

AD-A152 162

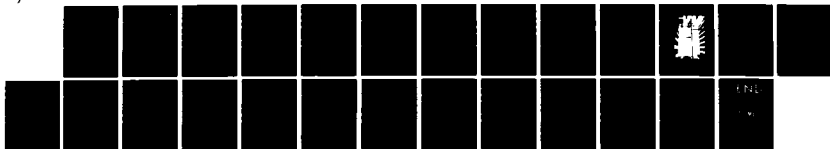
THE DETERMINATION OF DRAG OF A CIRCULATION CONTROL
AIRFOIL TESTED IN THE 7... (U) DAVID W TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER BET.. T C TAI APR 81

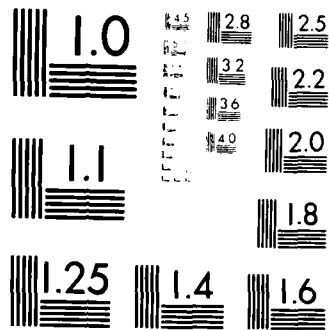
1/1

UNCLASSIFIED

F/G 28/4

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A152 162

THE DETERMINATION OF DRAG OF A CIRCULATION CONTROL AIRFOIL TESTED IN THE 7- BY 10-FOOT TRANSONIC WIND TUNNEL

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084



THE DETERMINATION OF DRAG OF A CIRCULATION CONTROL
AIRFOIL TESTED IN THE 7- BY 10-FOOT TRANSONIC WIND TUNNEL

by

Tsze C. Tai

David Taylor Naval Ship Research and Development Center
Bethesda, Maryland, U.S.A.

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

DTIC FILE COPY

Paper Presented at
55th Semiannual Meeting
Supersonic Tunnel Association
Amsterdam, The Netherlands

27-29 April 1981

DTIC
ELECTE
3 APR 9 1985
A

THE DETERMINATION OF DRAG OF A CIRCULATION CONTROL
AIRFOIL TESTED IN THE 7- BY 10-FOOT TRANSONIC WIND TUNNEL

by

Tsze C. Tai

David Taylor Naval Ship Research and Development Center
Bethesda, Maryland, U.S.A.

Paper Presented at
55th Semiannual Meeting
Supersonic Tunnel Association
Amsterdam, The Netherlands

27-29 April 1981

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By
Dist
Av
Dist



ABSTRACT

A special procedure for using the Jones method for determining the profile drag in highly disturbed wake behind a circulation control airfoil is proposed. The procedure suggests that the value of the freestream dynamic pressure be adjusted so that the baseline of the integrand in the Jones method coincides with the zero reference line. Excellent agreement was observed between the results of the new procedure and those of the simultaneous solution values of the Jones and the Squire-Young methods.

INTRODUCTION

The drag of a two-dimensional airfoil in a wind tunnel usually can be determined in three ways; namely, (a) integration of the surface pressure force in the free-stream direction along with the skin friction, (b) integration of the momentum deficiency in the wake sufficiently far downstream of the airfoil, and (c) direct force measurement. Approach (a) has been found to yield serious inaccuracies^{1,2,3} which far exceed theoretical expectations. Approach (c), on the other hand, is relatively inconvenient to implement. The momentum deficiency method, Approach (b) therefore, often has been employed by experimental aerodynamicists because of its simplicity and reliability.

The approach involves the measurements of traversing ~~pitot~~^{pitot} and static tubes across the wake of the airfoil. The experimental data can then be deduced either by the method of Betz or that of Jones⁴. These methods offer reasonable accuracy in conventional airfoils at small to moderate angles of attack. For airfoils at high angles of attack or bluff bodies where the fluctuations of the downstream flow are caused by the shedding of vortices, either method tends to erroneous results.⁵ Other critical comments on these methods are given by Taylor.⁶

In testing the circulation control airfoil in a wind tunnel,* the determination of drag presents a problem that has not been considered previously. As opposed to the conventional airfoil, a typical circulation control airfoil is equipped with a blowing slot on the upper surface for energizing the flow in the viscous layer and a rounded trailing edge for deflecting the jet. The presence of the blowing jet and its influence on the downstream wake pattern require careful treatment in applying the usual traverse method.

*During 1977 to 1980, the circulation control airfoils have been applied to an A-6 testbed aircraft, an H-2 helicopter, and a stopped rotor (X-Wing) aircraft at DTNSRDC.

In the present paper, special consideration has been given in using the Jones method for the determination of drag of a circulation control airfoil tested in a transonic wind tunnel. To assure the drag values obtained by the new procedure, a modified Squire-Young formula has been employed and operated with the same wake data for the Jones method.

WAKE SURVEY DATA

A circulation control airfoil model, which is a 16-percent thick, cambered ellipse with a tangential blowing slot near the blunt trailing edge, was tested in the 7- by 10-ft transonic wind tunnel at the David Taylor Naval Ship Research and Development Center. The model, designated 103, has a rectangular planform with an 18-in. (45.7-cm) chord and a 10-ft (3.05-m) span. The test arrangement is depicted in Figure 1. To measure the drag of the model, a wake survey mechanism consisting of five pitot-static tubes is mounted about one-chord length downstream of the airfoil. The wake flow was then measured by moving the mechanism vertically, as schematically shown in Figure 2. The measurements include the total pressure survey and the static pressure survey. Although the tunnel has a height of 84 in. (21.3-cm), the survey mechanism travels only inside a range of -15 to 18 in. (-38.1 to 45.7 cm). Outside this range, the variation of the flow was considered minimal, and its contribution to the drag value would be negligible. A typical wake survey (Run 216) is listed in Table 1. The variation of the measured total pressures and static pressures across the wake is shown in Figure 3.

DETERMINATION OF DRAG

JONES METHOD

The drag coefficient given by the Jones method is

$$C_{D_J} = \frac{2}{c} \int_{\text{wake}} \sqrt{\frac{g_2 - p_2}{q_\infty}} \left(1 - \sqrt{\frac{g_2 - p_\infty}{q_x}} \right) dy \quad (1)$$

where g is the total pressure and p and q have their usual meaning. Suffix ∞ represents flow properties of an undisturbed stream far downstream and suffix 2 denotes those at the measuring station.

The basic advantage of using the Jones method is that it allows the wake measurement to be performed at a short distance behind the body. As the form appears, the C_{D_J} value not only depends on the direct measurements of g_2 and p_2 , but

also is very sensitive to the freestream quantities p_∞ and q_∞ . A small inaccuracy in the freestream dynamic pressure measurement may result in a large discrepancy in drag values. As indicated in Figure 4, for a given set of g_2 and p_2 , and a fixed p_∞ , a 1-percent variation in q_∞ (that is, $q_\infty = 127 \text{ lb/ft}^2 \pm 1 \text{ percent}$) yields a 30 percent variation in C_D . A 2.5-percent error in q_∞ may double the drag coefficient.

The heavy dependency on the q_∞ quantity makes the precise determination of the q_∞ value a necessity. Generally the downstream flow pattern may alter the upstream condition due to the propagation of the downstream disturbance through a subcritical stream in a transonic or subsonic test. The feedback may become noticeable (that is, a 1- to 2-percent variation in q_∞ is possible) in the case of a circulation control airfoil where the downstream flow is substantially affected by the blowing jet.

The situation for such a critical requirement is significantly eased by graphically analyzing the integrand, F , of the Jones method:

$$F = 2 \sqrt{\frac{g_2 - p_2}{q_\infty}} \left(1 - \sqrt{\frac{g_2 - p_\infty}{q_\infty}} \right) \quad (2)$$

A series of plots of F quantity across the wake survey station are shown in Figure 5 using q_∞ as the variable (Run 216, $M_\infty = 0.3$, $\alpha = -0.01$ and $C_D = 0.022$, with $p_\infty = 2002.95 \text{ lb/ft}^2$). Keeping everything fixed, a subsequent increase in q_∞ value moves the wiggling baseline of the F pyramid upward, as indicated in Figure 5. Somewhere near $q_\infty = 126 \text{ lb/ft}^2$, the F baseline coincides with the reference (zero) line. There the fluctuation of F contributes nothing to the C_D value. It is therefore postulated that q_∞ takes on the value that satisfies the condition

$$\int_{y_{\text{lower}}}^{y_a} F \, dy + \int_{y_b}^{y_{\text{upper}}} F \, dy = 0 \quad (3)$$

The determination of y_a and y_b is arbitrary, however. It may be guided by experience and observation so that the resulting C_D will be fairly independent of the arbitrariness. It is of interest to note that the distribution of F outside the main wake region is fairly equal for both the upper and lower sides, unlike those of p_2 and V_2 ; see Figures 3 and 6.

MODIFIED SQUIRE-YOUNG METHOD

This method has been popularly used for calculating the profile drag from theoretical boundary layer considerations.⁷ Two versions were formulated, one with pressure gradient and the other without it. The method was modified by Young⁸ to account for the compressibility. Although the method was developed primarily for theoretical calculations, it can also be used to determine the profile drag from wake surveys.⁹ Application of the method to given wake flows can be found elsewhere.^{1,10}

The modified Squire-Young method allowing for variation of the static pressure across the wake can be written in the form

$$C_{D_{SY}} = 2 \frac{\bar{\theta}}{c} \frac{\rho_e}{\rho_\infty} \left(\frac{u_e}{V_\infty} \right) \frac{\bar{H} + H_\infty + 1}{2} \quad (4)$$

where

$$\begin{aligned} \bar{\theta} &= \int_{\text{wake}} \frac{\rho u}{\rho_e u_e} \left(1 - \frac{u}{u_e} \right) dy - \int_{\text{wake}} \frac{p-p_e}{\rho_e u_e^2} dy \\ H &= \frac{\Delta^*}{\lambda} \\ \Delta^* &= \int_{\text{wake}} \left(1 - \frac{\rho u}{\rho_e u_e} \right) dy \\ H_\infty &= 1 + (\gamma - 1) M_\infty^2 \end{aligned} \quad (5)$$

In the case of a wake flow, the quantities ρ_e and u_e should be determined at the edge of the wake.

Using the same wake survey data of Run 216 (Table 1), the velocity profile is depicted in Figure 6. Taking the edge properties by the mean value of the first 30 points of the upper side, the results of C_D versus q_∞ were plotted in Figure 7. The figure indicates that the drag coefficients calculated by the modified Squire-Young method are fairly insensitive to the variation of the freestream velocity. As opposed to the Jones method, the drag coefficient decreases as q_∞ increases. The range of the drag coefficients calculated by the modified Squire-Young method is about the same as that found by the Jones method.

SIMULTANEOUS SOLUTION

The opposite trend of the drag coefficients calculated by the two preceding approaches offers an excellent opportunity to determine the value of q_∞ uniquely by intersecting the two C_D curves based on the same set of raw data; see Figure 8. A $q_\infty = 126.07$ from both methods can be found that yields the same C_D value ($C_D = 0.0424$). For $q_\infty = 126.07$, the integrand F of the Jones method is shown in Figure 9, where the simultaneous solution is surprisingly close to the newly proposed technique for adequately using the Jones method. The figure also shed some light regarding the selection of y_a and y_b values for Equation (3). It was found that:

$$\begin{aligned}y_a &= -0.5 \\y_b &= 0.5\end{aligned}$$

satisfy Equation (3). The nature of empiricisms for selecting y_a and y_b has not been removed, however. Further, close to the disturbed center, $y_a = -0.043$ and $y_b = 0.08$ will also satisfy Equation (3). By the same token, one finds that numerous pairs of y_a and y_b values exist when they move away from the disturbed center (i.e., toward y_{upper} and y_{lower}). As a rule of thumb, the pair $(-0.5, 0.5)$ seems to be the best choice. Inasmuch as the wiggling F baseline is close enough to the zero reference line, the C_D result should be virtually independent of the

DISCUSSION OF RESULTS

Results of drag coefficients for the circulation control airfoil (Model 19) with $\alpha = 10^\circ$ and $\mu = -0.01$ for a series of blowing coefficient C_b values (Runs 212 through 216) are summarized in Table 2. Also, an additional case of $M_\infty = 0.5$, $\alpha = 10^\circ$, and $\mu = 0$ (Run 34) was considered. For each case, the methods of Jones and modified Squire-Young were applied for three consecutive q_∞ values, with all other quantities fixed. Results of the simultaneous solution based on the two approaches are then obtained.

In all seven cases considered, the simultaneous solution consistently determines the q_∞ value that brings the baseline of the integrand F to coincide with the zero reference line. Figure 9b shows the graphical display of such a coincidence. The newly proposed special procedure for the Jones method seems to be fully supported by the modified Squire-Young analysis.

Figure 10 shows a second-order least square fit for the simultaneous solution results. Also plotted in Figure 10 are the results obtained by a preliminary data reduction program and by an earlier version of the new procedure for the Jones method. The former are labeled "Preliminary," and the latter, designated as "Earlier Version," have been reported in Reference 2. The "Earlier Version" data were formed independently by inspecting only the F baseline behavior and were never checked by any other data reduction schemes, including the Squire-Young method. It appears that the agreement between the "Earlier Version" data and the simultaneous solution values is reasonably well within the allowable experimental fluctuations. The "Preliminary" data, on the other hand, are generally 20 to 30 percent lower than the values obtained by the new procedure.

To see how the integration of the surface pressure (the so-called pressure drag) compares with the profile drag, Figure 11 is presented. Again, Run 216 is used for illustration. The integrated pressure drag coefficient was found to be $C_{dp} = 0.1185$, based on the measured surface pressures listed in Table 3. If the equation, that the total drag is the sum of the pressure drag and skin friction, less the blowing momentum coefficient² holds, a sizable negative frictional drag could result, which is physically impossible. Therefore, the idea of using the pressure drag should be discarded.

CONCLUDING REMARKS

The present work has allowed the following conclusions:

1. The Jones method is very sensitive to the fluctuation of the freestream dynamic pressure. To remedy the problem, a procedure that forces the mean of the integrand to vanish outside the disturbed region is proposed which seems to yield the correct drag values.
2. The simultaneous solution of the Jones and the modified Squire-Young methods seems to offer a reliable profile drag coefficient from the wake survey data.
3. The integration of airfoil surface pressure in the freestream direction may lead to erroneous drag values.

ACKNOWLEDGMENTS

The present work was supported by the Independent Research Program at the David Taylor Naval Ship Research and Development Center under Work Unit 1606-105. The author is indebted to S. de los Santos and R.M. Williams for their enlightening discussions. Thanks are also due to J.B. Wilkerson, J.S. Abramson, and S.M. Gottlieb for providing the wind tunnel data.

REFERENCES

1. Smith, A.M.O. and Cebeci, T., "Remarks on Methods for Predicting Viscous Drag," AGARD, CP-124, 1974.
2. Tai, T.C., Kidwell, G.H., Jr., and Vanderplaats, G.N., "Numerical Optimization of Circulation Control Airfoils," David Taylor Naval Ship R&D Center, DTNSRDC Report 80/060, Apr 1980.
3. Carlson, L.A., "TRANSEP: A Program for High Lift Separated Flow About Airfoils," NASA CR-3376, Dec 1980.
4. Schlichting, H., "Boundary Layer Theory," McGraw-Hill, 4th Edition, 1960, pp. 616-620.
5. Maull, D.J. and Bearman, P.W., "The Measurement of the Drag of Bluff Bodies by the Wake Traverse Method," Journal of the Royal Aeronautical Society, Vol. 68, Dec 1964, p. 843.
6. Taylor, G.I., "The Determination of Drag by the Pilot Traverse Method," ARC R&M 1808, Nov 1937.
7. Squire, M.B. and Young, A.D., "The Calculation of the Profile Drag of Aerofoils," ARC R and M 1838, 1937.
8. Young, A.D., "Notes on the Effect of Compressibility on Jones' Momentum Method of Measuring Profile Drag," ARC R and M 1881, 1939.
9. Firmin, M.C.P. and Cook, T.A., "Detailed Exploration of the Compressible, Viscous Flow over Two-Dimensional Aerofoils at High Reynolds Numbers," ICAS Paper No. 68-09, 1968.
10. Zwaaneveld, J., "Comparison of Various Methods for Calculating Profile Drag from Pressure Measurements in the Near Wake at Subcritical Speeds," AGARD CP-124, 1974.

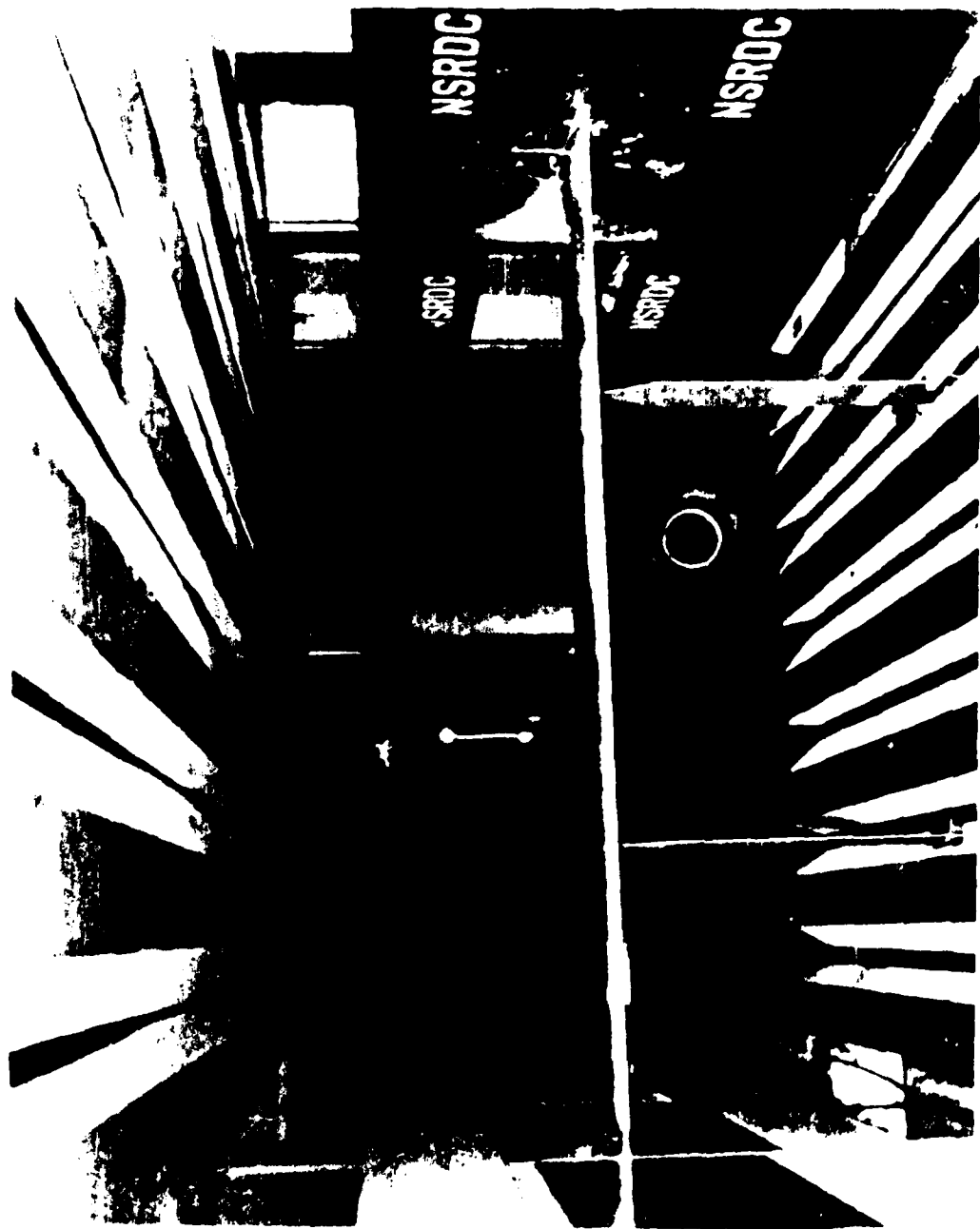


Fig. 1 - The Circulation Control Arrangement Model Installed in the
NSRDC Building, Washington, D.C.

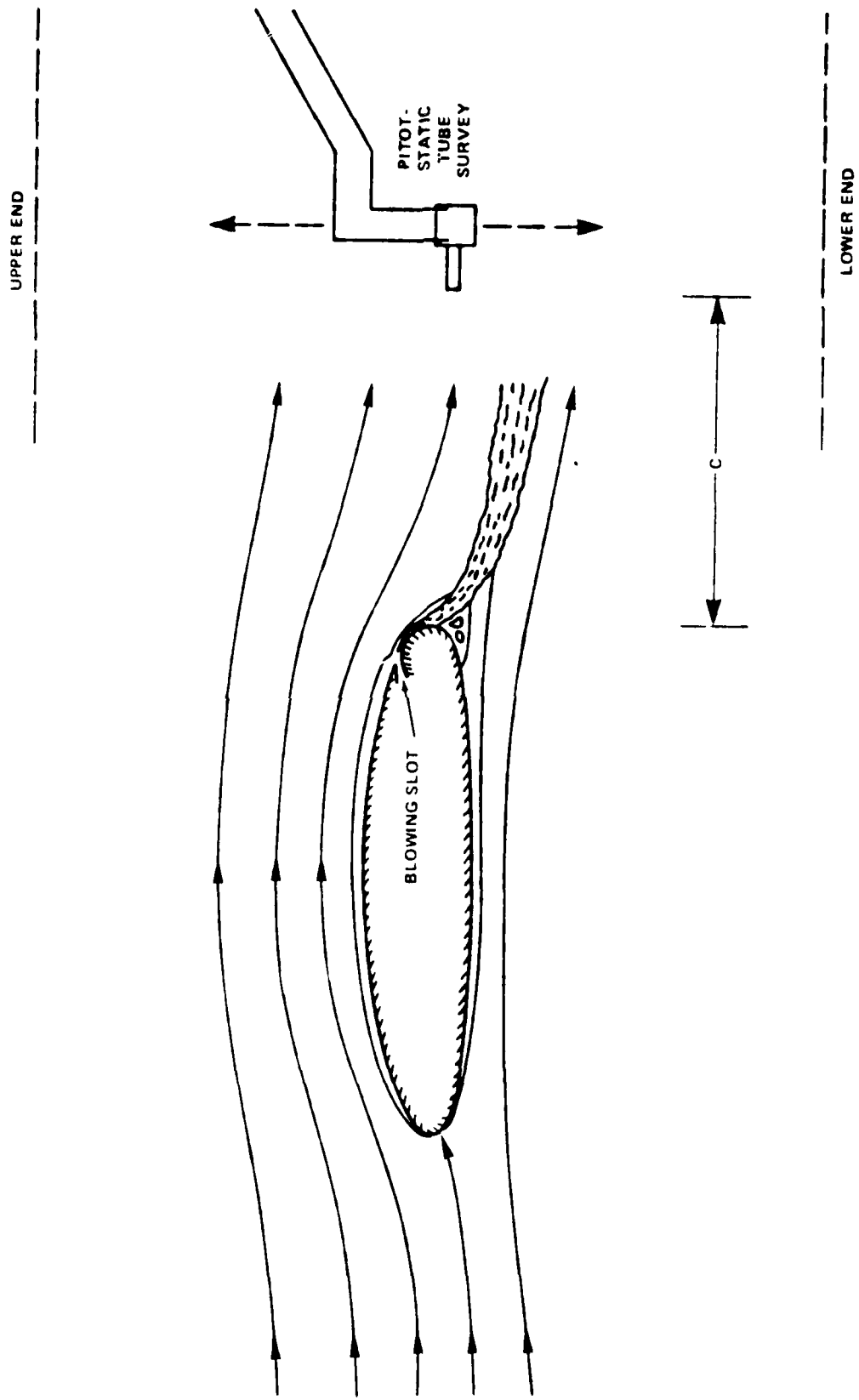


Fig. 2 - Schematic of the wake survey

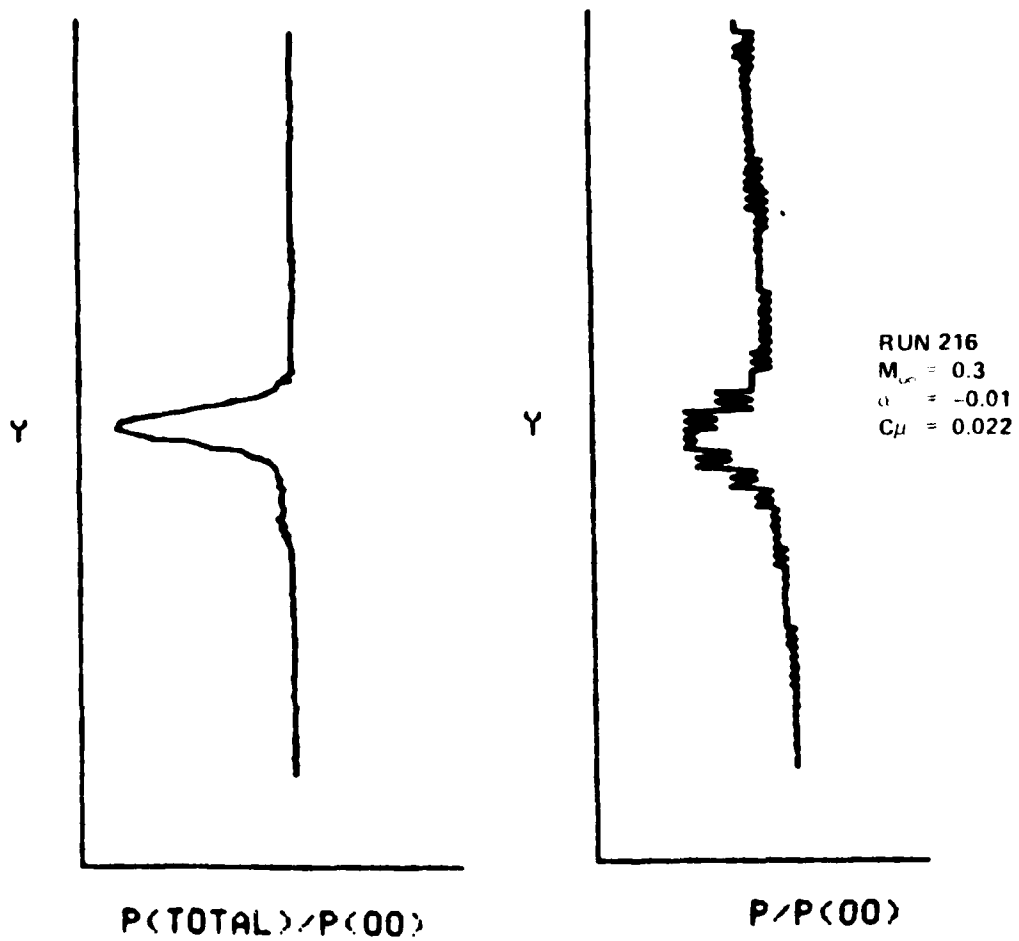


Fig. 3 - Total and Static Pressure Profiles Measured in the Wake of a Circulation Control Airfoil

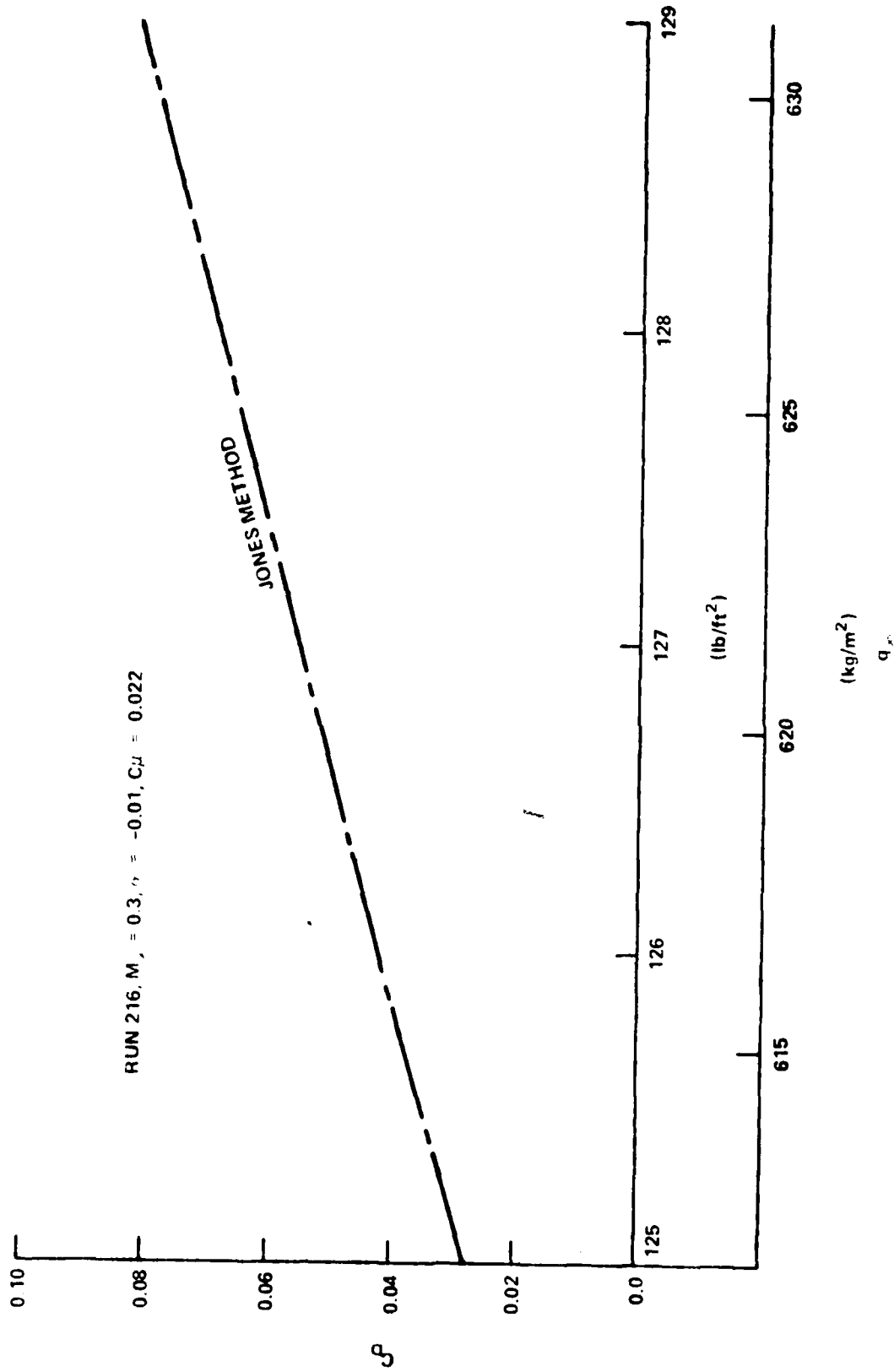


Fig. 4 - Effect of Freestream Dynamic Pressure Variation on Drag Coefficient Using the Jones Method

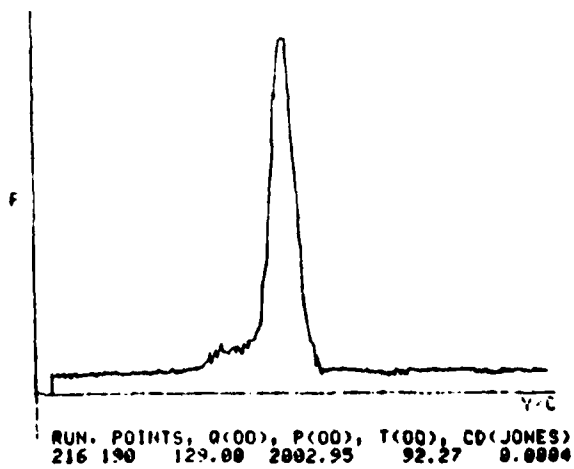
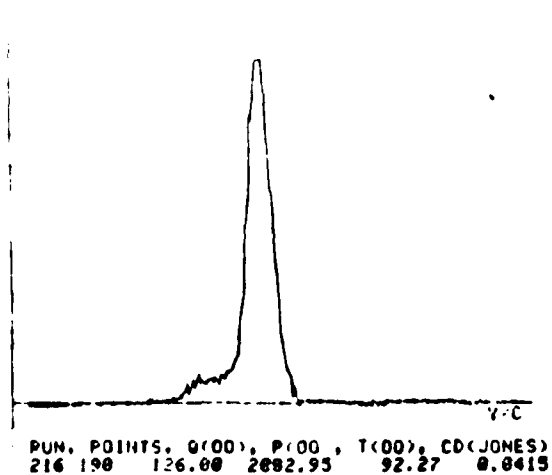
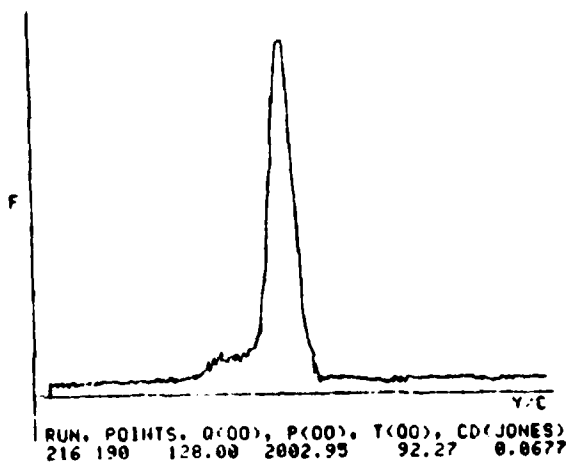
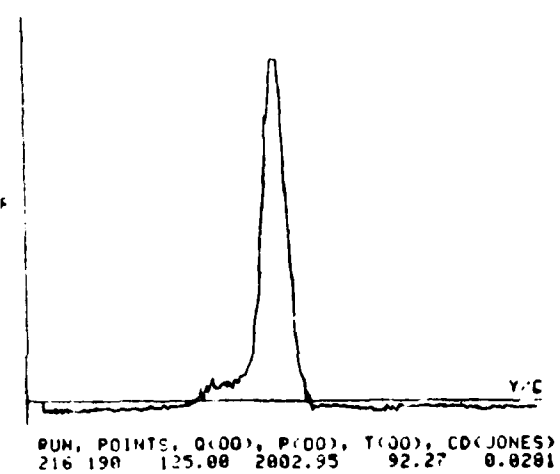
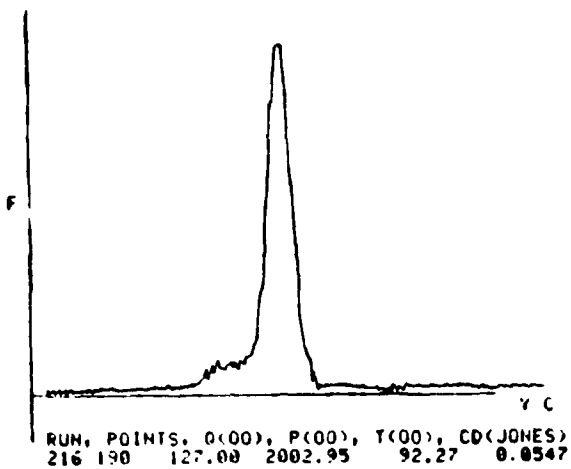
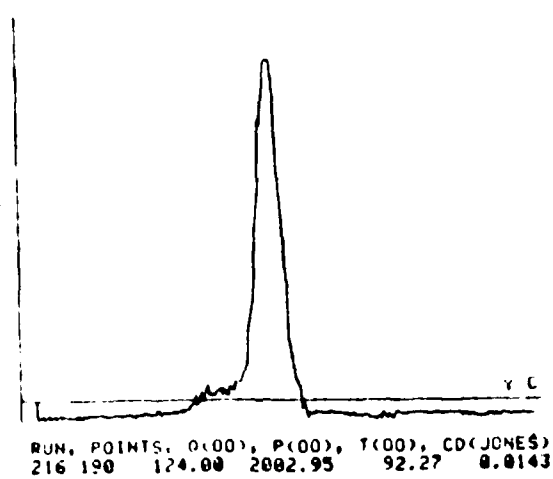
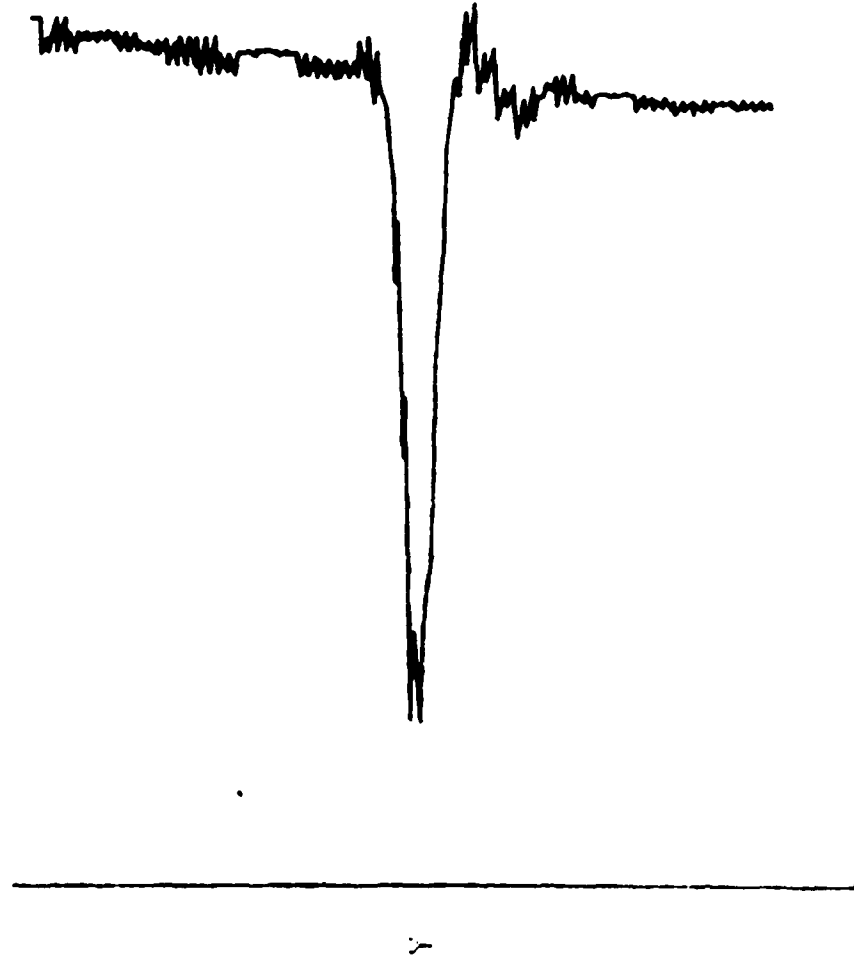


Fig. 5 - Effect of Freestream Dynamic Pressure on the Integrand of the Jones Method

UMIN, UMAX
 0.75, 1.01
 RUN, Q(00), P(00), T(00), U(00), UE, H, THETA, CD(SQUIRE-YOUNG)
 216 126.07 2002.95 92.27 345.29 346.38 1.5608 0.3780 0.0424



U-UE

Profile of a Circulation Contour
 Y-axis: Y
 X-axis: U-UE

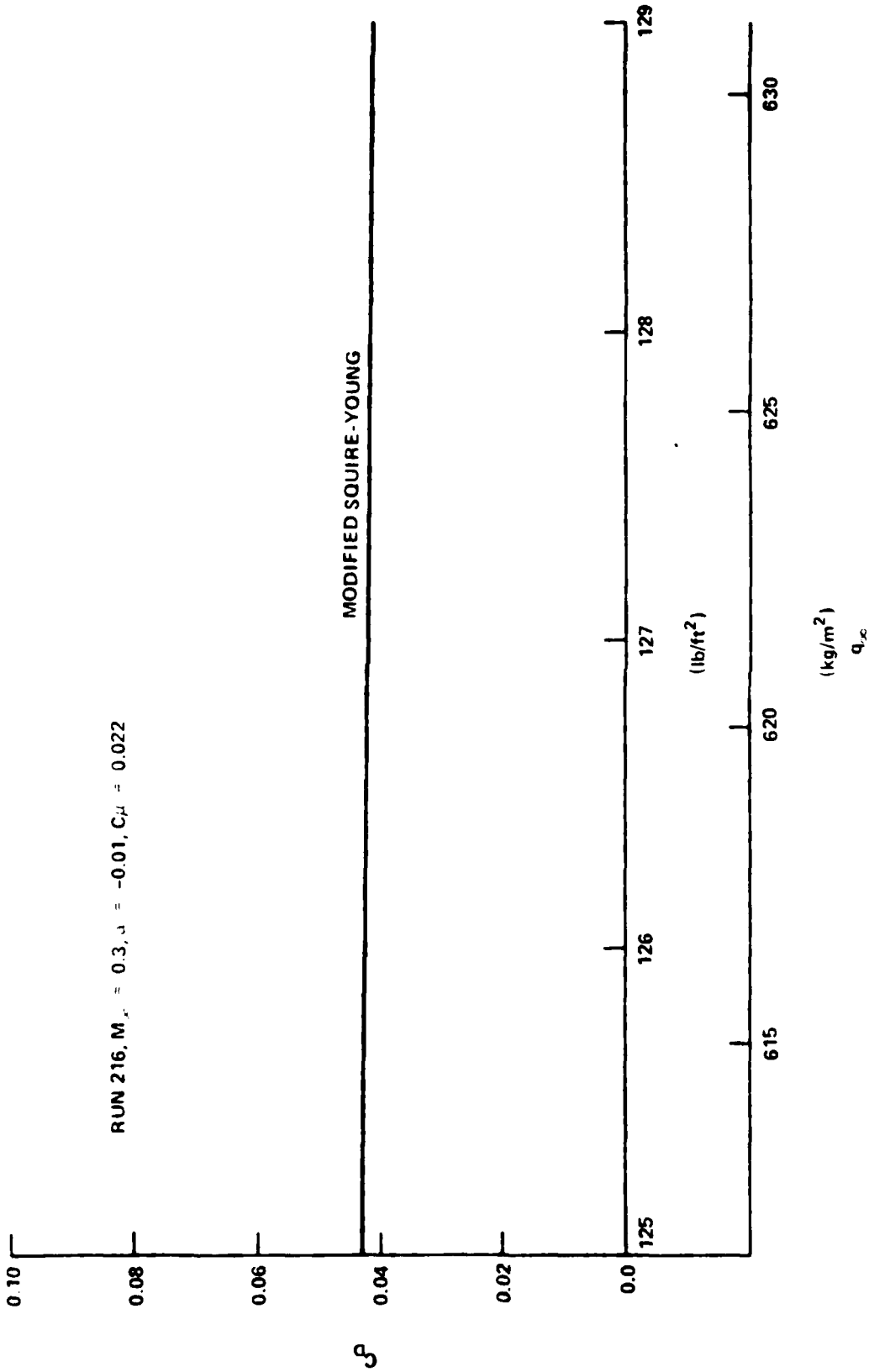


Fig. 7 - Effect of Freestream Dynamic Pressure Variation on Drag Coefficient Using the Modified Squire-Young Method

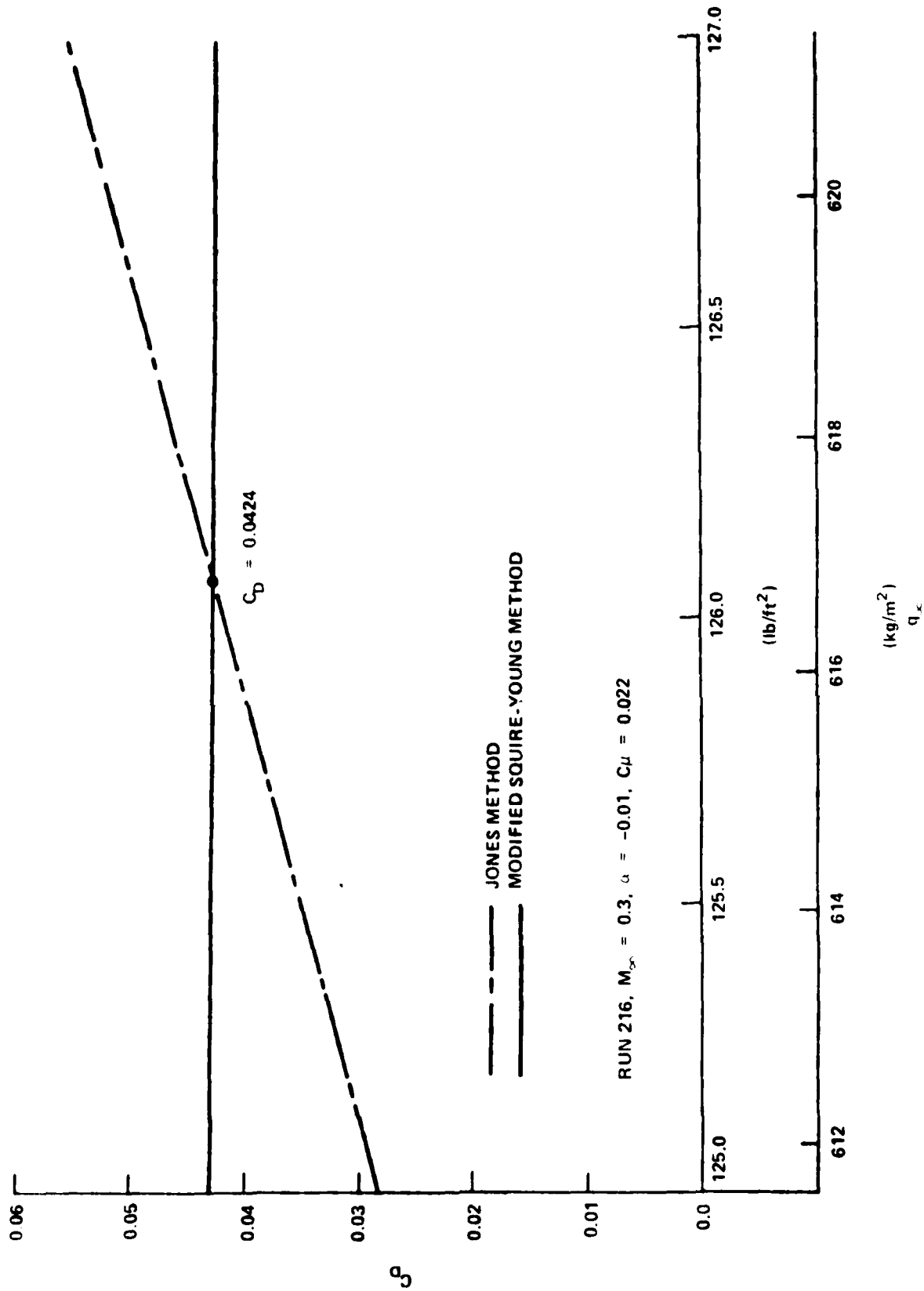


Fig. 8 - Simultaneous Solution of the Jones Method and the Modified Squire-Young Method

YMIN, YMAX
-.05, .4
RUN, POINTS, Q(00), P(00), T(00), CD(JONES)
216 190 126.07 2002.95 92.27 0.0424

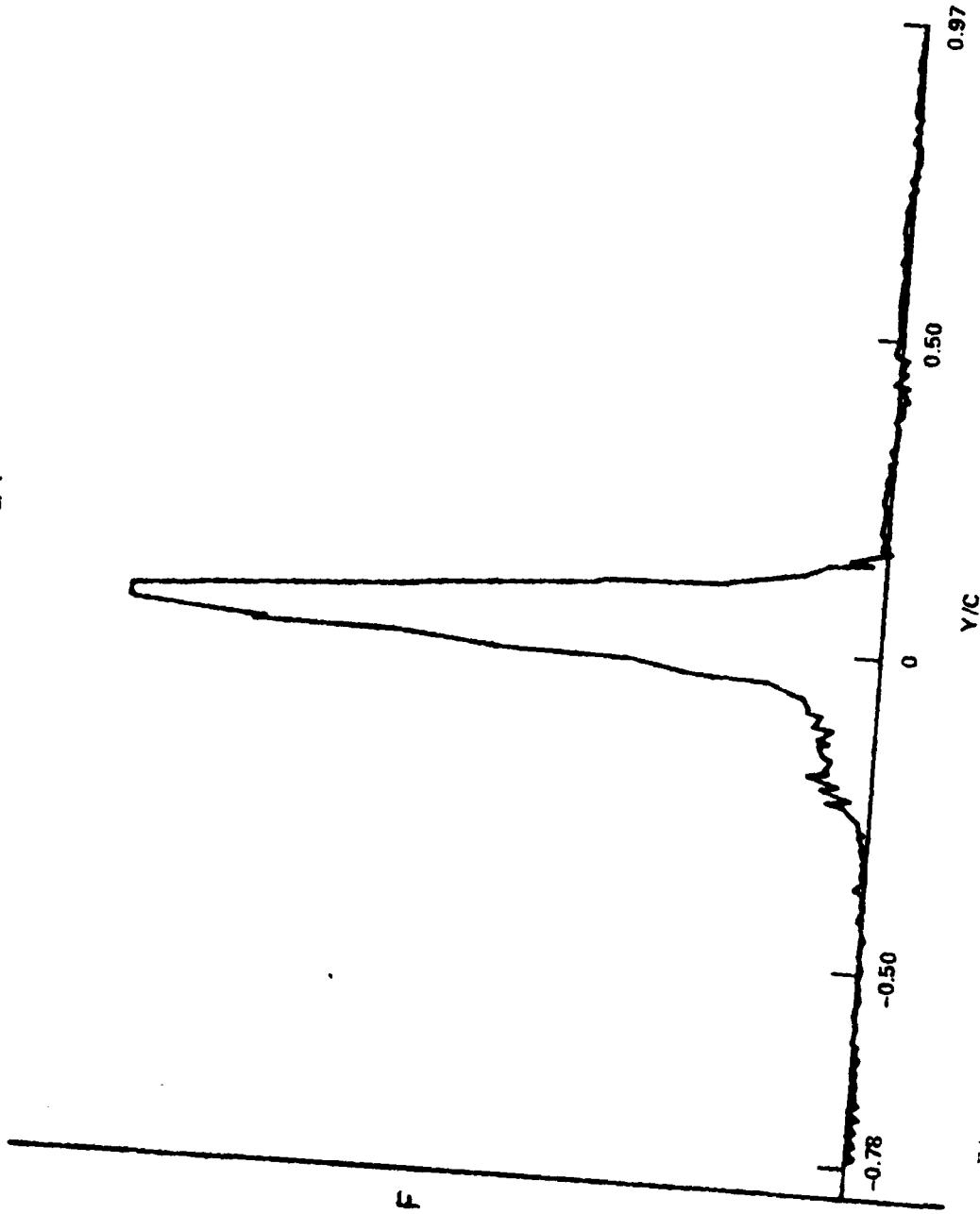


Fig. 9 - The Distribution of Integrand in the Jones Method with q_0 Obtained by Simultaneous Solution

Fig. 9a - Run 216

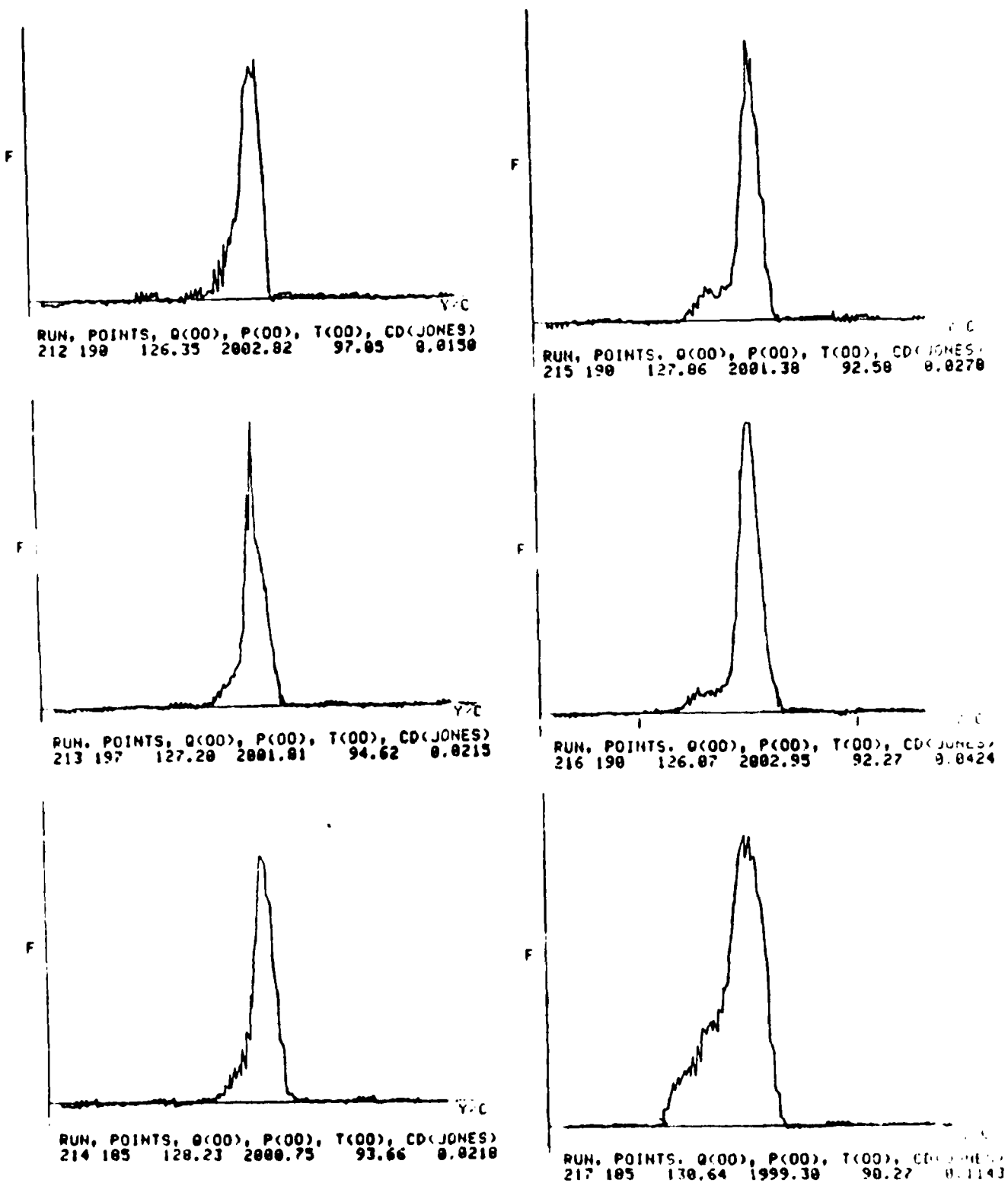


Fig. 9b - Runs 212 through 217

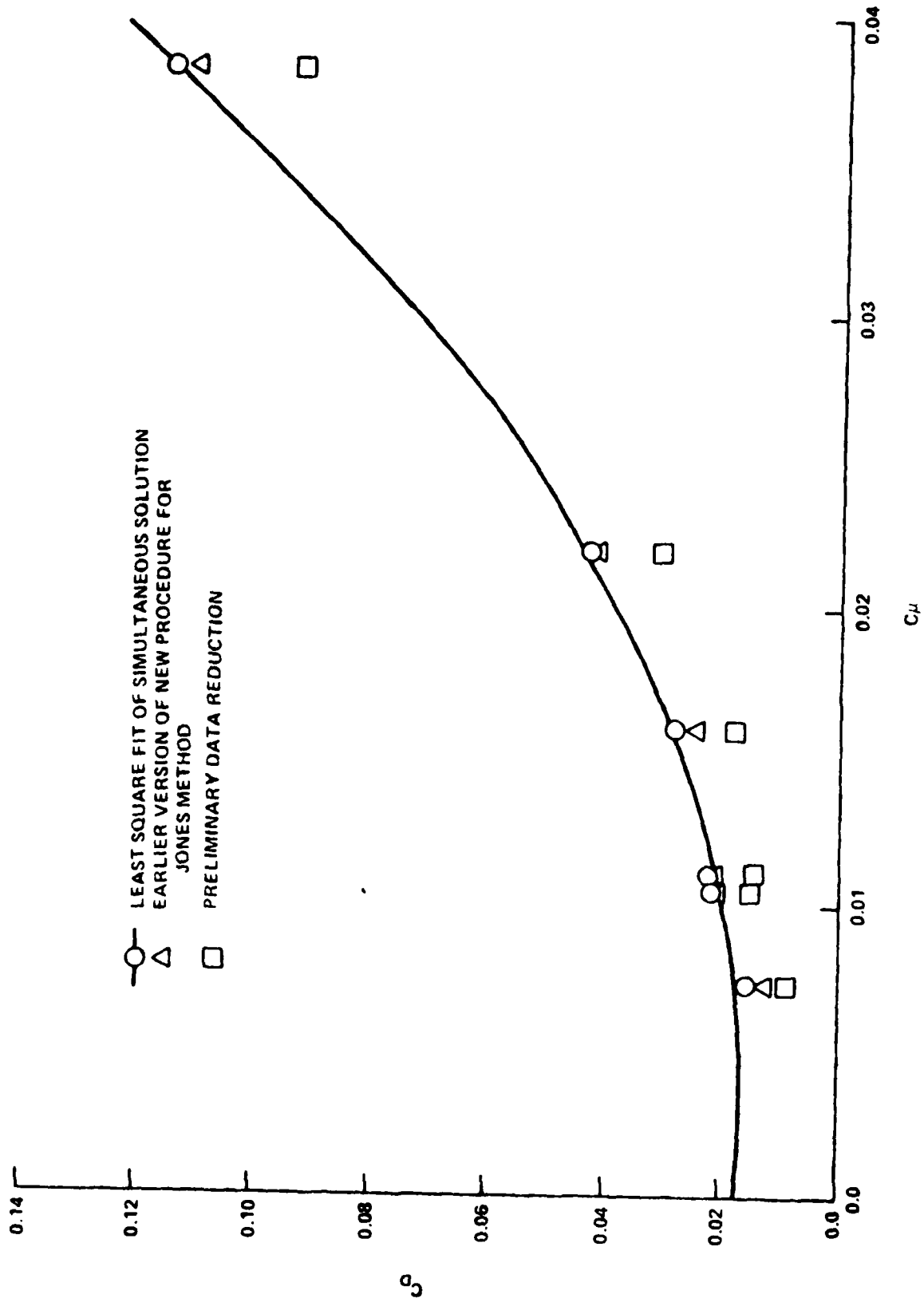


Fig. 10 - Drag Coefficients Determined by Three Different Methods (Model 103, Runs 212 through 217)

RUN, NI, ALPHA, CL, CD(PRES),
216 57 -0.0100 1.3592 0.1185

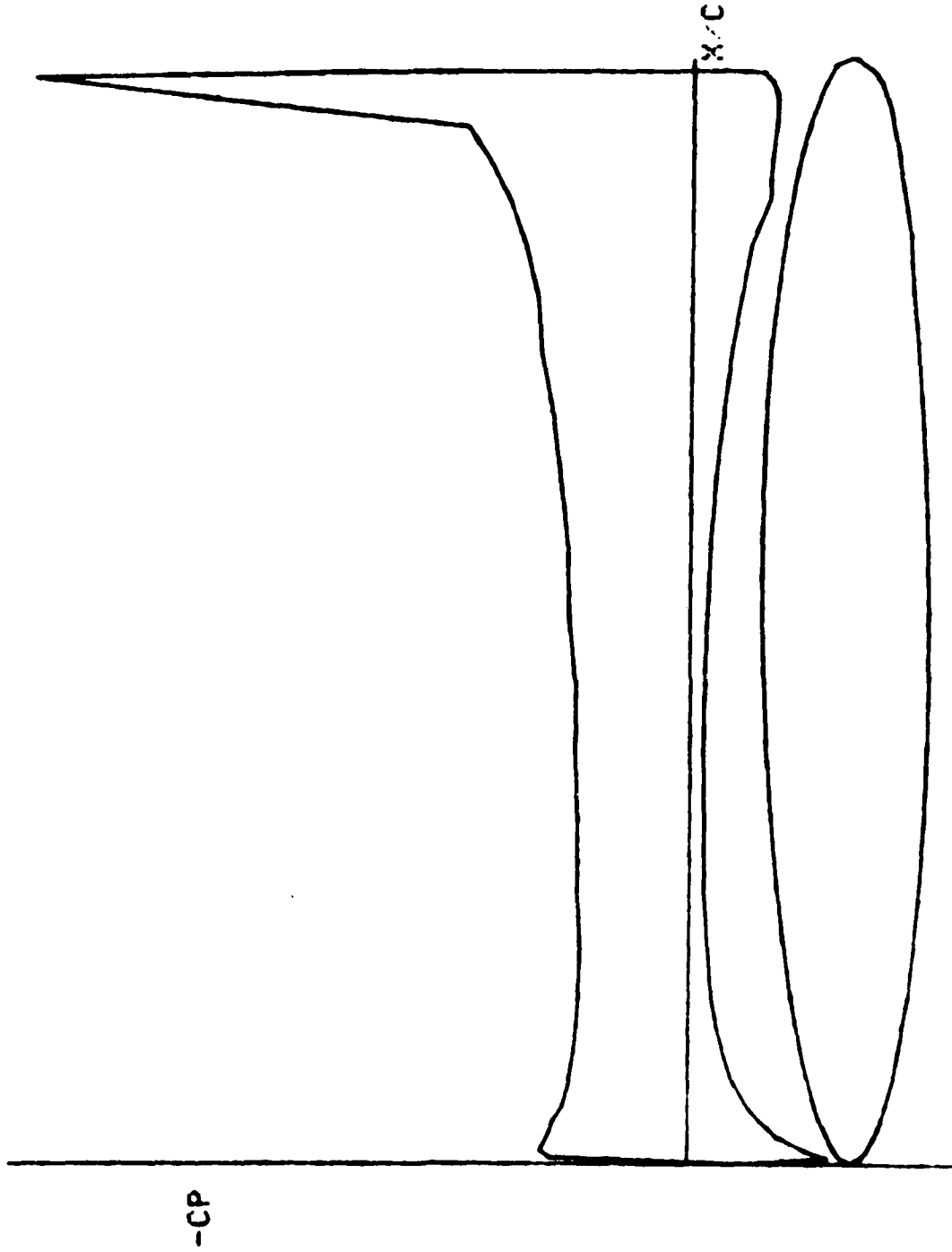


Figure 1. Distribution of Circulation Coefficients for $\alpha = 0.01$, $\beta = 0.02$, and $C_{L0} = 0.02$ (Re = 100)

TABLE 1 - WAKE SURVEY DATA, RUN 216

N	Y (in)	$\frac{K_2}{(lb/ft^2)}$	$\frac{P_2}{(lb/ft^2)}$	N	Y (in)	$\frac{K_2}{(lb/ft^2)}$	$\frac{P_2}{(lb/ft^2)}$	N	Y (in)	$\frac{K_2}{(lb/ft^2)}$	$\frac{P_2}{(lb/ft^2)}$
1	17.462	2128.93	2000.67	67	6.192	2129.08	2001.27	133	-4.891	2126.76	2004.77
2	17.032	2129.07	2008.67	68	6.014	2129.10	2003.45	134	-4.898	2126.42	2004.77
3	16.717	2129.07	2003.04	69	5.836	2129.10	2007.65	135	-5.176	2126.04	2004.77
4	16.548	2128.76	2002.04	70	5.659	2128.97	2004.45	136	-5.263	2125.63	2004.77
5	16.379	2128.93	2000.67	71	5.481	2128.97	2003.45	137	-5.551	2125.97	2004.77
6	16.210	2128.93	2001.63	72	5.304	2128.76	2004.45	138	-5.739	2126.76	2006.07
7	16.041	2128.93	2000.67	73	5.126	2128.76	2003.45	139	-6.013	2129.91	2006.07
8	15.872	2128.93	2001.63	74	4.949	2128.76	2002.45	140	-6.101	2129.76	2006.07
9	15.703	2128.93	2001.63	75	4.771	2128.76	2001.45	141	-6.389	2129.12	2006.07
10	15.534	2128.93	2001.63	76	4.594	2128.76	2000.45	142	-6.477	2128.47	2006.07
11	15.365	2128.93	2001.63	77	4.416	2128.76	2000.45	143	-6.765	2128.54	2006.07
12	15.196	2128.93	2001.63	78	4.239	2128.76	2000.45	144	-6.853	2128.06	2006.07
13	15.027	2128.93	2001.63	79	4.061	2128.76	2000.45	145	-6.941	2128.93	2006.07
14	14.858	2128.93	2001.63	80	3.884	2128.76	2000.45	146	-7.229	2129.12	2006.07
15	14.689	2128.93	2001.63	81	3.706	2128.76	2000.45	147	-7.317	2129.77	2006.07
16	14.520	2128.93	2001.63	82	3.529	2128.76	2000.45	148	-7.405	2129.19	2006.07
17	14.351	2128.93	2001.63	83	3.351	2128.76	2000.45	149	-7.493	2129.10	2006.07
18	14.182	2128.93	2001.63	84	3.174	2128.93	2000.45	150	-7.581	2129.10	2006.07
19	14.013	2128.93	2001.63	85	2.996	2129.32	2000.45	151	-7.669	2129.10	2006.07
20	13.844	2128.93	2001.63	86	2.819	2129.32	2000.45	152	-7.757	2129.10	2006.07
21	13.675	2128.93	2001.63	87	2.641	2129.32	2000.45	153	-7.845	2129.10	2006.07
22	13.506	2128.93	2001.63	88	2.464	2129.32	2000.45	154	-7.933	2129.10	2006.07
23	13.337	2128.93	2001.63	89	2.286	2129.32	2000.45	155	-8.021	2129.10	2006.07
24	13.168	2128.93	2001.63	90	2.109	2129.32	2000.45	156	-8.109	2129.10	2006.07
25	12.999	2128.93	2001.63	91	1.931	2129.32	2000.45	157	-8.197	2129.10	2006.07
26	12.830	2128.93	2001.63	92	1.754	2129.32	2000.45	158	-8.285	2129.10	2006.07
27	12.661	2128.93	2001.63	93	1.576	2129.32	2000.45	159	-8.373	2129.10	2006.07
28	12.492	2128.93	2001.63	94	1.399	2129.32	2000.45	160	-8.461	2129.10	2006.07
29	12.323	2128.93	2001.63	95	1.221	2129.32	2000.45	161	-8.549	2129.10	2006.07
30	12.154	2128.93	2001.63	96	1.044	2129.32	2000.45	162	-8.637	2129.10	2006.07
31	11.985	2128.93	2001.63	97	0.866	2129.32	2000.45	163	-8.725	2129.10	2006.07
32	11.816	2128.93	2001.63	98	0.689	2129.32	2000.45	164	-8.813	2129.10	2006.07
33	11.647	2128.93	2001.63	99	0.511	2129.32	2000.45	165	-8.901	2129.10	2006.07
34	11.478	2128.93	2001.63	100	0.334	2129.32	2000.45	166	-8.989	2129.10	2006.07
35	11.309	2128.93	2001.63	101	0.156	2129.32	2000.45	167	-9.077	2129.10	2006.07
36	11.140	2128.93	2001.63	102	0.078	2129.32	2000.45	168	-9.165	2129.10	2006.07
37	10.971	2128.93	2001.63	103	0.000	2129.32	2000.45	169	-9.253	2129.10	2006.07
38	10.802	2128.93	2001.63	104	0.000	2129.32	2000.45	170	-9.341	2129.10	2006.07
39	10.633	2128.93	2001.63	105	0.000	2129.32	2000.45	171	-9.429	2129.10	2006.07
40	10.464	2128.93	2001.63	106	0.000	2129.32	2000.45	172	-9.517	2129.10	2006.07
41	10.295	2128.93	2001.63	107	0.000	2129.32	2000.45	173	-9.605	2129.10	2006.07
42	10.126	2128.93	2001.63	108	0.000	2129.32	2000.45	174	-9.693	2129.10	2006.07
43	9.957	2128.93	2001.63	109	0.000	2129.32	2000.45	175	-9.781	2129.10	2006.07
44	9.788	2128.93	2001.63	110	0.000	2129.32	2000.45	176	-9.869	2129.10	2006.07
45	9.619	2128.93	2001.63	111	0.000	2129.32	2000.45	177	-9.957	2129.10	2006.07
46	9.450	2128.93	2001.63	112	0.000	2129.32	2000.45	178	-10.045	2129.10	2006.07
47	9.281	2128.93	2001.63	113	0.000	2129.32	2000.45	179	-10.133	2129.10	2006.07
48	9.112	2128.93	2001.63	114	0.000	2129.32	2000.45	180	-10.221	2129.10	2006.07
49	8.943	2128.93	2001.63	115	0.000	2129.32	2000.45	181	-10.309	2129.10	2006.07
50	8.774	2128.93	2001.63	116	0.000	2129.32	2000.45	182	-10.397	2129.10	2006.07
51	8.605	2128.93	2001.63	117	0.000	2129.32	2000.45	183	-10.485	2129.10	2006.07
52	8.436	2128.93	2001.63	118	0.000	2129.32	2000.45	184	-10.573	2129.10	2006.07
53	8.267	2128.93	2001.63	119	0.000	2129.32	2000.45	185	-10.661	2129.10	2006.07
54	8.098	2128.93	2001.63	120	0.000	2129.32	2000.45	186	-10.749	2129.10	2006.07
55	7.929	2128.93	2001.63	121	0.000	2129.32	2000.45	187	-10.837	2129.10	2006.07
56	7.760	2128.93	2001.63	122	0.000	2129.32	2000.45	188	-10.925	2129.10	2006.07
57	7.591	2128.93	2001.63	123	0.000	2129.32	2000.45	189	-11.013	2129.10	2006.07
58	7.422	2128.93	2001.63	124	0.000	2129.32	2000.45	190	-11.101	2129.10	2006.07
59	7.253	2128.93	2001.63	125	0.000	2129.32	2000.45	191	-11.189	2129.10	2006.07
60	7.084	2128.93	2001.63	126	0.000	2129.32	2000.45	192	-11.277	2129.10	2006.07
61	6.915	2128.93	2001.63	127	0.000	2129.32	2000.45	193	-11.365	2129.10	2006.07
62	6.746	2128.93	2001.63	128	0.000	2129.32	2000.45	194	-11.453	2129.10	2006.07
63	6.577	2128.93	2001.63	129	0.000	2129.32	2000.45	195	-11.541	2129.10	2006.07
64	6.408	2128.93	2001.63	130	0.000	2129.32	2000.45	196	-11.629	2129.10	2006.07
65	6.239	2128.93	2001.63	131	0.000	2129.32	2000.45	197	-11.717	2129.10	2006.07
66	6.070	2128.93	2001.63	132	0.000	2129.32	2000.45	198	-11.805	2129.10	2006.07
67	5.901	2128.93	2001.63	133	0.000	2129.32	2000.45	199	-11.893	2129.10	2006.07
68	5.732	2128.93	2001.63	134	0.000	2129.32	2000.45	200	-11.981	2129.10	2006.07

TABLE 2 - SUMMARY OF REDUCED DRAG COEFFICIENTS OF CIRCULATION CONTROL AIRFOIL MODEL 103

Run	M_∞	α (deg)	C_L	P^a (lb/ft ²)	T (F ^a)	q_∞ (lb/ft ²)	C_D		
							Jones	Squire- Young	Simultaneous Solution
212	0.3	-0.01	0.0073	2002.82	97.05	126.11	0.0117	0.0151	
							0.0238	0.0149	
							0.0372	0.0147	0.0150
213	0.3	-0.01	0.0105	2001.81	94.62	126.00	0.0050	0.0219	
							0.0196	0.0216	
							0.0323	0.0213	0.0215
214	0.3	-0.01	0.0111	2000.75	93.66	127.00	0.0052	0.0221	
							0.0211	0.0218	
							0.0320	0.0216	0.0218
215	0.3	-0.01	0.0160	2001.38	92.58	127.00	0.0161	0.0281	
							0.0298	0.0278	
							0.0432	0.0274	0.0278
216	0.3	-0.01	0.0220	2002.95	92.27	125.00	0.0281	0.0430	
							0.0415	0.0425	
							0.0547	0.0419	0.0424
217	0.3	-0.01	0.0384	1999.30	90.27	129.00	0.0934	0.1167	
							0.1106	0.1148	
							0.1313	0.1124	0.1143
34	0.5	-5.99	0	1816.71	110.26	311.00	0.0055	0.0122	
							0.0126	0.0121	
							0.0170	0.0121	0.0121

TABLE 1. Summary of the results of the analysis of variance for the different parameters of the model.

Parameter	MS	DF	F	P	MS	DF	F	P
1	0.0000	35	0.4166	0.8825	0.0605	35	0.8825	-1.3418
2	0.0051	36	1.0428	0.8405	0.0677	36	0.8405	-1.2210
3	0.0120	37	0.8645	0.7945	0.0750	37	0.7945	-1.1276
4	0.0251	38	0.6615	0.7436	0.0806	38	0.7436	-1.1032
5	0.0379	39	0.5422	0.6926	0.0843	39	0.6926	-1.0243
6	0.0507	40	0.4390	0.6306	0.0871	40	0.6306	-0.9649
7	0.0757	41	0.3269	0.5667	0.0890	41	0.5667	-0.8965
8	0.1012	42	0.2525	0.5037	0.0891	42	0.5037	-0.8882
9	0.1263	43	0.2020	0.4407	0.0877	43	0.4407	-0.8407
10	0.1513	44	0.1614	0.3776	0.0843	44	0.3776	-0.8437
11	0.1999	45	0.1344	0.3148	0.0803	45	0.3148	-0.8179
12	0.2518	46	0.1071	0.2517	0.0733	46	0.2517	-0.8193
13	0.3153	47	0.0864	0.2009	0.0672	47	0.2009	-0.8058
14	0.3787	48	0.0985	0.1507	0.0588	48	0.1507	-0.8161
15	0.4417	49	0.1015	0.1259	0.0547	49	0.1259	-0.8244
16	0.5047	50	0.1242	0.1007	0.0496	50	0.1007	-0.8444
17	0.5692	51	0.1419	0.0753	0.0421	51	0.0753	-0.8699
18	0.6314	52	0.1842	0.0504	0.0343	52	0.0504	-0.9215
19	0.6936	53	0.2419	0.0376	0.0296	53	0.0376	-0.9863
20	0.7446	54	0.2956	0.0248	0.0239	54	0.0248	-1.0260
21	0.7945	55	0.3673	0.0126	0.0168	55	0.0126	-1.0826
22	0.8415	56	0.4350	0.0049	0.0103	56	0.0049	-1.0071
23	0.8835	57	0.5089	0.0000	0.0000	57	0.0000	0.4166
24	0.9165		0.5910					
25	0.9544		0.6197					
26	0.9794		0.6197					
27	0.9939		0.5985					
28	0.9994		0.5259					
29	1.0000		0.2225					
30	0.9934		0.4720					
31	0.9734		-2.4720					
32	0.9754		-4.0237					
33	0.9494		-3.4785					
34	0.9164		-1.6469					
			-1.4780					

END

FILMED

4-85

DTIC

