\tau) < 4.20$ which are on the high side compared with other experiments in the same Reynolds number range (cf. Fig. 3.3.6 of AG 253). The expansion causes the Mach number for the second set to rise from 2.57 to 2.84 at the corner which should, if anything, decrease the wake strength (cf. Fig. 5.2.3) but this is not observed (0202). The outer law plot for series 01 shows some similarity with the adverse pressure-gradient profiles of Thomas (cf. Fig. 5.2.4 of AG 253) while the profiles of series 02 behave as if they were in a zero pressure gradient (Fig. 2).

From among the boundary layers (series 03 to 07) recovering from a strong disturbance, series 05 is the most illuminating one. Fig. 3 shows the log-law plot in which there is an astonishing long log-law region with a wake component characteristic of severe adverse pressure gradients. The profiles relax in downstream direction recovering to a wake with about the same wake strength as the profiles in series 01 and 02. This "unfinished" recovery to the zero pressure-gradient case can be readily observed in Fig. 4a. A proper ZPG "equilibrium" profile should fall on the full line which represents eqn. (3.3.17) of AG 253. Fig. 5 shows velocity profiles downstream of the expansion corner when a 6° shock strikes the surface 20 mm upstream of the corner (series 06). These profiles are distinguished by being self-similar. They have nearly constant Mach number, and skin friction, Reynolds number and shape parameter. This is certainly a unique case the relevance of which the authors overlooked in their discussion of the results, and which was, it seems, unplanned. The profiles in the outer law plot (Fig. 4b) are very similar to those of Thomas (CAT 7401) in a moderate adverse pressure gradient (Fig. 5.2.4, AG 253).

The velocity profiles do not extend into the viscous sublayer ($Y^+_{min} \approx 30$) and they are relatively short (18 data points). Since pressure gradients were weak in the flow regions investigated measurements of skin friction by means of a FEB would have been possible and would have given an even firmer basis for the general validity of the log-law as claimed by the authors. By the same token Preston tube values here should be reasonably reliable.

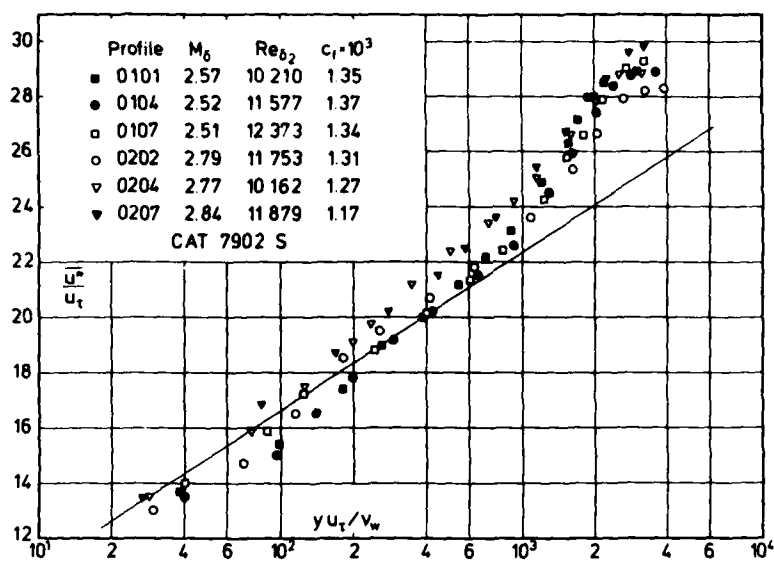


Fig. 1 Law of the wall for a compressible boundary layer (adiabatic wall, origin not defined). Chew & Squire (1979).

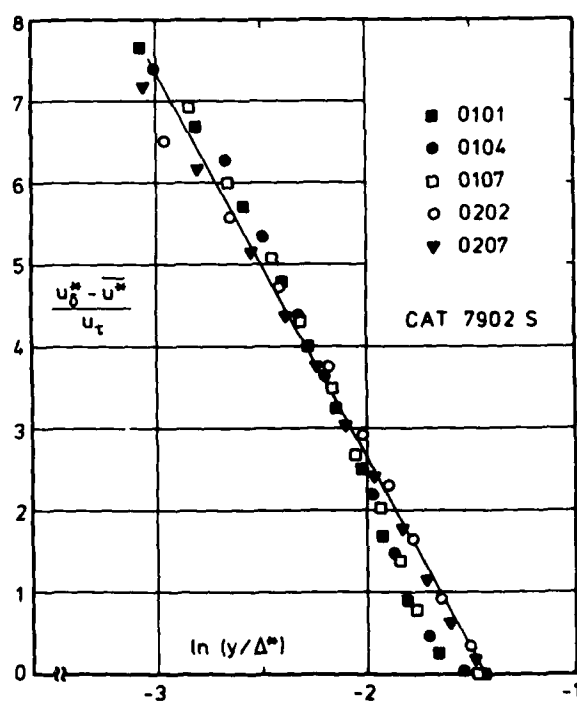


Fig. 2 Outer law for a compressible boundary layer (adiabatic wall, origin not defined). Chew & Squire (1979).

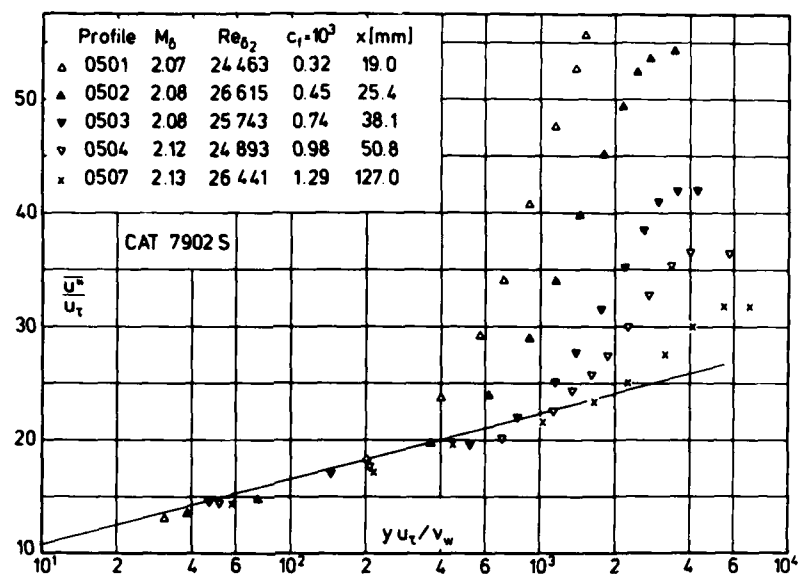


Fig. 3 Law of the wall for a compressible boundary layer (adiabatic wall, origin not defined, strong shock interaction).
Chew & Squire (1979).

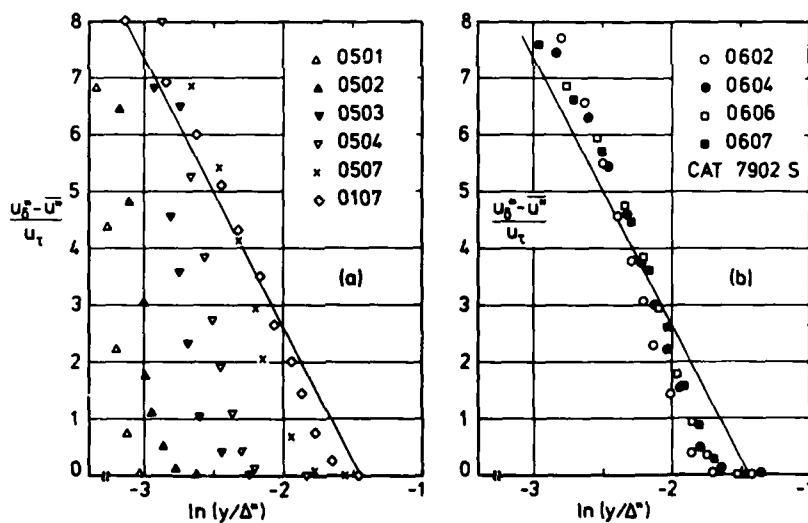


Fig. 4 Outer law for a compressible boundary layer (adiabatic wall, origin not defined; (a) strong shock interaction).
Chew & Squire (1979).

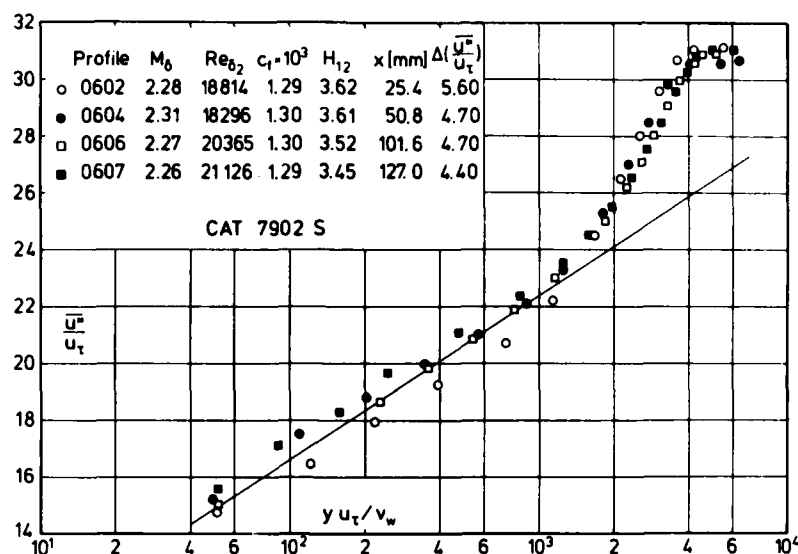


Fig. 5 Law of the wall for a compressible boundary layer (adiabatic wall, origin not defined). Chew & Squire (1979).

CAT 7902S	CHEW / SQUIRE		BOUNDARY CONDITIONS AND EVALUATED DA				SI UNITS		
RUN	MD *	TW/TR	RED2W	CF *	H12	H12K	PW	PD*	
X *	POD	PW/PD*	RED2D	CO *	H32	H32K	TW*	TD	
RZ	TOD*	TAUW	DZ	PI2*	H42	D2K	UD	TR	
7902S0101	2.5610	1.0482	1.0051 ⁺⁺⁰⁴	1.3600 ⁻⁻⁻⁰³	4.1830	1.3709	2.8062 ⁺⁺⁰⁴	2.8062 ⁺⁺⁰⁴	
-1.0160 ⁻⁻⁻⁰¹	5.2711 ⁺⁺⁰⁵	1.0000	2.0282 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.7973	1.7799	2.8976 ⁺⁺⁰²	1.2708 ⁺⁺⁰²	
INFINITE	2.9378 ⁺⁺⁰²	1.7521 ⁺⁺⁰²	4.0705 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0607	5.8366 ⁻⁻⁻⁰⁴	5.7884 ⁺⁺⁰²	2.7644 ⁺⁺⁰²	
7902S0102	2.5340	1.0381	1.0339 ⁺⁺⁰⁴	1.3400 ⁻⁻⁻⁰³	4.0576	1.3504	2.8544 ⁺⁺⁰⁴	2.8544 ⁺⁺⁰⁴	
-7.6200 ⁻⁻⁻⁰²	5.1417 ⁺⁺⁰⁵	1.0000	2.0464 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.8055	1.7888	2.8967 ⁺⁺⁰²	1.2975 ⁺⁺⁰²	
INFINITE	2.9637 ⁺⁺⁰²	1.7192 ⁺⁺⁰²	4.2030 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0697	5.9079 ⁻⁻⁻⁰⁴	5.7872 ⁺⁺⁰²	2.7904 ⁺⁺⁰²	
7902S0103	2.5340	1.0430	1.0859 ⁺⁺⁰⁴	1.3800 ⁻⁻⁻⁰³	4.0811	1.3547	2.8751 ⁺⁺⁰⁴	2.8751 ⁺⁺⁰⁴	
-5.0800 ⁻⁻⁻⁰²	5.1790 ⁺⁺⁰⁵	1.0000	2.1583 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.8028	1.7865	2.8992 ⁺⁺⁰²	1.2925 ⁺⁺⁰²	
INFINITE	2.9523 ⁺⁺⁰²	1.7834 ⁺⁺⁰²	4.3769 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0649	6.1844 ⁻⁻⁻⁰⁴	5.7760 ⁺⁺⁰²	2.7797 ⁺⁺⁰²	
7902S0104	2.5200	1.0431	1.1441 ⁺⁺⁰⁴	1.3800 ⁻⁻⁻⁰³	4.0653	1.3602	2.9096 ⁺⁺⁰⁴	2.9096 ⁺⁺⁰⁴	
-3.8100 ⁻⁻⁻⁰²	5.1283 ⁺⁺⁰⁵	1.0000	2.2625 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.7986	1.7822	2.8937 ⁺⁺⁰²	1.2975 ⁺⁺⁰²	
INFINITE	2.9455 ⁺⁺⁰²	1.7849 ⁺⁺⁰²	4.5845 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0641	6.4927 ⁻⁻⁻⁰⁴	5.7553 ⁺⁺⁰²	2.7741 ⁺⁺⁰²	
7902S0105	2.5310	1.0420	1.1905 ⁺⁺⁰⁴	1.3600 ⁻⁻⁻⁰³	4.0806	1.3579	2.9234 ⁺⁺⁰⁴	2.9234 ⁺⁺⁰⁴	
-2.5400 ⁻⁻⁻⁰²	5.2414 ⁺⁺⁰⁵	1.0000	2.3613 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.7997	1.7830	2.8989 ⁺⁺⁰²	1.2953 ⁺⁺⁰²	
INFINITE	2.9547 ⁺⁺⁰²	1.7828 ⁺⁺⁰²	4.7295 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0656	6.7025 ⁻⁻⁻⁰⁴	5.7754 ⁺⁺⁰²	2.7821 ⁺⁺⁰²	
7902S0106	2.4970	1.0546	1.1751 ⁺⁺⁰⁴	1.3700 ⁻⁻⁻⁰³	4.0230	1.3467	2.9785 ⁺⁺⁰⁴	2.9785 ⁺⁺⁰⁴	
-1.2700 ⁻⁻⁻⁰²	5.0654 ⁺⁺⁰⁵	1.0000	2.3250 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.8037	1.7880	2.9062 ⁺⁺⁰²	1.3015 ⁺⁺⁰²	
INFINITE	2.9245 ⁺⁺⁰²	1.7810 ⁺⁺⁰²	4.6646 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0527	6.5538 ⁻⁻⁻⁰⁴	5.7116 ⁺⁺⁰²	2.7557 ⁺⁺⁰²	
7902S0107	2.5100	1.0427	1.2344 ⁺⁺⁰⁴	1.3400 ⁻⁻⁻⁰³	4.0158	1.3439	2.9923 ⁺⁺⁰⁴	2.9923 ⁺⁺⁰⁴	
-6.3500 ⁻⁻⁻⁰³	5.1928 ⁺⁺⁰⁵	1.0000	2.4300 ⁺⁺⁰⁴	0.0000 ⁺⁺⁰⁰	1.8027	1.7873	2.8986 ⁺⁺⁰²	1.3058 ⁺⁺⁰²	
INFINITE	2.9511 ⁺⁺⁰²	1.7683 ⁺⁺⁰²	4.8502 ⁻⁻⁻⁰⁴	0.0000 ⁺⁺⁰⁰	0.0643	6.8200 ⁻⁻⁻⁰⁴	5.7507 ⁺⁺⁰²	2.7800 ⁺⁺⁰²	

CAT 79025		CHEM / SQUIRE		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS				
RUN X *	MO *	TW/TR	REDZW	CF *	H12	H12K	PW	PD*
RZ	POD	PW/PD*	REDZO	CQ *	H32	H32K	Td*	TD
	YOD*	TAUW	DZ	PI2*	H42	D2K	UD	TR
7902S0201	2.7630	1.0650	1.0939 ⁺ 04	1.3300 ⁻ 03	4.5013	1.2863	2.0753 ⁺ 04	2.0753 ⁺ 04
1.9050 ⁻ 02	5.3223 ⁺ 05	1.0000	2.4260 ⁺ 04	0.0000 ⁺ 00	1.8341	1.8190	2.8921 ⁺ 02	1.1467 ⁺ 02
INFINITE	2.8976 ⁺ 02	1.4750 ⁺ 02	5.2667 ⁻ 04	0.0000 ⁺ 00	0.0543	7.5258 ⁻ 04	5.9322 ⁺ 02	2.7155 ⁺ 02
7902S0202	2.7940	1.0531	1.1753 ⁺ 04	1.3100 ⁻ 03	4.5526	1.2960	2.0408 ⁺ 04	2.0408 ⁺ 04
2.5400 ⁻ 02	5.4880 ⁺ 05	1.0000	2.6130 ⁺ 04	0.0000 ⁺ 00	1.8314	1.8136	2.8753 ⁺ 02	1.1382 ⁺ 02
INFINITE	2.9192 ⁺ 02	1.4609 ⁺ 02	5.6433 ⁻ 04	0.0000 ⁺ 00	0.0664	8.1137 ⁻ 04	5.9764 ⁺ 02	2.7304 ⁺ 02
7902S0203	2.7860	1.0531	1.1379 ⁺ 04	1.2800 ⁻ 03	4.5392	1.2982	2.0064 ⁺ 04	2.0064 ⁺ 04
3.8100 ⁻ 02	5.3298 ⁺ 05	1.0000	2.5210 ⁺ 04	0.0000 ⁺ 00	1.8306	1.8130	2.8832 ⁺ 02	1.1451 ⁺ 02
INFINITE	2.9226 ⁺ 02	1.3953 ⁺ 02	5.6024 ⁻ 04	0.0000 ⁺ 00	0.0660	8.0526 ⁻ 04	5.9773 ⁺ 02	2.7377 ⁺ 02
7902S0204	2.7710	1.0480	1.0153 ⁺ 04	1.2700 ⁻ 03	4.4946	1.3033	1.9719 ⁺ 04	1.9719 ⁺ 04
5.0800 ⁻ 02	5.1194 ⁺ 05	1.0000	2.2263 ⁺ 04	0.0000 ⁺ 00	1.8318	1.8135	2.8794 ⁺ 02	1.1564 ⁺ 02
INFINITE	2.9321 ⁺ 02	1.3460 ⁺ 02	5.1335 ⁻ 04	0.0000 ⁺ 00	0.0704	7.3260 ⁻ 04	5.9744 ⁺ 02	2.7475 ⁺ 02
7902S0205	2.8680	1.0526	1.0881 ⁺ 04	1.2300 ⁻ 03	4.7035	1.2903	1.8340 ⁺ 04	1.8340 ⁺ 04
7.6200 ⁻ 02	5.5200 ⁺ 05	1.0000	2.4894 ⁺ 04	0.0000 ⁺ 00	1.8373	1.8187	2.8770 ⁺ 02	1.1048 ⁺ 02
INFINITE	2.9223 ⁺ 02	1.2989 ⁺ 02	5.5831 ⁻ 04	0.0000 ⁺ 00	0.0697	8.0711 ⁻ 04	6.0441 ⁺ 02	2.7333 ⁺ 02
7902S0206	2.7270	1.0471	1.0931 ⁺ 04	1.2000 ⁻ 03	4.4199	1.3129	1.9857 ⁺ 04	1.9857 ⁺ 04
1.0160 ⁻ 01	4.8191 ⁺ 05	1.0000	2.3541 ⁺ 04	0.0000 ⁺ 00	1.8237	1.8053	2.8783 ⁺ 02	1.1784 ⁺ 02
INFINITE	2.9311 ⁺ 02	1.2404 ⁺ 02	5.6284 ⁻ 04	0.0000 ⁺ 00	0.0692	8.0582 ⁻ 04	5.9353 ⁺ 02	2.7488 ⁺ 02
7902S0207	2.8430	1.0470	1.1879 ⁺ 04	1.1700 ⁻ 03	4.6584	1.3005	1.8823 ⁺ 04	1.8823 ⁺ 04
1.2700 ⁻ 01	5.4541 ⁺ 05	1.0000	2.6773 ⁺ 04	0.0000 ⁺ 00	1.8287	1.8099	2.8786 ⁺ 02	1.1230 ⁺ 02
INFINITE	2.9383 ⁺ 02	1.2460 ⁺ 02	6.0426 ⁻ 04	0.0000 ⁺ 00	0.0736	8.8038 ⁻ 04	6.0405 ⁺ 02	2.7495 ⁺ 02
7902S0301	2.3510	1.0287	1.5092 ⁺ 04	1.1100 ⁻ 03	3.7254	1.3837	3.7301 ⁺ 04	3.7301 ⁺ 04
1.9050 ⁻ 02	5.0514 ⁺ 05	1.0000	2.7658 ⁺ 04	0.0000 ⁺ 00	1.7886	1.7704	2.8495 ⁺ 02	1.3916 ⁺ 02
INFINITE	2.9300 ⁺ 02	1.6019 ⁺ 02	5.1740 ⁻ 04	0.0000 ⁺ 00	0.0705	7.0925 ⁻ 04	5.5606 ⁺ 02	2.7700 ⁺ 02
7902S0302	2.4250	1.0307	1.6745 ⁺ 04	1.0200 ⁻ 03	3.9270	1.4042	3.8128 ⁺ 04	3.8128 ⁺ 04
2.5400 ⁻ 02	5.7961 ⁺ 05	1.0000	3.1633 ⁺ 04	0.0000 ⁺ 00	1.7734	1.7550	2.8489 ⁺ 02	1.3458 ⁺ 02
INFINITE	2.9287 ⁺ 02	1.6009 ⁺ 02	5.3534 ⁻ 04	0.0000 ⁺ 00	0.0707	7.6059 ⁻ 04	5.6405 ⁺ 02	2.7641 ⁺ 02
7902S0303	2.4060	1.0302	1.5603 ⁺ 04	1.1800 ⁻ 03	3.8166	1.3671	3.6060 ⁺ 04	3.6060 ⁺ 04
3.8100 ⁻ 02	5.3215 ⁺ 05	1.0000	2.9248 ⁺ 04	0.0000 ⁺ 00	1.7897	1.7730	2.8493 ⁺ 02	1.3255 ⁺ 02
INFINITE	2.9291 ⁺ 02	1.7242 ⁺ 02	5.3397 ⁻ 04	0.0000 ⁺ 00	0.0713	7.4147 ⁻ 04	5.6204 ⁺ 02	2.7657 ⁺ 02
7902S0304	2.4560	1.0327	1.5300 ⁺ 04	1.2100 ⁻ 03	3.8607	1.3351	3.3577 ⁺ 04	3.3577 ⁺ 04
5.0800 ⁻ 02	5.3571 ⁺ 05	1.0000	2.9310 ⁺ 04	0.0000 ⁺ 00	1.8070	1.7922	2.8457 ⁺ 02	1.2433 ⁺ 02
INFINITE	2.9218 ⁺ 02	1.7155 ⁺ 02	5.4356 ⁻ 04	0.0000 ⁺ 00	0.0719	7.4888 ⁻ 04	5.6666 ⁺ 02	2.7557 ⁺ 02
7902S0305	2.4570	1.0413	1.3973 ⁺ 04	1.2600 ⁻ 03	3.8092	1.2927	3.1785 ⁺ 04	3.1785 ⁺ 04
7.6200 ⁻ 02	5.0790 ⁺ 05	1.0000	2.6983 ⁺ 04	0.0000 ⁺ 00	1.8238	1.8124	2.8468 ⁺ 02	1.3132 ⁺ 02
INFINITE	2.8986 ⁺ 02	1.6924 ⁺ 02	5.2215 ⁻ 04	0.0000 ⁺ 00	0.0647	7.0694 ⁻ 04	5.4451 ⁺ 02	2.7338 ⁺ 02
7902S0306	2.4910	1.0480	1.4204 ⁺ 04	1.2000 ⁻ 03	3.8844	1.2846	3.1095 ⁺ 04	3.1095 ⁺ 04
1.0160 ⁻ 01	5.2331 ⁺ 05	1.0000	2.7959 ⁺ 04	0.0000 ⁺ 00	1.8237	1.8123	2.8461 ⁺ 02	1.2859 ⁺ 02
INFINITE	2.8817 ⁺ 02	1.6208 ⁺ 02	5.2945 ⁻ 04	0.0000 ⁺ 00	0.0598	7.2337 ⁻ 04	5.6636 ⁺ 02	2.7158 ⁺ 02
7902S0307	2.4920	1.0355	1.5917 ⁺ 04	1.2000 ⁻ 03	3.8454	1.2715	3.1578 ⁺ 04	3.1578 ⁺ 04
1.2700 ⁻ 01	5.3287 ⁺ 05	1.0000	3.1006 ⁺ 04	0.0000 ⁺ 00	1.8181	1.8081	2.8416 ⁺ 02	1.2988 ⁺ 02
INFINITE	2.9119 ⁺ 02	1.6472 ⁺ 02	5.8620 ⁻ 04	0.0000 ⁺ 00	0.0713	8.0550 ⁻ 04	5.6941 ⁺ 02	2.7441 ⁺ 02
7902S0401	2.2030	1.0458	2.0326 ⁺ 04	8.3000 ⁻ 04	3.8143	1.5640	4.9366 ⁺ 04	4.9366 ⁺ 04
1.9050 ⁻ 02	5.3034 ⁺ 05	1.0000	3.5723 ⁺ 04	0.0000 ⁺ 00	1.7137	1.6927	2.8508 ⁺ 02	1.4580 ⁺ 02
INFINITE	2.8731 ⁺ 02	1.3920 ⁺ 02	5.7531 ⁻ 04	0.0000 ⁺ 00	0.0443	8.2333 ⁻ 04	5.3333 ⁺ 02	2.7259 ⁺ 02
7902S0402	2.2660	1.0337	2.3047 ⁺ 04	8.7000 ⁻ 04	3.8523	1.5313	4.8953 ⁺ 04	4.8953 ⁺ 04
2.5400 ⁻ 02	5.8040 ⁺ 05	1.0000	4.1069 ⁺ 04	0.0000 ⁺ 00	1.7213	1.7002	2.8439 ⁺ 02	1.3428 ⁺ 02
INFINITE	2.9042 ⁺ 02	1.5308 ⁺ 02	6.3281 ⁻ 04	0.0000 ⁺ 00	0.0588	9.1064 ⁻ 04	5.4383 ⁺ 02	2.7512 ⁺ 02
7902S0403	2.2590	1.0425	2.0715 ⁺ 04	1.0900 ⁻ 03	3.7434	1.4641	4.5436 ⁺ 04	4.5436 ⁺ 04
3.8100 ⁻ 02	5.3284 ⁺ 05	1.0000	3.7086 ⁺ 04	0.0000 ⁺ 00	1.7451	1.7269	2.8513 ⁺ 02	1.4286 ⁺ 02
INFINITE	2.8867 ⁺ 02	1.7691 ⁺ 02	6.1505 ⁻ 04	0.0000 ⁺ 00	0.0514	8.6801 ⁻ 04	5.4136 ⁺ 02	2.7351 ⁺ 02
7902S0404	2.2700	1.0311	1.8207 ⁺ 04	1.2000 ⁻ 03	3.6235	1.3979	4.2885 ⁺ 04	4.2885 ⁺ 04
5.0800 ⁻ 02	5.1166 ⁺ 05	1.0000	3.2376 ⁺ 04	0.0000 ⁺ 00	1.7664	1.7521	2.8766 ⁺ 02	1.4504 ⁺ 02
INFINITE	2.9452 ⁺ 02	1.8563 ⁺ 02	5.7827 ⁻ 04	0.0000 ⁺ 00	0.0637	7.9938 ⁻ 04	5.4813 ⁺ 02	2.7897 ⁺ 02
7902S0405	2.3210	1.0339	1.7108 ⁺ 04	1.2300 ⁻ 03	3.6544	1.3599	3.9438 ⁺ 04	3.9438 ⁺ 04
7.6200 ⁻ 02	5.0961 ⁺ 05	1.0000	3.1103 ⁺ 04	0.0000 ⁺ 00	1.7864	1.7720	2.8723 ⁺ 02	1.4135 ⁺ 02
INFINITE	2.9365 ⁺ 02	1.8292 ⁺ 02	5.6983 ⁻ 04	0.0000 ⁺ 00	0.0643	7.8071 ⁻ 04	5.5327 ⁺ 02	2.7781 ⁺ 02
7902S0406	2.3080	1.0357	1.8066 ⁺ 04	1.2800 ⁻ 03	3.6092	1.3460	3.9783 ⁺ 04	3.9783 ⁺ 04
1.0160 ⁻ 01	5.0372 ⁺ 05	1.0000	3.2741 ⁺ 04	0.0000 ⁺ 00	1.7926	1.7795	2.8652 ⁺ 02	1.4154 ⁺ 02
INFINITE	2.9233 ⁺ 02	1.8988 ⁺ 02	5.9910 ⁻ 04	0.0000 ⁺ 00	0.0624	8.1378 ⁻ 04	5.5054 ⁺ 02	2.7665 ⁺ 02
7902S0407	2.2930	1.0318	1.9313 ⁺ 04	1.3000 ⁻ 03	3.5728	1.3468	4.0817 ⁺ 04	4.0817 ⁺ 04
1.2700 ⁻ 01	5.0483 ⁺ 05	1.0000	3.4672 ⁺ 04	0.0000 ⁺ 00	1.7920	1.7791	2.8721 ⁺ 02	1.4332 ⁺ 02
INFINITE	2.9403 ⁺ 02	1.9529 ⁺ 02	6.3343 ⁻ 04	0.0000 ⁺ 00	0.0654	8.5724 ⁻ 04	5.5038 ⁺ 02	2.7835 ⁺ 02

7902S0602		CHEW / SQUIRE	PROFILE TABULATION		20 POINTS, DELTA AT POINT 20			
I	Y	PT2/P	P/PO	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.97292	0.00000	0.00000	1.98445	0.00000
2	9.0000 ⁻ 05	1.6876 ⁺ 00	NM	0.97363	0.39386	0.51505	1.71008	0.30118
3	2.1000 ⁻ 04	1.9220 ⁺ 00	NM	0.97539	0.44430	0.57083	1.65071	0.34581
4	3.8000 ⁻ 04	2.1772 ⁺ 00	NM	0.97717	0.48991	0.61874	1.59508	0.38791
5	6.9000 ⁻ 04	2.4456 ⁺ 00	NM	0.97893	0.53202	0.66080	1.54273	0.42833
6	1.2800 ⁻ 03	2.7849 ⁺ 00	NM	0.98104	0.57982	0.70604	1.48273	0.47617
7	1.9800 ⁻ 03	3.1915 ⁺ 00	NM	0.98340	0.63158	0.75204	1.41782	0.53042
8	2.4700 ⁻ 03	3.5511 ⁺ 00	NM	0.98536	0.67368	0.78723	1.36550	0.57652
9	2.9100 ⁻ 03	3.9361 ⁺ 00	NM	0.98733	0.71579	0.82049	1.31393	0.62445
10	3.3200 ⁻ 03	4.3327 ⁺ 00	NM	0.98924	0.75658	0.85092	1.26493	0.67270
11	3.6900 ⁻ 03	4.7202 ⁺ 00	NM	0.99099	0.79430	0.87756	1.22063	0.71894
12	4.0700 ⁻ 03	5.0789 ⁺ 00	NM	0.99252	0.82763	0.89994	1.18238	0.76113
13	4.4300 ⁻ 03	5.4128 ⁺ 00	NM	0.99387	0.85746	0.91909	1.14893	0.79996
14	4.7300 ⁻ 03	5.8056 ⁺ 00	NM	0.99537	0.89123	0.93980	1.11197	0.84517
15	5.2800 ⁻ 03	6.2898 ⁺ 00	NM	0.99711	0.93114	0.96300	1.06961	0.90033
16	5.6700 ⁻ 03	6.6321 ⁺ 00	NM	0.99827	0.95833	0.97806	1.04159	0.93901
17	6.2300 ⁻ 03	6.9557 ⁺ 00	NM	0.99931	0.98333	0.99138	1.01644	0.97535
18	7.3000 ⁻ 03	7.1528 ⁺ 00	NM	0.99993	0.99825	0.99910	1.00172	0.99739
19	8.3200 ⁻ 03	7.1645 ⁺ 00	NM	0.99996	0.99912	0.99955	1.00086	0.99869
D 20	9.6700 ⁻ 03	7.1762 ⁺ 00	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST

7902S0604		CHEW / SQUIRE	PROFILE TABULATION		21 POINTS, DELTA AT POINT 21			
I	Y	PT2/P	P/PO	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.98664	0.00000	0.00000	2.03688	0.00000
2	9.0000 ⁻ 05	1.7814 ⁺ 00	NM	0.98050	0.41049	0.53778	1.71634	0.31333
3	2.0000 ⁻ 04	2.1693 ⁺ 00	NM	0.98217	0.48288	0.61545	1.62446	0.37886
4	3.7000 ⁻ 04	2.4221 ⁺ 00	NM	0.98328	0.52232	0.65511	1.57309	0.41645
5	6.4000 ⁻ 04	2.7104 ⁺ 00	NM	0.98453	0.56307	0.69412	1.51966	0.45676
6	1.0400 ⁻ 03	2.9661 ⁺ 00	NM	0.98562	0.59645	0.72460	1.47588	0.49096
7	1.6300 ⁻ 03	3.2753 ⁺ 00	NM	0.98691	0.63416	0.75746	1.42669	0.53092
8	2.2900 ⁻ 03	3.6569 ⁺ 00	NM	0.98844	0.67750	0.79323	1.37082	0.57866
9	2.8800 ⁻ 03	4.0699 ⁺ 00	NM	0.99003	0.72128	0.82725	1.31542	0.62889
10	3.3000 ⁻ 03	4.4078 ⁺ 00	NM	0.99127	0.75509	0.85212	1.27351	0.66911
11	3.7500 ⁻ 03	4.7618 ⁺ 00	NM	0.99251	0.78890	0.87582	1.23249	0.71061
12	4.1900 ⁻ 03	5.1612 ⁺ 00	NM	0.99384	0.82531	0.90008	1.18938	0.75676
13	4.5900 ⁻ 03	5.5234 ⁺ 00	NM	0.99499	0.85696	0.92014	1.15289	0.79811
14	5.0100 ⁻ 03	5.9470 ⁺ 00	NM	0.99627	0.89250	0.94159	1.11302	0.84597
15	5.4600 ⁻ 03	6.3444 ⁺ 00	NM	0.99741	0.92458	0.96000	1.07810	0.89046
16	6.0000 ⁻ 03	6.7674 ⁺ 00	NM	0.99855	0.95752	0.97802	1.04328	0.93745
17	6.4200 ⁻ 03	7.0076 ⁺ 00	NM	0.99918	0.97573	0.98761	1.02451	0.96398
18	7.3800 ⁻ 03	7.2465 ⁺ 00	NM	0.99978	0.99350	0.99673	1.00651	0.99028
19	8.6600 ⁻ 03	7.2819 ⁺ 00	NM	0.99987	0.99610	0.99804	1.00390	0.99416
20	9.9300 ⁻ 03	7.3055 ⁺ 00	NM	0.99993	0.99783	0.99891	1.00216	0.99675
D 21	1.1740 ⁻ 02	7.3351 ⁺ 00	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST

7902S0606		CHEW / SQUIRE	PROFILE TABULATION		19 POINTS, DELTA AT POINT 19			
I	Y	PT2/P	P/PO	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.97267	0.00000	0.00000	1.97420	0.00000
2	9.0000 ⁻ 05	1.7268 ⁺ 00	NM	0.97391	0.40502	0.52670	1.69108	0.31146
3	4.1000 ⁻ 04	2.3273 ⁺ 00	NM	0.97820	0.51653	0.64463	1.55755	0.41388
4	6.3000 ⁻ 04	2.5906 ⁺ 00	NM	0.97990	0.55575	0.68269	1.50898	0.45242
5	9.7000 ⁻ 04	2.8510 ⁺ 00	NM	0.98150	0.59145	0.71577	1.46459	0.48872
6	1.4200 ⁻ 03	3.1198 ⁺ 00	NM	0.98307	0.62583	0.74626	1.42190	0.52483
7	2.0700 ⁻ 03	3.4665 ⁺ 00	NM	0.98500	0.66725	0.78123	1.37080	0.56991
8	2.6500 ⁻ 03	3.8050 ⁺ 00	NM	0.98678	0.70516	0.81158	1.32463	0.61269
9	3.2900 ⁻ 03	4.1336 ⁺ 00	NM	0.98842	0.73997	0.83812	1.28287	0.65332
10	4.0100 ⁻ 03	4.6192 ⁺ 00	NM	0.99068	0.78845	0.87301	1.22599	0.71208
11	4.6100 ⁻ 03	5.0117 ⁺ 00	NM	0.99239	0.82547	0.89810	1.18370	0.75872
12	5.1600 ⁻ 03	5.4478 ⁺ 00	NM	0.99417	0.86470	0.92328	1.14009	0.80983
13	5.9100 ⁻ 03	6.0583 ⁺ 00	NM	0.99647	0.91670	0.95456	1.08429	0.88035
14	6.5800 ⁻ 03	6.5484 ⁺ 00	NM	0.99818	0.95637	0.97688	1.04336	0.93629
15	7.3500 ⁻ 03	6.9155 ⁺ 00	NM	0.99938	0.98502	0.99222	1.01469	0.97786
16	8.2000 ⁻ 03	7.0945 ⁺ 00	NM	0.99995	0.99868	0.99932	1.00129	0.99804
17	9.1700 ⁻ 03	7.1411 ⁺ 00	NM	1.00009	1.00220	1.00113	0.99786	1.00328
18	1.0150 ⁻ 02	7.1353 ⁺ 00	NM	1.00007	1.00176	1.00090	0.99829	1.00262
D 19	1.1160 ⁻ 02	7.1120 ⁺ 00	NM	1.00000	1.00000	1.00000	1.00000	1.00000

INPUT VARIABLES Y,M ASSUME P=PD AND VAN DRIEST

AD-A111 638

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 20/4
A FURTHER COMPILATION OF COMPRESSIBLE BOUNDARY LAYER DATA WITH --ETC(U)
NOV 81 H H FERNHOLZ, P J FINLEY, V MIKULLA
AGARD-A8-263

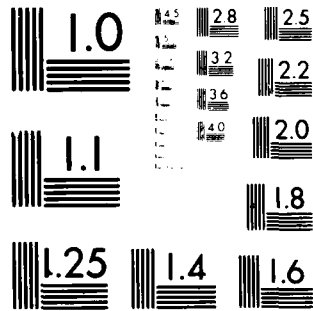
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CAT 7902S		CHEW / SQUIRE		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS					
RUN X * RZ	MD * POD TOD*	TW/TR PW/PD* TAUW	RED2W RED2D D2	CF * CQ * PI2*	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD* TD TR	
7902S0501 1.9050**-02 INFINITE	2.0670 5.0003**+05 2.9349**+02	1.0259 1.0000 5.5098**+01	2.4463**+04 4.0126**+04 6.6218**-04	3.2000**-04 0.0000**+00 0.0000**+00	4.2367 1.6173 0.0528	2.0264 1.5875 9.6488**-04	5.7571**+04 2.8667**+02 5.2136**+02	5.7571**+04 1.5826**+02 2.7943**+02	
7902S0502 2.5400**-02 INFINITE	2.0800 5.1823**+05 2.9232**+02	1.0302 1.0000 7.9680**+01	2.6386**+04 4.3653**+04 6.9539**-04	4.5000**-04 0.0000**+00 0.0000**+00	4.1071 1.6238 0.0496	1.9091 1.5967 1.0179**-03	5.8467**+04 2.8663**+02 5.2208**+02	5.8467**+04 1.5672**+02 2.7822**+02	
7902S0503 3.8100**-02 INFINITE	2.0710 4.9292**+05 2.8882**+02	1.0397 1.0000 1.2700**+02	2.5217**+04 4.1931**+04 6.8774**-04	7.5000**-04 0.0000**+00 0.0000**+00	3.7821 1.6597 0.0419	1.6939 1.6400 9.8913**-04	5.6399**+04 2.8586**+02 5.1773**+02	5.6399**+04 1.5566**+02 2.7495**+02	
7902S0504 5.0800**-02 INFINITE	2.1170 5.0309**+05 2.9156**+02	1.0343 1.0000 1.6470**+02	2.4513**+04 4.1262**+04 6.8632**-04	9.8000**-04 0.0000**+00 0.0000**+00	3.6327 1.6994 0.0509	1.5609 1.6830 9.6998**-04	5.3572**+04 2.8673**+02 5.2630**+02	5.3572**+04 1.5375**+02 2.7723**+02	
7902S0505 7.6200**-02 INFINITE	2.1810 5.1097**+05 2.8903**+02	1.0411 1.0000 1.9506**+02	2.3195**+04 4.0251**+04 6.7131**-04	1.1900**-03 0.0000**+00 0.0000**+00	3.5422 1.7483 0.0497	1.4291 1.7349 9.2811**-04	4.9229**+04 2.8564**+02 5.3219**+02	4.9229**+04 1.4812**+02 2.7437**+02	
7902S0506 1.0160**-01 INFINITE	2.1640 5.0940**+05 2.9362**+02	1.0261 1.0000 2.0817**+02	2.4587**+04 4.1839**+04 7.0970**-04	1.2600**-03 0.0000**+00 0.0000**+00	3.4086 1.7658 0.0640	1.3948 1.7527 9.5599**-04	5.0401**+04 2.8613**+02 5.3425**+02	5.0401**+04 1.5162**+02 2.7885**+02	
7902S0507 1.2700**-01 INFINITE	2.1250 4.9500**+05 2.9233**+02	1.0290 1.0000 2.1226**+02	2.6352**+04 4.4304**+04 7.5454**-04	1.2900**-03 0.0000**+00 0.0000**+00	3.3302 1.7706 0.0598	1.3867 1.7583 1.0039**-03	5.2055**+04 2.8597**+02 5.2804**+02	5.2055**+04 1.5360**+02 2.7790**+02	
7902S0601 1.9050**-02 INFINITE	2.2520 5.0864**+05 2.9138**+02	1.0277 1.0000 1.9459**+02	1.8899**+04 3.3333**+04 5.8473**-04	1.2500**-03 0.0000**+00 0.0000**+00	3.5629 1.7647 0.0661	1.3826 1.7517 8.0613**-04	4.3851**+04 2.8378**+02 5.4306**+02	4.3851**+04 1.4466**+02 2.7612**+02	
7902S0602 2.5400**-02 INFINITE	2.2800 5.1553**+05 2.9191**+02	1.0274 1.0000 1.9969**+02	1.8814**+04 3.3526**+04 5.8985**-04	1.2900**-03 0.0000**+00 0.0000**+00	3.6257 1.7689 0.0678	1.3938 1.7552 8.1466**-04	4.2541**+04 2.8401**+02 5.4688**+02	4.2541**+04 1.4312**+02 2.7644**+02	
7902S0603 3.8100**-02 INFINITE	2.2800 4.9717**+05 2.9147**+02	1.0286 1.0000 1.9556**+02	1.7629**+04 3.1450**+04 5.7258**-04	1.3100**-03 0.0000**+00 0.0000**+00	3.5745 1.7810 0.0673	1.3635 1.7680 7.8115**-04	4.1024**+04 2.8392**+02 5.4647**+02	4.1024**+04 1.4290**+02 2.7602**+02	
7902S0604 5.0800**-02 INFINITE	2.3070 5.0380**+05 2.8766**+02	1.0425 1.0000 1.9301**+02	1.8296**+04 3.3387**+04 5.9681**-04	1.3000**-03 0.0000**+00 0.0000**+00	3.6127 1.7954 0.0560	1.3388 1.7831 8.1007**-04	3.9852**+04 2.8382**+02 5.4600**+02	3.9852**+04 1.3934**+02 2.7224**+02	
7902S0605 7.6200**-02 INFINITE	2.3070 5.0553**+05 2.9142**+02	1.0247 1.0000 1.8474**+02	1.8784**+04 3.3763**+04 6.1256**-04	1.2400**-03 0.0000**+00 0.0000**+00	3.5527 1.7995 0.0731	1.3298 1.7883 8.2366**-04	3.9990**+04 2.8262**+02 5.4956**+02	3.9990**+04 1.4116**+02 2.7579**+02	
7902S0606 1.0160**-01 INFINITE	2.2690 4.9279**+05 2.9156**+02	1.0268 1.0000 1.9530**+02	2.0093**+04 3.5645**+04 6.5142**-04	1.3100**-03 0.0000**+00 0.0000**+00	3.5111 1.7945 0.0692	1.3452 1.7828 8.7353**-04	4.1368**+04 2.8359**+02 5.4525**+02	4.1368**+04 1.4365**+02 2.7618**+02	
7902S0607 1.2700**-01 INFINITE	2.2640 4.9710**+05 2.9213**+02	1.0295 1.0000 1.9467**+02	2.1126**+04 3.7359**+04 6.7698**-04	1.2900**-03 0.0000**+00 0.0000**+00	3.4530 1.8031 0.0707	1.3176 1.7918 8.9803**-04	4.2058**+04 2.8381**+02 5.4519**+02	4.2058**+04 1.4425**+02 2.7675**+02	
7902S0701 3.1750**-02 INFINITE	2.2390 5.0702**+05 2.9119**+02	1.0362 1.0000 5.9486**+01	1.9378**+04 3.4227**+04 5.9794**-04	3.8000**-04 0.0000**+00 0.0000**+00	4.1844 1.6905 0.0537	1.7846 1.6574 8.7016**-04	4.4609**+04 2.8601**+02 5.4132**+02	4.4609**+04 1.4540**+02 2.7603**+02	
7902S0702 3.8100**-02 INFINITE	2.2110 5.1078**+05 2.9192**+02	1.0301 1.0000 8.3550**+01	2.0023**+04 3.4818**+04 5.9767**-04	5.2000**-04 0.0000**+00 0.0000**+00	4.0933 1.6782 0.0577	1.7382 1.6490 8.7250**-04	4.6953**+04 2.8525**+02 5.3858**+02	4.6953**+04 1.4761**+02 2.7691**+02	
7902S0703 5.0800**-02 INFINITE	2.1870 4.9556**+05 2.9189**+02	1.0293 1.0000 1.2985**+02	2.1315**+04 3.6703**+04 6.4176**-04	8.2000**-04 0.0000**+00 0.0000**+00	3.8442 1.6927 0.0583	1.6240 1.6703 9.2429**-04	4.7298**+04 2.8516**+02 5.3557**+02	4.7298**+04 1.4918**+02 2.7705**+02	
7902S0704 6.3500**-02 INFINITE	2.2440 5.1100**+05 2.9193**+02	1.0293 1.0000 1.6039**+02	2.0948**+04 3.6869**+04 6.4294**-04	1.0200**-03 0.0000**+00 0.0000**+00	3.7434 1.7296 0.0625	1.4969 1.7121 9.1351**-04	4.4609**+04 2.8481**+02 5.4261**+02	4.4609**+04 1.4545**+02 2.7670**+02	
7902S0705 7.6200**-02 INFINITE	2.2780 5.0977**+05 2.9262**+02	1.0287 1.0000 1.7320**+02	1.9738**+04 3.5170**+04 6.2730**-04	1.1300**-03 0.0000**+00 0.0000**+00	3.7067 1.7487 0.0654	1.4383 1.7325 8.8319**-04	4.2196**+04 2.8508**+02 5.4731**+02	4.2196**+04 1.4359**+02 2.7712**+02	
7902S0706 1.0160**-01 INFINITE	2.3230 5.1032**+05 2.9148**+02	1.0295 1.0000 1.8441**+02	1.9477**+04 3.5353**+04 6.4075**-04	1.2400**-03 0.0000**+00 0.0000**+00	3.7007 1.7732 0.0678	1.3874 1.7590 8.9035**-04	3.9369**+04 2.8389**+02 5.5146**+02	3.9369**+04 1.4019**+02 2.7575**+02	
7902S0707 1.2700**-01 INFINITE	2.3080 5.0547**+05 2.9215**+02	1.0346 1.0000 1.8458**+02	1.9357**+04 3.5054**+04 3.6864**-04	1.2400**-03 0.0000**+00 0.0000**+00	3.6481 1.7795 0.0628	1.3652 1.7668 8.8035**-04	3.9921**+04 2.8603**+02 5.5036**+02	3.9921**+04 1.4145**+02 2.7648**+02	

	M: 9.3 R THETA $\times 10^{-3}$: 3-12 TW/TR: 0.32	7903
Gun tunnel with contoured axisymmetric nozzle. Running time 5 ms. D = 0.4 m. PO: 15, 67 MN/m ² . TO: 995, 1025K. Nitrogen. $14 < RE/m \ 10^{-6} < 55$.		
BARTLETT R.P., EDWARDS A.J., HARVEY J.K., HILLIER R., 1979a. Pitot pressure and total temperature profile measurements in a hypersonic, turbulent boundary layer at M = 9. Aero Rep. 79-01. Imperial College London. And Bartlett R.P. (1981), Edwards A.J. (1981), Bartlett et al. (1979b), private communications.		

- 1 The test boundary layer was formed on a flat plate 0.18 m wide and 0.76 m long with leading edge thickness 10 μ m. The model was mounted with the test surface facing upwards 10 mm below the tunnel centre line so as to avoid focused effects of upstream disturbances on the axis. Hanging sideplates were used to suppress the effect of disturbances generated on the underside of the model. A slot was machined in the model surface to receive a range of interchangeable instrumented test surface modules. The slot was 0.10 m wide and extended from X = 0.11 m to 0.76 m, where X = 0 at the leading edge. "A high order of surface finish and fit between the modules was maintained; the surface roughness being better than 15 microns." Measurements of surface pressure showed a systematic fall of about 3-6% along the instrumented section, a consequence of a residual nozzle expansion field, with scatter of less than 10%. For the low Reynolds number tests (series 01) a transition trip consisting of a single row of vortex generators 1 mm high and 3 mm apart at X=10 mm was used. The delta-shaped generators were inclined at about 30° to the flow direction. Transition was natural for the high Reynolds number series (02). Transition position was deduced from both surface heat flux measurements and surface Pitot (Preston tube) pressures. The peak heat flux and wall shear values occurred at or upstream of X = 0.16 m. Pressure and heat flux measurements across the width of the instrumented area at 3-4 and 7-9 X-stations showed that these quantities were "uniform to within $\pm 5\%$ over the central third of the model."
- 6 Static pressure tapings (D = 1.37 mm) were positioned at about 30 streamwise stations. Surface temperature and heat transfer rates were measured with thin film gauges at up to 50 X-stations. These gauges were formed by either painting or evaporation through a machined mask onto 3 mm diameter quartz substrates. Special care was taken to ensure that these were mounted accurately level with the model surface, earlier work having shown that this was vital if a consistent result was to be obtained. Surface Pitot readings were taken at 7-11 stations using circular Preston tubes (d = 1.25, 2.07, 2.96 mm).
- 7 Pitot and TO profiles were taken. The Pitot probes were FPP (typically $b_1 = 2.0$, $h_1 = 0.5$, $h_2 = 0.35$ mm). Four tubes were mounted on a rake, and the profiles built up by the superposition of many sets of normalised data. A 'kink' was observed in the inner part of some profiles measured with the original probes similar to that reported by Allen (1972). The tube length was increased by 90%, and this anomaly disappeared. The TO probes were miniature STP using a fine chromel-alumel thermocouple bead. The junction was mounted at the rearward apex of a V formed in the 12.5 μ m diameter wire. This was attached at the forward end to two support prongs (d = 100 μ m) which were splayed outwards within the shield (d₁ appr. 2 mm). The ceramic central support (d = 0.9 mm) was chamfered to minimise blockage, and much attention paid to a proper control of the flow within the shield. The probe was calibrated over a range of Reynolds number in the tunnel, using different total pressures and the expansion field of a flat plate at incidence. The uncorrected reading was low by about 2% at test free stream conditions and by 12% at the lowest Reynolds number used. (The design and development is described in detail by Bartlett et al., 1979b.) Pitot traverses were made at X = 0.36, 0.41, 0.46, 0.51 and 0.56 m, while TO profiles were measured for X = 0.36, 0.46, 0.56.

- 7 Mean and fluctuating density values were obtained for a single profile at $X = 0.56$ m at the LP (series 01) running condition, using the electron beam fluorescence technique. The 1 mm diameter 30 kV electron beam was projected through the boundary layer from beneath the model surface. The density of the flow was deduced from the resulting fluorescence in the $[0,0]$ band of the $N_2(2+)$ system, which in the absence of oxygen and the pressure levels used shows a linear relationship between density and light intensity. Two optical detectors were used, one focused at the measuring point within the layer, the other on the beam outside the layer to monitor beam current. Corrections for secondary electron excitation were made. Measurements up to 100 kHz were possible using digital processing.
- 9 All profile data were normalised for run to run variations in tunnel stagnation conditions, assuming that for each nominal condition, $(T_0 - T_W)/(T_{0D} - T_W)$, PT_2/POD and PW/POD were functions of position only and that
- 10 $P = PW$. PT_2 data were interpolated to the Y values of T_0 measurements. No corrections for shear or wall
- 11 proximity were applied. Viscosity was calculated from the Sutherland relationship.
- 12 The editors have presented the data as received from the authors, incorporating their data reduction and
- 13 interpolation procedures. The D-state is that selected by the authors. The profiles given here are the two sets of three for which both Pitot and T_0 measurements were made. The wall data given with the profiles
- 14 are the values selected by the authors. The very large amount of heat flux and wall shear data from which these values were derived are tabulated in Edwards (1981).
- § DATA: 79030101-0203. Pitot and T_0 profiles obtained piecemeal, separately, in a great number of runs. $NX = 3$. CF from Preston tubes. Heat transfer from thin film gauges. Electron beam studies.
- 15 Editors' comments. This experiment is potentially of great interest as it bridges the gap between wall measurements made in short run (here 5 ms) facilities and profile measurements, usually obtained in tunnels with running times of at least some seconds. (AG 253; §1.1, §1.3). There is an obvious comparison here with the case studied by Watson (CAT 7804S), where, even with a running time of only 5 seconds, substantial local wall temperature changes occurred. The Reynolds number, Mach number and, for 78040201-07, the wall temperature ratio T_W/TR are fairly close.

The mean temperature/velocity relationship agrees fairly well with the van Driest correlation (AG 253, eqn. 2.5.37). Agreement with the log-law is reasonable (Fig. 1), implying an error range of about $\pm 10\%$ in $TAUW$. The wake component is however small though well within the range shown in AG 253 Fig.(3.3.7) except for profile 0201. In the outer law plots (Fig. 2) there is a corresponding tendency for the data to fall below the 'incompressible norm'. We suggest that the profiles, especially in the outer region, have yet to complete transition. The comparable profiles by Watson (see section 4.4 in AG 223 and 0202,3 for series 1; 0204/6/7 for series 2 in section 6) are generally similar except for a more pronounced wake component, which also shows as a much better agreement with the outer law. The Watson CF values seem to be about 20% low, perhaps a result of using an uncooled balance element in a cooled wall.

The electron beam technique and results are discussed in detail in § 4.5.16 of Bartlett (1981). The principal feature is the extension of the technique to high number densities ($n > 10^{24} \text{ m}^{-3}$) in a range more typical of high Reynolds number flow in wind tunnels than the rarified flows in which it was developed and has been extensively used. Here the only comparisons are with McDonald (1975 - see Laderman and Demetriades, CAT 7403) and Wallace (1968), both at lower densities, and both using air as the working fluid so that quenching by the oxygen present would cause significant difficulty. The mean densities deduced from the fluorescence measurements were in good agreement with values deduced from probe measurements in the outer part of the layer, but were increasingly low as the wall was approached. Reflections from the wall are suggested as a possible cause for the discrepancy. Fluctuation measurements were also made and presented both as r.m.s profiles and as spectral distributions at six y -values. Although this work was performed as a feasibility study it would seem to be the most serious attempt to date at applying the technique in turbulent boundary layers but many questions of interpretation must be answered before it may be considered as established.

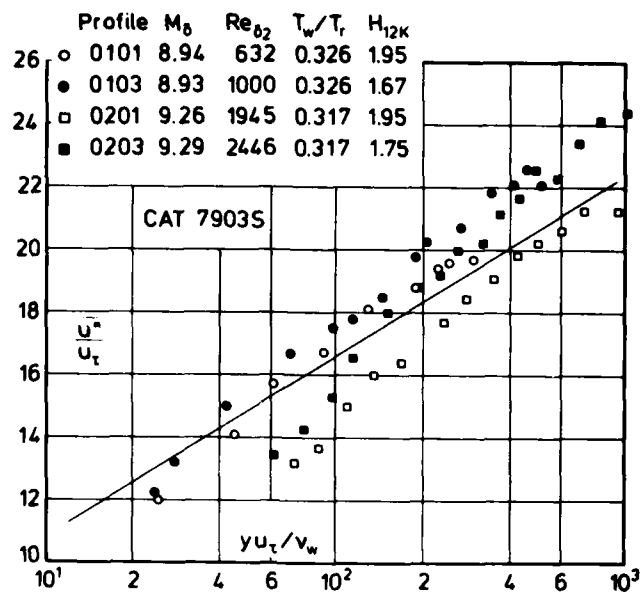


Fig. 1 Law of the wall for a compressible boundary layer with zero pressure gradient (isothermal wall, origin not defined). Bartlett et al. (1979).

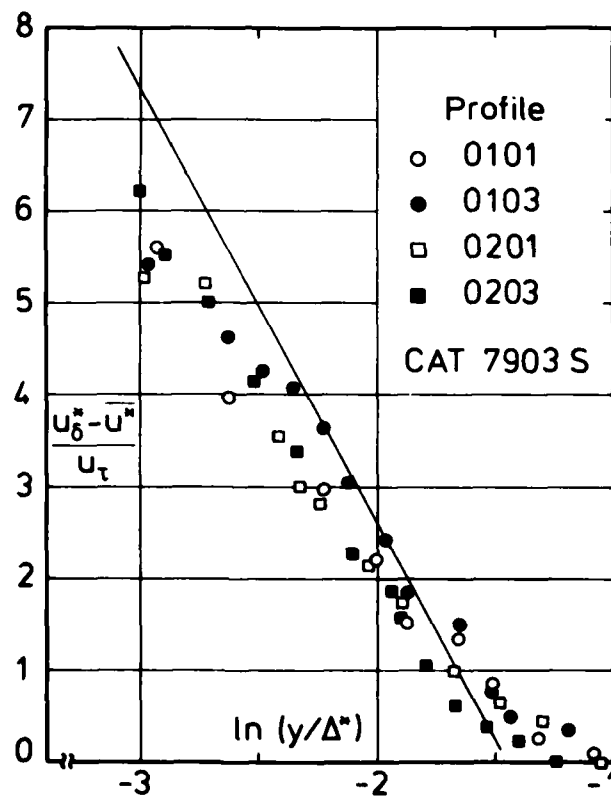


Fig. 2 Outer law for a compressible boundary layer with a zero pressure gradient (isothermal wall, origin not defined). Bartlett et al. (1979).

CAT 79035 BARTLETT/E/H/H BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS								
RUN X * RZ	MD * POD* TOD*	TW/TR PW/PD* TAUW *	RED2W RED2D D2	CF CQ * PI2*	H12 H32 H42	H12K H32K D2K	PW TW* UD	PD TD TR
7903S0101	8.9380	0.3258	6.3202**+02	1.0757**+03	17.3669	1.9534	7.5384**+02	7.5384**+02
2.6000**+01	1.5200**+07	1.0000	2.7304**+03	3.1391**+04	1.8853	1.8360	2.9300**+02	5.8725**+01
INFINITE	9.9700**+02	4.5347**+01	1.8720**+04	0.0000**+00	1.0425	4.7383**+04	1.3733**+03	8.9942**+02
7903S0102	8.9300	0.3258	8.4210**+02	9.8626**+04	16.7021	1.8100	7.5830**+02	7.5830**+02
3.6000**+01	1.5200**+07	1.0000	3.6319**+03	2.8443**+04	1.8892	1.8405	2.9300**+02	5.8824**+01
INFINITE	9.9700**+02	4.1748**+01	2.4839**+04	0.0000**+00	1.0536	6.0774**+04	1.3732**+03	8.9943**+02
7903S0103	8.9300	0.3262	9.9994**+02	8.5122**+04	20.5341	1.6759	7.5830**+02	7.5830**+02
5.6000**+01	1.5200**+07	1.0000	4.3187**+03	2.5353**+04	1.8732	1.8310	2.9300**+02	5.8741**+01
INFINITE	9.9560**+02	3.6032**+01	2.9474**+04	0.0000**+00	0.8373	8.5294**+04	1.3722**+03	8.9817**+02
7903S0201	9.2591	0.3173	1.9450**+03	8.7651**+04	19.1743	1.9513	2.6193**+03	2.6193**+03
3.6000**+01	6.6670**+07	1.0000	8.7454**+03	2.6257**+04	1.8869	1.8421	2.9300**+02	5.6442**+01
INFINITE	1.0242**+03	1.3778**+02	1.5691**+04	0.0000**+00	1.0148	4.2114**+04	1.3947**+03	9.2356**+02
7903S0202	9.3211	0.3173	2.0616**+03	7.6769**+04	21.1024	1.8636	2.5061**+03	2.5061**+03
4.6000**+01	6.6670**+07	1.0000	9.3883**+03	2.3918**+04	1.8814	1.8394	2.9300**+02	5.5734**+01
INFINITE	1.0242**+03	1.1701**+02	1.7159**+04	0.0000**+00	0.9161	4.8302**+04	1.3952**+03	9.2348**+02
7903S0203	9.2850	0.3174	2.4459**+03	6.6558**+04	22.7713	1.7528	2.5713**+03	2.5713**+03
5.6000**+01	6.6670**+07	1.0000	1.1060**+04	2.1640**+04	1.8708	1.8215	2.9300**+02	5.6128**+01
INFINITE	1.0239**+03	1.0328**+02	1.9988**+04	0.0000**+00	0.8177	6.1933**+04	1.3947**+03	9.2325**+02

TRAPEZOIDAL RULE FOR ALL INTEGRATIONS

7903S0101 BARTLETT/E/H/H PROFILE TABULATION 19 POINTS, DELTA AT POINT 15								
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000**+00	1.0000**+00	NM	0.29388	0.00000	0.00000	4.98940	0.00000
2	6.9983**+04	9.4789**+00	NM	0.78140	0.29583	0.69577	5.53149	0.12578
3	7.9903**+04	1.0502**+01	NM	0.78680	0.31222	0.71354	5.22304	0.13661
4	1.2818**+03	1.8796**+01	NM	0.81220	0.42212	0.79918	3.58443	0.22296
5	1.7499**+03	3.0405**+01	NM	0.86780	0.53951	0.87116	2.60732	0.33412
6	2.5908**+03	4.2074**+01	NM	0.90050	0.63603	0.91030	2.04843	0.44439
7	3.2108**+03	5.0058**+01	NM	0.93500	0.69438	0.93775	1.82383	0.51416
8	3.7006**+03	5.5494**+01	NM	0.96510	0.73144	0.95818	1.71605	0.55836
9	4.5996**+03	7.0838**+01	NM	0.95470	0.82716	0.96407	1.35845	0.70969
10	5.3382**+03	8.0154**+01	NM	0.97310	0.88021	0.97812	1.23485	0.79210
11	5.4684**+03	8.0245**+01	NM	0.96390	0.88071	0.97353	1.22189	0.79674
12	6.4503**+03	9.5146**+01	NM	0.99310	0.95944	0.99402	1.07339	0.92606
13	7.0083**+03	1.0160**+02	NM	0.99750	0.99161	0.99825	1.01344	0.98501
14	6.2011**+03	1.0271**+02	NM	0.99450	0.99700	0.99707	1.00013	0.99694
D 15	8.4165**+03	1.0332**+02	NM	1.00000	1.00000	1.00000	1.00000	1.00000
16	9.5100**+03	1.0458**+02	NM	0.99110	1.00609	0.99589	0.97983	1.01640
17	1.0050**+02	1.0460**+02	NM	0.98760	1.00619	0.99414	0.97618	1.01839
18	1.1200**+02	1.0417**+02	NM	0.99700	1.00410	0.99874	0.98936	1.00948
19	1.2955**+02	1.0334**+02	NM	0.99510	1.00010	0.99755	0.99491	1.00265

INPUT VARIABLES Y,M/MD,TO/TOD ASSUME P=PD

7903S0102 BARTLETT/E/H/H PROFILE TABULATION 20 POINTS, DELTA AT POINT 19								
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000**+00	1.0000**+00	NM	0.29388	0.00000	0.00000	4.98099	0.00000
2	7.2540**+04	7.7647**+00	NM	0.73604	0.26634	0.64436	5.85297	0.11009
3	8.4045**+04	1.1083**+01	NM	0.76033	0.32143	0.70912	4.86695	0.14570
4	1.1300**+03	1.6499**+01	NM	0.80404	0.39511	0.78078	3.90492	0.19995
5	1.4011**+03	2.3974**+01	NM	0.80902	0.47849	0.82153	2.94786	0.27869
6	1.8496**+03	2.7176**+01	NM	0.84616	0.51004	0.85122	2.78534	0.30561
7	2.4911**+03	3.1434**+01	NM	0.87882	0.54920	0.87932	2.56344	0.34302
8	2.8938**+03	3.5485**+01	NM	0.90361	0.58402	0.90064	2.37823	0.37870
9	3.3501**+03	3.9683**+01	NM	0.92881	0.61804	0.92080	2.21970	0.41483
10	3.9409**+03	4.7727**+01	NM	0.92662	0.67847	0.93095	1.88275	0.49446
11	4.5757**+03	5.3984**+01	NM	0.94703	0.72199	0.94781	1.72341	0.54996
12	5.1499**+03	5.6071**+01	NM	0.95798	0.73593	0.95520	1.68468	0.56699
13	5.7496**+03	5.9886**+01	NM	0.97013	0.76076	0.96446	1.60723	0.60008
14	6.4223**+03	7.7357**+01	NM	0.98078	0.86539	0.98069	1.28421	0.76365
15	7.1000**+03	8.2647**+01	NM	0.98676	0.89467	0.98613	1.21491	0.81169
16	8.2310**+03	9.7787**+01	NM	0.99134	0.97359	0.99405	1.04246	0.95356
17	9.2099**+03	1.0251**+02	NM	0.98218	0.99693	0.99087	0.98787	1.00304
18	1.1300**+02	1.0293**+02	NM	0.98994	0.99901	0.99490	0.99179	1.00314
D 19	1.1749**+02	1.0314**+02	NM	1.00000	1.00000	1.00000	1.00000	1.00000
20	1.3806**+02	1.0130**+02	NM	0.98616	0.99100	0.99252	1.00307	0.98948

INPUT VARIABLES Y,M/MD,TO/TOD ASSUME P=PD

7903S0103		BARTLETT/E/H/H		PROFILE TABULATION		30 POINTS, DELTA AT POINT 29		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NH	0.29429	0.00000	0.00000	4.98798	0.00000
2	7.6960 ⁻ 04	6.6732 ⁺ 00	NH	0.77599	0.24530	0.63575	6.70602	0.09480
3	8.9960 ⁻ 04	8.5632 ⁺ 00	NH	0.78540	0.28060	0.68164	5.90120	0.11551
4	1.3429 ⁻ 03	1.4300 ⁺ 01	NH	0.81023	0.36700	0.76651	4.36213	0.17572
5	1.8499 ⁻ 03	1.9171 ⁺ 01	NH	0.82075	0.42680	0.80552	3.56210	0.22614
6	2.2503 ⁻ 03	2.1500 ⁺ 01	NH	0.85670	0.45260	0.83490	3.40282	0.24535
7	2.6702 ⁻ 03	2.5624 ⁺ 01	NH	0.86631	0.49500	0.85618	2.99173	0.28618
8	3.1161 ⁻ 03	2.7172 ⁺ 01	NH	0.87482	0.51000	0.86550	2.88004	0.30052
9	3.6504 ⁻ 03	2.7413 ⁺ 01	NH	0.90106	0.51230	0.87915	2.94496	0.29853
10	4.1002 ⁻ 03	3.0283 ⁺ 01	NH	0.89575	0.53890	0.88481	2.69579	0.32822
11	4.6501 ⁻ 03	3.1524 ⁺ 01	NH	0.92019	0.55000	0.90000	2.67767	0.33611
12	5.2000 ⁻ 03	3.7699 ⁺ 01	NH	0.93241	0.60220	0.91913	2.32956	0.39455
13	6.0502 ⁻ 03	4.5910 ⁺ 01	NH	0.94663	0.66530	0.93870	1.99076	0.47153
14	6.6001 ⁻ 03	5.0803 ⁺ 01	NH	0.97026	0.70020	0.95613	1.86461	0.51278
15	7.8000 ⁻ 03	6.0897 ⁺ 01	NH	0.97126	0.76720	0.96581	1.58478	0.60943
16	8.2498 ⁻ 03	6.5830 ⁺ 01	NH	0.96145	0.79790	0.96443	1.46098	0.66013
17	8.5995 ⁻ 03	6.8311 ⁺ 01	NH	0.96465	0.81290	0.96762	1.41690	0.68292
18	9.6005 ⁻ 03	8.2121 ⁺ 01	NH	0.98117	0.89180	0.98311	1.21525	0.80897
19	1.0250 ⁻ 02	8.8181 ⁺ 01	NH	0.98828	0.92430	0.98916	1.14527	0.86369
20	1.1099 ⁻ 02	9.6473 ⁺ 01	NH	0.99269	0.96700	0.99430	1.05727	0.94045
21	1.1350 ⁻ 02	9.5700 ⁺ 01	NH	0.98768	0.96310	0.99154	1.05993	0.93548
22	1.2178 ⁻ 02	9.9172 ⁺ 01	NH	0.99740	0.98050	0.99752	1.03501	0.96377
23	1.2350 ⁻ 02	1.0437 ⁺ 02	NH	0.98568	1.00600	0.99316	0.97464	1.01900
24	1.3144 ⁻ 02	1.0116 ⁺ 02	NH	1.00100	0.99030	0.99992	1.01952	0.98077
25	1.4300 ⁻ 02	1.0314 ⁺ 02	NH	1.00681	1.00000	1.00340	1.00681	0.99661
26	1.4352 ⁻ 02	1.0314 ⁺ 02	NH	0.99429	1.00000	0.99714	0.99429	1.00287
27	1.4599 ⁻ 02	1.0310 ⁺ 02	NH	1.01833	0.99980	1.00911	1.01871	0.99058
28	1.5405 ⁻ 02	1.0375 ⁺ 02	NH	1.01682	1.00300	1.00855	1.01111	0.99748
29	1.6354 ⁻ 02	1.0314 ⁺ 02	NH	1.00000	1.00000	1.00000	1.00000	1.00000
30	1.8096 ⁻ 02	1.0318 ⁺ 02	NH	1.01943	1.00020	1.00968	1.01904	0.99081

INPUT VARIABLES Y,M/MD,TO/TOD ASSUME P=PD

7903S0201		BARTLETT/E/H/H		PROFILE TABULATION		30 POINTS, DELTA AT POINT 29		
I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NH	0.28608	0.00000	0.00000	5.19118	0.00000
2	6.3000 ⁻ 04	1.0538 ⁺ 01	NH	0.77285	0.30193	0.70626	5.47162	0.12908
3	7.6968 ⁻ 04	1.3235 ⁺ 01	NH	0.76135	0.34003	0.73184	4.63221	0.15799
4	9.5976 ⁻ 04	1.7668 ⁺ 01	NH	0.81184	0.39474	0.79069	4.01224	0.19707
5	1.1801 ⁻ 03	2.1851 ⁺ 01	NH	0.85473	0.44014	0.83383	3.58890	0.23233
6	1.3097 ⁻ 03	2.2863 ⁺ 01	NH	0.80064	0.45045	0.81127	3.24373	0.25010
7	1.4702 ⁻ 03	2.4001 ⁺ 01	NH	0.86973	0.46175	0.85015	3.38985	0.25079
8	1.5300 ⁻ 03	2.4782 ⁺ 01	NH	0.83583	0.46935	0.83631	3.17499	0.26340
9	2.0700 ⁻ 03	3.2468 ⁺ 01	NH	0.91862	0.53845	0.89966	2.79161	0.32227
10	2.2702 ⁻ 03	3.6171 ⁺ 01	NH	0.93871	0.56876	0.91745	2.60200	0.35259
11	2.4502 ⁻ 03	3.7361 ⁺ 01	NH	0.92671	0.57816	0.91382	2.49819	0.36579
12	2.4797 ⁻ 03	3.8273 ⁺ 01	NH	0.94251	0.58526	0.92323	2.48842	0.37101
13	2.5200 ⁻ 03	3.9484 ⁺ 01	NH	0.94181	0.59456	0.92498	2.42031	0.38217
14	2.5798 ⁻ 03	4.1156 ⁺ 01	NH	0.92701	0.60716	0.92036	2.29779	0.40054
15	2.7698 ⁻ 03	4.2671 ⁺ 01	NH	0.94691	0.61836	0.93248	2.27400	0.41006
16	3.0499 ⁻ 03	4.9552 ⁺ 01	NH	0.95321	0.66687	0.94437	2.00544	0.47091
17	3.1997 ⁻ 03	5.3271 ⁺ 01	NH	0.96071	0.69167	0.95198	1.89433	0.50254
18	3.2897 ⁻ 03	5.5758 ⁺ 01	NH	0.97540	0.70777	0.96158	1.84581	0.52095
19	3.5201 ⁻ 03	5.9653 ⁺ 01	NH	0.95891	0.73227	0.95670	1.70690	0.56049
20	3.7001 ⁻ 03	6.3363 ⁺ 01	NH	0.97161	0.75488	0.96582	1.63696	0.59001
21	3.9902 ⁻ 03	7.1741 ⁺ 01	NH	0.96431	0.80358	0.96748	1.44951	0.66745
22	4.1998 ⁻ 03	7.8921 ⁺ 01	NH	0.95611	0.84308	0.96703	1.31563	0.73503
23	4.3603 ⁻ 03	8.2213 ⁺ 01	NH	0.97261	0.86059	0.97683	1.28838	0.75818
24	5.2798 ⁻ 03	1.0042 ⁺ 02	NH	0.97560	0.95160	0.98490	1.07122	0.91942
25	6.1200 ⁻ 03	1.0706 ⁺ 02	NH	0.97431	0.98270	0.98610	1.00694	0.97930
26	6.3598 ⁻ 03	1.0660 ⁺ 02	NH	1.00230	0.98060	1.00005	1.04006	0.96153
27	7.0502 ⁻ 03	1.1029 ⁺ 02	NH	0.99650	0.99750	0.99811	1.00123	0.99689
28	7.3699 ⁻ 03	1.1049 ⁺ 02	NH	0.99630	0.99840	0.99806	0.99932	0.99874
29	8.2202 ⁻ 03	1.1084 ⁺ 02	NH	1.00000	1.00000	1.00000	1.00000	1.00000
30	1.0020 ⁻ 02	1.1191 ⁺ 02	NH	0.99950	1.00480	1.00001	0.99049	1.00961

INPUT VARIABLES Y,M/MD,TO/TOD ASSUME P=PD

7903S0203

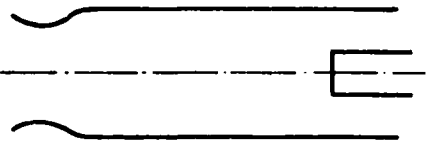
BARTLETT/E/H/H

PROFILE TABULATION

63 POINTS, DELTA AT POINT 61

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000 ⁺ 00	1.0000 ⁺ 00	NM	0.28616	0.00000	0.00000	5.22023	0.00000
2	6.2992 ⁻ 04	8.6468 ⁺ 00	NM	0.67987	0.27127	0.63424	5.46649	0.11602
3	6.5028 ⁻ 04	8.5989 ⁺ 00	NM	0.62886	0.27047	0.60919	5.07305	0.12008
4	7.2982 ⁻ 04	8.4089 ⁺ 00	NM	0.70667	0.26728	0.64238	5.77631	0.11121
5	8.0013 ⁻ 04	8.8094 ⁺ 00	NM	0.75338	0.27396	0.67054	5.99069	0.11193
6	9.8975 ⁻ 04	1.1249 ⁺ 01	NM	0.77098	0.31156	0.71457	5.26029	0.13584
7	1.1701 ⁻ 03	1.4267 ⁺ 01	NM	0.81558	0.35255	0.76704	4.73364	0.16204
8	1.3496 ⁻ 03	1.7348 ⁺ 01	NM	0.83088	0.38995	0.79772	4.18494	0.19062
9	1.5503 ⁻ 03	1.8515 ⁺ 01	NM	0.86229	0.40321	0.82001	4.13596	0.19826
10	1.5697 ⁻ 03	1.8631 ⁺ 01	NM	0.89169	0.40451	0.83458	4.25679	0.19606
11	1.7704 ⁻ 03	2.0306 ⁺ 01	NM	0.85699	0.42276	0.82737	3.83018	0.21601
12	1.8204 ⁻ 03	2.0344 ⁺ 01	NM	0.86519	0.42316	0.83152	3.86133	0.21534
13	1.8500 ⁻ 03	2.0362 ⁺ 01	NM	0.85769	0.42336	0.82800	3.82513	0.21646
14	1.9804 ⁻ 03	2.1110 ⁺ 01	NM	0.90149	0.43124	0.85266	3.90953	0.21810
15	2.0396 ⁻ 03	2.1676 ⁺ 01	NM	0.88969	0.43712	0.84977	3.77920	0.22485
16	2.1599 ⁻ 03	2.2635 ⁺ 01	NM	0.87399	0.44689	0.84651	3.58804	0.23593
17	2.3199 ⁻ 03	2.3727 ⁺ 01	NM	0.89499	0.45776	0.86118	3.53920	0.24333
18	2.3402 ⁻ 03	2.3960 ⁺ 01	NM	0.91179	0.46006	0.87017	3.57749	0.24323
19	2.3597 ⁻ 03	2.4195 ⁺ 01	NM	0.89179	0.46235	0.86149	3.47177	0.24814
20	2.3902 ⁻ 03	2.4555 ⁺ 01	NM	0.90589	0.46584	0.86966	3.48512	0.24953
21	2.4697 ⁻ 03	2.5428 ⁺ 01	NM	0.92809	0.47422	0.88352	3.47114	0.25453
22	2.6797 ⁻ 03	2.7256 ⁺ 01	NM	0.93969	0.49127	0.89531	3.32121	0.26957
23	2.7001 ⁻ 03	2.7430 ⁺ 01	NM	0.92639	0.49287	0.88950	3.25711	0.27310
24	2.7102 ⁻ 03	2.7528 ⁺ 01	NM	0.91729	0.49377	0.88543	3.21565	0.27535
25	2.8601 ⁻ 03	2.9396 ⁺ 01	NM	0.95830	0.51052	0.91067	3.18199	0.28620
26	2.8999 ⁻ 03	2.9634 ⁺ 01	NM	0.92939	0.51262	0.89750	3.06540	0.29278
27	3.0497 ⁻ 03	3.0548 ⁺ 01	NM	0.92479	0.52059	0.89775	2.97380	0.30189
28	3.0997 ⁻ 03	3.0849 ⁺ 01	NM	0.92279	0.52319	0.89756	2.94316	0.30497
29	3.2310 ⁻ 03	3.1971 ⁺ 01	NM	0.93819	0.53276	0.90785	2.90378	0.31264
30	3.3096 ⁻ 03	3.2243 ⁺ 01	NM	0.91589	0.53506	0.89765	2.81459	0.31893
31	3.4502 ⁻ 03	3.3728 ⁺ 01	NM	0.93409	0.54742	0.90995	2.76309	0.32933
32	3.4697 ⁻ 03	3.4044 ⁺ 01	NM	0.95310	0.55001	0.91987	2.79704	0.32887
33	3.4798 ⁻ 03	3.4203 ⁺ 01	NM	0.91489	0.55131	0.90158	2.67433	0.33712
34	3.4900 ⁻ 03	3.4362 ⁺ 01	NM	0.94299	0.55261	0.91567	2.74563	0.33350
35	3.5104 ⁻ 03	3.4570 ⁺ 01	NM	0.90309	0.55430	0.89652	2.61593	0.34272
36	3.7703 ⁻ 03	3.6840 ⁺ 01	NM	0.95420	0.57245	0.92614	2.61740	0.35384
37	3.9497 ⁻ 03	3.9078 ⁺ 01	NM	0.94419	0.58981	0.92532	2.46127	0.37595
38	4.1098 ⁻ 03	3.9945 ⁺ 01	NM	0.94799	0.59639	0.92863	2.42453	0.38302
39	4.3697 ⁻ 03	4.4102 ⁺ 01	NM	0.97920	0.62701	0.95016	2.29640	0.41376
40	4.4400 ⁻ 03	4.5926 ⁺ 01	NM	0.95480	0.63997	0.94067	2.16051	0.43539
41	4.4696 ⁻ 03	4.6894 ⁺ 01	NM	0.96175	0.64675	0.94532	2.13637	0.44249
42	4.6999 ⁻ 03	4.9243 ⁺ 01	NM	0.97450	0.66291	0.95436	2.07261	0.46046
43	4.9996 ⁻ 03	5.5166 ⁺ 01	NM	0.98140	0.70200	0.96384	1.88508	0.51130
44	5.1902 ⁻ 03	5.7951 ⁺ 01	NM	0.96860	0.71966	0.95999	1.77942	0.53949
45	5.2300 ⁻ 03	5.8638 ⁺ 01	NM	0.98140	0.72395	0.96688	1.78376	0.54205
46	5.4001 ⁻ 03	6.0366 ⁺ 01	NM	0.97910	0.73462	0.96714	1.73324	0.55800
47	5.6897 ⁻ 03	6.5429 ⁺ 01	NM	0.97650	0.76503	0.96953	1.60605	0.60367
48	5.7600 ⁻ 03	6.5633 ⁺ 01	NM	0.97320	0.76623	0.96802	1.59608	0.60650
49	5.9598 ⁻ 03	6.8861 ⁺ 01	NM	0.99010	0.78498	0.97847	1.55375	0.62975
50	6.6803 ⁻ 03	8.3203 ⁺ 01	NM	0.99250	0.86337	0.98705	1.30702	0.75519
51	6.7904 ⁻ 03	8.1397 ⁺ 01	NM	0.99530	0.85389	0.98764	1.33780	0.73826
52	6.9199 ⁻ 03	8.8859 ⁺ 01	NM	0.99120	0.89239	0.98868	1.22745	0.80548
53	7.0596 ⁻ 03	8.8978 ⁺ 01	NM	0.97410	0.89299	0.98016	1.20477	0.81357
54	7.4398 ⁻ 03	9.8722 ⁺ 01	NM	0.99540	0.94086	0.99417	1.11653	0.89041
55	7.7302 ⁻ 03	9.9327 ⁺ 01	NM	0.97880	0.94375	0.98603	1.09160	0.90329
56	7.7496 ⁻ 03	1.0027 ⁺ 02	NM	0.99140	0.94824	0.99264	1.09585	0.90582
57	8.4203 ⁻ 03	1.0849 ⁺ 02	NM	0.99230	0.98654	0.99539	1.01804	0.97776
58	8.8754 ⁻ 03	1.0741 ⁺ 02	NM	0.99290	0.98155	0.99541	1.02844	0.96788
59	9.2796 ⁻ 03	1.1164 ⁺ 02	NM	0.98380	1.00080	0.99191	0.98232	1.00977
60	1.0080 ⁻ 02	1.1087 ⁺ 02	NM	0.99010	0.99731	0.99489	0.99516	0.99973
D 61	1.0420 ⁻ 02	1.1146 ⁺ 02	NM	1.00000	1.00000	1.00000	1.00000	1.00000
62	1.0990 ⁻ 02	1.1087 ⁺ 02	NM	0.99110	0.99731	0.99539	0.99616	0.99923
63	1.1390 ⁻ 02	1.1157 ⁺ 02	NM	1.01380	1.00050	1.00690	1.01285	0.99413

INPUT VARIABLES Y,M/MD,TO/TOD ASSUME P=PD
 AT I= 41 VALUES OF INPUT PROFILES WERE AVERAGED BECAUSE OF SAME Y

axisymmetric 	M: 1.45 (upstream) R THETA $\times 10^{-3}$: 40-110 TW/TR: 1.0	8001 SBLI-APG AW
Axisymmetric blowdown tunnel. Running time up to one hour. $D = 0.25$, $L = 2.7$ m. PO: 0.14 (0.034-0.54) MN/m². TO: 283K. Air. RE/m $\times 10^6$: 21, (4-25) (upstream).		
MATEER G.G., VIEGAS J.R., 1979. Effect of Mach and Reynolds numbers on a normal shock-wave/turbulent boundary-layer interaction. AIAA P-79-1052. And Mateer et al. (1976); private communications, Mateer G.G., Horstman C.C.		

- 1 The test boundary layer was formed on the inner surface of a cylindrical duct of constant (0.248 m) diameter and 2.69 m long. The surface was honed to give a roughness less than 1.6 μ m and plated. At the rear end of the duct a hollow cylindrical choke of varying cross-section was inserted and its position adjusted to give a suitable position for a normal shock in the test section. This was more than 1 m upstream of the choke and, by implication, greater than 1.6 m for the case studied here. The duct is essentially the test section used by Kussoy et al. (CAT 7802S) fitted with a nozzle designed to give a Mach number of about 1.5 at entry to the duct. $X = 0$ is defined as the start of the initial pressure rise through the shock. The first profile measured extends well into the core flow and shows Mach number variations of about 1%. An axial Mach number gradient of $-0.074/\text{m}$ existed in the tube. No information on trips is given, but RE THETA at the first station is 40×10^3 so that the flow may be presumed to be fully turbulent. The test layer has passed through the expansion field of the nozzle but on the evidence of the first profile has not relaxed to equilibrium characteristics in the outer region.
- 2 Static pressure was measured by tappings 0.5 mm in diameter (E) "at intervals of 25.4 mm in the upstream portions and 50.8 mm in the downstream portions." Measurements were also made on the opposite diameter at a number of stations to check flow symmetry. "Instrumentation ports were located on a line at seven positions along the tube and at 45° from the static tap line. Buried wire surface-shear gauges were used to measure the wall shear stress. These appear (E) to be the same as, or at least similar to, those used by Kussoy et al. (CAT 7802S). Preston tube measurements were also made. A surface flow direction indicator was used to detect separation. This consisted of three thin films mounted on the surface, across the flow, one after the other in the mean flow direction. The central film was heated, and the local flow direction shown by a rise in temperature of the, unheated, film which is locally downstream of the hot film. This was calibrated in a step flow. The number of CF values and of flow direction readings is very much greater than the number of ports. These readings were obtained as a function of X by altering the position of the shock, using fixed instrumentation. The profiles were measured at the seven ports with a fixed shock position (E).
- 3 Pitot, total temperature static pressure and turbulence profiles were measured. The probe in use was supported on the downstream side by a slotted strut extending 100 mm into the flow, with the probe tip 50 mm ahead of the strut. The FPP used was constructed of 1.6 mm tube flattened to give a rectangular tip for which $h_2 = 0.076$, $b_2 = 1.0$ mm. The temperature probe was a FWP as proposed by Vas (1972). Static pressures were measured with a wedge probe made by flattening 1.6 mm tube to give a wedge tip of total included angle 12.5°. Static tappings ($d = 0.25$ mm) were drilled in each face of the wedge 1.6 mm back from the tip. The probe was calibrated in the undisturbed boundary layer upstream of the shock. Turbulence measurements were made using a supported X-probe of the type described by Mikulla & Horstman (1976).
- 4 Mean flow data are the average of 10 to 15 measurements for each Y position. (This is probably true for the Pitot measurements only - E). "Additional surveys indicate that the static pressure was equal to the wall pressure and that the total temperature was constant throughout the flow." These results may have been assumed in the original data reduction, but see §15 below.

- 12 The editors have presented the data as received from the authors with the exception of a further profile at $X = 1.60$ m, for which we received no wall data. We have set the wall temperature at the recovery temperature with $r = 0.896$. We have moved the D-state out to higher Y values on the basis of the total pressure profiles (see §15 below).
- 13 The profiles form a single set, profile 0101 being upstream of the shock which lies ahead of profile 0102. The complete wall data for this case are given in Table 1, Sect. D. Data for various other cases, at constant shock Mach number for a range of free stream unit Reynolds numbers, and at constant free stream Reynolds number for a range of shock Mach numbers may be found presented graphically in the source paper. These data are also presented in tabular form as cases A-G in the working papers for the 1981 Stanford meeting on calculation of turbulent flows.
- § DATA 8001 0101-0107. Pitot, (T_0), (static pressure) and cross-wire Reynolds shear stress profiles. $NX = 7$. CF from embedded wire gauges (and Preston tubes).
- 15 Editors' comments. The principal value of this study lies in the provision of seven successive Reynolds shear-stress profiles measured with a device analogous to a pair crossed hot wires. These are coupled to mean flow profiles which present certain difficulties of interpretation.

Firstly, there is the question of whether there is a separation bubble or not. Although one is sketched in a paper discussing these data by Coakley, Viegas & Horstman (1977), Mateer and Viegas (1979) consider that it did not occur. It is difficult to match the cases discussed in that paper to the data here, but if their opinion, based on the flow direction indicator results is accepted, while separation is incipient, it has not happened. G.G. Mateer (private communication) considers that the separation gauge results in Mateer et al. (1976) should be disregarded.

The development of some principal flow parameters is shown in Fig. 1. Profile 01 is nominally upstream of the interaction and represents the undisturbed flow. The shock occurs somewhere between 01 and 02. The changes in POD and PW that would be predicted for one-dimensional flow are shown by arrows labelled NS. The POD values will be discussed further below, but the general level of change is consistent with that expected in a one-dimensional normal shock. The PW value, however, as is usual in shock-boundary layer interactions, rises relatively slowly and does not reach, or tend to, the one-dimensional value. This is the consequence of the marked growth in boundary layer thickness, shown also by the curve for D1, which causes a constriction of the subsonic flow behind the shock. The Mach number is therefore higher, and the pressure lower, than for an isentropic one-dimensional flow. The changes in direction, and position, of the displacement surface also cause the shock, a single near-plane surface on the axis, to split into two or more branches near the wall. In this region the total pressure loss is not so great as in the normal shock.

The total pressure profiles for $Y > 30$ mm are shown in Fig. 2. Profile 01, in nominally undisturbed flow, shows little scatter, but in the free stream, shows a systematic variation which suggests the presence of a residual nozzle wave structure. In preparing the figure, the static pressure was assumed constant, but it seems likely that the variation seen here is due to static pressure changes rather than non-uniform total pressure. The downstream profiles show much more scatter (the authors remark on a $\pm 5\%$ variation in Pitot readings in the boundary layer), and all show a total pressure maximum in the range $50 < Y < 60$, with a marked fall as Y increases to the highest values measured at approximately $Y = 100$ mm. The profiles do not, in the range of measurement, show any tendency to a constant value for high Y , but do reach or fall below values characteristic of those behind a normal shock. This is shown more clearly in Fig. 3, presenting the POD curve of Fig. 1 to a much enlarged scale. There is an error band for profile 01, corresponding to the free stream variation, and this results in an error band for the value behind a normal shock, shown hatched. The point values shown downstream represent the highest values recorded and are in all cases significantly above the value for a normal shock. They are probably uncharacteristically high because of the scatter in the data (see Fig. 2), but even with this taken into account confirm the presence of a wall-jet-like flow, with a high total pressure region which has passed through a number of oblique shocks merging on one side with the boundary layer and on the other with the low total

pressure flow which has traversed the normal shock. The gradient observed at high Y is probably more due to time averaging as the shocks move than to any strong mixing at a slip surface springing from the shock intersection.

The data for profile 02 do not extend out into this region, so that in Fig. 3 no arrow showing the extent of the fall in total pressure is shown. For the other profiles, the trend seen in Fig. 2 suggests that they have not reached a final P_0 minimum by $Y = 100$ mm, but if there is a change in the trend at or near this Y value it could easily be obscured by the scatter in the data. If large fluctuations of the normal shock are present, then a low P_0 value might well result. The total pressure loss in a shock is a nonlinear function of shock Mach number, so that an oscillating shock may cause a greater mean total pressure loss than a stationary shock with the same mean Mach number.

The wall shear stress variation shown in Fig. 1 has very little scatter and probably represents a fit of some kind. The earlier results, using Preston tubes (Mateer et al. 1976, Fig. 9) show a marked spread in values. The general picture of a flow with an embedded high total pressure region is further born out by the shear stress profiles, which are presented in §4.5 of the main text. The shear stress reverses sign in all the profiles, including the first (at low levels in the outer region, where this may be an instrumental effect). The sign reversal in profiles 03-07 is not precisely positioned, as there are very large gaps in all profiles except 07. The P_0 maximum lies between the readings for which the sign change occurs, except for 07 where the gap is smaller and the sign change occurs near the maximum in terms of P_0 but substantially closer to the wall in terms of Y . The fairly constant maximum value for P_0 in profiles 04-07 suggests that outwards diffusing shear from the wall has not yet met inwards diffusing shear from the slip surface and that this is therefore an appropriate D-state for the 'boundary layer'.

We assume a flow of wall-jet character in discussing the profiles. Profile 01 is nominally upstream of the interaction, and fits the wall law (Fig. 4) very well for a full decade. The wake component is uncharacteristically weak. This may be a history effect as (E) the profile is probably quite close to the nozzle exit plane. If there are oscillations, this profile should not be affected as it is in a supersonic region. The profiles downstream (we have not plotted 02 as the CF value is our own estimate) do not initially appear to relate to the wall very well. If their position is ignored, however, they all appear to have well defined inner, semilog-law, regions with large wake components leaving at about $y/\delta = 0.1$. It would be easy to obtain a convincing Coles wall-and-wake fit with a CF value about 30% lower than the reported measured value. The buried wire skin-friction gauges used in the experiment are sublayer devices and so should not be strongly affected by pressure gradients, which are in any case quite modest for profiles 03-07. The gauges are however heat transfer devices and so likely to be much affected by oscillating flow. We consider the high apparent shear stress a further indicator of oscillation, and suspect that, particularly with the very high Reynolds number in this case, a wall-and-wake value might well be more representative. The very large wake components are then a result of, firstly, a low TAUW value associated with the adverse pressure gradient, and secondly high U values in consequence of the P_0 values in the "jet".

The data as received by the editors were in the form of profiles of velocity and density. When processed, the resulting total temperature profiles generally show departures of about 1% from the author's implied assumption of constant T_0 , with higher excursions of 3% in profile 05 and 8% in 02. It is not clear whether these represent scattered measurements or some as yet unexplained interaction in the data reduction procedure. In particular, for profile 02, the assumption of constant static pressure may be doubtful and cause these differences to appear.

We feel that the data presented here describe a very interesting case, but that it would be unwise to base any argument on results which need to be known at the 5% level or better. The overall pattern seems clear, but many minor discrepancies remain. More generally, it seems probable that there is a high level of unsteadiness which is related to shock wave fluctuation rather than to turbulence as such. Our feeling is that calculations using this flow as a test case should not commence before profile 03, as there are insufficient data to fix the details of the shock interaction and no CF value for 02. We feel also that

mixing may be much enhanced by unsteady mean flow by comparison with a steady calculation case, and that those working with calculation methods should bear this in mind.

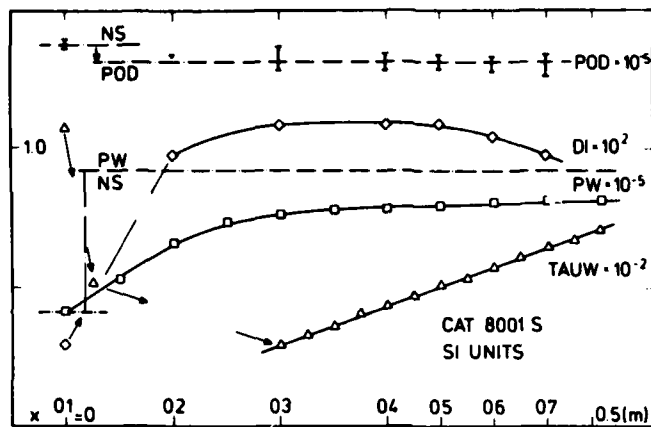


Fig. 1
Streamwise variation of principal flow parameters. (Mateer et al. 1976).

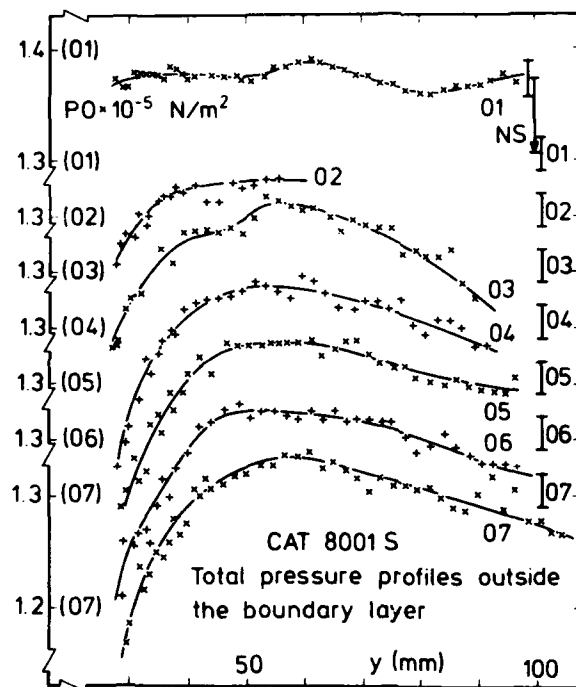


Fig. 2
Total pressure profiles outside the boundary layer. (Mateer et al. 1976).

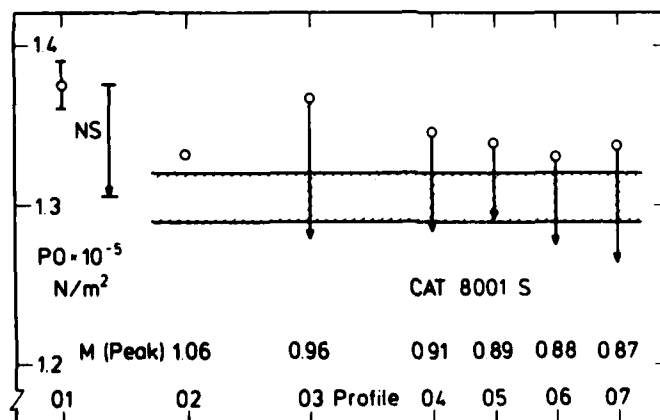


Fig. 3
Range of downstream total pressure measurements outside the boundary layer downstream of a normal shock compared to plane shock value. (Mateer et al. 1976).

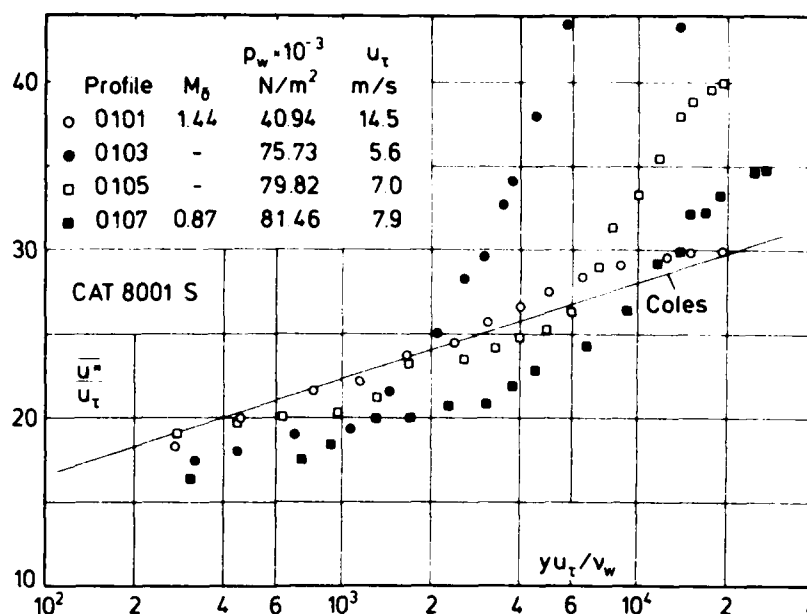


Fig. 4 Law of the wall for a transonic turbulent boundary layer with shock interaction (adiabatic wall, origin not defined $0.9 < M_0 < 1.44$). (Mateer & Viegas 1980).

CAT 8001S		BOUNDARY CONDITIONS AND EVALUATED DATA. SI UNITS							
RUN	MD	TW/TR*	RED2W	CF	H12	H12K	PW*	PD	
X *	P0D	PW/PD*	RED2D	CQ	H32	H32K	TW	TD*	
RZ *	TOD	TAUW *	DZ	PI2	H42	D2K	UD*	TR	
8001S0101	1.4378	1.0000	3.0484**+04	1.8060**-03	1.6099	1.3788	4.0935**+04	4.0935**+04	
0.0000**+00	1.3743**+05	1.0000	3.9369**+04	NM	1.8593	1.8545	2.7990**+02	2.0424**+02	
-1.2385**-01	2.8868**+02	1.0698**+02	1.8601**-03	NM	0.4370	1.9754**-03	4.1197**+02	2.7990**+02	
8001S0102	1.0574	1.0000	6.0742**+04	NM	3.2004	2.0631	6.5496**+04	6.5496**+04	
1.0160**-01	1.3273**+05	1.0000	7.0423**+04	NM	1.6239	1.6155	2.6466**+02	2.2048**+02	
-1.2385**-01	2.6978**+02	NM	3.1316**-03	NM	-0.2833	3.7078**-03	3.1480**+02	2.6466**+02	
8001S0103	0.9561	1.0000	8.6861**+04	6.1002**-04	2.4572	1.9370	7.5730**+04	7.5730**+04	
2.0320**-01	1.3630**+05	1.0000	9.8004**+04	NM	1.6549	1.6457	2.8137**+02	2.4177**+02	
-1.2385**-01	2.8597**+02	2.9560**+01	4.7070**-03	NM	0.0143	5.2357**-03	2.9806**+02	2.8137**+02	
8001S0104	0.9053	1.0000	9.4118**+04	9.6795**-04	2.1907	1.7065	7.8596**+04	7.8596**+04	
3.0480**-01	1.3370**+05	1.0000	1.0498**+05	NM	1.6782	1.6747	2.7708**+02	2.4160**+02	
-1.2385**-01	2.8120**+02	4.3647**+01	5.1261**-03	NM	-0.0174	5.6431**-03	2.8214**+02	2.7708**+02	
8001S0105	0.8898	1.0000	9.8308**+04	1.1411**-03	2.0434	1.6092	7.9824**+04	7.9824**+04	
3.5560**-01	1.3353**+05	1.0000	1.0931**+05	NM	1.7095	1.7078	2.7331**+02	2.3935**+02	
-1.2385**-01	2.7725**+02	5.0484**+01	5.2815**-03	NM	-0.0061	5.7495**-03	2.7601**+02	2.7331**+02	
8001S0106	0.8733	1.0000	9.8696**+04	1.3331**-03	1.9257	1.5665	8.0643**+04	8.0643**+04	
4.0640**-01	1.3254**+05	1.0000	1.0932**+05	NM	1.7238	1.7227	2.7417**+02	2.4121**+02	
-1.2385**-01	2.7800**+02	5.7386**+01	5.3821**-03	NM	0.0233	5.7732**-03	2.7193**+02	2.7417**+02	
8001S0107	0.8705	1.0000	9.9778**+04	1.5037**-03	1.9515	1.5275	8.1461**+04	8.1461**+04	
4.5720**-01	1.3349**+05	1.0000	1.1047**+05	NM	1.7435	1.7420	2.7241**+02	2.3984**+02	
-1.2385**-01	2.7619**+02	6.4974**+01	5.3609**-03	NM	-0.0207	5.7900**-03	2.7029**+02	2.7241**+02	

TRAPEZOIDAL RULE FOR ALL INTEGRATIONS

8001S0103

MATEER

PROFILE TABULATION

75 POINTS, DELTA AT POINT 59

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000+00	1.0000+00	NM	0.98393	0.00000	0.00000	1.16380	0.00000
2	1.0700-03	1.0600+00	NM	1.01172	0.30305	0.32877	1.17692	0.27934
3	1.4800-03	1.0632+00	NM	1.01180	0.31075	0.33699	1.17602	0.28655
4	1.9200-03	1.0722+00	NM	1.01661	0.33184	0.36027	1.17874	0.30564
5	2.3300-03	1.0709+00	NM	1.01939	0.32881	0.35753	1.18238	0.30239
6	2.7500-03	1.0740+00	NM	1.02380	0.33578	0.36575	1.18651	0.30826
7	3.1700-03	1.0725+00	NM	1.02139	0.33233	0.36164	1.18421	0.30539
8	3.5900-03	1.0734+00	NM	1.021692	0.33436	0.36301	1.17874	0.30797
9	4.0000-03	1.0803+00	NM	1.01957	0.34937	0.37945	1.17965	0.32167
10	4.4300-03	1.0774+00	NM	1.02590	0.34312	0.37397	1.18789	0.31482
11	4.7700-03	1.0840+00	NM	1.03412	0.35709	0.39041	1.19531	0.32662
12	4.8600-03	1.0923+00	NM	1.02043	0.37376	0.40548	1.17692	0.34453
13	5.2700-03	1.1055+00	NM	1.02551	0.39871	0.43288	1.17874	0.36724
14	5.7100-03	1.1083+00	NM	1.02548	0.40391	0.43836	1.17783	0.37217
15	6.1100-03	1.1288+00	NM	1.01446	0.43897	0.47260	1.15909	0.40774
16	6.5400-03	1.1011+00	NM	1.02042	0.39063	0.42329	1.17421	0.36049
17	6.9700-03	1.1255+00	NM	1.02135	0.43350	0.46849	1.16794	0.40113
18	7.3900-03	1.1316+00	NM	1.02371	0.44348	0.47945	1.16883	0.41020
19	7.8200-03	1.1275+00	NM	1.02421	0.43681	0.47260	1.17062	0.40372
20	8.2300-03	1.1407+00	NM	1.01289	0.45782	0.49178	1.15385	0.42621
21	8.6500-03	1.1647+00	NM	1.01360	0.49355	0.52877	1.14779	0.46068
22	9.0800-03	1.1731+00	NM	1.02025	0.50520	0.54247	1.15298	0.47049
23	9.5000-03	1.1645+00	NM	1.02042	0.49316	0.53014	1.15559	0.45876
24	9.9200-03	1.1811+00	NM	1.01918	0.51618	0.55342	1.14951	0.48144
25	1.0340-02	1.2002+00	NM	1.01170	0.54112	0.57671	1.13586	0.50773
26	1.0770-02	1.2125+00	NM	1.01994	0.55638	0.59452	1.14179	0.52069
27	1.1190-02	1.2022+00	NM	1.01746	0.54356	0.58082	1.14179	0.50869
28	1.1620-02	1.2269+00	NM	1.01206	0.57367	0.60959	1.12915	0.53986
29	1.2030-02	1.2458+00	NM	1.00831	0.59541	0.63014	1.12006	0.56259
30	1.2450-02	1.2518+00	NM	1.00456	0.60212	0.63562	1.11435	0.57039
31	1.2890-02	1.2855+00	NM	1.00562	0.63794	0.67123	1.10709	0.60630
32	1.3930-02	1.2476+00	NM	1.00211	0.59737	0.63014	1.11273	0.56630
33	1.4980-02	1.3234+00	NM	0.99597	0.67521	0.70411	1.08742	0.64750
34	1.6020-02	1.3305+00	NM	0.99327	0.68192	0.70959	1.08280	0.65533
35	1.7080-02	1.3857+00	NM	0.98946	0.73099	0.75479	1.06620	0.70793
36	1.8130-02	1.3754+00	NM	0.99707	0.72213	0.74932	1.07671	0.69593
37	1.9190-02	1.4497+00	NM	0.99952	0.78249	0.80685	1.06324	0.75886
38	2.0250-02	1.4721+00	NM	0.99492	0.79936	0.82055	1.05372	0.77872
39	2.1310-02	1.5248+00	NM	0.99132	0.83709	0.85342	1.03940	0.82107
40	2.2370-02	1.5578+00	NM	0.98008	0.85936	0.86849	1.02136	0.85033
41	2.3430-02	1.5427+00	NM	0.99126	0.84928	0.86438	1.03588	0.83444
42	2.4480-02	1.6000+00	NM	0.99024	0.88664	0.89726	1.02410	0.87615
43	2.5540-02	1.6120+00	NM	0.99370	0.89416	0.90548	1.02547	0.88299
44	2.6580-02	1.6262+00	NM	0.99485	0.90289	0.91370	1.02410	0.89220
45	2.7630-02	1.6348+00	NM	0.99969	0.90813	0.92055	1.02754	0.89588
46	2.8690-02	1.6735+00	NM	0.99769	0.93109	0.93973	1.01864	0.92253
47	2.9730-02	1.6811+00	NM	0.99831	0.93547	0.94384	1.01796	0.92718
48	3.0790-02	1.6899+00	NM	0.99190	0.94056	0.94521	1.00990	0.93594
49	3.4290-02	1.7426+00	NM	0.99082	0.96986	0.96986	1.00000	0.96986
50	3.6400-02	1.7279+00	NM	0.99363	0.96186	0.96438	1.00526	0.95934
51	3.8510-02	1.7635+00	NM	0.99096	0.98105	0.97945	0.99674	0.98265
52	4.0600-02	1.7642+00	NM	0.99302	0.98146	0.98082	0.99869	0.98210
53	4.2710-02	1.7668+00	NM	0.99344	0.98283	0.98219	0.99869	0.98348
54	4.4820-02	1.7650+00	NM	0.99510	0.98187	0.98219	1.00065	0.98155
55	4.6940-02	1.7688+00	NM	0.99441	0.98388	0.98356	0.99935	0.98420
56	4.9060-02	1.7591+00	NM	0.99220	0.97872	0.97808	0.99869	0.97936
57	5.1140-02	1.7794+00	NM	0.99871	0.98944	0.99041	1.00196	0.98847
58	5.3250-02	1.8021+00	NM	1.00894	1.00120	1.00548	1.00857	0.99694
D 59	5.5350-02	1.7997+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000
60	5.7460-02	1.7927+00	NM	1.00346	0.99634	0.99863	1.00460	0.99406
61	5.9570-02	1.7882+00	NM	1.00738	0.99405	0.99863	1.00923	0.98949
62	6.1690-02	1.7909+00	NM	1.01049	0.99546	1.00137	1.01190	0.98959
63	6.3790-02	1.7824+00	NM	1.00710	0.99100	0.99589	1.00990	0.98613
64	6.5890-02	1.7623+00	NM	1.00318	0.98041	0.98493	1.00923	0.97592
65	6.8000-02	1.7779+00	NM	1.00838	0.98865	0.99452	1.01190	0.98282
66	7.0100-02	1.7694+00	NM	1.00500	0.98418	0.98904	1.00990	0.97934
67	7.2230-02	1.7673+00	NM	1.00136	0.98307	0.98630	1.00658	0.97985
68	7.4340-02	1.7664+00	NM	0.99662	0.98260	0.98356	1.00196	0.98163
69	7.6430-02	1.7351+00	NM	0.98959	0.96575	0.96575	1.00000	0.96575
70	7.8540-02	1.7415+00	NM	1.01724	0.96927	0.98219	1.02685	0.95651
71	8.0650-02	1.7340+00	NM	1.01326	0.96515	0.97671	1.02410	0.95373
72	8.2760-02	1.7355+00	NM	1.00610	0.96598	0.97397	1.01661	0.95806
73	8.4870-02	1.7431+00	NM	0.99874	0.97015	0.97397	1.00791	0.96633
74	8.6980-02	1.7028+00	NM	0.97600	0.94784	0.94384	0.99157	0.95186
75	8.9080-02	1.6850+00	NM	0.97689	0.93775	0.93562	0.99545	0.93990

INPUT VARIABLES Y,U/UD,RHO/RHOD ASSUME P=PD
 AT I= 6 VALUES OF INPUT PROFILES WERE AVERAGED BECAUSE OF SAME Y

8001S0104

MATEER

PROFILE TABULATION

81 POINTS, DELTA AT POINT 63

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000E+00	1.0000E+00	NM	0.98535	0.00000	0.00000	1.14687	0.00000
2	5.3000E-04	1.1268E+00	NM	1.12736	0.46006	0.51809	1.26816	0.40854
3	9.0000E-04	1.0990E+00	NM	1.00467	0.40829	0.43560	1.13825	0.38269
4	1.3100E-03	1.1055E+00	NM	1.00350	0.42110	0.44863	1.13500	0.39526
5	1.7200E-03	1.1091E+00	NM	1.01021	0.42802	0.45731	1.14152	0.40061
6	2.1400E-03	1.1080E+00	NM	1.01356	0.42590	0.45586	1.14564	0.39791
7	2.5700E-03	1.1125E+00	NM	1.01327	0.43433	0.46454	1.14399	0.40607
8	2.9900E-03	1.1123E+00	NM	1.01469	0.43401	0.46454	1.14564	0.40549
9	3.4000E-03	1.1191E+00	NM	1.00272	0.44651	0.47467	1.13016	0.42001
10	3.8300E-03	1.1267E+00	NM	1.00538	0.45995	0.48915	1.13096	0.43250
11	4.2300E-03	1.1220E+00	NM	1.01065	0.45170	0.48191	1.13825	0.42338
12	4.6700E-03	1.1279E+00	NM	1.00855	0.46202	0.49204	1.13419	0.43383
13	5.0900E-03	1.1147E+00	NM	1.00732	0.43845	0.46744	1.13662	0.41125
14	5.5100E-03	1.1263E+00	NM	1.00885	0.45914	0.48915	1.13500	0.43097
15	5.9400E-03	1.1278E+00	NM	1.01505	0.46189	0.49349	1.14152	0.43231
16	6.3600E-03	1.1264E+00	NM	1.01981	0.45937	0.49204	1.14729	0.42887
17	6.7800E-03	1.1543E+00	NM	1.01090	0.50522	0.53690	1.12935	0.47541
18	7.2000E-03	1.1425E+00	NM	1.01226	0.48648	0.51809	1.13419	0.45679
19	7.6300E-03	1.1496E+00	NM	1.00050	0.49797	0.52677	1.11901	0.47075
20	8.0500E-03	1.1594E+00	NM	1.00788	0.51312	0.54414	1.12455	0.48387
21	8.4700E-03	1.1698E+00	NM	1.00266	0.52881	0.55861	1.11587	0.50061
22	8.8900E-03	1.1719E+00	NM	0.99687	0.53186	0.56006	1.10886	0.50507
23	9.3100E-03	1.1656E+00	NM	0.99952	0.52251	0.55137	1.11352	0.49516
24	9.7400E-03	1.1854E+00	NM	1.00504	0.55112	0.58177	1.11431	0.52209
25	1.0160E-02	1.1704E+00	NM	1.00990	0.52968	0.56151	1.12376	0.49967
26	1.0590E-02	1.1955E+00	NM	1.00677	0.56503	0.59624	1.11352	0.53545
27	1.1000E-02	1.2050E+00	NM	1.00764	0.57777	0.60926	1.11197	0.54791
28	1.1430E-02	1.1969E+00	NM	1.00501	0.56699	0.59768	1.11119	0.53788
29	1.1850E-02	1.2302E+00	NM	1.00241	0.60998	0.63965	1.09965	0.58169
30	1.2270E-02	1.2261E+00	NM	1.00491	0.60479	0.63531	1.10347	0.57574
31	1.2690E-02	1.2149E+00	NM	1.00790	0.59074	0.62229	1.10964	0.56080
32	1.3110E-02	1.2312E+00	NM	1.01244	0.61114	0.64399	1.11041	0.57996
33	1.4160E-02	1.2392E+00	NM	1.00034	0.62093	0.64978	1.09511	0.59335
34	1.5220E-02	1.2727E+00	NM	1.00799	0.65965	0.69030	1.09511	0.63035
35	1.6270E-02	1.3063E+00	NM	1.01133	0.69565	0.72648	1.09060	0.66613
36	1.7320E-02	1.3049E+00	NM	1.01521	0.69422	0.72648	1.09511	0.66339
37	1.8380E-02	1.3593E+00	NM	1.00905	0.74785	0.77569	1.07583	0.72101
38	1.9430E-02	1.3548E+00	NM	0.99329	0.74356	0.76556	1.06004	0.72220
39	2.0490E-02	1.3703E+00	NM	0.99189	0.75797	0.77858	1.05511	0.73791
40	2.1540E-02	1.4137E+00	NM	0.99615	0.79645	0.81621	1.05023	0.77717
41	2.2600E-02	1.4177E+00	NM	0.99562	0.79980	0.81910	1.04884	0.78096
42	2.3650E-02	1.4245E+00	NM	1.00362	0.80561	0.82779	1.05581	0.78403
43	2.4710E-02	1.4841E+00	NM	1.00211	0.85348	0.87120	1.04197	0.83611
44	2.5770E-02	1.4674E+00	NM	1.00615	0.84050	0.86107	1.04954	0.82043
45	2.6830E-02	1.4918E+00	NM	0.99967	0.85942	0.87554	1.03788	0.84358
46	2.7870E-02	1.4937E+00	NM	1.00003	0.86084	0.87699	1.03788	0.84498
47	2.8930E-02	1.5262E+00	NM	0.99967	0.88502	0.89870	1.03115	0.87155
48	2.9970E-02	1.5396E+00	NM	1.00609	0.89467	0.91027	1.03518	0.87934
49	3.1030E-02	1.5689E+00	NM	1.00368	0.91530	0.92764	1.02715	0.90312
50	3.2080E-02	1.6157E+00	NM	1.00306	0.94668	0.95514	1.01794	0.93831
51	3.3140E-02	1.5996E+00	NM	0.99828	0.93611	0.94356	1.01598	0.92871
52	3.4200E-02	1.6205E+00	NM	1.00328	0.94986	0.95803	1.01729	0.94175
53	3.5250E-02	1.6382E+00	NM	1.00062	0.96122	0.96671	1.01146	0.95576
54	3.6310E-02	1.6489E+00	NM	1.00633	0.96800	0.97540	1.01534	0.96067
55	3.7360E-02	1.6432E+00	NM	1.00086	0.96441	0.96961	1.01081	0.95924
56	3.8420E-02	1.6754E+00	NM	1.00070	0.98449	0.98698	1.00506	0.98201
57	4.0520E-02	1.6809E+00	NM	0.99784	0.98780	0.98842	1.00126	0.98718
58	4.2620E-02	1.6846E+00	NM	0.99098	0.99008	0.98698	0.99375	0.99319
59	4.4720E-02	1.6854E+00	NM	1.00177	0.99057	0.99276	1.00442	0.98839
60	4.6850E-02	1.6904E+00	NM	0.99946	0.99359	0.99421	1.00126	0.99296
61	4.8950E-02	1.6952E+00	NM	1.00027	0.99648	0.99711	1.00126	0.99585
62	5.1050E-02	1.7046E+00	NM	0.99933	1.00208	1.00145	0.99874	1.00271
63	5.3160E-02	1.7011E+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000
64	5.5250E-02	1.6928E+00	NM	0.99986	0.99503	0.99566	1.00126	0.99441
65	5.7360E-02	1.6866E+00	NM	0.99756	0.99132	0.99132	1.00000	0.99132
66	5.9480E-02	1.7124E+00	NM	0.99438	1.00667	1.00289	0.99250	1.01047
67	6.1600E-02	1.7043E+00	NM	0.98810	1.00190	0.99566	0.98757	1.00819
68	6.3710E-02	1.6921E+00	NM	0.98608	0.99462	0.98842	0.98757	1.00086
69	6.5790E-02	1.6775E+00	NM	0.99852	0.98573	0.98698	1.00252	0.98449
70	6.7910E-02	1.6739E+00	NM	1.00234	0.98355	0.98698	1.00697	0.98014
71	7.0020E-02	1.6819E+00	NM	1.01140	0.98843	0.99566	1.01469	0.98125
72	7.2120E-02	1.6816E+00	NM	1.00877	0.98825	0.99421	1.01210	0.98232
73	7.4240E-02	1.6757E+00	NM	1.00330	0.98468	0.98842	1.00761	0.98096
74	7.6340E-02	1.6851E+00	NM	0.99919	0.99038	0.99132	1.00189	0.98945
75	7.8450E-02	1.6574E+00	NM	0.99384	0.97334	0.97395	1.00126	0.97272
76	8.0560E-02	1.6448E+00	NM	0.99607	0.96542	0.96816	1.00570	0.96268
77	8.2680E-02	1.6625E+00	NM	1.01781	0.97653	0.98842	1.02450	0.96479
78	8.4790E-02	1.6630E+00	NM	1.01136	0.97681	0.98553	1.01794	0.96816
79	8.6890E-02	1.6544E+00	NM	0.99711	0.97150	0.97395	1.00506	0.96905
80	8.9000E-02	1.6328E+00	NM	0.98588	0.95779	0.95658	0.99749	0.95899
81	9.1110E-02	1.6350E+00	NM	0.98936	0.95918	0.95948	1.00063	0.95888

INPUT VARIABLES Y,U/UD,RHD/RHDD ASSUME P=PD
 AT I= 41 VALUES OF INPUT PROFILES WERE AVERAGED BECAUSE OF SAME Y

8001S01G5

MATEER

PROFILE TABULATION

83 POINTS, DELTA AT POINT 64

I	Y	PT2/P	P/PD	TO/TOD	M/MD	U/UD	T/TD	R/RD*U/UD
1	0.0000"-00	1.0000"+00	NM	0.98578	0.00000	0.00000	1.14189	0.00000
2	6.7000"-04	1.1183"+00	NM	1.01749	0.45274	0.48373	1.14156	0.42374
3	1.0600"-03	1.1290"+00	NM	1.01527	0.47190	0.50296	1.13598	0.44275
4	1.5000"-03	1.1338"+00	NM	1.00460	0.48027	0.50888	1.12267	0.45327
5	1.9200"-03	1.1544"+00	NM	0.99674	0.51432	0.54142	1.10816	0.48857
6	2.3000"-03	1.1379"+00	NM	0.99945	0.48736	0.51479	1.11575	0.46139
7	2.7300"-03	1.1586"+00	NM	0.99980	0.52081	0.54882	1.11043	0.49424
8	3.1600"-03	1.1522"+00	NM	1.00440	0.51082	0.53994	1.11728	0.48326
9	3.5900"-03	1.1517"+00	NM	1.00772	0.50994	0.53994	1.12113	0.48160
10	4.0000"-03	1.1844"+00	NM	1.00887	0.55936	0.59024	1.11347	0.53009
11	4.4400"-03	1.1528"+00	NM	1.01217	0.51167	0.54290	1.12578	0.48224
12	4.8500"-03	1.1670"+00	NM	1.00599	0.53376	0.56361	1.11499	0.50548
13	5.2700"-03	1.1691"+00	NM	0.99967	0.53699	0.56509	1.10741	0.51028
14	5.7100"-03	1.1504"+00	NM	0.99371	0.50781	0.53402	1.10591	0.48288
15	6.1300"-03	1.1902"+00	NM	0.99130	0.56751	0.59320	1.09256	0.54294
16	6.5400"-03	1.1787"+00	NM	0.99658	0.55113	0.57840	1.10142	0.52514
17	6.9500"-03	1.1659"+00	NM	1.00160	0.53204	0.56065	1.11043	0.50490
18	7.3800"-03	1.1692"+00	NM	1.00447	0.53711	0.56657	1.11270	0.50918
19	7.8100"-03	1.1995"+00	NM	1.00770	0.58037	0.61095	1.10816	0.55131
20	8.2300"-03	1.1961"+00	NM	1.01310	0.57578	0.60799	1.11499	0.54529
21	8.6400"-03	1.1980"+00	NM	1.01914	0.57840	0.61243	1.12113	0.54626
22	9.0600"-03	1.1859"+00	NM	1.02181	0.56148	0.59615	1.12734	0.52882
23	9.5000"-03	1.2079"+00	NM	1.01873	0.59178	0.62574	1.11805	0.55967
24	9.9100"-03	1.2092"+00	NM	1.00864	0.59342	0.62426	1.10666	0.56410
25	1.0340"-02	1.1948"+00	NM	1.00452	0.57392	0.60355	1.10591	0.54575
26	1.0760"-02	1.1854"+00	NM	1.00430	0.56069	0.59024	1.10816	0.53263
27	1.1190"-02	1.2087"+00	NM	1.00580	0.59281	0.62278	1.10366	0.56429
28	1.1620"-02	1.2206"+00	NM	1.00861	0.60830	0.63905	1.10366	0.57903
29	1.2030"-02	1.2262"+00	NM	1.00927	0.61555	0.64645	1.10291	0.58613
30	1.2450"-02	1.2203"+00	NM	1.00514	0.60792	0.63757	1.09993	0.57965
31	1.2870"-02	1.2252"+00	NM	0.99488	0.61424	0.64053	1.08745	0.58902
32	1.3290"-02	1.2242"+00	NM	0.98937	0.61303	0.63757	1.08167	0.58943
33	1.4340"-02	1.2445"+00	NM	0.99535	0.63821	0.66420	1.08311	0.61323
34	1.5390"-02	1.2620"+00	NM	1.00132	0.65887	0.68639	1.08528	0.63246
35	1.6440"-02	1.2635"+00	NM	1.00301	0.66061	0.68935	1.08890	0.63307
36	1.7500"-02	1.3021"+00	NM	1.00897	0.70336	0.73225	1.08383	0.67561
37	1.8530"-02	1.3032"+00	NM	1.01394	0.70456	0.73521	1.08890	0.67518
38	1.9600"-02	1.3596"+00	NM	1.01141	0.76112	0.78846	1.07312	0.73474
39	2.0660"-02	1.3620"+00	NM	1.00595	0.76338	0.78846	1.06680	0.73909
40	2.1720"-02	1.3588"+00	NM	0.99809	0.76037	0.78254	1.05917	0.73883
41	2.2770"-02	1.4053"+00	NM	0.99478	0.80291	0.82101	1.04557	0.78522
42	2.3820"-02	1.4245"+00	NM	0.99674	0.81962	0.83728	1.04356	0.80233
43	2.4850"-02	1.4440"+00	NM	0.99934	0.83608	0.85355	1.04223	0.81897
44	2.5890"-02	1.4515"+00	NM	1.00339	0.84225	0.86095	1.04490	0.82395
45	2.6950"-02	1.4499"+00	NM	1.00629	0.84089	0.86095	1.04826	0.82131
46	2.7980"-02	1.4910"+00	NM	1.00852	0.87375	0.89201	1.04223	0.85587
47	2.9040"-02	1.5083"+00	NM	1.00799	0.88704	0.90385	1.03824	0.87056
48	3.0070"-02	1.5420"+00	NM	1.00730	0.91200	0.92604	1.03101	0.89818
49	3.1140"-02	1.5187"+00	NM	1.00547	0.89484	0.90976	1.03363	0.88016
50	3.2180"-02	1.5288"+00	NM	1.00357	0.90237	0.91568	1.02971	0.88926
51	3.3260"-02	1.5815"+00	NM	1.00131	0.94004	0.94822	1.01749	0.91793
52	3.4310"-02	1.5905"+00	NM	0.99918	0.94621	0.95266	1.01369	0.93980
53	3.5380"-02	1.5693"+00	NM	0.99847	0.93153	0.93935	1.01685	0.92378
54	3.6410"-02	1.6162"+00	NM	1.00128	0.96357	0.96893	1.01117	0.95823
55	3.7480"-02	1.5961"+00	NM	1.00143	0.95002	0.95710	1.01495	0.94300
56	3.8520"-02	1.6167"+00	NM	1.00074	0.96387	0.96893	1.01055	0.95882
57	3.9590"-02	1.6384"+00	NM	0.99652	0.97809	0.97929	1.00245	0.97689
58	4.1660"-02	1.6379"+00	NM	0.98955	0.99062	0.98669	0.99208	0.99456
59	4.3790"-02	1.6375"+00	NM	0.99149	0.97753	0.97633	0.99755	0.97873
60	4.5910"-02	1.6721"+00	NM	0.99195	0.99953	0.99556	0.99208	1.00351
61	4.7990"-02	1.6682"+00	NM	0.99615	0.99709	0.99556	0.99694	0.99862
62	5.0110"-02	1.6705"+00	NM	0.99655	0.99857	0.99704	0.99694	1.00010
63	5.2210"-02	1.6691"+00	NM	0.99813	0.99765	0.99704	0.99877	0.99827
D 64	5.4320"-02	1.6728"+00	NM	1.00000	1.00000	1.00000	1.00000	1.00000
65	5.6430"-02	1.6733"+00	NM	0.99947	1.00031	1.00000	0.99939	1.00061
66	5.8530"-02	1.6748"+00	NM	0.99789	1.00123	1.00000	0.99755	1.00246
67	6.0660"-02	1.6762"+00	NM	0.99935	1.00209	1.00148	0.99877	1.00271
68	6.2730"-02	1.6568"+00	NM	0.99971	0.98991	0.99112	1.00246	0.98869
69	6.4870"-02	1.6661"+00	NM	1.00132	0.99582	0.99704	1.00246	0.99459
70	6.6940"-02	1.6747"+00	NM	1.00094	1.00117	1.00148	1.00061	1.00086
71	6.9070"-02	1.6762"+00	NM	0.99935	1.00209	1.00148	0.99877	1.00271
72	7.1190"-02	1.6606"+00	NM	0.99852	0.99230	0.99260	1.00061	0.99199
73	7.3290"-02	1.6494"+00	NM	0.99904	0.98517	0.98669	1.00308	0.98366
74	7.5420"-02	1.6420"+00	NM	0.99838	0.98044	0.98225	1.00370	0.97863
75	7.7510"-02	1.6475"+00	NM	1.00118	0.98396	0.98669	1.00556	0.98124
76	7.9620"-02	1.6347"+00	NM	1.00080	0.97568	0.97929	1.00742	0.97208
77	8.1730"-02	1.6315"+00	NM	1.00148	0.97360	0.97781	1.00867	0.96941
78	8.3840"-02	1.6283"+00	NM	0.99908	0.97156	0.97485	1.00680	0.96827
79	8.5950"-02	1.6338"+00	NM	0.99880	0.97511	0.97781	1.00556	0.97241
80	8.8060"-02	1.6270"+00	NM	0.99761	0.97068	0.97337	1.00556	0.96800
81	9.0160"-02	1.6230"+00	NM	0.99937	0.96801	0.97189	1.00804	0.96414
82	9.2270"-02	1.6198"+00	NM	1.00005	0.96594	0.97041	1.00929	0.96148
83	9.4380"-02	1.6189"+00	NM	1.00424	0.96531	0.97189	1.01369	0.95877

INPUT VARIABLES Y,U/UD,RHO/RHOD ASSUME P=PD

8001S

MATEER

TURBULENCE DATA

8001S0101 UT= 1.4493E+01 RHOW= 5.0933E-01 TW= 2.7990E+02 D*= 9.1879E-02
 8001S0103 UT= 5.6157E+00 RHOW= 9.3735E-01 TW= 2.8137E+02 D*= 5.9400E-01
 8001S0104 UT= 6.6470E+00 RHOW= 9.8788E-01 TW= 2.7708E+02 D*= 4.5489E-01

8001S0101			8001S0103		8001S0104	
I	Y [M]	RHO*U*V RHOW*UT2	Y [M]	RHO*U*V RHOW*UT2	Y [M]	RHO*U*V RHOW*UT2
1	1.5900E-3	6.7165E-3	2.0300E-3	-6.5984E-1	4.0600E-3	-6.7987E+0
2	2.0300E-3	-4.8309E-2	2.5400E-3	-9.1927E-1	4.5700E-3	-6.3785E+0
3	2.5400E-3	-5.3608E-2	2.7900E-3	-8.4031E+0	4.8300E-3	-1.6386E+1
4	2.7900E-3	-6.4516E-2	3.3000E-3	-1.0321E+1	5.8400E-3	-8.3647E+0
5	3.3000E-3	-4.8777E-2	4.0600E-3	-1.1731E+1	6.6000E-3	-1.0236E+1
6	3.8100E-3	-5.1582E-2	5.0800E-3	-1.6299E+1	7.3700E-3	-1.2108E+1
7	4.0600E-3	1.4321E-2	6.3500E-3	-1.7032E+1	8.6400E-3	-1.2337E+1
8	4.5700E-3	-2.9609E-2	7.1100E-3	-1.9626E+1	9.9100E-3	-1.5507E+1
9	5.0800E-3	-6.3269E-2	8.6400E-3	-2.5773E+1	9.9100E-3	-1.4629E+1
10	5.3300E-3	-6.3581E-2	1.0160E-2	-2.4363E+1	1.1180E-2	-1.4896E+1
11	5.8400E-3	-1.1173E-1	1.0920E-2	-2.2672E+1	1.2450E-2	-1.5125E+1
12	6.3500E-3	-2.2596E-1	1.2700E-2	-2.1544E+1	1.3720E-2	-1.4017E+1
13	6.6000E-3	-2.0570E-1	1.4220E-2	-1.5171E+1	1.5240E-2	-1.4476E+1
14	7.1100E-3	-3.7245E-1	1.5240E-2	-1.3986E+1	1.7270E-2	-1.3559E+1
15	7.6200E-3	-3.0856E-1	1.7530E-2	-7.3316E+0	1.9560E-2	-1.1267E+1
16	7.8700E-3	-3.7401E-1	5.2070E-2	2.3517E+0	2.0570E-2	-8.2119E+0
17	8.3800E-3	-4.3478E-1	6.0710E-2	3.6827E+0	2.1590E-2	-1.1802E+1
18	8.8900E-3	-4.6439E-1	6.9090E-2	3.7899E+0	2.3620E-2	-8.4029E+0
19	9.1400E-3	-4.8153E-1	7.1120E-2	4.0549E+0	2.5910E-2	-7.7154E+0
20	9.6500E-3	-5.7192E-1	7.7470E-2	3.2033E+0	2.8960E-2	-6.6459E+0
21	1.0160E-2	-5.6101E-1	8.7880E-2	NM	3.2000E-2	-5.4619E-1
22	1.0410E-2	-5.2673E-1	9.8550E-2	NM	5.0040E-2	3.5903E+0
23	1.0920E-2	-5.3452E-1	1.0185E-1	NM	5.6390E-2	3.8042E+0
24	1.1430E-2	-5.6257E-1			6.2480E-2	2.9868E+0
25	1.1680E-2	-5.6101E-1			6.8830E-2	2.5476E+0
26	1.2190E-2	-5.0647E-1			7.1120E-2	3.1854E+0
27	1.2950E-2	-4.7998E-1			7.5180E-2	2.5285E+0
28	1.3460E-2	-4.7218E-1			8.1530E-2	2.9601E+0
29	1.3970E-2	-4.9088E-1			8.7880E-2	1.4705E+0
30	1.4220E-2	-4.4881E-1			9.3980E-2	NM
31	1.4730E-2	-5.2673E-1			9.6270E-2	NM
32	1.5750E-2	-4.2543E-1			9.8550E-2	NM
33	1.6760E-2	-3.8492E-1			1.0160E-1	NM
34	1.8800E-2	-2.6180E-1				
35	1.9810E-2	-2.9609E-1				
36	2.1080E-2	-1.7609E-1				
37	2.2100E-2	-2.0103E-1				
38	2.3110E-2	-1.8233E-1				
39	2.4130E-2	-1.1002E-1				
40	2.5150E-2	-1.0114E-1				
41	2.7430E-2	-6.2802E-2				
42	2.8450E-2	-4.7218E-2				
43	3.1240E-2	-4.6283E-2				
44	3.1750E-2	-2.5245E-2				
45	3.4800E-2	3.6621E-2				
46	3.8100E-2	0.				
47	4.2160E-2	5.8439E-2				
48	4.8510E-2	7.9476E-2				
49	5.2580E-2	8.6489E-2				
50	5.8930E-2	1.2451E-1				
51	6.3250E-2	1.3386E-1				
52	6.7560E-2	1.2950E-1				
53	7.1630E-2	1.2062E-1				
54	7.5690E-2	1.0722E-1				
55	8.0010E-2	8.3372E-2				
56	8.6360E-2	1.0799E-1				
57	8.8390E-2	8.8671E-2				
58	9.2710E-2	6.3425E-2				
59	9.7030E-2	NM				
60	9.9060E-2	NM				

8001S

MATEER

TURBULENCE DATA

8001S0105 UT= 7.0451E+00 RHOW= 1.0172E+00 TW= 2.7331E+02 D*= 4.0743E-01
 8001S0106 UT= 7.4847E+00 RHOW= 1.0244E+00 TW= 2.7417E+02 D*= 3.7059E-01
 8001S0107 UT= 7.8986E+00 RHOW= 1.0414E+00 TW= 2.7241E+02 D*= 3.4393E-01

8001S0105			8001S0106			8001S0107		
I	Y [M]	RHO*U*V RHOW*UT2	Y [M]	RHO*U*V RHOW*UT2	Y [M]	RHO*U*V RHOW*UT2		
1	7.1100E-3	-7.4960E+0	2.0300E-3	-1.1039E+0	2.0300E-3	-1.0802E+0		
2	7.8700E-3	-8.2886E+0	2.5400E-3	-1.2521E-1	2.5400E-3	-1.6601E+0		
3	8.8900E-3	-7.4960E+0	2.7900E-3	-1.7430E+0	2.7900E-3	-1.9038E+0		
4	1.0160E-2	-9.5434E+0	3.3000E-3	-3.0793E+0	3.3000E-3	-2.3451E+0		
5	1.1430E-2	-9.6425E+0	4.0600E-3	-3.6313E+0	4.0600E-3	-2.3785E+0		
6	1.2700E-2	-1.0930E+1	5.0800E-3	-3.8056E+0	5.0800E-3	-3.4125E+0		
7	1.3970E-2	-1.1591E+1	5.8400E-3	-4.5028E+0	5.8400E-3	-4.6697E+0		
8	1.5240E-2	-1.1690E+1	6.6000E-3	-4.8514E+0	7.1100E-3	-4.8750E+0		
9	1.7530E-2	-9.8406E+0	7.8700E-3	-6.5364E+0	8.6400E-3	-6.2348E+0		
10	2.0570E-2	-9.6094E+0	9.1400E-3	-6.0715E+0	1.0410E-2	-7.3638E+0		
11	2.3620E-2	-7.1328E+0	1.0410E-2	-7.8146E+0	1.1680E-2	-7.4408E+0		
12	2.6920E-2	-3.7975E+0	1.2190E-2	-7.1755E+0	1.2950E-2	-8.0822E+0		
13	2.9970E-2	-3.3352E+0	1.3460E-2	-8.6861E+0	1.4220E-2	-7.2868E+0		
14	3.3270E-2	-8.1565E-1	1.4730E-2	-8.6280E+0	1.6260E-2	-8.5697E+0		
15	6.2740E-2	3.3683E+0	1.6760E-2	-9.5866E+0	1.9560E-2	-9.2625E+0		
16	6.6040E-2	3.5334E+0	2.0070E-2	-8.0760E+0	2.2610E-2	-8.1079E+0		
17	6.9090E-2	3.3022E+0	2.3110E-2	-5.8972E+0	2.5910E-2	-6.5684E+0		
18	7.5440E-2	2.4469E+0	2.7430E-2	-7.2336E+0	2.9970E-2	-6.7737E+0		
19	8.1790E-2	2.3710E+0	3.1750E-2	-3.7185E+0	3.4290E-2	-4.6184E+0		
20	8.8140E-2	2.2323E+0	3.4540E-2	-2.9631E+0	3.7590E-2	-3.7460E+0		
21	9.4490E-2	NM	3.7850E-2	-1.8069E+0	4.0640E-2	4.5414E+0		
22	9.8550E-2	NM	5.5880E-2	3.8056E+0	4.3690E-2	5.0546E+0		
23	1.0185E-1	NM	6.2230E-2	3.1084E+0	4.8010E-2	4.0796E+0		
24			6.8580E-2	3.1374E+0	5.6130E-2	3.2072E+0		
25			7.4930E-2	4.2704E+0	6.2990E-2	2.6684E+0		
26			8.3060E-2	5.2291E+0	6.9090E-2	2.6941E+0		
27			9.1440E-2	4.6771E+0	7.5440E-2	3.5664E+0		
28			9.7790E-2	NM	8.1790E-2	3.4381E+0		
29					8.8140E-2	3.1302E+0		
30					9.4490E-2	2.8224E+0		
31					9.8550E-2	2.5658E+0		
32					1.0185E-1	2.2117E+0		

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