

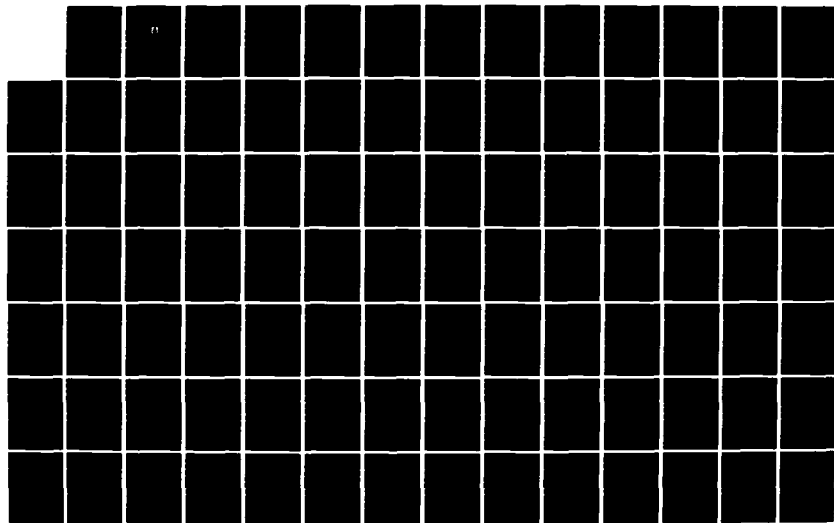
AD-A132 689

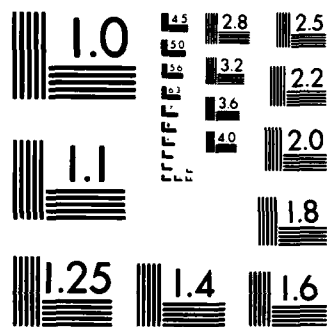
DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS(U)
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH
25 AUG 83 FTD-ID(R5)T-8673-83

1/3

UNCLASSIFIED

F/G 20/4 NL



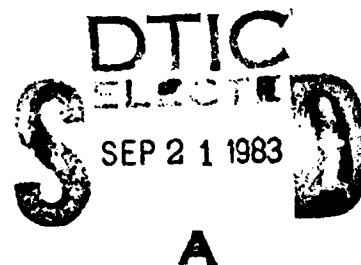
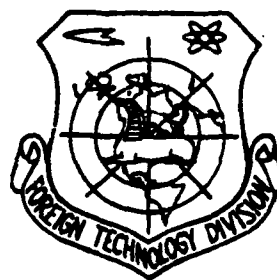


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FOREIGN TECHNOLOGY DIVISION



DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS



Approved for public release;
distribution unlimited.

83 09 16 030

A132 689

DTIC FILE COPY

UNEDITED MACHINE TRANSLATION

FTD-ID(RS)T-0673-83

25 August 1983

MICROFICHE NR: FTD-83-C-001057

DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS

English pages: 277

Source: Trudy Tsentral'nogo Aero-Gidrodinamicheskogo
Instituta im. Prof. M.Ye. Zhukovskogo,
Nr. 1411, Publishing House "Otdel TsAGI",
Moscow, 1972, pp. 1-152

Country of origin: USSR

This document is a machine translation.

Requester: FTD/TQTA

Approved for public release; distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

Table of Contents

U.S. Board on Geographic Names Transliteration System	ii
Aerodynamic Characteristics of Bodies in the Transition Region at Hypersonic Speeds of Flow, by V.N. Gusev, T.V. Klimova, A.V. Lipin	2
Application of the Monte Carlo Method in Dynamics of Strongly Rarefied Gas, by V.A. Perepukhov	89
Study of Internal and External Free Molecular Flows About an Arbitrary Group of Complex Bodies, by M.A. Zakirov	135
Appendix 1. Universal Program for Studying Internal and External Free-Molecular Flows Near an Arbitrary Group of Complex Bodies ...	234
Appendix 2. Calculation Examples	271

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh ⁻¹
cos	cos	ch	cosh	arc ch	cosh ⁻¹
tg	tan	th	tanh	arc th	tanh ⁻¹
ctg	cot	cth	coth	arc cth	coth ⁻¹
sec	sec	sch	sech	arc sch	sech ⁻¹
cosec	csc	csch	csch	arc csch	csch ⁻¹

Russian English

rot curl
lg log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

DOC = 83067301

PAGE 1

DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS.

Page 2. (No Typing).

AERODYNAMIC CHARACTERISTICS OF BODIES IN THE TRANSITION REGION AT
HYPERSONIC SPEEDS OF FLOW.

V. N. Gusev, T. V. Klimova, A. V. Lipin.

SUMMARY.

Is conducted the analysis of the special features/peculiarities of the hypersonic flow around bodies in the transition region, which lies between the region of free molecular flows and the zone of flow of gas as continuous medium. Are discussed questions of the simulation of actual conditions in the transition region on the basis of the vast experimental material, obtained in the low-pressure wind tunnel of TsAGI [ЦАГИ - Central Institute of Aerohydrodynamics im. N Ye Zhukovskiy]. Work gives the aerodynamic characteristics of the broad class of bodies.

ADOPTED DESIGNATIONS.

c_i - aerodynamic coefficient;

$c_x = \frac{x}{\frac{\rho_\infty U_\infty^2}{2} S}$ - drag coefficient;

$$c_y = \frac{y}{\frac{\rho_{\infty} U_{\infty}^2}{2} S} - \text{lift coefficient;}$$

d - diameter of blunting;

D - diameter of maximum cross section;

$K = c_y/c_x$ - lift-drag ratio;

$$m_z = \frac{M_z}{\frac{\rho_{\infty} U_{\infty}^2}{2} SL} - \text{coefficient of pitching moment;}$$

n - exponent in law $\mu \sim T^n$;

Pr - Prandtl number;

Re, - Reynolds number, in whom the coefficient of viscosity/ductility/toughness is calculated from the temperature of stagnation,

$$Re_{0L} = \frac{\rho_{\infty} U_{\infty} L}{\mu_0}; \quad Re_{0l} = \frac{\rho_{\infty} U_{\infty} l}{\mu_0}; \quad Re_{0D} = \frac{\rho_{\infty} U_{\infty} D}{\mu_0};$$

S - area;

T_0, T_s - temperature of stagnation and the temperature of body surface;

U_{∞} - speed in the undisturbed flow;

α - angle of attack;

$\alpha_{\max}$ - angle of attack when $K = K_{\max}$;

γ - specific heat ratio;

θ - half-apex angle of the cone and semicone;

δ - thickness of plate,

$$\bar{\delta}_L = \delta/L; \quad \bar{\delta}_l = \delta/l;$$

λ - elongation of plate, equal to the ratio of its width to the chord in the root section;

χ - sweep angle;

ρ_{∞} - density in the undisturbed flow;

μ - coefficient of viscosity/ductility/toughness;

μ_0 - coefficient of viscosity/ductility/toughness with $T=T_0$.

Indices "t" and "n" designate respectively wind tunnel tests and full-scale.

Page 4.

Introduction.

The technical progress in aviation and rocket engineering led to the intense development of theoretical and experimental studies in the region of aerodynamics of hypersonic flows. The greatest number of these investigations relates to two sufficiently to well studied regions of general gas dynamics. One of them - this is usual gas fluid dynamics in which the characteristic mean free path of molecules is much lower than the significant dimension of body. The detailed presentation of the theory of hypersonic flows in this region with its numerous applications/appendices is contained in monographs [1, 2]. Another region - dynamics of the free molecular and adjacent it medium where the course of gas proves to be such rarefied that the characteristic mean free path of molecules becomes much more than the significant dimension of body. Latest achievements in this region are presented in monograph [3]. Are least investigated flows of rarefied gas in the intermediate transition region. A strict theoretical studies of such courses can be carried out only on the basis of kinetic theory, which uses an equation of Boltzmann. The solution of this equation is at present connected with the great mathematical difficulties.

Not easy here proves to be the experimental path. Creation of hypersonic low-density flows, their diagnostics and conducting in them experimental investigations - most complex task of contemporary experimental aerodynamics of hypersonic flows. At present on one experimental installation it is not possible to carry out complete simulation during model tests in hypersonic flow, since besides Mach numbers and Re in the wind tunnel it is necessary to reproduce the high value of the enthalpy of hypersonic flows. The coincidence of these conditions in one installation/setting up is extremely difficult. In connection with this experimental research of hypersonic flows divide into the investigations of the effects of hydrodynamic character, caused by change Mach numbers and Re , and investigation of the effects of imperfect gas, caused by high energy of flow. To the discussion of hydrodynamic special features/peculiarities indicated above of the hypersonic flow around bodies in the transition region, which lies between the region of free molecular flows and the zone of flow of gas as continuous medium, and is dedicated this work. In it is systematized the vast experimental material, obtained in the low-pressure wind tunnel of TsAGI.

Page 5.

Simulation of actual conditions in a transition region ¹.

FOOTNOTE ¹. As the basis of this part of the work is assumed V. N. Gusev's report "Problems of simulation in the dynamics of the rarefied gases" at the III All-Union conference on the dynamics of the rarefied gases (Novosibirsk, 1969). ENDFOOTNOTE.

Questions of the similarity of hypersonic flows in the transition region were examined in work [4]. On the basis of the equation of Boltzmann in it it is shown that under the power law of interaction of molecules for observing the similarity in the mode/conditions of hypersonic stabilization besides the geometric similarity it is necessary to maintain/withstand the equality of the following parameters: Reynolds number Re_0 , in whom the coefficient of viscosity/ductility/toughness is calculated from the temperature of stagnation, exponent n in the dependence of the coefficient of viscosity/ductility/toughness on temperature $\mu \sim T^n$, temperature factor T_0/T_s , where T_s and T_0 - respectively the temperature of stagnation and body surface, specific heat ratio γ , number of Prandtl of accommodation. Of the parameters mentioned, the Re_0 number Pr and coefficient Ait is basic similarity criterion: with its change the values of the aerodynamic characteristics of the streamlined body

can change to the orders.

When $T_\infty/T_0=1$ basic laws governing the supersonic flow around characteristic bodies over a wide range of a change in criterion Re_∞ were revealed in work [4]. Data for the transient region were obtained in the low-pressure wind tunnel employing the presented in work [4] procedure. For the zone of flow, close to free-molecular, when is applicable the theory of the first intermolecular collisions, the aerodynamic characteristics of bodies were obtained by calculation [5, 6]. Experimental data for the case of viscous flows of continuous medium were borrowed from works [7, 8], theoretical - from works [9, 10]. For the cone with the half-angle of solution/opening θ and plate whose relative thickness $\delta/L=0.03$, these data are cited in Fig. 1-6. During the calculation of aerodynamic coefficients as the characteristic area was selected the area of body S in the plan/layout; pitching moment m , was calculated relatively "nose/leading edge"; through α was designated the angle of attack.

As it follows from given data, the results of experiment and calculations according to the theory of the first intermolecular collisions and according to the theory of the viscous flows of continuous medium make it possible to obtain information in the entire transient zone of flow. In this case experimental and theoretical data, obtained taking into account the parameter of similarity Re_∞ , will agree sufficiently well with each other.

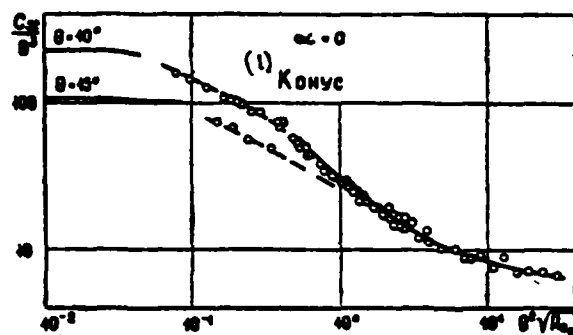


Fig. 1.

Key: (1). Cone.

Page 6.

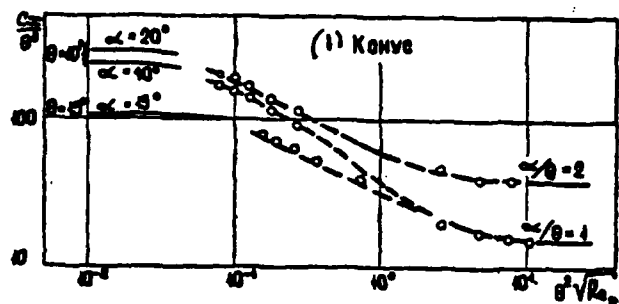


Fig. 2. Key: (1). Cone.

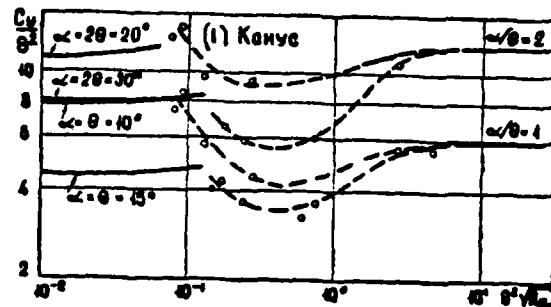


Fig. 3. Key: (1). Cone.

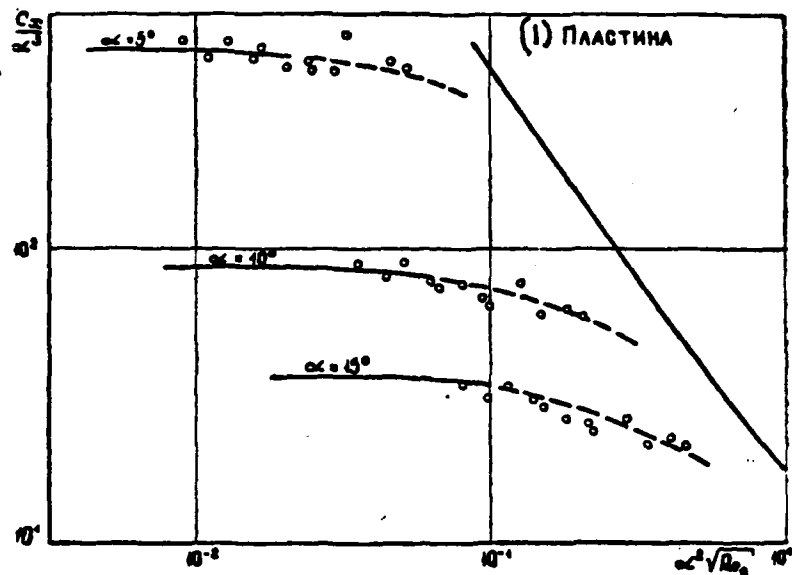


Fig. 4. Key: (1). Plate.

Page 7.

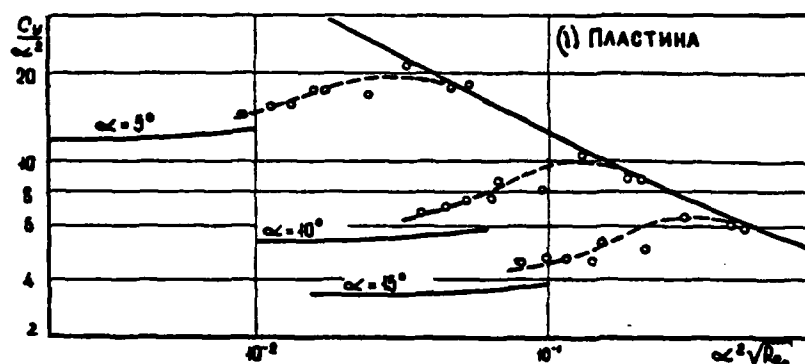


Fig. 5. Key: (1). Plate.

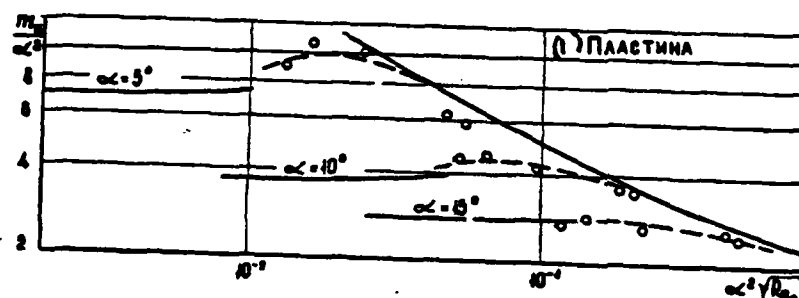


Fig. 6. Key: (1). Plate.

Should be focused attention on the nonmonotony of a change of some characteristics in the transition region where their values prove to be more than the values, obtained in the free molecular flow, and in certain cases except the maximum indicated they have even and a minimum (for example, the coefficient of lift force of cone). All this speaks, that the laws of the behavior of aerodynamic characteristics in the transition region are very complicated and they cannot be obtained by simple interpolation of given for

continuous medium and free molecular courses.

During the simulation of actual conditions in the wind tunnels besides the basic criterion of similarity Re , it is necessary to maintain/withstand a whole series of other important similarity criteria. However, the installations/settings up existing at present in which the temperature of stagnation is close to the room, by no means provide this simulation. In connection with this arises the question about the procedure of the recalculation of the results of tube experiment for the actual conditions with the noncoincidence of some similarity parameters. In the case of the thermodynamically ideal gas these parameters include T_0/T_∞ , n , γ , a number of Prandtl, accommodation coefficients. As are shown available in works [11, 12] data, under the conditions of the viscous hypersonic flows at the speeds of less or the order of the first space, effects of imperfect gas to the aerodynamic characteristics are insignificant, and air can be considered as the thermodynamically ideal gas.

It is known that for air at low temperatures ($T < 150^\circ K$) $\mu \sim T$, i.e., $n=1$, and with $T > 400^\circ K$ value n is close to 0.67. In other words, at low temperatures of the molecule of air they behave as Maxwellian, i.e., with large T they are nearer to the elastic spheres.

Therefore obtained in the low-temperature wind tunnels data cannot be transferred to nature, even if we ensure a sufficient cooling of models for obtaining the full-scale values T_w/T_0 .

For the courses, close to the free molecular ones, a question about the recalculation of tube data to the full-scale ones was examined in monograph [3]. In the region of viscous hypersonic flows for this purpose was applied the approximate law of similarity of Cheng [11, 13]. The detailed analysis of the effect of different similarity criteria on the aerodynamic characteristics of simple bodies in this region is given in works [14-16]. The results represented in them of the parametric analyses of the flow around the simplest bodies make it possible to explain the degree of the nearness of the aerodynamic characteristics, obtained under the wind tunnel and the actual conditions, and in certain cases [14] to introduce the appropriate corrections during the complete simulation on criteria T_w/T_0 , n , γ .

It is possible to attempt to find the approximate laws of simulation with the aid of the experimental data (for example, see [17, 18]). In this case one should only have in mind that the boundary of free molecular hypersonic flows and the aerodynamic

characteristics of bodies in such flows depend on the form of body, temperature of its surface and laws of interaction of the molecules between themselves and body surface [3].

Let us present arbitrary aerodynamic value c_i in the form

$$c_i = c_{i\infty} + (c_{i0} - c_{i\infty}) f \left[\text{Re}_0 \left(\frac{T_w}{T_0} \right)^\beta, \frac{T_w}{T_0}, n, \gamma, \dots \right],$$

where $c_{i\infty}$ and c_{i0} - value c_i with $\text{Re}_0 = \infty$ and to zero, and β is the function of the similarity parameters and in the general case depends on the shape of body. Relying on experimental data, it is possible to attempt to find such value β , at which the dependence of functions f on the criteria of similarity T_w/T_0 and n will be weak. In this case the data, obtained in the low-temperature wind tunnel, can be converted to the full-scale ones. Actually/really, let c_i^T - obtained in the wind tunnel value of value c_i when $T_w/T_0 = 1$ and $n=1$, and c_i^H - corresponding to it full-scale value c_i at fixed value $T_w/T_0 \ll 1$ and $n=0.67$.

Then

$$c_i^H = c_{i\infty}^H + (c_{i0}^H - c_{i\infty}^H) f \left[\text{Re}_0^H \left(\frac{T_w}{T_0} \right)^\beta, \gamma, \dots \right],$$

where

$$f \left[\text{Re}_0^H \left(\frac{T_w}{T_0} \right)^\beta, \gamma, \dots \right] - f [\text{Re}_0^T, \gamma, \dots] = \frac{c_i^T - c_{i\infty}^T}{c_{i0}^T - c_{i\infty}^T},$$

$$\text{Re}_0^H \left(\frac{T_w}{T_0} \right)^\beta = \text{Re}_0^T.$$

It is obvious that with this recalculation it is necessary to know values c_{10} and $c_{1\infty}$ obtained under the wind tunnel and the actual conditions. The latter can be determined by calculation.

For the drag coefficient of sphere and cone the identification of parameter β was produced on the basis of experimental data, given in the works [4, 17]. Analysis showed that with $\beta = -0.1$ the experimental values, obtained at the essentially different values of temperature factor, will agree sufficiently well with each other over a wide range of a change in Mach numbers and Re.

Page 9.

The results of this comparison are given in Fig. 7 and 8. There solid lines gave the results of calculation according to the theory of first intermolecular collisions [5].

It is obvious that approximation method examined above of the recalculation data, obtained in the low-temperature wind tunnels, by the full-scale ones is not strict and cannot encompass entire diversity of bodies and ranges of a change in the similarity criteria. However, the absence at present of a sufficient quantity of experimental data at substantially the higher values of gas enthalpy makes it possible to propose nothing the best. In proportion to the

accumulation of such data this gap/spacing will be eliminated.

It is necessary to keep in mind that in certain cases with the accuracy acceptable for practical purposes there is no need for increasing the temperature of stagnation of flow in the wind tunnel to its full-scale values. For example, the given in work [14] estimations show that in the region of viscous interaction heating gas in the precombustion chamber to $T_0 = 2000^\circ \text{K}$ provides the simulation of the full-scale values of resistance and lift of plate with an error less than 4%, when $T_0/T_\infty > 0.05$. The latter fact in many respects facilitates the way of the straight/direct simulation of actual conditions in the wind tunnels.

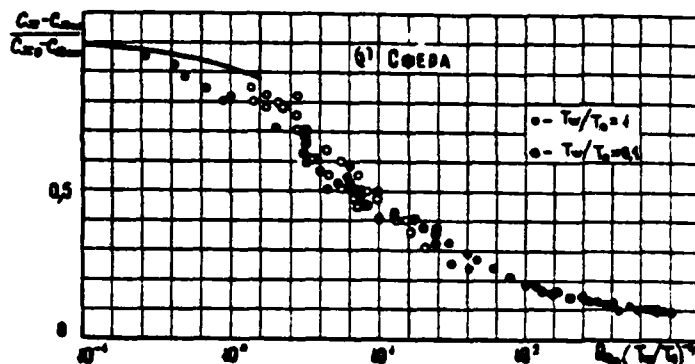


Fig. 7. Key: (1). Sphere.

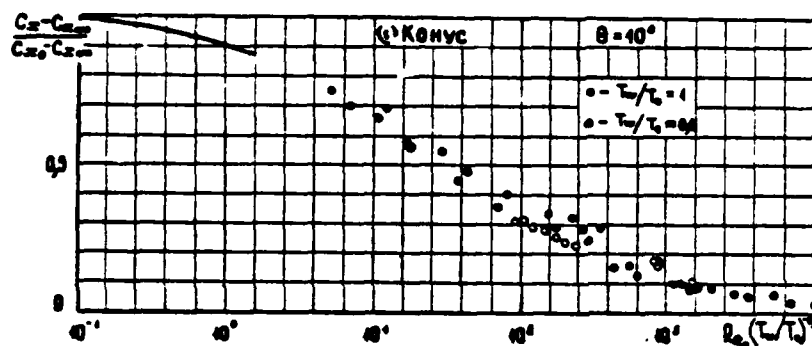


Fig. 8. Key: (1). Cone.

Page 10.

AERODYNAMIC CHARACTERISTICS OF BODIES IN TRANSIENT ZONE OF FLOW.

The special features/peculiarities of the flow around the bodies of the simplest forms, arranged/located at the arbitrary angle of attack α in the hypersonic low-density flow, were examined in the series/row of the works (for example, see [7], [8], [17], [19] -

[23]). Are represented below systematized experimental data, obtained in the low-pressure wind tunnel of TsAGI. The coefficients of drag c_x , lift c_y , pitching moment m , and lift-drag ratio K of the broad class of bodies are given in the dependence on the angle of attack α when $T_w/T_0=1$ and $n=1$. Aerodynamic coefficients are everywhere related to velocity head q and characteristic area S , pitching moment m , is related to the significant dimension of L and is calculated relative to the end section of model.

Tests were conducted in the low-pressure wind tunnel of TsAGI. For the formation of the supersonic flow served calculated conical nozzle with the aperture angle of 25° . As the working gas was utilized air at a room temperature. A maximum change in Mach number along the length of model did not exceed 2%.

During the determination of aerodynamic coefficients were utilized the values of the parameters of the undisturbed flow at the point, which corresponds to the middle of model. As applied to the low-pressure wind tunnels the procedure of the recalculation of aerodynamic characteristics in the nonuniform flow the not corresponding characteristics in the uniform for some simplest bodies in the maximum modes/conditions of flow is presented in the works [24, 25]. For the cone with a half-angle of solution/opening of $\theta=30^\circ$ at the angle of attack $\alpha=0$ the following from work [24] correction to

ϵ_x for the heterogeneity of flow in given conditions of experiments did not exceed 4%. For the cones with the smaller aperture angles it was less.

For measuring of the aerodynamic forces and moments of forces were utilized three-component magnetoelectric weights. The sensitivity of balance comprises the tenths of milligram. A relative error of measurement of forces does not exceed, as a rule, $\pm 2\%$, the moments of forces - $\pm 5\%$.

Taking into account errors of measurement of the flow parameters a relative error in the determination of aerodynamic coefficients comprised in the majority of cases of 5-6%. Somewhat greater errors occurred for the models of small sizes/dimensions - they reached 7-10%.

The installation/setting up of symmetrical models relative to the axis of flow was realized with the aid of the mechanism α of weights. Angle of attack α was considered equal to zero when simultaneously they turned into zero normal to the model force and pitching moment. An error of measurement α composed $10'$. With the same accuracy the "angular dimensions" of models accepted correspond to real ones.

Cone. The aerodynamic characteristics of the thin pointed cones with different aperture angles ($7^\circ \leq 2\theta \leq 40^\circ$) at the fixed value of number $Re_{0L}^I = 162$, cone designed along the length, are represented in Fig. 9-12. During the calculation of aerodynamic coefficients as the characteristic area S here, as subsequently is selected the area of the basis/base of cone, and as the significant dimension of L - its length.

The analogous characteristics of the pointed cones with half-angles of solution/opening of $\theta = 30^\circ$, 45° and 60° at the fixed value of number $Re_{0D}^I = 65$, basis/base calculated according to the diameter, are given in Fig. 13-15.

At large angles of attack the aerodynamic characteristics of the pointed cones with half-angles of solution/opening of $\theta = 15^\circ$, 20° and 30° at the fixed value of number $Re_{0D}^I = 97$ are given in Fig. 16-19.

Page 11.

The effect of the flat/plane blunting whose relative size/dimension $\bar{d} = d/D$, where d and D - respectively the diameters of blunting and basis/base of cone, to the aerodynamic characteristics of slender cones with different half-angles of solution/opening at the fixed value of number $Re_{0L}^I = 162$ for $\theta = 2^\circ.5$ and $3^\circ.75$;

$Re_{0L}^I = 154$ for $\theta = 6^\circ$ and $Re_{0L}^I = 92$ for $\theta = 10^\circ$ is illustrated in Fig. 20-35.

For the low angles of attack, i.e., when the dependences of aerodynamic coefficients on the angle of attack are linear, given higher experimental data, which correspond to number $Re_{0L}^I = 162$, are represented in Fig. 36-38 in the form of dependences c_{x0} , c_{y0}^* and m_{z0}^* on the half-apex angle of the cone θ at different values of $\bar{d}$ of flat/plane blunting (c_{x0} , c_{y0}^* , m_{z0}^* - corresponding values c_x , dc_y/da , dm_z/da with $\alpha=0$). At the fixed value of number Re_{0L}^I the aerodynamic characteristics of cone in proportion to decrease θ considerably exceed the values, valid under the conditions for inviscid ideal flow. The effect of a small blunting of cone on its aerodynamic characteristics under the same conditions is unessential, at least in comparison with the analogous effect during the ideal flow.

The effect of spherical blunting on the aerodynamic characteristics of cone over a wide range changes in the parameters θ and $\bar{d}$ are given in Fig. 39-70. Criterion of similarity Re_{0D}^I for each θ was here by constant, its values were given below:

θ	3,5	5	7,5	10	12,5	15	17,5	20
Re_{0D}^I	20	29	43	57	72	87	102	118

Cylinder. The aerodynamic characteristics of cylinders ($\theta=0$) at different values of L/D , where L and D - length and the diameter of cylinder, are given in Fig. 71-78. As the characteristic area S is

selected the area of basis/base, as the significant dimension of L - length of cylinder. At the fixed/recorded length of cylinder ($Re_{0L}=162$) the experimental data are given in Fig. 71-74, with fixed/recorded diameter ($Re_{0D}=13$) - in Fig. 75-78.

Body of revolution with the generatrix $Re \sim x^{3/4}$. The aerodynamic characteristics of the bodies of revolution, which have the equation of generatrix in the form of exponential monomial with the exponent of $3/4$, are given in Fig. 79-82 at the different values of the relative thickness D/L , where D and L - diameter of basis/base and the length of body. As the characteristic area is accepted the area of basis/base S , as the significant dimension - length of body of revolution L . Criterion Re_{0L} , designed along the length of model, for each value of D/L is given below:

D/L	0,115	0,16	0,32	0,80
Re_{0L}	228	162	162	98

For the comparison in Fig. 79 and 80 dotted lines plotted/applied the drag coefficients and lift of acute cone at the same values of D/L and Re_{0L} .

Sphere. Resistance of sphere was studied both theoretically and by experimentally many authors. Basic experimental data are obtained in works [4, 17, 18] and are given in Fig. 7. The values of the drag coefficient $\bar{c}_x$ of sphere with the needle of variable of length, pertaining to drag coefficient of the sphere, in hypersonic flow of

rarefied gas are given in Fig. 83. On the same figure for the comparison are cited analogous data, obtained in work [26] with the large Re numbers. It is evident that with the small Re numbers a change in the length of needle weakly affects resistance of sphere.

Page 12.

Plate. Are given below the dependences of the aerodynamic characteristics of plate on its geometric parameters. As the characteristic area is accepted the area of plate S in the plan/layout, as the significant dimension - chord length in the root section L .

In the case of rectangular plate the effect of its relative thickness $\bar{\delta}_L = \delta/L$ at several fixed values of the elongation of a plate λ and number Re_L^* , designed along the length L , are illustrated Fig. 84-95, and the effect of the elongation of plate λ at constant values $\bar{\delta}_L$ and Re_L^* - Fig. 96-104. Fig. 105-107 presents dependences c_x , c_z and K on the angle of attack α for the rectangular plates with constant values of S and $\bar{\delta}_L = \delta/l = 0,028$, where $l = \sqrt{S}$, over a wide range of change λ . Number Re_L^* here was calculated from the reference length l and was equal to 39.

The effect of sweep angle χ on the aerodynamic characteristics

of triangular plate at different values Re_0^I and $\bar{\delta}_I$ is shown in Fig. 108-115. The values of the aerodynamic characteristics of triangular plates over a wide range of change λ at constant values of S and $\bar{\delta}_I = \delta_I l = 0,028$, where $l = \sqrt{S}$, are given in Fig. 116-119. Number Re_0^I here again was calculated from the reference length l and was equal to 39.

As it follows from given experimental data, viscosity effect significantly changes the character of the flow around body, as a result of which the dependence of the aerodynamic characteristics of bodies on their geometric parameters becomes different from that which is observed with the large Reynolds numbers. For example, the given in works [19, 20] results of the systematic studies of the aerodynamic characteristics of the plates of the fixed/recorded area showed that with a change in the elongation λ the dependence of maximum lift-drag ratio K_{max} , has a maximum at the finite value λ . The results of these investigations are given in Fig. 120-123 in the form of the dependences of maximum lift-drag ratio K_{max} and angle of attack α_{max} , which corresponds K_{max} on the elongation λ and relative thickness $\bar{\delta}_I$ for the plates of different planform. As it follows from given data, in the hypersonic low-density flow the wings with the elongations $\lambda = 0.4-0.8$ have advantages from the point of view of lift effectiveness in comparison with the wings of other elongations, moreover with the sufficiently small wing chord ratio $\bar{\delta}_I \leq 0,03$ independent of its form optimum is wing with the elongation $\lambda = 0.6$.

The aerodynamic coefficients of the plates of various forms and fixed/recorded area S , streamlined at the high angles of attack ($\alpha=90^\circ$), are represented in Table 1.

Table 1.

(1) Коэффициенты	(2) Форма пластин						(7) Равносторонний треугольник
	(3) Окружность	(4) Эллипс	(5) Ромб	(6) Прямоугольник			
λ	1	0,496	0,509	1	0,491	0,317	1,155
$\bar{\delta}_l$	0,2	0,2	0,2	0,25	0,19	0,18	0,195
c_{x0}	1,81	1,81	1,85	1,85	1,85	1,88	1,92
c_{y0}	0,0207	0,0220	0,0220	0,0195	0,0226	0,0255	0,0200

Key: (1). Coefficients. (2). Form of plates. (3).

Circle/circumference. (4). Ellipse. (5). Rhomb. (6). Rectangle. (7).

Equilateral triangle.

Page 13.

Number $Re_{\delta_l}^*$ was calculated in this case over the reference length $\sqrt{S}$ and was equal to 65. As with the large Re numbers [27] the form of flat/plane blunting virtually does not affect the value of aerodynamic coefficients.

Three-dimensional bodies. The aerodynamic characteristics of three-dimensional bodies are analyzed based on the examples of semicone and combination of wing with the semicone. As the characteristic area is accepted the area of model in plan/layout S , as the significant dimension - chord length in the root section L .

The effect of blind sectors of body on its aerodynamic characteristics was investigated based on the example of semicone. In the case when the conical part of the semicone is turned towards the flow, aerodynamic coefficients for the semicone are compared with the appropriate characteristics of complete cone. When $Re_{0L}^I = 130$ corresponding data for the cone with a half-angle of solution/opening of $\theta = 15^\circ$ are cited in Fig. 124-127.

In the case when the flat surface of semicone is turned towards the flow, the aerodynamic characteristics of semicone with $\theta = 15^\circ$ with number $Re_{0L}^I = 130$ are compared with the appropriate characteristics of triangular plate with the sweep angle of $\chi = 75^\circ$ ($\bar{\delta}_L = 0,025$) in Fig. 128-131.

As follows from given data, in the mode/conditions hypersonic flows of rarefied gas the effect of blind sectors of body on its aerodynamic characteristics it becomes essential.

Fig. 132-139 gives the values of the aerodynamic characteristics of the model, which is the combination of the blunted semicone with the tapered wing. The sweep angle of wing of $\chi = 75^\circ$, chord length in the root section is equal to the length of semicone L , and the length of leading edge - to diameter of the flat/plane blunting d of semicone. Number $Re_{0L}^I = 130$, angles of attack α are considered positive, when the flat surface of model is turned towards the flow.

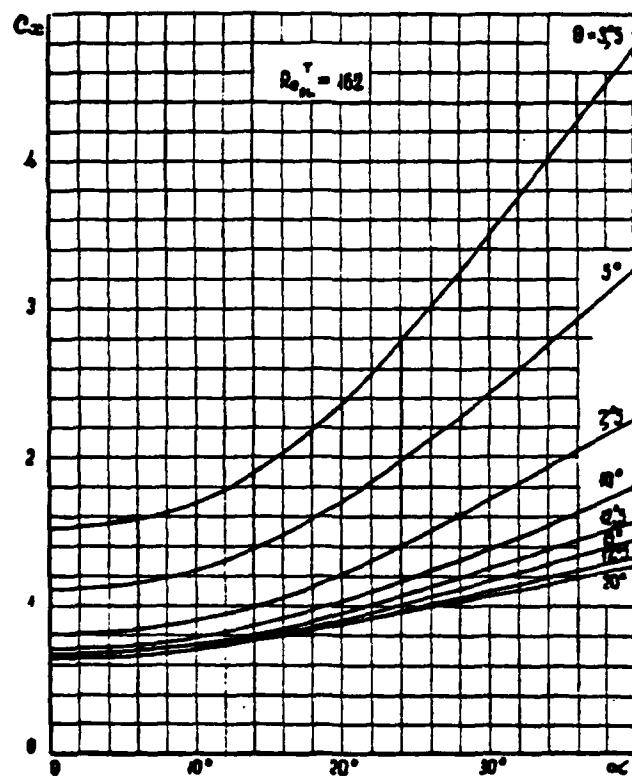


Fig. 9.

Page 14.

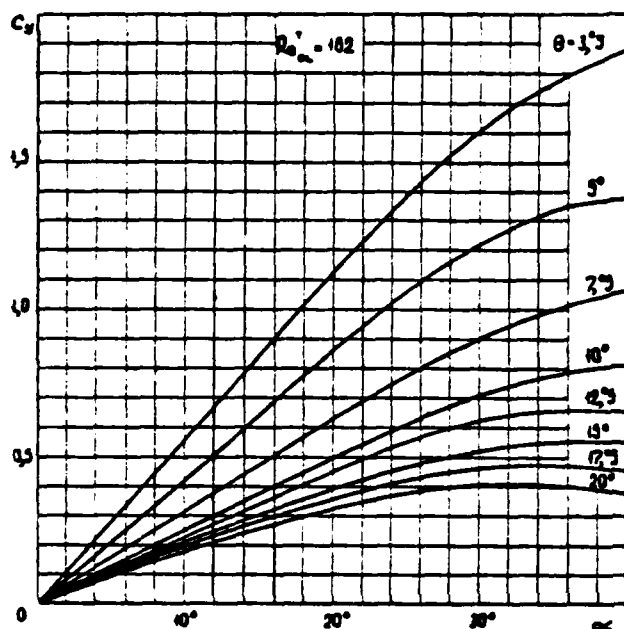


Fig. 10.

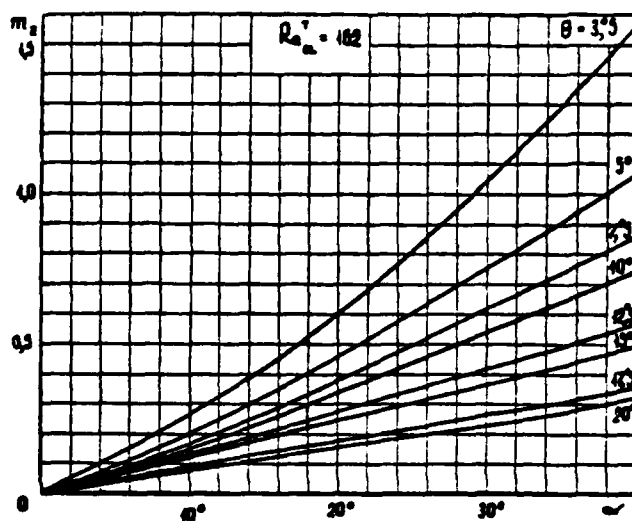


Fig. 11.

Page 15.

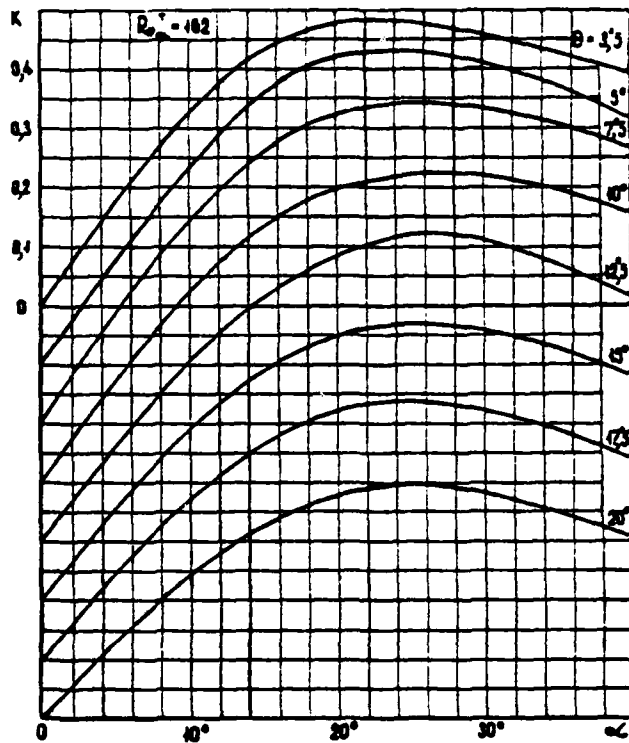


Fig. 12.

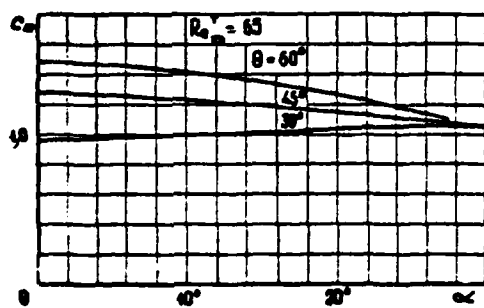


Fig. 13.

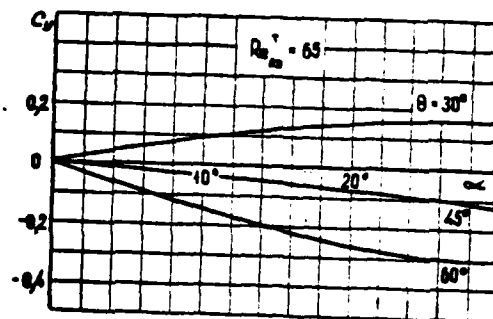


Fig. 14.

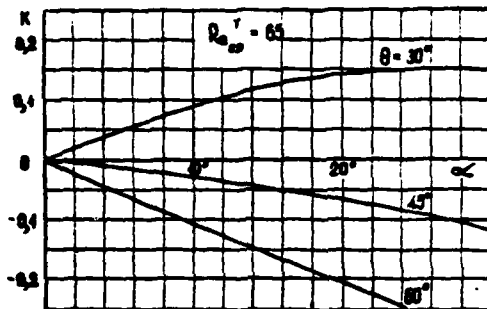


Fig. 15.

Page 16.

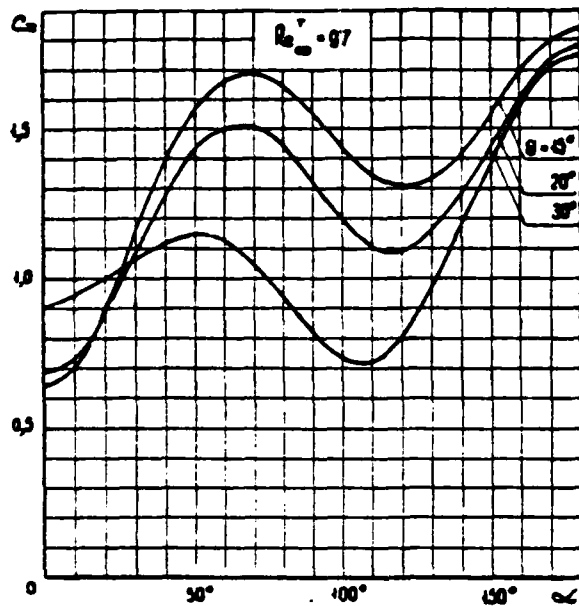


Fig. 16.

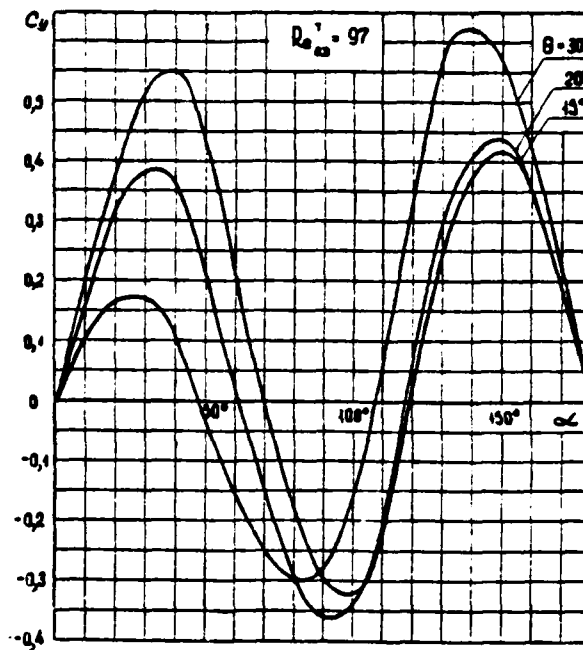


Fig. 17.

Page 17.

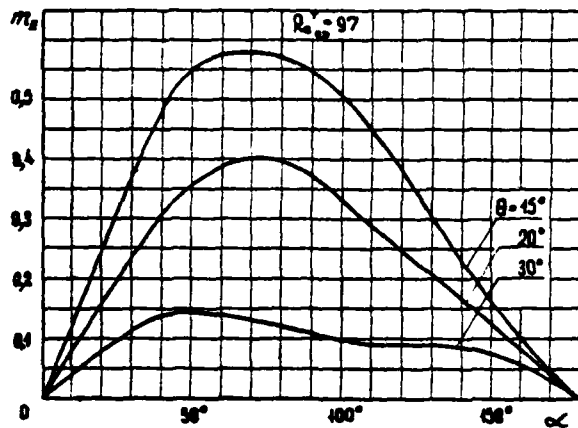


Fig. 18.

Page 18.

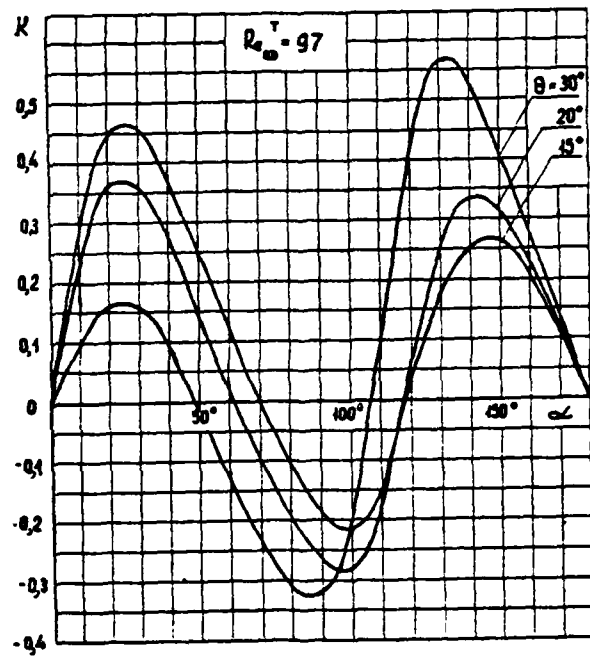
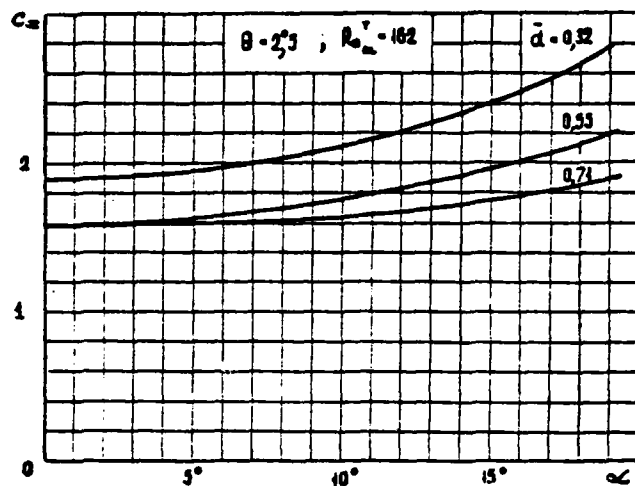


Fig. 19.

Fig. 20.



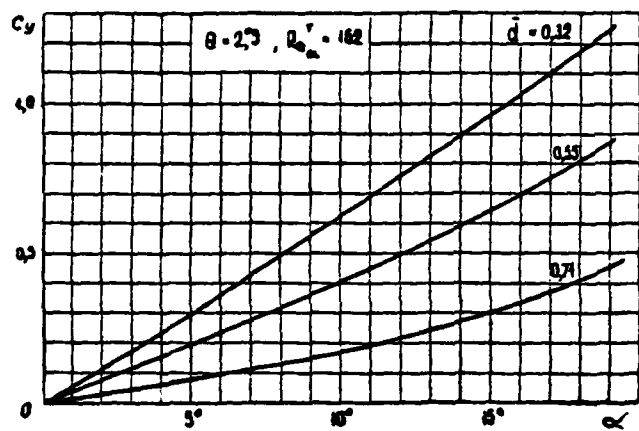


Fig. 21.

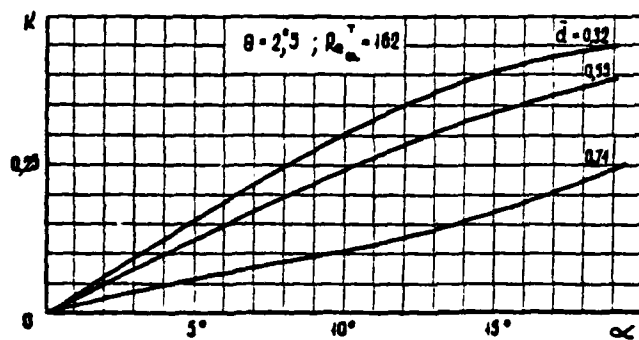


Fig. 23.

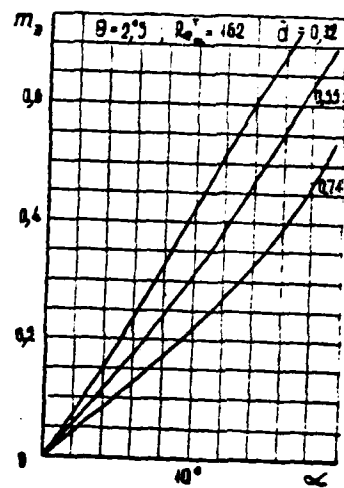


Fig. 22.

Page 19.

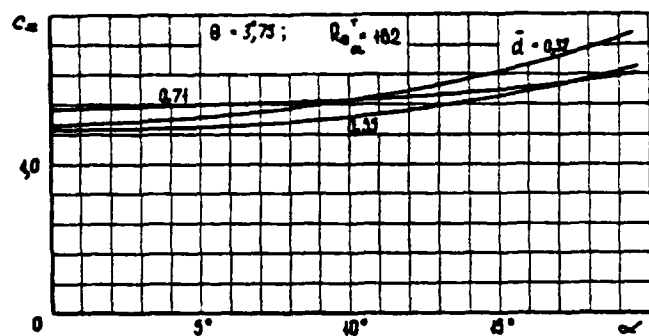


Fig. 24.

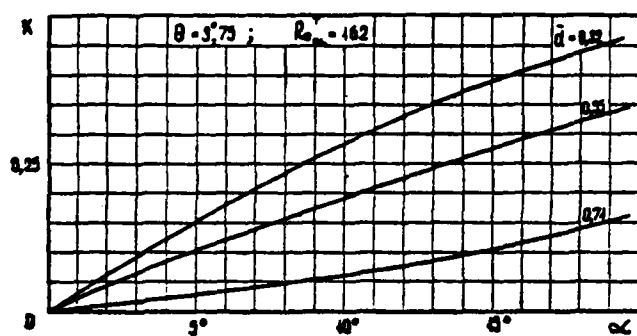


Fig. 25.

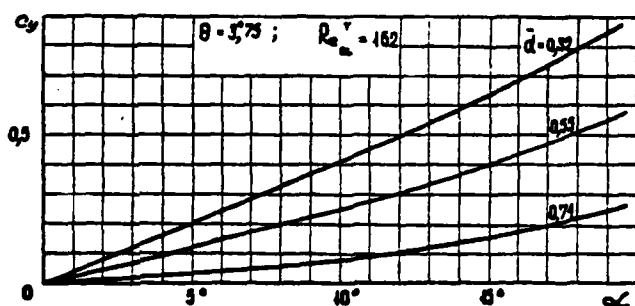


Fig. 27.

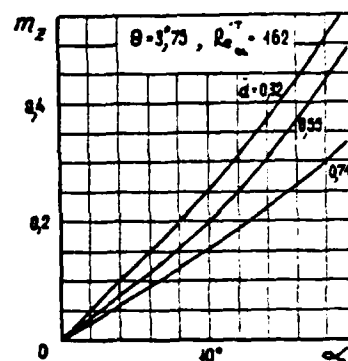


Fig. 26.

Page 20.

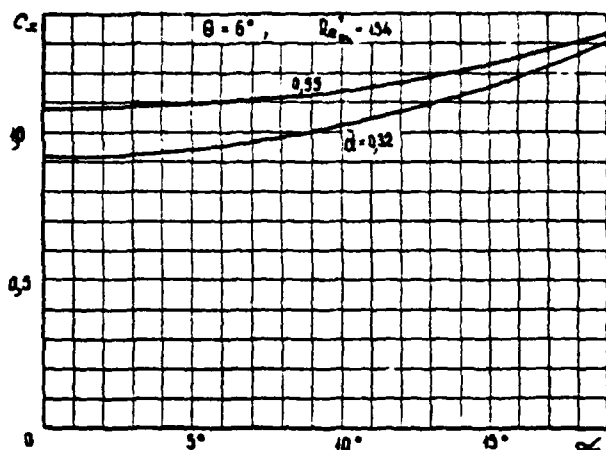


Fig. 28.

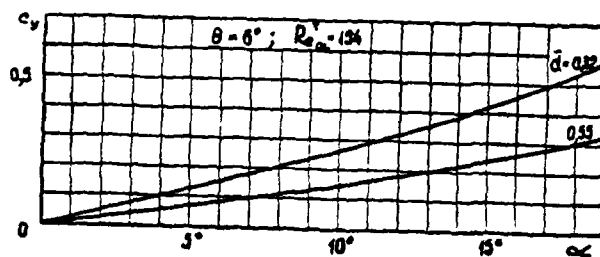


Fig. 29.

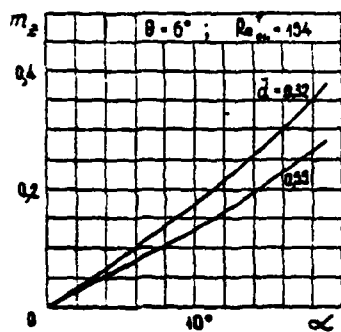


Fig. 30.

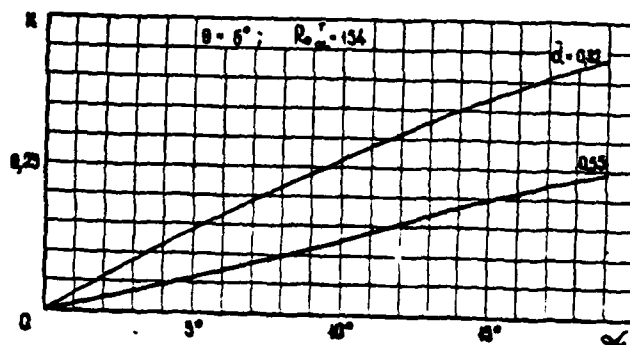


Fig. 31.

Page 21.

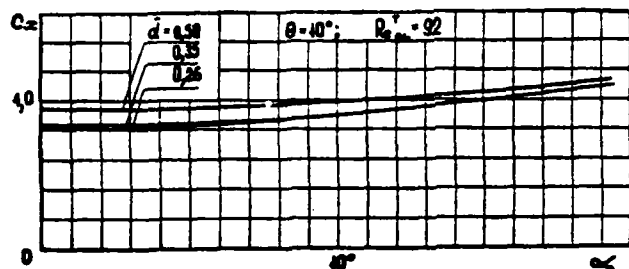


Fig. 32.

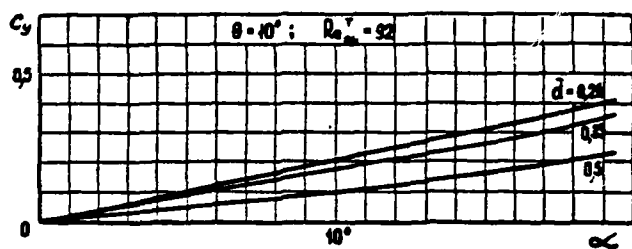


Fig. 33.

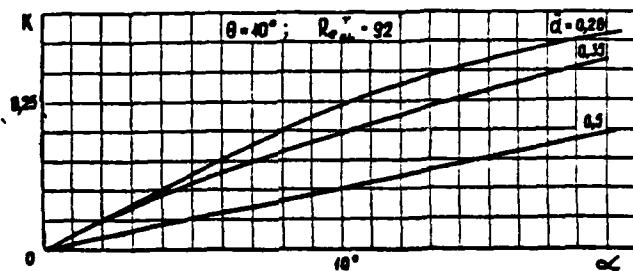


Fig. 35.

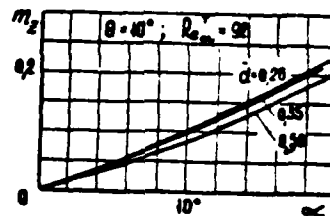


Fig. 34.

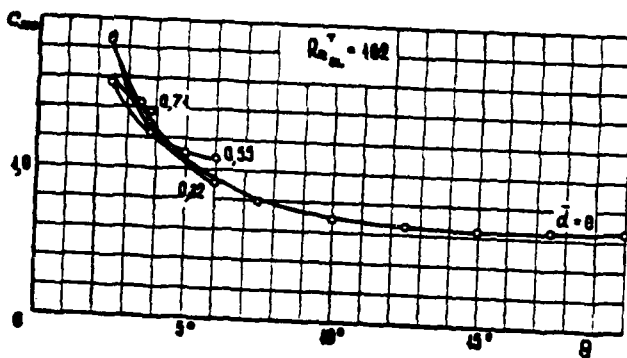


Fig. 36.

Page 22.

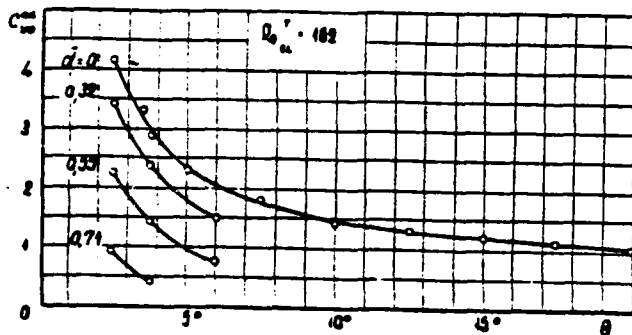


Fig. 37.

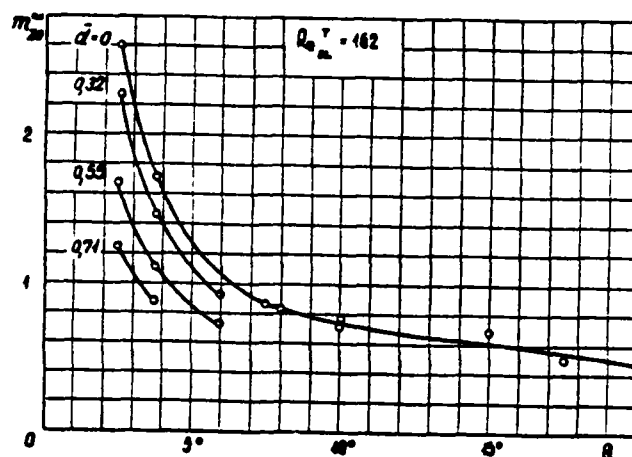


Fig. 38.

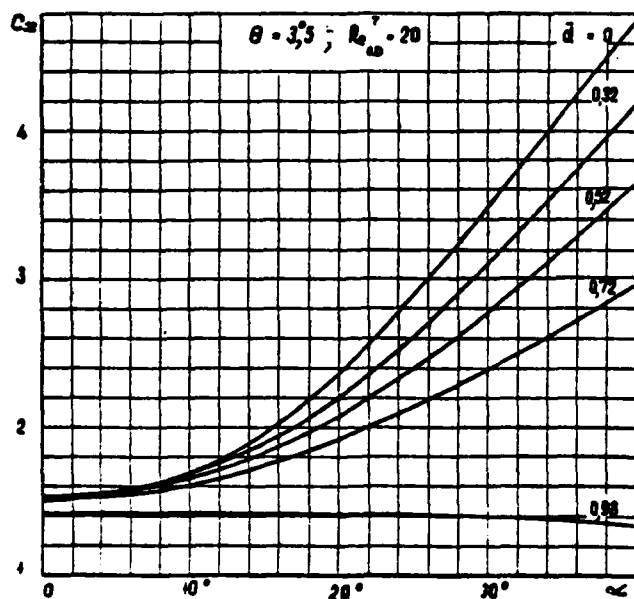


Fig. 39.

Page 23.

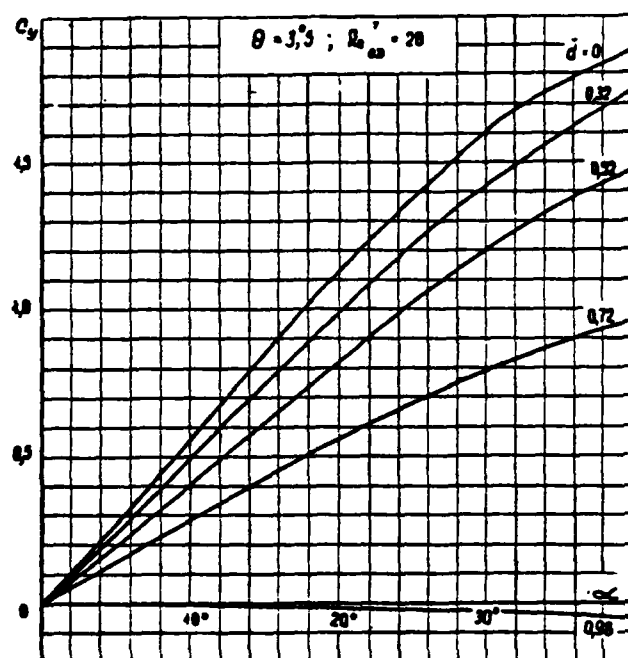


Fig. 40.

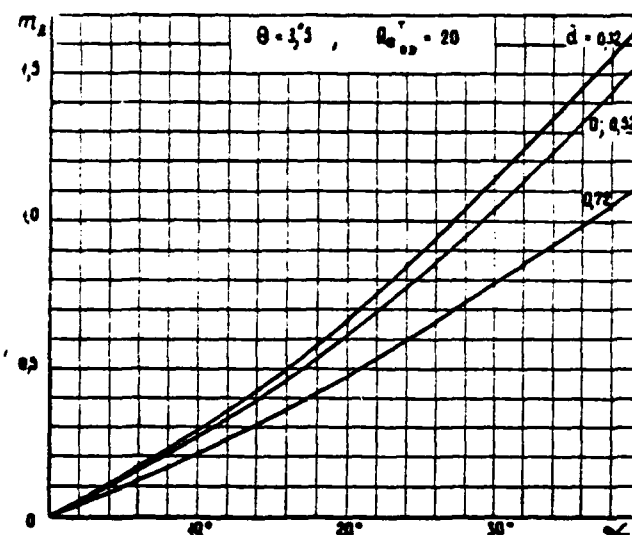


Fig. 41.

Page 24.

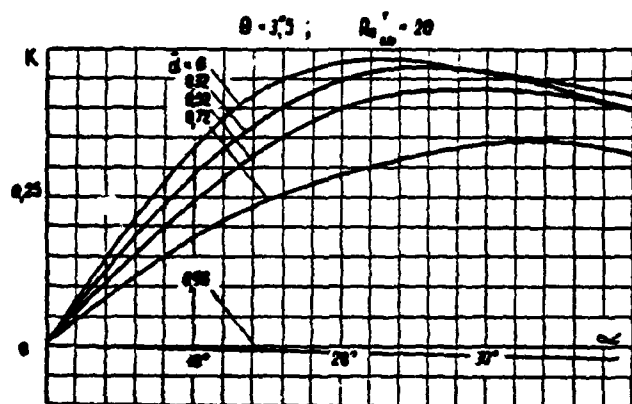


Fig. 42.

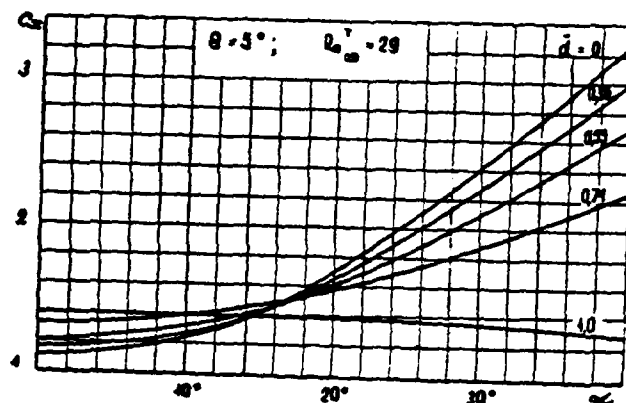


Fig. 43.

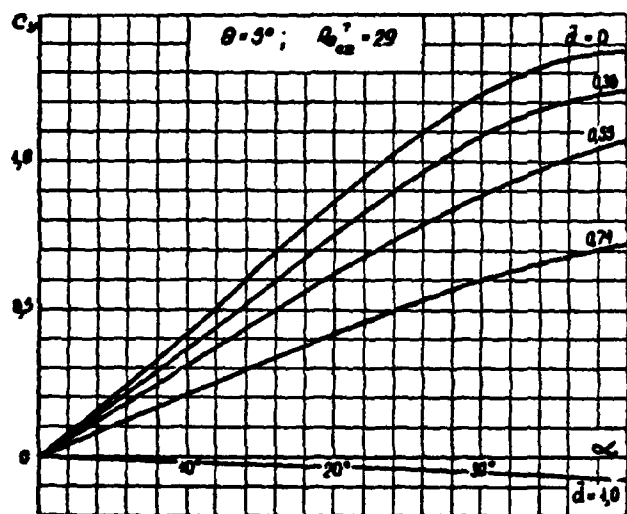


Fig. 44.

Page 25.

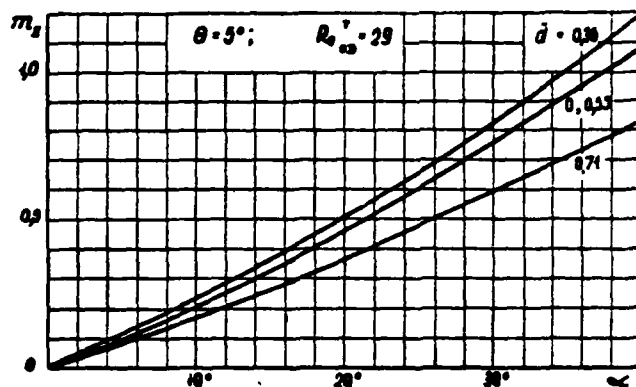


Fig. 45.

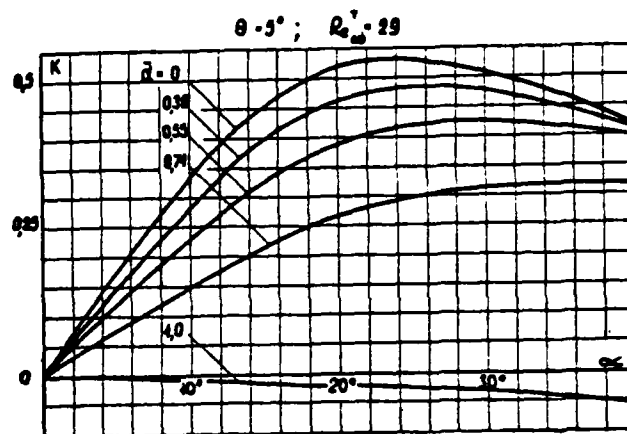


Fig. 46.

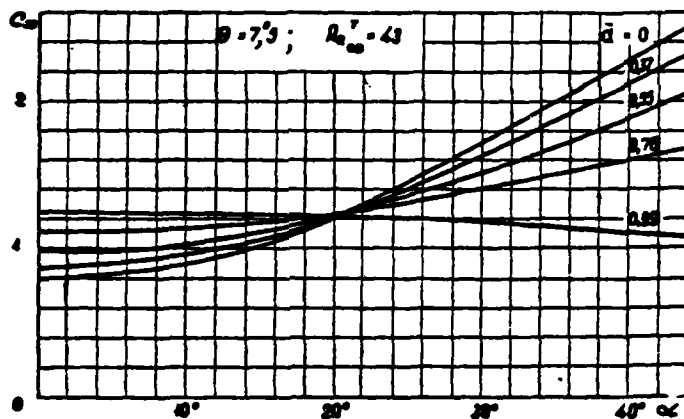


Fig. 47.

Page 26.

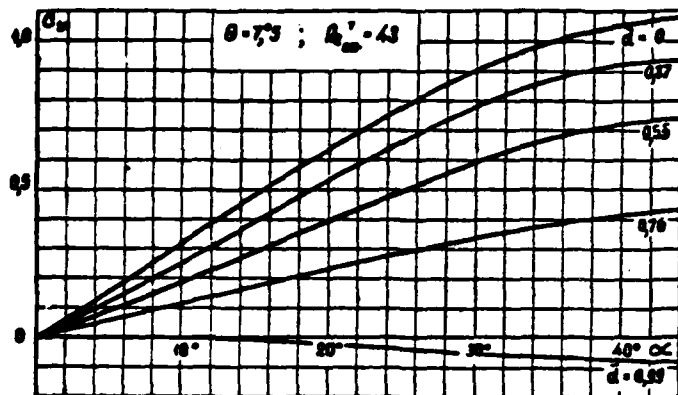


Fig. 48.

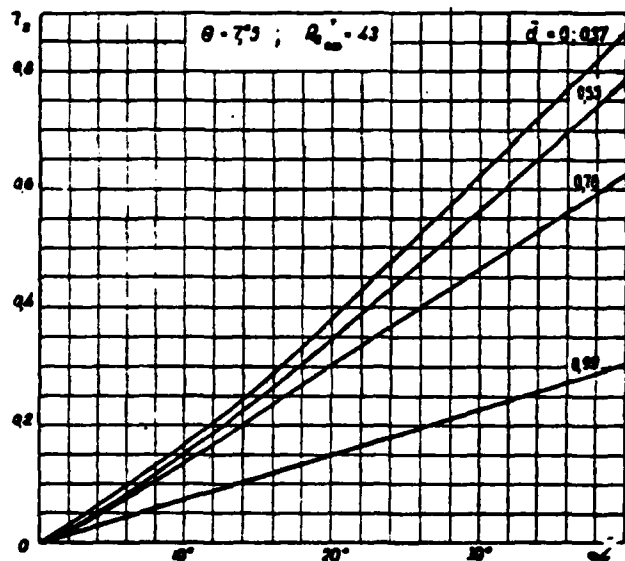


Fig. 49.

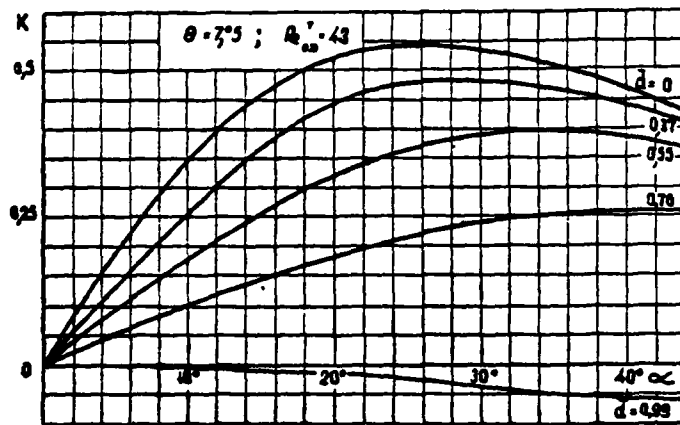


Fig. 50.

Page 27.

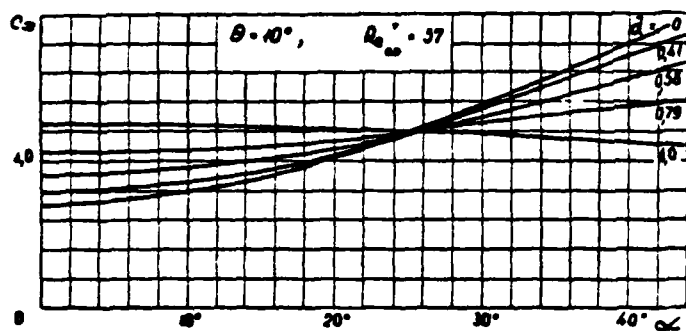


Fig. 51.

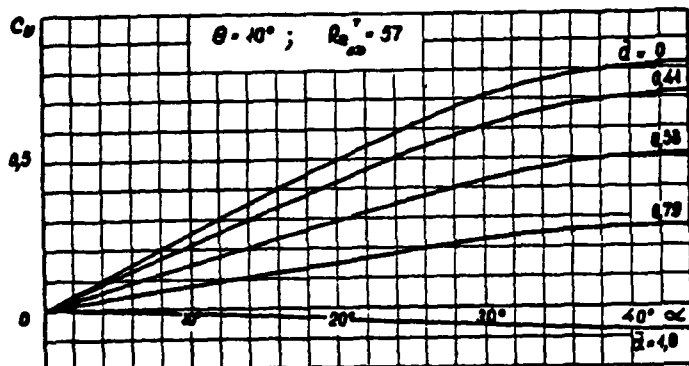


Fig. 52.

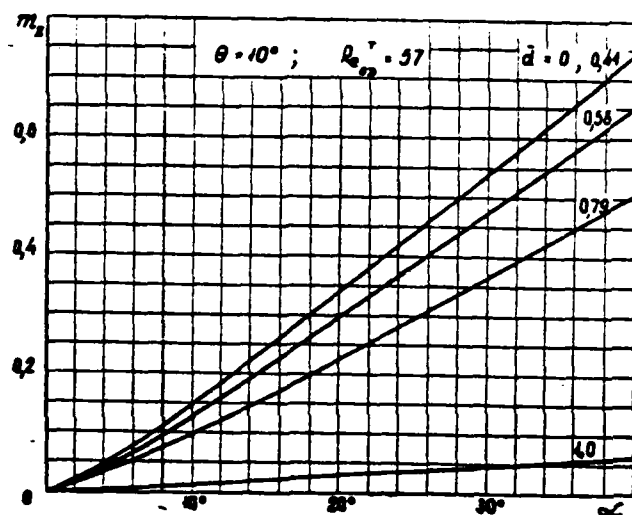


Fig. 53.

Page 28.

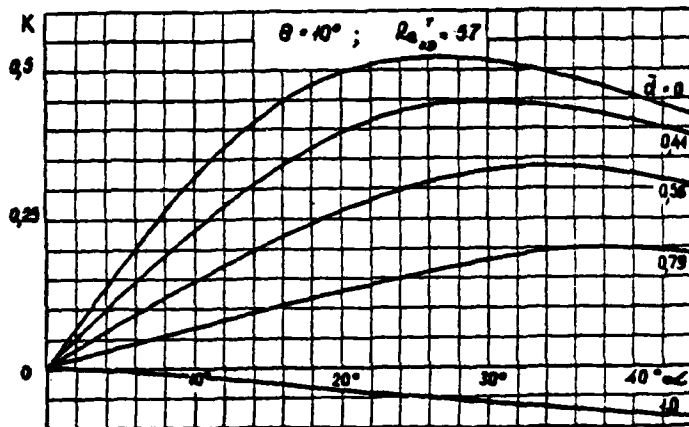


Fig. 54.

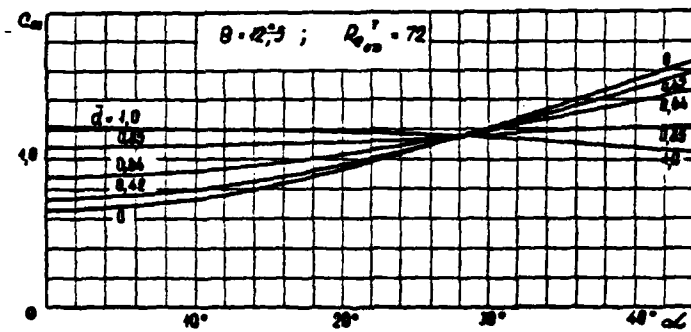


Fig. 55.

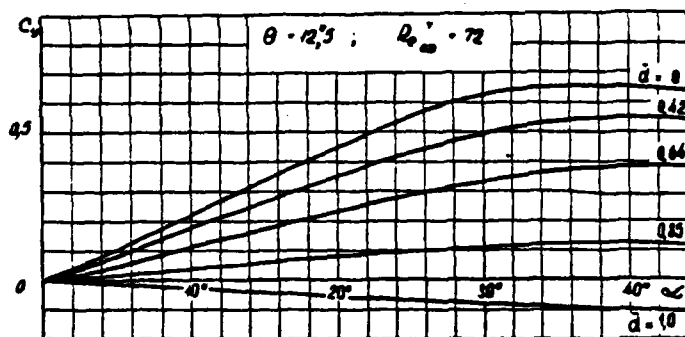


Fig. 56.

Page 29.

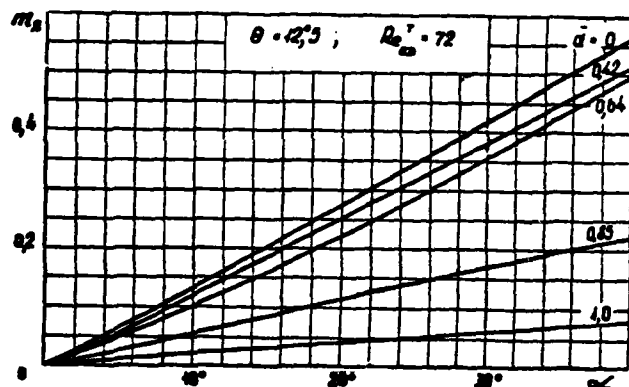


Fig. 57.

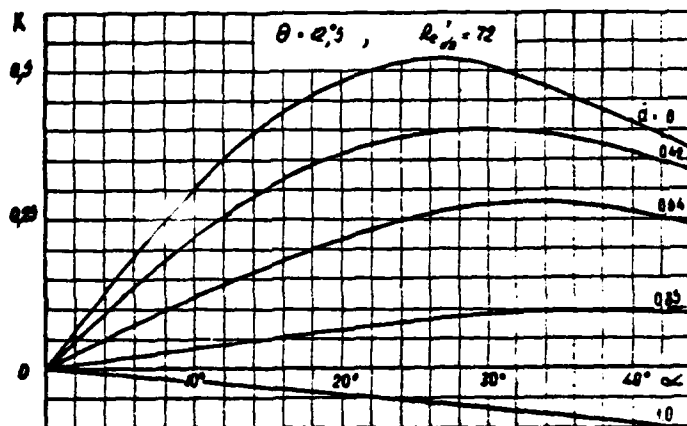


Fig. 58.

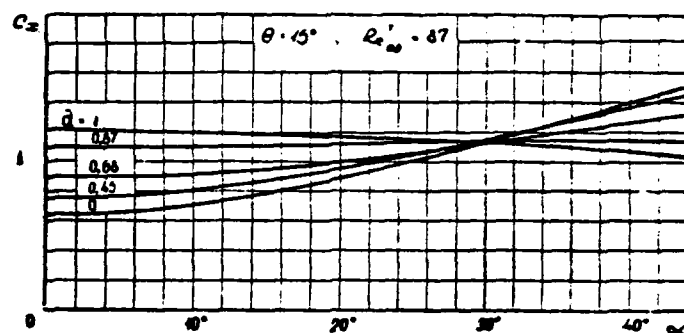


Fig. 59.

Page 30.

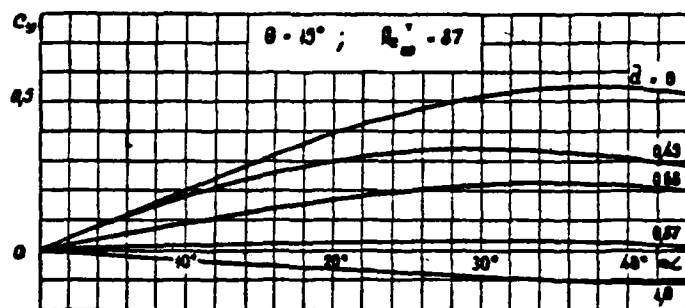


Fig. 60.

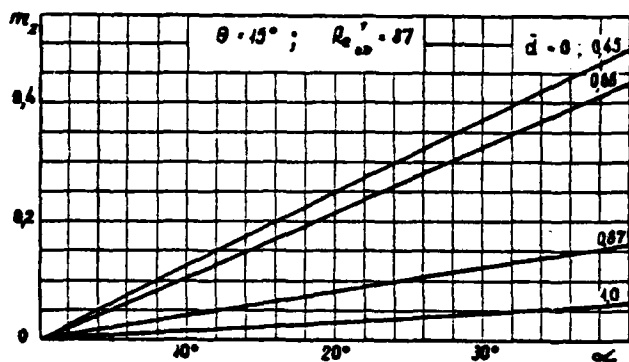


Fig. 61.

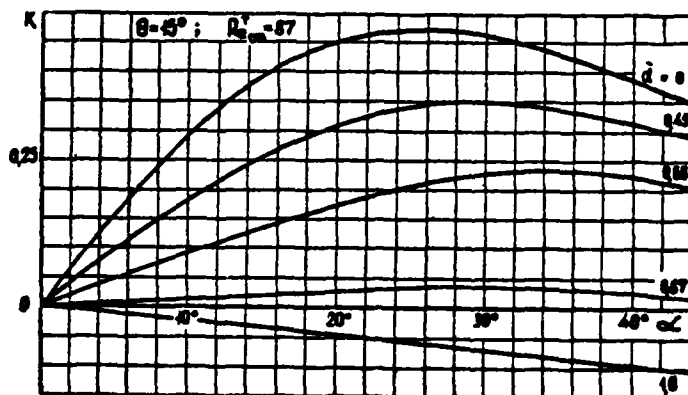


Fig. 62.

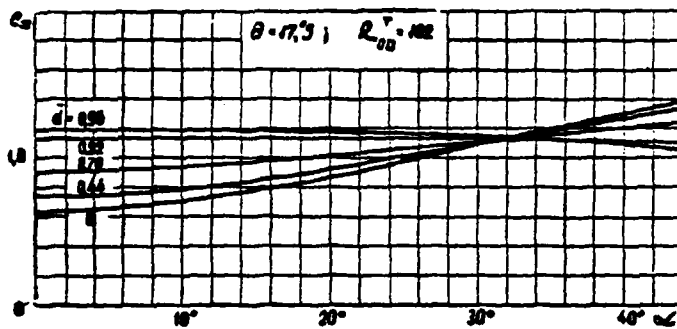


Fig. 63.

Page 31.

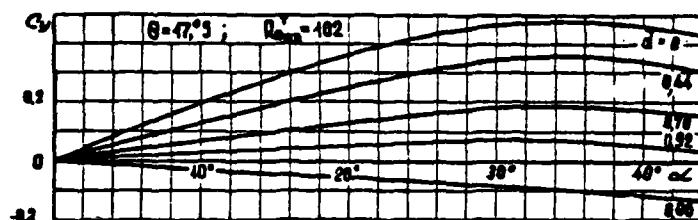


Fig. 64.

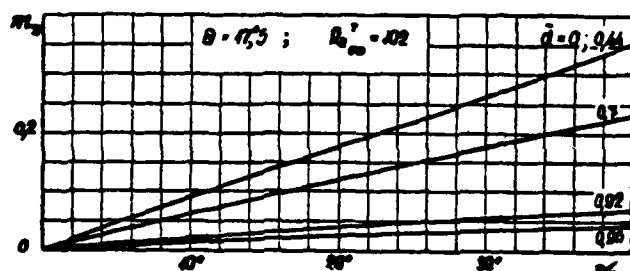


Fig. 65.

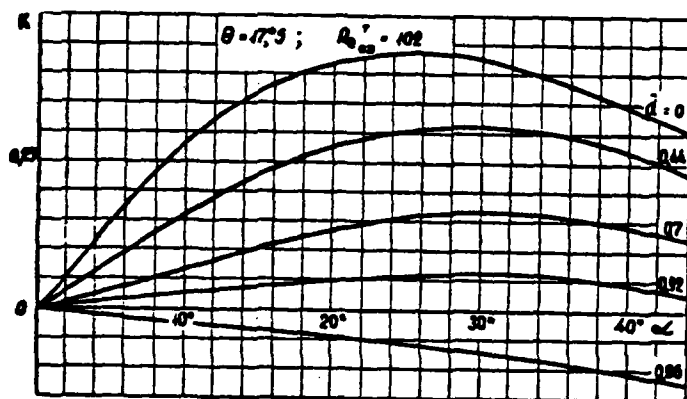


Fig. 66.

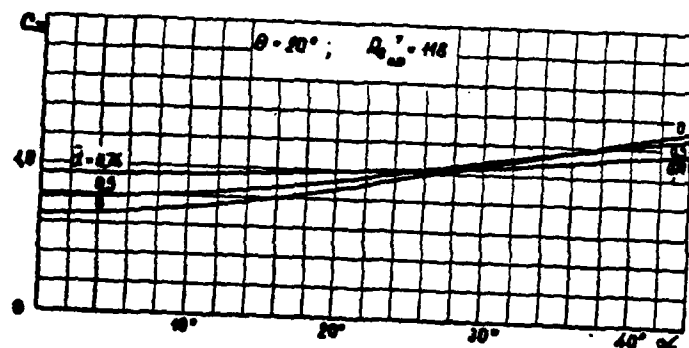


Fig. 67.

Page 32.

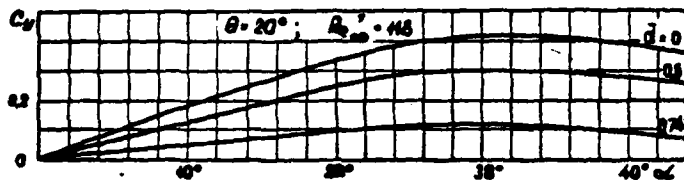


Fig. 68.

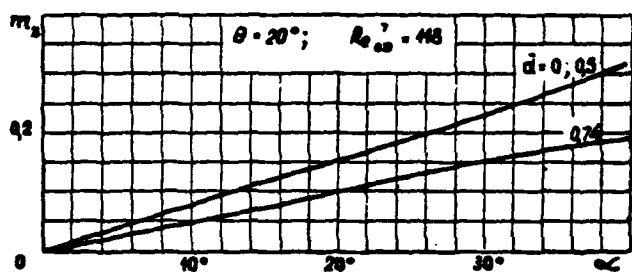


Fig. 69.

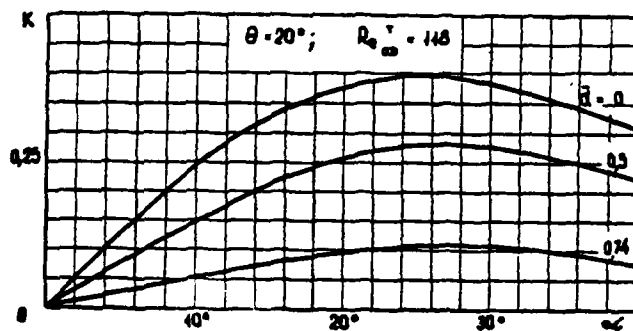


Fig. 70.

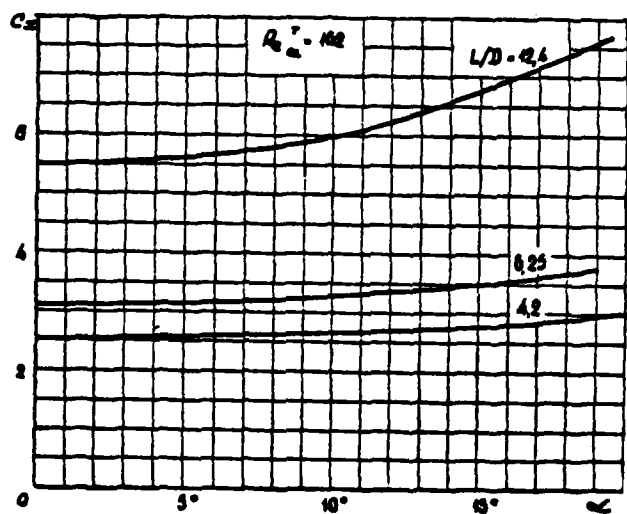


Fig. 71.

Page 33.

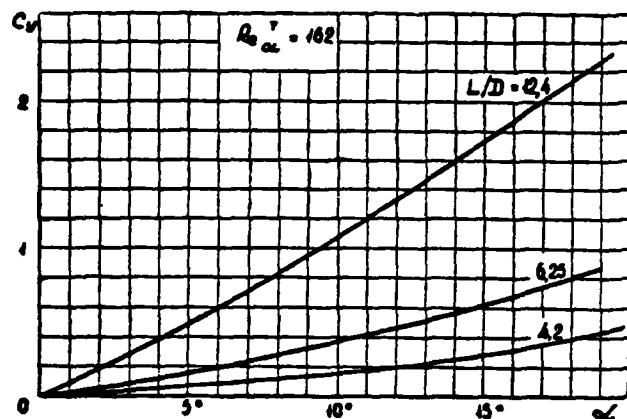


Fig. 72.

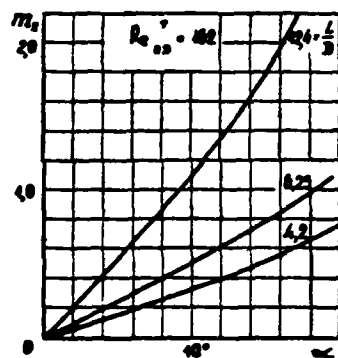


Fig. 73.

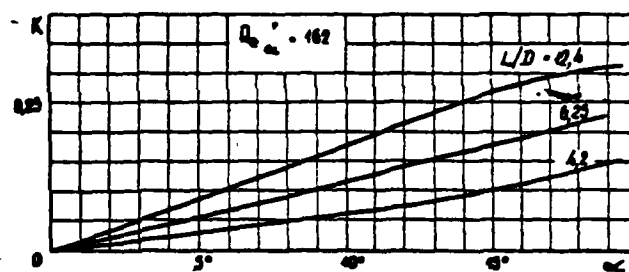


Fig. 74.

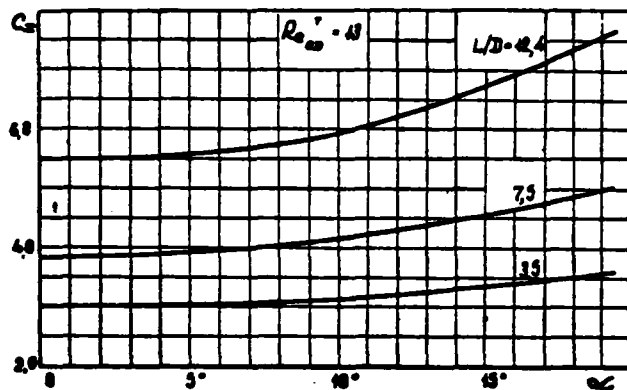


Fig. 75.

Page 34.

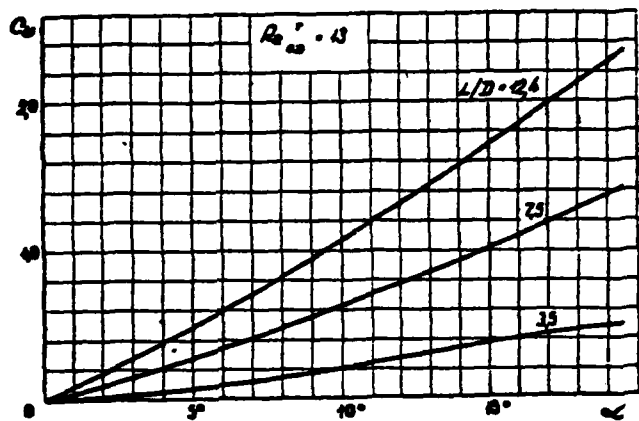


Fig. 76.

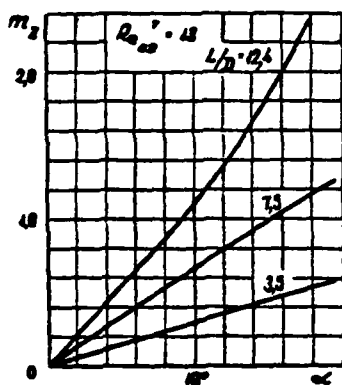


Fig. 77.

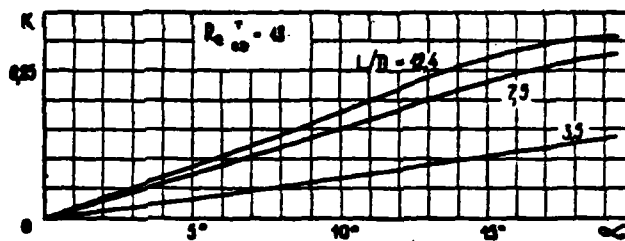


Fig. 78.

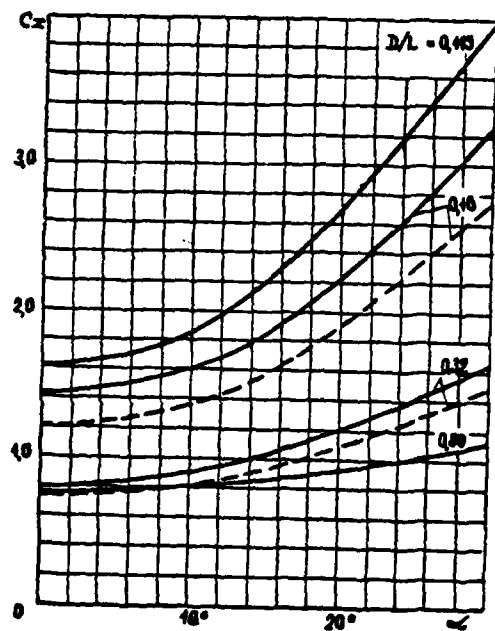


Fig. 79.

Page 35.

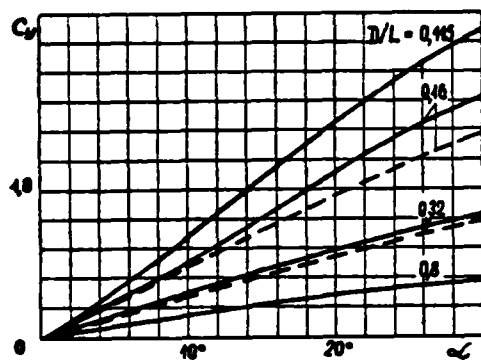


Fig. 80.

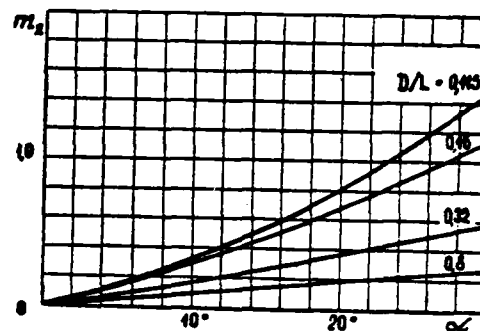


Fig. 81.

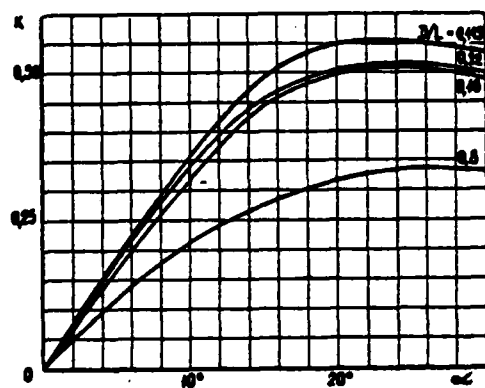


Fig. 82.

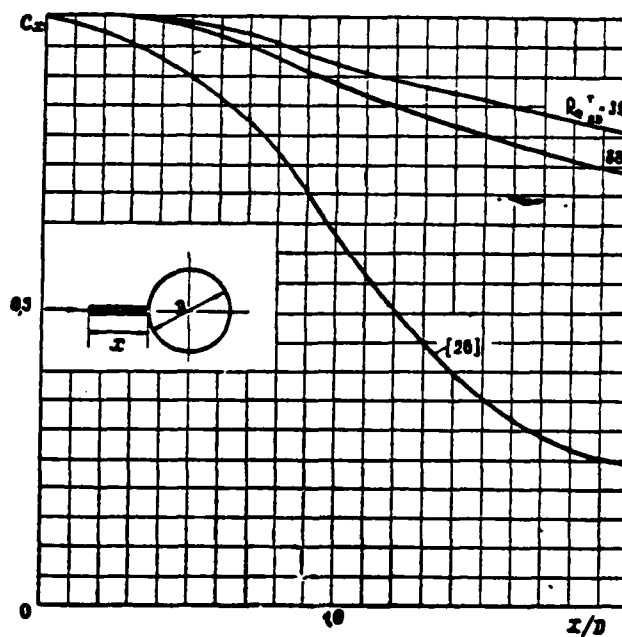


Fig. 83.

Page 36.

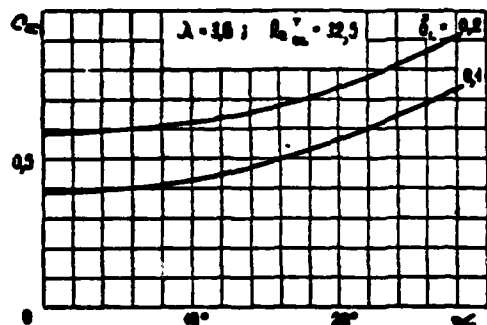


Fig. 84.

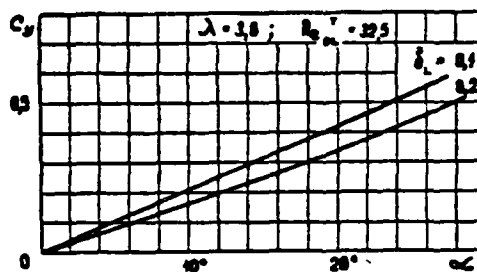


Fig. 85.

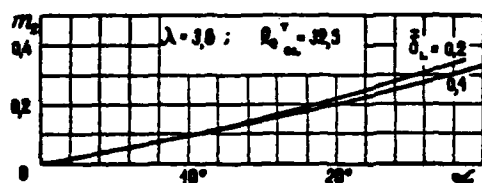


Fig. 86.

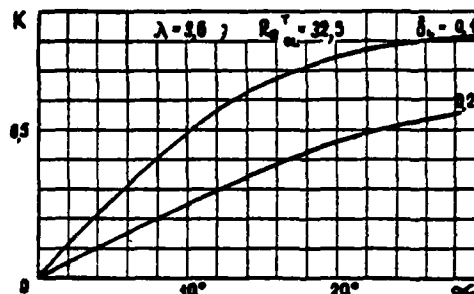


Fig. 87.

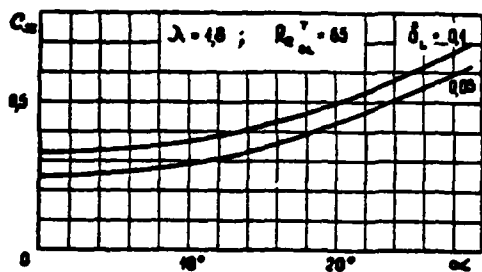


Fig. 88.

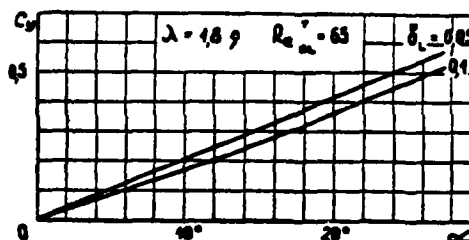


Fig. 89.

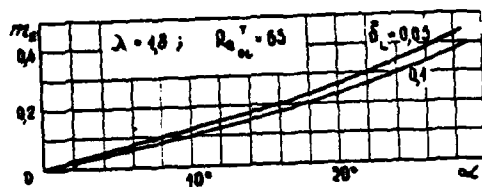


Fig. 90.

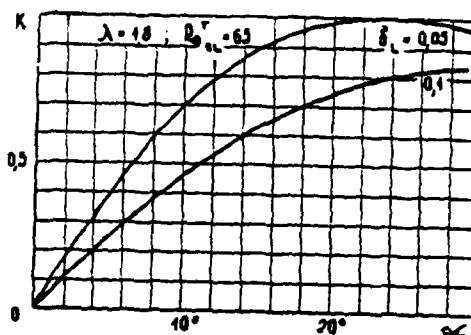


Fig. 91.

Page 37.

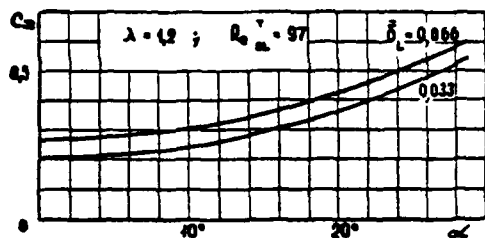


Fig. 92.

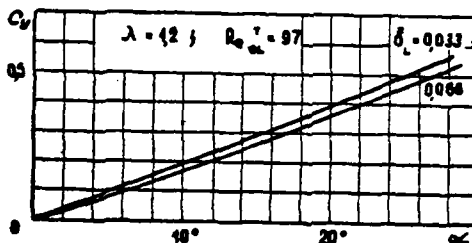


Fig. 93.

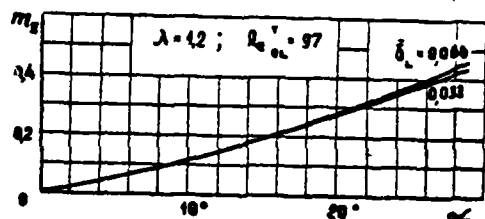


Fig. 94.

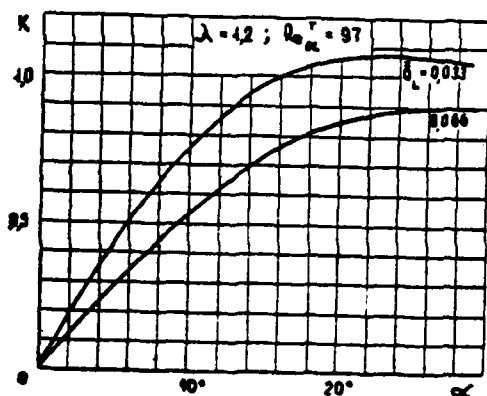


Fig. 95.

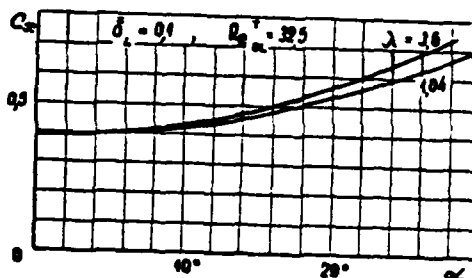


Fig. 96.

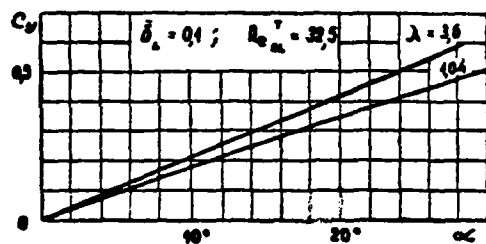


Fig. 97.

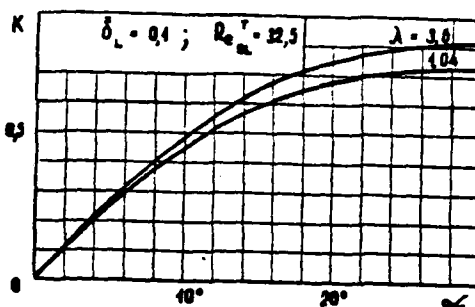


Fig. 98.

Page 38.

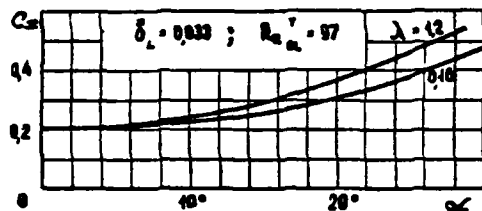


Fig. 99.

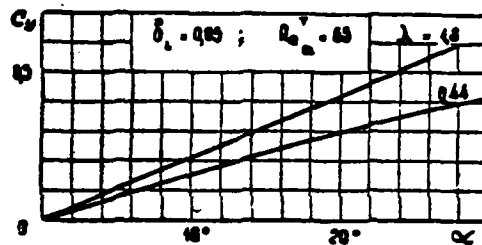


Fig. 100.

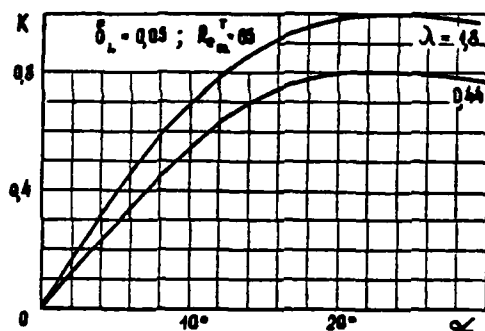


Fig. 101.

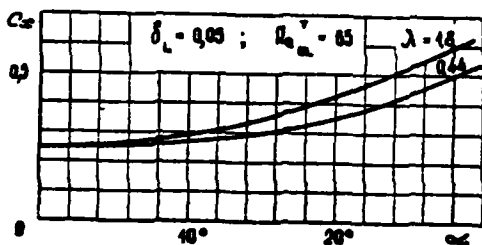


Fig. 102.

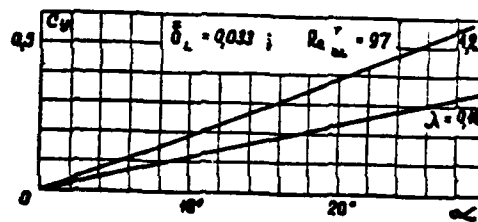


Fig. 103.

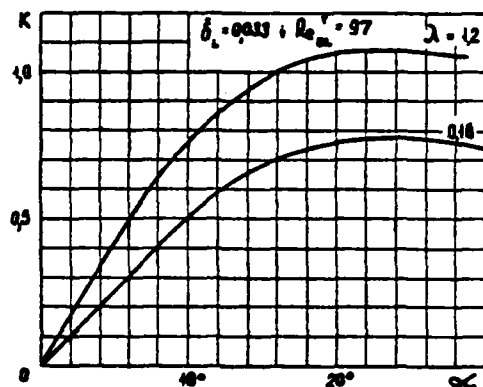


Fig. 104.

Page 39.

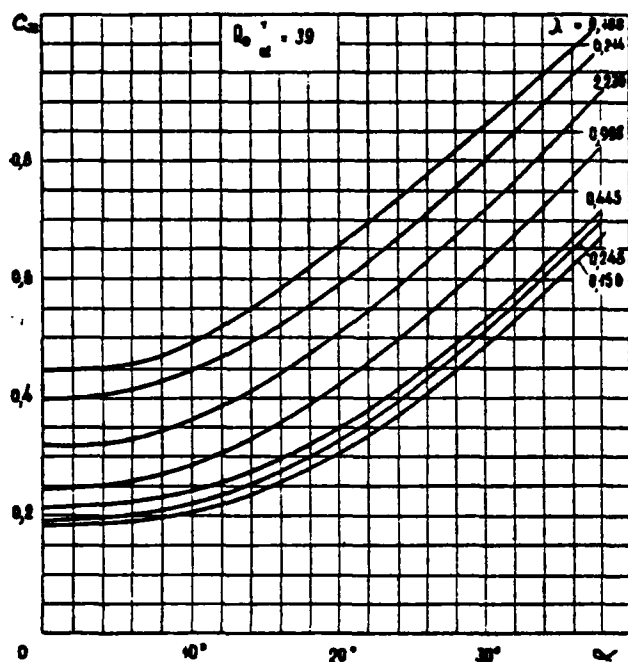


Fig. 105.

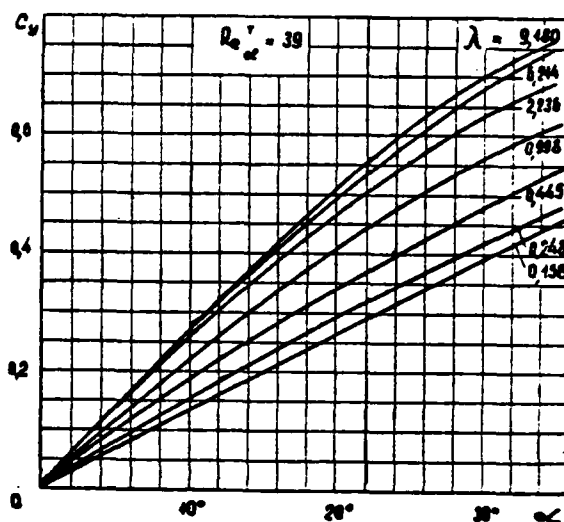


Fig. 106.

Page 40.

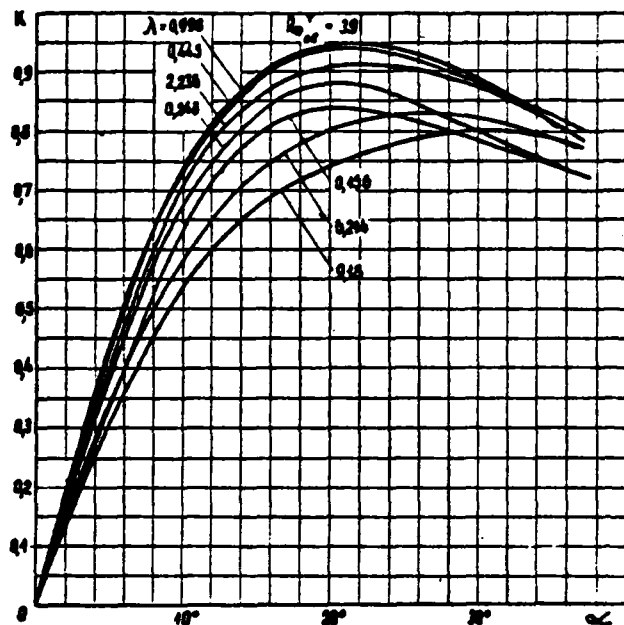


Fig. 107.

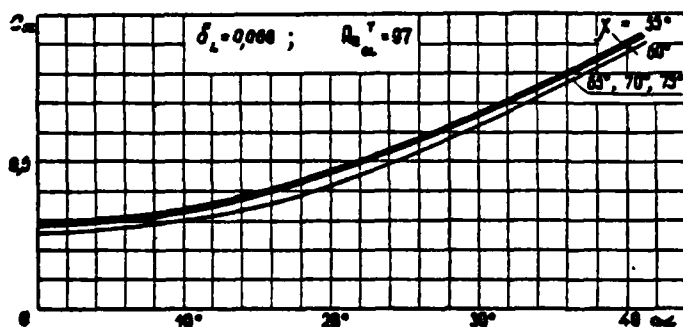


Fig. 108.

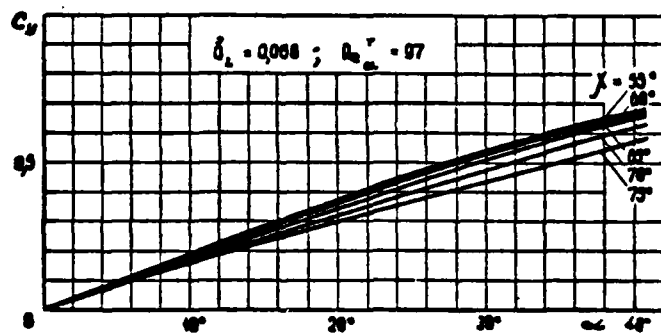


Fig. 109.

Page 41.

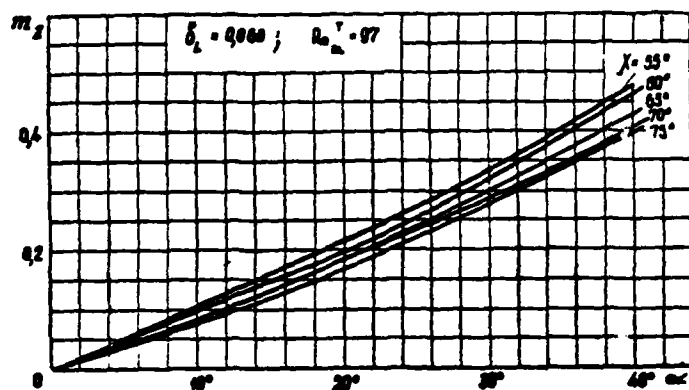


Fig. 110.

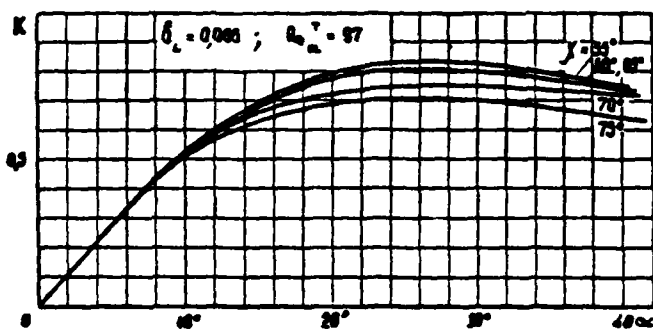


Fig. 111.

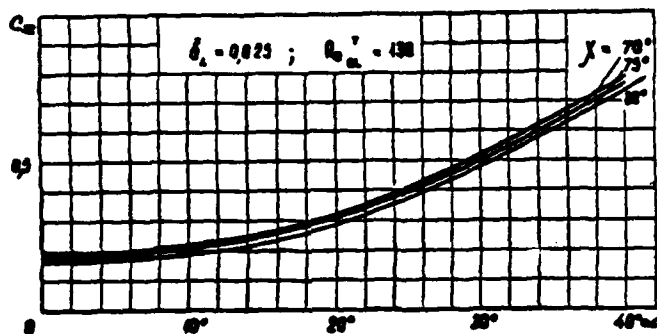


Fig. 112.

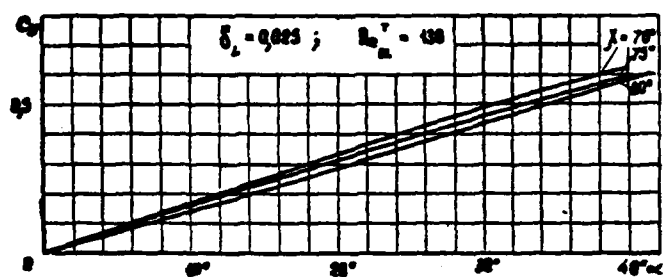


Fig. 113.

Page 42.

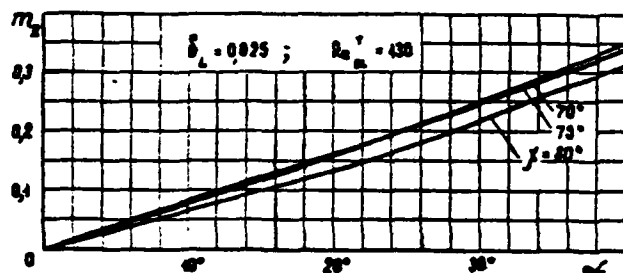


Fig. 114.

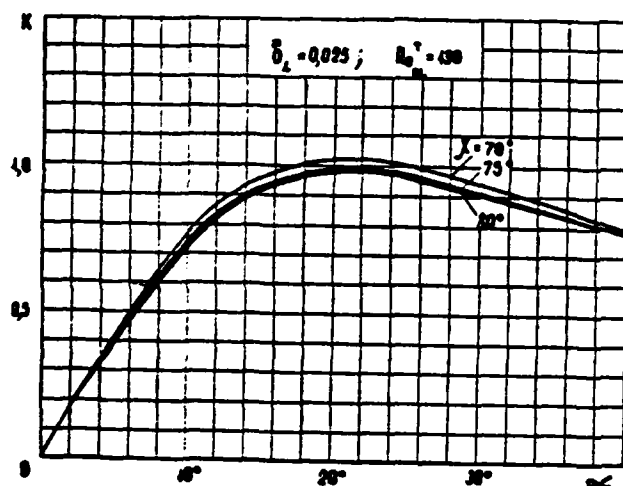


Fig. 115.

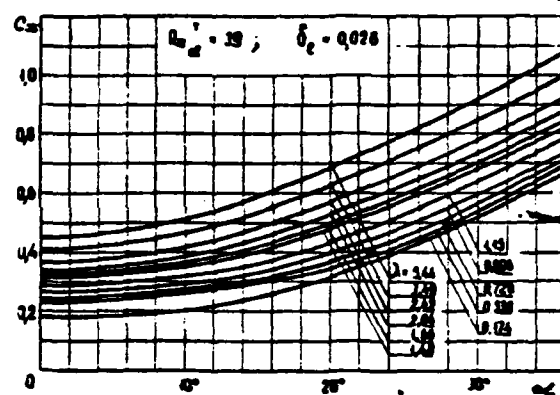


Fig. 116.

Page 43.

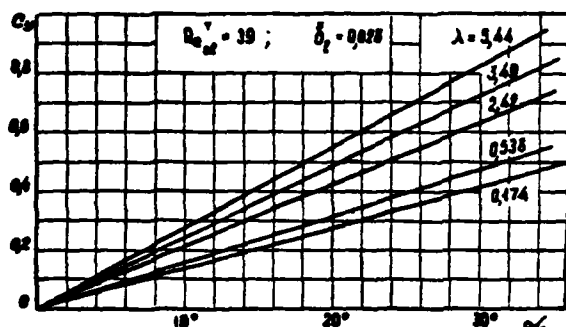


Fig. 117.

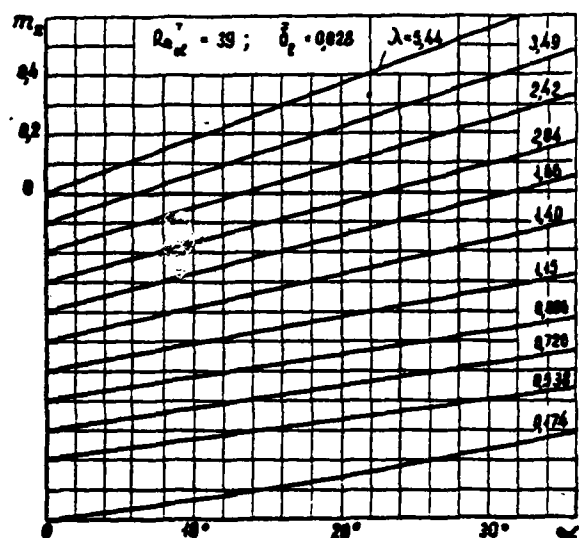


Fig. 118.

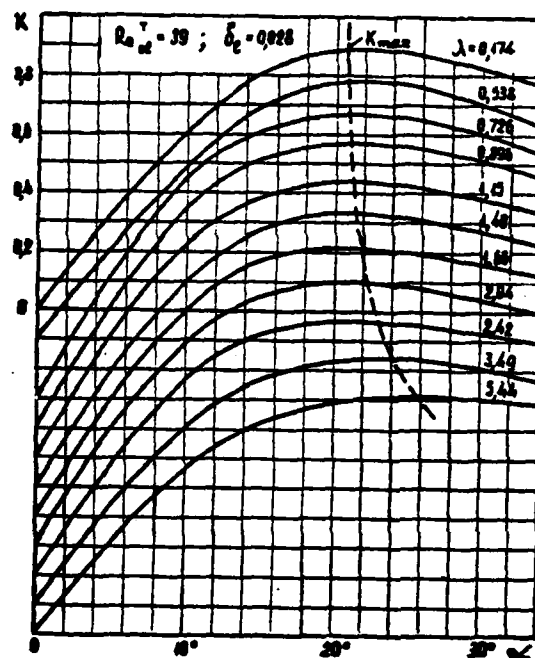


Fig. 119.

Page 44.

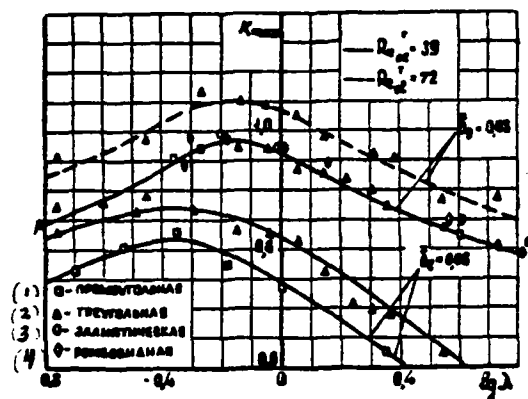


Fig. 120.

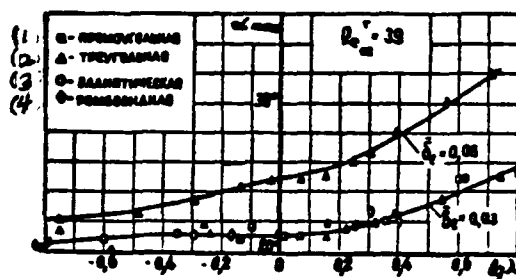


Fig. 121.

Fig. 120. Key: (1). rectangular. (2). triangular. (3). elliptical.
(4). rhombiform.

Fig. 121. Key: (1). rectangular. (2). triangular. (3). elliptical.
(4). rhombiform.

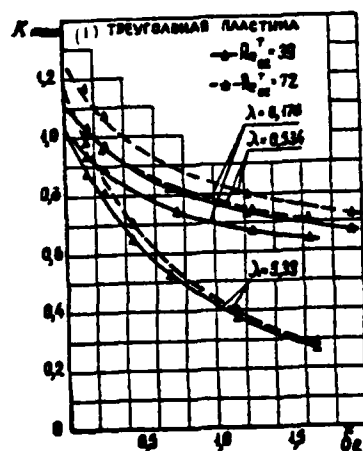


Fig. 122.

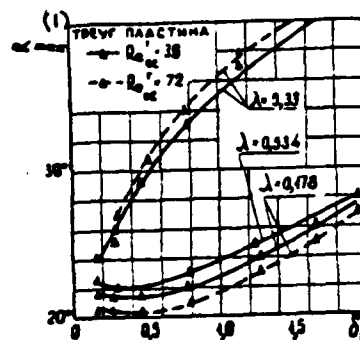


Fig. 123.

Fig. 122. Key: (1). triangular plate.

Fig. 123. Key: (1). triangular plate.

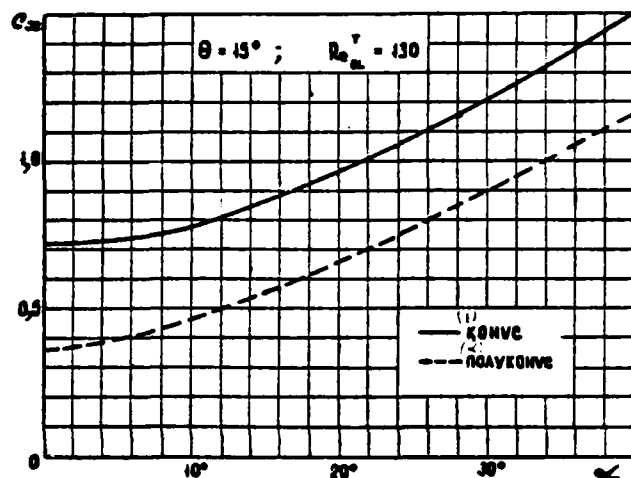


Fig. 124. Key: (1). cone. (2). semicone.

Page 45.

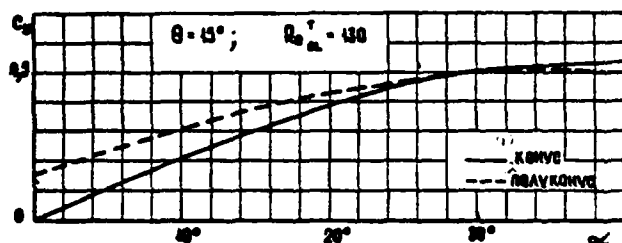


Fig. 125.

Fig. 125. Key: (1). cone. (2). semicone.

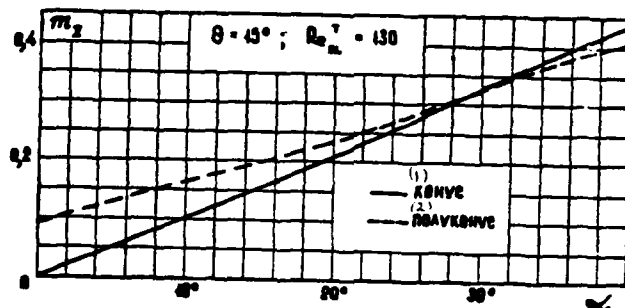


Fig. 126.

Fig. 126. Key: (1). cone. (2). semicone.

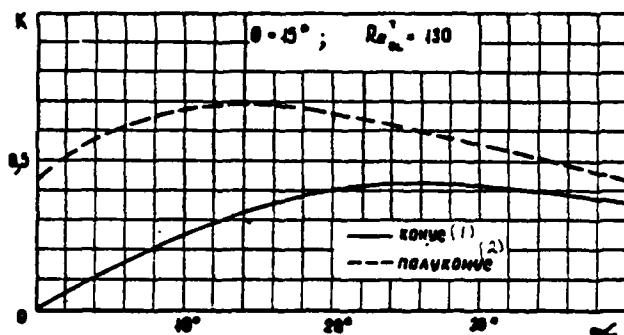


Fig. 127.

Key: (1). cone. (2). semicone.

Page 127.

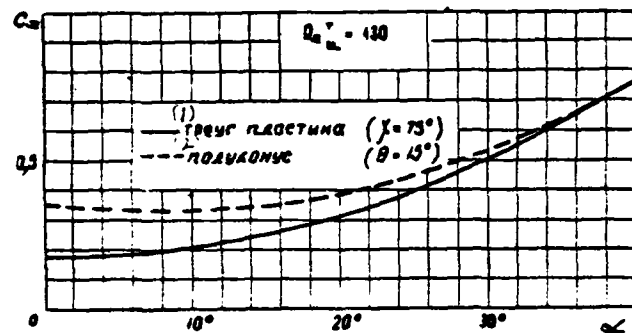


Fig. 128.

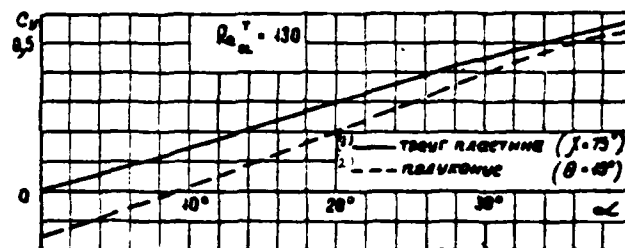


Fig. 129.

Fig. 128. Key: (1). triangular plate. (2). semicone.

Fig. 129. Key: (1). triangular plate. (2). semicone.

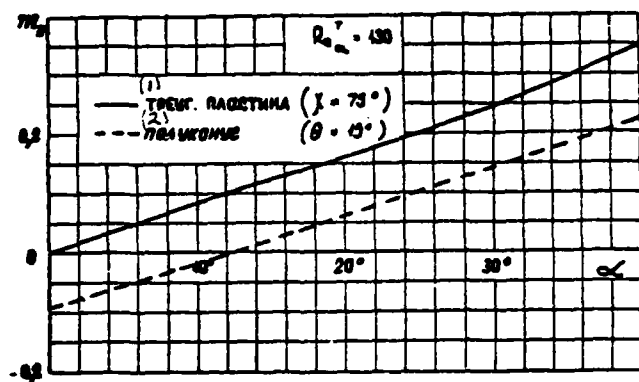


Fig. 130. Key: (1). triangular plate. (2). semicone.

Page 47.

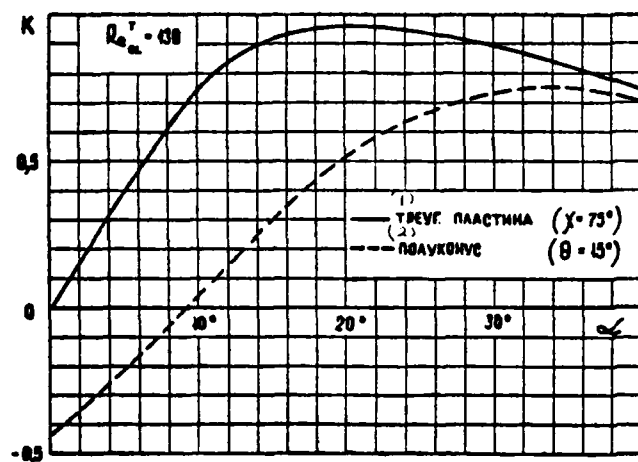


Fig. 131. Key: (1). triangular plate. (2). semicone.

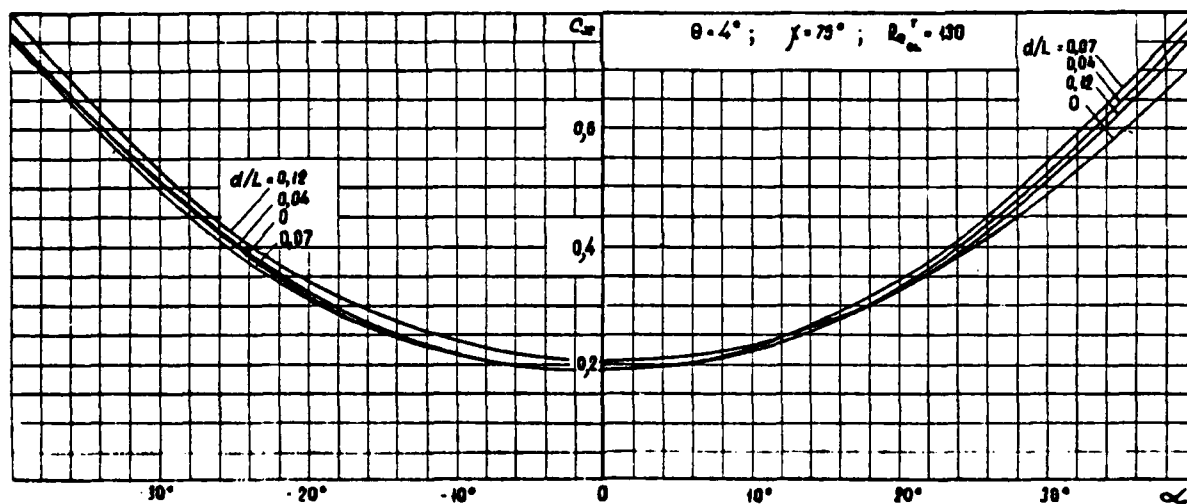


Fig. 132.

Page 48.

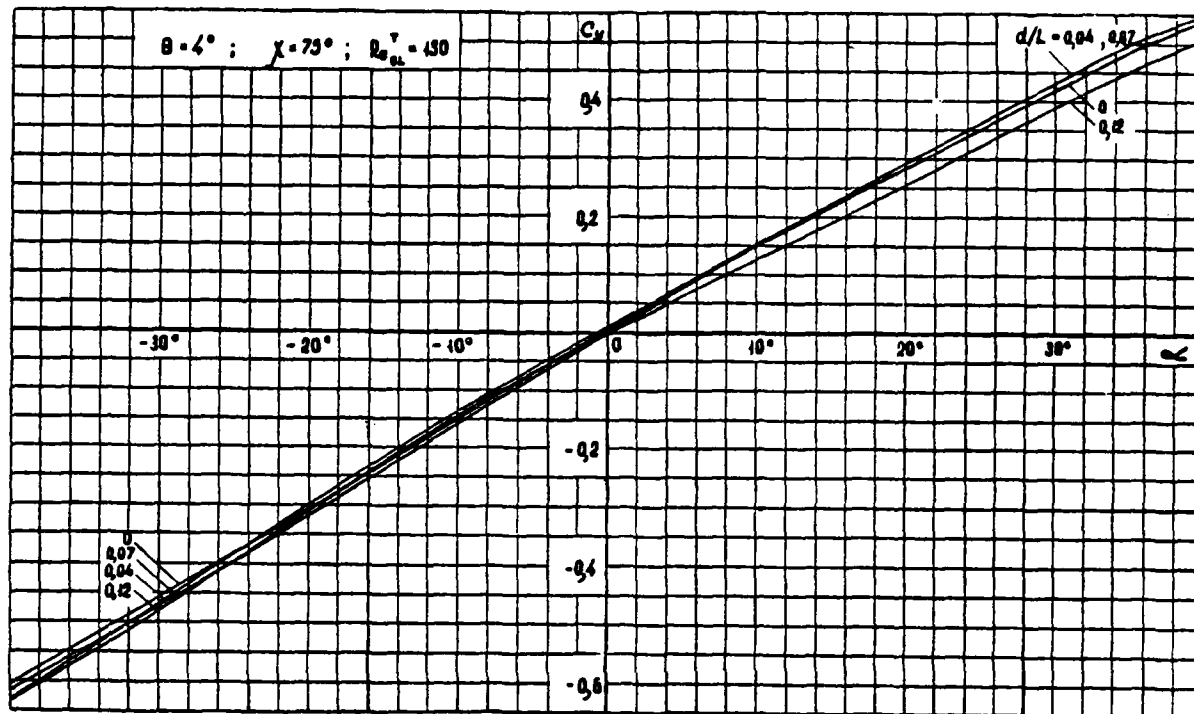


Fig. 133.

Page 49.

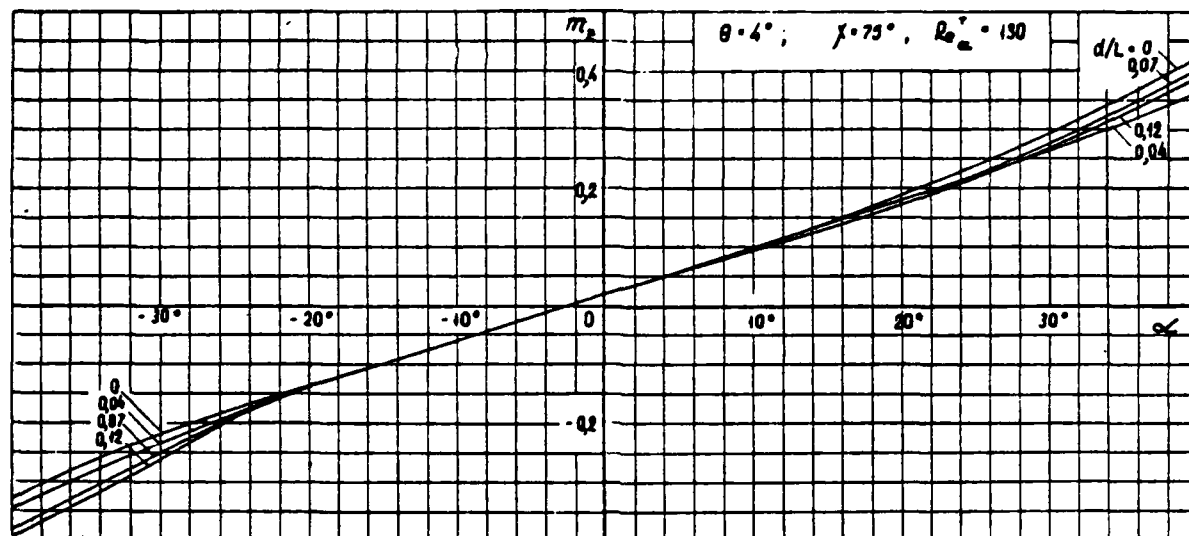


Fig. 134.

Page 50.

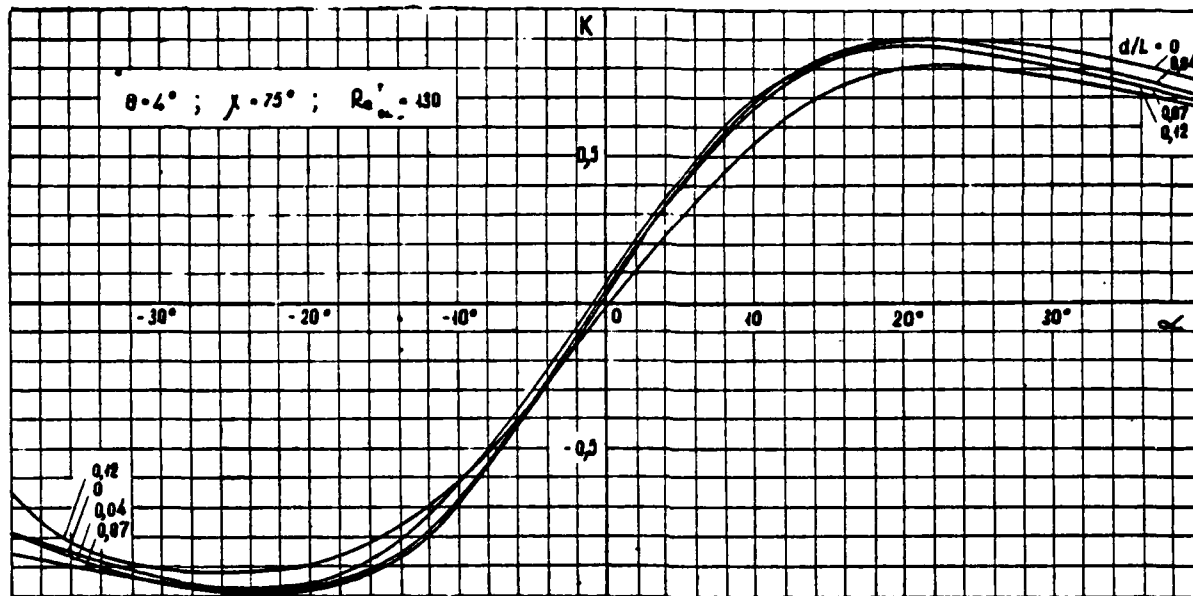


Fig. 135.

Page 51.

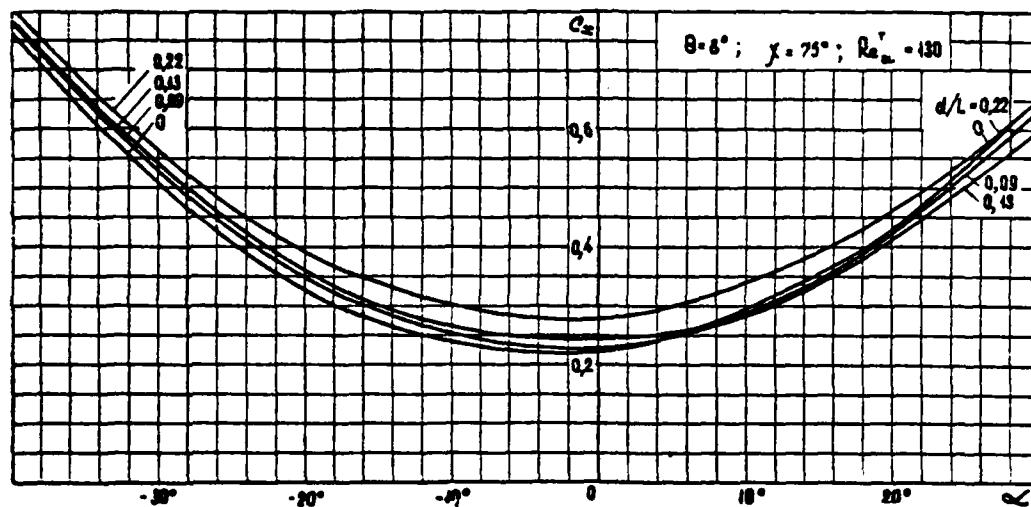


Fig. 136.

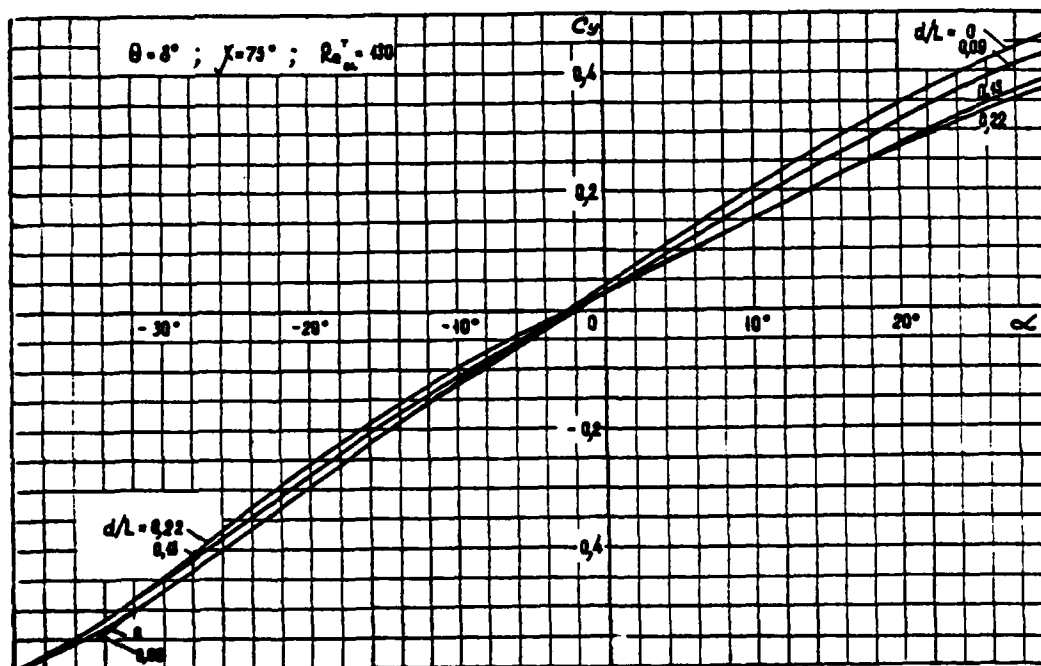


Fig. 137.

Page 52.

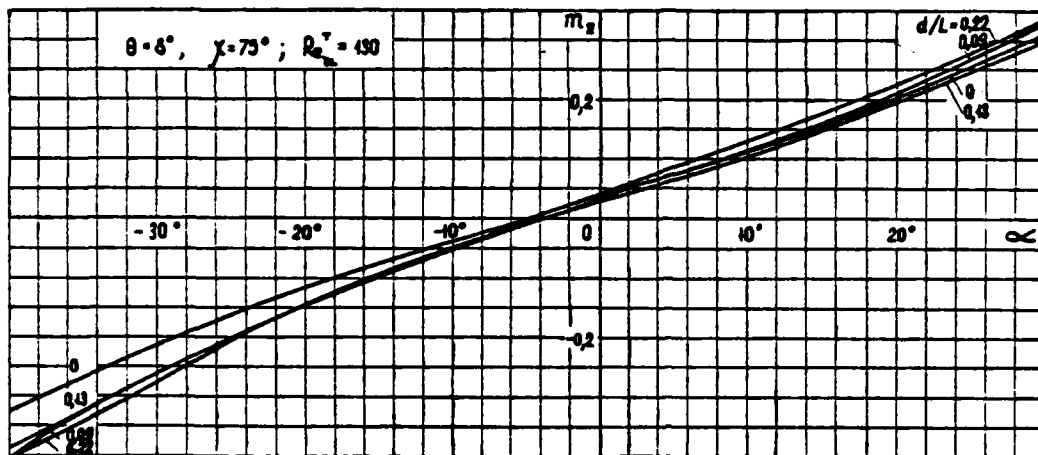


Fig. 138.

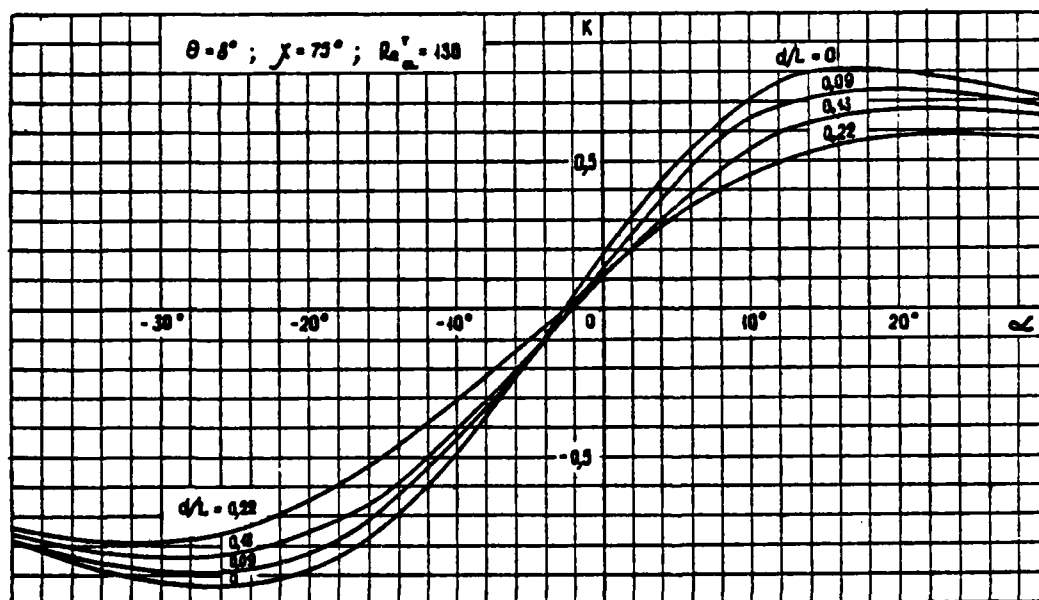


Fig. 139.

REFERENCES

1. G. G. Chernyy. Flow of gas with the high supersonic speed. M., Fizmatgiz, 1959.
2. U. D. Hayes. R. F. Probstin. Theory of hypersonic flows. M., Publ. of foreign lit., 1962.
3. M. N. Kogan. Dynamics of the rarefied gas. M., "Science", 1967.
4. V. N. Gusev, M. N. Kogan, V. A. Perepukhov. On similarity and change of the aerodynamic characteristics in the transition region at the hypersonic speeds of flow. The "Scientific notes of TsAGI", Vol. I, No 1, 1970.
5. V. A. Perepukhov. Aerodynamic characteristics of sphere and blunt-nosed cone in the flow of the strongly rarefied gas. "J. of comp. math. and math. physics," Vol. VII, No 2, 1967.
6. V. A. Perepukhov. Flow around the flat/plane plate, arranged/located at the zero angle of attack, by the flow of the strongly rarefied gas. "J. of comp. math. and math. physics," Vol.

III, No 3, 1963.

7. V. N. Gusev, T. V. Klimova, A. S. Korolev, S. G. Kryukova, V. S. Nikolayev. Flow around the thin pointed cones of viscous hypersonic flow of gas. "Eng. journal", Vol. V, No 3, 1965.

8. V. S. Galkin, V. N. Gusev, T. V. Klimova. Special features/peculiarities of flow and the aerodynamic characteristics of the bodies of the simplest forms in viscous hypersonic flow of gas. "Eng. journal", Vol. V, No 6, 1965.

9. V. S. Nikolayev. Flow around slender cone of viscous hypersonic flow. "Eng. journal", Vol. II, No 3, 1962.

10. V. S. Galkin, A. V. Zhabkova, B. S. Nikolayev. Aerodynamic characteristics of plate at the angle of attack in viscous hypersonic flow. Izv. of AS USSR, MZhG, 1969, No 1.

11. Cheng H. K. The blunt-body problem in hypersonic flow at low Reynolds number. Gas Paper. 1963, No 63-92.

12. V. P. Provorotov. On viscous interaction on the plate in hypersonic flow of the nonequilibrium dissociating gas. The "Scientific notes of TsAGI", Vol. II, No 1, 1971.

13. Cheng H. K., Hall J. G., Gollan T. C., Hertzberg A. Boundary-layer displacement and leading-edge effects in high-temperature hypersonic flow. JAS, XXVIII, 5, 1961.

14. V. S. Galkin, V. S. Nikolayev. On the simulation of viscous hypersonic flows in the wind tunnels. The "scientific notes of TsAGI", Vol. I, No 4, 1970.

15. A. I. Tolstoys. Aerodynamic characteristics of the cooled spherical blunting in hypersonic flow of the weakly-rarefied gas. Izv. of the AS USSR, MZhG, 1969, No 6.

16. V. P. Provorotov. Flow around the blunted axisymmetric cone of hypersonic flow of viscous gas. Transactions of TsAGI, iss. 1208, 1970.

17. Potter J. L. The transitional rarefied-flow regime. Fifth Intern. Sympos. on Rarefied Gas Dynamics, 1966.

18. Potter J. L., Miller J. T. Sphere drag and dynamic simulation in near-free-molecular flow. Sixth Intern. Sympos. on Rarefied Gas Dynamics, 1968.

19. M. D. Ladyzhenskiy, A. V. Lipin. Aerodynamic characteristics of rectangular plates in the hypersonic low-density flow. Izv. of the AS USSR, MZhG, 1966, No 1. (See also the transactions of TsAGI, iss. 1008, 1966).

20. A. V. Lipin. Aerodynamic characteristics of triangular plates in the hypersonic low-density flow. Transactions of TsAGI, iss. 1137, 1969.

21. Aerodynamics of rarefied gases. Edited by S. V. Vallander. Publ. LGU, iss. 4, 1969.

22. Smolderen J. J., Wendt J. F., Naveau J., Bramlette T. T. Drag coefficients in hypersonic transitional flow. Sixth Intern. Symposium on Rarefied Gas Dynamics, 1968.

23. Koppenwallner G. Drag and pressure distribution of a circular cylinder at hypersonic Mach numbers in the range between continuum flow and free molecular flow. Sixth Intern. Sympos. on Rarefied Gas Dynamics, 1968.

24. V. S. Nikolayev. Cone in the viscous hypersonic nonuniform flow. Transactions of TsAGI, iss. 980, 1965.

25. V. S. Nikolayev, A. I. Omelik. Aerodynamic characteristics of simple bodies in the free molecular nonuniform flow. Transactions of TsAGI, iss. 1311, 1971.

26. Bogdanoff S., Vas J. Hypersonic separated flows. 7-th Anglo-American Aeronautical conference, New York, 1959.

27. V. N. Gusev, S. G. Kryukova. Flow around the strongly blunted bodies of hypersonic flow of helium. "Eng. journal", Vol. V, No 2, 1965.

Page 54.

APPLICATION OF THE MONTE CARLO METHOD IN DYNAMICS OF STRONGLY
RAREFIED GAS.

V. A. Perepukhov.

Summary.

Are described setting, method and some results of solving the specific problems by the Monte Carlo method for two types of flows - free molecular and almost free molecular (the slight disturbance of free molecular flow).

CALCULATION OF FREE MOLECULAR FLOWS.

In the case of convex body the solution of the problem of free molecular ¹ flow does not represent labor/work; however, during the study of flow by the free molecular flow of concave bodies and bodies of complex form it is necessary to consider the possibility of contact with the element/cell of the body surface of the molecules in

question, reflected from other elements/cells of surface or from other bodies, i.e., to consider interference.

FOOTNOTE ¹. Flow is free molecular, if the number of Knudsen $Kn = \lambda/d \rightarrow \infty$, where d - significant dimension of body, λ - minimum local mean free path of the molecules of gas. ENDFOOTNOTE.

Analogous situation appears also during the calculation of internal free molecular flows (for example, flows in the channels), when molecule, "stray" within the channel, can many times clash with its walls. In the most general/most common/most total setting such tasks for arbitrary law of reflection are examined in works [1-3]. The mathematical formulation of the problem for the concave bodies is given in work [1]. Fundamental equation is here the integral equation of Fredholm of the second order with the symmetrical kernel for the particle flux to the element/cell of the surface

$$N(dS_1) = N_{\infty}(dS_1) + \int_{S_1} N(dS_2) G(dS_1, dS_2) dS_2, \quad (1)$$

where $G(dS_1, dS_2)$ - probability that the molecule reflected from element/cell dS_2 falls on the element/cell of surface dS_1 . The solution of this equation in the general case presents great difficulties. Moreover, and the subsequent calculations of the aerodynamic characteristics of body require bulky calculations on computer(s).

Page 55.

In this setting in works [4, 5] were calculated the aerodynamic characteristics of the circular cylindrical and spherical surfaces, converted by concave side to the flow, which encounters at the angle of attack α (Fig. 1). Since in these works it was disregarded with the thermal velocities of molecules in comparison with the macroscopic gas velocity and were not examined the cases, when some elements/cells of surface were shaded by others, then the obtained results were valid for the angles of attack α , which satisfy relationship/ratio $\alpha + \omega \neq \pi/2$, where ω - half-angle of the solution/opening of segment. The reflection of molecules from the surface was assumed to be diffuse. In work [4] was allowed the miscalculation, which then was corrected in [5]. If $S_\infty = \frac{U_\infty}{\sqrt{2RT_\infty}} \gg 1$, and the accommodation coefficient of energy $\alpha_E \approx 1$, then the temperature of the molecules $T_2 = T_\infty \approx T_\infty$ reflected and the effect of concavity can be disregarded/neglected. In this case the interference of bodies in the free molecular flow will be determined only by the shading action of bodies on each other. In work [6] was undertaken the attempt compute the aerodynamic characteristics of the internal surface of hemisphere with arbitrary S_∞ , however in it was allowed error in mathematical calculations and its results were not accurate. The aerodynamic characteristics of concave cylindrical surface when $S_\infty \gg 1$ were designed in work [7], moreover taking into account

shading/blanketing, i.e., with the arbitrary α . To the study of the interference of the groups of bodies in the free molecular flow is devoted a small number of works. Let us note, two of them. Work [8] examines the task of flow of the free molecular flow about two identical plates of the finite dimensions, perpendicular to each other and arranged/located at the zero angle of attack. Work [9] examines the task about the free molecular flow of gas in the flat ducts and the lattices.

During the calculation of internal flows in the majority of works is used the method of Clausing. Fundamental equation in this case is also the integral equation, analogous to that led above, for the flows of a number of particles to the element/cell of surface. For the tube of round cross section this equation takes the following form:

$$N(l) = N_1(l) + \int_0^l G(x) dN_2(x). \quad (2)$$

Here l - length of tube; $N_1(l)$ - a number of molecules, which fly without the collisions with the surface from the entrance to the output of tube; N_2 - number of molecules, which fly into the tube and encountering its surface at least one time; $G(x)dN_2(x)$ - a number of molecules which enter the tube and encounter wall in interval $x-(x+dx)$ and then either immediately or after further collisions they leave it. Basic difficulty during the use of this method consists in the determination of the form of the function $G(x)$. Examples of the calculation of internal courses by the method of Clausing can be found in a number of works (see for example, [10-12]).

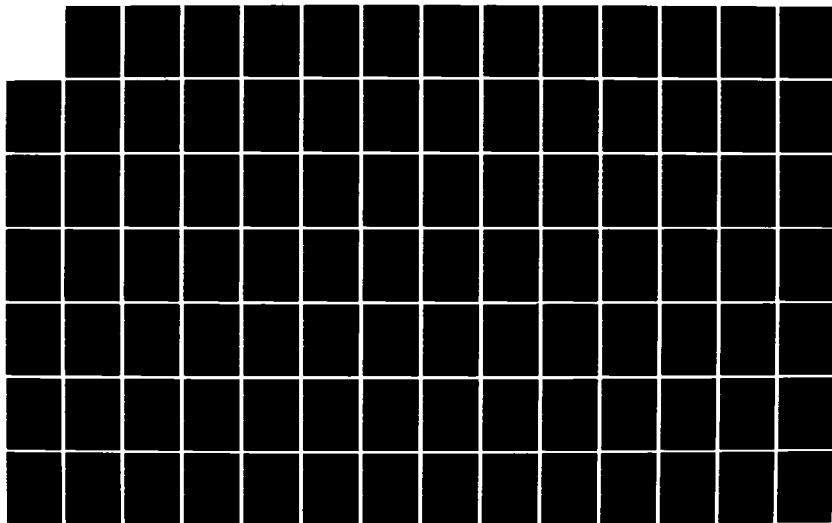
AD-A132 689

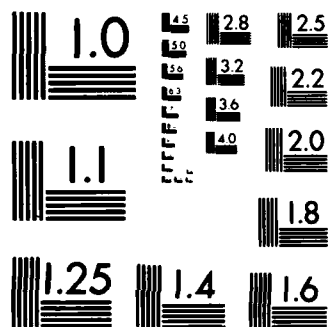
DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS(U)
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH
25 AUG 83 FTD-ID(RS)T-0673-83

2/3

UNCLASSIFIED

F/G 20/4 NL





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

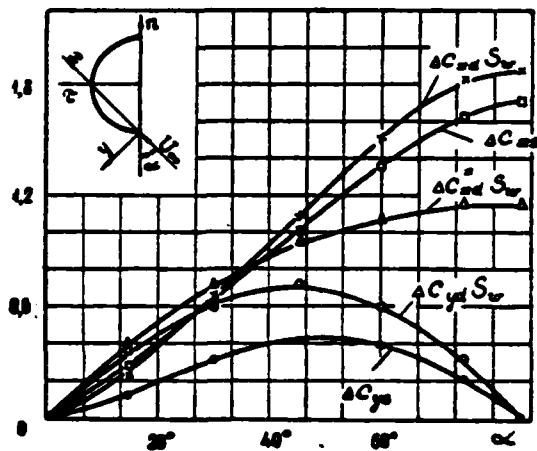


Fig. 1.

Page 56.

For calculating the internal flows in works [13, 14] is used the Monte Carlo method, with the help of which were calculated the flows in the tubes of different configuration under the law of the diffuse reflection of molecules from the surface. The essence of the Monte Carlo method in connection with internal flows is reduced to the following. Let there be the tube with the section at entrance S_1 and at output S_2 , then the gas flow through tube $N=N_1P_{12}-N_2P_{21}$, where N_1 - number of molecules, which fall into the tube through section S_1 , and N_2 - a number of molecules, which fall into the tube through section S_2 , P_{12} - probability that the molecule, which passed through section S_1 , will reach section S_2 . The procedure of determination P_{12}

and P_{11} is such. In section S_1 are developed with certain probability density the coordinates of the point from which begins its motion the molecule. Then with the probability density, which corresponds to the function of the distribution of molecules in the undisturbed flow, is developed the velocity vector of molecule. If particle immediately flies through the tube before section S_1 , then from section S_1 is started new particle, in this case in the memory of electronic computer is memorized one. But if particle falls on the surface of tube, in accordance with law of reflection is developed the velocity vector of particle, which is reflected from the surface. When as a result of many reflections particle nevertheless achieves section S_1 , then in the memory of machine is written/recorded one, but if particle achieves again section S_1 , then - zero. The ratio of a number of particles N_i of those flown from section S_1 to section S_1 , to total number of particles N , launched in section S_1 , approaches P_{11} with $N \rightarrow \infty$:

$$P_{11} = \lim_{N \rightarrow \infty} \frac{N_i}{N}. \quad (3)$$

Analogously is determined value P_{11} .

The use/application of the Monte Carlo method proved to be efficient and during the solution of the problems of external flow. For the first time this method was proposed and used in work [15], in which were determined the aerodynamic characteristics of the internal surface of hemisphere, which moves at a velocity, arbitrary according

to the value and the direction. During the calculation by the Monte Carlo method automatically drop out all difficulties, which appear during the determination of the aerodynamic characteristics of the isolated/insulated concave bodies, which have points of inflection, and especially the groups of bodies.

Formulation of the problem. Let us consider the overall diagram of the solution of the problem of free molecular flow of the Monte Carlo method about. Let us assume is assigned the body of arbitrary form (or the group of bodies). Let us assume that the flow of gas about the body everywhere free molecular, are assigned the function of the distribution of the molecules of the non-traveling flow and the law of interaction of molecules with the surface in any form, even in the form of table. It is first of all necessary to select the control surface whose form depends on the form of the function of the distribution of the molecules of the incident flow and on the shape of body. The only condition for its selecting is the following: not one molecule of the incident flow, which reaches body, must omit control surface. It is natural that it is better to choose this surface in such a way that it would take as less than the molecules, which fly past the body. Let us register the flow value of the molecules, which possess the speed in the range from $\vec{V}$ to $\vec{V}+d\vec{V}$, through the element/cell of control surface $d\vec{\Phi}$:

$$dN = f_{\infty} V^3 dV \sin \psi \cos \psi d\psi d\varphi d\vec{\Phi}, \quad (4)$$

where ψ - angle between the normal to element/cell $d\vec{\Phi}$ (standard/normal inside the control surface) and the direction of speed $\vec{V}$;

ϕ - orbital angle.

Page 57.

We choose with certain probability density of the coordinate of element/cell of $d\vec{\Phi}$ on the control surface, velocity V and its direction, given by angles ψ and ϕ . We determine, did fall the flow of molecules dN on body surface (or one of the group of bodies). If the flow of molecules achieved body surface, then it brought into the point of entry/incidence on the surface the following molecular signs/criteria: the flow of molecules dN , pulse streams dNV_x, dNV_y, dNV_z , in direction x, y, z , energy flow $(1/2)dNV^2$ and the "flow" of moment/torque $dN(\vec{R} \times \vec{V})$, where $\vec{R}$ - radius-vector of the point indicated. All these values are memorized in storage cells of computer(s). If on the body surface there is no accumulation of particles, then the arrived flow of molecules dN completely will be reflected from the surface, but if there is an accumulation, then will be reflected only the part of flow dN . The law of interaction of molecules with the body surface is assigned, i.e., is assigned the probability of reflection in this direction with the given speed;

therefore we develop with certain probability density the speed of the flow reflected and its direction. With the reflection the flow of molecules takes away from the surface the following molecular signs/criteria: the flow of molecules $dN_{0,1}$, pulse streams $dN_{0,1} \vec{V}_{0,x,1}$, $dN_{0,1} \vec{V}_{0,y,1}$, $dN_{0,1} \vec{V}_{0,z,1}$ in directions x , y , z , energy flow $dN_{0,1} V^2_{0,1}/2$ and the "flow" of moment/torque $dN_{0,1} (\vec{R}_x \vec{V}_{0,1})$. All these values are memorized in storage cells of computer(s).

Further we determine, crossed the flow reflected body surface or not. If it crossed, then we find the coordinates of point of intersection and send into storage cells of computer(s) the appropriate molecular signs/criteria and again develop reflection, etc. This process is continued until the flow of molecules $dN_{0,n}$ reflected after the n reflection flies out from the control volume. This entire process is called one testing. Furthermore, one testing is called such process when the flow of molecules dN after "starting/launching" from the control surface not at all intersects body surfaces and flies past it.

After conducting k of tests we compute local aerodynamic characteristics, summarizing all values of the corresponding molecular signs/criteria, memorized upon contact of the flow of molecules with the element/cell of body surface dF , and subtracting the sum of the corresponding molecular signs/criteria, memorized at

the moment of the reflection of the flow of molecules from element/cell dF_j . Difference we divide into a number of drawings k and a value of the area of element/cell dF_j .

During the calculation of total aerodynamic characteristics it is necessary to memorize molecular signs/criteria at the moment of the first entry/incidence of the flow of molecules dN to the surface and at the moment of its latter/last reflection, after which the particles will fly out from the control volume. Differences in the sums of these two values for the appropriate molecular signs/criteria are divided into a number of tests k .

Scanning/sweep of process on the time, i.e., successive tracking the particle fluxes dN , is possible because the molecules do not interact with each other and flow pattern can be then represented as the imposition of many flow patterns of body of the separate flows of molecules dN . It is possible to give another interpretation to the method presented. If we integrate expression (4) with respect to V , ψ , ϕ and over the entire control surface, then this integral N is equal to total number of molecules, which fly through the control surface. Ratio dN/N is nothing else but the probability of the flight/span of molecules from this by speed $\vec{V}$ through this point control surface.

Page 58.

Then, after making the procedure described above not for the flow of molecules dN , but for one molecule, it is possible to compute the average/mean values of the aerodynamic characteristics, which correspond to one molecule, which flies through the control surface. For the determination of the aerodynamic characteristics of body, determined by the total flux of its reaching molecules, it is necessary the mentioned above aerodynamic characteristics, calculated for one molecule, to multiply by the flow value of molecules N through the control surface. These two approaches correspond in a sense by known in the method Monte Carlo to the diagrams of uniform and essential selection. In the diagram of essential selection the accuracy with the given number of tests is above, but in certain cases the use/application of this diagram causes difficulty due to the sharp increase in the number of computer operations, connected with obtaining of random numbers with the assigned law of distribution from the uniform sequence.

The calculations of aerodynamic characteristics were performed for the cases of diffuse and mirror laws of reflection; therefore will be given below basic formulas for the drawing of the "start" of particle from the control surface and the formula for the drawing of the report/event of the reflection of particle from the body

(analogous formulas can be obtained also for the arbitrary law). Let to the quiescent body attack the flow of molecules the function of distribution of which takes the following form:

$$f_{\infty} = n_{\infty} (2\pi RT_{\infty})^{-3/2} \exp \left\{ -\frac{1}{2RT_{\infty}} [(V_x - U_{\infty x})^2 + (V_y - U_{\infty y})^2 + (V_z - U_{\infty z})^2] \right\}.$$

Then flow dN (y axis is directed along the normal to $d\bar{\Phi}$) can be registered thus:

$$dN = \frac{n_{\infty} U_{\infty}}{2} b \left\{ \frac{e^{-(bS_{\infty})^2}}{\sqrt{\pi} b S_{\infty}} + [1 + \Phi(\sqrt{2} b S_{\infty})] \right\} \bar{\Phi} \times \\ \times f(V_x) f(V_y) f(V_z) dV_x dV_y dV_z \frac{d\bar{\Phi}}{\bar{\Phi}};$$

$$f(V_x) = \frac{1}{\sqrt{\pi}} e^{-(V_x - aS_{\infty})^2};$$

$$f(V_y) = \frac{1}{A_0} V_y e^{-(V_y - bS_{\infty})^2};$$

$$f(V_z) = \frac{1}{\sqrt{\pi}} e^{-(V_z - cS_{\infty})^2};$$

$$N = \int dN = n_{\infty} U_{\infty} \frac{b}{2} \left\{ \frac{e^{-(bS_{\infty})^2}}{\sqrt{\pi} b S_{\infty}} + [1 + \Phi(\sqrt{2} b S_{\infty})] \right\} \bar{\Phi}.$$

In these formulas

$$U_{\infty x} = U_{\infty} a; \quad U_{\infty y} = U_{\infty} b; \quad U_{\infty z} = U_{\infty} c;$$

$$a^2 + b^2 + c^2 = 1;$$

$$V_i = \frac{v_i}{\sqrt{2RT_{\infty}}}; \quad S_{\infty} = \frac{U_{\infty}}{\sqrt{2RT_{\infty}}};$$

$$A_0 = \frac{1}{2} \left\{ e^{-(bS_{\infty})^2} + \sqrt{\pi} b S_{\infty} [1 + \Phi(bS_{\infty} \sqrt{2})] \right\}.$$

Page 59.

The probability of the "start" of molecule from the point of

control surface with coordinates $d\bar{\Phi}$ at a rate of $\bar{v}$ is equal to

$$\eta = \frac{dN}{N} = f(V_x)f(V_y)f(V_z)dV_xdV_ydV_z\frac{d\bar{\Phi}}{\bar{\Phi}}.$$

Let us take the known procedure of obtaining random numbers with the assigned law of distribution from pseudorandom numbers [16], evenly distributed in the interval $[0; 1]$. For V_x, V_y, V_z it consists of the following. Since when $V_{0y} = V_{y\max} + 3$ (where $V_{y\max}$ — value V_y , with which $f(V_y) = f_{\max}(V_y)$) function f is in effect equal to zero, let us bound the range of change V_y by interval $[0, V_{0y}]$:

$$V_{0y} = \frac{1}{2}(S_{\infty}b + \sqrt{2 + b^2 S_{\infty}^2}) + 3.$$

Let $V_y^* = \frac{V_y}{V_{0y}}, 0 \leq V_y^* \leq 1, f^*(V_y^*) = \frac{f(V_y)}{f_{\max}(V_y)}$, so that

$$f_{\max}(V_y^*) = f\left(\frac{S_{\infty}b + \sqrt{2 + b^2 S_{\infty}^2}}{2V_{0y}}\right).$$

As a result of simple conversions we obtain

$$f^*(V_y^*) = \frac{2 \left[\frac{1}{2}(bS_{\infty} + \sqrt{2 + b^2 S_{\infty}^2}) + 3 \right] V_y^*}{bS_{\infty} + \sqrt{2 + b^2 S_{\infty}^2}} \times \\ \times \exp \left\{ \left[\frac{1}{2}(\sqrt{2 + b^2 S_{\infty}^2} - bS_{\infty}) \right]^2 - \left[\frac{1}{2}(bS_{\infty} + \sqrt{2 + b^2 S_{\infty}^2}) + 3 \right] \times \right. \\ \left. \times V_y^* - bS_{\infty} \right\}^2.$$

Further from the sequence of the random numbers evenly distributed in interval $[0, 1]$ we choose two numbers (ξ_1 and ξ_2) and we check inequality $\xi_1 < f^*(\xi_2)$. If inequality is fulfilled, then

$$V_y = \xi_2 V_{0y}, \sqrt{2RT_{\infty}} = \xi_2 \frac{V_{0y}}{S_{\infty}} U_{\infty}.$$

For V_x and V_z the procedure is analogous. For their drawing are valid the following formulas

$$\xi_3 \leq \exp[-(6\xi_4 - 3)^2]; \\ \xi_5 \leq \exp[-(6\xi_6 - 3)^2].$$

With executing of first inequality we have

$$V_r = \frac{(6\xi_1 + S_\infty a - 3)}{S_\infty} U_\infty,$$

with executing of second inequality we have

$$V_s = \frac{(6\xi_2 + S_\infty c - 3)}{S_\infty} U_\infty.$$

Let us register the flow of the diffuse reflected molecules with the function of velocity distribution

$$f = n_\bullet (\pi 2RT_\bullet)^{-3/2} \exp[-(2RT_\bullet)^{-1} V^2]$$

from the element/cell of body surface dF :

$$dN_\bullet = n_\bullet (\pi 2RT_\bullet)^{-3/2} \exp[-(2RT_\bullet)^{-1} V^2] V^3 \sin \psi \cos \psi d\psi dV dF.$$

Page 60.

Total number of molecules, reflected from element/cell dF , is equal

$$N_\bullet = \int dN_\bullet = n_\bullet \frac{V \sqrt{2RT_\bullet}}{2\sqrt{\pi}} dF.$$

The probability of reflection with this speed V in this direction (θ, μ) is equal to

$$\frac{dN_\bullet}{N_\bullet} = f(V) f(\theta) f(\mu) dV d\theta d\mu,$$

where

$$f(V) = 2 V^3 e^{-V^2} dV; \quad f(\theta) = 2 \sin \theta \cos \theta;$$

$$f(\mu) = \frac{1}{2\pi}; \quad V = \frac{\sigma}{(2RT_\bullet)^{1/2}}.$$

Formulas for the drawing θ, μ :

$$\sin \theta = \sqrt{\xi_i}; \quad \mu = 2\pi\xi_{i+1}.$$

For drawing V is applicable this procedure. We choose ξ_j and ξ_{j+1} and we require executing of the inequality

$$\xi_j \leq \left[\left(\frac{2}{3} \right)^{1/2} k_1 \xi_{j+1} \right]^3 \exp \left(-k_1^2 \xi_j^2 + \frac{3}{2} \right).$$

If it is carried out, then $V = \frac{1}{k_1}$, where $k_1 = 3$. For the law of mirror reflection $V_{y_{\text{наз}}} = -V_{y_{\text{отр}}}$, $V_{x_{\text{наз}}} = V_{x_{\text{отр}}}$, $V_{z_{\text{наз}}} = V_{z_{\text{отр}}}$.

By this method were carried out the calculations of the aerodynamic characteristics of the following bodies: the hemisphere, converted by concave side to the flow at arbitrary value S_∞ [15]; cylinder with the spherical blunting and the blades/vanes, arranged/located perpendicularly to the axis of cylinder; the body, which consists of the hemisphere and the circle and arranged/located under the angle of attack; the body of that consisting of the cylinder, the blades/vanes and the cone; the body, which consists of three cones with the spherical blunting; the body, which consists of the cylinder with the spherical blunting and disk [17]. For an example we analyze the results of calculating the aerodynamic characteristics of hemisphere and body, which consists of the cylinder, blades/vanes and cone.

Hemisphere. The aerodynamic characteristics of hemisphere were determined for the laws of diffuse and mirror reflection. Any aerodynamic characteristic can be registered in the form

$$\Pi_i = \Pi_{i\infty} + \Delta\Pi_{i0}.$$

Here $\Pi_{i\infty}$ — aerodynamic characteristic of body in the free

molecular flow, encompassing the aerodynamic characteristic of the internal part of the surface without taking into account of reflection and exterior of the surface taking into account reflection; $\Delta\bar{\Pi}_{10}$ is caused by interference.

Fig. 1 gives dependence Δc_x , Δc_y , and $\Delta c_x^* = \frac{2}{3} S_w^{-1} \pi^{-1/2} (2\alpha + \sin 2\alpha)$ (taking into account only the first reflection of molecules from the internal surface) on α when $S_\infty = \infty$. Index d corresponds to diffuse reflection, index s - mirror; $S_w = \frac{U_\infty}{\sqrt{2RT_w}}$, where T_w - temperature of the molecules reflected. Fig. 2 depicts the dependence of addition to the value of the "flow of moment/torque" $\Delta\bar{E}_d$ from

$$\alpha \left(\Delta M_{zd} = \Delta \bar{M}_{zd} \frac{mn_\infty U_\infty^2 \pi R_0^3}{S_w} \right).$$

Page 61.

Fig. 3 depicts dependence $\Delta\bar{E}_d$ on $\alpha \left(\Delta E_d = \Delta\bar{E}_d \frac{mn_\infty U_\infty^3 \pi R_0^3}{2S_w^2} \right)$. Let us note that here in the case of completely diffuse reflection the interference of molecules plays no role and value $\Delta E_d = \Delta E_d^*$, where ΔE_d^* - correction only due to the first reflection of molecules from the internal surface of hemisphere. This fact can serve as the further testing of the accuracy of method.

In the free molecular flow for the computed aerodynamic characteristics in the case of the laws of diffuse and mirror

reflection taking into account the effect of the exterior of the surface are valid the following formulas:

with the diffuse reflection

$$\begin{aligned}
 c_x &= c_{x1} + c_{x2} + \Delta c_{xd}; \quad c_y = c_{y1} + \Delta c_{yd}; \quad M_z = M_{z1} + 2\Delta M_{zd}; \\
 c_{x1} &= 2 \sin \alpha; \quad c_{x2} = 2 \sin^2 \left(\frac{\pi}{4} - \frac{\alpha}{2} \right) - \pi^{-1/2} (\pi - 2\alpha + \sin 2\alpha) (3S_\infty)^{-1}; \\
 c_{y2} &= -\frac{2}{3} \pi^{1/2} S_\infty^{-1} \cos^2 \alpha; \quad M_{z2} = -\frac{4}{3} \pi^{-1} \cos^2 \alpha; \\
 c_E &= c_{E1} + c_{E2} + \Delta c_E; \quad c_{E1} = \sin \alpha; \\
 c_{E2} &= \left(1 - \frac{2}{S_\infty^2} \right) \sin^2 \left(\frac{\pi}{4} - \frac{\alpha}{2} \right); \\
 \Delta c_E^* &= \Delta c_E = -\frac{2}{S_\infty^2} \sin \alpha;
 \end{aligned}$$

with the mirror reflection

$$\begin{aligned}
 c_x &= c_{x1} + c_{x2} + \Delta c_{xs}; \quad c_y = c_{y2} + \Delta c_{ys}; \\
 c_{x1} &= 2 \sin \alpha; \quad c_{x2} = 2(2 + \sin \alpha) \sin^4 \left(\frac{\pi}{4} - \frac{\alpha}{2} \right); \quad c_{y2} = -\frac{1}{2} \cos^2 \alpha.
 \end{aligned}$$

Here coefficients c_x and c_y are related to $0,5 \pi R_0^2 m n_\infty U_\infty^2$, moment/torque is calculated relative to the center of sphere and is related to $0,5 \pi R_0^3 m n_\infty U_\infty^2$, coefficient c_E is related to $0,5 \pi R_0^2 m n_\infty U_\infty^2$. Index 1 designates the internal part of the surface of hemisphere in the free molecular flow without taking into account reflection, index 2 - the exterior of the surface in the free molecular flow taking into account reflection. From the calculations conducted it follows that the interference has an effect on different aerodynamic characteristics differently. The most sensitive value is c_y .

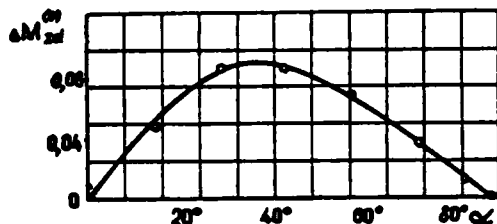


Fig. 2.

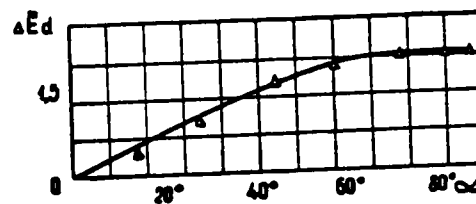


Fig. 3.

Page 62.

In the case of the law of diffuse reflection the interference plays important role for all aerodynamic characteristics, if only body surface has sufficiently high temperature, i.e., $S_w \approx 1$.

Body, which consists of the cylinder, blades/vanes and cone (Fig. 4). Calculation was carried out at $\theta = 45^\circ$, $R_1 = L_1 = L_2$. All geometric dimensions are related to $R = L_1 + L_2 / 2 [1 + (R_1 + L_2 / L_2)^2]$. Formulas for any aerodynamic characteristic are written/recorded in the form $\Pi_i = \Pi_{i\infty} + \Delta\Pi_i$, where $\Pi_{i\infty}$ is determined by first contact of molecules with body; $\Delta\Pi_i$ — correction, caused by interference and first reflection. At $\alpha > 90^\circ$ it is necessary to consider the effect of the end/face of cylinder on the aerodynamic characteristics. In this case any aerodynamic characteristic is written/recorded in the form

$$\Pi_i = \Pi_{i\infty} + \Delta\Pi_i + \Pi_{i\infty\tau} + \Delta\Pi_{i\tau},$$

where $\Pi_{i\infty\tau}$ is determined by the molecules, falling on the end/face from infinity, $\Delta\Pi_{i\tau}$ - by the molecules reflected from the end/face.

In the case of diffuse reflection

$$P_{\infty\tau x} = -mn_{\infty}U_{\infty}^2 \pi R_1^2 \cos \alpha \sin \alpha; \quad \Delta P_{\tau x} = 0;$$

$$P_{\infty\tau y} = -mn_{\infty}U_{\infty}^2 \pi R_1^2 \cos^2 \alpha; \quad \Delta P_{\tau y} = -\pi R_1^2 mn_{\infty}U_{\infty}^2 \frac{\sqrt{\pi}}{S_{\sigma}} \cos \alpha.$$

In the case of the mirror reflection

$$P_{\infty\tau y} + \Delta P_{\tau y} = -2mn_{\infty}U_{\infty}^2 \pi R_1^2 \cos^2 \alpha.$$

Fig. 5-8 gives the dependences of dimensionless aerodynamic characteristics $P_{\tau\infty}$, $P_{N\infty}$, E_{∞} , $M_{x\infty}$ on the angle of attack α .

Corrections to the aerodynamic characteristics in the case of diffuse reflection are given for Fig. 9-11, in the case of mirror reflection - for Fig. 12-14. From the given results follows the conclusion that the interference exerts a substantial influence on c_p and M_x in the case of mirror and diffuse reflection and "hot" wall.

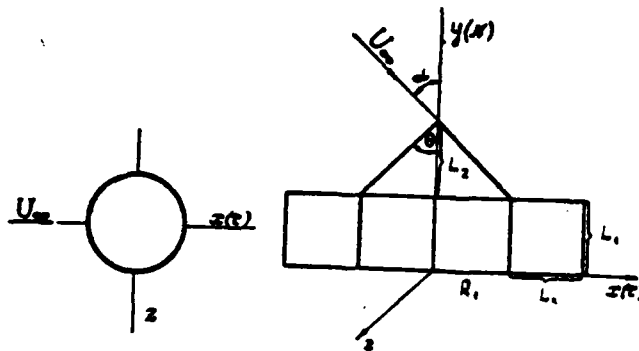


Fig. 4.

The graph shows the function $D_2 = 11.7 \cdot 10^{-2} \sin^2 \frac{\alpha}{2}$ for α ranging from 0 to 90 degrees. The curve is a downward-opening parabola starting at (0,0), peaking at (60, 0.12), and ending at (90, 0). The x-axis is labeled α° and the y-axis is labeled D_2 .

The graph shows a periodic function D_{μ} plotted against μ . The y-axis is labeled $D_{\mu} = \frac{1}{2} \frac{d^2 \sigma}{d\mu^2}$ and ranges from -0.02 to 0.04. The x-axis is labeled μ and ranges from 0 to 180 degrees. The curve starts at approximately -0.015 at $\mu = 0^\circ$, reaches a minimum of about -0.018 at $\mu \approx 30^\circ$, crosses the zero line at $\mu \approx 60^\circ$, reaches a maximum of about 0.04 at $\mu \approx 120^\circ$, and returns to zero at $\mu = 180^\circ$.

Detailed description: The graph shows a smooth curve representing the relationship between $E/(U_0^2 \cdot h^2)$ and the angle α for the 110 reflection of ZnO. The y-axis is labeled $\frac{E}{U_0^2 \cdot h^2}$ and ranges from 0 to 0.08 with major ticks every 0.02. The x-axis is labeled α and ranges from 0 to 160 degrees with major ticks every 40 degrees. The curve starts at approximately (0, 0.04), rises to a maximum of about 0.065 at $\alpha \approx 45^\circ$, and then decreases, passing through approximately (80, 0.05), (120, 0.03), and ending at (160, 0).

α (degrees)	$\frac{E}{U_0^2 \cdot h^2}$
0	0.040
10	0.050
20	0.055
30	0.060
40	0.063
45	0.065
50	0.063
60	0.055
70	0.045
80	0.035
90	0.025
100	0.015
110	0.005
120	0.000

The graph shows a parabolic curve on a grid. The horizontal axis is labeled α and has major ticks at 0, 15°, 30°, 45°, and 60°. The vertical axis is labeled $\frac{M}{R_{max}} \frac{U_1}{2 R^2}$ and has major ticks at 0, 0.004, 0.006, and 0.008. The curve starts at (0,0), reaches a maximum value of approximately 0.006 at $\alpha = 30^\circ$, and returns to 0 at $\alpha = 60^\circ$.

Fig 8.

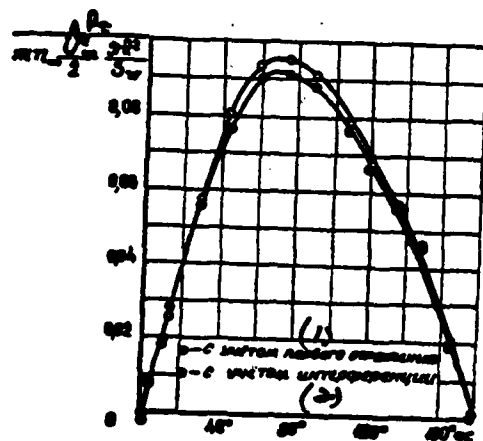


Fig. 9.

Fig. 9.

Key: (1). taking into account the first reflection. (2). taking into account interference.

Page 64.

From the numerous calculations conducted it is possible to draw the following general/common/total conclusions:

- if molecules are reflected from the body, which has one significant dimension, with speed, there is much lower speed of the molecules of the incident flow, then the basic contribution to the interference is determined by shading/blanketing the some parts of the body by others;

- if body has the large surfaces, situated in parallel to the incident flow, then interference can exert a substantial influence on the value of some aerodynamic characteristics even in the case of "cold" body;

- interference can very substantially affect aerodynamic characteristics in the case of hot wall, i.e., when molecules are reflected at a velocity, equal in order of velocity of incident flow.

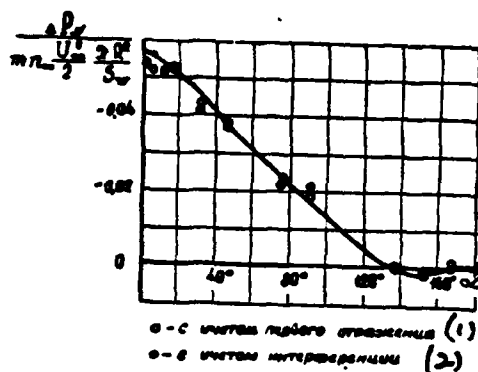


Fig. 10.

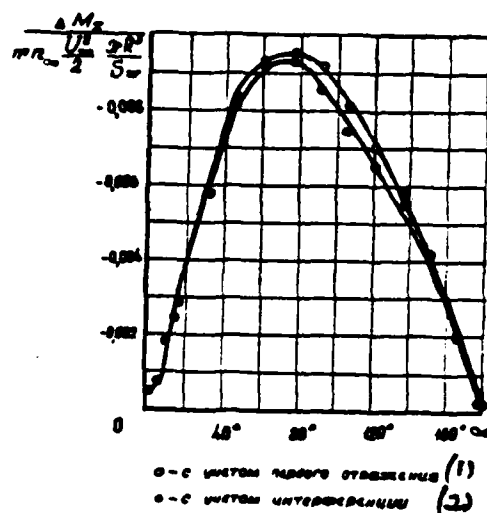


Fig. 11.

Key: (1). taking into account the first reflection. (2). taking into account interference.

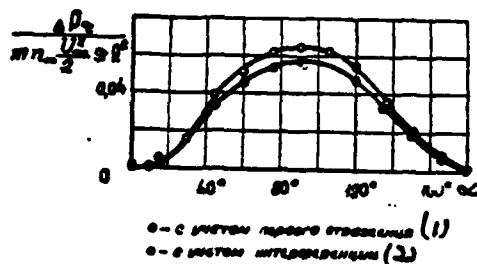


Fig. 12.

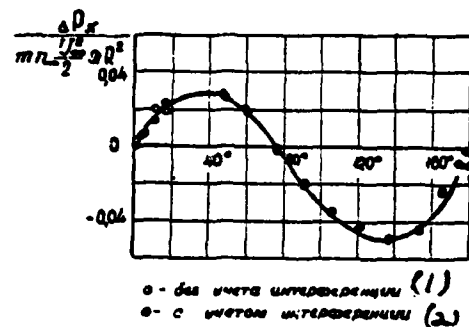


Fig. 13.

Key: (1). taking into account the first reflection. (2). taking into account interference.

Key: (1). without taking into account interference. (2). taking into account interference.

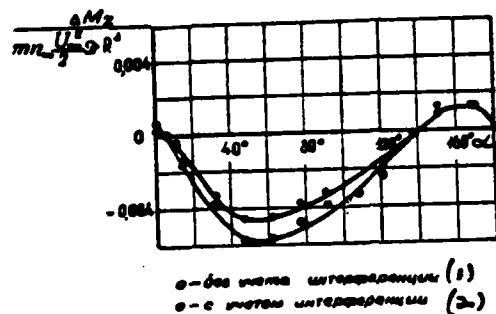


Fig. 14.

Key: (1). without taking into account interference. (2). taking into account interference.

Page 65.

Calculation of flows, close to free molecular.

With the decrease of the local Knudsen number the collisions of molecules begin to play the significant role in the flow pattern of body and must be considered them. During the determination of the distribution function for the flow, different from the free molecular, it is possible to use the formal resolution of the solution of the equation of Boltzmann in the series/row for $1/Kn$.

Attempt to find solution in this form taking into account in essence only of the terms of order $1/Kn$ they were undertaken in works [18-20]. However, for this case of lining/calculation they were very bulky and the obtained results did not have practical interest. In work [21] was for the first time proposed the theory, which was subsequently called the theory of the first intermolecular collisions. Was solved the problem about resistance of the circular disk, arranged/located normal to impinging hyperthermal flow of molecules, in this case was considered the correction to resistance in the free molecular flow due to the single collisions between the molecules reflected and the molecules of the incident flow. Within the framework of the theory of the first intermolecular collisions were evaluated the aerodynamic characteristics of infinite band [22], infinite cylinder [23] and sphere [24] (in the linings/calculations of latter/last work was allowed the error, which led to the fact that the obtained allowance of the value of drag coefficient in the free flow was overstated approximately/exemplarily doubly).

Several on another path went in his studies of flows, close to the free molecular ones, Willis [25]. He used instead of the equation of Boltzmann the modified model equation of Crooke and he computed his first approximation, after making for the zero approximation free molecular decision. The formulation of the problems in this form is qualitatively close to the formulation of the problem in the theory

of the first intermolecular collisions. To a deficiency/lack in this method it is necessary to relate the use of model equation of Crooke whose suitability is doubtful for the flows, distant from the equilibrium ones. Furthermore, and in the case of model equation linings/calculations are bulky, so that calculations were carried out only for the sphere, cylinder [26] and flow of Couette [25]. In work [27] for calculating the aerodynamic characteristics of sphere was used the method of resolving the solution of the model equation of Crooke in the series/row for $1/Kn$ and was found the first term of series/row; the obtained results qualitatively coincide with results [26]. In works [28, 29] was used the method of successive approximations for the integral kinetic equation, for which was designed the first approximation. In particular, in [28] was determined stagnation pressure of the mirror reflecting sphere.

The most complete analysis of the flows, close to the free molecular ones, was carried out in the work of M. N. Kogan [30, 31]. In particular, in them it was shown that in the theory of the first intermolecular collisions for the convex finite bodies in the cases, which are of practical interest, it is necessary to seek corrections and to the free molecular value of aerodynamic characteristics only due to the single collisions between the molecules, reflected from the body, and by the molecules of the incident flow. These works examine also a question about the limits of the applicability of the

theory of the first collisions, are qualitatively analyzed the basic types of the flows, which have practical interest both for the "cold ones" and for the "hot" bodies (i.e. for the actual conditions and the test conditions in the indraft wind tunnels), are indicated the similarity parameters and the methods of the recalculation of obtained theoretical data to the actual conditions and the conditions for experiment in the wind tunnels.

Page 66.

M. N. Kogan also showed that if we use the formal method of solving the equation of Boltzmann, expanding the distribution function in series/row according to $1/Kn$, then the solution, found with an accuracy down to the terms $1/Kn$, corresponds to the theory of the first intermolecular collisions. Use/application of the Monte Carlo method in the theory of the first intermolecular collisions made possible to create the universal calculation method, which makes it possible to determine the aerodynamic characteristics of convex bodies under arbitrary law of reflection of molecules from the body and arbitrary law of interaction between the molecules.

Formulation of the problem. Since during the motion of flight vehicle at the high altitudes its speed, as a rule, is much more than the average/mean thermal velocity of molecules, then we during the

solution of the problems of flow will disregard the thermal velocity of the molecules of the incident flow in comparison with its macroscopic speed and consider that the body attacks the hyperthermal flow with a speed V_∞ . As it was said, that in the theory of the first intermolecular collisions it is necessary to examine only the collisions between the molecules, reflected from the body, and by the molecules of the incident flow.

Let us register the number of collisions, which occur in certain volume element between the molecules, reflected from the element/cell of surface dF with the speeds in the range from $\vec{V}_1$ to $\vec{V}_1 + d\vec{V}_1$, and the molecules of the incident flow per unit time in the element of volume $d\vec{r}$:

$$dN = f_\infty(\vec{V}_1) f_\infty(\vec{V}_2) g_{12}^{\frac{1}{2}} b (2k)^{\frac{1}{2}} db d\vec{r} d\vec{V}_1 d\vec{V}_2 d\vec{r}.$$

If this expression is integrated over entire physical and high-speed/high-velocity space, then we will obtain total number of collisions N per unit of time. Ratio dN/N is nothing else but the probability of this collision. The collisions of molecules in a two-fold manner affect the aerodynamic characteristics of the body: on one hand, due to the collisions to the body comes the further flow of molecular signs/criteria, on the other hand, due to the collisions to the body does not come certain flow of the molecular signs/criteria which carried from infinity of molecule, which clashed with the molecules, reflected from the body. Consequently, for any

aerodynamic characteristic of body taking into account the first collisions is valid the recording: $\Pi_i = \Pi_{i,c.m} + \Pi_{i+} - \Pi_{i-}$, where $\Pi_{i,c.m}$ — value of aerodynamic characteristic in the free molecular flow; Π_{i+} — addition, caused by collisions; Π_{i-} — loss due to the collisions. Developing randomly the sufficiently large number of collisions K in the space, it is possible to determine the local and total values of the aerodynamic characteristics of body, averaging additions Π_{i+} and Π_{i-} according to the number of collisions K . If molecules are reflected from the body with the average speed which is much lower than the speed of the molecules of the incident flow, then at the moment of colliding the molecules it is possible to consider that the speed of the molecule reflected is equal to zero; this assumption makes it possible to find in the form of quadratures the function of the distribution of molecules on the body. In this case the Monte Carlo method is applied to the calculation of the repeated integrals, through which are written/recorded the aerodynamic characteristics of body.

Page 67.

Let us illustrate based on the example of the flow around sphere, how occurs the simulation of flow pattern with the help of the Monte Carlo method. Let us introduce the following assumptions:

- 1) the reflection of molecules from the body occurs according to the

diffuse law, 2) molecules are elastic spheres by diameter σ . Let us introduce dimensionless parameters $S_\infty = \frac{U_\infty}{\sqrt{2RT_\infty}}$ and $Kn_\infty = \frac{1}{2\sqrt{2}\pi\sigma^2 n_\infty R_0}$, where T_∞ — temperature of the reflected according to the Maxwellian law molecules

$$f = n_\infty (2\pi RT_\infty)^{-3/2} \exp\left(-\frac{v^2}{2RT_\infty}\right);$$

R — gas constant; $\pi\sigma^2$ — collision cross section for the solid spheres; n_∞ — density at infinity.

Let us register the number of collisions, which occur at point $A(x, y, z)$ (Fig. 15) between the molecules, reflected from element/cell dF of the surface of sphere with the speeds in the range $\vec{v}, \vec{v}+d\vec{v}$, and by the molecules of the incident flow per unit time in the element of volume $\rho^2 d\rho \sin \psi d\psi d\varphi$:

$$dN = n_\infty n_\infty (2\pi RT_\infty)^{-3/2} \exp\left(-\frac{v^2}{2RT_\infty}\right) v^2 \cos \psi \sin \psi d\psi d\varphi \sigma^2 G_{21} \sin \nu \cos \nu \times \\ \times d\nu d\mu \exp\left(-\frac{\rho}{\lambda_{21}}\right) d\rho dF.$$

Molecules were reflected from the element/cell of surface $dF=R^2 \sin \theta d\theta d\beta$ in the direction ψ, φ . At the moment of collision the direction of center line is assigned by angles ν, μ relative to the direction of relative speed $\vec{G}_{21} = \vec{V} - \vec{U}_\infty$. Collision occurred at a distance ρ from element/cell dF . The molecules reflected possessed the speeds in the interval $(\vec{v}; \vec{v}+d\vec{v})$, and their quantity is proportional to $\exp(-\rho/\lambda_{21})$, where $\lambda_{21} = \frac{\sigma}{n_\infty \pi \sigma^2 G_{21}}$ — the mean free path of the molecules reflected on the molecules of the incident

flow. From the law of conservation of a number of particles on the surface of sphere it follows that $n_{\theta} = 2n_{\infty} \sqrt{\pi} S_{\theta} \cos \theta$.

The collision frequency let us register in the form

$$dN = \pi R_0^2 n_{\infty} U_{\infty} f(\theta) f(\psi) f(\nu) f(\rho) f(\varphi) f(\beta) \times \\ \times f(V) f(\mu) d\theta dV d\psi d\nu d\rho d\varphi d\beta d\mu,$$

where

$$f(\theta) = 2 \sin \theta \cos \theta;$$

$$f(V) = 2 (2RT_{\infty})^{-2} \exp\left(-\frac{V^2}{2RT_{\infty}}\right) V^2;$$

$$f(\psi) = 2 \sin \psi \cos \psi;$$

$$f(\nu) = 2 \sin \nu \cos \nu; \quad f(\rho) = \frac{1}{\lambda_{21}} \exp\left(-\frac{\rho}{\lambda_{21}}\right);$$

$$f(\varphi) = f(\mu) = f(\beta) = \frac{1}{2\pi};$$

moreover for all variable/alternating

$$\int_{x_i} f(x_i) dx_i = 1.$$

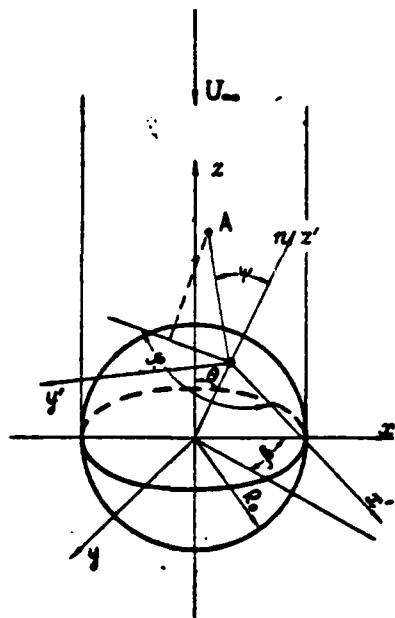


Fig. 15.

Page 68.

Then the probability of this collision exists

$$\eta = \frac{dN}{N} = f(\theta) f(\varphi) f(\nu) f(\rho) f(\varphi) f(\beta) f(\mu) f(V) d\theta d\varphi d\nu d\rho d\varphi d\beta d\mu dV.$$

One drawing let us name the collision, characterized by the random sampling of eight parameters, moreover each parameter was chosen randomly with an appropriate probability density of $f(x_i)$. After the collision was played, were determined the trajectories of molecules after collision, was fixed/recorded the fact of falling of molecule into this point of surface and were memorized the corresponding values of the molecular signs/criteria, yielded by

molecule to the body. Simultaneously it was checked, did not occur collisions at the point of space which is projected/designed along the direction of speed U_∞ to the body surface; if this is so, then at this point of body surface we fix/record the report/event of the loss of the molecular signs/criteria which carried the molecule from infinity. The parameters of each collision are developed according to the following formulas:

$$\begin{aligned} V &= \sqrt{2RT_\infty} \sqrt{-\ln \xi_i \xi_{i+1}}; & \sin \psi &= \sqrt{\xi_{i+2}}; \\ \sin \gamma &= \sqrt{\xi_{i+3}}; & \rho &= \left(-2\sqrt{2} \operatorname{Kn}_\infty \frac{V}{G_{21}} \right) \ln \xi_{i+4}; \\ \varphi &= 2\pi \xi_{i+5}; & \mu &= 2\pi \xi_{i+6}; & \beta &= 2\pi \xi_{i+7}; \\ & & \sin \theta &= \sqrt{\xi_{i+8}}, \end{aligned}$$

where ξ_{i+n} — evenly distributed random numbers [0-1].

After playing collision, we determine the speeds of molecules after collisions V_i and V_{i+1} . Each molecule after collision has the "weight", equal to

$$mn_\infty U_\infty \approx R_0^2 \text{ — for the flow of molecules;}$$

$$mn_\infty U_\infty \approx R_0^2 U_{n/j+1} \text{ — for the flow of normal impulse/momentum/pulse;}$$

$$mn_\infty U_\infty \approx R_0^2 U_{z/j+1} \text{ — for the pulse stream in direction } U_\infty;$$

$$mn_\infty \frac{U_\infty}{2} \approx R_0^2 V_{j,j+1}^2 \text{ — for the energy flow.}$$

If collision occurred above any point of body surface, then at this point of surface occurred the loss of the following molecular signs/criteria:

$mn_{\infty} U_{\infty} \pi R_0^2$ — for the flow of molecules;

$mn_{\infty} U_{\infty} \pi R_0^2 (\vec{U}_{\infty} \vec{n})$ — for the flow of normal impulse/momentum/pulse;

$mn_{\infty} U_{\infty} \pi R_0^2 U_{\infty}$ — for the pulse stream in direction U_{∞} ;

$mn_{\infty} U_{\infty} \pi R_0^2 \frac{U_{\infty}^2}{2}$ — for the energy flow.

If it is necessary to know the distribution of the computed flows from the body surface, it is necessary body surface to decompose into the elements/cells (value of which it is determined from the considerations of accuracy), to count the sums of the flows of the molecular signs/criteria interesting us and to relate them to the area of the element/cell of surface and to a number of drawings K. For the total characteristics necessary to count the sums of the corresponding molecular signs/criteria, which arrive at entire body surface and lost as a result of collisions above the entire body surface relate them to K.

Thus, we compute $\Pi_{k,i}$ and $\Pi_{k,j}$, where index k indicates the

appropriate molecular sign/criterion.

Page 69.

A number of drawings K is determined by the assigned accuracy of calculation according to known formulas [16], moreover dispersion is determined in the process of calculation. By the method proposed were determined the aerodynamic characteristics of the whole class of bodies.

1. Sphere. (Fig. 16). Aerodynamic characteristics of the sphere were computed for arbitrary value S_∞ when $\frac{S_\infty}{Kn_\infty} < 1$ [32]. It was assumed that the reflection of molecules from the surface diffuse and the molecules interact: a) as elastic spheres; b) as pseudo-Maxwellian molecules. Calculations showed that value C_x in the mode/conditions of the first intermolecular collisions is reduced in comparison with its free molecular value approximately/exemplarily to 15% within the framework of the applicability of theory. The results of detailed calculations are given in works [32-34].

Cone (Fig. 16 and 17). In this case the effect of the first intermolecular collisions on different aerodynamic characteristics is different. Allowance to resistance, energy flow and to the value of the pitching moment of "cold" cone when $S_\infty \theta < 1$ (with exception of the

thick cones when $\theta > 60^\circ$, where θ - half-angle of solution/opening) is negative and does not exceed 10% of value of these aerodynamic characteristics in the free molecular flow in the region of the applicability of the theory of the first collisions. For example, correction due to the collisions for the cone with the significant dimension of $h=1$ m when $\theta=15^\circ$, $\alpha=72^\circ$, $S_\infty=10$ for the height/altitude of 120 km is equal to approximately/exemplarily 7%. Allowance as a result of the collisions to the free molecular value of the lift of "cold" cone in the dependence on the combination of the half-apex angle of the cone and angle of attack can be both positive and by negative and on the average are approximately 50% of $c_{y, \infty}$. In the "resonance" case when $\alpha \approx \pi/2 - \theta$, value Δc_y can be several times more than $c_{y, \infty}$ (in the given higher example at the height/altitude of 120 km relative value of correction Δc_y it is equal to approximately/exemplarily 150% $c_{y, \infty}$ and only at the height/altitude of 230 km it composes 10%).

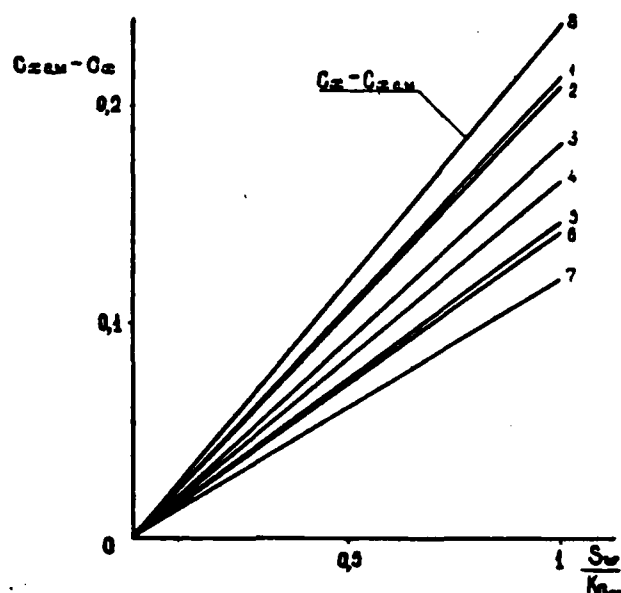


Fig. 16. 1 - circle; 2 - square; 3 - rectangle; 4 - cone, $\theta=60^\circ$; 5 - sphere; 6 - cone, $\theta=45^\circ$; 7 - cone, $\theta=30^\circ$; 8 - circle (along the flow).

Page 70.

For the thick "cold" cones the allowance due to the collisions to free molecular to the value of pitching moment can be both the positive and negative, and its value can be much more than the free molecular value of pitching moment. In the case of very slender cones when $S_w \theta \gg 1$ the value of resistance taking into account the first collisions is more than free molecular value. From the given calculations it is possible to draw the following basic conclusions:

- the boundary of free molecular courses for different aerodynamic characteristics of cone lies/rests on different height/altitude and there cannot be determined only on the basis of the Knudsen number; it in many respects depends on the geometry of task, laws of interaction of molecules with each other and with the surface of cone;

- ignorance of the laws of interaction of molecules with the surface (accommodation coefficients) to a high degree affects the determination of lift and pitching moment of cone and to the considerably smaller degree - the determination of the value of resistance and heat flux.

Plate. The results of detailed calculations are published in works [33, 35-40]. Plate is most "convenient" body for obtaining the qualitative laws governing the flow around bodies by the strongly rarefied gas. In work [30] based on the example of plate were determined different types of courses, realized in the case of the flow around the plate, arranged/located at different angles of attack, under different laws of interaction of molecules with each other and with the surface of plate.

The calculations conducted completely confirmed qualitative results [30]. If plate is arranged/located normal to flow [36, 39, 40], then its resistance and energy flow to it in the mode/conditions, close to the free molecular, are reduced within the framework of the applicability of theory approximately/exemplarily to 10%. In the case of the plate, arranged/located in parallel to flow [33, 35, 37, 38], possibly several types of flows depending on the "type" of molecules, law of their interaction with the surface and values of numbers S_{∞} , S_* and Kn_{∞} . Thus, in the "cold" case when

$S_* \leq Kn_{\infty}$ resistance of plate and energy flow in the flow conditions, close to the free molecular, are more than the free molecular value of maximum by ~10%.

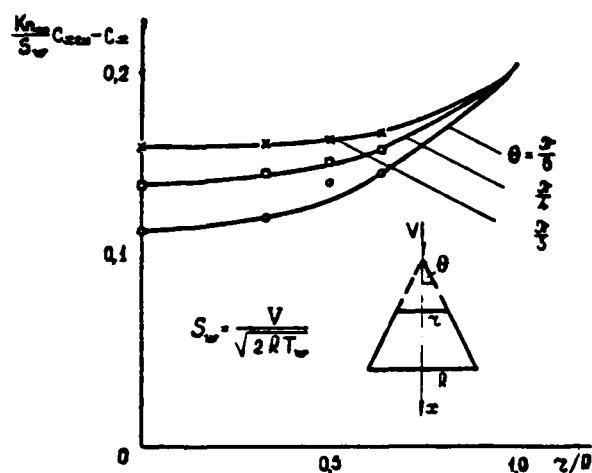


Fig. 17.

Page 71.

But if are realized the conditions of the so-called molecular boundary layer when $1 \ll K n_{\infty} \ll S_w \ll K n_{\infty}^2$, then within the framework of the applicability of the theory of the first intermolecular collisions value c_x and energy flow can be many times of more than their value in the free molecular flow. Even to the larger degree grows pressure on the surface of plate. For the plate, just as for the thin pointed bodies, high value has a precise knowledge of law of reflection of molecules from the surface, since depending on the law of interaction of molecules with the surface of the value of aerodynamic characteristics they can increase or be reduced by an order. Fig. 16 gives some results of calculations for the plates of various forms.

Skimmer (Fig. 18). Calculations were carried out for the purpose of the determination of flow disturbances at the entrance into the skimmer, the caused by collisions molecules of hypersonic ($S_\infty = \infty$) incident flow with the molecules, reflected from surface [34]. In the investigated modes/conditions the mean free path of molecules in the incident flow was much more than the diameter of the entrance, molecule they were assumed elastic spheres, $S_w = 10$ and 1.57. From the obtained results it is evident that even when $Kn_d = 40$ and $S_w = 10$ density at the entrance increases by 10% in comparison with its free molecular value. Axial inlet velocity falls, average/mean longitudinal quadratic speed is reduced, all this together undertaken speaks, that at the entrance begin to predominate the oblique collisions. With an increase in the wall temperature the effect of collisions is reduced. Consequently, cooling skimmer can contribute to the decrease of the distortion of flow only in the case of the complete freezing of gas on its surface. The calculations conducted show that even in the case when $Kn_d \gg 1$ and $Kn_p > 1$, intermolecular collisions significantly distort the picture of flow after the skimmer.

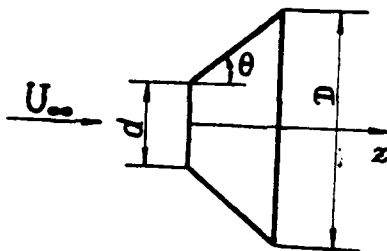


Fig. 18.

REFERENCES.

1. Cohen J. M. Free molecule flow over nonconvex bodies. ARS J., vol. 30, No 3, 1960.
2. E. Larish. Aerodynamic interference during the free molecular flow. Izv. of the AS USSR. "Mechanics and machine building", 1960, No 3.
3. E. Larish. Equations of free molecular flow. Izv. of the AS USSR, "Mechanics and machine building", 1961, No 2.
4. Pratt M. J. Concave surfaces in free molecule flow. AIAA J., vol. 1, No 7, 1963.
5. Chahine M. T. Free molecule flow over nonconvex surfaces. Rarefied gas dynamics, Proc. of the Second Internat. Symposium on rarefied gas dynamics. New York and London, 1961.
6. I. P. Otmakhova. Resistance of the hemisphere, which moves with the constant velocity in the gas. "Herald of MGU". Series "Mathematics, mechanics", 1958, No 4.
7. Sparrow E. W., Jonsson V. R., Lundgreen T. S., Chen T. S. Heat transfer and forces for free molecule flow on a concave cylindrical surface. J. Heat Transfer, vol. 86, No 1, 1964.
8. Wani T. Aerodynamic interference in free molecule flow. Trans. of Japan Soc. for Aeron. and Space Sciences, vol. 3, No 4, 1960.
9. A. I. Bunimovich, M. L. Kagan. Free molecular flow of gas in the flat ducts and the lattices. Izv. of the AS USSR, "Mechanics of fluid

and gas", 1966, No 3.

10. Sparrow E. W., Jonsson V. R., Lundgreen T. S. Free molecule tube flow and adiabatic wall temperature. J. Heat Transfer, vol. 85, No 2, 1963.

11. Patterson G. N. Recent trends in the mechanics of highly rarefied gases. Aeronautics and Astronautics Proc. of the Durand Centennial Conference Held at Stanford University 1959, New York and London, 1960.

12. Yu. I. Lyubotov. Calculation of interaction of the molecular flows with their enclosing containers. M., "Science", 1964.

Page 72.

13. Davis D. H., Levenson L. L., Milleron N. Theoretical and experimental studies of molecular flow through short ducts. Rarefied gas dynamics proc. of the second international symposium on rarefied gas dynamics, New York and London, 1961.

14. Kruger C. H., Shapiro A. H. The axial-flow compressor in the free-molecule range. Rarefied gas dynamics proc. of the second international symposium on rarefied gas dynamics. New York and London, 1961.

15. A. A. Bogacheva, V. A. Perepukhov, E. Ye. Rukhman.

Use/application of the Monte Carlo method to the calculations of the aerodynamic characteristics of concave bodies and bodies of complex form in the free molecular flow. "J. of comp. math. and math. physics", Vol. 8, No 6, 1968.

16. N. P. Buslenko, Yu. A. Shreyder. Method of statistical tests, M., Fizmatgiz, 1961.

17. A. A. Bogacheva, V. A. Perepukhov, E. I. Rukhman. Use/application of the Monte Carlo method to the calculation of the aerodynamic characteristics of bodies in the free molecular flow. Transactions of TsAGI, iss. 1227, 1970.

18. Lotte G. Zur Methodik der kinetischen Gastheorie. Ann. der Physik, 1930, Ser 5, 6.
19. Keller J. B. On the solution of the Boltzmann equation for rarefied gases. Comm. on appl. mathem., vol. 1, No 3, 1948.
20. Szymanosky Z. Some flow problems of rarefied gases. Archiwum Mech. Stosowanej, vol. 8, No 4, 1956.
21. Heineman M. Theory of drag in highly rarefied gases. Comm. on appl. mathem., vol. 1, No 3, 1948.
22. Lunc M., Lubonski J. La perturbation de l'écoulement moléculaire libre produite par un obstacle. Bull. de L'Académie Polonaise des sciences, 1957, t. 5, n° 1.
23. R. S. Iroshnikov. On the almost free molecular flow around bodies of the rarefied gas. "Engineering journal", Vol. I, No 3, 1961.
24. Boker R. M. L., Charwat A. P. Transitional correction to the drag of a sphere in free molecule flow. Phys of Fluids, vol. 1, No 2, 1958.
25. D. Willis. Theoretical resolutions of some problems of almost free molecular flow. In the collection: "Gas dynamics of the rarefied gases". M., Publ. of foreign lit., 1965.
26. Willis D. R. General Electric Co. Space Sci. Lab. TIS. R 60. SD 399, 1960.
27. Rose M. (Heineman M.). Drag on an object in nearly-free molecular flow. The Physics of fluids, vol. 7, No 8, 1964.
28. Ye. V. Alekseyeva, R. G. Barantsev. Flow around the mirror reflecting sphere of the strongly rarefied gas. Coll. "Aerodynamics of the rarefied gases", Vol. I. Publ. of LGU, 1965.
29. G. Pfau. Resistance of rhombic profile/airfoil in the almost free molecular flow. Coll. Aerodynamics of the rarefied gases", Vol. I, izd. LGU, 1965.
30. M. N. Kogan. On the hypersonic flows of rarefied gas. "Applied mathematics and mechanics", Vol. XXVI, No 3, 1962.
31. M. N. Kogan. Dynamics of the rarefied gas. M., "Science", 1967.

32. V. A. Perepukhov. Aerodynamic characteristics of sphere and blunt-nosed cone in the flow of the strongly rarefied gas. "J. of comp. math. and math. physics", Vol. 7, No 2, 1967.

33. M. N. Kogan, L. M. Degtarev. On the calculations of flows with the large Knudsen numbers. "Astronautica acta", iss. 11, No 1, 1965.

34. V. A. Perepukhov. Aerodynamic characteristics of the acute round cone, arranged/located at the angle of attack to the flow of the strongly rarefied gas. In the collection: "Study of the flow around bodies by hypersonic low-density flow". Transactions of TsAGI, iss. 1311, 1971.

35. V. N. Gusev, M. N. Kogan, V. A. Perepukhov. On similarity and change of the aerodynamic characteristics in the transition region at the hypersonic speeds of flow. "Scientific notes of TsAGI", Vol. I, No 1, 1970.

36. V. A. Perepukhov. On the flat-plate drag in the flow of the strongly rarefied gas. "J. of comp. math. and math. physics", Vol. I, No 4, 1961.

37. V. A. Perepukhov. Flow around the flat/plane plate, arranged/located at the zero angle of attack, by the flow of the

strongly rarefied gas. "J. of comp. math. and math. physics", Vol. 3, No 3, 1963.

38. V. A. Perepukhov. Flow around circular plate under the conditions of molecular boundary layer. PMTF, 1964, No 5.

39. V. A. Perepukhov. On resistance of the flat/plane plate, arranged/located normal to the flow of the strongly rarefied gas. "Engineering journal", Vol. 5, No 5, 1965.

40. O. G. Friedlander. On resistance of the flat/plane plate, perpendicular to hypersonic low-density flow. PMTF, 1965, No 3.

Page 73.

STUDY OF INTERNAL AND EXTERNAL FREE MOLECULAR FLOWS ABOUT AN
ARBITRARY GROUP OF COMPLEX BODIES.

M. A. Zakirov.

Are given formulas and universal program comprised on them for calculating of aerodynamic coefficients, local flows through the surfaces and local parameters of gas in the field of flow at the flow of the free molecular flow about the group of complex bodies. Calculations can be carried out under different laws of interaction of molecules with the wall. Body surface is assigned analytically. The velocity vector of the incident flow is arbitrary in the value and in the direction. Program makes it possible to carry out the flow-field analyses of bodies by the flow of light/world and by hypersonic inviscid flow (according to Newton's theory).

ADOPTED DESIGNATIONS.

$V, Vh^{1/2}, h^{-1/2}, T, n, m$ — average/mean and relative gas velocity, the most probable speed, temperature, density and the mass of particles;

Xx_i, Yy_j, Ww_n — coordinate systems, connected with entire body, with the separate surface and with the surface element on surface of $(i, j, n=1, 2, 3)$;

δ_{ji} — unit matrix ($j, i=1, 2, 3$);

$c_{\pm i}, c_{ri}, m_{\pm i}, m_{ri}$ — coefficients of total aerodynamic forces and moments/torques;

$E_{\pm}, E_r$ — coefficients of total energy flows to the body;

E_k — flux coefficient of the energy through the control surface;

$\left. \begin{matrix} (n_{\pm}, n_r), (p_{\pm}, p_r) \\ (\tau_{\pm}, \tau_r), (e_{\pm}, e_r) \end{matrix} \right\}$ — coefficients of the average/mean local particle fluxes, normal and tangential impulses/momenta/pulses and energy through the surface;

w_{λ} - probability of the flight/span of molecule;

p_{λ} - static pressure;

$\left. \begin{matrix} n_{\lambda}, V_{j(\lambda)}, T_{\lambda}, M_{ij(\lambda)}, \\ p_{ij(\lambda)}, E_{j(\lambda)}, q_{j(\lambda)} \end{matrix} \right\}$ - particle density, the average speed, temperature, the tensors of the flux of momentum and stresses/voltages, the flows of complete and thermal energy along the field of flow of gas;

u_{λ} - particle flux;

$M[X], D[X]$ - mathematical expectation and dispersion;

$N_p(N_{pk})$ - number of particles, played through entire (through the k-th) face of control surface.

Page 74.

Indices.

∞ - undisturbed flow;

w - condition on the wall;

k - number of the face of control surface;

ν - ν -th surface;

ω, β, γ - local flows through the surface;

λ - local parameters on the field of flow in the vicinity of formal surface S_λ ;

n - coefficients in Newton's theory;

f - flow of light/world (photons).

Introduction.

The tasks of the study of free molecular flows appear in connection with the flights of bodies in the free molecular flow and the calculations of flows in the vacuum devices.

The calculations of free molecular flows are performed through two directions: in the first case solve the complicated integral equations of the type of Fredholm the second kind for the function of the distribution of particles [1-6] reflected; in the second case free molecular flow, they simulate by the method of the Monte Carlo [7-12].

The solution of integral equation is obtained for the case of flow of the hypersonic free molecular flow about of the concave sphere and cylinder with the diffuse reflection of particles from surface [2, 13, 14]. Numerical calculations are carried out during the free molecular flow around the infinite cylinder [15] and wedge [16]; cone, hemisphere and cylinder with wings [5, 8]; flat ducts and lattices [17].

In the tasks about the internal flows, the first settings and solutions of which were given in the works of Knudsen, Smoluxovsky

and Clausing (see vast bibliography in the works [1, 5, 6]), are determined the probability of the flight/span of molecules and the density of gas during the flow through the rectangular cylindrical, the conical and wedge channels [17-20]. Is determined also gas density in the vicinity of sphere and cone [21-23].

In the present work is given the calculation procedure by the method of the Monte Carlo of the aerodynamic coefficients of separate surfaces and entire body, and also coefficients of local stresses/voltages in the body surface and local parameters of gas (density, temperature, speed, heat flux, etc.) on the field of internal and external free molecular flows. Calculations can be carried out for arbitrary combination of the complex bodies whose surfaces are assigned analytically. The velocity vector of the incident flow of gas can be arbitrary in the value and the direction. For gaming the reflection of molecules it is possible to apply different models. Employing this procedure it is possible to lead calculations for the bodies in the flow of light/world and according to Newton's theory.

Chapter 1.

UNIVERSAL ALGORITHM OF THE STUDY OF FREE MOLECULAR FLOWS.

The overall diagram of the solution of problem is the following. The geometry of the arbitrarily arranged/located bodies in the space is assigned with the help of set of parameters of surfaces. In accordance with the function of particle distribution of the undisturbed flow is produced the drawing of the random parameters of particles at the "start" from the control surface, which surrounds body. Are developed consecutive collisions and reflections (in accordance with the assigned density) of particles with the body surfaces up to their escape from the control volume. At the moment of the intersection with the molecule of body surface are summarized all necessary flows, throughout which then are calculated the mathematical expectations of the corresponding flows per unit time.

Page 74.

1. On the analytical method of the assignment to surface of complex body.

Let us consider the complex body whose entire surface can be

represented by the set of the arbitrary parts of the surfaces of the second order. The numbered parts of the surfaces we will call thus: the first surface, the second surface, etc. Let us introduce the system of coordinates Xx_i ($i=1, 2, 3$) connected with the body.

All surfaces are determined by assignment for each of them the ordered array from the coefficients of the equations of the second order

$$b_{jm}y_jy_m + 2b_{j4}y_j + b_{44} = 0 \quad (j, m = 1, 2, 3), \quad (1.1)$$

written for the convenience relative to the arbitrary system of coordinates Yy_j , oriented relative to system Xx_i by direction cosines a_{ji} between axes x_i and y_j and by coordinates x_{0i} of point Y . In formula (1.1) b_{jm} - tensor (affine tensor); b_{j4} - vector; b_{44} - scalar.

Analytical method includes also the assignment to region D of changing the variable/alternating y_j . During the assignment to D region use Cartesian, polar, cylindrical and spherical coordinates. Then almost for all surfaces, presenting interest from the point of view for the theory and practice, the form D region becomes simplest - rectangular. For the assignment to D region are used: in the Cartesian system of coordinates (y_j) the variable/alternating y_1, y_2 , in polar (ϕ, r, y_3) - ϕ, r , in the cylindrical (ϕ, r, y_3) - ϕ, y_3 and into the spherical (ϕ, θ, r) - ϕ, θ . Let us agree on subsequently to

call y_1 and ϕ external variable/alternating, and y_2 , r , y , and θ - internal variable/alternating.

Let us do some notes. In the Cartesian and polar coordinate systems D region does not set limitations on values of y_1 ; therefore for achievement of uniqueness is considered only the part of the surface, which falls into half-space $y_1 > 0$. By the appropriate selection of the coefficients of equation (1.1) it is possible to achieve entry/incidence into half-space $y_1 > 0$ of different parts or entire surface. In the case of conical surface it is necessary to throw/reject a small vicinity about the apex/vertex, since the direction of standard/normal at this point is not determined.

Thus, each surface is assigned by set of parameters b_{jm} , $2b_{j1}$, b_{j2} , a_{j1} , x_{0j1} , β_1 , β_2 , γ_1 , γ_2 and π_* . Here (β_1, β_2) , (γ_1, γ_2) - the limits of the rectangular region D on by external and internal variable/alternating; π_* - sign/criterion, which designates the coordinate system, in which is assigned D region.

The following space is the introduction of the typical classes of surfaces and complex bodies. For example, if are examined only axisymmetric surfaces (circle, cylinder, cone, spherical segment), then a number of assigned parameters about the surfaces substantially is reduced. Complicated surfaces also can be assigned by a smaller

number of parameters; for example, the surface of parallelepiped is determined by the assignment of the coordinates of three apexes/vertexes and height/altitude.

Particle trajectories are calculated relative to axes Xx_i , therefore the equations of all surfaces are converted from one axes Yy_i to the next Xx_i . This is realized into two stages. First is produced the rotation of axes Yy_i so that new axes $Yy'_i \parallel Xx_i$ and equation (1.1) takes the form

$$\left. \begin{aligned} \psi_{ik} y'_i y'_k + 2\psi_{i4} y'_i + b_{44} &= 0; \quad \psi_{ik} = a_{ji} a_{mk} b_{jm}; \\ \psi_{i4} &= a_{ji} b_{j4}; \quad y_j = a_{ji} y'_i; \quad y_m = a_{mk} y'_k; \quad i, k = 1, 2, 3. \end{aligned} \right\} \quad (1.2)$$

Page 76.

Then is realized the parallel shift/shear of axes Yy'_i before the coincidence with axes Xx_i

$$y'_i = x_i - x_{0i}, \quad (1.3)$$

and the equation of surface takes the form

$$\left. \begin{aligned} a_{ik} x_i x_k + 2a_{i4} x_i + a_{44} &= 0; \quad a_{ik} = \psi_{ik}; \\ a_{i4} &= \psi_{i4} - \psi_{ik} x_{0k}; \quad a_{44} = x_{0i} (\psi_{ik} x_{0k} - 2\psi_{i4}) + b_{44}. \end{aligned} \right\} \quad (1.4)$$

2. Selection of the form of control surface.

On control surface (S_0) we will produce gaming the random values

of the components of vector of the particle speed and coordinates of the start of particle. In this case the value of the probability of contact with the body surface of the particle, which starts with S_0 ,

$$p_n = \frac{N_n}{N_p} \quad (2.1)$$

must be closest possible to one. Here N_n — number of particles fallen on body of all that played N_p on S_0 .

If we as S_0 take sphere, then value p_n will be small for the bodies, extended on one or two measurements, but if elliptical cylinder or ellipsoid, then are obtained complicated formulas for the drawing of random variables.

In the present work as the control surface is selected parallelepiped (S_1), since for it value p_n will be sufficient high, and the density function of random variables for faces S_i are simplest.

In the examination of flows within the channels it is profitable to develop flight of particle only through the part of control surface, for example only through one face in plane of which is arranged/located the entrance. After the drawing of the random coordinates of particle on rectangular face S_1 is checked their entry/incidence in the section of inlet whose form is arbitrary.

3. On the laws of the distribution of the random parameters of particles.

We will examine Knudsen's gas ($Kn \rightarrow \infty$). If about body (final) flows uniform equilibrium (limitless) flow, then the function of the distribution of the incoming particles is equal to Maxwellian

$$f_{\infty} = n_{\infty} (h_{\infty} / \pi)^{3/2} \exp \left[- h_{\infty} \sum_{i=1}^3 (\xi_i - V_{\infty i})^2 \right]; \quad h_{\infty} = \frac{m}{2 k T_{\infty}}. \quad (3.1)$$

Here designation conventional (for example, see [1]).

Let us consider now formulas for the drawing of the random components of speed and coordinates of particles on surface S_k .

Preliminary analysis showed that the random components of the particle speed on faces S_k to more simply develop in the Cartesian coordinates. In the cylindrical and spherical coordinates the random variables, which characterize value and direction of the particle speed, are dependent, which strongly complicates drawing. Only when $V_{\infty} = 0$ are obtained simple formulas for the drawing of the velocity vector of the particle [see formula (4.10)].

Page 77.

Six faces S_k , which satisfy the equations

$$x_i - x_{i1} = 0, \quad k=i; \quad x_i - x_{i2} = 0, \quad k=i+3; \quad x_{i1} < x_{i2}, \quad (3.2)$$

let us number by index $k=1, 2, 3, \dots, 6$. Let us designate through n_{ki} the internal normals to faces S_k .

Expressing the standardized/normalized particle fluxes through faces S_k , we will obtain expressions for the densities of random components ξ_{ki} of particle speed:

components ξ_{ki} , parallel to standards/normals $\tilde{n}_{ki}$

$$f(\xi_{ki}) = 2\chi^{-1}(V'_{\infty k}) \exp[-(\xi_{ki} - V'_{\infty k})^2] \xi_{ki}, \quad (3.3)$$

$$i=k \quad (k=1, 2, 3), \quad i=k-3 \quad (k=4, 5, 6), \quad \xi_{ki} \in (0, \infty);$$

components ξ_{ki} , parallel to faces S_k ,

$$f(\xi_{ki}) = (\pi)^{-1/2} \exp\{-(\xi_{ki} - S_{\infty i})^2\}, \quad (3.4)$$

$$i \neq k \quad (k=1, 2, 3), \quad i \neq k-3 \quad (k=4, 5, 6);$$

here

$$V'_{\infty k} = n_{ki} S_{\infty i}; \quad S_{\infty i} = v_{\infty i} S_{\infty}; \quad v_{\infty i} = V_{\infty i} / |V_{\infty}|^{-1} = \{-\cos \alpha_0 \cos \beta_0, \\ \sin \alpha_0 \cos \beta_0, -\sin \beta_0\}; \quad \chi(x) = \exp(-x^2) + \sqrt{\pi} x (1 + \operatorname{erf} x); \\ S_{\infty} = V_{\infty} h_{\infty}^{1/2}, \quad \xi_{ki} = \xi_{ki} h_{\infty}^{1/2};$$

α_0 and β_0 - angles of attack and slip.

Let us note that function (3.3) reaches maximum at the point

$$\xi'_{0k} = 0,5 V'_{\infty k} + (0,25 V_{\infty k}^2 + 0,5)^{1/2}, \quad (3.5)$$

but function (3.4) - at point $S_{\infty i}$.

Integral laws take the form:

distribution (3.3)

$$R_{ki}(\xi'_{ki}) = \int_0^{\xi'_{ki}} f(\xi'_{ki}) d\xi'_{ki} = 1 + \{ \sqrt{\pi} V'_{\infty k} [\operatorname{erf}(\xi'_{ki} - V'_{\infty k}) - 1] - \exp[-(\xi'_{ki} - V'_{\infty k})^2] \} \chi^{-1}(V'_{\infty k}); \quad (3.6)$$

the distribution (3.4)

$$R_{ki}(\xi'_{ki}) = \int_{-\infty}^{\xi'_{ki}} f(\xi'_{ki}) d\xi'_{ki} = \frac{1}{2} [1 + \operatorname{erf}(\xi'_{ki} - S_{\infty i})]. \quad (3.7)$$

For the drawing of the random values of components ξ'_{ki} it is necessary to find intervals $(\xi'_{ki}^a, \xi'_{ki}^b)$, the probability of the entry/incidence into which of random variables ξ'_{ki} is close to one.

On the basis of the preliminary estimations for the components of speed ξ'_{ki} parallel to standards/normals n_{ki} , let us consider the following cases:

$$\begin{aligned}
 & \text{A. } V'_{\infty k} > 3,25, \xi'_{ki} = V'_{\infty k} - 3,25, \xi'_{ki} = V'_{\infty k} + 3,25; \\
 & \text{B. } 0 \leq V'_{\infty k} < 3,25, \xi'_{ki} = 0, \xi'_{ki} = V'_{\infty k} + 3,25; \\
 & \text{C. } -4,55 < V'_{\infty k} < 0, \xi'_{ki} = 0.
 \end{aligned} \quad (3.8)$$

Page 78.

For case of A, by considering the probability

$$\begin{aligned}
 p[\xi'_{ki} < (V'_{\infty k} - 3,25)] &= R_{ki}(V'_{\infty k} - 3,25) = 1 - \\
 &- (\sqrt{\pi} V'_{\infty k} [1 + \operatorname{erf}(3,25)] + \exp(-3,25^2)) \chi^{-1}(V'_{\infty k}),
 \end{aligned} \quad (3.9)$$

derivative of which

$$\frac{dR_{ki}}{dV'_{\infty k}} = \frac{\sqrt{\pi} \exp(-3,25^2) (1 + \operatorname{erf}(3,25))}{\chi^2(V'_{\infty k})} \left[\frac{1 + \operatorname{erf} V'_{\infty k}}{1 + \operatorname{erf}(3,25)} - \frac{\exp(-V_{\infty k}^2)}{\exp(-3,25^2)} \right] \quad (3.10)$$

is positive when $V'_{\infty k} \geq 3,25$, we will obtain that function (3.9) reaches when $V'_{\infty k} \rightarrow \infty$ the maximum, equal to

$$\lim_{V'_{\infty k} \rightarrow \infty} p \approx \frac{1}{\sqrt{\pi}} \exp(-3,25^2) \left(\frac{1}{2 \cdot 3,25} - \frac{1}{2^2 \cdot 3,25^3} + \dots \right) \approx 0,214 \cdot 10^{-5}. \quad (3.11)$$

It is analogous, for case of A, considering probability $p[\xi'_{ki} > (V'_{\infty k} + 3,25)]$, we find that it is not more than value

$$1 - \lim_{V'_{\infty k} \rightarrow 3,25} p \approx \exp(-3,25^2) (\sqrt{\pi} 3,25)^{-1} \approx 0,428 \cdot 10^{-5}. \quad (3.12)$$

Thus, for case of A is proved the formula

$$p[(V'_{\infty k} - 3,25) < \xi'_{ki} < (V'_{\infty k} + 3,25)] > (1 - 10^{-5}). \quad (3.13)$$

Accurately also for case of B we find

$$p[0 < \xi_{kl}^* < (V'_{\infty k} + 3,25)] \geq (1 - 2,47 \cdot 10^{-3}). \quad (3.14)$$

For case of B after numerical calculations according to formula (3.6) was obtained the empirical formula

$$\begin{aligned} \xi_{kl}^* &= 1,523 (V'_{\infty k} + 4,55)^{1/2}; \\ p(0 < \xi_{kl}^* < \xi_{kl}^*) &\geq (1 - 10^{-3}). \end{aligned} \quad (3.15)$$

When $V'_{\infty k} \leq -4,55$ the quantity of molecules, which fall to appropriate face S_k and which constitute from all those falling the portion, approximately equal to

$$S_k \chi(V'_{\infty k}) \left[\sum_{k=1}^{k=6} S_k \chi(V'_{\infty k}) \right]^{-1} \leq 10^{-3}, \quad (3.16)$$

can be disregarded/neglected. Here S_k — area of face k .

Is analogous, for ξ_{kl}^* , parallel to faces S_k , let us find that

$$p[(S_{\infty l} - 3,25) < \xi_{kl}^* < (S_{\infty l} + 3,25)] > (1 - 10^{-3}). \quad (3.17)$$

Since (3.6) and (3.7) are not solved relative to ξ_{kl}^* , then the drawing of random values ξ_{kl}^* is produced according to Baird's method [12]. In this method in comparison with Neumann's method [25] the condition for the selection of random numbers does not require gaming

the further irregularly distributed random number, designated further by symbol R , since it is formed/shaped on the course of calculations.

The random coordinates of the start of molecules have density function:

$$f(x_{i+k}) = \delta(x_i - x_{1i}); \quad f(x_{i+k}) = (x_{2i} - x_{1i})^{-1}, \quad k = 1, 2, 3; \quad (3.18)$$

$$f(x_{i+k-3}) = \delta(x_i - x_{2i}); \quad f(x_{i+k-3}) = (x_{2i} - x_{1i})^{-1}, \quad k = 4, 5, 6; \quad (3.19)$$

here $\delta(x)$ - Dirac's delta-function.

Since the drawing of trajectories is produced relative to coordinates $x_{i,k}$, then to components ξ'_{ki} of particle speed after drawing according to formula (3.3) for cases of $k=4, 5, 6$ it is necessary to confer minus sign.

Page 79.

4. Drawing of random particle trajectories under different laws of reflection of particles from the wall.

Let us designate x_{1i} and x_{2i} - the coordinate of initial and end point of one of the elements/cells of break - particle trajectory, which tests/experiences collisions with the concave surface. With the start with S_k we have

$$\left. \begin{aligned} x_{1i}(l=k) &= x_{1i}, \quad x_{1i}(l+k) = x_{1i} + R_1(x_{2i} - x_{1i}); \quad k=1, 2, 3; \\ x_{1i}(l=k-3) &= x_{2i}, \quad x_{1i}(l+k-3) = x_{1i} + R_2(x_{2i} - x_{1i}); \quad k=4, 5, 6. \end{aligned} \right\} \quad (4.1)$$

From point x_{1i} the molecule moves over the straight line

$$x_i = x_{1i} + \xi_{-1i} t; \quad \xi_{-1i} = \xi_{-1i} \left(\sum_{i=1}^{i=3} \xi_{-1i}^2 \right)^{-1/2}. \quad (4.2)$$

Index - "in the speeds designates the emitted, "+" arriving flying particle, and superscript " ° " designates the unit vector of vector of velocity. Solving system from equations (1.4) and (4.2), we determine values of t_1 and t_2 :

$$t_{1,2} = [-b \pm (b^2 - 4ac)^{1/2}] (2a)^{-1}, \quad (4.3)$$

where $a = a_{ik} \xi_{-1i} \xi_{-1k}$; $b = 2(a_{ik} x_{1i} \xi_{-1k} + a_{i4} \xi_{-1i})$; $c = a_{ik} x_{1i} x_{1k} + 2a_{i4} x_{1i} + a_{44}$,

for which straight line (4.2) can intersect surface (1.4).

Due to the final accuracy of arithmetic operations by ETsVM [- digital computer] the coordinates of the collision of molecules with the surface can be computed with the "short round" or the "flight/passage". In order to eliminate the effects of these cases, we will accept, that with

$$(b^2 - 4ac) < 0; \quad t_1 < t_1, \quad t_2 < t_1 \quad (4.4)$$

the molecule does not encounter surface, but with

$$t_1 \geq t_1, \quad -\infty < t_2 < \infty; \quad t_2 \geq t_1, \quad -\infty < t_1 < \infty \quad (4.5)$$

is possible the collision of particle with the surface with t_1 or t_2 or when $t_{1,2} \geq \epsilon_1$. Calculations show that it is possible to take $\epsilon_1 \approx 10^{-5}$.

Thus, are found one or two points of intersection of particle with the surface

$$x_{im} = x_{1,i} + \xi_{-1,i} t_m, \quad m = 1, 2. \quad (4.6)$$

After this is produced checking the entry/incidence of points x_{im} to the assigned piece of surface, determined by D region, for which it is necessary to calculate coordinates x_{im} in that system, in which is assigned D region. Values $t_1(t_2)$, with which the intersection of surface did not take place or the corresponding points do not fall into D region, are substituted by number $L_1 > L_2$; L_1 is equal to maximum size S_1 .

The cycle of this checking is completed for all surfaces (1.4) of body. From the obtained set t is determined t_{min} . If $t_{min} \geq L_1$, then particle does not intersect body, otherwise intersects it at the point

$$x_{pi} = x_{1,i} + \xi_{-1,i} t_{min}. \quad (4.7)$$

The reflection of particle from point x_{pi} is realized depending on the assigned boundary conditions on the surface.

With the mirror reflection of molecule the speed of reflections of molecule is equal to

$$\dot{\mathbf{r}}_{-r} = \dot{\mathbf{r}}_{+r} - 2(\dot{\mathbf{r}}_{+r} \mathbf{n}_i) \mathbf{n}_i. \quad (4.8)$$

Here $\mathbf{n}_i$ -- internal normal to the surface.

Page 80.

In the case of diffuse reflection from the surface is introduced local system of coordinates $\mathcal{W}\mathbf{w}_n$ with beginning $\mathcal{W}(\mathbf{x}_i)$ and axes $\mathbf{w}_n$ such, that cosines c_{ni} of the angles between $\mathbf{w}_n$ and $\mathbf{x}_i$ are equal to

$$c_{1i} = [\dot{\mathbf{r}}_{+r} - (\dot{\mathbf{r}}_{+r} \mathbf{n}_i) \mathbf{n}_i] [1 - (\dot{\mathbf{r}}_{+r} \mathbf{n}_i)^2]^{-1/2}; \quad c_{2i} = (\mathbf{n}_i \times \mathbf{c}_{1i}); \quad c_{3i} = \mathbf{n}_i; \quad (\dot{\mathbf{r}}_{+r} \mathbf{n}_i) < 0. \quad (4.9)$$

If $(\dot{\mathbf{r}}_{+r} \mathbf{n}_i) \geq 0$, then vectors c_{2i} and c_{3i} vary directions to the opposite ones; if $(\dot{\mathbf{r}}_{+r} \mathbf{n}_i) = \pm 1$ then, accepting $c_{1i} = 0$ and taking into account that $|c_{1i}| = 1$, $(c_{1i} \mathbf{n}_i) = 0$, we will obtain $c_{1i} = -\mathbf{n}_i c_{2i} / n_i$, $c_{2i} = -[1 + (\mathbf{n}_2 / n_i)^2]^{-1/2}$,

The speed of the diffuse reflected particle is developed according to the formulas (see also [11])

$$\left. \begin{aligned} \dot{\mathbf{r}}_{-r} &= \dot{\mathbf{r}}_{-r} |\dot{\mathbf{r}}_{-r}|; \quad \dot{\mathbf{r}}_{-r} = c_{1i} \dot{\mathbf{r}}_{+r}; \quad \dot{\mathbf{r}}_{-r} = [\cos \varphi \sin \theta, \sin \varphi \sin \theta, \cos \theta]; \\ \varphi &= 2\pi R_3; \quad \sin \theta = \sqrt{R_4}; \quad |\dot{\mathbf{r}}_{-r}| = (-h_r^{-1} \ln(R_5 R_6))^{1/2}; \\ h_r^{-1} &= a_0 (h_w)^{-1} + \frac{\dot{\mathbf{r}}_{+r}^2 (1 - a_0)}{2}. \end{aligned} \right\} \quad (4.10)$$

Here α_* — accommodation coefficient of energy with the mirror-diffused reflection.

With the mirror-diffused reflection each molecule with probability p_* is reflected diffuse, i.e., if $p_* > R_*$, then reflection is diffuse, otherwise it is mirror.

Let us consider law of reflection of molecules, given by Maxwell's function

$$f_r = n_r (h_r/\pi)^{3/2} \exp \left[-h_r \sum_{n=1}^3 (\xi_{rn} - V_{rn})^2 \right] \quad (4.11)$$

with five macroparameters n_r, h_r, V_{rn} . Designating the average/mean values of the components of the speed of the molecules reflected in system Ww_n , constructed in accordance with formulas (4.9), through $\bar{\xi}_{rn} = (\bar{\xi}_{r1}, 0, \bar{\xi}_{r3})$, the average/mean value of energy of the molecules (per unit of mass) reflected — through $\bar{\xi}_r^2/2$ and the relative average speed — through $S_{rn} = (S_{r1}, 0, S_{r3}) = V_{rn} h_r^{1/2}$, we will obtain

$$\begin{aligned} \bar{\xi}_{r1} &= V_r \sin \theta_r; \quad \bar{\xi}_{r3} = V_r \varphi' / S_r; \quad \bar{\xi}_r^2/2 = \frac{V_r^2}{2S_r^2} [2 + S_r^2 + S_{r3}(\varphi' - S_{r3})]; \\ \varphi' &= S_{r3} + 0,5 \sqrt{\pi} (1 + \operatorname{erf} S_{r3}) \chi^{-1}(S_{r3}); \quad \cos \theta_r = -(n_1 V_{r1}). \end{aligned} \quad (4.12)$$

Hence we obtain the transcendental equation

$$\psi = \varphi^2 (2 + S_{r, \varphi})^{-1} = \bar{\xi}_{r,3}^2 (\bar{\xi}_r^2 - \bar{\xi}_{r,1}^2)^{-1}. \quad (4.13)$$

It is evident that this model does not limit the physical picture of phenomenon, since the left side where $0 \leq \psi \leq 1$, does not contradict right: $\bar{\xi}_r^2 \geq \sum_{n=1}^{n=3} \bar{\xi}_{r,n}^2$.

Average/mean values $\bar{\xi}_{r,n}$ were determined with $V_{\infty} \geq 10^6$ cm/s in work [10] in the form

$$\alpha_r = \bar{\xi}_1^{-2} (\bar{\xi}_1^2 - \bar{\xi}_r^2); \quad \alpha_n = \bar{\xi}_1^{-1} (\bar{\xi}_{r,3} - \bar{\xi}_{1,3}); \quad \alpha_1 = \bar{\xi}_1^{-1} (\bar{\xi}_{1,1} - \bar{\xi}_{r,1}). \quad (4.14)$$

Components $\bar{\xi}_{1,n}$ and $\bar{\xi}_{r,n}$ are expressed in system Ww_n .

From (4.13) and (4.14) we obtain the condition of the solvability

$$(\sin \theta_1 - \alpha_r)^2 + (\alpha_n - \cos \theta_1)^2 \leq (1 - \alpha_r), \quad \cos \theta_1 = (n_1 \bar{\xi}_{1,1}), \quad (4.15)$$

i.e., the terminuses of vector (α_r, α_n) must be placed in upper half of circle with the center at point $(\sin \theta_1, \cos \theta_1)$ and with radius $(1 - \alpha_r)^{1/2}$.

Page 81.

The sequence of calculations is the following.

1. Are calculated $\theta_1, \alpha_e, \alpha_n, \alpha, \bar{\xi}_r^2, \bar{\xi}_{r,3}, \bar{\xi}_{r,1}$ and ψ .

2. Is solved equation (4.13). With $0.04 \leq \psi \leq 0.9612$ was applied the method of linear interpolation. With $\psi > 0.9612$ it is obtained with error 0.1%

$$S_{r,3} = \{[1.5 + (16\psi - 13.75)^{1/2}][2(1 - \psi)]^{-1}\}^{1/2}, \quad (4.16)$$

while with $\psi < 0.04$

$$S_{r,3} = -[(1 + (1 - 18\psi)^{1/2})(2\psi)^{-1}]^{1/2}. \quad (4.17)$$

These relationships/ratios are found from asymptotic expansions of function $\psi(S_{r,3})$ when $S_{r,3} \rightarrow \infty$ and $S_{r,3} \rightarrow -\infty$.

3. It is calculated φ' , then

$$S_{r,1} = \varphi' \bar{\xi}_{r,1} / \bar{\xi}_{r,3}; \quad (h_r)^{-1/2} = \bar{\xi}_{r,3} / \varphi'; \quad V_r = S_r (h_r)^{-1/2}; \quad S_r^2 = S_{r,1}^2 + S_{r,3}^2. \quad (4.18)$$

The drawing of the components of speed $\xi_{r,n}$ of particle is produced employing the procedure, presented in Section 3. Then is computed $\xi_{r,n} = c_{1n} \xi_{r,n}$. It is obvious, in the general case with the multiple reflections of particle from the concave surface coefficients α_e, α_n and α it is not possible to consider constants. Assuming that the particle, which falls at a high speed to the surface, reduces its energy due to the multiple reflections and it reaches equilibrium with the surface, with which

$$\bar{\xi}_r^2 = 2h_e^{-1}; \quad \bar{\xi}_{r,3}^2 = \frac{\pi}{4} h_e^{-1}; \quad \bar{\xi}_{r,1}^2 = 0; \quad \psi = \frac{\pi}{8}; \quad \varphi' = \frac{\sqrt{\pi}}{2}, \quad (4.19)$$

we will describe the process of achieving the equilibrium, by the dependences, which give a change in the values, which characterize energy of the particle:

$$\begin{aligned} \bar{\xi}_r^2 \xi_1^{-2} &= 2h_w^{-1} \xi_1^{-2} + \varphi_r [(1 - \alpha_r) - 2h_w^{-1} \xi_1^{-2}]; \quad \bar{\xi}_r^2 \xi_1^{-2} = \frac{\pi}{4} h_w^{-1} \xi_1^{-2} + \\ &+ \varphi_n [(\alpha_n - \cos \theta_1)^2 - \frac{\pi}{4} h_w^{-1} \xi_1^{-2}]; \quad \bar{\xi}_r^2 \xi_1^{-2} = \varphi_r (\sin \theta_1 - \alpha_r)^2. \end{aligned} \quad (4.20)$$

Coefficients φ_r , φ_n and φ_r vary from one (with the high energies) to zero (with low energies). Were examined the following cases:

1) coefficients φ_r , φ_n and φ_r depend on the number of multiple reflections on the exponential dependence

$$\varphi_r = \varphi_n = \varphi_r = \exp(aa_1), \quad a < 0, \quad a_1 = p - p_0, \quad (4.21)$$

on the linear dependence

$$\varphi_r = \varphi_n = \varphi_r = (p_{00} - p)(p_{00} - p_0)^{-1}, \quad p_{00} - p_0 \geq 1; \quad (4.22)$$

2) coefficients φ_r , φ_n and φ_r are assigned by the arbitrary monotonic functions of energy of incident particles.

In formulas (4.21), (4.22) p - reference number of the collision of particle; p_0 - number of reflections (inclusively), in which during calculation $\bar{\xi}_r$ and $\bar{\xi}_r$ coefficients α_r , α_n and α_r are assumed to be constants; $\alpha < 0$ - arbitrary coefficient. Reflection with the

number of collision $p_{..}$ (inclusively) in (4.22) becomes diffuse with the complete accommodation. Let us note that assigned dependences $\alpha_e, \alpha_n, \alpha_r, \varphi_e, \varphi_n$ and φ_r must satisfy the condition of solvability (4.15).

5. Calculation of the total particle fluxes, impulse/momentum/pulse and energy. Calculation of dispersions.

Let us designate the flows from the first collision by index "+", from first reflection "-" and from the second collision and the reflection and so forth to the escape of particle into infinity from point x_n — by index r . Particle fluxes relate to $n_\infty V_\infty$, impulses/momenta/pulses - to $mn_\infty V_\infty^2/2$, energies - to $kmn_\infty V_\infty^3/2$. During the calculation of aerodynamic flux coefficients of forces relate to $mn_\infty \dot{V}_\infty^2 S_n/2$, moments/torques to $-mn_\infty V_\infty^2 S_n d_n/2$. When $V_\infty = 0$ instead of V_∞ is used $h_\infty^{-1/2}$

Page 82.

Mathematical expectations of the aerodynamic force coefficients and moments/torques of the compound:

$$\left. \begin{aligned}
 c_{\pm i} &= \pm A \sum_{\mu=1}^{\mu=N_n} \xi_{\pm i \mu}; & c_{ri} &= A \sum_{\mu=1}^{\mu=N_n} (\xi_{+2i} - \xi_{-ri}); \\
 m_{\pm i} &= \pm \frac{A}{d_m} \sum_{\mu=1}^{\mu=N_n} (x_{1i} \times \xi_{\pm i \mu}); \\
 m_{ri} &= \frac{A}{d_m} \sum_{\mu=1}^{\mu=N_n} [(x_{2i} \times \xi_{+2i}) - (x_{ri} \times \xi_{-ri})]; & A &= \frac{2B\rho_n}{V_{\infty} N_n S_m}; \\
 B &= \frac{0,5}{\sqrt{\pi S_{\infty}}} \sum_{k=1}^{k=6} S_k \chi(V'_{\infty k}).
 \end{aligned} \right\} (5.1)$$

Here μ - number of the particle, played with S_k and that fallen on body. Total coefficients of complicated body:

$$c_i = c_{+i} + c_{-i} + c_{ri}; \quad m_i = m_{+i} + m_{-i} + m_{ri}. \quad (5.2)$$

Examining the sequence of the random values of the aerodynamic coefficients, obtained according to the results of the drawing of each μ -th particle trajectory, we will obtain for calculating the dispersions the following recursion relations:

$$\left. \begin{aligned}
 M[X] &= a_0 M_{\mu}; & D[X] &= a_0^2 D_{\mu}; & M_{\mu} &= [(\mu-1)M_{\mu-1} + Z_{\mu}]/\mu; \\
 D_{\mu} &= \{[D_{\mu-1} + (M_{\mu-1} - M_{\mu})^2](\mu-1) + (Z_{\mu} - M_{\mu})^2\}/\mu; & a_0 &= \frac{2B\rho_n}{b_0 V_{\infty}}.
 \end{aligned} \right\} (5.3)$$

Here M and D designate mathematical expectation and dispersion;

$$\begin{aligned}
 Z_{\mu} &= (\xi_{+1i} - \xi_{-ri}), & b_0 &= S_m \text{ при } X \equiv c_i; \\
 Z_{\mu} &= (x_{1i} \times \xi_{+1i}) - (x_{ri} \times \xi_{-ri}), & b_0 &= S_m d_m \text{ при } X \equiv m_i.
 \end{aligned}$$

Key: (1). with.

The central axis of the system of the forces, applied to the body, is parallel to vector c_i and it passes through the point

$$x_{i0} = -d_m [m_i \times c_i] [|m_i|^2 |c_i|^2 - (c_i m_i)^2] [|c_i|^2 |m_i \times c_i|^2]^{-1}, \quad (5.4)$$

moreover moment with respect to this point

$$m_{i0} = c_i (c_i m_i) |c_i|^{-2}, \quad m_{i0} \parallel c_i. \quad (5.5)$$

Flux coefficients of energy to the body:

$$\left. \begin{aligned} E &= E_+ + E_- + E_r; \quad E_{\pm} = \pm A_1 \sum_{\mu=1}^{\mu=N_a} \xi_{\pm 1}^2; \quad E_r = A_1 \sum_{\mu=1}^{\mu=N_a} (\xi_{+1}^2 - \xi_{-1}^2) \kappa \\ A_1 &= \frac{B p_a}{V_{\infty}^2 N_a} \end{aligned} \right\} \quad (5.6)$$

Flux coefficient of the energy through the control surface

$$E_s = A_1 \sum_{\mu=1}^{\mu=N_p} |\xi_{s1}|^2.$$

When $S_{\infty} \gg 1$ value E_+ is approximately equal to the area of the "shadow" of complicated body for the plane, perpendicular V_{∞} .

Is calculated also relative value of further collisions $(N_{\infty} + N_r) N_{\infty}^{-1}$, where N_{∞} and N_r — quantity of all particles, which fall on body from infinity and after the first reflection.

With the diffuse reflection of particles from the concave

surface with the complete accommodation easily is established/installed the dependence of coefficients on temperature T_w of the surface:

$$c_{-1} \sim S_w^{-1}, c_{r1} \sim S_w^{-1}, E_{-1} \sim S_w^{-2}, E_r \sim S_w^{-2}, S_w = S_\infty (T_\infty / T_w)^{1/2}. \quad (5.7)$$

Here and throughout symbol "~" designates proportionality.

Page 83.

6. Calculation of the aerodynamic interaction coefficients of surfaces and bodies.

We will examine the aerodynamic force coefficients and moments/torques, which function on the surface of concave body as a result of multiple collisions of particles with the surface. Indices "+", "-" and r will designate flows from the first collision, from the first reflection and from the multiple collisions of particles with the surface. Aerodynamic force coefficients relate to

$h n_\infty V_\infty^2 S_w / 2$ moments/torques - to $m n_\infty V_\infty^2 S_w d_w / 2$. When $V_\infty = 0$ instead of V_∞ is used $h_\infty^{-1/2}$.

Mathematical expectations of the aerodynamic force coefficients and the moments/torques, which function on ν -th surface of complicated body in body axes Xx_i :

$$\begin{aligned}
 c_{\pm vi} &= \pm A \sum_{\mu=1}^{\mu=N_n} \xi_{\pm 1vi}; \quad c_{rvi} = A \sum_{\mu=1}^{\mu=N_n} (\xi_{+2vi} - \xi_{-2vi} + \dots - \xi_{-rvi}); \\
 m_{\pm vi} &= \pm \frac{A}{d_m} \sum_{\mu=1}^{\mu=N_n} (x_{1i} \times \xi_{\pm 1vi}); \\
 m_{rvi} &= \frac{A}{d_m} \sum_{\mu=1}^{\mu=N_n} [(x_{2i} \times \xi_{+2vi}) - (x_{2i} \times \xi_{-2vi}) + \dots - (x_{ri} \times \xi_{-rvi})]; \\
 A &= \frac{2Bp_n}{V_{\infty} N_n S_m}; \quad B = \frac{0,5}{\sqrt{\pi} S_{\infty}} \sum_{k=1}^{k=6} \chi(V'_{\infty k}) S_k.
 \end{aligned} \tag{6.1}$$

In these formulas are summarized the impulses/momenta/pulses during the incidence/drop in the particle on ν -th surface with the drawing of all $\mu=1+N_n$ particle trajectories.

Aerodynamic coefficients of the surface:

$$c_{vi} = c_{+vi} + c_{-vi} + c_{rvi}; \quad m_{vi} = m_{+vi} + m_{-vi} + m_{rvi}. \tag{6.2}$$

If complex body consists of several separate bodies, then, summarizing coefficients (6.1) for the surfaces of which consists separate body, it is possible to compute the aerodynamic interaction coefficients of the bodies, which fly on certain distance from each other.

7. Calculation of the local particle fluxes, impulse/momentum/pulse and energy through the surface of complex body.

The coefficients of local particle fluxes (n_+ and n_-) we will carry to $n_\infty V_\infty$, normal ($p_\pm$ and p_r) and tangential ($\tau_\pm$ and τ_r) impulses/momenta/pulses - to $mn_\infty V_\infty^2/2$ and energies $(e_\pm e_r) \rightarrow mn_\infty V_\infty^3/2$.

For calculating the local flows the surface is divided on the pads ΔS : first is divided the rectangular region D of the assignment to surface $O\eta$ the large number m^2 of equal rectangles with the help of $2(m-1)$ straight lines, carried out through each side of rectangle D in parallel to its sides. Let the centers of all areas/sites ΔS have integral coordinates on the external variable/alternating region $D\beta=1-m$ and in terms of the internal variable/alternating $\gamma=1-m$ and the general/common/total numbering:

$$\bullet = (\beta - 1)m + \gamma, \quad \bullet \in (1 + m^2). \quad (7.1)$$

Page 84.

Each of m^2 rectangles D region determines on the surface area/site $\Delta S_\bullet$ of the arbitrary form whose area is computed from the formula

$$\Delta S_\bullet = \int_{\beta_1 + \Delta\beta(\beta-1)}^{\beta_2 + \Delta\beta\beta} \left[\int_{\gamma_1 + \Delta\gamma(\gamma-1)}^{\gamma_2 + \Delta\gamma\gamma} f(z_\beta, z_\gamma) dz_\gamma \right] dz_\beta; \quad \Delta\beta = \frac{\beta_2 - \beta_1}{m}; \quad \Delta\gamma = \frac{\gamma_2 - \gamma_1}{m}; \quad (7.2)$$

here $(\beta_1, \beta_2), (\gamma_1, \gamma_2)$ - limits D region. Functions (z_β, z_γ) and the variable/alternating z_β, z_γ during the assignment regions D take the

form:

in Cartesian coordinates: (y_j)

$$f(z_0, z_1) = -n_3^{-1}; \quad z_0 \equiv y_1; \quad z_1 \equiv y_3; \quad (7.3)$$

in the polar coordinates (φ, r, y_3) :

$$f(z_0, z_1) = -rn_3^{-1}; \quad z_0 \equiv \varphi; \quad z_1 \equiv r; \quad (7.4)$$

in the cylindrical coordinates (φ, r, y_3)

$$f(z_0, z_1) = -r(n_1 \cos \varphi + n_2 \sin \varphi)^{-1}; \quad z_0 \equiv \varphi; \quad z_1 \equiv y_3; \quad (7.5)$$

in the spherical coordinates (φ, θ, r)

$$f(z_0, z_1) = -\sin \theta r^2 (n_1 \cos \varphi \sin \theta + n_2 \sin \varphi \sin \theta + n_3 \cos \theta)^{-1}; \\ z_0 \equiv \varphi; \quad z_1 \equiv \theta; \quad (7.6)$$

$$n_j = l_j \left(\sum_{j=1}^3 l_j^2 \right)^{-1/2}; \quad l_j = -\partial F(y_j, y_m) / \partial y_j = -(b_{jm} y_m + b_{j4}). \quad (7.7)$$

The components of the unit vector of internal standard/normal n_j , value y , in the Cartesian and polar coordinate systems, value r in the cylindrical and spherical coordinates are computed with the help of the equation of the surface

$$F(y_j, y_m) = b_{jm} y_j y_m + b_{j4} y_j + b_{44} = 0, \quad (j, m = 1, 2, 3), \quad (7.8)$$

moreover in the solutions of corresponding square equations before the radicals is taken sign "+".

By the values of the coordinates of the impact point in the particle on the surface are determined coordinates (z_0, z_1) in D region, through which is located the number

$$\omega = m(\beta - 1) + \gamma, \quad (7.9)$$

where

$$\beta = \text{entier} [(z_\beta - \beta_1) \Delta_\beta^{-1} + 1], \quad \gamma = \text{entier} [(z_\gamma - \gamma_1) \Delta_\gamma^{-1} + 1],$$

using the address of area/site Δ_{S_0} . Here entier (x) indicates the near whole, which does not exceed x.

For each area/site in terms of the value of address ω occurs the accumulation of the corresponding sums from which are computed the flux coefficients:

the normal impulses/momenta/pulses

$$p_{\pm\omega} = A_2 \sum_{\mu=1}^{\mu=N_\omega} |\xi_{\pm 1\omega} n_{\mu}|; \quad p_{r\omega} = A_2 \sum_{\mu=1}^{\mu=N_\omega} (|\xi_{+2\omega} n_{\mu}| + |\xi_{-2\omega} n_{\mu}| + \dots + |\xi_{r\omega} n_{\mu}|); \quad (7.10)$$

the tangential impulses/momenta/pulses

$$\tau_{\pm\omega} = \pm A_2 \sum_{\mu=1}^{\mu=N_\omega} (\xi_{\pm 1\omega} c_{1\mu}); \quad \tau_{r\omega} = A_2 \sum_{\mu=1}^{\mu=N_\omega} [(\xi_{+2\omega} c_{1\mu}) - (\xi_{-2\omega} c_{1\mu}) + \dots - (\xi_{r\omega} c_{1\mu})]; \quad (7.11)$$

the energies

$$e_{\pm\omega} = A_3 \sum_{\mu=1}^{\mu=N_\omega} \xi_{\pm 1\omega}^2; \quad e_{r\omega} = A_3 \sum_{\mu=1}^{\mu=N_\omega} (\xi_{+2\omega}^2 - \xi_{-2\omega}^2 + \dots - \xi_{r\omega}^2); \quad (7.12)$$

the particles

$$n_{+0} = A_4 \sum_{\mu=1}^{\mu=N_n} \mu_{10}; \quad n_{r0} = A_4 \sum_{\mu=1}^{\mu=N_n} (\mu_{20} + \mu_{30} + \dots + \mu_{r0}); \quad (7.13)$$

$$A_2 = \frac{2B\rho_n}{V_\infty N_n \Delta S_0}; \quad A_3 = \frac{B\rho_n}{V_\infty^2 N_n \Delta S_0}; \quad A_4 = \frac{B\rho_n}{N_n \Delta S_0};$$

$$c_{1i} = [v_{\infty i} - (v_{\infty i} n_i) n_i] [1 - (v_{\infty i} n_i)^2]^{-1/2}, \quad v_{\infty i} = V_{\infty i} |V_{\infty}|^{-1}. \quad (7.14)$$

If $(v_{\infty i} n_i) = \pm 1$, then $c_{1i} = \{\sin \alpha_0, \cos \alpha_0, 0\}$.

Page 85.

In formulas (7.13) $\mu_{10} = 1$ during the incidence/drop the particles on ΔS_0 from infinity, otherwise $\mu_{10} = 0$; $\mu_{20}, \mu_{30}, \dots, \mu_{r0}$ are equal to one during the incidence/drop in the particle on ΔS_0 after the first reflection, otherwise they are equal to zero.

In the case of the symmetry of flow can be of interest medium stresses/voltages along the bands, parallel to the sides D region. Designating by the index β averaged stresses over the bands in parallel to side γ of D region, and by index γ the averaged stresses/voltages on the bands, parallel to the side β D region, we will obtain

$$p_{+\beta} = \frac{1}{m} \sum_{\gamma=1}^{\gamma=m} p_{+\gamma}, \quad p_{+\gamma} = \frac{1}{m} \sum_{\beta=1}^{\beta=m} p_{+\beta}, \dots \quad (7.15)$$

and medium stresses/voltages on over the entire surface

$$p_{+} = \frac{1}{m^2} \sum_{\alpha=1}^{\alpha=m^2} p_{+\alpha}, \dots \quad (7.16)$$

Varying in formulas (7.15) and (7.16) p on r , e and n , and index "+" on "-" and r , we will obtain formulas for all averaged flows.

With the diffuse reflection of particles from the concave surface with the complete accommodation easily is established/installed the dependence of coefficients on temperature $\bar{T}_\bullet$ of the surface:

$$p_{-+} \sim S_\bullet^{-1}; \quad p_{r+} \sim S_\bullet^{-1}; \quad \tau_{-+} \sim S_\bullet^{-1}; \quad \tau_{r+} \sim S_\bullet^{-1}; \quad e_{-+} \sim S_\bullet^{-2}; \quad e_{r+} \sim S_\bullet^{-2} \quad (1.17)$$

8. Calculation of the local parameters of the flow of the strongly rarefied gas in the vicinity of compound.

Let us consider the procedure of calculation of the penetration probabilities of the particles through the specific surfaces, and also densities, the average speeds and the temperatures of gas, stress tensors and fluxes of momentum, vectors of complete and thermal energy, mass flow rates and static pressures at arbitrary points in the vicinity of compound.

Let us introduce formally into the examination the flat surface which will serve for fixing of the parameters of gas and will not affect particle trajectory. Index λ will designate the number of this

"formal" surface, S_λ — its area.

We will examine the flows of sign/criterion φ , transferred by the particles through the "formal" surface from the outer side [index "+", $(\xi_+, n_j) > 0$] and from inside [index "-", $(\xi_-, n_j) < 0$]. The parameters without the index will relate to entire particle flux. Let f - function of particle distribution in the vicinity of this surface. Let us write formula for the flow of sign/criterion φ through surface

S_λ :

$$S_\lambda^{-1} \left[\int_{S_\lambda(\xi_+, n_j) > 0} \varphi f(\xi_+, n_j) dS_\lambda d\xi_j + \int_{S_\lambda(\xi_-, n_j) < 0} \varphi f(\xi_-, n_j) dS_\lambda d\xi_j \right] = \\ = \frac{n_\infty B V_\infty}{N_p S_\lambda} \left[\sum_{p=1}^{p=N_p} \varphi_+ - \sum_{p=1}^{p=N_p} \varphi_- \right]. \quad (8.1)$$

Here is conducted averaging over surface S_λ , which must be sufficient small.

The penetration probabilities of the particles through the formal surface λ from the external and from inside are equal to

$W_{\pm\lambda} = N_{\pm\lambda} N_p^{-1}$. Here $N_{\pm\lambda}$ — number of molecules from N_p , that fell on formal surface from the external or from inside.

Page 86.

The densities (concentration) of particles, averaged over

surface S_λ , through which they pass, and those referred to the particle density on infinity n_∞ , are expressed from formula (8.1) when $\varphi = (\xi_{\pm}/n_j)^{-1}$:

$$\begin{aligned} n'_{\pm\lambda} = n_{\pm\lambda}/n_\infty = \pm B_1 S_\lambda^{-1} \sum_{j=1}^{p=N} (\xi_{\pm}/n_j)^{-1}; \quad n'_\lambda = n_\lambda/n_\infty = n'_{+\lambda} + n'_{-\lambda}, \\ B_1 = BV_\infty N_p^{-1}. \end{aligned} \quad (8.2)$$

The average/mean mass flow rates of molecules, in reference to $(h_\infty)^{-1/2}$, are obtained from (8.1) when $\varphi = \xi_j (\xi_{\pm}/n_j)^{-1}$:

$$\left. \begin{aligned} V'_{\pm j(\lambda)} = V_{\pm j(\lambda)} h_\infty^{1/2} = \pm B_2 (S_\lambda n'_{\pm\lambda})^{-1} \sum_{j=1}^{p=N} \xi_{\pm j} (\xi_{\pm}/n_j)^{-1}; \\ V'_{j(\lambda)} = V_{j(\lambda)} h_\infty^{1/2} = B_2 (S_\lambda n'_\lambda)^{-1} \sum_{j=1}^{p=N} (\xi_{+j} (\xi_{+}/n_j)^{-1} - \xi_{-j} (\xi_{-}/n_j)^{-1}); \\ B_2 = B_1 h_\infty^{1/2}. \end{aligned} \right\} \quad (8.3)$$

Taking into account that the temperature of gas is expressed as mean-kinetic energy of the particles

$$\frac{3}{2} kT = \frac{1}{n} \int m (\bar{\xi} - \bar{V})^2 / 2 f d\xi_j = \frac{m}{2n} \int \xi^2 f d\xi_j = \frac{m V^2}{2}, \quad (8.4)$$

where n , m - density and the mass of particles, we will obtain from (8.1) when $\varphi = \xi^2 (\xi_{\pm}/n_j)^{-1}$

$$\begin{aligned} T'_{\pm\lambda} = \frac{T_{\pm\lambda}}{T_\infty} = \frac{2}{3} T_{\pm\lambda^0} (n'_{\pm\lambda} S_\lambda)^{-1} - \frac{2}{3} V_{\pm\lambda}^2; \\ T'_\lambda = \frac{T_\lambda}{T_\infty} = \frac{2}{3} (T_{+\lambda^0} + T_{-\lambda^0}) (n'_\lambda S_\lambda)^{-1} - \frac{2}{3} V_\lambda^2; \quad T_{\pm\lambda^0} = \pm B_2 \sum_{j=1}^{p=N} \xi_j^2 (\xi_{\pm}/n_j)^{-1}; \\ B_2 = B_1 h_\infty^{1/2}; \quad V'_{\pm\lambda} = |V'_{\pm j(\lambda)}|; \quad V'_\lambda = |V'_{j(\lambda)}|. \end{aligned} \quad (8.5)$$

Determining the tensor of the flux of momentum by the expression

$$M'_{ij} = M_{ij} (mn_{\infty} h_{\infty}^{-1})^{-1}; \quad M_{ij} = m \int \xi_i \xi_j f d\xi_j, \quad (8.6)$$

we will obtain from (8.1) when $\varphi = \xi_i \xi_j (\xi_{\pm j} n_j)^{-1}$

$$M'_{\pm ij(\lambda)} = \pm B_3 S_{\lambda}^{-1} \sum_{j=1}^{N_p} \xi_i \xi_j (\xi_{\pm j} n_j)^{-1}; \quad M'_{ij(\lambda)} = M_{+ij(\lambda)} + M_{-ij(\lambda)}. \quad (8.7)$$

Determining stress tensor by the expression

$$p'_{ij} = p_{ij} (mn_{\infty} h_{\infty}^{-1})^{-1}; \quad p_{ij} = m \int (\xi_i - V_i)(\xi_j - V_j) f d\xi_j = \\ = m \int \xi_i \xi_j f d\xi_j - mn V_i V_j, \quad (8.8)$$

we will obtain from (8.1) when $\varphi = \xi_i \xi_j (\xi_{\pm j} n_j)^{-1}$

$$p'_{\pm ij(\lambda)} = M'_{\pm ij(\lambda)} - n_{\pm \lambda} V_{\pm i(\lambda)} V'_{\pm j(\lambda)}; \quad p'_{ij(\lambda)} = M'_{ij(\lambda)} - n_{\lambda} V_{i(\lambda)} V'_{j(\lambda)}. \quad (8.9)$$

Determining the vector of the flow of total energy by the expression

$$E'_j = E_j \left(\frac{m}{2} n_{\infty} h_{\infty}^{-3/2} \right)^{-1}; \quad E_j = \frac{m}{2} \int \xi^2 \xi_j f d\xi_j, \quad (8.10)$$

we will obtain from (8.1) when $\varphi = \xi^2 \xi_j (\xi_{\pm j} n_j)^{-1}$

$$E'_{\pm j(\lambda)} = \pm B_4 S_{\lambda}^{-1} \sum_{j=1}^{N_p} \xi^2 \xi_j (\xi_{\pm j} n_j)^{-1}; \quad E'_{j(\lambda)} = E'_{+j(\lambda)} + E'_{-j(\lambda)}; \quad B_4 = B_3 h_{\infty}^{1/2}. \quad (8.11)$$

Page 87.

Determining the vector of thermal energy by the expression

$$q'_j = q_j \left(\frac{m}{2} n_{\infty} h_{\infty}^{-3/2} \right)^{-1}; \quad q_j = \frac{m}{2} \int (\vec{\xi} - \vec{V})^2 (\xi_j - V_j) f d\xi_j, \quad (8.12)$$

we will obtain from (3.1)

$$\left. \begin{aligned} \dot{q}_{\pm j}(\lambda) &= E'_{\pm j}(\lambda) - 2V'_{\pm j}(\lambda) \dot{p}_{\pm j}(\lambda) - V'_{\pm j}(\lambda) T_{\pm \lambda} S_{\lambda}^{-1}; \\ \dot{q}_j(\lambda) &= E'_j(\lambda) - 2V'_j(\lambda) \dot{p}_j(\lambda) - V'_j(\lambda) (T_{+\lambda} + T_{-\lambda}) S_{\lambda}^{-1}. \end{aligned} \right\} \quad (8.13)$$

Static pressure p_{λ}

$$p'_{\lambda} = p_{\lambda} p_{\infty}^{-1} = n_{\lambda} T'_{\lambda}, \quad (8.14)$$

but average/mean particle flux u_{λ} through S_{λ}

$$u'_{\lambda} = u_{\lambda} (mn_{\infty} h_{\infty}^{-1/2})^{-1} = n_{\lambda} V'_{n\lambda}; \quad (8.15)$$

here $V'_{n\lambda}$ projection V'_{λ} on the normal to S_{λ} .

Let us note that the started from the formal area of the particle can for a second time clash with the same surface due to an error in the calculations. So that this could not occur, the coordinates of particle with the start must be displaced by the low value $\epsilon, \approx 10^{-4}$ in the direction of particle motion.

9. Calculation of aerodynamic coefficients in the flow of Newton and in the flow of light/world.

Employing the procedure, comprised for calculating the free molecular flows, it is possible to calculate the aerodynamic coefficients of the bodies, which fly in the flows of Newton and

light/world.

The total aerodynamic coefficients of bodies c_{iH} , m_{iH} and the coefficients of the local flows of normal impulse/momentum/pulse $p_{\pm H}$ in Newton's flow are equal to

$$c_{iH} = (c_{+i} + c_{-i})/2; \quad m_{iH} = (m_{+i} + m_{-i})/2; \quad (9.1)$$

$$p_{\pm H} = (p_{+0} + p_{-0})/2. \quad (9.2)$$

Entering the right sides of these formulas coefficients $c_{\pm i}$, $m_{\pm i}$ and $p_{\pm 0}$ [see formulas (5.1) (7.10) are calculated from the procedure of calculation of free molecular flows under the following conditions: $S_{\infty} \gg 1$, the falling/incident from infinity particle encounters surface only one time and is reflected mirror.

Sometimes appears the need for calculating the aerodynamic characteristics of bodies in the luminous flux, which proceeds from any point source. The luminous flux consists of the photons, which have energy $\epsilon_{\phi} = h\nu$, mass $m_{\phi} = \frac{h\nu}{c_0^2}$, impulse/momentum/pulse $p_{\phi} = \frac{h\nu}{c_0}$ and numerical density $n_{\phi} = \frac{E_{\phi}}{h\nu c_0}$; here h - Planck's constant; c_0 , ν - speed and the frequency of light/world; E_{ϕ} - light energy, which falls per unit time per unit of area.

With the drawing of particle-photons necessary to assign $S_{\infty} \gg 1$; the speed of the falling/incident and reflected particles

are equal to V_∞ ; the designed aerodynamic characteristics will be related to velocity head

$$q_\phi = \frac{p_\phi c_0^2}{2} = \frac{E_\phi}{2c_0}, \quad p_\phi = n_\phi m_\phi. \quad (9.3)$$

Let k_1 , k_2 , and k_3 be equal to the portions of that reflected, absorbed and passing through the surface of the luminous flux, moreover $k_1 + k_2 + k_3 = 1$. With the drawing of the reflection of particle-photon from the surface of the probability of its reflection, absorption and passage through the surface are equal to respectively k_1 , k_2 , and k_3 .

We will examine the surface, which does not pass light/world ($k_3 = 0$) and isolated/insulated, so that the absorbed photons will be again scattered according to "cosine law" (diffuse reflection) with the function of the distribution

$$f_\phi = \frac{n_\phi \delta(c - c_0)}{4\pi}. \quad (9.4)$$

Here $\delta(c - c_0)$ - Dirac's delta-function. In this case with probability $p_\phi = k_2(1 - k_1)$ particle-photon will be reflected diffusively and with probability k_1 - it is mirror.

Let us note that the worked out methodology makes it possible to

DOC = 83067303

PAGE *A175*

solve also the problems about the diffusion of light in the arbitrary channels.

Page 88.

Chapter II.

DESCRIPTION OF UNIVERSAL PROGRAM.

The program, given in appendix 1, is comprised in accordance with the algorithm, described in Chapter I. Turnings to IS-2, to the standard programs (SP) for calculating the functions $\ln(x)$, $\exp(x)$, $\sin(x)$, $\arcsin(x)$, $\arctg(x)$, $\operatorname{erf}(x)$, to SP of the multiplication of matrix/die by the vector, the multiplication of matrices/dies and to SP of the group translation/conversion into the binary system from the decimal (10 $\rightarrow$ 2) of the array of numbers are written in accordance with [26]. Remaining turnings to IS-2 are given in Table 1 and are isolated in the program with feature to the left.

Номер СП (1)	Наименова- ние СП (2)	Вторая строка * обращения к СП (3)						Примечания (4)
0041	Печать мас- сива чисел от a до b с переводом из 2→10 (5)	$\pi_1 0 \pi_2$	52	a	0041	b		Содержимое ячеек $a-b$ не пор- тится (6)
0150	Линейная интерполя- ция функ- ций одной переменной (7)	000 00	$\langle n \rangle$	0150	$\langle x_0 \rangle$			n — число узлов интер- поляции без одного; $x_0, f(x_0)$ — аргумент и функция в первом узле интер- поляции; (8) x — текущее значение ар- гумента (9)
0122	Вычисление двойного интеграла методом (10) Симпсона (11)	000 00	$\langle a \rangle$	0122	$\langle b \rangle$			$I = \int_a^b F(x) dx, F(x) = \int_{c(x)}^{d(x)} f(x, y) dy;$ (12) аргументы x и y берутся из $\langle x \rangle$ и $\langle x \rangle + 1$; в ячейках $\gamma + \gamma + m - 1$ счет $c(x)$ и $d(x)$, причем $c(x) \rightarrow \langle c(x) \rangle$, а $d(x) \rightarrow$ $\langle c(x) \rangle + 1$; в ячейках $\alpha + \alpha +$ $+ r - 1$ счет $f(x, y)$; $\gamma + m$ и $\alpha +$ $+ r$ — пустые ячейки; погрешно- сти $\pm \epsilon_1$ и $\pm \epsilon_2$ вычисления I и $F(x)$ абсолютные, когда знак (-), и относительные, когда знак (+); значение I в ячейке 0001

Key: (1). Number. (2). Designation. (3). Second row * of turning to SP.

FOOTNOTE *. The first row, which is located in nucleus x-1, takes the form 016 x 7501 7610; $\langle x \rangle$ - cell in which is located number x.
ENDFOOTNOTE.

(4). Notes. (5). Press/printing array of numbers from a to b with translation/conversion from 2→10. (6). Contents of nuclei $a-b$ does

not spoil. (7). Linear interpolation of functions of one variable/alternating. (8). number of interpolation points without one; argument and function in first interpolation point. (9). instantaneous value of argument. (10). Calculation of double integral by method. (11). Simpson. (12). argument x and y they are taken from $\langle x \rangle$ and $\langle x \rangle + 1$; in nuclei $\gamma - \gamma + m - 1$ calculation $c(x)$ and $d(x)$, moreover $c(x) \rightarrow \langle c(x) \rangle$, and $(x) \rightarrow \langle c(x) \rangle + 1$; in nuclei $\sigma - \sigma + r - 1$ calculation $f(x, y)$; $\gamma + m$ and $\sigma + r$ - empty nuclei; error $\pm \epsilon$, and $\pm \epsilon$, calculation I and $F(x)$ absolute, when sign $(-)$, and relative, when sign $(+)$; value I in nucleus 0001.

Page 89.

I. Block I(0) for calculating of total aerodynamic coefficients and local particle fluxes, impulse/momentum/pulse and energy.

This block, which occupies nuclei 0001-6763, is basic the work of all remaining blocks II-IX it occurs with block I(0).

During calculations with block the I (0) reflection of molecules is mirror-diffused, moreover the accommodation coefficient of energy is received as constant. For the calculations with the reflection of molecules according to the law (4.11) are used blocks II and III.

Into the initial information of the version of calculation enters the information about the surfaces of combination of which consists entire/all surface of the compound; the signs/criteria of surfaces, calculation of local flows; the sign/criterion of the mirror-diffused reflection of molecules from the wall (into nucleus 0332 are sent zero); number $\dot{N}_r$, more than which there cannot be the number of reflections of molecule from the concave surface of compound with the drawing of one trajectory of molecule; the angles of attack α_0 and slip β_0 (α_0 and β_0 are assigned in degrees); parameter H; the accommodation coefficient of energy α_* ; the portion of diffuse reflecting molecules p_* ; area and the diameter of midsection S_m and d_m ; the coordinate of the first x'_{r1} and the second x'_{r2} of the points at which it can be placed the center of gravity; the coordinate of the faces of parallelepiped (control surface) x'_{11} and x'_{21} ($x'_{11} < x'_{21}$); L_1 and L_2 ; T_w ; number N_{1p} , N_{2p} , N_{3p} and N_{4p} , controlling the readout of calculation. Are assigned also numbers $n(P)$, $n(\alpha_0)$, $n(\beta_0)$, $n(H)$ and $n(\alpha_*)$, the designating quantities of surfaces, angles α_0 , β_0 , H and α_* . Addresses for the introduction/input of the parameters enumerated above are indicated into block I(O).

Information about each surface is designed in the form of the array of 30 numbers in the sequence, indicated in Table 2.

In this table ν - the number of surface; $a=1$, if surface is flat/plane, otherwise of $a=0$, $b=0$ in the absence of the recording of local flows over the surface ν , otherwise of $b=-1$ during the calculation of local flows according to inside of surface and $b=+1$ over the external surface. The recording of local flows can be produced only for one surface. With the work of program with the recording of local flows into nucleus 0330 is sent a number one, otherwise - zero. If limits β_1 , β_2 , γ_1 and γ_2 D region designate angles, then they are assigned in the radians.

Table 2.

№ позиция (1)	Параметр (2)	№ позиция (1)	Параметр (2)	№ позиция (1)	Параметр (2)
1	v	11	a_{13}	21	β_1
2	b_{11}	12	a_{21}	22	β_2
3	b_{22}	13	a_{32}	23	γ_1
4	b_{33}	14	a_{23}	24	γ_2
5	$2b_{14}$	15	a_{31}	25	a
6	$2b_{24}$	16	a_{22}	26	b
7	$2b_{34}$	17	a_{33}	27	0
8	b_{44}	18	x_{01}	28	0
9	a_{11}	19	x_{02}	29	0
10	a_{12}	20	x_{03}	30	0

Key: (1). position. (2). Parameter.

Page 90.

The information comprised in accordance with Table 2 about all surfaces is introduced into nuclei 0420-1415 (0420-0455 about surface of 1, 0456-0513 about surface of 2, etc.). In all it is possible to introduce information about 17 surfaces (nucleus 0420-1415).

For the designation of the system of coordinates of the assignment of limits β_1 , β_2 , γ_1 and γ_2 , the rectangular region D each surface is accompanied by the indicative code (Table 3). The codes are joined into the array by way of the location of surfaces in

nuclei (0420-1415) and are introduced into nuclei 5201-5221.

Let us note that during the assignment to D region in the Cartesian and polar coordinates it is necessary, in order to for all points of surface $y, > 0$. In the case of cone it is necessary to reject a small vicinity about the apex/vertex. According to calculation data the linear dimensions of this vicinity must be not less than 10^{-4} (for machine M-20), otherwise can occur the stop of machine.

Calculation according to the program can be produced for certain limited quantity of the parameters: $\alpha_*(12)$, $\beta_*(12)$, $H(3)$ and $\alpha_*(3)$. Are here in the brackets indicated maximum quantities of corresponding parameters. During the calculation occurs the consecutive sorting/excess of all combinations of the values of these parameters: first is sorted out every α_* , then β_* , H and α_* . Numbers $n(P)$, $n(\alpha_*)$, $n(\beta_*)$, $n(H)$ and $n(\alpha_*)$, equal to a number of assigned surfaces α_* , β_* , H and α_* , are introduced by the octal codes with the second address into the nuclei (Table 4).

During the calculation according to the value of parameter H with the help of linear interpolation are computed values V_∞ , of the average speed of molecules $\bar{V}$ and T_∞ . The interpolation points H_* and value V_∞ , $\bar{V}$ and T_∞ in them are assigned in the nuclei, indicated in block 1(0) (see numerical information). Number N_{**} is introduced by

the octal code with the second address into nucleus 6615.

The drawing of particle trajectories through all faces S_i is produced by "portions" $N_{1,p}$. A maximum quantity of developed particle trajectories is equal to $N_{2,p}$. Printout of total aerodynamic coefficients is produced periodically after the drawing of next "portion" of trajectories $N_{3,p} = k_3 N_{1,p}$ ($k_3 = 1, 2, 3 \dots$), and the coefficients of local flows - after the drawing of "portions" of trajectories $N_{4,p} = k_4 N_{1,p}$ ($k_4 = 1, 2, 3, \dots$). Number $N_{2,p}$ must be integral multiple of numbers $N_{3,p}$ and $N_{4,p}$. Numbers $N_{1,p} \div N_{4,p}$ are sent into nuclei $N_{1,p} - 0253$, $N_{2,p} - 0254$, $N_{3,p} - 0256$ and $N_{4,p} - 0333$.

Let us note that the values of some parameters ($N_{r,s}$, H_0 , V_∞ , $\bar{V}$, T_∞ , T_w , L_1 , L_2) are given in block 1(0).

The described initial information is introduced into the memory of machine with block 1(0) in the following sequence: is introduced block 1(0) with the previously specific and pierced on the latter/last punch card check sum (KS); after the comparison of KS of block I control automatically is transmitted to the first nucleus; on the command/crew, which is located in the fifth nucleus, is produced the input of initial information and begins the calculation of problem from nucleus 0006.

Table 3.

Система координат (1)	Код (2)
Декارتская (3)	0 00 0000 0000 0000
Полярная (4)	0 00 0001 0000 0000
Цилиндрическая (5)	0 00 0000 0001 0000
Сферическая (6)	0 00 0000 0000 0001

Key: (1). Coordinate system. (2). Code. (3). Cartesian. (4). Polar.
(5). Cylindrical. (6). Spherical.

Table 4.

Адрес (1)	Код (2)
6616	0 00 0000 $n(\Pi)$ 0000
6617	0 00 0000 $n(\alpha_0)$ 0000
6620	0 00 0000 $n(\beta_0)$ 0000
6621	0 00 0000 $n(H)$ 0000
6622	0 00 0000 $n(\alpha_s)$ 0000

Key: (1). Address. (2). Code.

Page 91.

Calculations according to the program are produced in the following sequence (in the brackets are given the numbers of the

nuclei of program):

- 1) the exchange between MOZU [core storage] MB-1 and MB-2, the press/printing the check sum of version (0006-0063);
- 2) the expansion of operating field (RP) IS-2 (1500-1501);
- 3) the translation/conversion of the array of numbers of initial information from the decimal system into the binary (1502-1503);
- 4) printout of initial information (2507-2512);
- 5) the recalculation of the coefficients of the equations of all surfaces upon transfer from one axes Yy_j to the next Xx_i (6015-6111);
- 6) calculation and printout of the values of areas/sites ΔS_i if contents of nucleus 0330 is equal to 1.0 (5327-5712);
- 7) the calculation of values
 $S_k, \alpha_0, \beta_0, H, \alpha_k, \sigma_{\infty i}, V_{\infty}, \bar{V}, T_{\infty}, S_x, h_{\infty}, h_w, B, 2\chi^{-1}(\dot{V}_{\infty k}), N_{pk} N_p^{-1},$
 $f_{max}^{-1}(\xi_0 k), \xi_{kl}^{\prime \alpha}, \xi_{kl}^{\prime \beta}$ (1514-1530, 4010-4266, 4610-4653, 6507-6513, 1541);
- 8) the drawing of the random speeds and coordinates of particles

with the start from faces S_k (1541-1753, 2005-2022);

9) the program of the drawing of the pseudorandom evenly distributed numbers R_1-R_k in interval of 0-1 (6676-6704), of constant to this block (6713-6750);

10) the calculation of the collision of particle with the surface of compound (2030-2536);

11) the calculation of the components of internal normal n_i to the surface at the impact point in the particle and value $\xi_{+i} n_i$ (2537-2577);

12) the calculation of the components of particle speed with diffuse reflection (2603-2633, 3425-3434, 3151-3166, 2634-2654, 1505-1513, 2655-2660, 3435-3440), with mirror reflection (2661-2673, 6237-6241) and with the reflection according to the law (4.11) (6320-6342, 2622-2634, 6343-6463, 6165-6207, 6465-6506, 6140-6160, 1506-1513, 2655-2660, 3435-3440);

13) the calculation of total flows (2674, 3037, 6271-6317, 2676-2715, 3066-3104);

14) the calculation of local flows (2717-3036, 6161-6164);

15) calculations before the printout of total aerodynamic coefficients (1754-1771, 3112, 6530-6535, 3113-3124, 3145-3150, 6536-6542, 4272-4306, 4667-4777, 4314-4433, 5000-5036, 4434-4450, 5037-5060, 4451, 4520-4545);

16) the command/crew of printout of total aerodynamic coefficients (4546-4547);

17) calculations before the printout of the coefficients of local flows (the same commands/crews as in p. 15 with the addition of commands/crews in nuclei 3124-3144, 3577-3631, 3057-3062, 6562-6607);

18) the command/crew of printout of the coefficients of local flows (3615-3616, 3627-3630, 6573-6574);

19) the sorting/excess of particles N_{α} , (4550-4554, 4654-4655);

20) sorting/excess α , β , H and α_{α} , (4655-4633, 4555-4567, 4452-4475, 3340);

21) the restoration/reduction of program and the introduction of the new version of calculation (3340, 3145-3147, 4571-4577,

0066-0076, 0006).

Let us note that during the transfer of control to nucleus 3340 at any moment of calculation occurs the restoration/reduction of program and the introduction of new version.

To monitor the correctness of the calculation of problem is possible on the printouts of initial information (2507-2512) from nuclei 0260-0346 and 0420-0646, and also by tracking after nucleus 3521, in which occurs the accumulation of number N , of the played trajectories, and by nucleus 3550, in which occurs a cyclic increase in the number of multiple reflections of particle from the concave surface in the developed trajectory.

Page 92.

During the calculation of areas/sites ΔS , varies the contents of nucleus 5672. To the press/printing areas/sites ΔS , are put out by one array (5704-5705) in the sequence, which corresponds to numbering $\omega = (\beta - 1) m + \gamma$.

In the program, the number $m = 10$, $\omega \in (0-100)$, $\beta \in (0-10)$, $\gamma \in (0-10)$.

The accuracy of calculation ΔS , is equal to 0.0001. The check of the correctness of the operation of program and machine can be also produced with calculation for the standard version.

Printout of total aerodynamic coefficients is produced by one

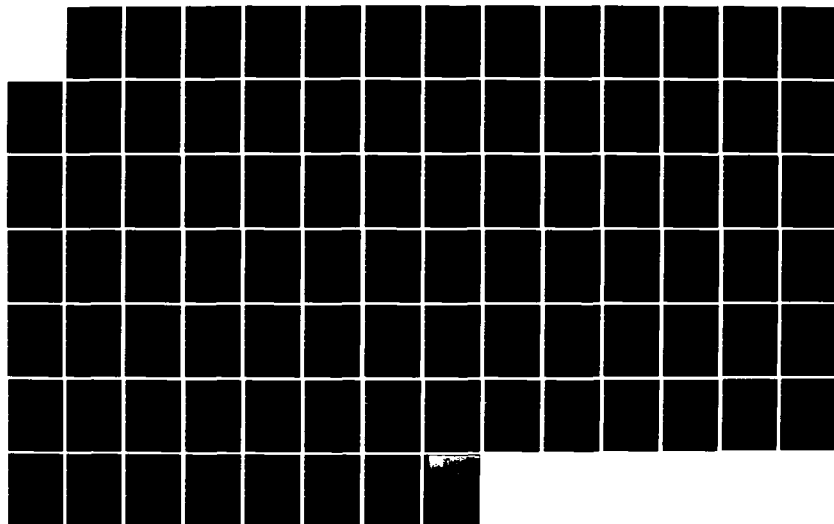
AD-A132 689

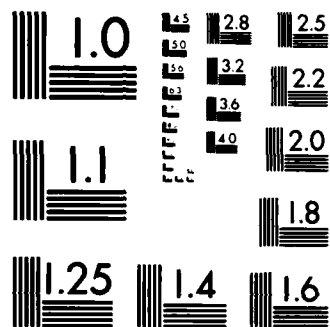
DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS(U)
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH
25 AUG 83 FTD-ID(R5)T-0673-83

3/3

UNCLASSIFIED

F/G 20/4 NL





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

array (4546-4547); the order of the location of the parameters in the array is given in Table 5.

In the printed array of the group of the parameters are isolated with the help of conditional number Π , of equal to $-+0099999999$, and with the help of index $\cdot - \cdot$ in the 45th digit of the binary code of the number (numbers of these numbers in Table 5 are isolated with prime). Aerodynamic coefficients in the drag axes are isolated with index $\cdot ^\circ$, and moment coefficients relative to points x'_{11} and $x'_{11}-$ by index $\cdot \tau i$ in accordance with one and two primes.

The coefficients of local flows are put out to press/printing 34 by arrays of numbers (Table 6). Arrays 1-11 give the coefficients of the average/mean local flows through areas/sites ΔS_{α} . Array 12 consists of 11 numbers $p'_+, \tau'_+, e'_+, n'_+, p'_r, \tau'_r, e'_r, n'_r, p'_-, \tau'_-, e'_-$. With the help of the parameters, which are contained in arrays 12-34, easily are expressed the coefficients of average/mean flows along the sides β and γ of the rectangular region D

$$p_{+\beta} = \frac{p'_{+\beta}}{10}; p_{+\gamma} = \frac{p'_{+\gamma}}{10}, \dots \quad (1.1)$$

and average/mean flows in the entire surface

$$p_+ = \frac{p'_+}{100}. \quad (1.2)$$

Varying in formulas (1.1) and (1.2) p on r , e and n , and index $_{+}$ to $_{-}$ and r , we will obtain formulas for all averaged flows. In the arrays 1-11 numbers are divided into the groups (by 10 numbers in the group) with the help of index $_{-}$ in the 45th digit of the binary code of a number.

2. Blocks II(M) and III(M) for the drawing of the reflection of particles from the surface according to the law (4.11).

Basic part of the program for the simulation of reflection

Table 5.

№ пози- ции (1)	Параметр (2)	№ пози- ции (1)	Пара- метр (2)	№ пози- ции (1)	Параметр (2)	№ пози- ции (1)	Пара- метр (2)	№ пози- ции (1)	Пара- метр (2)	№ пози- ции (1)	Пара- метр (2)
1	a_0	26	c_i	51	Π	76		101		126	
2	ρ_0	27		52		77		102		127	Π
3	H	28		53	x_{i0}	78	c_{-i}	103	$c_{+i}^* + c_{-i}^*$	128	
4	S_{∞}	29		54		79		104		129	$D[c_i]$
5	S_{∞}	30	m_i	55		80		105		130	
6	V_{∞}	31		56	m_{i0}	81	m_{-i}	106	$m_{+i}^* + m_{-i}^*$	131	
7	T_{∞}	32		57		82		107		132	$D[m_i]$
8	T_{∞}	33	$m_{i\tau}$	58	Π	83		108		133	
9	a_*	34		59		84	c_{ri}	109	c_{-i}^*	134	Π
10	p_0	35		60	c_{+i}	85		110		135	
11	B	36	$m_{i\tau}$	61		86		111		136	$\sqrt{D[c_i]}$
12	N_p	37		62		87	m_{ri}	112	m_{-i}	137	
13	$N_{\infty} - N_r$	38	Π	63	m_{+i}	88		113		138	
14	N_r	39		64		89	Π	114		139	$\sqrt{D[m_i]}$
15	N_r	40	c_i	65		90		115	c_{ri}^*	140	
16	$1 + N_r/N_{\infty}$	41		66	$c_{-i} + c_{ri}$	91	c_{+i}^*	116		141	Π
17	E_+	42		67		92		117		142	
18	E_-	43	m_i^*	68		93		118	m_{ri}^*	143	$3\sqrt{D[c_i]}$
19	E_r	44		69	$m_{-i} + m_{ri}$	94	m_{+i}^*	119		144	
20	$E_+ + E_-$	45		70		95		120	Π	145	
21	$E_+ + E_- + E_r$	46	$m_{i\tau}^*$	71		96		121		146	$3\sqrt{D[m_i]}$
22	$E_- + E_r$	47		72	$c_{+i} + c_{-i}$	97	$c_{-i}^* + c_{ri}^*$	122	$[M c_i]$	147	
23	E_k	48		73		98		123			
24	0	49	$m_{i\tau}^{**}$	74		99	$m_{-i}^* + m_{ri}^*$	124			
25	Π	50		75	$m_{+i} + m_{-i}$	100		125	$M[m_i]$		

Key: (1). No. of position. (2). Parameter.

according to the law (4.11) is contained in block I(0). The misplaced part is designed by blocks II(M) and III(M). With blocks II(M) and III(M) is introduced also initial information - value of the accommodation coefficients $\alpha_e, \alpha_n, \alpha_p$, of number $a, p_{-1}, p_{-2}, p_{-3}$, function $\varphi_e, \varphi_n, \varphi_p$, and also the codes into nuclei 5222-5242. In nucleus 0332 is introduced the number, equal to one.

Table 6.

Номер массива (1)	Массив (2)	Коли- чество чисел (3)	Номер массива (1)	Массив (2)	Коли- чество чисел (3)
1	p_{+e}	100	18	$\tau_{r\beta}$	10
2	τ_{+e}	100	19	$e_{r\beta}$	10
3	e_{+e}	100	20	$n_{r\beta}$	10
4	n_{+e}	100	21	$p_{-\beta}$	10
5	p_{re}	100	22	$\tau_{-\beta}$	10
6	τ_{re}	100	23	$e_{-\beta}$	10
7	e_{re}	100	24	p_{+T}	10
8	n_{re}	100	25	τ_{+T}	10
9	p_{-e}	100	26	e_{+T}	10
10	τ_{-e}	100	27	n_{+T}	10
11	e_{-e}	100	28	p_{rT}	10
12	$p_{+}, \tau_{+}, \dots$	11	29	τ_{rT}	10
13	$p_{+\beta}$	10	30	e_{rT}	10
14	$\tau_{+\beta}$	10	31	n_{rT}	10
15	$e_{+\beta}$	10	32	p_{-T}	10
16	$n_{+\beta}$	10	33	τ_{-T}	10
17	$p_{r\beta}$	10	34	e_{-T}	10

Key: (1). Number of array. (2). Array. (3). Quantity of numbers.

Page 94.

Let the accommodation coefficients for each surface be determined and dependences on the angle θ_1 (angle between vectors of the speed of the falling/incident molecule and vector of internal normal to the surface). In the program are provided the nuclei for dispatching six functions $\alpha_{n,1}=f(\theta_1)$, $\alpha_{n,2}=f(\theta_1)$ and $\alpha_{n,3}=f(\theta_1)$. The values of these functions at points $\theta_1=0; 15^\circ; 30^\circ; 45^\circ; 60^\circ; 75^\circ; 90^\circ$ are sent into nuclei 0134-0205 [see the numerical information of block 1(0)]. For each surface is comprised also the special code whose first address is the number of the first nucleus of dependence $\alpha_n=f(\theta_1)$ (for this surface), the second address - number of the first nucleus of dependence $\alpha_{n,1}=f(\theta_1)$, the third address - number of the first nucleus of dependence $\alpha_{n,2}=f(\theta_1)$. All these codes are joined into the array and are introduced into nuclei 5222-5242 (into 5222 - for surface of 1, into 5223 - for surface of 2, etc.). In the given program values $\alpha_n, \alpha_{n,1}, \alpha_{n,2}$ [see the numerical information of block I(0)] are undertaken from [10].

With block II are introduced numbers (p_0-1) (1420), $a<0$ (0313) in the implementation of dependence (4.21) and (p_0-1) (1420), $(p_0-p_0): \Rightarrow 1$ (0313) in the implementation of dependence (4.22). Are

here in the brackets indicated the numbers of nuclei.

Block II+III makes it possible to simulate arbitrary monotonic dependences φ_n , φ_a , φ_r on the square of speed u^2 , of incident particle. With block II+III are sent the values of interpolation points u_i into nuclei 6764-6774 and respectively the value of functions in them φ_r (6775-7005), φ_a (7006-7016), φ_r (7017-7027).

3. Block IV (P) for calculating the coefficients of the aerodynamic forces, which function on each surface.

Printout of the aerodynamic coefficients of surfaces is produced periodically after the drawing of next "portion" of trajectories N_i , (see the description of block I). The coefficients of surfaces are put out to the press/printing by the arrays each of which relates to the specific surface with respect to the location of information about the surfaces in nuclei 0420-1415. Table 7 gives the order of the location of the aerodynamic coefficients of surface in the array.

After printout of the coefficients of all surfaces is produced the printout of total coefficients just as in block I.

4. Block V(V) for the simulation of free molecular flow in the concave cavity.

In the case of concave cavity for studying the internal flows it suffices to develop random particle trajectories on the plane of entrance.

Table 7.

№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)
1	c_{+v}	7	c_{-v}	13	c_{rv}	19	c_{vi}
2		8		14		20	
3		9		15		21	
4		10		16		22	
5	m_{+v}	11	m_{-v}	17	m_{rv}	23	m_{vi}
6		12		18		24	

Key: (1). position. (2). Parameter.

Page 95.

Concave surface is oriented so that the plane of entrance would coincide with the plane of the fourth face of control surface ($k=4$), moreover the center of the area of the figure of entrance to the center of the fourth face of control surface they must coincide. Depending on the form of the duct/contour of entrance into nucleus 3344 is introduced the special code, indicated in Table 8.

In the case of the rectangular form of entrance its duct/contour must coincide with the duct/contour of the fourth face of control surface, in the case of the elliptic form of the entrance, inscribed into the duct/contour of the fourth face, into nuclei 0243 and 0244

are sent the sizes/dimensions of the semi-axes of ellipse, parallel with respect to axes x_1 and x_2 .

With the printout of total coefficients are printed parameters 1-120 (see Table 5), then they are printed (4551-4552) two numbers: number of particle trajectories, played from the fourth face and which did not fall on the entrance into the concave cavity and which fell on entrance. Printout of the coefficients of local flows is produced just as in block I.

5. Block VI (K) for the calculations of the local parameters according to the field of internal and external flows.

With the work with this block the drawing can be produced over the entire surface of parallelepiped - control surface or only on the fourth face of control surface (entrance into the internal cavity, see block V). In the first case into nucleus 3344 are sent zero, in the second case into nuclei 3344, 0243 and 0244 is sent the information according to the description of block V.

Information about the "formal" surfaces whose number must not exceed 16, is introduced into nuclei 0420-1415 just as for the usual surfaces, the order of the location of "formal" and usual surfaces not playing role. In the sequence $\nu=1, 2, 3 \dots$ of all surfaces there is the numeration $\lambda=1, 2, 3 \dots$ of the formal surfaces. In nuclei

3242-3261 are introduced the sizes/dimensions of areas S_i of all "formal" surfaces (into the nucleus 3242-S₁, in 3243-S₂ and so forth). In nuclei 5222-5242 with the information described in blocks II and II+ III, is introduced further information about all surfaces: instead of the code of operation are introduced zero in the case of usual surface and number λ (by octal code) in the case of "formal". For example, if surface of 1 and 3 usual, surface is 2 "is formal", then into nuclei 5222-5224 are introduced the codes

0	00	0000	0000	0000
0	01	0000	0000	0000
0	00	0000	0000	0000

In the third address of nucleus 6137 by octal code is introduced a number of "formal" surfaces.

Printout of the results of calculating the local parameters of gas according to the field of flow is produced periodically after the drawing of a number of trajectories N_i .

Table 8.

Форма входного сечения (1)	К о д (2)
Прямоугольник (3)	0 00 0001 0000 0000
Эллипс (4)	0 00 0000 0001 0000

Key: (1). Form of entrance. (2). Code. (3). Rectangle. (4). Ellipse.

Page 96.

Are printed 5 arrays. In arrays 2-5 to the press/printing are put out 55 groups of numbers (in array 2 - group 1-15, in array 3 - group 16-30, in array 4 - group 31-45, in array 5 - group 46-55) in the sequence, indicated in Table 9. In each group of numbers are contained the values of the corresponding parameter for all "formal" surfaces, in the sequence, which corresponds to numbering $\lambda=1, 2, 3$ For example, in the beginning of array 2 are printed all values W_{+1} , then all values W_{-1} and so forth. The number, arranged/located in the beginning of each group, i.e., the value of the corresponding parameter for $\lambda=1$, is isolated with the help of index $_{-}$ in the 45th digit of the binary code of a number.

Apparently, in certain cases it is useful to use this calculation procedure: through each point of field of flow whose vicinities are investigated, to carry out through three mutually perpendicular "formal" surfaces, and the results of calculation to average according to the formulas:

$$\left. \begin{aligned} n'_k &= \frac{1}{3} \sum_{\lambda=3k-2}^{\lambda=3k} n'_\lambda; & T'_k &= \frac{1}{3} \sum_{\lambda=3k-2}^{\lambda=3k} T'_\lambda; \\ p'_k &= \frac{1}{3} \sum_{\lambda=3k-2}^{\lambda=3k} p'_\lambda; & V'_k &= \frac{1}{3} \sum_{\lambda=3k-2}^{\lambda=3k} V'_\lambda. \end{aligned} \right\} \quad (5.1)$$

In array 1 are printed n'_k, T'_k, p'_k, V'_k for all $k=1, 2, 3, \dots$ the points of the field (numbers with numbers 1-4 designate n'_1, T'_1, p'_1, V'_1 ; numbers 5-8 they designate n'_2, T'_2, p'_2, V'_2 and so forth).

Printout of the coefficients of total flows is produced just as in block V, after printout of the coefficients of the local parameters in the field of flow.

Table 9.

№ группы чисел (1)	Параметры массива 2 (2)	№ группы чисел (1)	Параметры массива 3 (2)	№ группы чисел (1)	Параметры массива 4 (2)	№ группы чисел (1)	Параметры массива 5 (2)
1	$W_{+\lambda}$	16	$M'_{-22(\lambda)}$	31	π'_λ	46	$P'_{22(\lambda)}$
2	$W_{-\lambda}$	17	$M'_{+33(\lambda)}$	32	$V'_{1(\lambda)}$	47	$P'_{33(\lambda)}$
3	$\pi'_{+\lambda}$	18	$M'_{-33(\lambda)}$	33	$V'_{2(\lambda)}$	48	$P'_{12(\lambda)}$
4	$\pi'_{-\lambda}$	19	$M'_{+12(\lambda)}$	34	$V'_{3(\lambda)}$	49	$P'_{23(\lambda)}$
5	$V'_{+1(\lambda)}$	20	$M'_{-12(\lambda)}$	35	T'_λ	50	$P'_{13(\lambda)}$
6	$V'_{-1(\lambda)}$	21	$M'_{+23(\lambda)}$	36	$M'_{11(\lambda)}$	51	$q'_{1(\lambda)}$
7	$V'_{+2(\lambda)}$	22	$M'_{-23(\lambda)}$	37	$M'_{22(\lambda)}$	52	$q'_{2(\lambda)}$
8	$V'_{-2(\lambda)}$	23	$M'_{+13(\lambda)}$	38	$M'_{33(\lambda)}$	53	$q'_{3(\lambda)}$
9	$V'_{+3(\lambda)}$	24	$M'_{-13(\lambda)}$	39	$M'_{12(\lambda)}$	54	V'_λ
10	$V'_{-3(\lambda)}$	25	$E'_{+1(\lambda)}$	40	$M'_{23(\lambda)}$	55	P'_λ
11	$T_{+\lambda^0}$	26	$E'_{-1(\lambda)}$	41	$M'_{13(\lambda)}$	—	—
12	$T_{-\lambda^0}$	27	$E'_{+2(\lambda)}$	42	$E'_{1(\lambda)}$	—	—
13	$M'_{+11(\lambda)}$	28	$E'_{-2(\lambda)}$	43	$E'_{2(\lambda)}$	—	—
14	$M'_{-11(\lambda)}$	29	$E'_{+3(\lambda)}$	44	$E'_{3(\lambda)}$	—	—
15	$M'_{+22(\lambda)}$	30	$E'_{-3(\lambda)}$	45	$P'_{11(\lambda)}$	—	—

Key: (1). the group of numbers. (2). Parameters of array.

Page 97.

6. Block VII(β) and VII(γ) for the detailed calculation of coefficients of the local flows through the surface.

In block I during the calculation of local flows the rectangular region D is divided on 100 equal pads with the help of 18 straight lines, carried out through each side D region in parallel to its sides. In certain cases can be required the division of region on the finer/smaller pads.

In blocks the VII and VIII rectangular region D is divided into 100 equal bands with the help of 99 straight lines, carried out in parallel to the side γ of region D (block VII) or in parallel to the side β of region D (block VIII). Let us designate the areas of bands ΔS_{α} , moreover the number of area/site $\omega = \beta \in (0-100)$ for block VII and $\omega = \gamma \in (0-100)$ for block VIII. This division D field proves to be useful during the detailed study of local flows, constants along any one side D region.

With the printout of the coefficients of local flows, which occurs periodically after the drawing of a number of trajectories N'_{ip} , are printed 23 arrays of numbers. The arrays 1-11, which contain according to 100 numbers, and Massey 12, who contains 11 numbers, contain information about the average coefficients of the local flows through areas ΔS_{α} and through entire surface; these arrays are analogous described in block I and given in Table 6.

Let us note that here index $\omega=\beta$ during the use/application of block VII and $\omega=\gamma$ during the use/application of block VIII.

In view of the smallness of areas/sites ΔS_{ω} are possible the considerable fluctuations of the values of the parameters upon transfer from one area/site to another. Therefore it is convenient to also have the averaged values of the parameters on several areas/sites ΔS_{ω} . Arrays 13-23, which contain according to 20 numbers, give the averaged values of the parameters, which are contained in arrays 1-11, on five areas/sites ΔS_{ω} ; for example, the parameters, which contain in array 13, are obtained according to the formula

$$p_{+k} = \frac{1}{5} \sum_{\omega=5k-4}^{\omega=5k} p_{+\omega}, \quad (6.1)$$

where $p_{+\omega}$ — parameters of array 1, and index k takes values of $k=1, 2, 3, \dots, 20$; for array 14 parameters are obtained analogously from array 2, etc.

Printout of the coefficients of the total of flows is produced just as in block I.

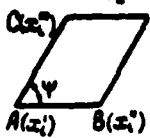
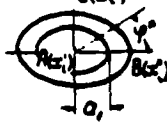
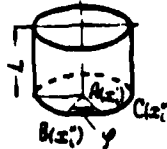
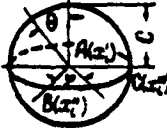
7. Block IX for the simplified assignment of the parameters of surfaces.

Applying block IX, it is possible to decrease and to simplify information about the following surfaces, most widespread in practice (Fig. 1-6 and Table 10); parallelogram, trapezoid (triangle), elliptical ring, elliptical cylinder and cone, ellipsoid.

Table 10 gives the order of the location of the parameters of the information, which contains 12 numbers, for each surface. Information about all surfaces whose number is not more than 17, is introduced into nuclei 0420-0733 (into nuclei 0420-0433 about surface of 1, 0434-0447 about surface of 2, etc.).

Page 99.

Table 10.

N sequence	$\psi \neq 90^\circ$	$C(x_i^+)$	$AB > AC, + \angle BAC = 90^\circ$	$\angle BAC < 90^\circ$	$\angle BAC = 90^\circ$	$\angle BAC = 90^\circ$
						
1	x_1^-					
2	x_2^-	x_1^-	x_1^-	x_1^-	x_1^-	x_1^-
3	x_3^-					
4	x_1^+					
5	x_2^+	x_1^+	x_1^+	x_1^+	x_1^+	x_1^+
6	x_3^+					
7	x_1^0					
8	x_2^0	x_1^0	x_1^0	x_1^0	x_1^0	x_1^0
9	x_3^0					
10	0	b	a_1/AB	-L	L	C
11	0	0	$1 - \psi^0/2\pi$	$1 - \psi/2\pi$	$1 - \psi/2\pi$	$1 - \psi/2\pi$
12	0	-1,0	0	0	a	$1 - \theta/\pi$

Page 100.

In Table 10 parameters 1-9 are the coordinates of points A, B and C, arranged/located relative to surface in accordance with Fig. 1-6 and figures, given in Table 10. Coordinates x_1^-, x_1^+ and x_1^0 are

assigned in the system of coordinates Xx . The angles of longitude/length φ^* and φ and the angle of latitude θ , with the help of which is selected the piece of surface in question, are changed in the ranges: $\varphi^* \in (0-360^\circ)$, $\varphi \in (0-360^\circ)$, $\theta \in (0-180^\circ)$. Angles φ and φ^* are counted off from AB, angle θ is counted off from the line, perpendicular to plane BAC.

If necessary for the recording of the local particle fluxes, impulse/momentum/pulse and energy into nucleus 0330 is sent the number, equal to the reference number of simple surface and which has plus sign during the recording of flows over the external surface and minus sign during the recording of flows over the internal surface. Let us note that the recording of local flows can be produced only over one surface.

Each surface is accompanied by the indicative codes (Table 11), which are joined into the array by way of the location of surfaces in nuclei (0420-0733) and are introduced into nuclei 5201-5221.

In the case when there are only simple surfaces or together with the simple ones there are complicated surfaces information about which can be been given only on Table 2, the information, which composes version, is introduced in the following order: with the address code (AK) 0420 information only about all simple surfaces,

comprised on Table 10; with AK5201 and AK5222 - codes for all surfaces (simple and complicated); AK6616 - number of all surfaces (simple and complicated); with AK 1364 - the number only of simple surfaces; then is placed all remaining information; the necessary blocks, moreover block IX is arranged always for information processing about the simple surfaces: after block IX are introduced zero into nucleus 1345 in the case of the presence together with the simple ones of complicated surfaces, otherwise it is not introduced; then is placed punch card with the check sum, equal to zero; without the address code is placed the information about the complicated surfaces, comprised according to Table 2; version is finished with punch card with the check sum, equal to zero. Information for calculating the local flows according to the complicated surface is introduced according to the description Section of 1 Chapter II. The examples of assignment to information are given in appendix 2.

Let us make some observation about the algorithm of the program of block IX, according to which are calculated the parameters of surfaces, described in block I (see Table 2).

Cosines a_{jl} are determined from the formula

$$a_{jl} = a_{jm}' a_{ml}' (l, m = 1, 2, 3); \quad (7.1)$$

$$a_{1l}' = \frac{x_l'' - x_l'}{|x_l'' - x_l'|}; \quad a_{2l}' = a_{3l}' \times a_{1l}'; \quad a_{3l}' = \frac{(x_l'' - x_l') \times (x_l''' - x_l')}{|(x_l'' - x_l') \times (x_l''' - x_l')|}. \quad (7.2)$$

Here a'_{mi} — cosines of the angles between axes x_i and axes y'_m of the intermediate coordinate system; a'_{jm} — cosines of the angles between axes y_j and y'_m (see Fig. 1-6).

Table 11.

Поверхность (1)	К о д (2)				
Параллелограмм (3)	0	00	0000	0000	0000
Трапеция (4)	0	00	0000	0001	0000
Эллиптическое кольцо (5)	0	00	0001	0000	0000
Эллиптические цилиндр и конус (6)	0	00	0000	0001	0000
Эллипсоид (7)	0	00	0000	0000	0001

Key: (1). Surface. (2). Code. (3). Parallelogram. (4). Trapezoid.

(5). Elliptical ring. (6). Elliptical cylinder and cone. (7).

Ellipsoid.

Page 101.

The sides of parallelogram AB and AC it is placed in the coordinate planes y, y_3 and y_1, y_3 . After conversions we find

$$\left. \begin{aligned} a'_{j1} &= \{\sqrt{1 - \cos \psi}, 0, \sqrt{\cos \psi}\}; \\ a'_{j2} &= \left\{ \frac{-\cos \psi}{\sqrt{1 + \cos \psi}}, \frac{1}{\sqrt{1 + \cos \psi}}, \left[\frac{\cos \psi (1 - \cos \psi)}{1 + \cos \psi} \right]^{1/2} \right\}; \\ a'_{j3} &= \left\{ -\left[\frac{\cos \psi}{1 + \cos \psi} \right]^{1/2}, -\left[\frac{\cos \psi}{1 + \cos \psi} \right]^{1/2}, \left[\frac{1 - \cos \psi}{1 + \cos \psi} \right]^{1/2} \right\}. \end{aligned} \right\} \quad (7.3)$$

Equation of the plane of the parallelogram

$$-\left(\frac{\cos \psi}{1 - \cos \psi} \right)^{1/2} (y_1 + y_2) + y_3 - 1 = 0. \quad (7.4)$$

Coordinates of point Y:

$$x_{0i} = x'_i - a_{3i}. \quad (7.5)$$

Limits D region:

$$\beta_1 = 0; \beta_2 = AB \sqrt{1 - \cos \psi}; \gamma_1 = 0; \gamma_2 = AC \sqrt{1 - \cos \psi}. \quad (7.6)$$

The side of trapezoid AB is directed in parallel to axis γ_1 .

ψ - angle between the plane of trapezoid and the plane $\gamma_1\gamma_2$.

From Fig. 2 we note

$$a_{j1} = \{-1, 0, 0\}; a_{j2} = \{0, -\cos \psi, \sin \psi\}; a_{j3} = \{0, \sin \psi, \cos \psi\}. \quad (7.7)$$

Equation of the plane of the trapezoid:

$$y_1 \sin \psi + y_2 \cos \psi - MN \cos \psi = 0. \quad (7.8)$$

Coordinates of point Y, which coincides with point N,

$$\left. \begin{aligned} \vec{x}_{01} &= \vec{x}_1 - \vec{NA}, \quad \vec{MA} = -\vec{AC} \cdot AB \cdot AC / (AB - b), \\ \vec{MN} &= -\vec{a}_{21} (\vec{a}_{21} \cdot \vec{AC}^\circ) \cdot \vec{MA}, \quad \vec{NA} = \vec{MA} - \vec{MN}. \end{aligned} \right\} \quad (7.9)$$

Limits D region:

$$\left. \begin{aligned} \beta_1 &= \varphi_1 = \arcsin(\vec{a}_{21} \cdot \vec{NA}^\circ), \quad (\vec{AB}^\circ \cdot \vec{NA}^\circ) < 0, \\ \beta_2 &= \varphi_2 = \arcsin(\vec{a}_{21} \cdot \vec{NB}^\circ), \quad (\vec{AB}^\circ \cdot \vec{NB}^\circ) < 0; \end{aligned} \right\} \quad (7.10)$$

$$\left. \begin{aligned} \beta_1 &= \varphi_1 = \pi - \arcsin(\vec{a}_{21} \cdot \vec{NA}^\circ), \quad (\vec{AB}^\circ \cdot \vec{NA}^\circ) > 0, \\ \beta_2 &= \varphi_2 = \pi - \arcsin(\vec{a}_{21} \cdot \vec{NB}^\circ), \quad (\vec{AB}^\circ \cdot \vec{NB}^\circ) > 0; \end{aligned} \right\} \quad (7.11)$$

$$\gamma_1 = y_{11} = 0, \quad \gamma_2 = y_{21} = (\vec{a}_{21} \cdot \vec{AC}^\circ) AC. \quad (7.12)$$

Here $\vec{AC}^\circ$, $\vec{NA}^\circ$, $\vec{NB}^\circ$, $\vec{AB}^\circ$ - unit vectors.

For the elliptical ring of axis y_m it is directed so that

$$a'_{j1} = \{\cos \psi, 0, -\sin \psi\}, a'_{j2} = \{0, 1, 0\}, a'_{j3} = \{\sin \psi, 0, \cos \psi\}, \cos \psi = \frac{AC}{AB}. \quad (7.13)$$

Equation of the plane of the ring:

$$y_1 \sin \psi + y_3 \cos \psi - (AB \sin \psi + 1) \cos \psi = 0. \quad (7.14)$$

Coordinates x_{0i} of point Y:

$$x_{0i} = x'_i - a_{ji} (AB \sin \psi + 1) \quad (7.15)$$

Page 102.

The limits D region are calculated from the formulas:

$$\varphi^* = k \cdot \pi / 2 + \Delta \varphi^*, \Delta \varphi^* < \frac{\pi}{2}, k = 0, 1, 2, 3, 4;$$

$$\beta_1 = \varphi_1 = 0; \quad (7.16)$$

$$\beta_2 = \varphi_2 = k \frac{\pi}{2} \quad \text{при } |\Delta \varphi^*| < 0,001; \quad (7.17)$$

$$\left. \begin{aligned} \beta_2 = \varphi_2 &= \arctg \frac{\tg \varphi^*}{\cos \psi}, k = 0; \\ \beta_2 = \varphi_2 &= \pi + \arctg \frac{\tg \varphi^*}{\cos \psi}, k = 1, 2; \\ \beta_2 = \varphi_2 &= 2\pi + \arctg \frac{\tg \varphi^*}{\cos \psi}, k = 3; \end{aligned} \right\} \begin{array}{l} \text{при } |\Delta \varphi^*| > 0,001 \end{array} \quad (7.17')$$

$$\tau_1 = AC \frac{a_1}{AB}, \tau_2 = AC. \quad (7.18)$$

Key: (1). with.

For the elliptical cylinder

$$\frac{y_1^2}{AB^2} + \frac{y_2^2}{AC^2} = 1 \quad (1) \text{ (уравнение поверхности);} \quad (7.19)$$

$$\left. \begin{aligned} a'_{jm} &= \delta_{jm}; \\ x_{0i} &= x'_i; \\ \beta_1 &= 0, \beta_2 = \varphi, \gamma_1 = 0, \gamma_2 = L. \end{aligned} \right\} \quad (7.20)$$

Key: (1). the equation of surface.

For the elliptical cone

$$\frac{y_1^2}{AB^2} + \frac{y_2^2}{AC^2} - \frac{y_3^2}{H^2} = 0 \quad (1) \text{ (уравнение поверхности)} \quad (7.21)$$

Key: (1). the equation of surface.

where $H = AC \cdot L \cdot (AC - a)$;

$$\left. \begin{aligned} a'_{jm} &= \delta_{jm}; \\ x_{0i} &= x'_i - a_{3i} H; \\ \beta_1 &= 0, \beta_2 = \varphi, \gamma_1 = H - L + 10^{-3}, \gamma_2 = H. \end{aligned} \right\} \quad (7.22)$$

For the ellipsoid

$$\frac{y_1^2}{AB^2} + \frac{y_2^2}{AC^2} + \frac{y_3^2}{C^2} = 1 \quad (1) \text{ (уравнение поверхности);} \quad (7.23)$$

$$\left. \begin{aligned} a'_{jm} &= \delta_{jm}; \\ x_{0i} &= x'_i; \\ \beta_1 &= 0, \beta_2 = \varphi, \gamma_1 = 0, \gamma_2 = 0. \end{aligned} \right\} \quad (7.24)$$

Key: (1). the equation of surface.

8. Calculations in the flow of Newton and in the flow of light/world.

For the calculations in Newton's flow it is necessary to introduce $S_{\infty} \gg 1$, $N_r = 1$, $p_s = 0$. In nucleus 0251 to send number 0.01. The corresponding coefficients are calculated from formulas (9.1) and (9.2) Chapter 1.

For the calculations in the flow of light/world it is necessary to be given $S_{\infty} \gg 1$, $p_s = k$, (portion of the light/world absorbed by surface), $N_r > 1$ and to introduce into nucleus 3637 the command/crew

0 00 0051 0000 6520

and into the nucleus 0251 number 0.01.

Page 103.

The designed coefficients in the flow of light/world are referred to "velocity head" $q_{\phi} = \frac{E_{\phi}}{2c_0}$.

During calculations in the flow of Newton and in the flow of light/world into nucleus 0332 are sent zero - sign/criterion of the mirror-diffused reflection.

9. On the sequence of the introduction/input of blocks.

During conducting of calculations with the use/application of

several blocks whose possible combinations are given in Table 12, blocks are introduced after block I and version of calculation in the order, which corresponds to an increase in the number of block. In Table 12 blocks I_0 and I_1 designate block I for calculating the coefficients of total (without the local ones) or local (and total) flows.

10. On the sensors of 0-1 pseudorandom numbers R_1-R_{10} , evenly distributed in the interval.

For the work of program it is necessary to develop ten numbers R_1-R_{10} . All ten programs for generating these numbers are obtained of one program (No 1) of obtaining pseudorandom numbers, given in [26]. Were preliminarily calculated the constants of sensor $d+1$, $d+2$ and $c+1$ after obtaining $i \cdot 2 \cdot 10^5$ of pseudorandom numbers. Here $i=1, 2, 3, \dots, 10$. The obtained constants are given in the nuclei of 6713-6750 blocks I. Turning to the program of obtaining random numbers 6676-6704 is produced at the value of index register (RA), equal to the number of address, in which is placed constant $d+1$. For example, during the turning to the program of sensor 6676-6704 at the value of RA, equal to 6713, constants $d+1$ and $d+2$ for the work of sensor are taken from nuclei 6713 and 6714, and next pseudorandom number is obtained in nucleus 6715.

For the work with another sensor it is necessary to introduce the new program of sensor into nuclei 6676-6703 and new constants into nuclei 6713-6750.

In appendix 2 in example 3 are given the program and the constants of another version of the sensor of pseudorandom numbers. Initial sensor with period $2^{31}-1$ was undertaken from work [26] (program No 5). Constants for all ten sensors in example 3 were obtained after drawing $i \cdot 6 \cdot 10^5$ ($i=1,2,3, \dots, 10$) pseudorandom numbers.

Table 12.

	I _c	I _a	II	II + III	IV	V	VI	VII, VIII	IX
I _c	-	+	+	+	+	+	+	+	+
I _a	+	-	+	+	-	+	-	+	+
II	+	+	-	+	+	+	+	+	+
II + III	+	+	+	-	+	+	+	+	+
IV	+	-	+	+	-	+	-	-	+
V	+	+	+	+	+	-	-	+	+
VI	+	-	+	+	-	-	-	-	+
VII, VIII	+	+	+	+	-	+	-	-	+
IX	+	+	+	+	+	+	+	+	-

Page 104.

11. Examples of calculation.

Let us consider the examples of assignment to initial information for the calculation according to the universal program of aerodynamic coefficients, local flows and parameters of gas for some bodies of the complex form whose diagrams are given in Fig. 7-9. The assignment of numbers and commands/crews for the calculation in these examples, and also the results of calculation are given in appendix 2.

For the compound (see Fig. 7) consisting of simple surfaces of

1-6 (1 - parallelogram, 2 - cone, 3 - cylinder, 4 - trapezoid, 5 - ring, 6 - sphere) and complicated surface of 7 (paraboloid of revolution), it is necessary to calculate aerodynamic coefficients for each surface of 1-7 with the diffuse reflection of molecules with the complete accommodation and with the reflection of molecules in accordance with law (4.11). The order of the location of information in the version and their numerical values are given in example 1 of appendix 2.

In nuclei 0420-0527 is placed the information about the simple surfaces, comprised according to Tables 10; then into the appropriate nuclei are placed the angles of attack α_0 , of slip β_0 , parameter H in terms of value of which with the help of linear interpolation are calculated values V_∞ , $\bar{V}$ and T_∞ , accommodation coefficient α_0 , portion p_0 of the diffuse reflecting molecules, S_m , d_m , coordinate x_1^0 , and x_2^0 , the faces of parallelepiped (control surface), coordinate x_1' , and x_2' , of two points X and O relative to which must be designed the moment coefficients, the temperature of surface T_w , of number N_{1p} , N_{2p} , N_{3p} , N_{4p} , the signs/criteria (nuclei 5201-5207) of all surfaces of 1-7 (simple and complicated), number N_s , a number of all simple and complicated surfaces (nucleus 6616) and only simple surfaces (nucleus 1364) and a number of remaining parameters (nucleus 6617-6621). Then are placed blocks II, IV and by IX.

In nucleus 1345 are sent zero in the case of the presence together with the simple ones of complicated surfaces, otherwise it is not sent. After punch card with the check sum, equal to zero, is placed the information about complicated surface of 7, comprised according to Table 2.

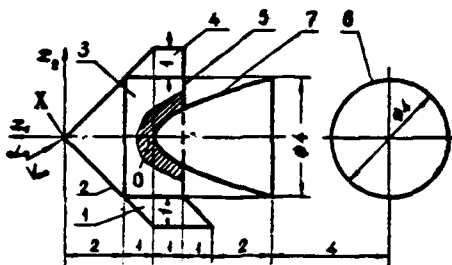


Fig. 7.

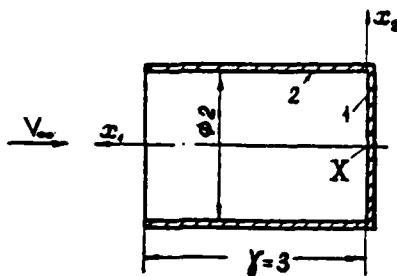


Fig. 8.

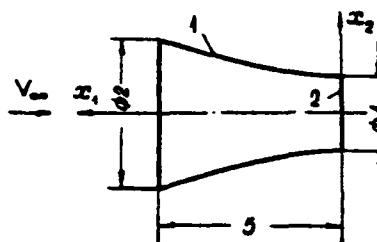


Fig. 9.

Page 105.

The introduction/input of version (example 1) occurs into two stages: first is introduced the first part of the version (command/crew from nucleus 0006), then the second (loading order from the nucleus of 1350 blocks IX). In appendix 2 is given the array of the aerodynamic coefficients of surface 6, obtained first during the calculation without block II (diffuse reflection of molecules), and then with block II (reflection in accordance with the law (4.11)).

In example 2 is examined the problem of calculating the local flows along the height/altitude γ according to inside of the cylinder (see Fig. 8) with those determined of value H , V_∞ , $\bar{V}$ and T_∞ , sent in the appropriate nuclei (see also the numerical information of block I). Were used the following blocks: V - for the drawing of the start of the molecules through the round entrance and block VIII - for the detailed recording of local flows on the areas/sites, which are obtained during the division of height/altitude γ into one hundred parts. Is given an example of the calculation of the flows of part n_k ($k=1, 2, 3, \dots, 20$) of the multiple reflections on the areas/sites, which are obtained during the division γ into twenty parts, moreover report k is conducted from the basis/base.

In example 3 are given the results of calculating some parameters of gas at the flow through the air intake, which is the element/cell of the hyperboloid (see Fig. 9).

The results of some interesting calculations with the help of the universal program are given also in works [27-29].

Was thoroughly checked the method of drawing of the random parameters of particles. From given for an example Fig. 10 it is evident that the agreement of histograms, obtained with the drawing according to the method of Baird of random values ξ_{ki} [see density function (3.3)], also, with drawing of speed with the diffuse reflection [see formula (4.10)], with the theoretical data $f(\xi_{ki})$ and $f_r(\xi) = 2\xi^2 \exp(-\xi^2)$ is good even with comparatively small numbers of played trajectories. In Fig. 10 N_r - a number of diffuse reflected particles; by lines they are designated the results of calculations according to precise formulas, by points - according to the Monte Carlo method.

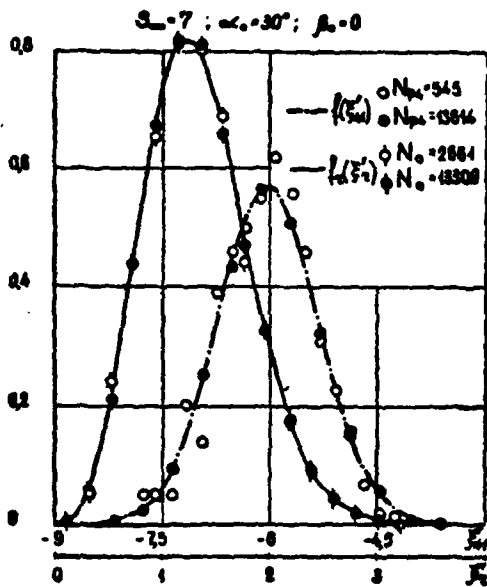


Fig. 10.

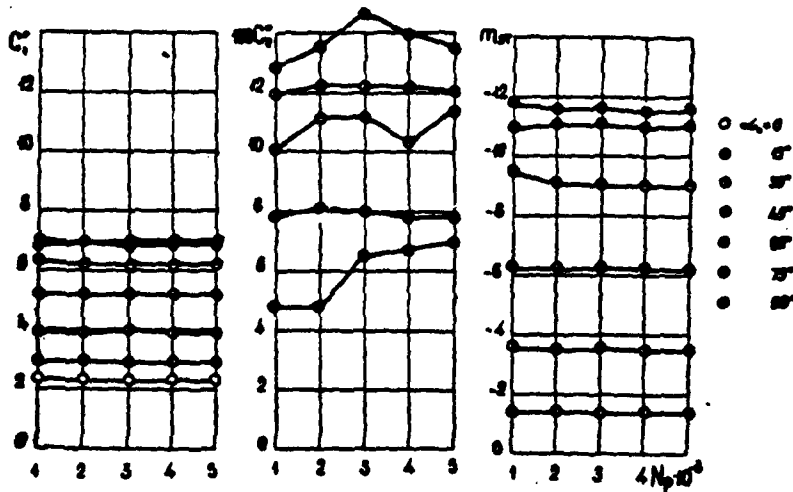


Fig. 11.

Page 106.

We will designate aerodynamic coefficients in the drag axes by index "0" on top. For the positive reference direction of drag let us take direction V_∞ , and for the projection of forces on body axis Xx_1 - opposite direction of axis Xx_1 , i.e., in the manner that this is accepted in aerodynamics.

The coordinates of the point, relative to which is designed the moment/torque, we will designate $x_{r,i}$, and moment coefficients relatively $x_{r,i}$ - by subscript r .

Fig. 11 gives the results of the calculations of total aerodynamic coefficients for ellipsoid $\sum_{j=1}^3 y_j^2 a_j^{-2} = 1$ at the values of parameters $a_1=10$, $a_2=3$, $a_3=2$, $x_{0,i}=0$, $a_{ji}=\delta_{ji}$, $S_\infty = 8.265$, $T_\infty = 1404^\circ K$, $T_w = 320^\circ K$, $\alpha_w = p_w = 1$, $x_{r,i} = \{10; 0; 0\}$, $S_w = \pi a_1 a_2$, $d_w = 2a_2$. Here δ_{ji} ($j, i=1, 2, 3$) - unit matrix. Fig. 12 compares the coefficients, obtained by the Monte Carlo method, with the calculated ones, obtained by calculating the integrals over the surface. From the given results it is possible to conclude that an error in the method of Comte-Porta for total coefficients c_i^0 and $m_{r,i}$, already when $N_p = 10^5$ is within the limits of 3-5%, for obtaining the coefficient c_i^0 with the same

error it is required $N_p \approx (3-5)$ by 10^3 and it is more.

Were produced also calculations for the compound, which consists of two ellipsoids, distant behind each other at certain distance.

First ellipsoid $\sum_{j=1}^3 y_j^2 a_j^{-2} = 1$, $a_1 = 50^{1/2}$, $a_2 = 90^{1/2}$, $a_3 = 10$, $x_{0i} = 0$, the second ellipsoid $a_1 = 10$, $a_2 = 3$, $a_3 = 2$, $x_{0i} = \{0; 12.5; -5\}$. For both ellipsoids $a_{ji} = \delta_{ji}$. Remaining parameters: $S_\infty = 8,265$, $T_\infty = 1404^\circ \text{K}$, $T_s = 320^\circ \text{K}$, $a_s = p_0 = 1$, $S_s = 2\pi(3 + 5\sqrt{90})$, $d_s = 10$, $x_{si} = \{10; 0; 0\}$.

In Fig. 13 results of this calculation, in which are considered multiple collisions of particles, they are equal with the results of the approximate computation of coefficients with the help of the integrals in the surfaces. During the calculation of integrals in the surface the local coefficients of tangential and normal impulses/momenta/pulses are considered equal to zero, if vector is opposite V_∞ and carried out from the point in question, it intersects concave surface, otherwise they are computed from the formulas for the single area/site. An error in this calculation will be, obviously, small with $S_\infty \gg 1$, the diffuse reflection of particles and when T_s order T_∞ . Fig. 13 shows a good agreement of results of calculation in limits of $\approx 3\%$.

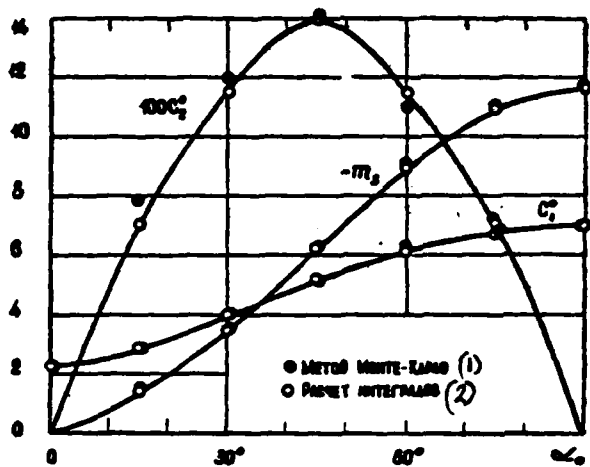


Fig. 12.

Key: (1). Monte Carlo method. (2). Calculation of integrals.

Page 226

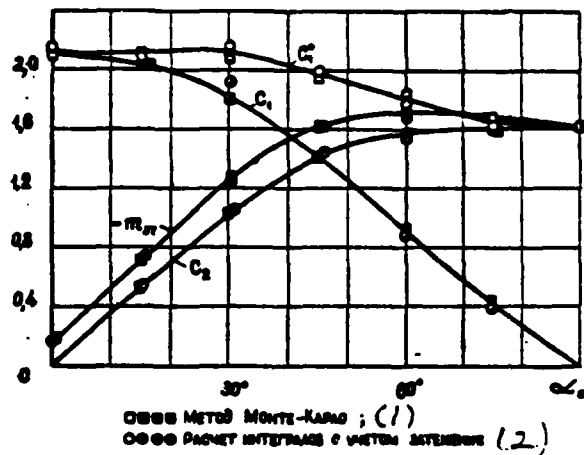


Fig. 13.

Key: (1). Monte Carlo method. (2). Calculation of integrals taking darkening into account.

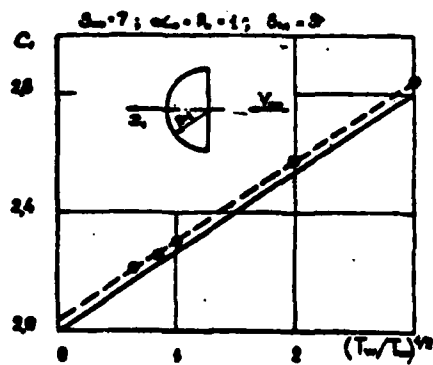


Fig. 14.

Page 107.

The results of calculations for the concave part of the hemisphere confirm dependences (5.7) (Fig. 14) and with the error less than 1% with $N_p > 1000$ coincide with the calculation according to the formula

$$c_1 = 2 + 1.06 \sqrt{\pi} / S_\infty \quad (11.3)$$

obtained in work [13] for the hypersonic approximation/approach (Fig. 15). Fig. 14 and 15 results of calculations by the method of Monte Carlo depict as small circles, and according to formula (11.3) - by solid lines.

Fig. 16 gives the results of calculating the dispersion of the drag coefficient c_d and lift c_l during the flow around single plate of the flow, normal to its surface. Here when $T_w = 0$ (cold surface) is valid the formula

$$\begin{aligned} D[c_1] &= 8 S_\infty^{-2} \chi^{-1}(S_\infty) (\exp(-S_\infty^2) [(1 + S_\infty^2)/2 - S_\infty M_p' + M_p'^2/2] + \\ &+ (1 + \operatorname{erf} S_\infty) [\sqrt{\pi} S_\infty (3/2 + S_\infty^2)/2 - \sqrt{\pi} M_p' (1/2 + S_\infty^2) + \sqrt{\pi} S_\infty M_p'^2/2]), \\ D[c_2] &= D[c_3] = 2/S_\infty^2, \quad M_p' = h_\infty^{1/2} M_p = S_\infty + \sqrt{\pi} (1 + \operatorname{erf} S_\infty) \chi^{-1}(S_\infty)/2. \end{aligned} \quad (11.4)$$

or when $S_\infty \gg 1$

$$D[c_1] = D[c_2] = D[c_3] \approx 2 S_\infty^{-2}. \quad (11.5)$$

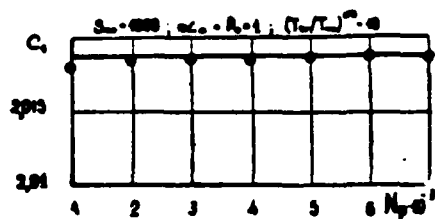


Fig. 15.

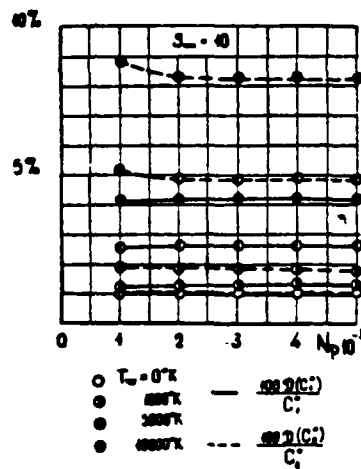


Fig. 16.

Page 108.

From Fig. 16 it is evident that when $T_w = 0$ the calculations by the Monte Carlo method with an error in less than 1% will be coordinated with the calculations according to formula (11.5).

The author is sincerely grateful to M. N. Kogan for the theme proposed, for more attention to the work and valuable observations. The author is grateful also to V. S. Galkin, V. A. Perepukhov and A. I. Yerofeyev for the useful observations with the execution of work, and also N. I. Larin and Ya. M. Natenzon, attentively read work and made useful observation.

Literature.

1. M. N. Kogan. Dynamics of the rarefied gas. M., "Science", 1967.

2. E. Larish. Aerodynamic interference during the free molecular flow. Izv. of the AS USSR. Mechanics and machine building, 1960, No 3.

3. Cohen J. M. Free molecule flow over nonconvex bodies. ARS J., vol. 30, No 3, 1960.

4. E. Larish. Equations of free molecular flow. Izv. of the AS USSR. Mechanics and machine building, 1961, No 2.

5. Aerodynamics of rarefied gases. In the collectors/collections Ed. by S. V. Vallander. Publishing house of LGU, collector/collection 1, 1963; collector/collection II, 1965; collector/collection III, 1967; collector/collection IV, 1969.

6. V. P. Shidlovsky. Introduction to the dynamics of the rarefied gas. M. "Science", 1965.

7. M. N. Kogan, L. M. Degtarev. On the calculations of flows with the large numbers of Knudsen. Astron. Acta, 1965, II, No 1.

8. A. A. Bogacheva, V. A. Perepukhov, E. Ye. Rukhman. Use/application of the Monte Carlo method to the calculation of the aerodynamic characteristics of the bodies of complex form in the free molecular flow. "J. comp. math. and math. physics ", Vol. 8, No 6, 1968.

9. V. A. Perepukhov. Aerodynamic characteristics of sphere and blunt-nosed cone in the flow of the strongly rarefied gas. "J. of

comp. math. and math. physics", Vol. 7, No 2, 1967.

10. A. I. Yerofey. On the effect of roughness on interaction of the flow of gas with the solid surface. Izv. of the AS USSR, MZhG, 1967, No 6; 1968, No 6.

11. J. K. Khevilend. Solution of two problems about the free-molecule flow by the Monte Carlo method. Coll. "Computational methods in the dynamics of the rarefied gases". M., "Mir", 1969.

12. Bird G. A. Aerodynamic properties of some simple bodies in the hypersonic transition regime. AIAA J., vol. 4, No 1, 1966.

13. Pratt M. J. Concave surfaces in free molecule flow. AIAA J., vol. 1, No 7, 1963.

14. Sparrow, E. W., Jonsson V. R., Lundgreen T. S., Chen T. S. Heat transfer and forces for free molecule flow on a concave cylindrical surface. J. Heat Transfer, vol. 86, No 1, 1964.

15. Stewart J. D. Free-molecular drag for flow along a concave cylindrical surface. AIAA J., vol. 7, No 8, 1969.

16. V. Ya. Ponomarev. Flow around nonconvex wedge of free molecular flow with a finite number of Mach. Izv. of the AS USSR, MZhG, 1967, No 4.

17. A. I. Bunimovich, K. L. Kagan. Free molecular course of gas in the flat ducts and the lattices. Izv. of the AS USSR, MZhG, 1966, No 3.

18. Kaplan M. H. Free-molecular diffuser. AIAA J., vol. 4, No 4, 1966.

19. Yu. N. Lyubitov. Calculation of interaction of the molecular

flows with their enclosing containers. M., "Science", 1964.

20. S. V. Musanov. Internal free molecular of course. Transactions of TsAGI [ЦАГИ - Central Institute of Aerohydrodynamics im. N Ye Zhukovskiy], iss. 1206, 1970.

21. Probstein R. F. Shock wave and flow field development in hypersonic Re-entry. ARS J., vol. 31, No 2, 1961.

22. Ya. L. Alpert, A. V. Gurevich, L. P. Pitaevskiy. Artificial satellites in the rarefied plasma. M., "Science", 1964.

23. I. N. Larina. Density field around the cone in the free molecular flow. Izv. of the AS USSR, MZhG, 1968, No 4.

24. S. Nochill. Law of reflection from the surface in the free molecular flow. Coll. "Interaction of gases with the surfaces". M., "Mir", 1965.

25. D. I. Golenko. Simulation and the statistical analysis of pseudorandom numbers in the electronic computers. M., "Science", 1965.

26. V. F. Lyashchenko. Programming for digital computers M-20, BESM-3M, BESM-4, M-220. M., "Soviet radio", 1967.

27. M. A. Zakirov. Gas-dynamic parameters of free molecular flow before the convex and concave bodies. The "Scientific notes of TsAGI", Vol. II, No 6, 1971.

28. M. A. Zakirov. Free molecular flow around the hollow wedge and cone from concave side. The "Scientific notes of TsAGI", Vol. III, No 2, 1972.

29. M. A. Zakirov. On the aerodynamic coefficients of the body, which flies in the vicinity of other, in the free molecular flow. The "Scientific notes of TsAGI", Vol. III, No 3, 1972.

Page 109

APPENDIX 1

UNIVERSAL PROGRAM FOR STUDYING INTERNAL AND EXTERNAL
FREE-MOLECULAR FLOWS NEAR AN ARBITRARY GROUP OF COMPLEX BODIES

BLOCK I (0)

0001	000	0000	0000	0000	0040	070	0025	0035	0000
0002	000	0000	0000	0000	0041	050	0016	6116	7767
0003	050	0010	7300	7767	0042	070	6116	0000	0000
0004	070	7300	0001	0000	0043	050	4412	6116	7767
0005	030	0001	0006	0077	0044	070	6116	0041	0000
0006	050	0016	4000	6114	0045	050	0015	5201	6113
0007	070	4000	0000	0000	0046	070	5201	0000	0000
0008	050	4412	4000	6114	0047	050	4411	5201	6113
0009	070	4000	0006	0000	0050	070	5201	0045	0000
0010	050	0015	2101	2600	0051	000	0000	0000	0000
0011	070	2101	0000	0000	0052	000	0000	0000	0000
0012	050	4411	2101	2600	0053	000	0000	0000	0000
0013	070	2101	0012	0000	0054	000	0000	0000	0700
0014	050	6135	0000	0016	0055	072	0000	0000	0000
0015	070	6136	0000	0017	0056	100	0000	0000	3500
0016	000	0000	0000	0000	0057	112	0033	0056	0001
0017	000	0000	0000	0000	0060	050	0411	2101	2600
0018	000	0000	0000	0000	0061	070	2101	0000	0000
0019	000	0000	0000	0000	0062	050	0500	0000	0077
0020	000	0000	0000	0000	0063	070	0077	0000	0000
0021	000	0000	0000	0000	0064	056	0000	1500	0000
0022	000	0000	0000	0000	0065	000	0000	0000	0000
0023	056	0000	0025	0000	0066	050	0412	6116	7767
0024	000	0000	0000	0000	0067	070	6116	0066	0000
0025	050	0015	4000	5177	0070	000	0000	0000	0000
0026	070	4000	0000	0000	0071	000	0000	0000	0000
0027	050	4411	4000	5177	0072	000	0074	0000	0016
0028	070	4000	0025	0000	0073	056	0075	0076	0017
0029	050	0016	0001	0023	0074	000	6135	0000	0016
0030	070	0001	0000	0000	0075	000	6136	0000	0017
0031	050	0016	0001	0023	0076	050	0001	0006	0077
0032	070	0001	0000	0000					
0033	050	4412	0001	0023					
0034	070	0001	0031	0000					
0035	050	0016	0025	3776					
0036	070	0025	0000	0000					
0037	050	4412	0025	3776					

Page 110

1300	052	7032	0000	7615	PI
1301	000	7504	0000	7541	
1302	016	1303	7501	7610	
1303	052	0100	0042	1477	
1304	056	0000	2507	8300	
1305	044	6524	0000	6517	COB
1306	009	1417	0051	6661	
1307	005	6520	6517	6657	
1310	003	6661	0009	6661	
1311	003	6657	0000	6657	
1312	052	0000	0032	0000	
1313	056	0000	2655	0000	
1314	002	0340	0337	0021	
1315	002	0342	0341	0022	
1316	002	0344	0343	0023	
1317	035	0022	0023	0024	
1320	005	0021	0023	0025	SK
1321	035	0021	0022	0020	
1322	072	0000	6611	0000	
1323	430	0260	0000	3500	L.
1324	072	0000	6612	0000	
1325	400	0274	0000	3501	B.
1326	072	0000	6613	0000	
1327	400	0310	0000	3502	H
1330	056	0000	3145	1530	
1331	056	0000	4013	0000	
1332	000	0000	0000	0000	
1333	000	0000	0000	0000	
1334	000	0000	0000	0000	
1335	000	0000	0000	0000	
1336	000	0000	0000	0000	
1337	000	0000	0000	0000	
1340	000	0000	0000	0000	
1341	000	0253	0000	3540	Fr
1342	056	0256	3341	3552	Fr
1343	005	6640	3540	6662	
1344	005	6641	3540	6663	
1345	005	6642	3540	6664	Npx
1346	005	6643	3540	6665	
1347	005	6644	3540	6666	
1350	005	6645	3540	6667	
1351	000	3707	0030	3723	
1352	015	6640	0030	0000	
1353	036	0000	1634	0000	
1354	002	6662	6670	0000	
1355	036	0337	1634	0346	IX
1356	001	7761	3521	3521	
1357	001	7761	6670	6670	
1360	072	0000	3715	0000	
1361	016	1562	6676	6704	
1362	430	0002	0000	0341	
1363	005	3731	0041	0041	
1364	001	3726	0041	0041	
1365	016	1566	3562	3572	
1366	005	3554	0042	0047	
1367	001	3720	0042	3720	
1370	002	3720	7761	0000	
1371	036	0000	1560	0000	
1372	002	3720	7761	3720	
1373	000	0041	0000	0365	

1374	013	3562	7722	3562	
1375	072	0000	3716	0000	
1376	016	1577	6676	6704	
1377	400	0002	0000	0041	
1380	035	3732	0041	0041	
1381	001	3727	0041	0041	
1382	016	1603	3573	3576	
1383	005	0414	0042	0042	
1384	001	3721	0042	3721	
1385	002	3721	7761	0000	
1386	036	0041	1575	0066	
1387	002	3721	7761	3721	
1388	013	3562	7722	3562	
1389	072	0000	3717	0000	
1390	016	1613	6676	6704	
1391	400	0002	0000	0041	
1392	005	3733	0041	0041	
1393	001	3730	0041	0041	
1394	016	1617	3573	3576	
1395	005	0414	0042	0042	
1396	001	3722	0042	3722	
1397	002	3722	7761	0000	
1398	036	0041	1611	0067	
1399	002	3722	7761	3722	
1400	016	1625	1772	2000	
1401	000	3560	0000	3562	
1402	000	0000	0000	0000	
1403	005	6627	0022	0042	
1404	005	6630	0023	0043	
1405	001	0042	0341	0047	IX
1406	001	0043	0343	0050	IX
1407	016	1554	2005	3111	
1408	000	3710	0000	3723	
1409	000	3772	0000	3724	
1410	013	1573	7721	1573	
1411	033	1606	7721	1606	
1412	013	1566	7724	1566	
1413	052	0000	0000	0000	
1414	500	3734	0000	3726	
1415	112	0005	1642	0001	
1416	013	3570	7724	3570	
1417	000	3713	0000	3715	
1418	000	3712	0000	3716	
1419	013	1557	7723	1557	
1420	000	3720	0000	0041	
1421	000	3721	0000	3720	
1422	000	0041	0000	3721	
1423	015	6641	0000	0000	
1424	036	0000	1665	0000	
1425	002	6663	6671	0000	
1426	036	0341	1665	0047	
1427	015	1660	1556	1626	
1428	005	6627	0021	0043	
1429	005	6630	0023	0044	
1430	071	0043	0337	0046	
1431	001	0044	0343	0050	
1432	016	1655	2005	3111	
1433	000	3711	0000	3723	
1434	000	3773	0000	3725	
1435	013	1573	7721	1573	

Page 111

1670	033	1622	7721	1622
1671	013	1566	7724	1566
1672	052	0000	0000	0000
1673	500	3742	0000	3726
1674	112	0005	1673	0001
1675	013	3570	7724	3570
1676	000	3714	0000	3715
1677	000	3713	0000	3717
1700	013	1557	7723	1557
1701	000	3720	0000	0041
1702	000	3722	0000	3720
1703	000	0041	0000	3722
1704	015	6642	0000	0000
1705	036	0000	1716	0000
1706	002	6664	6672	0000
1707	036	0343	1716	0050
1710	016	1711	1556	1626
1711	005	6627	0021	0043
1712	005	6630	0022	0044
1713	001	0043	0337	0046
1714	001	0044	0341	0047
1715	016	1706	2005	3111
1716	013	1606	7721	1606
1717	013	1622	7721	1622
1720	000	0000	0000	0000
1721	013	3570	7724	3570
1722	013	1566	7724	1566
1723	013	1557	7723	1557
1724	000	3720	0000	0041
1725	000	3721	0000	3720
1726	000	3722	0000	3721
1727	000	0041	0000	3722
1730	000	3364	0000	1573
1731	013	1555	7724	1555
1732	013	1656	7724	1656
1733	013	1707	7724	1707
1734	052	0000	0000	0000
1735	500	6643	0000	6640
1736	500	3712	0000	3715
1737	500	3772	0000	3723
1740	302	0000	3772	3707
1741	112	0002	1735	0001
1742	500	3745	0000	3723
1743	112	0024	1742	0001
1744	000	0000	0000	1626
1745	000	0000	0000	0000
1746	000	0000	0000	0000
1747	013	1554	3365	1554
1750	013	1655	3365	1655
1751	013	1706	3365	1706
1752	016	1753	1551	1700
1753	000	0000	0000	1720
1754	552	0000	0000	0000
1755	100	0000	0000	2507
1756	112	0005	1755	0001
1757	000	3361	0000	3570
1760	000	3367	0000	1557
1761	000	3366	0000	1566
1762	033	1554	3365	1554
1763	033	1655	3365	1655

Draw of
N_p
parti-
cles

1764	033	1706	3365	1706
1765	033	1555	7724	1555
1766	033	1656	7724	1656
1767	033	1707	7724	1707
1770	000	0000	0000	1626
1771	056	3363	3112	1573
1772	052	0000	6724	0000
1773	016	1774	6676	6704
1774	000	6726	0000	6627
1775	052	0000	6727	0000
1776	016	1777	6676	6704
1777	000	6731	0000	6630
2000	000	0000	0000	0000
2001	052	0000	6732	0000
2002	016	2003	6676	6704
2003	000	6734	0000	6637
2004	000	0000	0000	0000
2005	005	0065	3510	0065
2006	005	0066	3510	0066
2007	005	0067	3510	0067
2010	005	0065	0065	0075
2011	005	0066	0066	0076
2012	005	0067	0067	0077
2013	001	0075	0076	0075
2014	001	0075	0077	1476
2015	044	1476	0000	0051
2016	004	0065	0051	0036
2017	004	0066	0051	0037
2020	004	0067	0051	0040
2021	001	1476	3537	3537
2022	056	0000	2030	0000
2023	452	0000	0000	2026
2024	100	0000	0000	6624
2025	112	0016	2024	0001
2026	000	0000	0000	0000
2027	056	0000	6577	0000
2030	000	0000	0000	0000
2031	452	0000	0000	2034
2032	500	0420	0000	1460
2033	112	0035	2032	0001
2034	000	0000	0000	0000
2035	015	1470	0000	0000
2036	036	0000	2043	0053
2037	000	0000	0000	0054
2040	016	2041	2112	2120
2041	016	2042	2144	2153
2042	056	0000	2210	2120
2043	005	0036	0036	0052
2044	005	0037	0037	0053
2045	005	0040	0040	0054
2046	005	1441	0052	0052
2047	005	1442	0053	0053
2050	005	1443	0054	0054
2051	005	0036	0037	0056
2052	005	0037	0040	0057
2053	005	0040	0036	0060
2054	005	1473	0056	0056
2055	005	1474	0057	0057
2056	005	1475	0060	0060
2057	001	0052	0053	0052

Page 112

2060 001 0052 0054 0052
2061 001 0052 0056 0052
2062 001 0052 0057 0052
2063 001 0052 0060 0052 Q
2064 000 0000 0000 0000
2065 005 0046 0036 1417
2066 005 0046 0037 1420
2067 005 0046 0040 1421
2068 005 0047 0036 1422
2071 005 0047 0037 1423
2072 005 0047 0040 1424
2073 005 0050 0036 1425
2074 005 0050 0037 1426
2075 005 0050 0040 1427
2076 005 1441 1417 1417
2077 005 1442 1423 1423
2100 005 1443 1427 1427
2101 001 1417 1423 0053
2102 001 1427 0053 0053
2103 005 7762 0053 0053
2104 001 1420 1422 1430
2105 001 1424 1426 1431
2106 001 1421 1425 1432
2107 005 1430 1473 1430
2110 005 1431 1474 1431
2111 005 1432 1475 1432
2112 005 1444 0036 1433
2113 005 1445 0037 1434
2114 005 1446 0040 1435
2115 001 1433 0053 0053
2116 001 1434 0053 0053
2117 001 1435 0053 0053
2120 000 0000 0000 0000
2121 001 0053 1430 0053
2122 001 0053 1431 0053 B
2123 001 0053 1432 0053
2124 005 0046 0046 1417
2125 005 0047 0047 1420
2126 005 0050 0050 1421
2127 005 1441 1417 1417
2130 005 1442 1420 1420
2131 005 1443 1421 1421
2132 005 0046 0047 1422
2133 005 0047 0050 1423
2134 005 0050 0046 1424
2135 005 1422 1473 1422
2136 005 1423 1474 1423
2137 005 1424 1475 1424
2140 000 0000 0000 0054
2141 072 0000 0000 0000
2142 401 1417 0054 0054
2143 112 0005 2142 0001
2144 001 0054 1447 0054
2145 005 0046 1444 1417
2146 005 0047 1445 1420
2147 005 0050 1446 1421
2150 001 0054 1417 0054
2151 001 0054 1420 0054
2152 001 0054 1421 0054 C
2153 000 0000 0050 0303

2154 015 0000 2432 0000
2155 036 0000 2210 0000
2156 005 0053 0053 0056
2157 005 0052 0054 0057
2160 005 7762 0057 0057
2161 005 7762 0057 0057
2162 002 0050 0057 0057
2163 036 0000 2437 0000
2164 044 0057 0000 0057
2165 002 0000 0053 0060
2166 001 0000 0057 0061
2167 002 0000 0057 0062
2170 005 7762 0052 0063
2171 004 0000 0063 0052 t
2172 056 0000 3377 0000
2173 005 0052 0036 1432
2174 005 0052 0057 1434
2175 005 0052 0040 1436
2176 005 0053 0036 1433
2177 005 0053 0037 1435
2200 005 0053 0040 1437
2201 001 0046 1432 0054
2202 001 0047 1434 0057 I_{im}
2203 001 0050 1436 0060 m-1
2204 001 0046 1433 0061
2205 001 0047 1435 0062 I_{im}
2206 001 0050 1437 0063 m-2
2207 056 0000 2231 0000
2210 015 0000 0053 0000
2211 036 0000 2437 2153
2212 056 0000 3405 0000
2213 002 0000 0054 0052
2214 005 0036 0052 1432
2215 005 0037 0052 1434
2216 005 0046 0052 1436
2217 000 1432 0000 1433
2220 000 1434 0000 1435
2221 000 1436 0000 1437
2222 001 0046 1432 0056
2223 001 0047 1434 0057
2224 001 0050 1436 0060
2225 000 0054 0000 0061
2226 000 0057 0000 0062
2227 000 0000 0000 0063
2230 000 0052 0000 0053
2231 002 0056 1461 0056
2232 002 0057 1462 0057
2233 002 0000 1463 0060
2234 002 0061 1461 0061
2235 002 0062 1462 0062
2236 002 0063 1463 0063
2237 016 2248 7501 7610
2240 052 1450 0033 0056
2241 052 0070 0000 0003
2242 016 2243 7501 7610
2243 052 1450 0033 0061
2244 052 0073 0000 0003
2245 000 0070 0000 1423
2246 000 0073 0000 1424
2247 000 0071 0000 1425

Page 113

2250	000	0074	0000	1426	2344	000	0000	0000	0000
2251	000	0072	0000	1427	2345	000	0000	0000	0000
2252	000	0075	0000	1430	2346	056	0000	2266	0000
2253	015	1472	0000	0000	2347	000	0000	0000	0000
2254	076	0000	2313	3477	2350	000	0000	0000	0000
2255	056	0000	2261	0000	2351	015	7722	1472	0000
2256	000	0345	0000	0070	2352	076	0000	2363	0000
2257	000	3446	0000	2304	2353	000	3453	0000	2363
2260	000	0000	0000	0000	2354	000	3454	0000	2364
2261	072	0000	3477	0000	2355	000	0345	0000	0070
2262	402	1427	0000	0000	2356	072	0000	3477	0000
2263	236	0000	2306	0000	2357	000	3452	0000	2364
2264	500	1423	0000	0074	2360	056	0000	2324	0000
2265	500	1425	0000	0076	2361	000	0000	0000	0000
2266	202	1465	0074	0000	2362	000	3446	0000	2364
2267	236	0000	2306	0000	2363	072	0000	3477	0000
2270	402	0074	1464	0000	2364	056	0000	2324	0000
2271	236	0000	2306	0000	2365	015	7721	1472	0000
2272	202	1467	0076	0000	2366	076	0000	2426	0000
2273	236	0000	2306	0000	2367	000	3456	0000	2363
2274	402	0076	1466	0000	2370	000	3457	0000	2366
2275	236	0000	2306	0000	2371	000	3455	0000	2364
2276	556	0032	2303	0070	2372	000	0000	0000	0000
2277	000	0000	0000	0000	2373	056	0000	2415	0000
2300	000	0000	0000	0000	2374	000	0000	0000	0000
2301	000	0000	0000	0000	2375	000	0000	0000	0000
2302	000	0000	0000	0000	2376	000	0000	0000	0000
2303	000	0000	0000	0000	2377	000	0000	0000	0000
2304	000	3446	0000	2304	2400	005	1427	1427	0062
2305	056	3476	2261	3477	2401	001	0060	0062	0060
2306	056	3476	2256	3477	2402	044	0060	0000	0060
2307	056	0345	2432	0071	2403	015	0000	0060	0000
2310	056	0000	2432	0000	2404	076	0000	2407	0000
2311	000	0000	0000	0000	2405	100	0000	0000	0076
2312	000	0000	0000	0000	2406	056	0000	2346	0000
2313	015	7724	1472	0000	2407	404	1427	0060	0060
2314	076	0000	2351	0000	2410	016	2411	7501	7610
2315	000	3450	0000	2305	2411	075	0060	0006	0061
2316	056	3451	2321	2306	2412	102	7756	0061	0076
2317	000	0345	0000	0070	2413	056	0000	2346	0000
2320	000	3446	0000	2304	2414	000	0000	0000	0000
2321	072	0000	3477	0000	2415	072	0000	3477	0000
2322	402	1427	0000	0000	2416	000	0345	0000	0070
2323	236	0000	2306	0000	2417	056	0000	2324	0000
2324	605	1423	1423	0060	2420	000	0000	0000	0000
2325	605	1425	1425	0061	2421	000	3446	0000	2364
2326	001	0060	0061	0060	2422	072	0000	3477	0000
2327	144	0060	0000	0076	2423	056	0000	2324	0000
2330	215	0000	0076	0000	2424	000	0000	0000	0000
2331	076	0000	2334	0000	2425	000	0000	0000	0000
2332	100	0000	0000	0074	2426	050	0500	0000	7747
2333	056	0000	2344	0000	2427	070	7747	0000	0000
2334	604	1423	0076	0062	2430	077	0000	0000	0000
2335	016	2336	7501	7610	2431	000	0000	0000	0000
2336	075	0062	0006	0061	2432	000	3447	0000	2364
2337	402	1425	0000	0000	2433	000	3460	0000	2365
2340	056	0000	2343	0000	2434	000	3461	0000	2366
2341	102	7756	0061	0074	2435	000	0000	0000	2364
2342	056	0000	2344	0000	2436	056	0000	3411	3477
2343	101	0412	0061	0076	2437	000	0345	0000	0070

Page 114

2440	000	0345	0000	0071	2534	001	0044	0071	6529
2441	000	0000	0000	0000	2535	001	0047	0072	6526
2442	000	0000	0000	0000	2536	001	0050	0073	6527
2443	002	0070	0071	0000	2537	005	1441	6529	1417
2444	076	0000	2447	0000	2540	005	1417	7742	1417
2445	000	0070	0000	0370	2541	005	6526	1473	1422
2446	056	0000	2450	0000	2542	005	6527	1475	1423
2447	000	0071	0000	0370	2543	005	1442	6526	1420
2450	000	2032	0000	0347	2544	056	0000	3346	0000
2451	000	0000	0000	0000	2545	005	6529	1473	1423
2452	013	7722	6610	6610	2546	005	6527	1474	1426
2453	015	6610	6616	0000	2547	005	1443	6527	1421
2454	036	0000	2463	0000	2550	005	1421	7742	1421
2455	013	7721	2445	2445	2551	005	6526	1474	1424
2456	013	7721	2447	2447	2552	005	6529	1475	1427
2457	013	7721	2450	2450	2553	452	0000	0000	2557
2460	013	2032	3443	2032	2554	601	1417	1422	1430
2461	000	0000	0000	0000	2555	501	1425	1430	0052
2462	056	0000	2031	0000	2556	112	0002	2554	0001
2463	000	0000	0000	0000	2557	000	0000	0000	0000
2464	000	3462	0000	2032	2560	072	0000	0000	0000
2465	000	3463	0000	2445	2561	701	1444	0052	0052
2466	000	3464	0000	2447	2562	112	0002	2561	0001
2467	000	3465	0000	2450	2563	705	0047	0047	1414
2470	000	0000	0000	6610	2564	112	0005	2563	0001
2471	015	6616	7722	0000	2565	001	1417	1420	1417
2472	036	0000	2515	0000	2566	001	1417	1421	1417
2473	452	0000	0050	2504	2567	044	1417	0000	1417
2474	202	0370	0371	0000	2570	002	0000	1417	1417
2475	076	0000	2501	0000	2571	504	0044	1417	0044
2476	000	0370	0000	0370	2572	112	0010	2571	0001
2477	000	0347	0000	0347	2573	005	0036	0052	1420
2500	056	0000	2503	0000	2574	005	0037	0053	1421
2501	400	0371	0000	0370	2575	005	0040	0054	1422
2502	400	0350	0000	0347	2576	001	1420	1421	1420
2503	112	0000	2474	0001	2577	001	1420	1422	1417
2504	000	0000	0050	0000	2600	014	2601	2001	2004
2505	000	0000	0000	0000	2601	002	6637	0334	0000
2506	056	0000	2515	0000	2602	076	0000	2601	0000
2507	016	2510	7501	7610	2603	072	0000	0000	0000
2510	052	0260	0041	0346	2604	705	0013	0052	1423
2511	016	2512	7501	7610	2605	112	0002	2604	0001
2512	052	0420	0041	0646	2606	001	1423	1424	1423
2513	056	0000	3632	0000	2607	001	1423	1425	1423
2514	000	0000	0000	0000	2610	505	0047	1423	1423
2515	002	0370	0346	0000	2611	112	0005	2610	0001
2516	036	0000	2522	0000	2612	702	1420	0005	0047
2517	015	0000	3550	0000	2613	112	0010	2612	0001
2520	036	0000	3110	0000	2614	005	1423	1423	1431
2521	056	0000	3064	0000	2615	002	0252	1431	1432
2522	000	0347	0000	2524	2616	056	0000	3331	0000
2523	452	0000	0000	2526	2617	004	0055	1432	0055
2524	000	0000	0000	0000	2620	004	0056	1432	0056
2525	112	0035	2524	0001	2621	004	0057	1432	0057
2526	000	0000	0000	0000	2622	000	0000	0000	0000
2527	000	0000	0000	2524	2623	056	0000	6215	0000
2530	000	0370	0000	0070	2624	005	0054	0056	1421
2531	005	0036	0070	0071	2625	005	0054	0055	1422
2532	005	0037	0070	0072	2626	005	0052	0057	1423
2533	005	0040	0070	0073	2627	005	0052	0056	1424

Page 115

2630 005 0053 0055 1425
2631 002 1420 1421 0060
2632 002 1422 1423 0061
2633 056 0000 3425 0000
2634 000 0000 0000 0000
2635 016 2640 6751 6653
2636 000 0000 0000 0000
2637 000 0000 0000 0000
2640 044 6631 0000 6631
2641 056 3503 3636 1433
2642 005 0416 6632 6521
2643 044 6633 0000 6523
2644 002 7761 6633 6524
2645 002 7756 6521 6522
2646 072 0000 0000 0000
2647 016 2650 7501 7610
2650 373 6521 0005 0075
2651 112 0001 2647 0001
2652 005 0076 6523 6516
2653 005 0075 6523 6516
2654 056 0000 1505 0000
2655 016 2656 7501 7610
2656 052 0052 0033 6515
2657 052 0036 0000 0003
2660 056 0000 3435 0000
2661 005 7762 1417 1420
2662 072 0000 0000 0000
2663 305 1420 0052 1421
2664 112 0002 2663 0001
2665 702 0033 1416 0033
2666 112 0005 2665 0001
2667 000 0051 0000 6520
2670 000 1476 0000 6521
2671 505 0030 6520 6514
2672 112 0010 2671 0001
2673 056 0000 6237 0000
2674 056 0000 6303 0000
2675 000 0000 0000 0000
2676 301 0065 3522 3522
2677 301 0066 3523 3523
2700 301 0067 3524 3524
2701 305 0067 6526 1420
2702 005 0066 6527 1421
2703 005 0065 6527 1422
2704 005 0067 6525 1423
2705 005 0066 6525 1424
2706 005 0065 6526 1425
2707 002 1420 1421 1420
2710 002 1422 1423 1421
2711 002 1424 1425 1422
2712 501 3525 1420 3525
2713 501 3526 1421 3526
2714 501 3527 1422 3527
2715 000 0000 0000 0000
2716 056 0000 3170 0000
2717 015 0000 1471 0000
2720 056 0000 3037 0000
2721 005 1471 1417 1420
2722 002 1420 0000 0000
2723 056 0000 3037 0000

2724 002 1465 1464 1420
2725 002 1467 1466 1421
2726 002 6525 1461 1422
2727 002 6526 1462 1423
2730 002 6527 1463 1424
2731 016 2732 7501 7610
2732 052 1450 0033 1422
2733 052 0075 0000 0003
2734 000 0075 0000 1423
2735 000 0076 0000 1425
2736 000 0077 0000 1427
2737 000 0000 0000 3477
2740 000 2266 0000 1437
2741 016 2742 2253 2266
2742 000 3460 0000 2305
2743 000 3461 0000 2306
2744 000 0000 0000 2344
2745 000 0000 0000 3477
2746 000 3467 0000 2304
2747 000 1437 0000 2266
2750 002 0074 1464 0074
2751 002 0076 1466 0076
2752 005 0257 0074 1422
2753 005 0257 0076 1423
2754 004 1422 1420 0074
2755 004 1423 1421 0076
2756 001 7764 0074 0074
2757 001 7764 0076 0076
2760 041 0074 7752 0074
2761 041 0076 7752 0076
2762 002 0074 7752 0074
2763 002 0076 7752 0076
2764 002 0074 7761 0074
2765 005 0074 0257 0074
2766 001 0074 0076 0074
2767 041 0074 7752 0074
2770 002 0074 7752 0074
2771 056 6624 6225 0055
2772 000 0000 0000 1420
2773 000 0000 0000 1421
2774 052 0000 0000 0000
2775 605 0065 0055 1422
2776 001 1422 1420 1420
2777 605 6522 0055 1423
3000 002 1421 1423 1421
3001 112 0002 2775 0001
3002 002 0000 6521 1434
3003 000 0000 0000 2622
3004 061 7751 0074 0075
3005 061 3475 0074 0076
3006 052 0000 0000 0000
3007 513 3016 0075 3016
3010 513 3016 0076 3016
3011 112 0007 3007 0001
3012 000 0000 0000 3022
3013 052 0000 0000 0000
3014 015 3550 0000 0000
3015 076 1476 3027 1430
3016 301 5661 4000 4000
3017 301 1420 4144 4144

Page 116

3020	301	1430	4310	4310
3021	301	7761	4454	4454
3022	000	0000	0000	0000
3023	301	6657	5440	5440
3024	301	1421	5604	5604
3025	301	1434	5750	5750
3026	056	0000	3034	0000
3027	001	6657	6661	6661
3030	001	1420	1421	1420
3031	002	1476	6521	1430
3032	052	0000	0620	0000
3033	016	3034	3016	3022
3034	000	3351	0000	3016
3035	000	3352	0000	3017
3036	056	3353	6161	3020
3037	056	0000	6271	0000
3040	013	3550	7722	3550
3041	015	3550	6615	0000
3042	036	0000	3064	0000
3043	000	6522	0000	0065
3044	000	6523	0000	0064
3045	000	6524	0000	0067
3046	000	6520	0000	0051
3047	000	6525	0000	0046
3050	000	6526	0000	0047
3051	000	6527	0000	0050
3052	000	6521	0000	1476
3053	072	0000	3000	0000
3054	100	0000	0000	6654
3055	112	0000	3054	0001
3056	356	0000	2030	0000
3057	072	0000	0000	0000
3060	100	0000	0000	6624
3061	112	0016	3060	0001
3062	056	0000	6562	6602
3063	000	0000	0000	0000
3064	056	0000	6314	2675
3065	000	0000	0000	0000
3066	502	3522	6522	3522
3067	502	3523	6523	3523
3070	502	3524	6524	3524
3071	005	6524	6526	1420
3072	005	6523	6527	1421
3073	005	6522	6527	1422
3074	005	6524	6525	1423
3075	005	6523	6525	1424
3076	005	6522	6526	1425
3077	002	1420	1421	1420
3100	002	1422	1423	1421
3101	002	1424	1425	1422
3102	502	3525	1420	3525
3103	502	3526	1421	3526
3104	056	0000	6301	0000
3105	002	3536	6521	3536
3106	002	3521	7761	3277
3107	056	0000	3177	3550
3110	056	0000	3260	0000
3111	000	0000	0000	0000
3112	056	0000	6530	0000
3113	004	3517	3521	1423

3114	004	3504	7762	1437
3115	004	1420	1432	1435
3116	004	1437	1420	1421
3117	005	1421	0335	1433
3120	005	1433	0336	1434
3121	015	0330	0000	0000
3122	036	0000	3145	0000
3123	002	3540	3553	0000
3124	036	0000	3145	0000
3125	016	3126	3342	3343
3126	000	0000	0000	3343
3127	052	0000	0000	0000
3130	452	0000	0000	3133
3131	704	4001	2101	4001
3132	112	0143	3131	0001
3133	000	0000	0000	0000
3134	013	3131	6132	3131
3135	112	0012	3130	0001
3136	000	6133	0000	3131
3137	000	0000	0000	0000
3140	004	1433	0335	0001
3141	072	0000	0000	0000
3142	504	4001	0001	4001
3143	504	4145	0001	4145
3144	056	0000	3577	0000
3145	050	0411	4000	5177
3146	070	4000	3145	0000
3147	054	0000	4010	3147
3150	056	0000	4272	0000
3151	452	0000	0000	3154
3152	500	0052	0000	1420
3153	112	0010	3152	0001
3154	000	0000	0000	0000
3155	000	1423	0000	0052
3156	000	1426	0000	0053
3157	000	1420	0000	0054
3160	000	1424	0000	0055
3161	000	1427	0000	0056
3162	000	1421	0000	0057
3163	000	1425	0000	0060
3164	000	1430	0000	0061
3165	000	0000	0000	0000
3166	056	1422	2634	0062
3167	000	0000	0000	0000
3170	000	0065	0000	3271
3171	000	0066	0000	3272
3172	000	0067	0000	3273
3173	000	1420	0000	3274
3174	000	1421	0000	3275
3175	000	1422	0000	3276
3176	056	0000	2717	0000
3177	056	0000	3261	0000
3200	002	3272	6523	3272
3201	002	3273	6524	3273
3202	002	3274	1420	3274
3203	002	3275	1421	3275
3204	002	3276	1422	3276
3205	072	0000	0000	0000
3206	505	3301	3277	0070
3207	112	0005	3206	0001

Calcula-
tion of
disper-
sions
(3170-
3255)

Page 117

3210	072	0000	0000	0000
3211	701	0070	3271	3307
3212	112	0005	3211	0001
3213	001	3277	7761	3300
3214	072	0000	0000	0000
3215	504	3307	3300	3307
3216	112	0005	3215	0001
3217	072	0000	0000	0000
3220	702	3301	3307	0070
3221	112	0005	3220	0001
3222	072	0000	0000	0000
3223	705	0070	0070	3070
3224	112	0005	3223	0001
3225	072	0000	0000	0000
3226	701	0070	3315	0070
3227	112	0005	3226	0001
3230	072	0000	0000	0000
3231	505	0070	3277	0070
3232	112	0005	3231	0001
3233	072	0000	0000	0000
3234	702	3271	3307	3323
3235	112	0005	3234	0001
3236	072	0000	0000	0000
3237	705	3323	3323	3323
3240	112	0005	3237	0001
3241	072	0000	0000	0000
3242	701	3323	0070	3323
3243	112	0005	3242	0001
3244	072	0000	0000	0000
3245	504	3323	3300	3323
3246	112	0005	3245	0001
3247	072	0000	0000	0000
3250	500	3323	0000	3315
3251	112	0005	3250	0001
3252	072	0000	0000	0000
3253	500	3307	0000	3301
3254	112	0005	3253	0001
3255	000	0000	0000	0000
3256	056	0000	3111	2675
3257	000	0000	0000	0000
3260	056	0000	3111	2675
3261	002	3514	7761	3277
3262	002	3271	6522	3271
3263	056	0000	3200	0000
3264	056	0000	3205	0000
3265	112	0132	6566	0012
3266	013	6566	7727	6566
3267	112	0011	6566	0001
3270	013	6566	3354	6566
3271	000	0000	0000	0000
3272	000	0000	0000	0000
3273	000	0000	0000	0000
3274	000	0000	0000	0000
3275	000	0000	0000	0000
3276	000	0000	0000	0000
3277	000	0000	0000	0000
3300	000	0000	0000	0000
3301	000	0000	0000	0000
3302	000	0000	0000	0000
3303	000	0000	0000	0000

3304	000	0000	0000	0000
3305	000	0000	0000	0000
3306	000	0000	0000	0000
3307	000	0000	0000	0000
3310	000	0000	0000	0000
3311	000	0000	0000	0000
3312	000	0000	0000	0000
3313	000	0000	0000	0000
3314	000	0000	0000	0000
3315	000	0000	0000	0000
3316	000	0000	0000	0000
3317	000	0000	0000	0000
3320	000	0000	0000	0000
3321	000	0000	0000	0000
3322	000	0000	0000	0000
3323	000	0000	0000	0000
3324	000	0000	0000	0000
3325	000	0000	0000	0000
3326	000	0000	0000	0000
3327	000	0000	0000	0000
3330	000	0000	0000	0000
3331	015	7761	1431	0000
3332	056	0000	3335	0000
3333	044	1432	0000	1432
3334	056	0000	2617	0000
3335	000	0020	0000	0055
3336	000	0016	0000	0056
3337	056	0000	2622	0057
3340	016	4571	3145	3147
3341	056	0333	1543	3553
3342	001	0333	3553	3553
3343	000	0000	0000	0000
3344	000	0000	0000	0000
3345	000	0000	0000	0000
3346	005	1420	7742	1420
3347	001	7761	3520	3520
3350	056	0000	6261	0000
3351	301	6661	4000	4000
3352	301	1420	4144	4144
3353	301	1430	4310	4310
3354	000	0012	0001	0001
3355	000	0000	1243	0000
3356	000	0000	0000	0000
3357	056	0000	4272	0000
3360	002	0041	3723	0043
3361	005	2507	0043	0042
3362	056	0000	1541	6513
3363	000	0041	0000	0045
3364	002	0000	0041	0045
3365	000	0003	0003	0000
3366	005	3554	0042	0042
3367	001	7761	6670	6670
3370	301	7761	4454	4454
3371	301	6657	5440	5440
3372	301	1421	5604	5604
3373	301	1434	5750	5750
3374	056	0000	6320	0000
3375	056	0000	6345	0000
3376	000	0000	0000	0000
3377	004	0062	0063	0063

Page 118

3400 002 0000 0053 0000
3401 036 0000 2173 0000
3402 002 0000 0052 0000
3403 036 0000 2173 0000
3404 036 0000 2437 0000
3405 004 0034 0053 0036
3406 002 0036 0000 0000
3407 036 0000 2213 2153
3410 036 0000 2437 0000
3411 002 0052 0000 0000
3412 076 0000 3414 0000
3413 000 0345 0000 0070
3414 003 0052 0255 0000
3415 076 0000 3417 0000
3416 000 0345 0000 0070
3417 002 0053 0000 0000
3420 076 0000 3422 0000
3421 000 0345 0000 0071
3422 003 0053 0255 0000
3423 076 0000 2441 0000
3424 036 0345 2441 0071
3425 002 1424 1425 0062
3426 002 1417 0000 0000
3427 036 0000 3151 0000
3430 302 0000 0041 0041
3431 112 0013 3430 0001
3432 302 0000 0044 0044
3433 112 0016 3432 0001
3434 036 0000 3151 0000
3435 505 0034 6520 6520
3436 112 0004 3435 0001
3437 005 6520 6520 6521
3440 036 0000 2674 0000
3441 500 0420 0000 5020
3442 500 5020 0000 0420
3443 000 0036 0000 0000
3444 000 0000 0000 0036
3445 500 0420 0000 1440
3446 036 0000 2310 0000
3447 000 3446 0000 2304
3450 036 3476 2321 3477
3451 036 3476 2317 3477
3452 500 1427 0000 0076
3453 036 3476 2363 3477
3454 036 3476 2362 3477
3455 036 0000 2400 0000
3456 036 3476 2422 3477
3457 036 3476 2421 3477
3460 036 3476 2261 3477
3461 036 3476 2256 3477
3462 500 0420 0000 1440
3463 000 0070 0000 0370
3464 000 0071 0000 0370
3465 000 2032 0000 0347
3466 000 0002 0000 0000
3467 000 0144 0001 0001
3470 401 4001 0000 0000
3471 000 0144 0000 0000
3472 000 0000 0007 0001
3473 075 3502 0137 3504

3474 000 0000 0000 0003
3475 144 0000 0000 0000
3476 000 0000 0001 0000
3477 000 0000 0000 0000
3500 000 0000 0000 0000
3501 000 0000 0000 0000
3502 000 0000 0000 0000
3503 000 0000 0000 0000
3504 000 0000 0000 0000
3505 000 0000 0000 0000
3506 000 0000 0000 0000
3507 000 0000 0000 0000
3510 000 0000 0000 0000
3511 000 0000 0000 0000
3512 000 0000 0000 0000
3513 000 0000 0000 0000
3514 000 0000 0000 0000
3515 000 0000 0000 0000
3516 000 0000 0000 0000
3517 000 0000 0000 0000
3520 000 0000 0000 0000
3521 000 0000 0000 0000
3522 000 0000 0000 0000
3523 000 0000 0000 0000
3524 000 0000 0000 0000
3525 000 0000 0000 0000
3526 000 0000 0000 0000
3527 000 0000 0000 0000
3530 000 0000 0000 0000
3531 000 0000 0000 0000
3532 000 0000 0000 0000
3533 000 0000 0000 0000
3534 000 0000 0000 0000
3535 000 0000 0000 0000
3536 000 0000 0000 0000
3537 000 0000 0000 0000
3540 000 0000 0000 0000
3541 000 0000 0000 0000
3542 000 0000 0000 0000
3543 000 0000 0000 0000
3544 000 0000 0000 0000
3545 000 0000 0000 0000
3546 000 0000 0000 0000
3547 000 0000 0000 0000
3550 000 0000 0000 0000
3551 000 0000 0000 0000
3552 000 0000 0000 0000
3553 000 0000 0000 0000
3554 000 0000 0000 0000
3555 000 0000 0000 0000
3556 000 0000 0000 0000
3557 000 0000 0000 0000
3560 000 0000 0000 0000
3561 000 0000 0000 0000
3562 002 0041 3723 0043
3563 005 0043 0043 0042
3564 002 0000 0042 0042
3565 016 3566 7501 7610
3566 075 0041 0003 0043
3567 000 0000 0000 0000

Page 119

3570 005 2507 0043 0042
3571 005 0042 0041 0042
3572 000 0080 0000 0000
3573 016 3574 3562 3567
3574 000 0000 0000 3567
3575 005 0325 0043 0042
3576 000 0000 0000 0000
3577 504 4621 0001 4621
3600 504 4765 0001 4765
3601 504 3641 0001 3641
3602 504 3605 0001 3605
3603 505 4311 1435 4311
3604 505 5131 1435 5131
3605 505 3751 1435 3751
3606 505 4455 1420 4455
3607 505 5275 1420 5275
3610 112 0143 3142 0001
3611 052 0000 0000 0000
3612 305 0331 4001 4001
3613 112 2102 3612 0012
3614 052 0000 0000 0000
3615 016 3616 7501 7610
3616 552 4001 0041 4144
3617 112 1750 3615 0144
3620 452 0000 0000 3623
3621 401 4001 0060 0060
3622 112 0143 3621 0001
3623 000 0000 0000 0000
3624 013 3621 3467 3621
3625 112 2126 3620 0001
3626 000 3670 0000 3621
3627 016 3630 7501 7610
3630 052 0060 0041 0072
3631 056 6566 3057 6643
3632 072 0000 0000 0000
3633 500 3715 0000 4501
3634 112 0176 3633 0001
3635 056 0000 3641 0000
3636 016 3637 6375 6401
3637 005 6627 6631 6520
3640 056 0000 2642 6401
3641 072 0000 0000 0000
3642 500 4501 0000 4015
3643 112 0176 3642 0001
3644 056 0000 4015 0000
3645 301 0065 4001 4001
3646 301 0066 4022 4022
3647 301 0067 4043 4043
3650 301 4232 1420 4232
3651 301 4253 1421 4253
3652 301 4274 1422 4274
3653 000 0000 0000 0000
3654 302 4001 6522 4001
3655 302 4022 6523 4022
3656 302 4043 6524 4043
3657 302 4232 1420 4232
3660 302 4253 1421 4253
3661 302 4274 1422 4274
3662 000 0000 0000 0000
3663 054 0050 1440 0001

3664 072 0000 0001 0000
3665 132 0000 3666 0145
3666 016 2717 3645 3653
3667 054 0050 1440 0001
3670 072 0000 0001 0000
3671 132 0000 3672 0062
3672 016 6245 3654 3662
3673 054 0050 1440 0001
3674 072 0000 0001 0000
3675 132 0000 3676 0145
3676 016 6245 3654 3662
3677 004 0077 0041 0041
3700 001 1420 0041 0041
3701 004 1437 1436 1421
3702 005 0041 1421 1421
3703 005 1436 0051 1422
3704 004 1422 0041 6627
3705 056 0000 6411 0000
3706 300 0000 0000 0000
3707 000 0000 0000 0000
3710 000 0000 0000 0000
3711 000 0000 0000 0000
3712 000 0000 0000 0000
3713 000 0000 0000 0000
3714 000 0000 0000 0000
3715 000 0000 0000 0000
3716 000 0000 0000 0000
3717 000 0000 0000 0000
3720 000 0000 0000 0000
3721 000 0000 0000 0000
3722 000 0000 0000 0000
3723 000 0000 0000 0000
3724 000 0000 0000 0000
3725 000 0000 0000 0000
3726 000 0000 0000 0000
3727 000 0000 0000 0000
3730 000 0000 0000 0000
3731 000 0000 0000 0000
3732 000 0000 0000 0000
3733 000 0000 0000 0000
3734 000 0000 0000 0000
3735 000 0000 0000 0000
3736 000 0000 0000 0000
3737 000 0000 0000 0000
3740 000 0000 0000 0000
3741 000 0000 0000 0000
3742 000 0000 0000 0000
3743 000 0000 0000 0000
3744 000 0000 0000 0000
3745 000 0000 0000 0000
3746 000 0000 0000 0000
3747 000 0000 0000 0000
3750 000 0000 0000 0000
3751 000 0000 0000 0000
3752 000 0000 0000 0000
3753 000 0000 0000 0000
3754 000 0000 0000 0000
3755 000 0000 0000 0000
3756 000 0000 0000 0000
3757 000 0000 0000 0000

Page 120

3760 000 0000 0000 0000
3761 000 0000 0000 0000
3762 000 0000 0000 0000
3763 000 0000 0000 0000
3764 000 0000 0000 0000
3765 000 0000 0000 0000
3766 000 0000 0000 0000
3767 000 0000 0000 0000
3770 000 0000 0000 0000
3771 000 0000 0000 0000
3772 000 0000 0000 0000
3773 000 0000 0000 0000
3774 000 0000 0000 0000
3775 000 0000 0000 0000
3776 000 0000 0000 0000
3777 000 0000 0000 0000
4000 000 0000 0000 0000
4001 000 0000 0000 0000
4002 000 0000 0000 0000
4003 000 0000 0000 0000
4004 000 0000 0000 0000
4005 000 0000 0000 0000
4006 000 0000 0000 0000
4007 000 0000 0000 0000
4010 072 0000 6614 0000
4011 400 0313 0000 3503 d_*
4012 000 0000 0000 0000
4013 000 0000 0000 0000
4014 000 0000 0000 0000
4015 000 0000 0000 0000
4016 004 3500 7754 0032
4017 004 3501 7754 0034
4020 002 7756 0032 0033
4021 002 7756 0034 0035
4022 432 0000 0000 4026
4023 016 4024 7501 7610
4024 575 0032 0005 0036
4025 112 0003 4023 0001
4026 000 0000 0000 0000
4027 000 0037 0000 0016
4030 000 0041 0000 0017
4031 000 0036 0000 0020
4032 000 3010 0000 3114
4033 005 0037 0041 0013 $\cos d, \cos \theta$
4034 005 0036 0041 0014
4035 002 0000 0014 0014 $\sin d, \cos \theta$
4036 000 0040 0000 0015 $\sin \theta$
4037 000 0036 0000 0020 $\sin d$
4040 432 0000 0000 4046
4041 016 4042 7501 7510
4042 000 0006 0150 0100
4043 075 3502 0107 3504 $V_\infty, \bar{V}, T_\infty$
4044 013 4043 3472 4043
4045 112 0002 4041 0001
4046 000 0000 0000 0000
4047 036 3473 4476 4043
4050 005 3505 0415 3510 $\rho^{-1/2}$
4051 004 3504 3510 3515 S_∞
4052 056 0000 4066 0000
4053 100 0000 0000 0050

4054 001 0041 0246 0043
4055 044 0043 0000 0043
4056 105 0247 0043 0056
4057 056 0000 4176 0000
4060 000 0000 0000 0003
4061 000 0003 0000 0000
4062 052 1421 0033 5573
4063 052 3432 0000 0003
4064 000 0000 0000 0000
4065 000 0000 0000 0000
4066 000 0000 0000 3517
4067 452 0000 0000 4120
4070 205 3515 0013 0041
4071 002 0000 0041 0041 $V'_{\infty K}$
4072 100 0041 0000 3772
4073 005 0041 0041 0042
4074 002 0000 0042 0042
4075 016 4076 7501 7610
4076 075 0041 0051 0043
4077 016 4100 7501 7610
4100 075 0042 0003 0044
4101 001 7761 0043 0043
4102 005 0043 0041 0043
4103 005 0043 0041 0043
4104 001 0043 0044 0044
4105 205 0046 0024 0046
4106 100 0046 0000 0027
4107 001 0046 3517 3517
4110 112 0002 4076 0001
4111 000 0000 0000 0000
4112 072 0000 0000 0000
4113 000 4071 0000 0050
4114 013 4072 3474 4072
4115 013 4106 3474 4106
4116 000 0000 0000 4071
4117 016 4120 4070 4111
4120 000 0000 0000 0000
4121 000 0050 0000 4071
4122 000 0000 0000 4111
4123 033 4072 3474 4072
4124 033 4106 3474 4106
4125 072 0000 0000 0000
4126 504 0027 3517 4640 N_{px}/N_p
4127 112 0005 4126 0001
4130 004 7761 3515 0041
4131 005 7762 0041 0042
4132 005 0041 3517 3517 B
4133 004 3517 0042 3517
4134 005 3510 3510 0043
4135 004 0250 3506 0044
4136 005 0043 0044 3547 ρ^{-1}
4137 044 3547 0000 3551
4140 004 0027 0024 0027
4141 004 0030 0025 0030
4142 004 0031 0026 0031 $\chi(V'_{\infty})$
4143 004 0032 0024 0032
4144 004 0033 0025 0033
4145 004 0034 0026 0034
4146 452 0000 0000 4153
4147 402 0027 0326 0040

Page 121

4150	076	0000	4152	0000		4244	000	0051	0000	3734
4151	100	0000	0000	6640		4245	002	3772	0251	3735
4152	112	0005	4147	0001		4246	002	3774	0251	3736
4153	000	0000	0000	0000		4247	002	0057	0051	3737
4154	452	0000	0000	41774		4250	001	0251	0251	3740
4155	400	3772	0000	0041	$\frac{1}{2} \frac{V_{max}}{V_{min}}$	4251	001	0251	0251	3741
4156	002	0041	0000	0000		4252	000	0052	0000	3742
4157	036	0000	4167	0000		4253	002	3772	0251	3743
4160	101	0041	0251	0056		4254	002	3773	0251	3744
4161	000	0000	0000	0000		4255	002	0060	0052	3745
4162	002	0041	0251	0042		4256	001	0251	0251	3746
4163	076	0000	4165	0000		4257	001	0251	0251	3747
4164	156	0000	4176	0050		4260	000	0053	0000	3750
4165	102	0041	0251	0050		4261	002	3773	0251	3751
4166	056	0000	4176	0000		4262	002	3774	0251	3752
4167	003	0041	0246	0043		4263	002	0061	0053	3753
4170	036	0000	4053	0000		4264	001	0251	0251	3754
4171	100	0000	0000	0050		4265	001	0251	0251	3755
4172	100	0000	0000	0056		4266	056	0000	4610	0000
4173	156	0000	4176	6640		4267	000	0000	0000	0000
4174	000	0000	0000	0000		4270	000	0000	0000	0000
4175	000	0000	0000	0000		4271	000	0000	0000	0000
4176	112	0005	4155	0001		4272	000	0013	0000	1421
4177	000	0000	0000	0000		4273	000	0014	0000	1422
4200	452	0000	0000	42264	$\frac{1}{2} \frac{V_{max}}{V_{min}}$	4274	000	0015	0000	1423
4201	415	6640	0000	0000		4275	000	0020	0000	1424
4202	036	0000	4225	0000		4276	000	0016	0000	1425
4203	000	0000	0000	0000		4277	000	0000	0000	1426
4204	404	3772	7762	0041		4300	005	0016	0015	1427
4205	005	0041	0041	0042		4301	002	0000	1427	1427
4206	001	7764	0042	0042		4302	005	0015	0020	1430
4207	044	0042	0000	0042		4303	000	0017	0000	1431
4210	001	0041	0042	0042		4304	000	1433	0000	0074
4211	202	0042	3772	0041		4305	000	1434	0000	0075
4212	005	0041	0041	0041		4306	056	0000	4667	0000
4213	002	0000	0041	0041		4307	000	0000	0000	0000
4214	016	4215	7501	7610		4310	000	0000	0000	0000
4215	075	0041	0003	0043		4311	000	0000	0000	0000
4216	008	7762	0043	0043		4312	000	0000	0000	0000
4217	204	0043	0027	0041		4313	000	0000	0000	0000
4220	005	0042	0041	0041		4314	005	3524	3505	0055
4221	000	0000	0000	0000		4315	005	3523	3506	0056
4222	104	7761	0041	3554		4316	005	3522	3506	0057
4223	000	0000	0000	0000		4317	005	3524	3504	0060
4224	000	0000	0000	0000		4320	005	3523	3504	0061
4225	112	0005	4201	0001		4321	005	3522	3505	0062
4226	000	0000	0000	0000		4322	002	0056	0055	0055
4227	000	0000	0000	0000		4323	002	0060	0057	0056
4230	052	0000	0000	0000		4324	002	0062	0061	0057
4231	415	6640	0000	0000		4325	004	0047	0336	0047
4232	036	0000	4234	0000		4326	112	0010	4325	0001
4233	304	7762	0027	2507	$\frac{2}{2} \frac{V_{max}}{V_{min}}$	4327	701	0044	3514	0044
4234	112	0005	4231	0001		4330	112	0013	4327	0001
4235	052	0000	0000	0000		4331	016	4332	7501	7610
4236	000	0050	0000	3726		4332	052	1421	0033	3522
4237	002	3773	0251	3727		4333	052	3530	0000	0003
4240	002	3774	0251	3730		4334	016	4335	7501	7610
4241	002	0056	0050	3731		4335	052	1421	0033	0055
4242	001	0251	0251	3732		4336	052	3533	0000	0003
4243	001	0251	0251	3733		4337	000	0000	0000	1421

Page 122

4340 072 0000 0000 0300
4341 605 3522 3522 1422
4342 001 1421 1422 1421
4343 112 0002 4341 0001
4344 044 1421 0000 1420
4345 504 3517 1420 1417
4346 112 0005 4345 0001
4347 005 3526 3524 1425
4350 005 3527 3523 1426
4351 005 3527 3522 1427
4352 005 3525 3524 1430
4353 005 3525 3523 1431
4354 005 3526 3522 1432
4355 002 1425 1426 1425
4356 002 1427 1430 1426
4357 002 1431 1432 1427
4360 000 0000 0000 1421
4361 000 0000 0000 0000
4362 000 0000 0000 0000
4363 072 0000 0000 0000
4364 005 1425 1425 1430
4365 001 1430 1421 1421
4366 112 0002 4364 0001
4367 044 1421 3000 1421
4370 015 1421 0000 0000
4371 076 0000 4404 0000
4372 000 0000 0000 3542
4373 000 0000 0000 3543
4374 000 0000 0000 3544
4375 000 3525 0000 3545
4376 000 3526 0000 3546
4377 000 3527 0000 3547
4400 000 0000 0000 0000
4401 000 0000 0000 0000
4402 000 0000 0000 0300
4403 056 0000 4433 0000
4404 504 1422 1421 1422
4405 112 0005 4404 0001
4406 005 1425 1427 1430
4407 005 1424 1426 1433
4410 005 1424 1425 1431
4411 005 1422 1427 1434
4412 005 1422 1426 1432
4413 005 1425 1425 1435
4414 702 1422 1425 1422
4415 112 0010 4414 0001
4416 016 4417 7501 7610
4417 052 1422 0033 3525
4420 052 1433 0000 0303
4421 000 0000 0000 0000
4422 000 0000 0000 0000
4423 005 1435 0336 1436
4424 004 1436 1420 1436
4425 305 1436 1414 3531
4426 112 0013 4425 0001
4427 302 0000 3526 3526
4430 112 0016 4427 0001
4431 305 1433 1403 3526
4432 112 0021 4431 0001
4433 050 0000 0000 0000

4434 005 0331 5501 5501
4435 005 0331 5511 5511
4436 005 0331 5521 5521
4437 005 0331 5532 5532
4440 005 0331 5535 5535
4441 005 0331 5540 5540
4442 005 0331 5543 5543
4443 005 0331 5547 5547
4444 005 0331 5552 5552
4445 005 0331 5555 5555
4446 005 0331 5560 5560
4447 005 0331 5564 5564
4450 056 0000 5037 0000
4451 056 0000 4520 0000
4452 050 0411 4000 5177
4453 070 4000 4452 0000
4454 000 0000 0000 6610
4455 013 7722 6611 6611
4456 015 6611 6617 0000
4457 076 0000 1514 3521
4460 000 0000 0000 6611
4461 013 7722 6612 6612
4462 015 6612 6620 0000
4463 076 0000 1514 0000
4464 000 0000 0000 6612
4465 013 7722 6613 6613
4466 015 6613 6621 0000
4467 076 0000 1514 0000
4470 000 0000 0000 6613
4471 013 7722 6614 6614
4472 015 6614 6622 0000
4473 076 0000 1514 0000
4474 000 0000 0000 6614
4475 056 0000 3340 0000
4476 003 3504 7757 0000
4477 076 5011 4050 6553
4500 000 4503 0000 4130
4501 000 4504 0000 3114
4502 056 4505 4050 6553
4503 000 7761 0000 0041
4504 004 3510 7762 1437
4505 005 3510 3510 1432
4506 000 0000 0000 0000
4507 000 0000 0000 0000
4510 000 0000 0000 0000
4511 000 0000 0000 0000
4512 000 0000 0000 0000
4513 000 0000 0000 0000
4514 000 0000 0000 0000
4515 000 0000 0000 0000
4516 000 0000 0000 0000
4517 000 0000 0000 0000
4520 004 0074 3514 0070
4521 004 0075 3514 0071
4522 005 0070 0070 0072
4523 005 0071 0071 0073
4524 052 0000 0000 0000
4525 504 3307 0070 5671
4526 504 3512 0071 5674
4527 504 3523 0072 5700

Page 123

4530	594	3326	0073	5703
4531	544	5700	0000	5707
4532	544	5703	0000	5712
4533	505	5707	7763	5716
4534	595	5712	7763	5721
4535	000	0000	0000	0000
4536	112	0002	4525	0001
4537	052	0000	0000	0000
4540	500	6000	0000	3500
4541	112	0053	4540	0001
4542	000	0000	0000	0000
4543	000	0000	0000	0000
4544	002	3540	3552	0000
4545	036	0000	4554	0000
4546	016	4547	7501	7610
4547	052	5501	0041	5723
4550	001	3552	0256	3552
4551	000	0000	0030	0000
4552	000	0000	0000	0000
4553	000	0000	0030	0000
4554	056	0000	4634	0000
4555	100	0000	0000	3500
4556	112	0053	4555	0001
4557	072	0000	0000	0000
4560	100	0000	0030	3271
4561	112	0037	4560	0001
4562	000	0000	0000	0000
4563	000	0000	0000	0000
4564	072	0000	0000	0000
4565	100	0000	0000	6670
4566	112	0005	4565	0001
4567	056	0000	4452	0000
4570	000	0000	0000	0000
4571	050	0412	0001	0023
4572	070	0001	4571	0000
4573	050	0412	0025	3776
4574	070	0025	4573	0000
4575	050	0411	5201	6113
4576	070	5201	4575	0000
4577	056	0000	0066	0000
4600	000	0000	0000	0000
4601	000	0000	0000	0000
4602	000	0000	0000	0000
4603	000	0000	0000	0000
4604	000	0000	0000	0000
4605	000	0000	0000	0000
4606	000	0000	0000	0000
4607	000	0000	0030	0000
4610	000	0054	0000	3756
4611	002	3772	0251	3757
4612	002	3774	0251	3760
4613	002	0062	0054	3761
4614	001	0251	0251	3762
4615	001	0251	0251	3763
4616	000	0055	0000	3764
4617	002	3772	0251	3765
4620	002	3773	0251	3766
4621	002	0063	0055	3767
4622	001	0251	0251	3770
4623	001	0251	0251	3771

4624	056	0000	4630	0000
4625	000	0000	6713	0000
4626	000	0000	6716	0000
4627	000	0000	6721	0000
4630	500	3772	0000	3707
4631	500	4625	0000	3712
4632	500	4625	0000	3715
4633	500	3772	0000	3723
4634	112	0002	4630	0001
4635	000	0000	0000	0000
4636	000	0000	0000	0000
4637	072	0000	3715	0000
4640	016	4641	6676	5704
4641	000	6715	0000	3720
4642	072	0000	3716	0000
4643	016	4644	6676	6704
4644	000	6720	0000	3721
4645	072	0000	3717	0000
4646	016	4647	6676	6704
4647	000	6723	0000	3722
4650	000	0000	0000	0000
4651	056	0000	5061	0000
4652	000	0000	0000	0000
4653	056	3362	6507	6513
4654	002	3540	0254	0000
4655	036	0000	4664	0000
4656	000	0000	0000	0000
4657	000	0000	0000	0000
4660	000	0000	0000	0000
4661	000	0000	0000	0000
4662	072	0000	0000	0000
4663	056	0000	4555	0000
4664	001	0253	3540	3540
4665	055	0000	6543	0000
4666	000	0000	0000	0000
4667	052	0000	0000	0000
4670	500	3500	0000	0000
4671	112	0053	4670	0001
4672	000	3500	0000	5501
4673	000	3501	0000	5502
4674	000	3502	0000	5503
4675	000	3515	0000	5504
4676	004	3504	3531	5505
4677	000	3504	0000	5506
4700	000	3506	0000	5507
4701	000	0250	0000	5510
4702	000	3503	0000	5511
4703	000	0334	0000	5512
4704	000	3517	0000	5513
4705	000	3521	0000	5514
4706	000	3520	0000	5515
4707	000	3514	0000	5516
4710	000	3516	0000	5517
4711	004	3520	3514	5520
4712	005	3507	1435	5521
4713	005	3511	1435	5522
4714	005	3512	1435	5523
4715	001	5521	5522	5524
4716	001	5524	5523	5525
4717	001	5522	5523	5526

Draw
of
Np2
mole-
cules

Page 124

4720	003	3537	1435	5527
4721	000	0000	0000	5530
4722	000	7730	0000	5531
4723	000	7730	0000	5546
4724	000	7730	0000	5563
4725	000	7730	0000	5572
4726	000	7730	0000	5631
4727	000	7730	0000	5670
4730	000	7730	0000	5677
4731	000	7730	0000	5706
4732	000	7730	0000	5715
4733	000	7730	0000	0000
4734	072	0000	0000	0300
4735	504	3522	1435	5573
4736	504	3530	1435	5615
4737	504	3541	1435	5623
4740	504	3525	1434	5576
4741	504	3533	1434	5620
4742	504	3544	1434	5626
4743	112	0002	4735	0001
4744	052	0000	0000	0000
4745	701	5615	5623	5601
4746	701	5615	5573	5607
4747	112	0005	4745	0001
4750	052	0000	0000	0000
4751	016	4752	7501	7610
4752	052	1421	0035	5573
4753	052	5632	0000	0003
4754	013	4752	4060	4752
4755	013	4753	4061	4753
4756	112	0011	4751	0001
4757	000	4062	0000	4752
4760	000	4063	0000	4753
4761	052	0000	0000	0000
4762	701	5573	5601	5532
4763	701	5632	5640	5547
4764	500	5532	0000	5522
4765	500	5547	0000	5530
4766	112	0005	4762	0001
4767	000	0000	0000	0000
4770	000	0000	0000	0000
4771	000	0000	0000	0000
4772	000	0000	0000	0000
4773	000	0316	0000	5504
4774	000	0320	0000	5505
4775	000	0322	0000	5506
4776	052	0000	0000	0000
4777	016	5000	4314	4433
5000	000	0000	0000	4433
5001	052	0000	0000	0000
5002	500	3542	0000	5564
5003	500	3545	0000	5567
5004	500	0055	0000	5540
5005	500	3533	0000	5555
5006	112	0002	5002	0001
5007	056	0000	5020	0000
5010	004	3504	7762	1437
5011	005	3504	3504	1432
5012	000	0000	0000	0000
5013	000	0000	0000	0000

5014	000	0000	0000	0000
5015	000	0000	0000	0000
5016	000	0000	0000	0000
5017	000	0000	0000	0000
5020	000	4304	0000	5010
5021	016	5022	4272	4304
5022	000	5010	0000	4304
5023	000	4340	0000	5010
5024	000	0317	0000	3504
5025	000	0321	0000	3505
5026	000	0323	0000	3506
5027	052	0000	0000	0000
5030	016	5031	4314	4340
5031	000	5010	0000	4340
5032	052	0000	0000	0000
5033	500	0055	0000	5543
5034	500	3533	0000	5560
5035	112	0002	5033	0001
5036	056	0000	4434	0000
5037	005	0331	5567	5567
5040	005	0331	5573	5573
5041	005	0331	5601	5601
5042	005	0331	5607	5607
5043	005	0331	5615	5615
5044	005	0331	5623	5623
5045	005	0331	5632	5632
5046	005	0331	5640	5640
5047	005	0331	5646	5646
5050	005	0331	5654	5654
5051	005	0331	5662	5662
5052	005	0331	0000	0000
5053	000	0000	0000	0000
5054	000	0000	0000	0000
5055	000	0000	0000	0000
5056	000	0000	0000	0000
5057	000	0000	0000	0000
5060	056	0000	4451	0000
5061	072	0000	6121	0000
5062	016	5063	6676	6704
5063	000	4737	0000	6115
5064	072	0000	6122	0000
5065	016	5066	6676	6704
5066	000	6742	0000	6116
5067	072	0000	6123	0000
5070	016	5071	6676	6704
5071	000	6745	0000	6117
5072	056	0000	4652	0000
5073	050	0412	6116	7767
5074	070	6116	5073	0000
5075	052	7032	0000	7615
5076	000	7504	0000	7541
5077	015	0332	0000	0000
5100	036	6134	5103	2600
5101	000	3374	0000	2600
5102	056	3375	6507	2634
5103	056	0000	6507	2634
5104	000	0000	0000	0000
5105	000	0000	0000	0000
5106	000	0000	0000	0000
5107	000	0000	0000	0000

pn

Page 126

5300	000	0000	0000	0000	5374	000	0010	0000	0012
5301	000	0000	0000	0000	5375	000	0011	0000	0013
5302	000	0000	0000	0000	5376	015	1472	0000	0000
5303	000	0000	0000	0000	5377	076	0000	5467	0000
5304	000	0000	0000	0000	5400	000	0000	0000	0000
5305	000	0000	0000	0000	5401	036	0000	5462	0000
5306	000	0000	0000	0000	5402	005	0012	0012	0020
5307	000	0000	0000	0000	5403	005	0013	0013	0021
5310	000	0000	0000	0000	5404	005	1441	0020	0020
5311	000	0000	0000	0000	5405	005	1442	0021	0021
5312	000	0000	0000	0000	5406	005	0012	1444	0022
5313	000	0000	0000	0000	5407	005	0013	1445	0023
5314	000	0000	0000	0000	5410	001	0020	0021	0020
5315	015	5051	0000	0000	5411	001	0020	0022	0020
5316	036	0000	6166	0000	5412	001	0020	0023	0020
5317	033	6023	5325	5321	5413	001	0020	1447	0020
5320	452	0000	0000	5323	5414	015	0000	1443	0000
5321	000	0000	0000	0000	5415	076	0000	5421	0000
5322	112	0035	5321	0001	5416	004	0020	1446	0014
5323	000	0000	0000	0000	5417	002	0000	0014	0014
5324	036	5052	6166	1472	5420	036	0000	5436	0000
5325	000	0000	0000	3360	5421	005	1446	1446	0021
5326	000	0000	0000	0000	5422	005	7762	1443	1022
5327	000	0000	0000	0032	5423	005	0020	0022	1023
5330	002	1465	1464	1420	5424	005	7762	0023	0023
5331	002	1467	1466	1421	5425	002	0021	0023	0021
5332	004	7757	7760	1422	5426	044	0021	0000	0021
5333	000	1422	0000	1434	5427	002	0000	1446	0023
5334	000	1422	0000	1435	5430	001	0023	0021	0024
5335	004	1420	0257	1423	5431	004	0024	0022	0014
5336	004	1421	0257	1424	5432	002	0014	0000	0000
5337	000	0000	0000	1430	5433	076	0000	5436	0000
5340	000	0000	0000	1431	5434	002	0023	0021	0024
5341	000	0000	0000	1432	5435	004	0024	0022	0014
5342	000	0000	0000	1433	5436	000	0000	0000	0032
5343	000	1464	0000	1430	5437	452	0000	0000	5453
5344	000	1466	0000	1432	5440	605	1441	0012	0030
5345	015	0330	0000	0000	5441	005	0030	7762	0030
5346	036	0000	5706	0000	5442	201	0030	1444	0030
5347	052	0000	0000	0000	5443	005	0030	0030	0031
5350	000	0000	0000	0000	5444	001	0031	0032	0032
5351	001	1430	1423	1431	5445	102	0000	0030	0033
5352	000	0000	0000	0000	5446	112	0002	5440	0001
5353	452	0000	0000	5677	5447	044	0032	0000	0032
5354	001	1432	1424	1433	5450	004	0033	0032	0033
5355	000	0000	0000	0000	5451	004	0034	0032	0034
5356	000	0000	0000	0000	5452	004	0035	0032	0035
5357	000	0000	0000	0000	5453	000	0000	0000	0000
5360	000	0000	0000	0000	5454	000	0000	0000	0000
5361	000	0000	0000	0000	5455	004	7761	0035	0015
5362	016	5363	7501	7610	5456	002	0000	0015	0015
5363	000	1430	0122	1431	5457	000	0000	0000	0000
5364	000	1434	5371	5372	5460	005	0015	0011	0015
5365	000	1435	5374	5667	5461	000	0000	0000	0000
5366	000	1432	0015	0010	5462	016	5463	5402	5457
5367	036	0000	5671	0000	5463	000	0000	0000	5457
5370	000	0000	0000	0000	5464	036	0000	5667	0000
5371	000	1432	0000	1432	5465	000	0000	0000	0000
5372	000	1433	0000	1433	5466	000	0000	0000	0000
5373	000	0000	0000	0000	5467	015	7724	1472	0000

Page 127

5470 076 0000 5511 0000
5471 016 5472 7501 7610
5472 075 0010 0003 9020
5473 008 0000 0000 0000
5474 008 0010 0000 0030
5475 002 7756 0010 0010
5476 008 0020 0000 0016
5477 014 5500 5471 5473
5500 000 0000 0000 5473
5501 000 0030 0000 0010
5502 000 0020 0000 0017
5503 005 0011 0017 0012
5504 005 0011 0016 0013
5505 016 5506 5402 5461
5506 000 0000 0000 5461
5507 056 0000 5467 0000
5510 050 0500 0000 0000
5511 015 7722 1472 0000
5512 076 0000 5565 0000
5513 000 5503 0000 0040
5514 016 5515 5471 5503
5515 008 0040 0000 5503
5516 005 0016 0016 0020
5517 005 0017 0017 0021
5520 005 1441 0021 0022
5521 005 1442 0020 0023
5522 001 0022 0023 0024
5523 005 1444 0017 0025
5524 005 1445 0016 0026
5525 001 0025 0026 0027
5526 005 0011 0011 0030
5527 005 1445 0030 0031
5530 005 1446 0011 0032
5531 001 0031 0032 0034
5532 001 0034 1447 0035
5533 001 0024 0024 0036
5534 005 0036 0035 0037
5535 005 0037 7762 0040
5536 005 0027 0027 0041
5537 002 0341 0040 0042
5540 044 0042 0000 0043
5541 002 0000 0027 0045
5542 001 0045 0043 0046
5543 004 0046 0036 0047
5544 002 0047 0000 0000
5545 076 0000 5550 0000
5546 002 0045 0043 0046
5547 004 0046 0036 0047
5550 005 0047 0017 0012
5551 005 0047 0016 0013
5552 000 0011 0000 0014
5553 016 5554 5436 5454
5554 000 0000 0000 5454
5555 005 0033 0017 0025
5556 005 0034 0014 0026
5557 001 0025 0026 0027
5560 004 0047 0027 0015
5561 002 0000 0015 0015
5562 556 0000 5467 0000
5563 500 0000 0000 0000

5564 000 5000 0000 0000
5565 015 7721 1472 0000
5566 076 0000 5511 0000
5567 000 5503 0000 0040
5570 016 5571 5471 5563
5571 000 0010 0000 0041
5572 000 0016 0000 0042
5573 000 0017 0000 0043
5574 000 0011 0000 0010
5575 016 5576 5471 5563
5576 000 0040 0000 5503
5577 000 0041 0000 0010
5600 000 0016 0000 0020
5601 000 0017 0000 0021
5602 000 0042 0000 0016
5603 000 0043 0000 0017
5604 005 0016 0016 0022
5605 005 0017 0017 0023
5606 005 0020 0020 0024
5607 005 0021 0021 0025
5610 005 0023 0024 0026
5611 005 1441 0026 0026
5612 005 0022 0024 0027
5613 005 1442 0027 0027
5614 005 1443 0025 0030
5615 001 0026 0027 0026
5616 001 0026 0030 0030
5617 005 0017 0020 0031
5620 005 1444 0031 0031
5621 005 0016 0020 0032
5622 005 1445 0032 0032
5623 005 1446 0021 0033
5624 001 0031 0032 0034
5625 001 0034 0033 0035
5626 000 1447 0000 0036
5627 001 0030 0030 0037
5630 005 0037 0036 0040
5631 005 7762 0040 0040
5632 005 0035 0035 0041
5633 002 0041 0040 0042
5634 044 0042 0000 0043
5635 002 0000 0035 0044
5636 001 0044 0043 0045
5637 004 0045 0037 0046
5640 002 0046 0000 0000
5641 076 0000 5644 0000
5642 002 0046 0043 0045
5643 004 0045 0037 0046
5644 005 0017 0020 0047
5645 005 0016 0020 0050
5646 005 0047 0046 0012
5647 005 0050 0046 0013
5650 005 0021 0046 0014
5651 000 0020 0000 0061
5652 000 0021 0000 0062
5653 016 5654 5436 5454
5654 000 0000 0000 5454
5655 005 0033 0047 0051
5656 005 0034 0050 0052
5657 005 0035 0062 0053

Page 128

3660 005 0046 0046 0054
3661 005 0054 0061 0055
3662 001 0051 0052 0056
3663 001 0056 0053 0057
3664 004 0055 0057 0015
3665 002 0000 0015 0015
3666 000 0000 0000 0000
3667 000 0000 0000 0000
3670 000 0000 0000 0000
3671 000 0000 0000 0000
3672 000 0001 0000 4001
3673 013 5672 7721 5672
3674 001 1432 1424 1432
3675 000 0000 0000 0000
3676 112 0011 5354 0001
3677 000 0000 0000 0000
3700 001 1430 1423 1430
3701 000 1466 0000 1432
3702 000 0000 0000 0000
3703 112 0011 5351 0001
3704 016 5705 7501 7610
3705 052 4001 0041 4144
3706 050 0015 0001 4500
3707 070 4001 0000 0000
3710 050 4411 0001 4500 ΔS_w
3711 070 4001 5706 0000
3712 056 0000 5073 0000
3713 000 0000 0000 0000
3714 000 0000 0000 0000
3715 000 0000 0000 0000
3716 000 0000 0000 0000 d_w
3717 000 0000 0000 0000
3720 000 0000 0000 0000 $2d_w$
3721 000 0000 0000 0000
3722 452 0000 0000 6025 d_w
3723 500 0420 0000 5020
3724 112 0035 6023 0001
3725 000 0000 0000 0000
3726 452 0000 0000 6042
3727 605 5030 5030 0054
3730 605 5033 5033 0055
3731 605 5034 5034 0056
3732 000 0000 0000 0000
3733 005 0054 5021 0054
3734 005 0055 5022 0055
3735 005 0054 5023 0056
3736 001 0054 0055 0054
3737 000 0000 0000 0000
3740 101 0054 0056 5121
3741 112 0002 6027 0001
3742 000 0000 0000 0000
3743 000 0000 0000 0000
3744 000 0000 0000 0000
3745 005 5030 5031 0054
3746 005 5033 5034 0055
3747 005 5036 5037 0056
3750 016 6051 6033 6037
3751 001 0054 0054 5053
3752 005 5031 5032 0054
3753 005 5034 5035 0055

5754 005 5037 5040 0056
5755 016 6056 6033 6037
5756 001 0054 0056 5054
5757 005 5030 5032 0054
5760 005 5033 5035 0055
5761 005 5036 5040 0056
5762 016 6063 6033 6037
5763 001 0054 0056 5055
5764 000 0000 0000 6037
5765 452 0000 0000 6074
5766 405 5030 5024 0054
5767 405 5033 5025 0055
5770 405 5036 5026 0056
5771 001 0054 0055 0054
5772 101 0054 0056 5124
5773 112 0002 6066 0001
5774 000 0000 0000 0000
5775 005 7762 5053 5053
5776 005 7762 5054 5054
5777 005 7762 5055 5055
6000 005 5041 5121 0054
6001 005 5042 5053 0055
6002 005 5043 5055 0056
6003 005 7762 0054 0054
6004 001 0054 0055 0054
6005 001 0054 0056 0054
6006 002 5124 0054 5056
6007 005 5041 5053 0054
6010 005 5042 5122 0055
6011 005 5043 5054 0056
6012 005 7762 0055 0055
6013 001 0054 0055 0054
6014 001 0054 0056 0054
6015 002 5125 0054 5057
6016 005 5041 5055 0054
6017 005 5042 5054 0055
6020 005 5043 5123 0056
6021 005 7762 0056 0056
6022 001 0054 0055 0054
6023 001 0054 0056 0054
6024 002 5126 0054 5060
6025 005 5041 5041 0054
6026 005 5042 5042 0055
6027 005 5043 5043 0056
6030 005 5041 5042 0057
6031 005 5042 5043 0060
6032 005 5043 5041 0061
6033 005 5121 0054 0062
6034 005 5122 0055 0063
6035 005 5123 0056 0064
6036 005 5053 0057 0065
6037 005 5054 0060 0066
6040 005 5055 0061 0067
6041 005 5041 5124 0070
6042 005 5042 5125 0071
6043 005 5043 5126 0072
6044 452 0000 0000 6167
6045 401 0062 5027 5027
6046 112 0005 6145 0001
6047 000 0000 0000 0000

Page 129

6050	002	5027	0070	5027
6051	002	5027	0071	5027
6052	002	5027	0072	5027
6053	000	5056	0000	5024
6054	000	5057	0000	5025
6055	000	5060	0000	5026
6056	000	5121	0000	5021
6057	000	5122	0000	5022
6060	000	5123	0000	5023
6061	472	0000	6610	6164
6062	400	5201	0000	5052
6063	400	5222	0000	5020
6064	000	0000	0000	0000
6065	056	0000	5315	0000
6066	452	0000	0000	6171
6067	500	5020	0000	0420
6070	112	0035	6167	0001
6071	000	0000	0000	0000
6072	013	6610	7722	6610
6073	013	6610	6616	0000
6074	836	0000	6201	0000
6075	013	6023	3443	6023
6076	013	6167	3444	6167
6077	000	0000	0000	0000
6100	056	0000	6022	0000
6101	000	3441	0000	6023
6102	000	3442	0000	6167
6103	000	0000	0000	6610
6104	056	0114	6616	0014
6105	013	2505	0014	2503
6106	033	2505	3466	2503
6107	000	0000	0000	0000
6110	000	0000	0000	0000
6111	056	0000	5327	0000
6112	000	0000	0000	0000
6113	000	0000	0000	0000
6114	000	0000	0000	0000
6115	000	0000	0000	0000
6116	000	0000	0000	0000
6117	000	0000	0000	0000
6120	000	0000	2204	0000
6121	000	0000	6735	0000
6122	000	0000	6740	0000
6123	000	0000	6743	0000
6124	005	0077	0042	0042
6125	000	0041	0000	6515
6126	056	0041	1575	6516
6127	056	0041	1611	6517
6130	002	0041	1420	0043
6131	005	0076	0043	0042
6132	000	0144	0000	0144
6133	704	4001	2101	4001
6134	016	2001	2001	2004
6135	050	0411	0001	2000
6136	070	2101	0016	0000
6137	000	0000	0000	0000
6140	500	3712	0000	6107
6141	500	0062	0000	3712
6142	112	0010	6140	0001
6143	033	1560	6120	1560

6144	033	1575	6120	1575
6145	033	1611	6120	1611
6146	605	6504	6504	1421
6147	001	1420	1421	1420
6150	112	0013	6146	0001
6151	044	1420	0000	6520
6152	000	6515	0000	1421
6153	004	6516	6520	6515
6154	004	6517	6520	6516
6155	004	1421	6520	6517
6156	005	6520	6627	6520
6157	000	0000	0000	0000
6160	056	0000	1506	0000
6161	000	3370	0000	3021
6162	000	3371	0000	3023
6163	000	3372	0000	3024
6164	056	3373	3037	3025
6165	005	0041	1420	0041
6166	001	0042	0041	0041
6167	005	0043	7762	0043
6170	004	0041	0043	0077
6171	004	7762	0041	0076
6172	002	1420	0000	0000
6173	056	0000	6201	0000
6174	001	1420	0251	0041
6175	002	1420	0251	0000
6176	056	0000	6207	3726
6177	002	1420	0251	3726
6200	056	0000	6207	0000
6201	003	1420	0246	0000
6202	056	0000	6204	3726
6203	056	0000	6207	0041
6204	001	1420	0246	0042
6205	044	0042	0000	0042
6206	005	0042	0247	0041
6207	056	0000	6465	0000
6210	400	0005	0000	1425
6211	456	0006	6353	1426
6212	000	0000	0000	1420
6213	056	0000	6411	1421
6214	456	0011	6353	1431
6215	005	0053	0057	1420
6216	015	0332	0000	0000
6217	076	0055	6222	6624
6220	000	0056	0000	6625
6221	056	0057	2624	6626
6222	000	0052	0000	6624
6223	000	0053	0000	6625
6224	056	0054	2624	6626
6225	015	0332	0000	0000
6226	076	6625	6230	0056
6227	056	6626	6234	0057
6230	000	6624	0000	0052
6231	000	6625	0000	0053
6232	000	6626	0000	0054
6233	016	2772	2603	2622
6234	002	6637	0334	0000
6235	076	0000	6233	0000
6236	056	0000	2772	0000
6237	005	1417	0051	6661

Page 130

6240 003 6661 0000 6661
6241 056 6661 2674 6657
6242 000 0000 0000 0000
6243 000 0000 0000 0000
6244 000 0000 0000 0000
6245 000 1420 0000 6242
6246 000 1421 0000 6243
6247 056 1422 3040 6244
6250 000 6242 0000 1420
6251 000 6243 0000 1421
6252 056 6244 3105 1422
6253 000 0000 0000 0000
6254 054 0050 1440 0001
6255 033 0001 7722 0001
6256 072 0000 0001 0000
6257 016 3170 3645 3653
6260 000 0000 0000 0000
6261 015 3550 0000 0000
6262 076 0000 6266 0000
6263 001 7761 3514 3514
6264 001 1476 3507 3507
6265 056 0000 2545 0000
6266 001 7761 3516 3516
6267 001 1476 3512 3512
6270 056 0000 2545 0000
6271 015 3550 0000 0000
6272 076 0000 6277 0000
6273 002 3511 6521 3511
6274 052 0000 0000 0000
6275 016 6245 3066 6302
6276 000 0000 0000 0000
6277 002 3512 6521 3512
6300 056 0000 3040 0000
6301 502 3527 1422 3527
6302 000 0000 0000 0000
6303 015 3550 0000 0000
6304 076 0000 6310 0000
6305 001 1476 3536 3536
6306 052 0000 0000 0000
6307 016 3170 2676 2715
6310 015 3550 7722 0000
6311 076 0000 2717 0000
6312 052 0000 0017 0000
6313 016 2717 2676 2715
6314 015 3550 7722 0000
6315 056 0000 6250 0000
6316 052 0000 0017 0000
6317 016 3105 3066 6302
6320 052 0000 0003 0000
6321 505 0047 1417 1423
6322 112 0005 6321 0001
6323 702 0030 1420 0047
6324 112 0010 6323 0001
6325 005 1417 1417 1431
6326 002 6252 1431 1432
6327 015 7761 1431 0000
6330 056 0000 6333 0000
6331 044 1432 0000 1432
6332 056 0000 2617 0000
6333 004 0053 0052 1420

6334 005 1420 1420 0055
6335 001 7761 0055 0055
6336 044 0055 0000 0055
6337 004 7761 0055 0056
6340 005 1420 0056 0055
6341 002 0000 0055 0055
6342 056 0000 2622 0057
6343 000 0000 0000 0000
6344 054 0044 1440 1437
6345 072 0000 1437 0000
6346 400 0000 0000 1420
6347 400 0001 0000 1421
6350 400 0002 0000 1422
6351 400 0003 0000 1423
6352 456 0004 6210 1424
6353 016 6354 7501 7610
6354 000 0006 0150 0206
6355 075 1432 1420 1433 de
6356 000 0000 0000 0000 du
6357 015 6355 7721 6355 de
6360 072 0000 1440 0000
6361 016 6362 6366 6356
6362 015 6355 7721 6355
6363 054 0114 1440 1437
6364 016 6365 6345 6356
6365 033 6355 7721 6355
6366 033 6355 7721 6355
6367 005 1417 0000 1420
6370 015 1433 7761 0000
6371 076 0000 6732 6356
6372 056 3551 6212 6627
6373 005 3567 1433 1422
6374 002 7761 1433 1421
6375 005 1476 1421 1421
6376 005 7764 1421 1421
6377 001 1421 1422 1421
6400 044 1421 0000 6627
6401 000 0000 0000 0000
6402 005 2601 0313 1422
6403 016 6404 7501 7610
6404 075 1422 0003 1423
6405 005 7762 3547 2652
6406 004 7756 7762 2653
6407 005 2633 3547 2653
6410 056 2635 2640 6405
6411 000 1566 0000 1423
6412 000 1573 0000 1424
6413 000 1606 0000 1425
6414 000 1622 0000 1426
6415 000 1624 0000 1427
6416 000 3562 0000 1430
6417 000 3570 0000 1431
6420 052 0000 0000 0000
6421 500 3726 0000 1432
6422 112 0005 6421 0001
6423 500 3712 0000 0062
6424 500 6107 0000 3712
6425 112 0010 6423 0001
6426 015 1560 6120 1560
6427 015 1570 6120 1575

Page 131

6430	013	1611	6120	1611
6431	000	6124	0000	1566
6432	000	6125	0000	1573
6433	000	6126	0000	1606
6434	000	6127	0000	1622
6435	000	6130	0000	3562
6436	000	6131	0000	3570
6437	000	0000	0000	1422
6440	005	1420	7764	0041
6441	005	0041	0041	0042
6442	001	7764	0042	0042
6443	044	0042	0000	0042
6444	001	0041	0042	0077
6445	002	0077	1420	0041
6446	005	0041	0041	0041
6447	002	0000	0041	0041
6450	016	6451	7531	7510
6451	075	0041	0003	0042
6452	000	0000	0000	0000
6453	005	0042	0077	0043
6454	000	1420	0000	0041
6455	016	6456	6446	6452
6456	000	0000	0000	6452
6457	016	6460	7531	7613
6460	075	1420	0031	0041
6461	001	7761	0041	0041
6462	005	0041	0414	0041
6463	056	0041	6165	0077
6464	000	0000	0000	0000
6465	002	1421	0251	3727
6466	002	0000	0251	3730
6467	000	0000	0000	0000
6470	002	0041	3726	3731
6471	001	0251	0251	3732
6472	001	0251	0251	3733
6473	016	6474	1550	1624
6474	000	1423	0000	1566
6475	000	1424	0000	1573
6476	000	1425	0000	1606
6477	000	1426	0000	1622
6500	000	1427	0000	1624
6501	000	1430	0000	3562
6502	000	1431	0000	3570
6503	052	0000	0000	0000
6504	000	1432	0000	3725
6505	112	0005	6504	0001
6506	056	0000	6140	1420
6507	452	0000	0030	6512
6510	100	0000	0030	4000
6511	112	2114	5510	0001
6512	000	0000	0030	0000
6513	000	0000	0030	0000
6514	056	0000	1514	0000
6515	000	0000	0000	0000
6516	000	0000	0000	0000
6517	000	0000	0000	0000
6520	000	0000	0000	0000
6521	000	0000	0000	0000
6522	000	0000	0000	0000
6523	000	0000	0000	0000

6524	000	0000	0000	0000
6525	000	0000	0000	0000
6526	000	0000	0000	0000
6527	000	0000	0000	0000
6530	056	0000	6553	0000
6531	050	0012	0001	0023
6532	070	0001	6531	0000
6533	016	6534	0006	0022
6534	000	0000	0000	0022
6535	016	6536	3113	3150
6536	000	3357	0000	3150
6537	050	0411	2101	2600
6540	070	2101	6537	0000
6541	016	6542	1514	4635
6542	056	0000	4272	4635
6543	050	0012	4000	6114
6544	070	4000	6543	0000
6545	000	0000	0000	0000
6546	000	0000	0000	0000
6547	000	3720	0000	0041
6550	000	3721	0000	3720
6551	000	3722	0000	3721
6552	056	0041	1543	3722
6553	005	3504	3504	1432
6554	072	0000	0000	0000
6555	100	0000	0000	0060
6556	112	0012	6555	0001
6557	056	0000	6531	0000
6560	000	0000	0000	0000
6561	000	0000	0000	0000
6562	000	6566	0000	6644
6563	072	0000	0000	0000
6564	452	0000	0000	6577
6565	452	0000	0000	6571
6566	401	4001	6624	6624
6567	112	0011	6566	0001
6570	013	6566	3354	6566
6571	000	0000	0000	0000
6572	112	0011	6565	0001
6573	016	6574	7531	7610
6574	052	6624	0041	6635
6575	013	6644	3471	6644
6576	056	6644	2023	6566
6577	000	0000	0000	0000
6600	112	0012	6564	0001
6601	000	6643	0000	6566
6602	000	0000	0000	0000
6603	000	3265	0000	6567
6604	000	3266	0000	6570
6605	016	6606	6562	6602
6606	000	3267	0000	6567
6607	056	3270	3145	6570
6610	000	0000	0000	0000
6611	000	0000	0000	0000
6612	000	0000	0000	0000
6613	000	0000	0000	0000
6614	000	0000	0000	0000
6615	000	0000	1000	0000
6616	000	0000	0000	0000
6617	000	0000	0000	0000

 N_{2*}
 $n(n)$ $n(2n)$

Page 132

6628	000	0000	0000	0000	n(p ₀)	6702	713	0001	0000	0002
6621	000	0000	0000	0000	n(H)	6703	521	0002	0000	0002
6622	000	0000	0000	0000	n(d ₀)	6704	000	0000	0000	0000
6623	000	0000	0000	0000		6705	300	0000	0000	0000
6624	000	0000	0000	0000		6706	000	0000	0000	0000
6625	000	0000	0000	0000		6707	002	2675	2602	2601
6626	000	0000	0000	0000		6710	056	0000	6402	0000
6627	000	0000	0000	0000		6711	005	1423	1437	1437
6630	000	0000	0000	0000		6712	056	0000	3677	0000
6631	000	0000	0000	0000		6713	545	0413	2636	2075
6632	000	0000	0000	0000		6714	100	0000	0000	0000
6633	000	0000	0000	0000		6715	075	4132	6362	0750
6634	000	0000	0000	0000		6716	130	3360	3661	0707
6635	000	0000	0000	0000		6717	100	0000	0000	0000
6636	000	0000	0000	0000		6720	077	6740	7542	1616
6637	000	0000	0000	0000		6721	620	4757	4005	7356
6640	000	0000	0000	0000		6722	100	0000	0000	0000
6641	000	0000	0000	0000		6723	100	4257	4005	7356
6642	000	0000	0000	0000		6724	771	3636	0576	7024
6643	000	0000	0000	0000		6725	100	0000	0000	0000
6644	000	0000	0000	0000		6726	077	7474	1375	6050
6645	000	0000	0000	0000		6727	367	7305	3574	6742
6646	005	6745	6750	6631		6730	100	0000	0000	0000
6647	016	4650	7501	7610		6731	100	7305	3574	6742
6650	000	6631	0004	6631		6732	377	7313	0013	7566
6651	002	0000	6631	6631		6733	100	0000	0000	0000
6652	000	0000	0000	0000		6734	100	7313	0013	7566
6653	000	0000	0000	0000		6735	060	6153	0513	2322
6654	000	0000	0000	0000		6736	100	0000	0000	0000
6655	000	0000	0000	0000		6737	100	6153	0513	2322
6656	000	0000	0000	0000		6740	012	6714	0665	6475
6657	000	0000	0000	0000		6741	100	0000	0000	0000
6660	000	0000	0000	0000		6742	100	6714	0665	6475
6661	000	0000	0000	0000		6743	453	4165	6507	0167
6662	000	0000	0000	0000		6744	100	0000	0000	0000
6663	000	0000	0000	0000		6745	100	4165	6507	0167
6664	000	0000	0000	0000		6746	074	3552	7726	1403
6665	000	0000	0000	0000		6747	100	0000	0000	0000
6666	000	0000	0000	0000		6750	077	7325	7654	3006
6667	000	0000	0000	0000		6751	052	0000	6735	0000
6670	000	0000	0000	0000		6752	016	6753	6676	6704
6671	000	0000	0000	0000		6753	000	6737	0000	6632
6672	000	0000	0000	0000		6754	052	0000	6740	0000
6673	000	0000	0000	0000		6755	016	6756	6676	6704
6674	000	0000	0000	0000		6756	000	6742	0000	6633
6675	000	0000	0000	0000		6757	052	0000	6743	0000
6676	354	0107	0000	0002		6760	016	6761	6676	6704
6677	715	0000	0002	0003	Transducer	6761	052	0000	6746	0000
6700	354	0045	0000	0002	for uni-	6762	016	6646	6676	6704
5701	707	0302	0000	0000	formly	6763	000	0000	0000	0000

distributed random numbers

Constants
for draw-
ing F_{KL}^{**}

R₁R₂R₇R₃R₄R₅R₆

Page 133

NUMERICAL INFORMATION FOR BLOCK I (0)

0100	++03	1000000000	0172	++00	5400000000
0101	++03	1010000000	0173	++00	7750000000
0102	++03	1020000000	0174	++01	1000000000
0103	++03	1600000000	0175	++01	1210000000
0104	++03	2000000000	0176	++01	1360000000
0105	++03	3000000000	0177	++00	0000000000
0106	++03	5000000000	0200	++00	1450000000
0107	++04	1500000000	0201	++00	2900000000
0110	++04	7000000000	0202	++00	4450000000
0111	++06	7000000000	0203	++00	5750000000
0112	++04	7010000000	0204	++00	6650000000
0113	++04	7786000000	0205	++00	7000000000
0114	++04	7728000000	0206	++00	0000000000
0115	++04	7615000000	0207	++00	2580000000
0116	++04	1128379000	0210	++00	5000000000
0117	++04	1128379000	0211	++00	7071000000
0120	++04	1128379000	0212	++00	8660000000
0121	++03	9547000000	0213	++00	9659000000
0122	++04	1063000000	0214	++01	1080000000
0123	++04	1172000000	0215	++01	4000000000
0124	++04	1351000000	0216	++01	6210000000
0125	++04	1000000000	0217	++00	1284000000
0126	++04	1800000000	0220	++00	2224700000
0127	++04	1000000000	0221	++00	3927000000
0130	++04	1207000000	0222	++00	6090100000
0131	++04	1404000000	0223	++00	7705540000
0132	++04	1423000000	0224	++00	8719000000
0133	++04	1576000000	0225	++00	9197600000
0134	++00	6000000000	0226	++00	9458100000
0135	++00	5750000000	0227	++00	9612200000
0136	++00	5400000000	0230	++01	4550000000
0137	++00	5000000000	0231	++01	3000000000
0140	++00	4450000000	0232	++01	2000000000
0141	++00	3620000000	0233	++01	1000000000
0142	++00	2480000000	0234	++00	0000000000
0143	++00	9000000000	0235	++01	1000000000
0144	++00	8900000000	0236	++01	2000000000
0145	++00	8700000000	0237	++01	3000000000
0146	++00	8400000000	0240	++01	4000000000
0147	++00	7950000000	0241	++01	5000000000
0150	++00	7300000000	0242	++01	6000000000
0151	++00	6300000000	0243	++01	1000000000
0152	++01	1480000000	0244	++01	1000000000
0153	++01	1460000000	0245	++03	1000000000
0154	++01	1360000000	0246	++01	4550000000
0155	++01	1240000000	0247	++01	1523000000
0156	++01	1100000000	0250	++03	4000000000
0157	++00	9400000000	0251	++01	3250000000
0160	++00	7800000000	0252	++01	1000000000
0161	++01	1280000000	0253	++00	0000000000
0162	++01	1175000000	0254	++00	0000000000
0163	++01	1110000000	0255	++04	1000000000
0164	++00	9800000000	0256	++00	0000000000
0165	++00	8000000000	0257	++02	1000000000
0166	++00	5650000000	0260	++00	0000000000
0167	++00	3000000000	0261	++00	0000000000
0170	++00	0000000000	0262	++00	0000000000
0171	++00	2750000000	0263	++00	0000000000

H_0

V_{∞} [m/s]

V [m/s]

T_{∞} [K]

de_1

de_2

dn_1

dn_2

dt_1

dt_2

$sin \theta_1$

ψ

S_2

E_2

T_w [K]

N_{1p}

N_{2p}

E_1

N_{3p}

d_o [deg]

Page 134

C264	++00	0300000000	L_0 [deg]	0342	++00	0000000000	I_2
C265	++00	0000000000		0343	++00	0000000000	I_3
C266	++00	0000000000		0344	++00	0000000000	I_3
0267	++00	0000000000		0345	++15	1000000000	L_1
0270	++00	0000000000		0346	++14	1000000000	L_2
0271	++00	0000000000		0347	++00	0000000000	
0272	++00	0000000000		0350	++00	0000000000	
0273	++00	0000000000		0351	++00	0000000000	
0274	++00	0000000000		0352	++00	0000000000	
0275	++00	0000000000		0353	++00	0000000000	
0276	++70	0000000000		0354	++00	0000000000	
0277	++70	0000000000		0355	++00	0000000000	
0300	++00	0000000000		0356	++00	0000000000	
0301	++70	0000000000	β [deg]	0357	++00	0000000000	
0302	++70	0000000000		0360	++00	0000000000	
0303	++00	0000000000		0361	++00	0000000000	
0304	++70	0000000000		0362	++00	0000000000	
0305	++00	0000000000		0363	++00	0000000000	
0306	++00	0000000000		0364	++00	0000000000	
0307	++00	0000000000		0365	++00	0000000000	
0310	++00	0000000000		0366	++00	0000000000	
0311	++00	0000000000	H	0367	++00	0000000000	
0312	++00	0000000000		0370	++00	0000000000	
0313	++00	0000000000		0371	++00	0000000000	
0314	++00	0000000000	L_4	0372	++00	0000000000	
0315	++00	0000000000		0373	++00	0000000000	
0316	++00	0000000000	I_{T1}	0374	++00	0000000000	
0317	++00	0000000000	I_{T1}	0375	++00	0000000000	
0320	++00	0000000000	I_{T2}	0376	++00	0000000000	
0321	++00	0000000000	I_{T2}	0377	++00	0000000000	
0322	++00	0000000000	I_{T3}	0400	++00	0000000000	
0323	++00	0000000000	I_{T3}	0401	++00	0000000000	
0324	++00	0000000000		0402	++00	0000000000	
0325	++00	564189580	$4/\pi$	0403	++00	0000000000	
0326	++09	1000000000		0404	++00	0000000000	
0327	++00	0000000000		0405	++00	0000000000	
0330	++00	0000000000		0406	++00	0000000000	
0331	++01	1000000000		0407	++00	0000000000	
0332	++70	0000000000		0410	++00	0000000000	
0333	++00	0000000000	N_p	0411	++01	3500000000	
0334	++00	0000000000	P_0	0412	++01	471238898	$3\pi/2$
0335	++00	0000000000	S_n	0413	++01	141421356	$\sqrt{2}$
0336	++00	0000000000	d_n	0414	++01	177245384	$\sqrt{2}$
0337	++00	0000000000	I_{T1}	0415	++00	886227000	
0340	++00	0000000000	I_{T2}	0416	++01	628318531	2π
0341	++00	0000000000	I_{T2}	0417	++01	314159265	π

Page 135

BLOCK II (M)

2001 015 3550 6615 0000
2002 036 0000 3064 0000

2513 056 1420 3632 2402

2635 056 0000 2640 0000
2636 005 1437 1437 1435
2637 000 0000 0000 0000
2640 004 2652 1476 1425
2641 016 2642 6646 2637
2642 002 1433 1425 1422
2643 002 1434 1427 1424

2661 002 1433 1435 1422
2662 004 1434 1422 1424
2663 002 1424 0215 0000
2664 036 0230 6756 1420
2665 002 0227 1424 0000

3040 001 7761 2675 2675
3041 013 3550 7722 3550

6373 002 0313 0000 0000
6374 036 0000 6402 0000
6375 002 0313 2601 1422

6646 004 2653 1476 1427
6647 002 7761 1433 1435
6650 002 1434 1420 1436
6710 056 0000 6373 0000
6732 002 2682 2675 0000
6733 036 7761 6707 1423

6746 005 1424 0314 1425
6747 001 1425 0334 1425
6750 044 1425 0000 1425
6751 001 0315 1425 1425
6752 002 7761 1424 1426
6753 005 7762 1426 1426
6754 004 1425 1426 1420

2003 056 0000 3045 0000
2004 000 0000 0000 0000

2644 005 1423 1422 1422
2645 005 1423 1424 1424
2646 005 1423 1435 1435
2647 001 1422 1425 1435
2650 001 1424 1427 1434
2651 056 6167 2661 1416

2666 036 0000 6746 0000
2667 016 2670 7501 7610
2670 000 0012 0150 0215
2671 075 1424 0230 1420
2672 056 0000 6756 0000

3042 056 0000 2001 0000

6376 036 0000 6372 0000
6377 004 1422 0313 1423
6400 056 0000 6406 0000

6651 002 1432 1435 1437
6652 005 1436 1436 1434
6653 056 0000 2636 0000

6734 016 2651 6647 2637

6755 044 1420 0000 1420
6756 044 1423 0000 1423
6757 000 1420 0000 0041
6760 016 6761 6455 6167
6761 044 1434 0000 1436
6762 005 7762 0041 0041
6763 056 1416 6711 6167

0314 002 0340 0000 0300 Number 0315 001 0520 0000 0000 Number

0332 001 0400 0000 0000 Number 0334 202 0467 2400 0000 Number
1.0 1.5 -13.75

Note: introduce data into cells 0313, 1420, 5222-5242

Page 136

BLOCK III (M)

2513 056 0000 3432 0000

2601 050 3000 0011 0300

2602 175 1476 6775 6373

2633 076 0000 2640 6356

2641 016 6402 6646 2637

2644 003 1422 6373 1422

2645 003 1424 6374 1424

2646 003 1435 6375 1435

6373 052 7032 0000 7615}pn

6374 000 7504 0000 7541}

6375 016 6376 7501 7613}

6376 052 6764 0042 7031}

6377 052 7032 0030 7615}pn

6400 000 7504 0030 7541}

6401 056 2635 2640 6371

6402 052 0000 0000 0000

6403 016 6404 7501 7618

6404 000 0010 0150 6764

6405 175 1476 6775 6373

6406 013 6405 2601 6405

6407 112 0002 6403 0001

6410 056 2602 2642 6405

6707 003 2653 3547 2653

6710 056 0300 6373 0300

6711 003 6375 1437 1437

6732 003 7762 3547 2652

6733 004 7756 7762 2653

6734 056 0000 6707 0000

6756 044 6375 0000 6375

BLOCK IV (H)

2717 056 0000 3037 0000

3064 056 0000 6250 0000

3122 000 0000 0000 0000

3130 504 4001 1433 4001

3131 504 4232 1434 4232

3132 112 0230 3130 0001

3133 052 0000 0000 0000

3134 505 4001 0331 4001

3135 112 0210 3134 0021

3136 056 0000 3625 0300

3137 112 0000 3140 0001

3140 400 4001 0000 4463

3141 400 4022 0000 4464

3142 400 4043 0000 4465

3143 400 4232 0000 4466

3144 456 4253 3577 4467

3577 400 4274 0000 4470

3600 400 4064 0000 4471

3601 400 4105 0000 4472

3602 400 4126 3000 4473

3603 400 4315 3000 4474

3604 400 4336 0000 4475

3605 400 4357 3000 4476

3606 400 4147 3000 4477

3607 400 4170 0000 4500

3610 400 4211 3030 4501

3611 400 4400 0000 4502

3612 400 4421 3000 4503

3613 400 4442 3000 4504

3614 452 0000 0030 3520

3615 701 4463 4471 4505

3616 701 4505 4477 4505

3617 112 0209 3615 0701

3620 000 0000 3000 0000

3621 016 3622 7501 7610

3622 052 4463 0041 4512

3623 112 0000 3140 0001

3624 056 3137 3145 3523

3625 052 0000 0000 0000

3626 054 0114 6616 0301

3627 013 3623 0001 3523

3630 033 3623 7724 3523

3631 056 0000 3140 0000

5346 056 0000 5706 0300

5715 054 0114 7724 1437

5716 056 1437 6022 1436

5717 053 5020 1436 5320

5720 053 1437 1436 1436

5721 056 0000 6164 0000

6063 456 5222 6017 5020

6254 054 0050 1440 0001

6255 033 0001 7722 0001

6256 072 0000 0001 0000

6257 016 3170 3645 3653

6275 016 3667 3066 6302

6300 032 0000 6317 0017

6304 076 0000 6312 0000

6307 016 6254 2676 2715

6313 016 3663 2676 2715

6317 016 3673 3066 6302

Page 137

BLOCK V (B)

1932	001	0043	0343	0050	4014	056	0000	4015	4111
1933	056	0000	3200	0300	4019	056	4516	4000	0029
1934	001	0043	0343	0050	4174	000	0029	0000	4516
1935	056	0000	3224	0000	4175	056	0026	4267	4517
1936	005	0002	0002	0002	4267	000	0000	0000	0029
1937	005	0001	3203	0001	4270	000	0000	0000	0026
1940	056	0000	3171	0300	4271	056	4514	4117	4104
3106	000	0000	0000	0000	4477	076	5011	4506	4553
3107	056	0000	3111	3550	4502	056	4505	4506	4553
3110	056	0000	3111	0300	4506	019	0000	3344	0000
3170	056	0000	2717	0000	4507	076	5114	4511	3113
3171	005	0002	3204	0302	4510	056	5012	4050	1632
3172	001	0001	0002	0001	4511	056	4012	3230	4052
3173	002	7761	0001	0000	4512	000	4013	0000	4116
3174	056	0000	3176	0000	4513	056	4014	4001	4122
3175	056	0000	3200	0000	4514	001	0043	0044	0046
3176	001	7761	3271	3271	4515	000	0000	0000	0046
3177	056	0000	1954	0300	4516	000	0000	0000	0000
3200	001	7761	3272	3272	4517	000	0000	0000	0000
3201	056	0000	1633	0000	4520	056	0000	4537	0000
3224	002	0047	3235	0001	4547	052	3501	0041	5671
3225	002	0050	3236	0002	4551	016	4552	7501	7610
3226	005	0001	0001	0001	4552	052	3271	0041	3272
3227	056	0000	1536	0000	4560	000	0000	0000	0000
3230	001	0341	0342	3235	4561	000	0000	0000	0000
3231	001	0343	0344	3236	4656	000	0000	0000	3271
3232	004	3235	7762	3235	4657	000	0000	0000	3272
3233	004	3236	7762	3236	5012	001	0043	0343	0050
3234	056	0000	5104	0000	5104	005	0243	0243	0001
3257	004	3517	3272	1420	5105	005	0244	0244	0002
3260	005	1420	3262	1420	5106	004	7761	0001	3203
3261	056	0000	3114	0000	5107	004	7761	0002	3264
3271	000	0000	0000	0000	5110	005	0243	0244	0001
3272	000	0000	0000	0000	5111	005	0417	0001	3262
4000	056	4517	4123	0026	5112	004	3262	0024	3262
4001	019	3344	7724	0000	5113	056	5115	5116	5115
4002	056	4006	4005	1632	5114	004	3517	3521	1420
4003	019	3344	7722	0000	5115	056	0000	3257	0000
4004	056	4007	4005	1632	5116	019	7722	3344	0000
4005	056	0000	4050	0000	5117	056	0000	4512	0000
4006	056	0000	1532	0000	5120	019	7724	3344	0000
4007	056	0000	1534	0000	5121	056	7761	4512	3262
4011	456	0313	4016	3503					
4012	056	4515	4046	4104					
4013	056	0300	4174	4071					

Note: introduce data into cells 0243, 0244, 3344

Page 138

BLOCK VI (K)

1504 056 0000 6603 0000

1532 001 0043 0343 0050
1533 056 0000 3035 0000
1534 001 0043 0343 0050
1535 056 0000 3224 0000

1536 003 0002 0002 0003
1537 003 0001 3203 0001
1540 056 0000 3026 0000

2527 056 0000 2720 2524

2717 056 0000 3037 0003
2720 056 0034 1440 0001
2721 013 0001 0000 0003
2722 036 0000 2530 0000
2723 000 0000 0000 0000
2724 000 0000 0000 0000
2725 000 2544 0000 0001
2726 000 2600 0000 0002
2727 000 3346 0000 2544
2730 016 2731 3171 2500
2731 000 0001 0000 2544
2732 000 0002 0000 2600
2733 003 1417 0031 3000
2734 013 3000 0000 0000
2735 036 7761 3001 4777
2736 016 2737 7501 7610
2737 052 1430 0033 0045
2740 052 1420 0000 0003
2741 004 7761 3000 3000
2742 003 1476 3000 3004
2743 452 0000 0000 2730
2744 303 1420 3000 3001
2745 703 3001 1420 3003
2746 303 1420 3004 3013
2747 112 0002 2744 0001
2750 000 0000 0000 0003
2751 003 3001 1421 3010
2752 003 3002 1422 3011
2753 003 3001 1422 3012
2754 034 0030 1440 0001
2755 031 0001 7722 0001
2756 072 0000 0001 0000
2757 002 1417 0000 0000
2760 036 0000 2766 0000
2761 301 4777 4001 4001
2762 013 2761 2773 2761
2763 013 2761 2774 0000
2764 073 0000 2761 0000
2765 056 2776 3030 2761
2766 301 4777 4021 4021
2767 013 2766 2773 2766

2770 013 2766 2773 0000
2771 076 0000 2766 0000
2772 056 2777 3000 2766
2773 000 3001 0040 0040
2774 301 3016 4741 4741
2775 301 3016 4761 4761
2776 301 4777 4001 4001
2777 301 4777 4021 4021
3000 000 0000 0000 0000
3001 000 6523 0000 0046
3002 000 6526 0000 0047
3003 000 6527 0000 0050
3004 000 0000 0000 0000
3005 056 0000 7030 0000
3006 000 6523 0000 3011
3007 000 6526 0000 3012
3010 056 6527 6271 3013
3011 000 0000 0000 0000
3012 000 0000 0000 0000
3013 000 0000 0000 0000
3014 302 3522 6522 3522
3015 000 3011 0000 6525
3016 000 3012 0000 6526
3017 056 3013 3067 6527
3020 000 0040 0040 0020
3021 000 0000 0000 0000
3022 000 0020 0000 0000
3023 000 0000 0020 0000
3024 000 0000 0000 0020
3025 000 0040 0000 0000
3026 003 0002 3264 0002
3027 001 0001 0002 0001
3030 002 7761 0001 0000
3031 036 0000 3033 0000
3032 056 0000 3035 0000
3033 011 7761 6606 6606
3034 056 0000 1554 0000
3035 011 7761 6607 6607
3036 056 0000 1633 0000
3037 056 0000 3006 0000

3066 056 0000 3014 0300

3106 000 0000 3000 0000
3107 056 0000 3111 3350

3110 056 0000 3111 0000

3122 000 0000 3030 3350

Page 139

3127 003 3504 7757 0300	3132 005 3517 3519 1420
3130 076 3521 3132 1421	3133 056 0000 2101 0000
3131 056 3517 2101 1420	
3170 056 0000 2717 0000	3172 001 0245 0070 0070
3171 000 0370 0000 0070	3173 056 0000 2531 0000
3224 002 0047 3235 0001	3233 004 3236 7762 3236
3225 002 0050 3236 0002	3234 056 0000 5104 0000
3226 003 0001 0001 0001	3235 000 0000 0000 0000
3227 056 0000 1536 0000	3236 000 0000 0000 0000
3230 001 0341 0342 3235	3237 004 3517 6607 1420
3231 001 0343 0344 3236	3240 003 1420 3262 1420
3232 004 3235 7762 3235	3241 056 0000 3114 0000
4000 056 4517 4123 0026	4007 056 0000 1534 0000
4001 015 3344 7724 0000	4010 072 0000 6614 0000
4002 056 4006 4005 1632	4011 456 0513 4016 3503
4003 015 3344 7722 0000	4012 056 4515 4006 4104
4004 056 4007 4005 1632	4013 056 0000 4174 4071
4005 056 0000 4050 0300	4014 056 0000 4015 4111
4006 056 0000 1532 0000	4015 056 4516 4000 0025
4174 000 0025 0000 4516	4175 056 0026 4267 4517
4267 000 0000 0000 0025	4271 056 4514 4117 4104
4270 000 0000 0000 0026	
4476 003 3504 7757 0300	4507 076 3114 4511 3113
4477 076 5011 4504 6553	4510 056 5012 4050 1632
4500 000 4503 0000 4130	4511 056 4012 3230 4052
4501 000 4504 0000 3114	4512 000 4013 0000 4110
4502 056 4505 4506 6553	4513 056 4014 4001 4122
4503 000 7761 0000 0041	4514 001 0043 0044 0046
4504 004 3510 7762 1437	4515 000 0000 0000 0046
4505 003 3510 3510 1432	4516 000 0000 0000 0000
4506 015 3344 0000 0000	4517 000 0000 0000 0000
4520 056 0000 4537 0000	
4547 052 3501 0041 5671	4561 000 0000 0000 0000
4560 000 0000 0000 0000	4567 000 0000 0000 6607
4566 000 0000 0000 6606	
4710 056 3516 5013 5517	
5012 001 0043 0343 0350	5013 000 0000 0000 4711
5013 015 3514 0000 0300	5016 056 5017 4711 4545
5014 076 0000 4711 0000	5017 100 0000 0000 1417
5104 005 0243 0243 0001	5113 056 5115 5116 3113
5105 005 0244 0244 0002	5114 004 3517 3521 1420
5106 004 7761 0001 3263	5115 056 0000 3237 0000
5107 004 7761 0002 3264	5116 015 7722 3344 0000
5110 005 0243 0244 0001	5117 056 0000 4512 0000
5111 005 0417 0001 3262	5120 015 7724 3344 0000
5112 004 3262 0024 3262	5121 056 7761 4512 3262

Page 140

5330 056 0000 3700 0000
5331 015 3344 0000 0000
5332 036 0000 2103 0000
5333 005 1420 3262 1420
5334 070 6537 0000 1421
5335 004 1420 1421 1422
5336 005 3510 1422 1423
5337 004 1422 3510 1424
5338 005 7762 7763 1427
5341 305 1427 1424 1425
5342 004 1424 3510 1426
5343 032 0000 2334 0000
5344 504 4001 1421 4001
5345 505 4041 1423 4041
5346 505 4241 1425 4241
5347 112 0037 2114 0001
5350 032 0000 2253 0000
5351 505 4101 1422 4101
5352 505 4301 1424 4301
5353 505 4441 1424 4441
5354 505 4601 1426 4601
5355 112 0137 2121 0001
5356 452 0000 0000 2132
5357 701 4041 4061 4741
5360 112 0017 2127 0001
5361 013 2127 3020 2127
5362 000 0000 0000 0000
5363 112 0155 2126 0001
5364 000 0010 0000 0000
5365 052 0000 0000 0000
5366 415 4741 0000 0000
5367 436 4741 2172 0007
5370 704 4761 4741 4761
5371 704 5001 4741 5001
5372 704 5021 4741 5021
5373 704 5041 4741 5041
5374 030 0000 0000 0700
5375 000 0000 0000 0300
5376 605 4761 4761 0301
5377 605 5001 5001 0002
5400 605 5021 5021 0003
5401 001 0301 0002 0004
5402 101 0004 0003 5521
5403 205 1427 5521 3004
5404 502 5041 0004 5041
5405 605 4761 5001 0004
5406 605 5001 5021 0305
5407 605 4761 5021 0006
5410 452 0000 0000 2163
5411 505 0001 0037 0301
5412 112 3005 2161 0301
5413 300 0000 0000 0303
5414 502 5061 0001 5301
5415 504 5101 0002 5321
5416 502 5121 0003 5341
5417 502 5141 0004 5361
5420 502 5161 0005 5401
5421 502 5201 0006 5421
5422 112 0017 2136 0301
5423 003 0000 0000 0000

5424 000 0000 0000 0000
5425 052 0000 0000 0000
5426 605 5301 4761 0001
5427 005 5361 5001 0002
5430 605 5421 5021 0003
5431 001 0001 0002 0004
5432 001 0004 0003 0004
5433 005 7762 0004 0004
5434 601 4241 4261 0005
5435 004 0005 1427 0005
5436 205 0005 4761 0005
5437 402 5221 0004 0002
5440 102 0002 0005 5441
5441 112 0017 2176 0001
5442 013 2207 3022 2207
5443 013 2206 3023 2206
5444 013 2210 3024 2210
5445 000 0000 0000 0000
5446 013 2176 3025 2176
5447 013 2176 3022 2176
5450 033 2177 3025 2177
5451 033 2200 3022 2200
5452 016 2223 2175 2215
5453 013 2176 3025 2176
5454 013 2177 3025 2177
5455 013 2177 3022 2177
5456 033 2200 3025 2200
5457 016 2230 2175 2215
5460 056 0000 2236 0000
5461 000 0000 0000 0000
5462 000 0000 0000 0000
5463 000 0000 0000 0000
5464 000 0000 0000 0000
5465 000 0000 0000 0000
5466 000 0000 0000 0000
5467 000 0000 0000 0000
5470 000 0000 0000 0000
5471 000 0000 0000 0000
5472 000 0000 0000 0000
5473 052 0000 0000 0000
5474 415 4041 0030 0000
5475 036 0000 2253 0000
5476 704 4101 4041 4101
5477 704 4141 4041 4141
5500 704 4201 4041 4201
5501 504 4241 1427 4241
5502 000 3000 0070 0000
5503 112 0037 2244 0001
5504 032 3000 2247 0000
5505 452 0000 3030 2260
5506 302 0030 4061 4061
5507 112 0017 2256 0001
5510 000 0000 0000 0000
5511 013 2256 2265 2256
5512 112 0015 2255 0001
5513 056 2264 2266 2256
5514 502 0000 4061 4061
5515 000 0000 0040 0040
5516 032 0000 2121 0000
5517 505 4001 0331 4001

Page 141

5520 112 1520 2267 0020
5521 054 0130 6137 1431
5522 013 2351 1431 2351
5523 013 3022 6137 1432
5524 052 0000 0000 0000
5525 544 5521 0000 5521
5526 705 4741 5041 5541
5527 112 0017 2275 0001
5530 000 0000 0000 1430
5531 032 0000 0000 0000
5532 100 0000 0000 2500
5533 112 0023 2302 0001
5534 052 0000 0000 0000
5535 452 0000 0000 2313
5536 401 4741 2500 2500
5537 401 5041 2501 2501
5540 401 5541 2502 2502
5541 401 5521 2503 2503
5542 112 0002 2306 0001
5543 000 0000 0000 0000
5544 452 0000 0000 2317
5545 513 2306 2322 2306
5546 112 0003 2315 0001
5547 000 0000 0000 0000
5550 112 0004 2305 0001
5551 032 0000 2327 0000
5552 000 0003 0004 0004
5553 401 4741 2500 2500
5554 401 5041 2501 2501
5555 401 5541 2502 2502
5556 401 5521 2503 2503
5557 500 2323 0000 2306
5560 112 0003 2327 0001
5561 504 2474 7763 2474
5562 112 0027 2331 0001
5563 032 0000 2374 0000
5564 054 0130 6137 1431
5565 013 2341 1431 2341
5566 013 3022 3024 0004
5567 452 0000 0000 2342
5570 704 4041 3242 4041

5706 050 0015 0001 6030
5707 070 5331 0000 0000

6603 016 6604 7501 7610
6604 052 3242 0042 3261
6605 056 0000 2507 0000

5571 112 7777 2340 0001
5572 000 0000 0000 0000
5573 013 2340 0004 2340
5574 112 0033 2337 0001
5575 032 0000 2114 0000
5576 452 0000 0000 2364
5577 452 0000 0000 2352
5600 500 4001 0000 4001
5601 112 7777 2350 0001
5602 000 0000 0000 0000
5603 013 2361 6137 2361
5604 013 2350 1432 2350
5605 013 1430 1431 1430
5606 000 0000 0000 0000
5607 112 0016 2347 0001
5610 016 2361 7501 7610
5611 052 4001 0041 4000
5612 013 2361 1430 2361
5613 000 0000 0000 1430
5614 000 0000 0000 0000
5615 112 0002 2346 0001
5616 000 0000 0000 0000
5617 033 2357 2373 2357
5620 013 2365 7724 2365
5621 016 3165 2346 2366
5622 000 0000 0000 0000
5623 000 0000 0000 0000
5624 013 2401 6137 2401
5625 052 0000 0000 0000
5626 705 4741 5521 2101
5627 112 0017 2376 0001
5630 000 0000 0000 0000
5631 000 0000 0000 0000
5632 000 6606 0000 2524
5633 000 6607 0000 2525
5634 016 2405 7501 7610
5635 052 2500 0041 2525
5636 000 0000 0000 0000
5637 000 0000 0000 0000
5640 032 0000 2346 0000

5710 050 4411 0001 6030
5711 070 5331 5706 0000

6606 000 0000 0000 0000
6607 000 0000 0000 0000

Note: introduce data into cells 0243,0244,3242-3261,
3344,5222-5242,6137

Page 142

BLOCK VII (p)

0257 003 0400 0000 0000
 2764 056 0000 2771 0000
 3336 000 1421 0000 1424
 3333 000 0000 0000 0000
 3676 000 0000 0000 0000
 3673 000 0000 0000 0000
 3676 000 0000 0000 0000
 3701 000 0000 0000 0000
 3702 000 0000 0000 0000
 3703 112 0143 3331 0001

BLOCK VIII (p)

0257 003 0400 0000 0000
 2764 056 0076 2771 0076
 3335 000 1420 0000 1423
 3676 112 0143 3334 0001
 3703 000 0000 0000 0000

PROGRAM A

2024 100 0000 0000 2101
 2023 112 0023 2024 0001
 3060 100 0000 0000 2101
 3061 112 0023 3060 0001
 3267 112 0004 6366 0001
 3334 000 0003 0001 0001
 6366 401 4001 2101 2101
 6367 112 0004 6366 0001
 6372 056 0000 6404 0000
 6374 052 2101 0041 2124
 6403 056 3267 3143 6367
 6604 001 7762 7763 0046
 6605 504 2101 0046 2101
 6606 112 0023 6363 0001
 6607 056 0000 6373 0000

Note: program A
 must be added to
 blocks VII and
 VIII

Page 143

BLOCK IX

					Num- ber										
0734	104	0400	0000	0000	10 ⁻⁵	1030	112	0126	4426	0001					
0735	050	0412	4000	0114		1031	000	7761	0000	5051					
0736	070	4000	0050	0000		1032	016	4433	4410	4422					
0737	056	0000	1504	0000		1033	000	0000	0000	4422					
0740	016	0741	7501	7610		1034	052	0000	0000	0000					
0741	052	0100	0042	0734		1035	500	5043	0000	5740					
0742	016	0743	7501	7610		1036	500	5035	0000	5743					
0743	052	1416	0042	1477		1037	112	0002	4435	0001					
0744	056	0734	1371	0034		1040	500	5732	0000	5032					
0745	500	0420	0000	4020		1041	112	0126	4440	0001					
0746	112	0775	0745	0001		1042	015	5034	0000	0000					
0747	056	0737	4350	0052		1043	076	7761	4477	1470					
0750	052	0000	0000	0000		1044	002	7761	5050	6001					
0751	054	0114	1364	0014		1045	044	4001	0000	5135					
0752	013	4742	0014	4742		1046	001	7761	5050	6002					
0753	452	0000	0000	4356		1047	044	6002	0000	6002					
0754	500	4020	0000	5020		1050	044	5050	0000	5143					
0755	112	0013	4354	0001		1051	000	0000	0000	5140					
0756	000	0000	0000	0000		1052	004	5050	6002	5136					
0757	400	5201	0000	5034		1053	002	0000	5136	5136					
0760	452	0000	0000	4741		1054	004	5143	6002	5137					
0761	100	0000	0000	5035		1055	002	0000	5137	5137					
0762	112	0142	4361	0001		1056	004	7761	6002	5141					
0763	100	0000	0000	1275		1057	000	5137	0000	5142					
0764	112	0200	4363	0001		1060	004	5135	6002	5145					
0765	052	0000	0000	0000		1061	005	5145	5143	5144					
0766	702	5023	5020	6001		1062	016	4463	7501	7610					
0767	702	5024	5020	6004		1063	052	5135	0036	5035					
0770	705	6001	6001	6007		1064	052	1450	0000	0003					
0771	705	6004	6004	6012		1065	000	0000	0000	0000					
0772	401	6007	5146	5146		1066	000	5137	0000	1444					
0773	401	6012	5147	5147		1067	000	5137	0000	1445					
0774	112	0002	4366	0001		1070	005	5135	5047	1467					
0775	044	5146	0000	5046		1071	002	0000	5145	1447					
0776	044	5147	0000	5047		1072	002	5020	1456	1461					
0777	504	5776	5046	5032		1073	002	5021	1457	1462					
1000	504	6001	5047	5147		1074	002	5022	1460	1463					
1001	112	0005	4377	0001		1075	005	5135	5046	1465					
1002	605	5027	5144	0001		1076	056	5145	4725	1466					
1003	001	6001	5050	5050		1077	015	5034	7724	0000					
1004	112	0010	4402	0001		1100	076	0000	4660	0000					
1005	005	5050	5050	6001		1101	000	0000	0000	0000					
1006	002	0252	6001	6001		1102	000	0000	0000	0000					
1007	044	6001	0000	5051		1103	056	0000	4602	0000					
1010	052	0000	0000	0000		1104	002	0000	7761	5135					
1011	005	5036	5154	6001		1105	044	7762	0000	0014					
1012	005	5155	5037	6004		1106	052	0000	0000	0000					
1013	005	5037	5152	6002		1107	100	0000	0000	5136					
1014	005	5035	5154	6005		1110	112	0007	4507	0001					
1015	005	5035	5155	6003		1111	004	0014	7762	5145					
1016	005	5036	5152	6004		1112	002	0000	5145	5141					
1017	702	6001	6004	6007		1113	000	5145	0000	5142					
1020	504	6007	5051	5045		1114	000	5145	0000	5144					
1021	112	0002	4417	0001		1115	016	4516	4462	4465					
1022	000	0000	0000	0000		1116	000	0000	0000	4465					
1023	052	0000	0000	0000		1117	002	5046	5031	6001					
1024	500	5035	0000	5735		1120	004	5046	6001	6001					
1025	112	0123	4424	0001		1121	005	5047	6001	5052					
1026	500	4711	0000	5026		1122	050	0000	4765	6102					
1027	500	4717	0000	4711		1123	052	0000	0000	0000					

Page 144

1124 603 1436 3132 6003
1125 301 6003 5102 6102
1126 112 0002 4324 0001
1127 005 6102 3032 6002
1130 303 1433 6002 6000
1131 303 3147 3032 6003
1132 732 6000 6003 6006
1133 702 3013 6006 1436
1134 703 6000 6000 6011
1135 401 6011 3103 3103
1136 702 3020 1436 6015
1137 703 6013 6015 6020
1140 401 6020 3102 3102
1141 703 6006 6006 6024
1142 401 6024 3101 3101
1143 112 3003 4330 0001
1144 044 3101 0000 3101
1145 044 3102 0000 3102
1146 044 3103 0000 3103
1147 304 6003 3101 6024
1150 304 6012 3132 6027
1151 703 1443 6024 6032
1152 703 1443 6027 6035
1153 703 3027 6024 6040
1154 703 3027 6027 6043
1155 401 6032 3104 3104
1156 401 6033 3103 3103
1157 401 6040 3106 3106
1160 401 6043 3107 3107
1161 112 0010 4347 0001
1162 332 0000 3100 0000
1163 310 4364 7301 7610
1164 373 3104 3006 6001
1165 112 0001 4363 0001
1166 002 3106 3000 0000
1167 376 3142 4371 1443
1170 000 6001 4372 1464
1171 002 0417 3031 1464
1172 302 3107 3030 0000
1173 376 3142 4373 1446
1174 330 6002 4376 1443
1175 307 0417 3032 1463
1176 303 6102 3047 1467
1177 303 3103 3142 1447
1200 002 0000 1447 1447
1201 036 0000 4723 0000
1202 004 3047 3046 3133
1203 303 3133 3133 6001
1204 302 7761 3071 6001
1205 352 0000 3030 0000
1206 100 0000 3030 3136
1207 112 3007 4630 0001
1210 344 6001 3030 3137
1211 302 3003 3137 3143
1212 000 3133 0000 3143
1213 000 7761 3000 3141
1214 310 4613 4662 4663
1215 000 3137 3000 1444
1216 000 3143 3000 1446
1217 003 3046 3137 1447

1220 001 1447 7761 6001
1221 003 6001 3133 1447
1222 002 0000 1447 1447
1223 032 0000 0000 0000
1224 303 1436 6001 1461
1225 702 3020 1461 1461
1226 112 0002 4624 0001
1227 002 7761 3032 3014
1230 003 0014 7762 6001
1231 003 6001 7762 6001
1232 021 6001 7733 6002
1233 002 6001 6002 6003
1234 002 6003 7737 6004
1235 074 0000 4640 1464
1236 003 7736 6002 1463
1237 036 3047 4636 1467
1240 303 0014 0416 6003
1241 016 4642 7301 7610
1242 073 6003 0011 6006
1243 004 6006 3133 6007
1244 316 4643 7301 7610
1245 073 6007 0012 6010
1246 013 6002 0000 0000
1247 376 3047 4631 1467
1250 036 6010 4634 1463
1251 013 7763 6002 0000
1252 076 0000 4633 0000
1253 001 0416 6010 1463
1254 036 0000 4636 0000
1255 001 0417 6010 1463
1256 003 3031 3047 1466
1257 036 0000 4723 4663
1260 036 0000 4777 0000
1261 300 3033 0000 1450
1262 112 0010 4661 0001
1263 300 3007 0000 1450
1264 112 0013 4663 0001
1265 303 3031 3031 3136
1266 304 7761 3132 1423
1267 112 0016 4666 0001
1270 002 7761 3032 6001
1271 003 0416 6001 1463
1272 013 3034 7722 0000
1273 076 0000 4717 1470
1274 002 3031 0000 0000
1275 076 0000 4700 1443
1276 002 0000 3031 1467
1277 036 3734 4723 1447
1300 034 0102 3033 6010
1301 034 0076 6010 6001
1302 003 3047 3031 6002
1303 002 3047 6001 6003
1304 004 6002 6003 1467
1305 003 1467 1467 6004
1306 004 7761 6004 1443
1307 002 0000 1443 1443
1310 032 0000 0000 0000
1311 403 1436 1467 6001
1312 302 3023 6001 1461
1313 112 0002 4711 3001

Page 145

1314	001	1467	0034	1466	1340	013	4736	3444	4736
1315	002	1466	5031	1466	1341	000	0000	0000	0000
1316	056	0000	4725	1447	1342	112	7777	4353	0001
1317	002	7761	5033	0001	1343	052	6764	0000	7615
1320	005	6001	0417	1467	1344	000	7504	0000	7541
1321	056	5734	4725	1447	1345	056	0000	0050	0000
1322	000	0000	0000	0002	1346	054	0130	4736	6000
1323	000	0000	0000	0001	1347	013	4750	6000	4750
1324	000	0014	0000	0000	1350	030	0000	4751	0077
1325	013	5733	7722	5733	1351	033	6616	4741	6001
1326	015	5732	5733	0000	1352	054	0114	6001	6002
1327	076	0000	4734	1471	1353	054	0050	6000	6003
1330	001	0330	0000	0000	1354	013	4762	6000	4762
1331	076	7761	4734	1471	1355	013	4762	6003	4762
1332	000	5734	0000	1471	1356	013	4760	6002	4760
1333	000	0000	0000	0000	1357	013	4762	3444	4762
1334	013	4354	4724	4334	1360	112	7776	4757	0001
1335	052	0000	0000	0000	1361	016	4762	7501	7610
1336	500	1440	0000	0420	1362	052	0000	0042	0000
1337	112	0035	4736	0001	1363	056	0000	0050	0000
1365	052	0000	0000	0000	1375	000	0000	0000	5733
1366	100	0000	0000	9100	1376	032	0000	0745	0000
1367	112	0010	4766	0001	1377	002	5031	0000	0000
1370	056	0000	4523	0000	1400	076	0000	5002	0000
1371	002	0000	7761	5734	1401	032	0000	4661	0000
1372	021	0330	7753	5732	1402	002	5033	0000	0000
1373	061	7751	5732	5732	1403	076	0000	5001	0000
1374	055	5732	7732	5732	1404	032	0000	4504	0000
1502	000	0735	0000	0050	1503	056	0736	0740	0051

Note: introduce data into cells 1364, 6616, and 1345
(except for block IX)

APPENDIX 2
CALCULATION EXAMPLES

Example 1

Assignment of numbers and instructions for calculating the aerodynamic coefficients of a complex body (see Fig. 7)

1. Numbers

Address	Number	Address	Number	Address	Number	Parameter
0420	-2	0457	0	0516	0	
0421	-2	0460	2	0517	-11	
0422	0	0461	-2	0520	0	
0423	-3	0462	0	0521	2	
0424	-3	0463	0	0522	-9	
0425	0	0464	-2	0523	0	
0426	-4	0465	2	0524	0	
0427	-2	0466	0	0525	2	
0430	0	0467	-4	0526	0	
0431	0	0470	2	0527	0	
0432	0	0471	0	0332	0	
0433	0	0472	-3	0260	0	α_0
0434	-2	0473	3	0274	0	β_0
0435	0	0474	0	0310	160	H
0436	0	0475	1	0313	1	α_s
0437	-2	0476	0	0334	1	p_0
0440	0	0477	-1	0335	12,5663706	S_M
0441	2	0500	-4	0336	4	d_M
0442	-2	0501	0	0337	-13,01	x_{11}^0
0443	2	0502	0	0340	0,01	x_{21}^0
0444	0	0503	-4	0341	-3	x_{12}^0
0445	2	0504	0	0342	3	x_{22}^0
0446	0	0505	2	0343	-2,01	x_{13}^0
0447	0	0506	-4	0344	2,01	x_{23}^0
0450	-4	0507	2	0317	-3	x_{T1}^0
0451	0	0510	0	0250	320	T_w
0452	0	0511	0,5	0253	1000	N_{1p}
0453	-4	0512	0	0254	6000	N_{2p}
0454	2	0513	0	0256	1000	N_{3p}
0455	0	0514	-11	0333	2000	N_{4p}
0456	-4	0515	0			

Page 147

2. Instructions

Address	Instructions	Address	Instructions
5201	000 0000 0000 0000	6615	000 0000 0100 0000
5202	000 0000 0001 0000	6616	000 0000 0007 0000
5203	000 0000 0001 0000	6617	000 0000 0001 0000
5204	000 0000 0001 0000	6620	000 0000 0001 0000
5205	000 0001 0000 0000	6621	000 000 0001 0000
5206	000 0000 0000 0001	6622	000 0000 0001 0000
5207	000 0000 0001 0000	1364	000 0000 0006 0000

3. Block II; numbers and instructions to block II

Address	Numbers and instructions	Address	Numbers and instructions
0313	-1	5225	000 0134 0152 0170
1420	10 ¹³	5226	000 0134 0152 0170
5222	000 0134 0152 0170	5227	000 0134 0152 0170
5223	000 0134 0152 0170	5230	000 0134 0152 0170
5224	000 0134 0152 0170		

4. Blocks IV, IX, instruction to block IX

Address	Instruction
1345	000 0000 0000 0000

5. Punched card with control sum equal to zero

6. Numbers (without address code)

Position #	Num- ber	Pos. #	Num- ber	Pos. #	Num- ber	Pos. #	Number	Pos. #	Number
1	7	7	-1	13	0	19	0	25	0
2	1	8	0	14	-1	20	0	26	0
3	1	9	0	15	-1	21	0	27	0
4	0	10	1	16	0	22	6,28318531	28	0
5	0	11	0	17	0	23	0	29	0
6	0	12	0	18	-3	24	4	30	0

7. Punched card with control sum equal to zero

Results of calculation of the aerodynamic coefficients of surface 6
with $N_p = 2000$

Parameter	Calculated values of the parameters	
	without the use of block II	using block II
c_{+6i}	+-- 00 25333314	
	+-- 02 38246653	
	++- 03 43034721	
	++- 02 16433219	
m_{+6i}	+-- 02 29514657	
	++- 01 14184753	
c_{-6i}	+-- 02 52467521°	+-- 01 95118551
	++- 03 13349649	+-- 02 63304634
	+-- 02 16996168	+-- 02 38108233
	++- 03 59884535	++- 02 60868448
m_{-6i}	+-- 02 47080428	+-- 01 12316268
	++- 06 10030515	++- 01 16308264
	+-- 03 23085248	++- 00 00000000
	+-- 05 40420692	++- 00 00000000
c_{r6i}	++- 03 18622387	++- 00 00000000
	++- 04 71240455	++- 00 00000000
	++- 03 42093157	++- 00 00000000
	++- 04 97449755	++- 00 00000000
c_{6i}	+-- 00 25881075	+-- 00 34845169
	+-- 02 36952109	+-- 01 10155128
	+-- 02 10830457	+-- 02 33804760
	++- 02 23134077	++- 02 77301667
m_{6i}	+-- 02 72385769	+-- 01 15267734
	++- 01 14282303	++- 01 30493017

Example 2

Assignment of numbers and instructions for calculating local flows to
the inner surface of a cylinder (see Fig. 8)

1. Numbers

Address	Number	Address	Number	Parameter	Address	Number	Parameter
0420	0	0440	1,0	-	0336	2,0	d_n
0421	0	0441	0	-	0337	-0,01	x_{11}^0
0422	0	0442	0	-	0340	3,0	x_{21}^0
0423	0	0443	0	-	0341	-1,0	x_{12}^0
0424	1,0	0444	1,0	-	0342	1,0	x_{22}^0
0425	0	0445	-3,0	-	0343	-1,0	x_{13}^0

Page 149

Continued

Address	Number	Address	Number	Parameter	Address	Number	Parameter
0426	0	0446	0	—	0344	1,0	x_{23}^0
0427	0	0447	0	—	0243	1,0	—
0430	1,0	0310	100	H	0244	1,0	—
0431	0	0107	3048	V_{∞}	0253	1000	$N_1 p$
0432	0	0116	574	$\bar{V}$	0254	5000	$N_2 p$
0433	0	0125	452	T_{∞}	0256	1000	$N_3 p$
0434	0	0313	1,0	α_*	0333	5000	$N_4 p$
0435	0	0250	300	T_w	0330	-2,0	—
0436	0	0334	1,0	p_0	—	—	—
0437	0	0335	3.14159265	S_M	—	—	—

2. Instructions

Address	Instructions	Address	Instructions
6616	000 0000 0002 0000	1364	000 0000 0002 0000
6617	000 0000 0001 0000	5201	000 0001 0000 0000
6620	000 0000 0001 0000	5202	000 0000 0001 0000
6621	000 0000 0001 0000	3344	000 0000 0001 0000
6622	000 0000 0001 0000		

3. Blocks V, VIII (with program A) and IX.

4. Punched card with control sum equal to zero

Results of calculation of the flow of particles to the inner
surface of a cylinder with $N_p = 5000$

Values of index k	Calculated values of n_{rk}	Values of index k	Calculated values of n_{rk}
1	—++ 01 162410450	11	—++ 01 110155920
2	+++ 01 166203118	12	+++ 01 102991993
3	—++ 01 152718078	13	—++ 01 100126422
4	+++ 01 151453855	14	+++ 00 967551620
5	—++ 01 140244416	15	—++ 00 855457225
6	+++ 01 147071217	16	+++ 00 808259585
7	—++ 01 129624947	17	—++ 00 751790980
8	+++ 01 126759376	18	+++ 00 644753475
9	—++ 01 119342604	19	—++ 00 589970500
10	+++ 01 116561314	20	+++ 00 473662030

Page 150

Example 3

Assignment of numbers and instructions for calculating flow parameters
in the outlet section of a complex channel (see Fig. 9)

1. Numbers

Address	Number	Address	Number	Address	Number	Parameter
0420	1	0453	0	0506	1	—
0421	1	0454	0	0507	0	—
0422	1	0455	0	0510	0	—
0423	-0, 12	0456	2	0511	0	—
0424	0	0457	0	0512	0	—
0425	0	0460	0	0513	0	—
0426	0	0461	0	0310	100	H
0427	-1	0462	0	0107	8000	V_{∞}
0430	0	0463	0	0313	1	a_*
0431	1	0464	1	0332	0	—
0432	0	0465	-1	0334	1	p_0
0433	0	0466	0	0335	3.14159265	S_m
0434	0	0467	1	0336	2	d_m
0435	1	0470	0	0337	0	x_{11}^0
0436	1	0471	0	0340	5	x_{21}^0
0437	0	0472	0	0341	-2, 0	x_{12}^0
0440	0	0473	1	0342	2, 0	x_{22}^0
0441	0	0474	1	0343	-2, 0	x_{13}^0
0442	0	0475	0	0344	2, 0	x_{23}^0
0443	0	0476	0	0243	2, 0	—
0444	0	0477	-1	0244	2, 0	—
0445	6, 25318531	0500	0	3242	3, 14159265	S_λ
0446	0	0501	0	0253	1000	$N_1 p$
0447	5	0502	0	0254	3000	$N_2 p$
0450	0	0503	6, 28318531	0256	1000	$N_3 p$
0451	0	0504	0	0333	1000	$N_4 p$
0452	0	0505	1	0250	1000	T_w

Page 151

2. Instructions

Address	Instructions	Address	Instructions
6616	000 0000 0002 0000	5202	000 0001 0000 0000
6617	000 0000 0001 0000	5222	000 0000 0000 0000
6620	000 0000 0001 0000	5223	001 0000 0000 0000
6621	000 0000 0001 0000	3344	000 0000 0001 0000
6622	000 0000 0001 0000	6137	000 0000 0000 0001
3201	000 0000 0001 0000		

3. Instructions of transducer of pseudo-random numbers

Address	Instructions	Address	Instructions
6676	3 14 0115.0000.0002	6727	1 00 0631.4552.5460
6677	6 15 0000.0002.0001	6730	0 00 7777.4000.0000
6700	2 55 0001.0001.0001	6731	0 00 0000.0000.0000
6701	0 14 0054.0001.0001	6732	1 00 1553.1637.2470
6702	5 75 0002.0001.0000	6733	0 00 7777.4000.0000
6703	5 21 0000.0000.0002	6734	0 00 0000.0000.0000
6704	0 00 0000.0000.0000	6735	1 00 5462.0414.7660
6713	1 00 5042.7732.6410	6736	0 00 7777.4000.0000
6714	0 00 7777.4000.0000	6737	0 00 0000.0000.0000
6715	0 00 0000.0000.0000	6740	1 00 0766.2410.1200
6716	1 00 2704.4152.0170	6741	0 00 7777.4000.0000
6717	0 00 7777.4000.0000	6742	0 00 0000.0000.0000
6720	0 00 0000.0000.0000	6743	1 00 2021.3542.3620
6721	1 00 0345.5747.7460	6744	0 00 7777.4000.0000
6722	0 00 7777.4000.0000	6745	0 00 0000.0000.0000
6723	0 00 0000.0000.0000	6746	1 00 7106.5141.5200
6724	1 00 1576.1653.0570	6747	0 00 7777.4000.0000
6725	0 00 7777.4000.0000	6750	0 00 0000.0000.0000
6726	0 00 0000.0000.0000		

Page 277

4. Block VI

5. Punched card with control sum equal to zero

Results of calculation of the parameters
of a gas in the outlet section of a
complex channel with $N_p = 3000$

Parameter	Calculated values of the parameters
$W_{+\lambda}$	---+ 00 35301507
n_{λ}	---+ 01 73347279
$V'_{3(\lambda)}$	---+ 01 15401366
T'_{λ}	---+ 01 46998838
$q'_{3(\lambda)}$	---+ 03 24781755

END

FILMED

10-83

DTIC