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INVISCID BLUNT BODY SHOCK LAYERS

Two-Dimensional Symmetric and Axisymmetric Flows

by

Gino Moretti

POLYTECHNIC INSTITUTE OF BROOKLYN

DEPARTMENT
of
AEROSPACE ENGINEERING
and
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ABSTRACT

The results of a time-dependent computation of blunt body shock layers for two-dimensional symmetric and axisymmetric flows are presented in a systematic form for a range of values of the free stream Mach number and bodies of different shapes and variable bluntness.

A brief discussion of the relevant features of the computational technique is given. The results are presented in a graphical form; the graphs have been produced by the computer.

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** Professor, Department of Aerospace Engineering and Applied Mechanics.

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1. Introduction

The main features of the flow field about the blunt nose of a vehicle flying at supersonic speed are, qualitatively, well-known. A complete, detailed description of the flow, however, is hard to obtain. Formulae for the determination of some relevant parameters are available, which generally rely on simplifying assumptions. More detailed results can be achieved through the use of numerical techniques on high-speed computers.*

One of these techniques, which was considered for the first time in 1965 (Refs. 1 and 2) appeared as well-suited for practical purposes. As in most numerical procedures, the flow field is computed at the nodal points of a mesh. The mesh covers the shock layer only. Its fineness is controlled by two parameters in plane and axisymmetric problems, and by three parameters in three-dimensional problems. Obviously, the finer the mesh, the longer the computational time required to obtain the solution.** One important advantage of the technique resides in the fact that, even when an extremely coarse mesh is used, the values at the nodal points may be sufficiently accurate to provide a useful

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* Hayes and Probstein's book on Hypersonic Flow (Academic Press, 1967) contains an exhaustive description and a critical analysis of practically all methods published in the open literature until 1965.

** In problems involving two space parameters, halving the mesh size in both directions lengthens the computational time by a factor of 8. A factor of 16 is related to the halving of the mesh size in all three directions in a three-dimensional problem.

preliminary description of the flow field. If the mesh is coarse, the computational time is of the order of a few seconds.* By increasing the number of nodal points, not only more detailed information is obtained but the accuracy is increased. A computation which requires about two minutes of machine operation yields results whose accuracy is generally greater than that of the most sophisticated experiments. In this connection, it may be noted that the use of a very coarse mesh is conceptually similar to the application of the method of integral relations (Ref. 3) with one or two strips. However, the present technique does not require a reformulation of the equations if the fineness of the mesh is increased, but merely a change in the two, or three, integers which define the number of nodal points.

Therefore, it was considered appropriate to perform a systematic series of computations with a twofold purpose:

1) to test the technique in the widest possible range of body shapes and flow properties, and

2) to provide a parametric compilation of cases which are of practical interest, in the hope that it could be used as a quick reference for neighboring cases.

Part of the results are published in the present report. Since the object of the report is a compilation and discussion of

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*All time estimates are based on actual computations performed on the CDC 6600 computer.

results, only a few words will be spent to describe the procedure used to obtain them. In what follows, the main features of the technique will be recalled from the previous communications referred to above and the adoption of new frames of reference will be justified.

2. Outline of the Computational Technique

For the sake of simplicity, we will focus our attention on the two-dimensional case. Let AB (Figs. 1 and 2) be a section of the body, CD a section of the shock wave, EF the sonic line. In Refs. 1

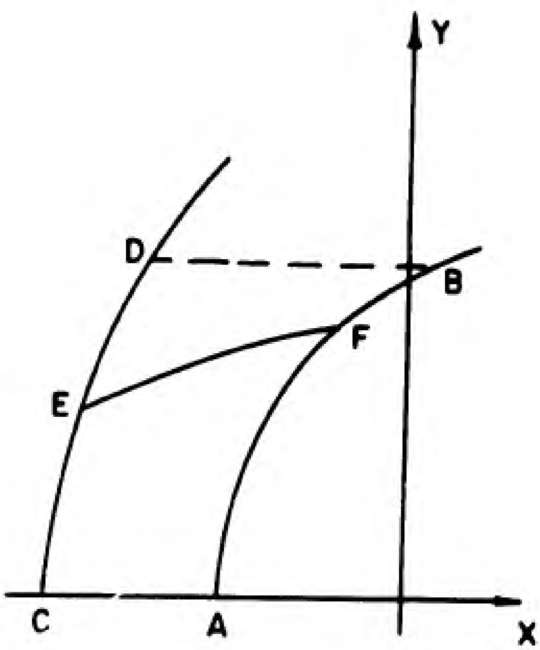


FIG. 1

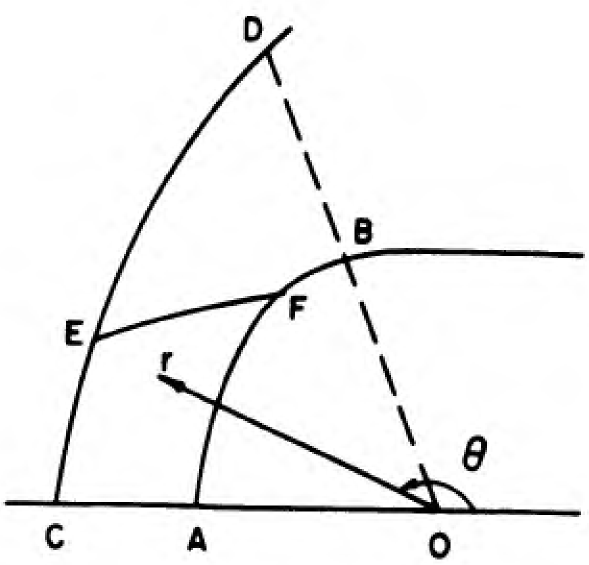


FIG. 2

and 2, the equations of motion are written in a Cartesian frame (x,y). A natural boundary of the region to be computed is then the closed line ABDCA, which has a segment, BD, parallel to the x-axis. Such a choice is possible only if (i) the body slope is positive up to a point inside the supersonic region, and (ii) the sonic line does not intersect the upper boundary. Both limitations are particularly severe if the free stream Mach number is low.

The present computations have been performed after reformulating the equations of motion in a polar (r,θ) frame, as in Fig. 2. In the axisymmetric case, a spherical frame (r,θ,φ) is used, with the polar axis along the body centerline. In any meridional plane the section of the flow field appears again as in Fig. 2.

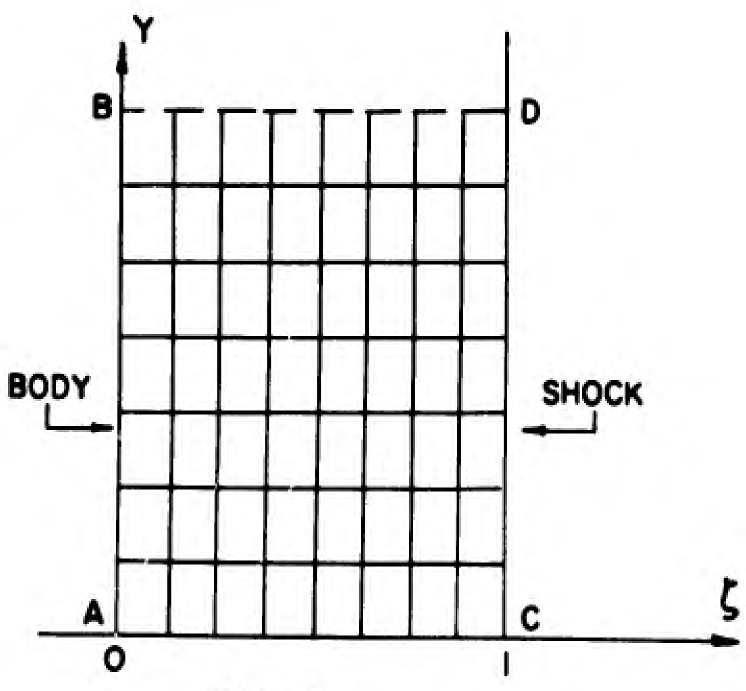


FIG. 3

As in Ref. 2, the region to be computed is first mapped onto a rectangle (Fig. 3) by linearly stretching the r-coordinate between shock and body. New coordinates, ζ, Y and T are introduced, defined by

$$\zeta = \frac{r - r_{body}}{r_{shock} - r_{body}}$$

$$Y = \pi - \theta$$

$$T = t$$

where t is the time.

To compute interior points, the equations of motion are reformulated in terms of the new independent variables. Then the derivatives of the equations of motion with respect to ζ, Y and T are formally evaluated. From such a system of equations the first and second order derivatives of density (ρ), velocity components (u and v), and entropy (S) with respect to T can be expressed as functions of first and second order derivatives of the same parameters with respect to ζ and Y. The increment of any parameter $f(f=\rho,u,v,S)$ in a time step, t, is computed as

$$\Delta f = \frac{\partial f}{\partial T} \Delta T + \frac{1}{2} \frac{\partial^2 f}{\partial T^2} \Delta T^2$$

The time step at each nodal point is taken equal to

$$\frac{\Delta s}{1.5(q+a)}$$

where $q = (u^2+v^2)^{\frac{1}{2}}$, a is the local speed of sound, and Δs is the length of the shorter local side of a mesh quadrangle in the physical plane. At the end of each step, the local increments are linearly interpolated to a common time step, chosen as the smallest of the local time steps.

Shock and body points are computed differently. In both cases the pressure is determined by a modified method of characteristics, as outlined in Ref. 2. At shock points a complete system of equations is obtained by considering the Rankine-Hugoniot conditions for a moving shock. The system is then solved by iterating on a preliminary guess until the relative error in the velocity component normal to the shock is less than a prescribed tolerance, ϵ.

At body points, two additional conditions are obtained by writing that the entropy is constant for a moving particle and by using the momentum equation for the tangential velocity. Again, the complete system is solved by iterating on a preliminary guess until the error in the distance between the body and the initial point on the characteristic is less than ϵ.

The computation is started by assuming a parabolic shape of the shock and prescribing a linear distribution of Mach numbers on the body. The shock is initially assumed at rest. The values of pressure (p), ρ, u, v, and S are computed behind the shock and at the body, and linearly distributed at the interior points of the mesh.

3. Presentation of the Numerical Results

The computational program has options to output partial results at any stage as well as at the end of the run. These include the mesh coordinates, the pressure, density, velocity components, entropy and Mach number at each mesh point. To get a direct feeling for the properties of the flow field, plots are necessary. Such plots, together with some typical numerical information, are obtained by processing the final output of the programs on a Stromberg-Carlson 4020 cathode tube display machine. Two pages of plots are printed, as shown in this report. It will be recalled that only two-dimensional symmetric and axisymmetric flows of a perfect gas are considered at this time.

In the first page, the physical nature of the flow is described by the free stream Mach number and the value of the ratio of specific heats, γ. The shape of the body and the extent of the computed region are shown in the figures of the second page and in the lower left figure in the first page. The number of mesh intervals is indicated in the first page; the first number denotes the number of intervals between shock and body and the second number denotes the number of intervals along the body.

As an example, in Fig. 4 a mesh is shown which corresponds to the legend "4 BY 6 MESH". The mesh points on the body are marked by short lines pointing toward the origin of coordinates. The origin is the intersection of the upper boundary line and the centerline of the body.

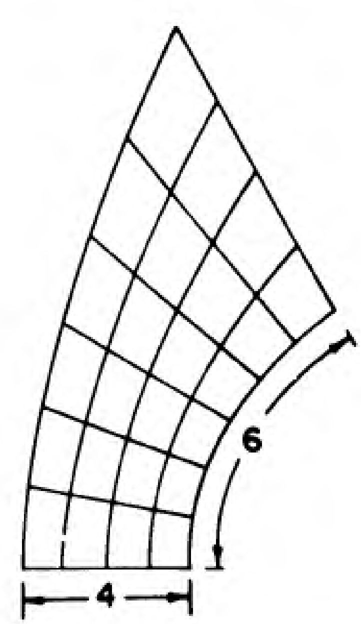


FIG. 4

The standoff distance is expressed in arbitrary units. The abscissa of the stagnation point is expressed in the same units. The latter can be measured on the drawings, starting from the origin, and the unit length can thus be determined. As a rule, the unit length has a simple geometrical meaning in relationship with the geometry of the body. If the cross-section of the nose is a circle, the unit length is its radius; if the cross-section is an ellipse, the unit length is its major semi-axis; if the cross-section is a rectangle with a rounded shoulder, the unit length is the height of the rectangle. Finally, if the cross-section is a parabola, it is defined by

$$y^2 = 2(x+x_o) + 4$$

Also, in the first page the number of time steps and the value of ϵ (called "TOLERANCE") used in the computation of shock and body points are shown. The values of the pressure printed in the first page are referred to the free stream pressure. The theoretical and computed values of the pressure at the stagnation point are printed, together with the relative error,

$$E = \frac{p_{st(comp)} - p_{st(theor)}}{p_{st(theor)}}$$

The temperatures printed in the first page are referred to the free stream temperature. Again, the theoretical and computed values of the temperature at the stagnation point are printed, together with the relative error,

$$E = \frac{T_{st(comp)} - T_{st(theor)}}{T_{st(theor)}}$$

The computed values of pressure, density and temperature at the body point where M=1, divided by the computed values of pressure, density and temperature at the stagnation point respectively are also printed, with their relative errors with respect to the theoretical ratios.

In the right-hand side of the first page, pressure, Mach number, and temperature along the body surface are plotted. The pressure is scaled to the computed pressure at the stagnation point and the temperature is scaled to the computed temperature at the stagnation point. The abscissae of these plots are angles, α (in degrees) measured between the centerline and a line joining the body point to the origin (Fig. 5).

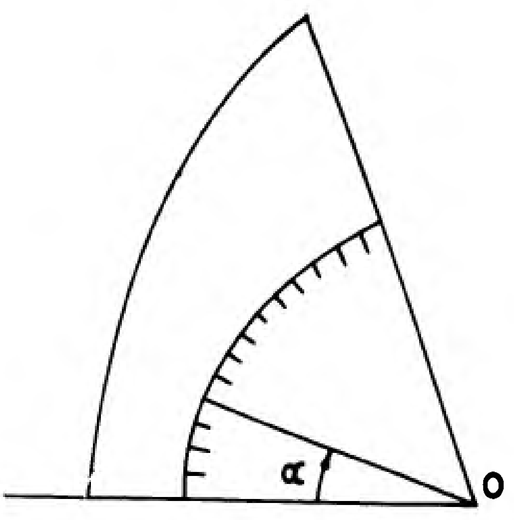
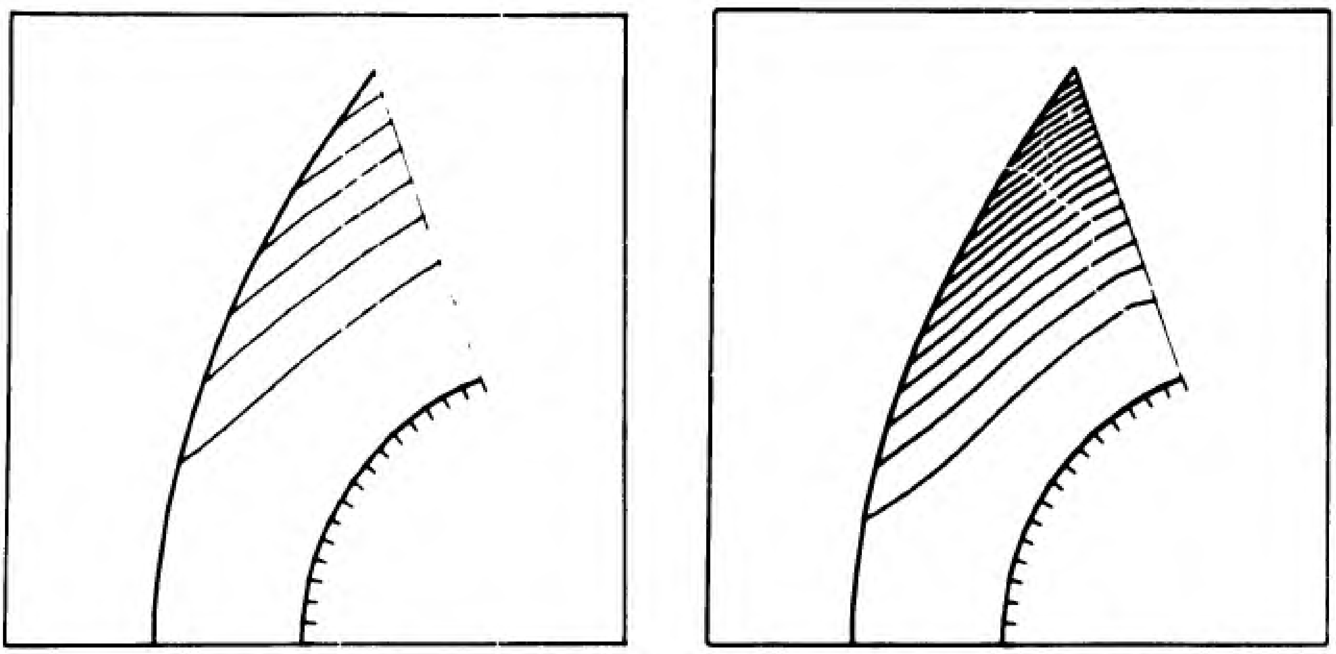


FIG. 5

In the bottom left of the first page and in the second page the body and shock geometries are repeated five times. In the figure of the first page, some streamlines are drawn. In a steady motion the streamlines can be defined either as lines of constant entropy or as lines of constant total pressure. When the first is used, S is defined as

$$S = \ln(p/p_{\infty}) - \gamma \ln(\rho/\rho_{\infty})$$

and the lines of constant entropy are spaced by 1/20 of the value of S at the stagnation point. Sometimes such a spacing does not provide enough information. In this case, lines of constant total pressure are used, spaced by 1/20 of the value of p at the stagnation point. As a proof of the equivalence of the two definitions, Fig. 6 shows, on the left, lines of constant entropy and, on the right, lines of constant total pressure for the same case, a two-dimensional flow about a circle at a free stream Mach number of 4. When superposed, the two figures match perfectly.



STREAMLINES　　　　CONSTANT TOTAL PRESSURE LINES

Fig. 6

The other figures are self-explanatory. To interpret them quantitatively, it must be kept in mind that the values of the Mach number on the M=constant lines are spaced .1 apart. The sonic line is drawn heavier than the other lines. The isobars correspond to constant values of p/p_{st}, .05 apart. The isopycnics correspond to constant values of ρ/ρ_{st}, .05 apart. The isotherms correspond to constant values of T/T_{st}, .025 apart.

4. Discussion

In the present report, only results for the two-dimensional and the axisymmetric problems and for a perfect gas at constant γ are presented. In addition, one single program has been used for the computation of all the two-dimensional cases and one single program for all the axisymmetric cases,* regardless of the geometry of the body. In other words, no special effort was made to achieve a greater accuracy in cases of a challenging geometry (very blunt ellipses, flat-faced bodies) and we wished to explore the range of acceptability of such basic programs.

A. Mesh-size effects

To study the effect of mesh-size on accuracy, a two-dimensional flow about a circle at $M_\infty=4$ was computed five times, using the following meshes:

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*These programs are labelled 2E and 2F, respectively.

Run No.	199	200	201	202	203
Mesh	2 x 4	3 x 5	5 x 8	7 x 12	10 x 16
Total number of steps	160	240	400	560	800
Total time at final step	6.354	7.590	7.861	7.395	7.948

(the time is scaled to $r_o\sqrt{\rho_\infty/p_\infty}$, where r_o is the radius of the circle and ρ_∞ and p_∞ are the free stream values of density and pressure, respectively). In Figs. 7 and 8, the time history of some representative parameters is shown for the coarsest and the finest mesh of the set above. In the top and bottom parts of the figures respectively, the standoff distance and the pressure at the stagnation point are plotted (the latter is scaled to the free stream pressure). The middle part is the plot of the logarithm (base 10) of the difference between the maximum and minimum values of the velocity of the shock points, divided by the free stream velocity. Since the time-dependent computation aims at reaching a steady state, the first and third functions should asymptotically tend to a constant value, and the second function should tend to $-\infty$. One can see from the graphs that the stagnation point pressure and the standoff distance reach a steady state in a relatively short time, whereas the shock wave is never perfectly at rest. This last feature is a result of the finiteness of the mesh, of the tolerance accepted in the iterations, and of the limited capacity of the computer. However, for all practical purposes, a

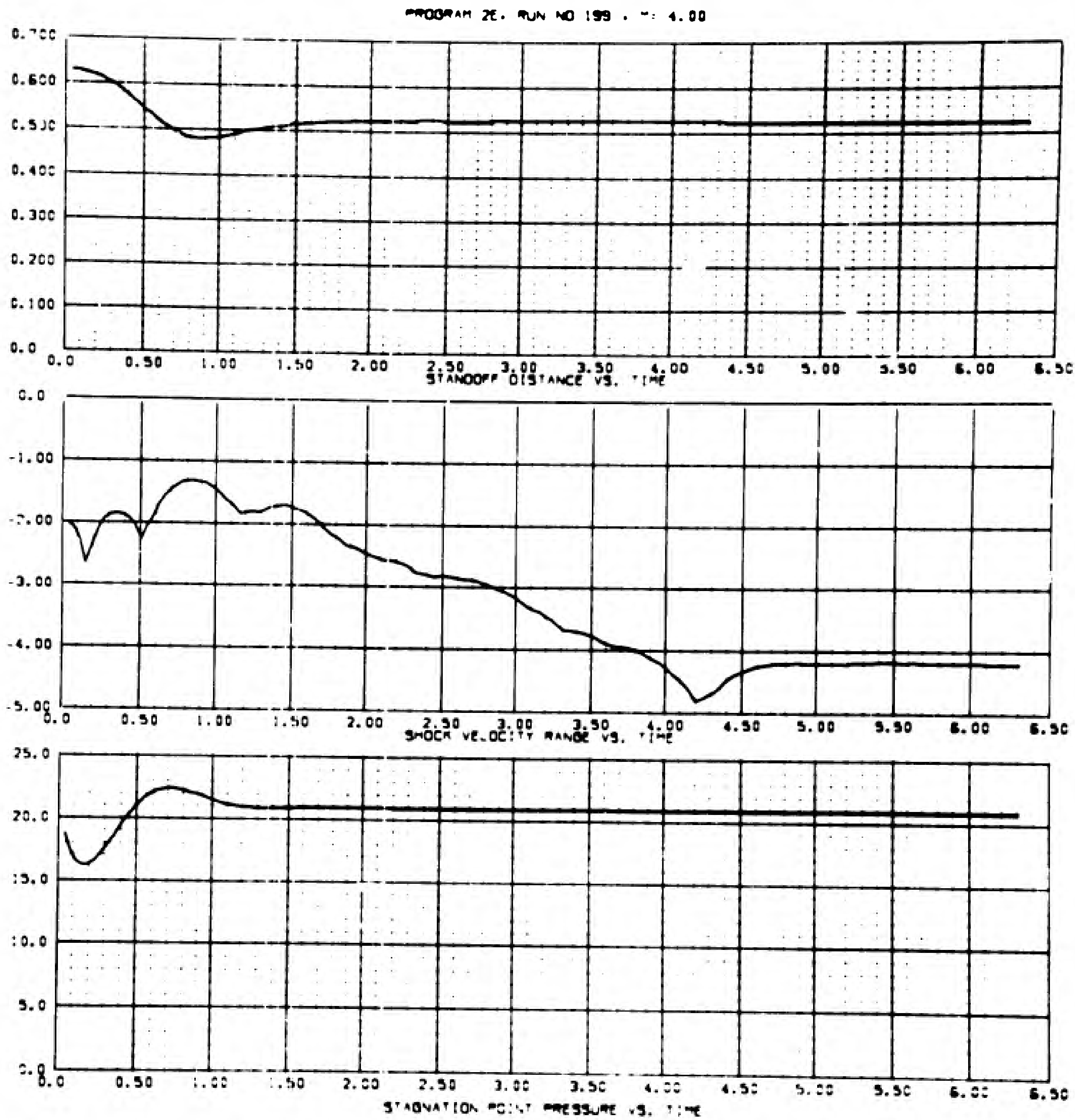

PROGRAM 2E. RUN NO 199 . ": 4.00
STANDOFF DISTANCE VS. TIME
SHOCK VELOCITY RANGE VS. TIME
STAGNATION POINT PRESSURE VS. TIME

Fig.

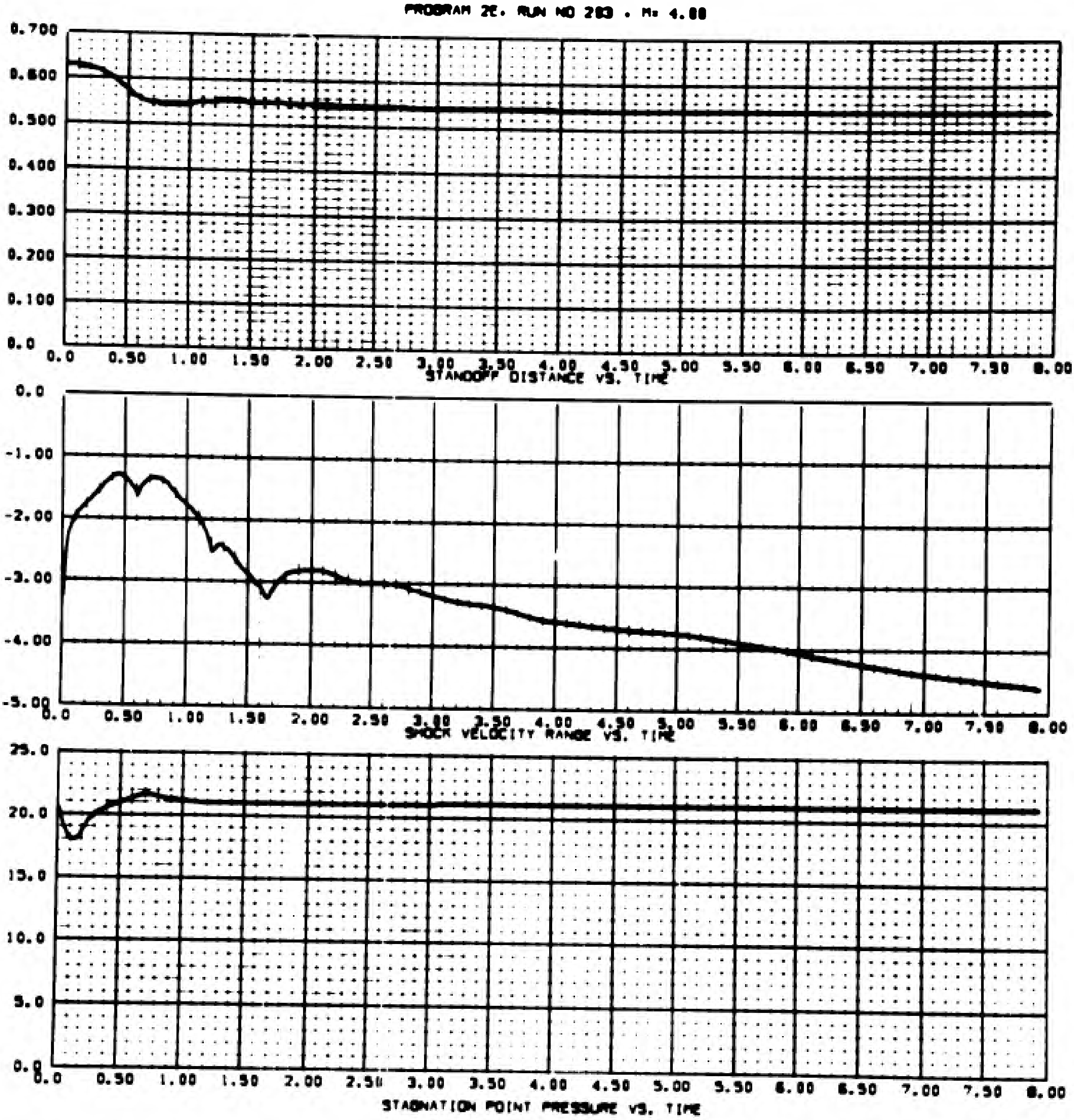

0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.0
0.50
1.00
1.50
2.00
2.50
5.50
7.00
STANDOFF DISTANCE VS. TIME
-1.00
-2.00
-3.00
-4.00
SHOCK VELOCITY RANGE VS. TIME
25.0
20.0
15.0
10.0
5.0
3.00
3.50
4.00
4.50
5.00
6.00
6.50
7.50
8.00
STAGNATION POINT PRESSURE VS. TIME

Fig. 8

shock wave whose velocity is five orders of magnitude smaller than the free stream velocity is a steady configuration.

No major differences can be noted between Fig. 7 and Fig. 8, despite the strong difference in mesh-size. The final results of all the cases mentioned above show, obviously, a better and smoother definition of values as the mesh-size is made finer and finer. The general trend of the curves, however, is the same in all cases. In addition, from a quantitative point-of-view, the differences between different cases at each point are surprisingly small.

One can conclude that, in a case where the body shape is fairly smooth, preliminary estimates can be made with a fast, inexpensive run using a very coarse mesh. To make the point clearer, the dependence of some relevant parameters on mesh-size is shown in Fig. 9. The first plot shows the logarithm (base 10) of the relative error in pressure and temperature, as computed at the stagnation point. These errors seem to level off at a value of about 10^{-4}, probably because of the worsening of round-off effects with decreasing mesh-size. The second plot shows similar errors in p, ρ, and T as computed at the critical point on the body. Here it must be noted that the critical point itself and all the attached values are computed by linear interpolation between adjacent points on the body. Therefore, the accuracy is affected in different ways for different mesh-sizes (the relative location of the critical point in a mesh interval is not the same in two different cases), and this explains a greater scattering in the plot. A line has been drawn to represent an estimate of the errors and it shows the same trend as the two lines in the first plot. The third plot shows the standoff distance whose third significant figure seems rather hard to stabilize. Finally, the fourth plot shows the location of the critical points on the body and on the shock (measured in the polar frame of reference in degrees).

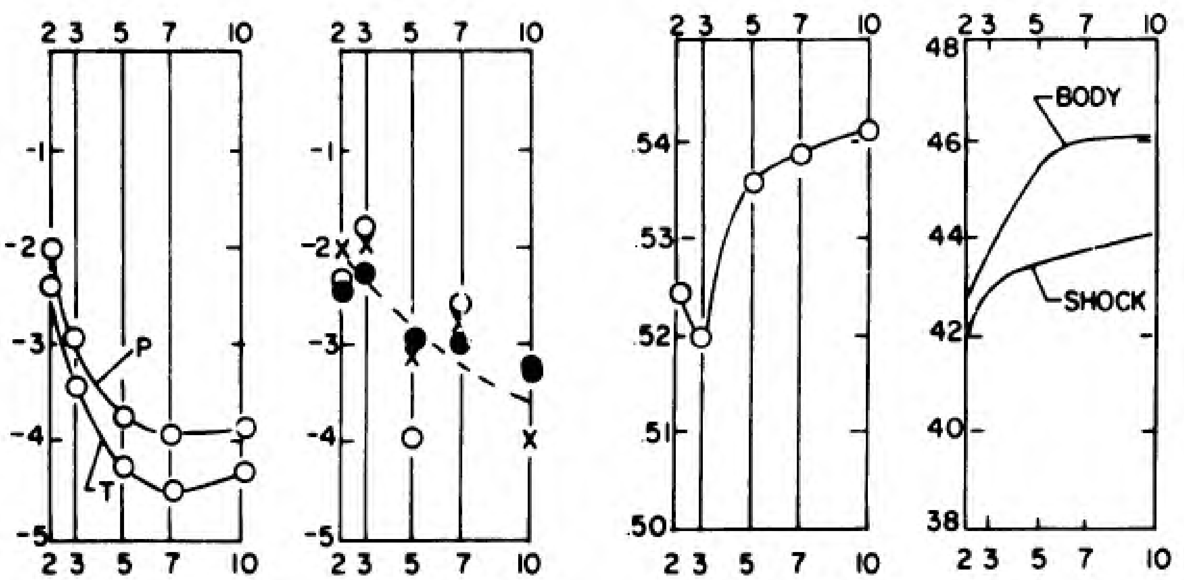


FIG. 9

To get an idea of the price one has to pay for a greater accuracy, here is a comparison of computational times for the five cases above, taking the time for case 199 as the unit:

Run No.	199	200	201	202	203
Computational time	1	2.5	10	28	73.5

(the time for Run 203 is about 3 minutes on the CDC 6600).

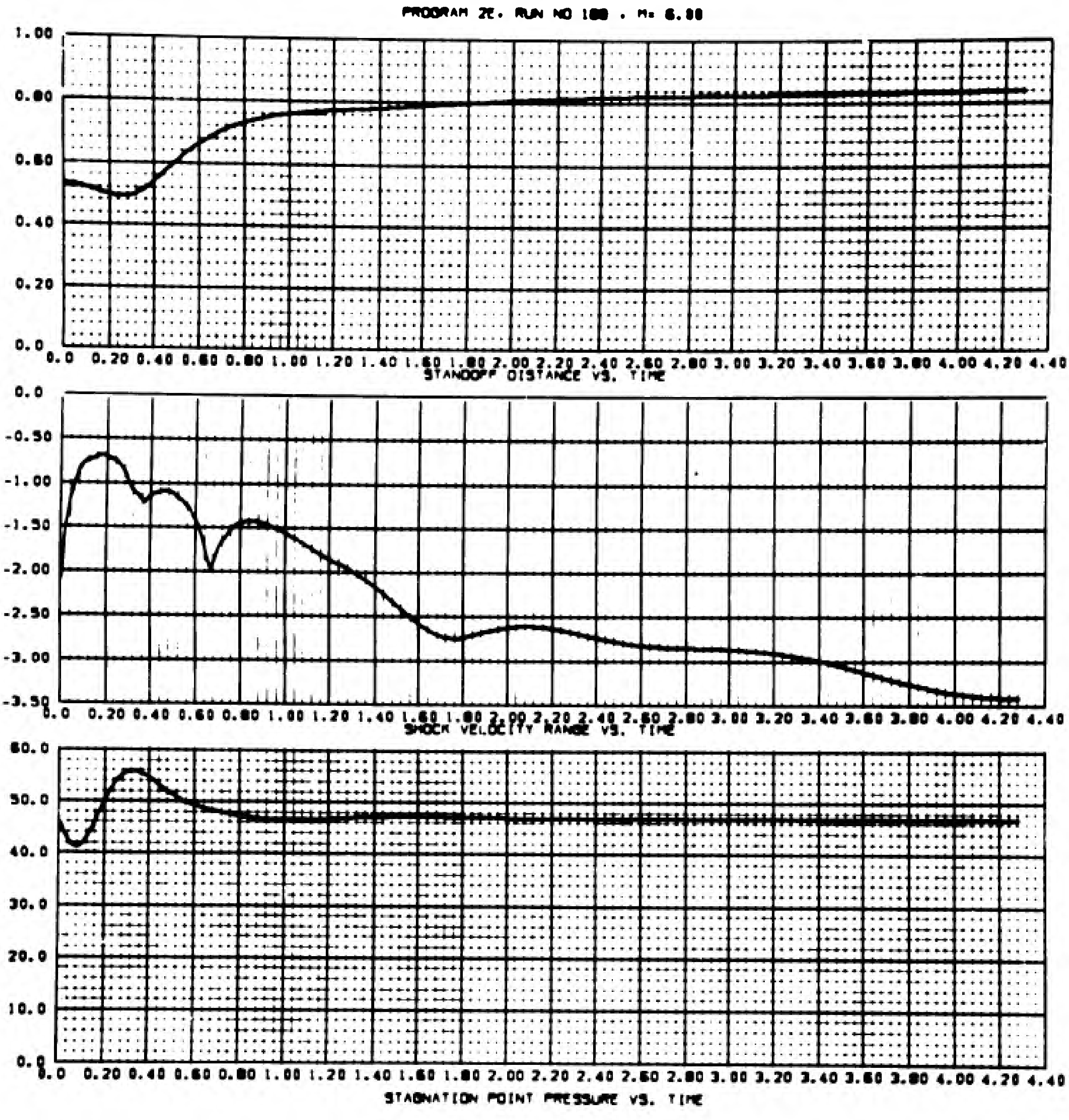
In order to test the mesh-size effect on a body of a more complicated geometry, runs No. 169 and 270 were made. Their time histories are shown in Figs. 10 and 11, respectively. At the end of run 169 (400 steps), the standoff distance is not yet perfectly stabilized. A better situation is achieved in run 270, only because the computation runs for a longer physical time. In the final plots, the pressure and temperature distributions on the body are not substantially different between the two runs. The Mach number distribution on the body is quite different in the region of high curvature. This results from a seemingly intrinsic difficulty in computing velocities on the body where the curvature is high. More comments on this matter will be found under D. The general trends of constant Mach number lines, isobars, isopycnics, isotherms, and streamlines is the same in both cases and let us once again draw the conclusion that, for a preliminary, inexpensive evaluation of the shock layer, a coarse mesh can be used.

B. Tolerance effect

Some runs were made with different values of the tolerance in the shock and body point iterations, namely, $\varepsilon=10^{-4}$, 10^{-5}, and 10^{-6}. No appreciable differences were observed, and $\varepsilon=10^{-5}$ was adopted uniformly throughout the present set of runs.

C. Number of time steps necessary to achieve convergence

In all runs, plots as in Fig. 10 were made. As a general rule, the stagnation pressure is the first parameter to become stabilized.



STANDOFF DISTANCE VS. TIME
SHOCK VELOCITY RANGE VS. TIME
STAGNATION POINT PRESSURE VS. TIME

Fig. 10

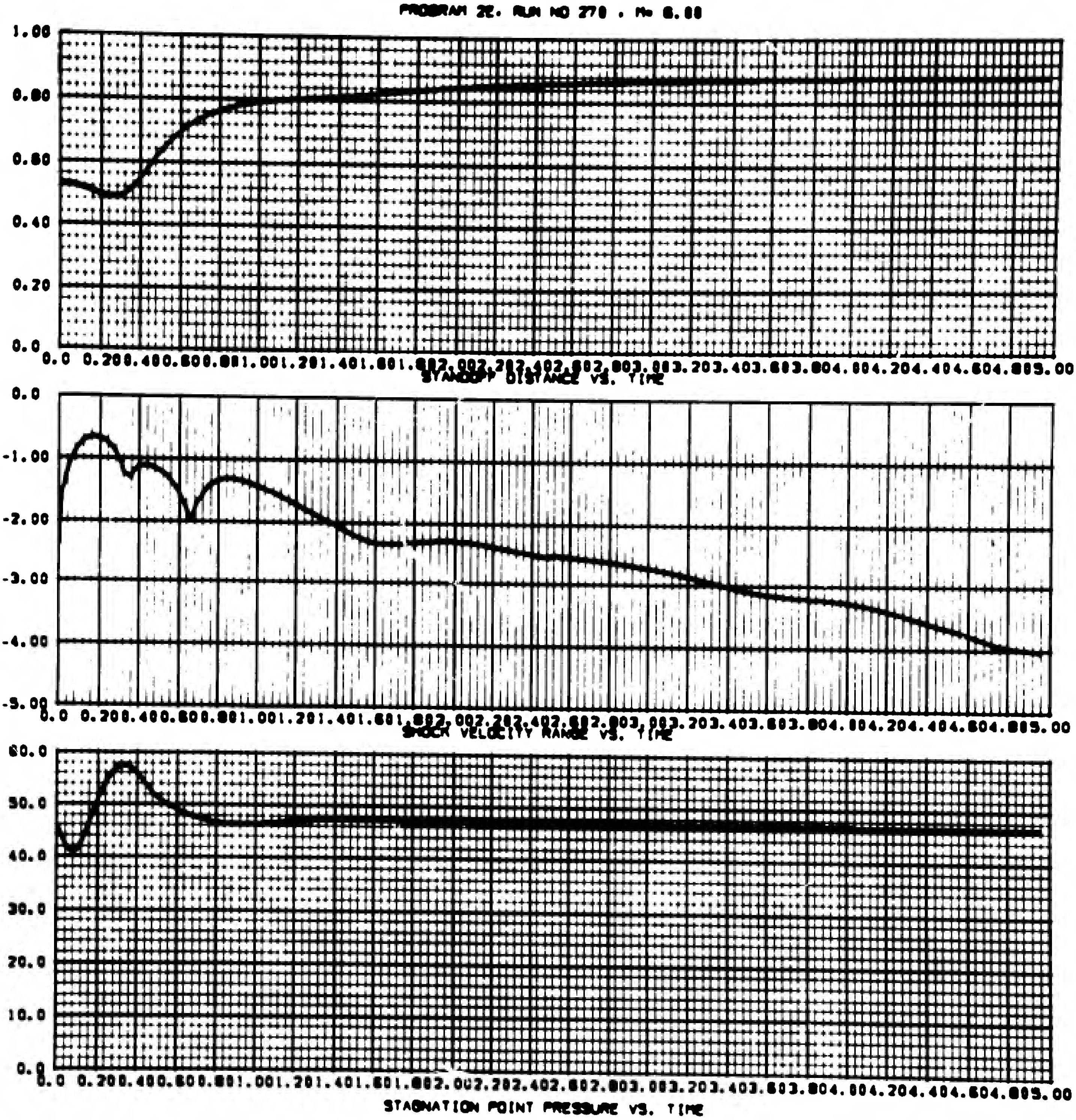

STANDOFF DISTANCE VS. TIME
SHOCK VELOCITY RANGE VS. TIME
STAGNATION POINT PRESSURE VS. TIME

Fig. 11

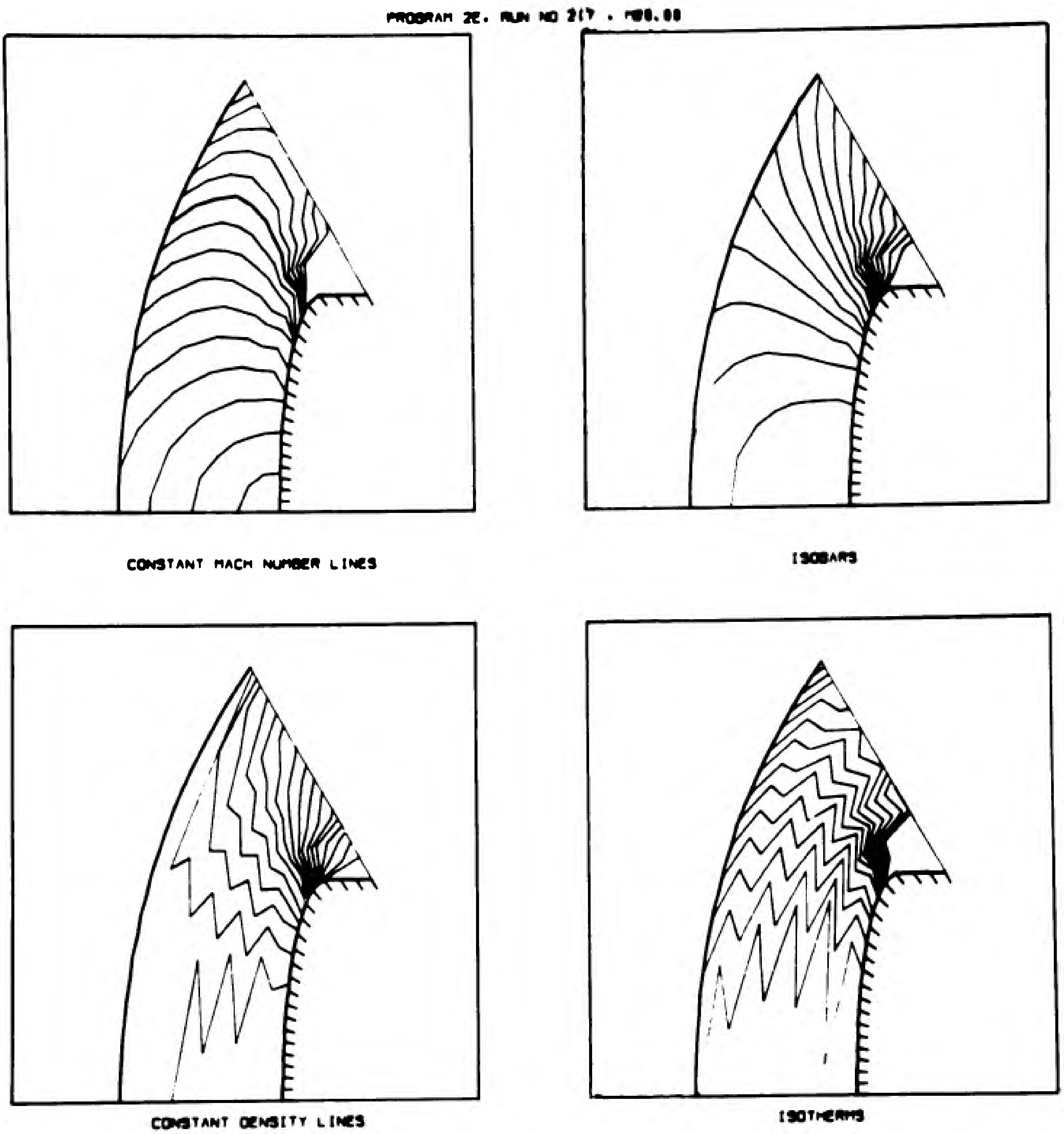

PROGRAM 2E. RUN NO 217
CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

Fig. 12

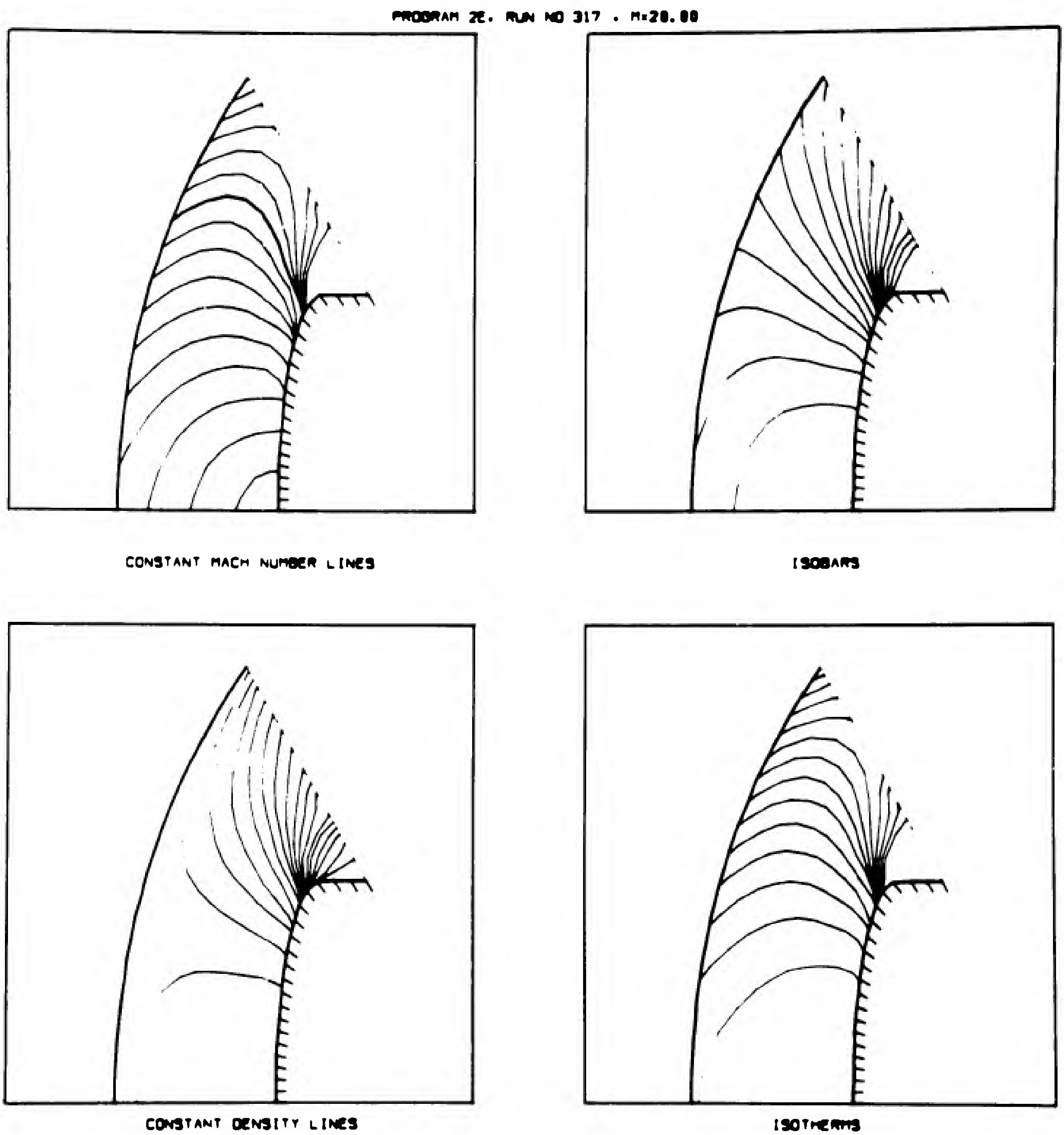

PROGRAM 2E. RUN NO 317 . M=20.00
CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

Fig. 13

However, if one is interested in obtaining an accurate description of the entire flow field, it would be a mistake to use the stagnation pressure as a criterion for stopping the computation. The standoff distance takes much longer to stabilize. Moreover, the logarithmic plot of the shock wave velocity range shows that an overall stabilization of the shock wave is achieved only after a long time has elapsed. There are evidently a number of wavelets travelling over the computational region, which sometimes are hard to damp. From a physical point-of-view, an inviscid flow does not provide any mechanism for the damping of such wavelets, except on the shock wave itself. We find a similar behavior in our numerical computations since their artificial viscosity is purposely kept very low.

No attempt is made at this time to analyze the propagation and damping of wavelets in the numerical computations in relation to the propagation and damping of sound waves in the present problem. Here we simply show the patterns obtained in a specific case, a two-dimensional flow field about a 5:1 ellipse at $M_\infty=20$. Fig. 12 is obtained by stopping the computation at step 1000. The constant Mach number lines and the isobars seem to be pretty smooth, but the isopycnics and the isotherms are full of ripples. Fig. 13 is obtained at step 2000. Now all wavelets are practically damped. For the sake of completeness, Fig. 14 shows the time history of the run up to step 2000. Between step 1000 and step 2000 the shock velocity range drops by an order of magnitude.

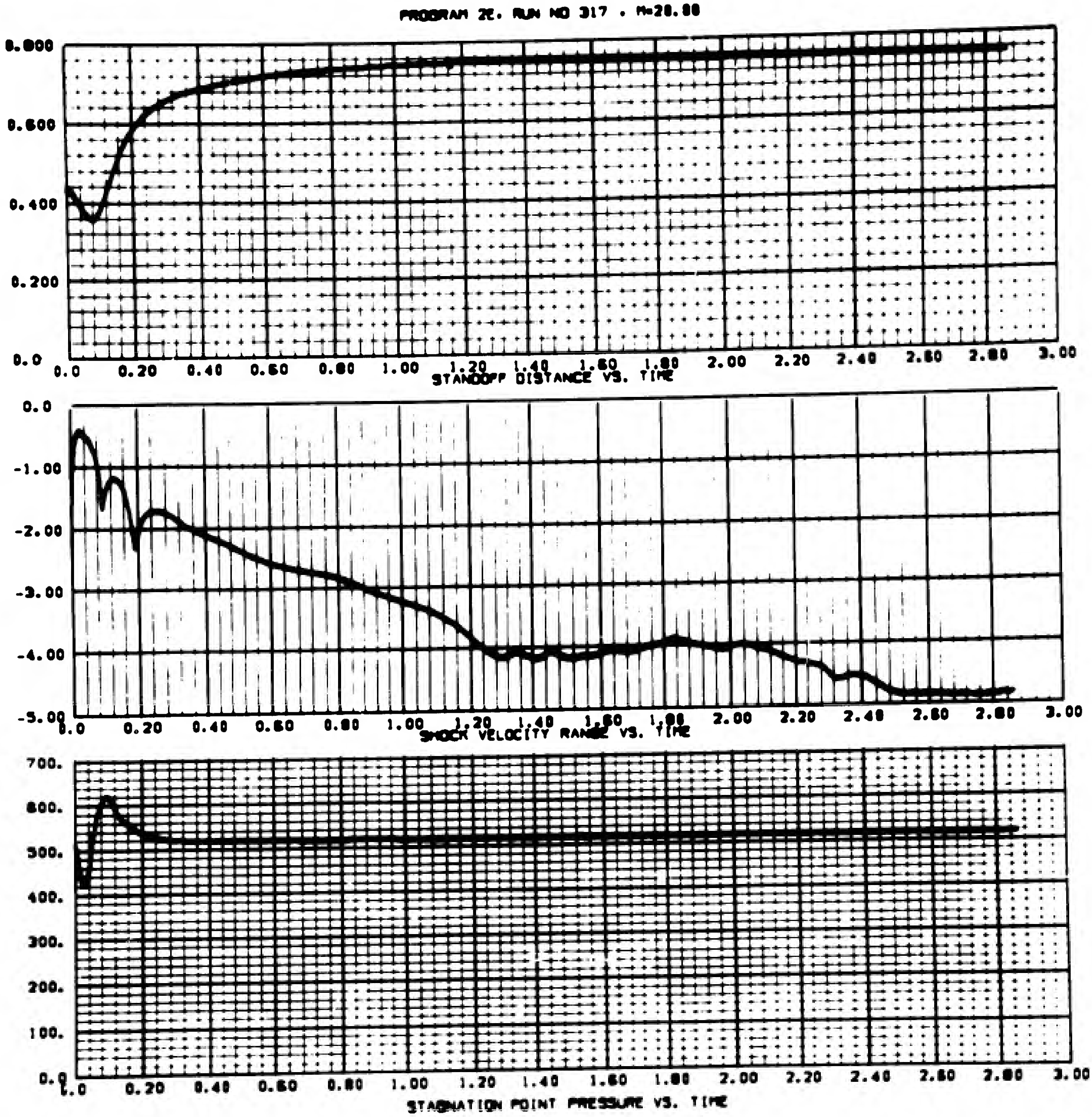
In a practical case, one must decide when to stop a computation by compromising between his need for accuracy and the available computational time. If a computation has to be stopped prematurely, smoother curves can be obtained by a crude averaging of values. Fig. 15 shows how the plots of Fig. 12 look like after averaging. Of course, these curves do not exactly fall on top of the curves of Fig. 13; however, they are qualitatively correct and probably good for all practical purposes.

Another important conclusion has been reached through the present numerical experimentation. For an arbitrarily prescribed set of initial conditions, the first phase of the transient is always very active. All the major changes take place in the first 5% of the total time necessary to achieve smooth results. Therefore, the discussion above is practically independent of the choice of initial conditions.

D. Mach number and bluntness effects

To study the effect of bluntness on accuracy, we have run several cases for bodies with an elliptical nose, the ratio of the two axes of the ellipse being taken as a measure of the bluntness. An ellipse with a bluntness of 1 is a circle; an ellipse with a bluntness of 6 is almost a flat-faced body with a rounded shoulder.

However, it turned out that a study of the bluntness effect could not be achieved independently of a study of the free stream Mach number effect. Fig. 16 shows the Mach number and bluntness



PROGRAM 2E. RUN NO 317
0.800
0.600
0.400
0.200
0.0
0.0 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.20 2.40 2.60 2.80 3.00
STANDOFF DISTANCE VS. TIME
0.0
-1.00
-2.00
-3.00
-4.00
-5.00
0.0 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.20 2.40 2.60 2.80 3.00
SHOCK VELOCITY RANGE VS. TIME
700.
600.
500.
400.
300.
200.
100.
0.0
0.0 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.20 2.40 2.60 2.80 3.00
STAGNATION POINT PRESSURE VS. TIME

Fig. 14

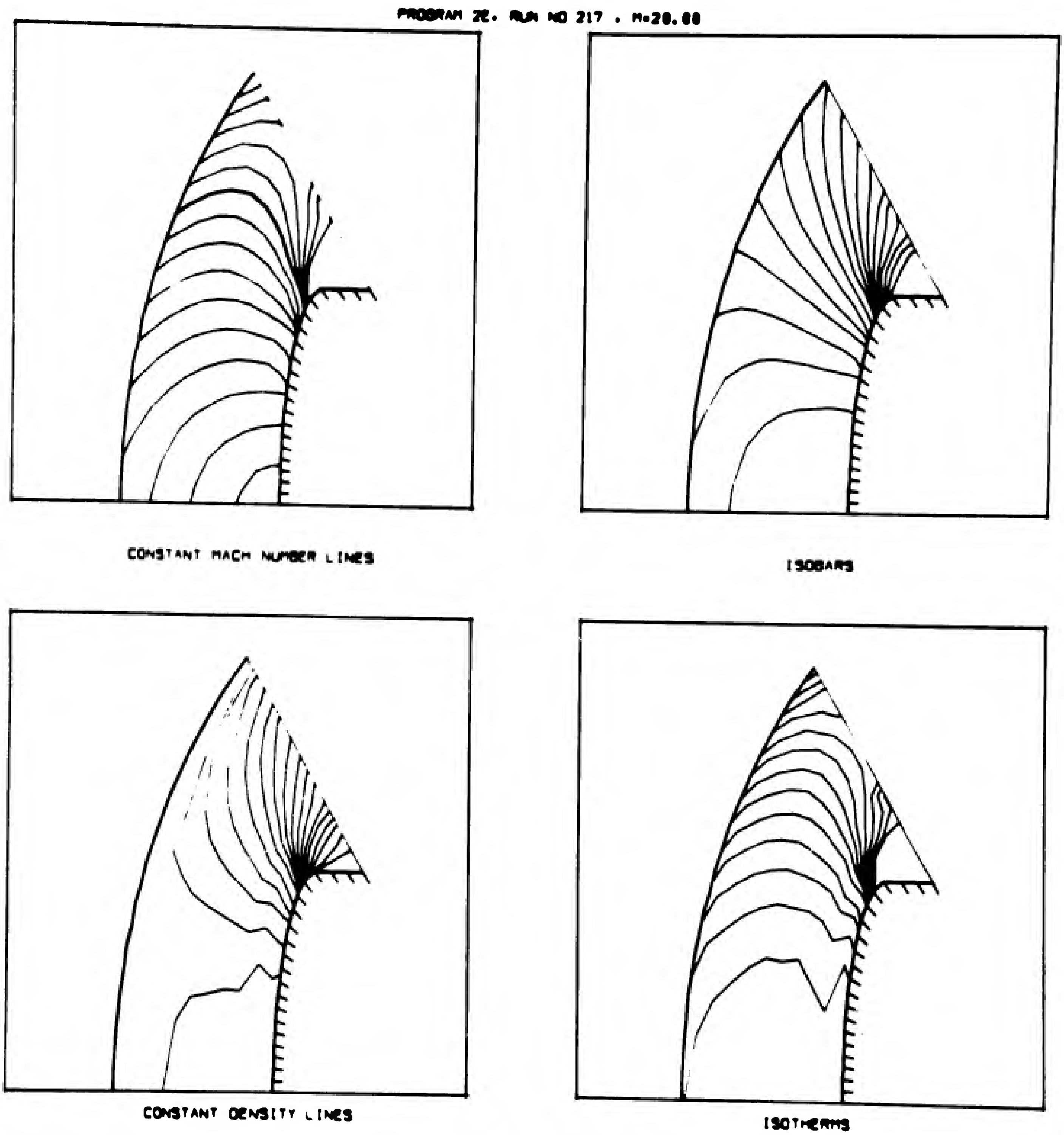

PROGRAM 2E. RUN NO 217 . M=20.00
CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

Fig. 15

parameters for the cases presented in this report (for both the two-dimensional and the axisymmetric problem).

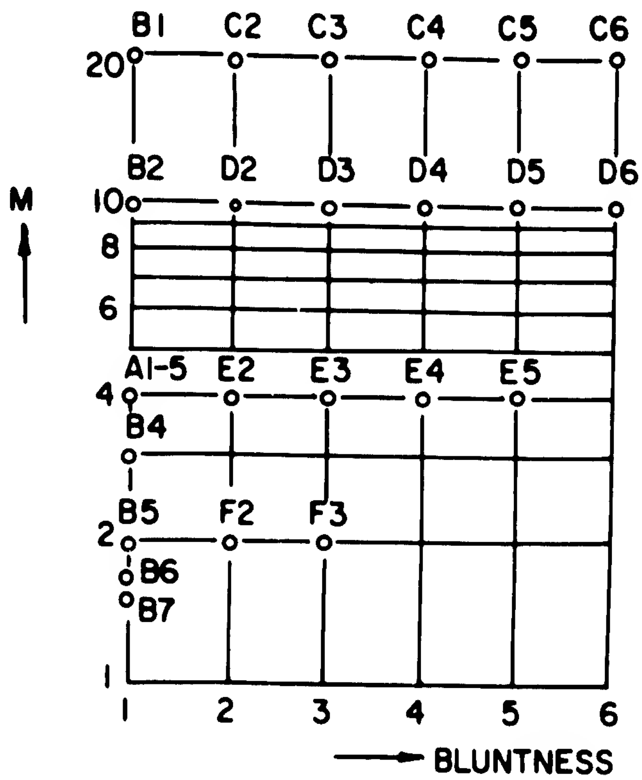


FIG. 16

No computations were made for a bluntness parameter greater than 6.* Below 6, some of the cases had to be discarded because the results were evidently poor (the relative errors mentioned in section 3 were too high; the plots were far from being smooth). Some other cases did not even run to completion. In general, it seems that, for a given free stream Mach number, the results worsen with increasing bluntness; the program fails for values of

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*See, however, a preliminary survey of flat-faced bodies under E.

the bluntness parameter above a limiting value. Such a limiting value is a function of the free stream Mach number; the lower the Mach number, the lower the limiting bluntness.

These limitations were, in a way, expected. Neither program has been tailored for handling high curvature effects on the body. The truncation errors due to the linear interpolations performed in computing the values on the wall grow excessively if the curvature of the particle paths and the consequent rate of change of physical parameters are too high. Such errors propagate within the shock layer and are steadily generated at each computational step. If we accept the hypothesis, mentioned under C, that the damping of the error waves is mostly due to a dissipative mechanism at the shock, we should conclude that a weak shock is less capable of producing damping than a strong shock. At a low Mach number, not only the error waves in the shock layer are harder to eliminate (and may even become unstable) but the shock itself is more sensitive to such perturbations and tends to wrinkle. It is interesting to note that, at very low Mach numbers, the shock wave is actually extremely sensitive to all perturbations, and it is hard to keep it stable in an experiment. However, it is not the intention here to suggest any quantitative correlation between the natural phenomenon and the present numerical effects. This is, at least, premature. It should be noted, also, that at a low Mach number the disturbance field to be computed becomes very large in comparison to the body size. Consequently, the overall accuracy tends to deteriorate. We would rather say that it is surprising how far one can force the bluntness, and how close to 1 the Mach number can be taken, with still acceptable results, and that this can be done without increasing the number of mesh points over 200 and without providing any special treatment for high curvature walls.

How to improve the situation at low Mach numbers and high bluntness is, at this time, hard to say. Any modification to the program which increases the artificial viscosity is not advisable. With a mesh as coarse as the ones used here (and let us recall that the object of the present program is to minimize the computation time), the artificial viscosity is bound to deface the whole flow pattern (when the flow tends to become steady, the time derivatives become smaller and smaller and eventually their effect is nullified by an equal and opposite contribution of the artificial terms).

One can note that the Mach number on the wall tends to oscillate more than the pressure and the temperature. This indicates that the weakest computation is that of the velocity on the body. In the present programs, the velocity is computed by using one of the momentum equations. The energy equation has been tried instead, with no success. The latter defines the square of the modulus of the velocity by the difference between the Lagrangian and the Eulerian derivatives of pressure. Truncation errors can occasionally make such a square become negative, so that the computation halts. Some attempts to damp the oscillations in velocity at the wall only resulted in a general catastrophic worsening of the computation, except perhaps, in the case of a sharp corner where the wall region before the corner is practically disconnected from the wall region behind the corner. The matter is being studied further.

In the range of validity of these programs, some interesting parametric results can be obtained, which confirm and extend the ones available in Hayes and Probstein's book. Fig. 17 shows different shapes of shock waves and sonic lines for two-dimensional elliptical bodies at different Mach numbers; Fig. 18 does the same in the axisymmetric case. Each part of these figures deals with a given Mach number to show the bluntness effect. Figs. 19 and 20 show the Mach number effect on the shock wave and the sonic line for a parabolic body in the two-dimensional and the axisymmetric case, respectively. Figs. 21 and 22 show the Mach number effect on the shock wave and the sonic line for a circular nose in the two-dimensional and the axisymmetric case, respectively.

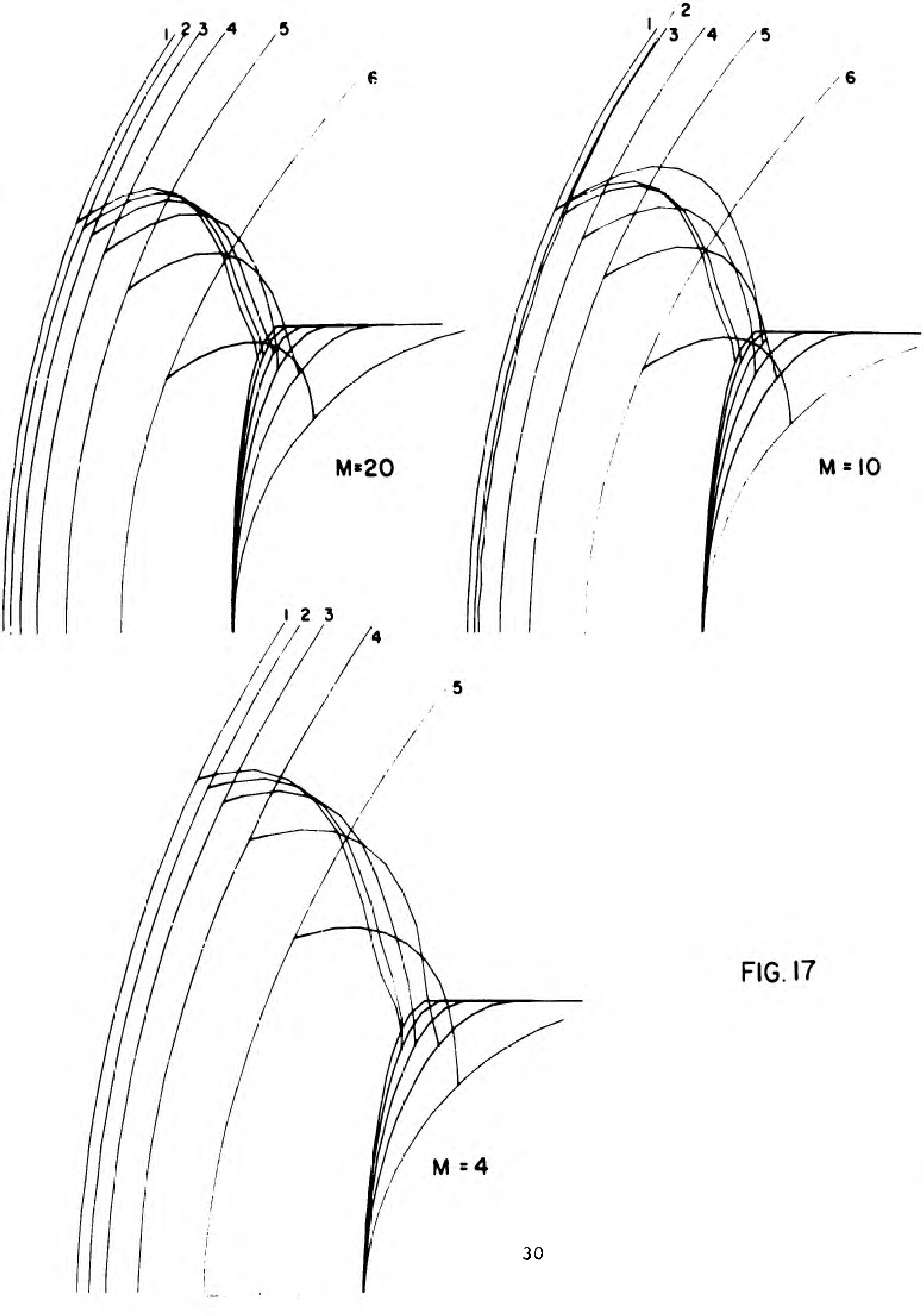


FIG. 17

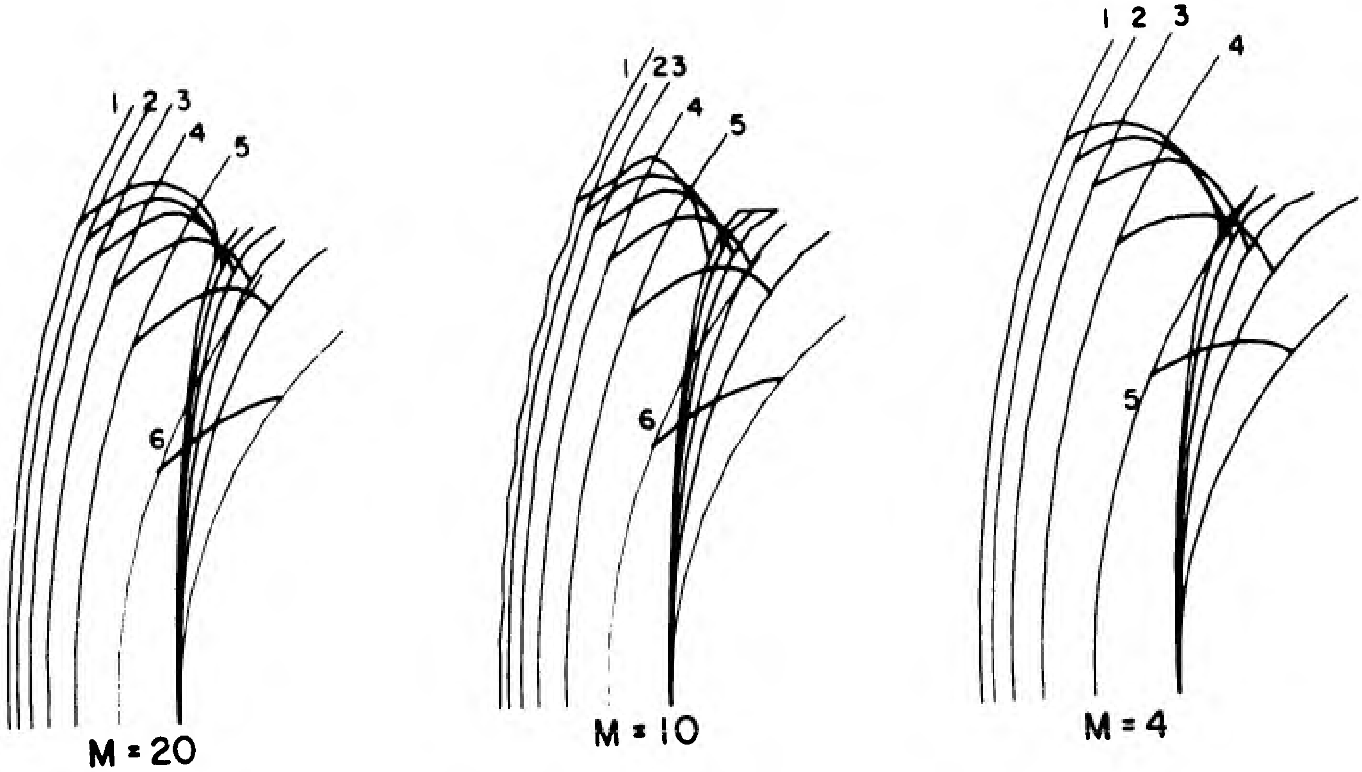


FIG. 18

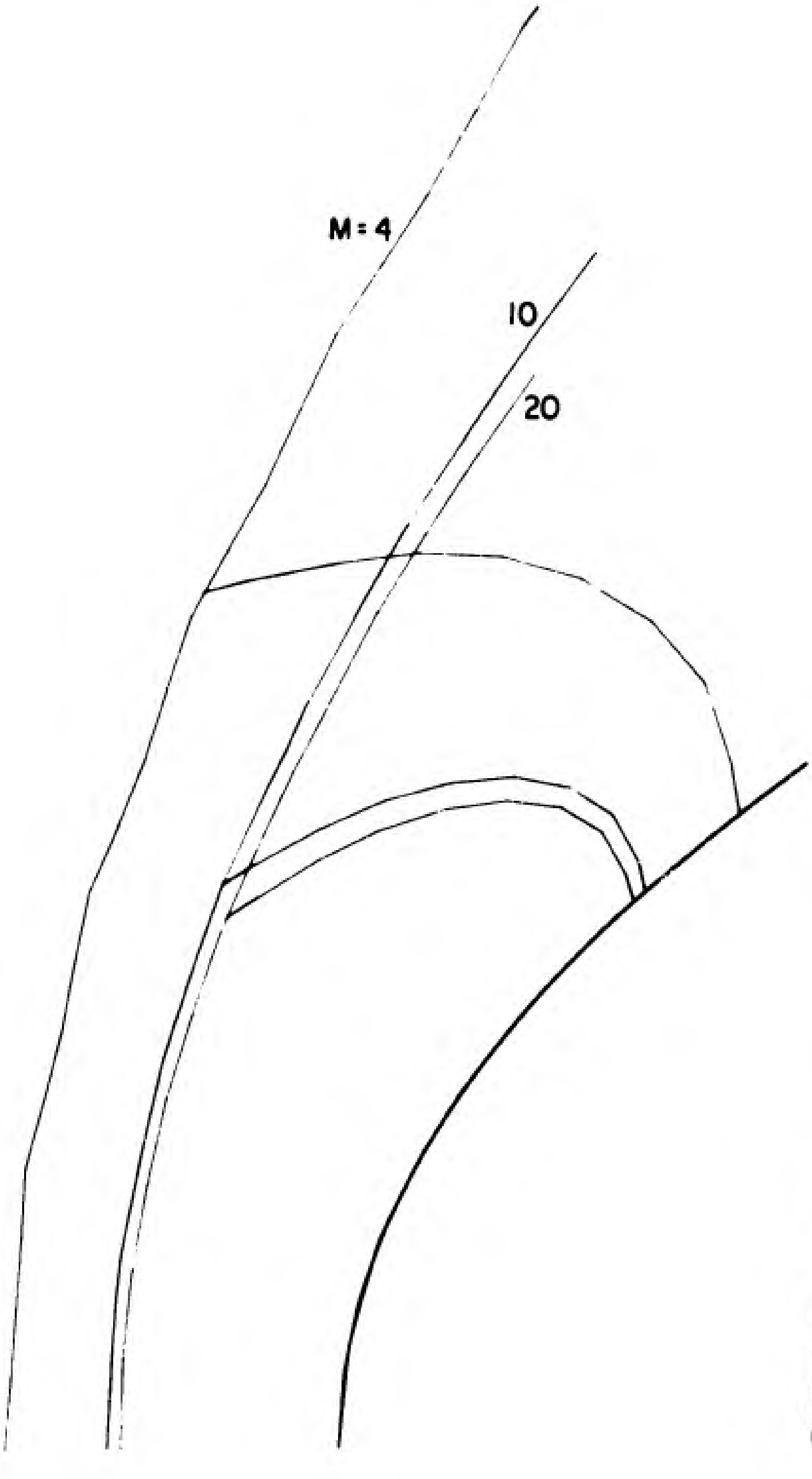


FIG. 19

FIG. 20

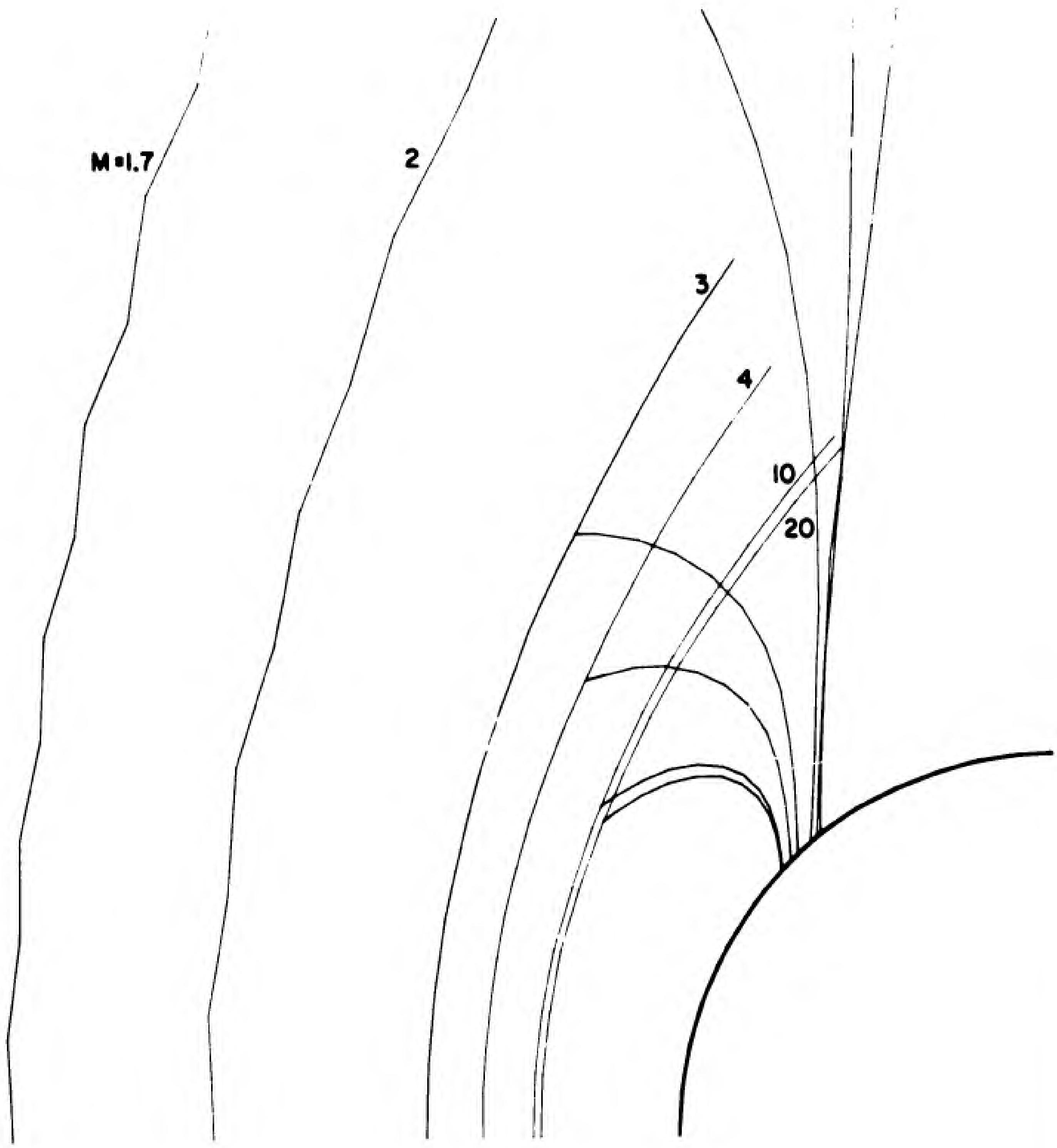


FIG. 21

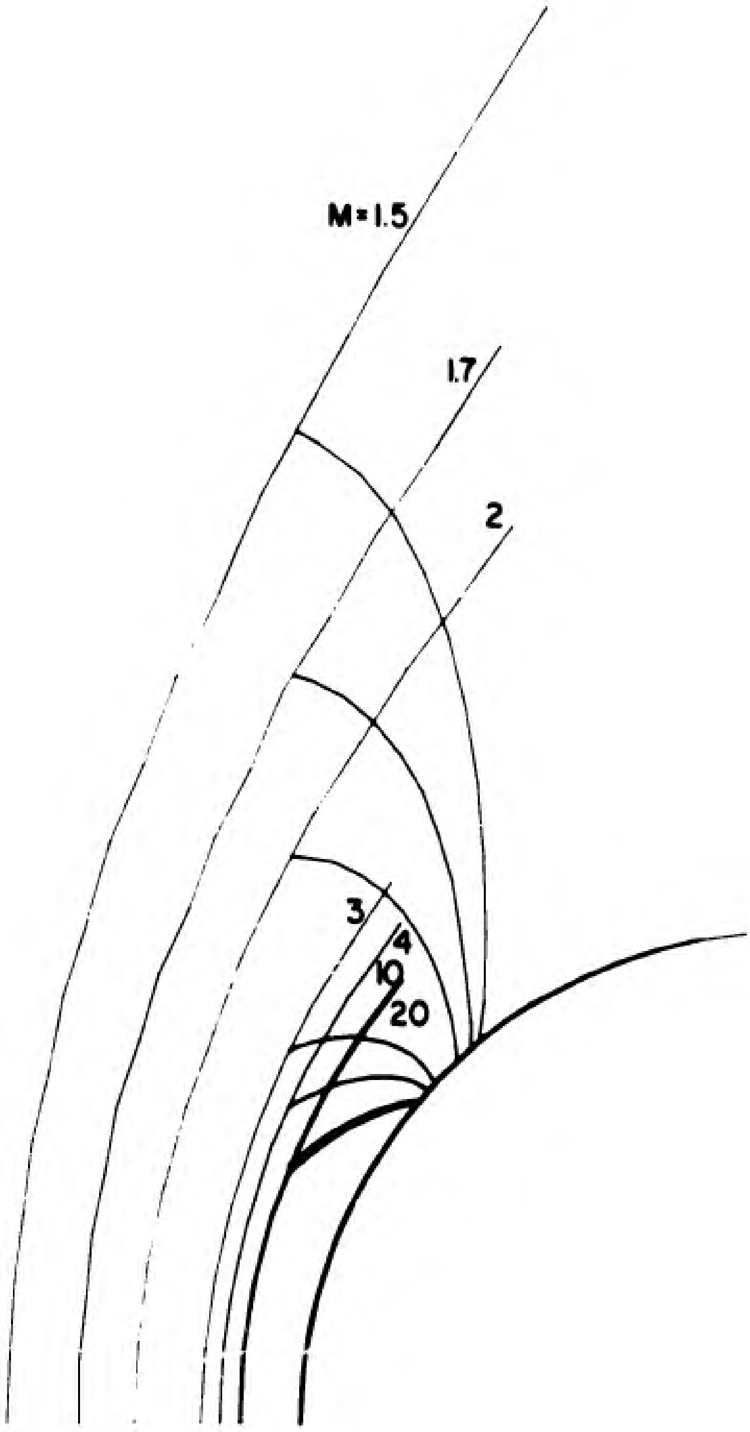


FIG. 22

5. List of Cases Reported

In this report, the results for the following cases are shown:

Two-dimensional problem (program 2E):

A. Study of the mesh size effect

A1	Run No.	199	circular nose, M_∞=4
A2		200	
A3		201	
A4		202	
A5		203	
A6	Run No.	169	flat-faced body with a rounded shoulder, M_∞=6
A7		270	

B. Mach number effect on a circular nose

B1	Run No.	320	M_∞=20
B2		221	10
B3	(see A5)		4
B4		222	3
B5		423	2
B6		324	1.7
B7		325	1.5

C. Elliptical nose at M_∞=20

C1	(see B1)		bluntness parameter = 1
C2	Run No.	215	2
C3		319	3
C4		316	4
C5		317	5
C6		318	6

D. Elliptical nose at M_∞=10

D1	(see B2)		bluntness parameter = 1
D2	Run No.	230	2
D3		331	3
D4		332	4
D5		233	5
D6		234	6

E. Elliptical nose at M_∞=4

E1	(see A5)		bluntness parameter = 1
E2	Run No.	210	2
E3		211	3
E4		212	4
E5		313	5

F. Elliptical nose at M_∞=2

F1	(see B5)		bluntness parameter = 1
F2	Run No.	340	2
F3		341	3

G. Parabolic nose

G1	Run No.	450	M_∞=20
G2		451	10
G3		352	4

Axisymmetric problem (program 2F):

B. Mach number effect on a spherical nose

B1	Run No.	120	M_∞=20
B2		121	10
B3		103	4
B4		122	3
B5		223	2
B6		124	1.7
B7		125	1.5

C. Ellipsoid, at M_∞=20

C1	(see B1)		bluntness parameter = 1
C2	Run No.	115	2
C3		119	3
C4		116	4
C5		117	5
C6		118	6

D. Ellipsoid, at $M_\infty=10$

D1	(see B2)	bluntness parameter =	1
D2	Run No. 130		2
D3	131		3
D4	132		4
D5	133		5
D6	134		6

E. Ellipsoid, at $M_\infty=4$

E1	(see B3)	bluntness parameter =	1
E2	Run No. 110		2
E3	111		3
E4	112		4
E5	113		5

F. Ellipsoid, at $M_\infty=2$

F1	(see B5)	bluntness parameter =	1
F2	Run No. 140		2
F3	141		3

G. Paraboloid

G1	Run No. 150	M_∞ 20
G2	151	10
G3	152	4

H. Flat-faced cylinder with a rounded shoulder, $M_\infty=10.5$

(·=ratio of the shoulder radius to the cylinder radius)

H1	Run No. 80	· = .50
H2	81	.25
H3	82	.10
H4	83	.05

The H-series of runs has been made to test the computational technique against a recently issued set of experimental data (Ref . 5 and 6). The computed pressure distributions on the body, when expressed as a function of the arc-length, fall exactly on top of the experimental curves. The shock waves also fit exactly the experimental shapes. Some of the computed patterns are rather irregular, particularly when σ is very small, but this should be expected, as we said in section 4. Note, for example, that the body shape assumed by the machine in case H4 is only a rough approximation to a flat-faced cylinder with a rounded shoulder, $\sigma = .05$.

6. Acknowledgements

The initial work on the two-dimensional and the axisymmetric problem for a perfect gas was performed at the General Applied Science Laboratories under the sponsorship of the Advanced Research Projects Agency in 1965 (Refs. 1 and 2). The extension to three-dimensional flows of a perfect gas was also performed at the General Applied Science Laboratories under the sponsorship of the Sandia Corporation, in 1966 (Ref. 4). More recently, the Sandia Corporation sponsored additional work, as a result of which the problem was reformulated in new frames of reference; the pertinent analysis, performed last year at the General Applied Science Laboratories, is not available in the open literature. The computations shown in the present report make use of the latter frames of reference, with some additional features added in the last few

months. The latter research, as well as the parametric study partially contained in the present report, has been performed at the Polytechnic Institute of Brooklyn under the sponsorship of the Office of Naval Research under Contract Nonr 839(34).

The plots have been obtained by transferring the pertinent information (as computed by the CDC 6600 machine at the Courant Institute of the New York University) to the Stromberg-Carlson 4020 plotter of the Polytechnic Institute of Brooklyn and by using an additional plotting program. I am glad to acknowledge the dedicated and efficient assistance of Mr. Martin Tillinger of the Polytechnic Institute of Brooklyn in the delicate manipulation necessary to obtain these plots.

7. References

1. Moretti, G. and Abbett, M., A fast, direct, and accurate technique for the blunt body problem. GASL TR 583, January 1966.
2. Moretti, G. and Abbett, M., A time-dependent computational method for blunt body flows. AIAA J., 4, 2136, 1966.
3. Belotserkovskii, O.M., (Editor), Supersonic gas flow around blunt bodies. NASA TT F-453, 1967.

4. Moretti, G. and Bleich, G., Three-dimensional flow around blunt bodies. AIAA J., 5, 1557, 1967.

5. Marvin, J.G. and Sinclair, A.R., Convective heating in regions of large favorable pressure gradient. AIAA J., 5, 1940, 1967.

6. Inouye, M., Marvin, J.G., and Sinclair, A.R., Comparison of experimental and theoretical shock shapes and pressure distributions on flat-faced cylinders at Mach 10.5. NASA TN D-4397, 1968.

TWO-DIMENSIONAL CASES

TWO DIM[illegible] SYMMETRIC BLUNT BODY [illegible]

2 BY 4 [illegible], 100 STEPS TOLERANCE=0.0[illegible]010

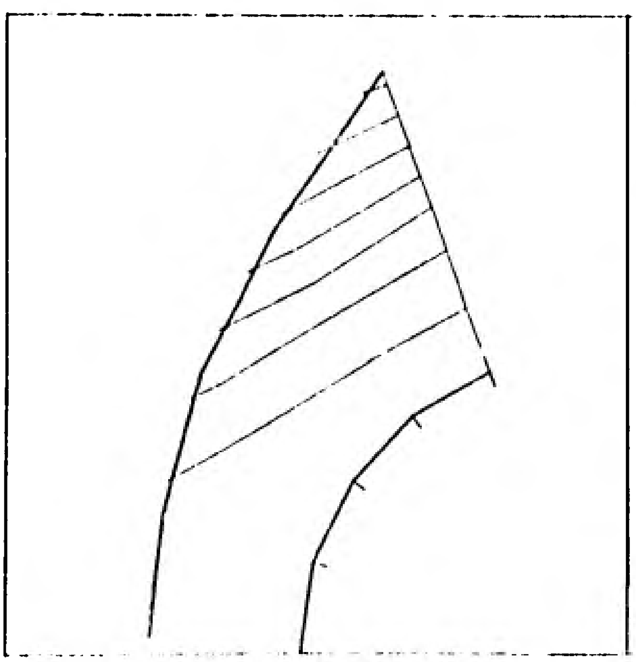
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.[illegible]
COMP. STAGNATION PRESSURE= 20.0[illegible]5
RELATIVE ERROR= 0.01[illegible]1

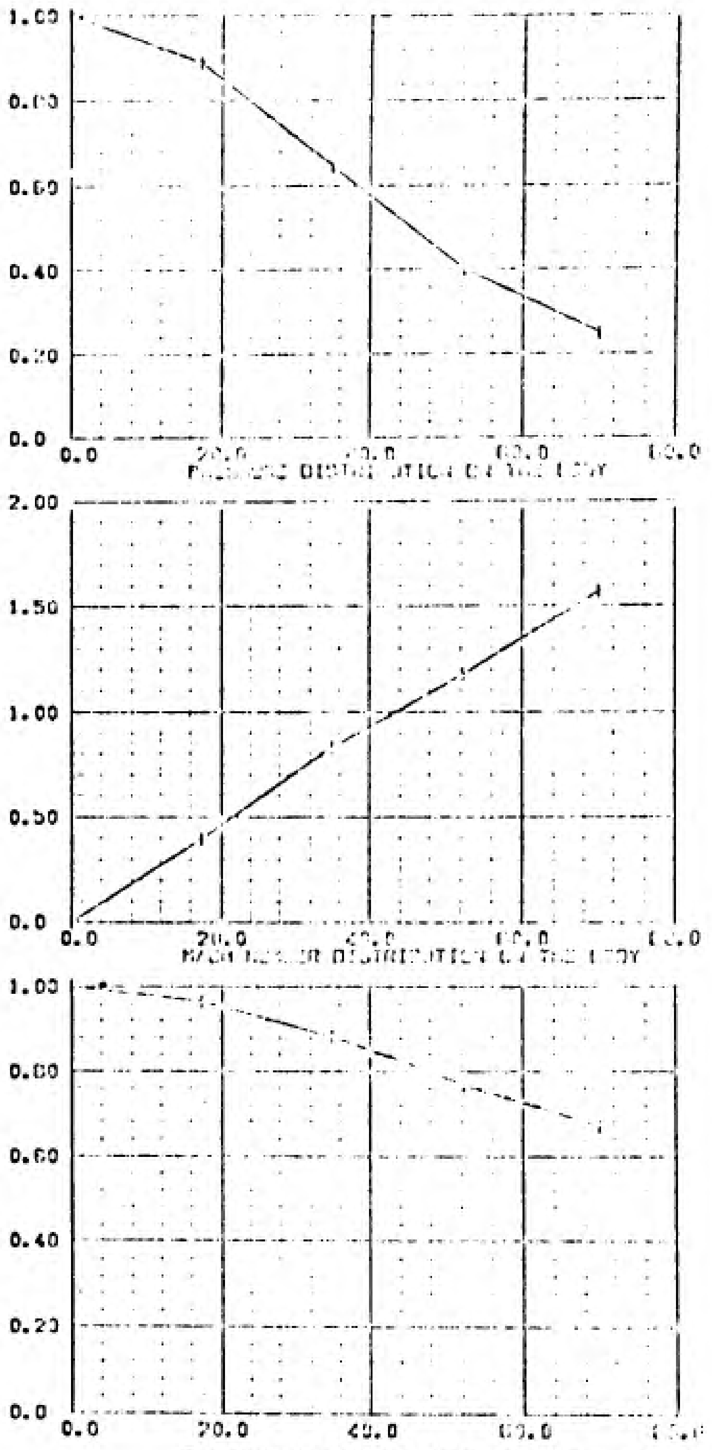
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.107
RELATIVE ERROR= 0.00304

CRITICAL PRESSURE RATIO= 0.5[illegible]55 (REL. ERROR= 0.0[illegible]3)
CRITICAL DENSITY RATIO= 0.[illegible]0 (REL. ERROR= 0.0[illegible]3)
CRITICAL TEMPERAT.RATIO= 0.[illegible] (REL. ERROR= 0.0041)

STANDOFF DISTANCE=0.5243
ABSCISSA OF STAGNATION POINT= -1.00000



STREAMLINES



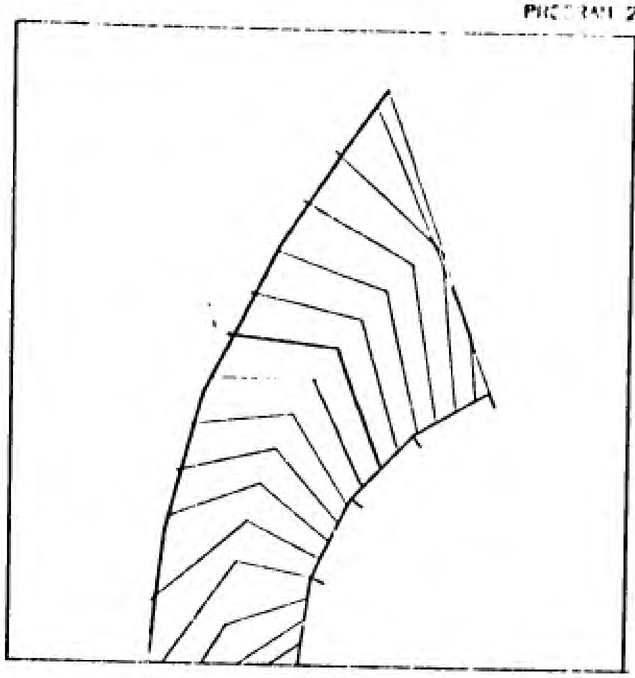
PRESSURE DISTRIBUTION ON THE BODY

MACH NUMBER DISTRIBUTION ON THE BODY

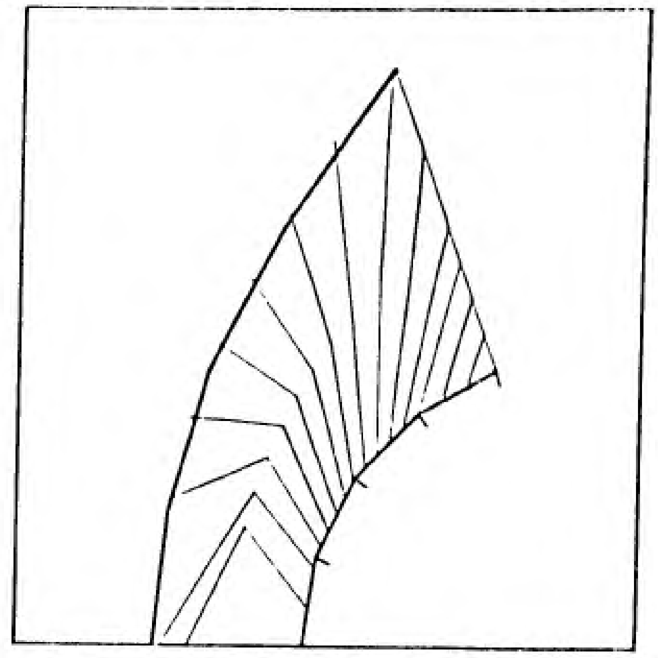
TEMPERATURE DISTRIBUTION ON THE BODY

A1

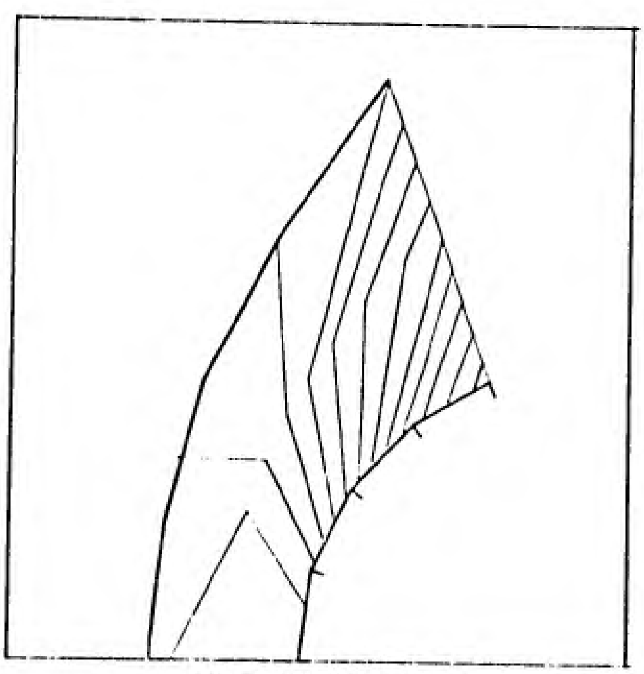
PROGRAM 2C, RUN NO 15.0 , M= 4.00



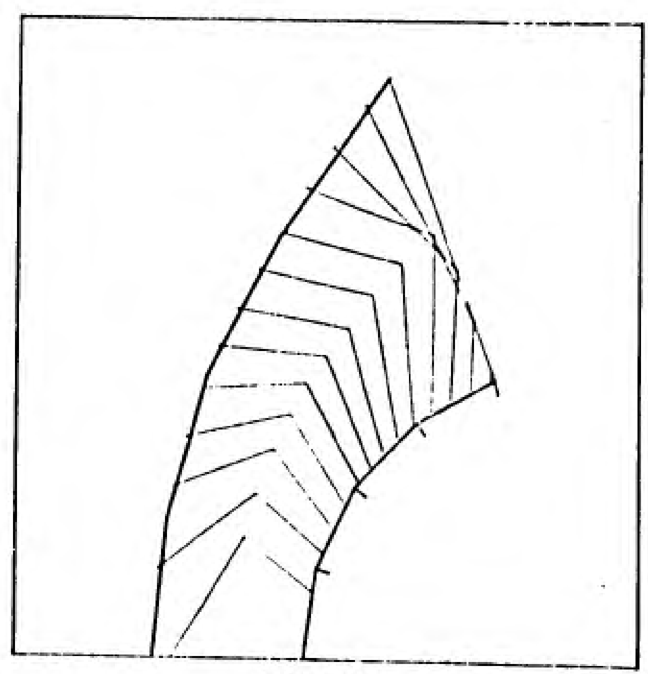
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 200

3 BY 5 MESH, 240 STEPS   TOLERANCE=0.000010

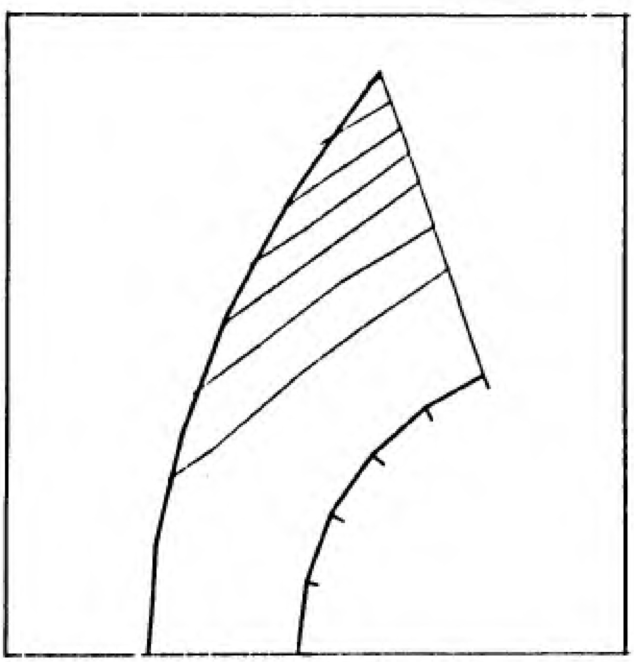
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.040
RELATIVE ERROR= 0.00131

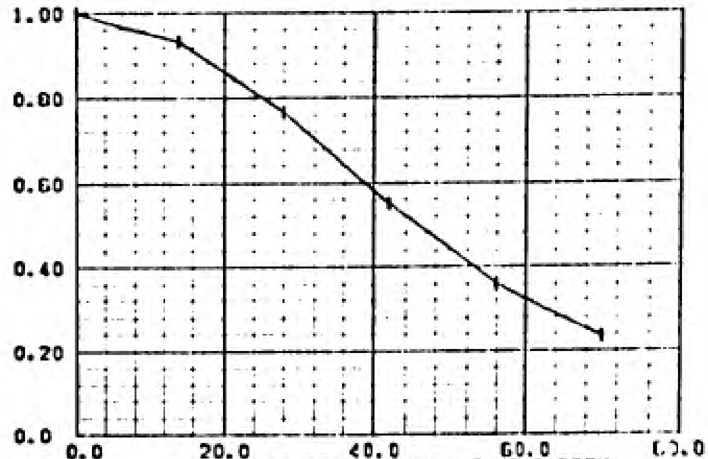
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.198
RELATIVE ERROR= 0.00037

CRITICAL PRESSURE RATIO=0.5339 (REL. ERROR= 0.0162)
CRITICAL DENSITY RATIO=0.6407 (REL. ERROR= 0.0106)
CRITICAL TEMPERAT.RATIO=0.8330 (REL. ERROR= 0.0006)

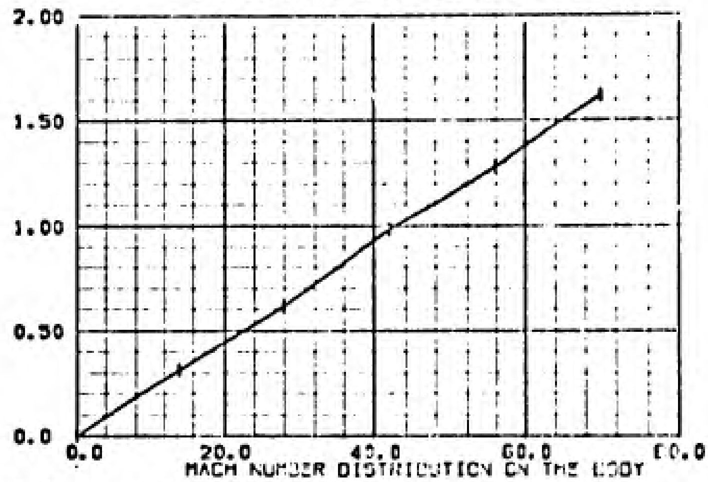
STANDOFF DISTANCE=0.5191
ABSCISSA OF STAGNATION POINT= -1.00000



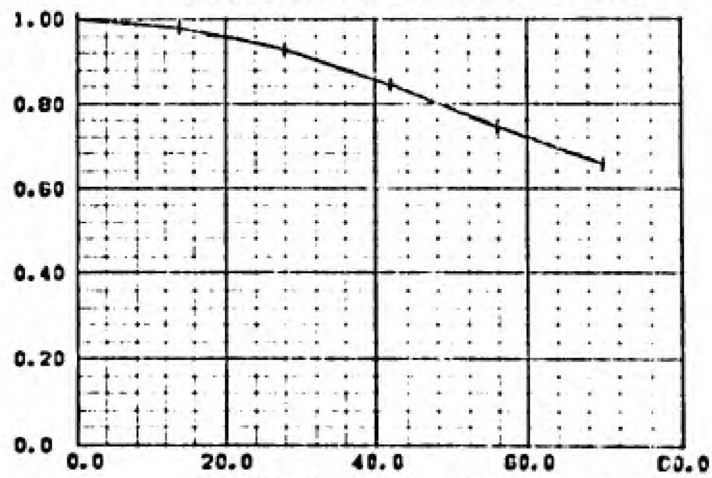
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



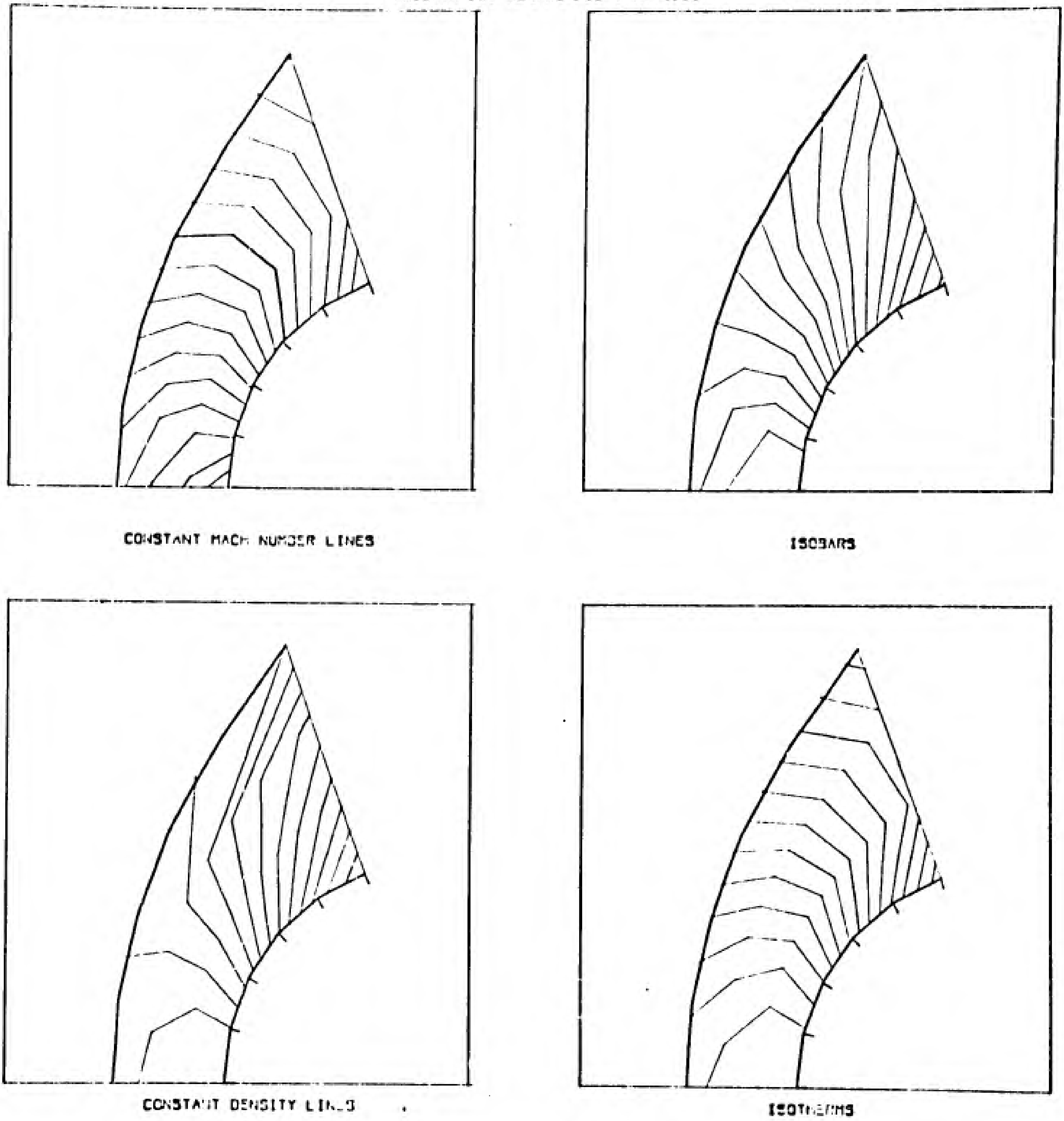
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

A2

PROGRAM 2E. RUN NO 200 . M= 4.00



TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 201

5 BY 8 MESH, 400 STEPS TOLERANCE=0.000010

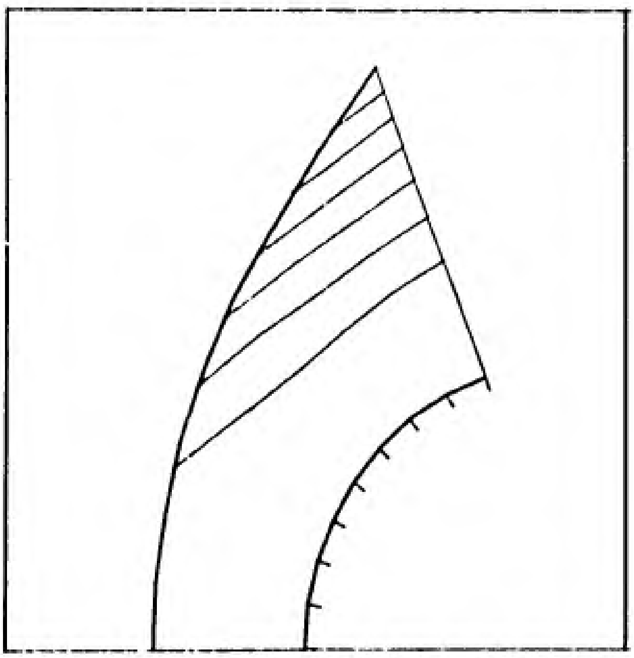
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.000
COMP. STAGNATION PRESSURE= 21.072
RELATIVE ERROR= 0.00020

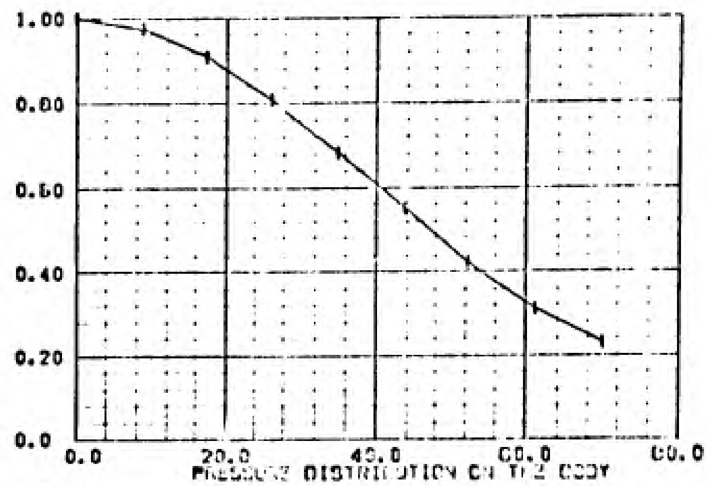
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5284 (REL. ERROR= 0.0001)
CRITICAL DENSITY RATIO=0.6334 (REL. ERROR= 0.0003)
CRITICAL TEMPERAT.RATIO=0.8342 (REL. ERROR= 0.0010)

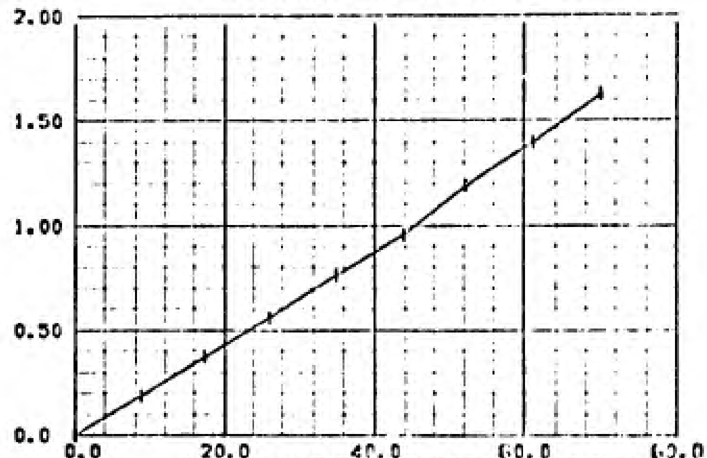
STANDOFF DISTANCE=0.5555
ABSCISSA OF STAGNATION POINT= -1.00000



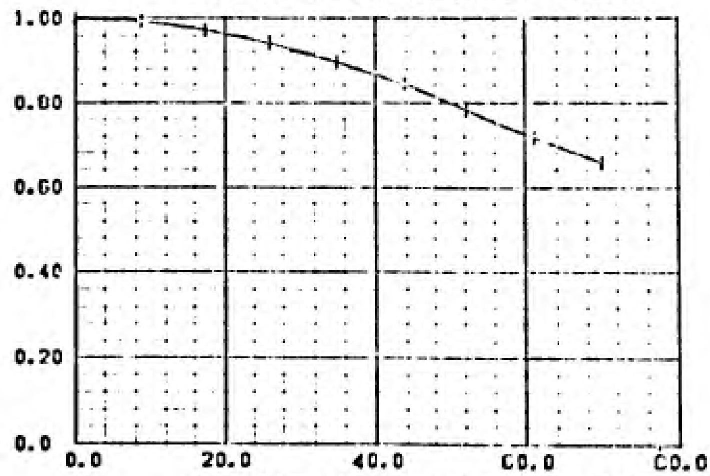
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



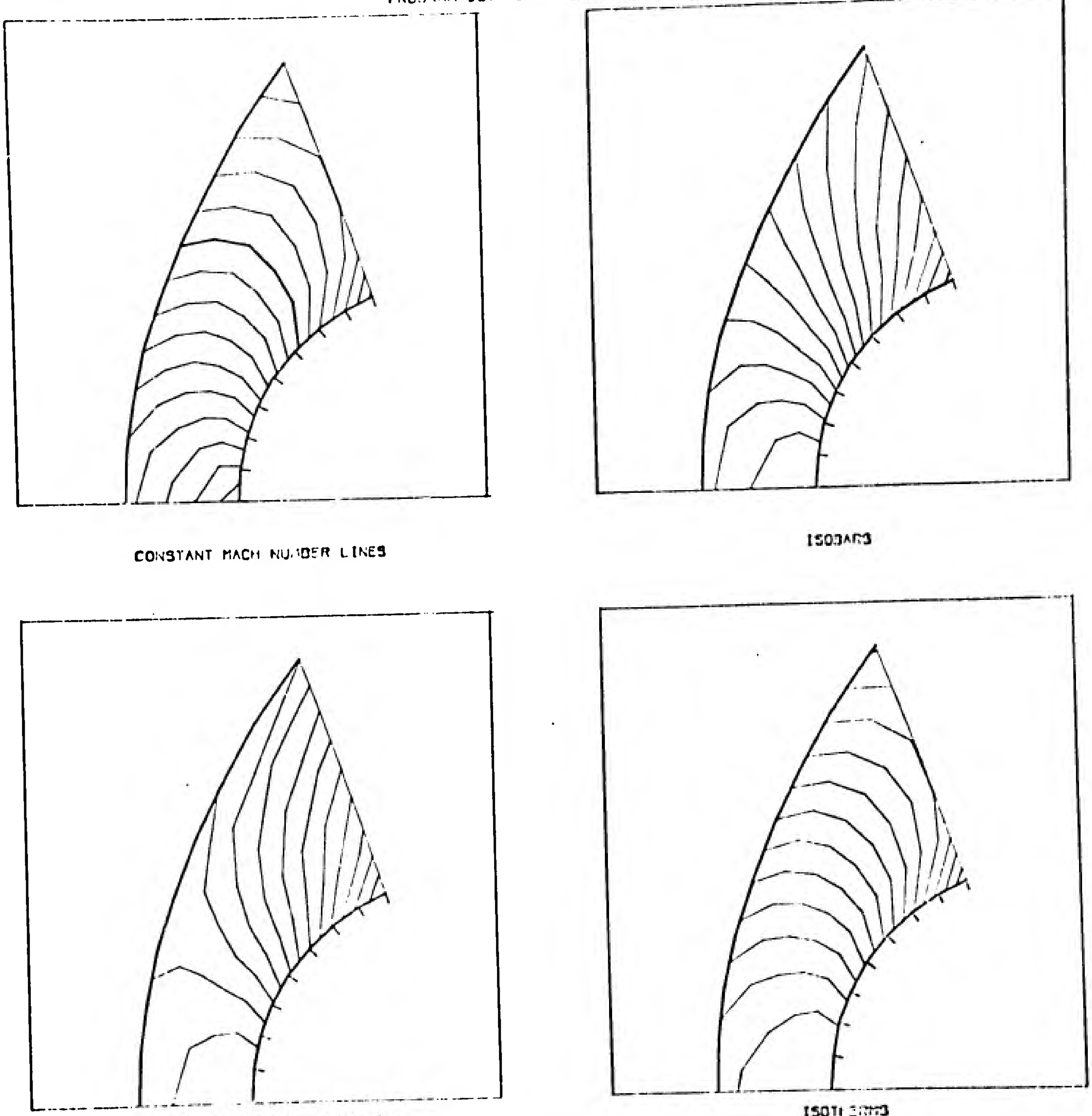
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

A3

PROGRAM 2E, RUN NO 201 , M= 4.00



TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 202

7 BY 12 MESH, 550 STEPS   TOLERANCE=0.000010

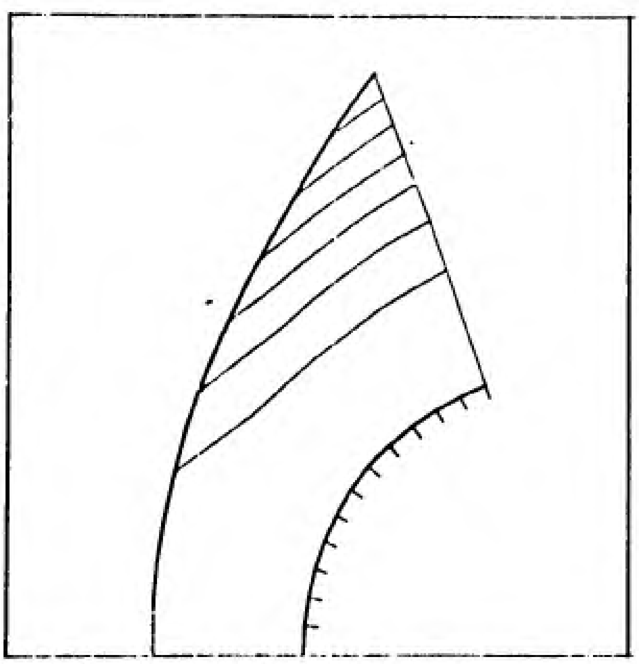
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.069
COMP. STAGNATION PRESSURE= 21.035
RELATIVE ERROR= 0.00013

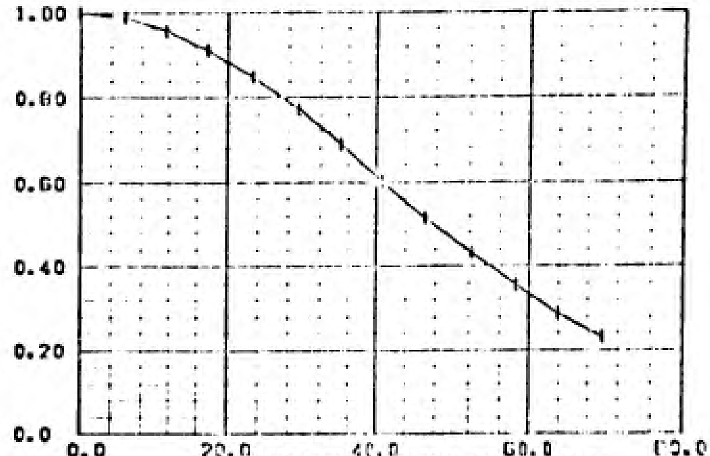
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5296 (REL. ERROR= 0.0023)
CRITICAL DENSITY RATIO=0.6349 (REL. ERROR= 0.0015)
CRITICAL TEMPERAT.RATIO=0.8342 (REL. ERROR= 0.0011)

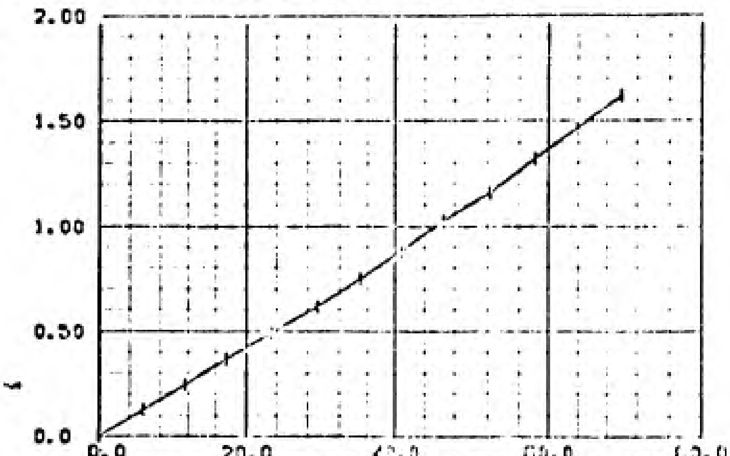
STANDOFF DISTANCE=0.5275
ABSCISSA OF STAGNATION POINT= -1.00000



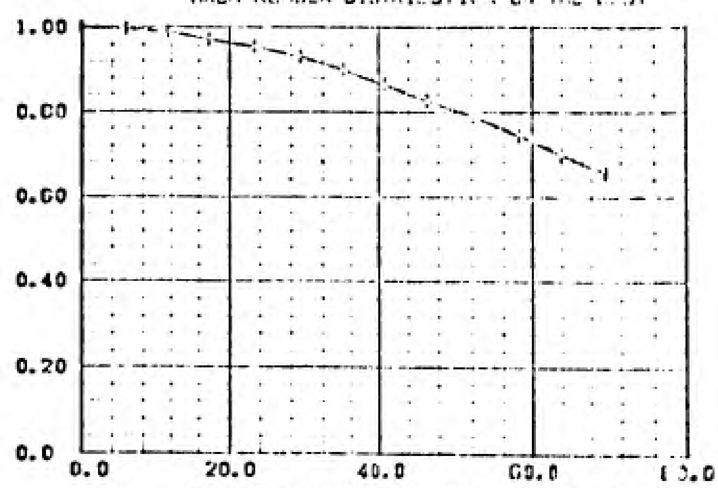
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

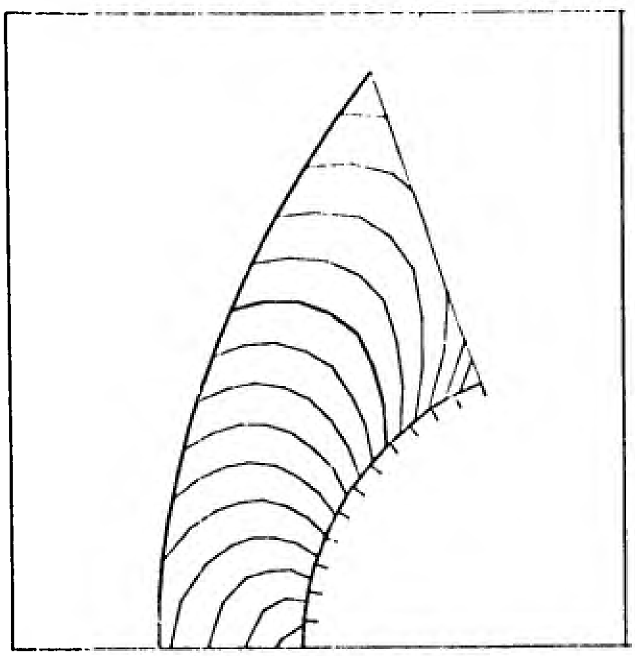


MACH NUMBER DISTRIBUTION ON THE BODY

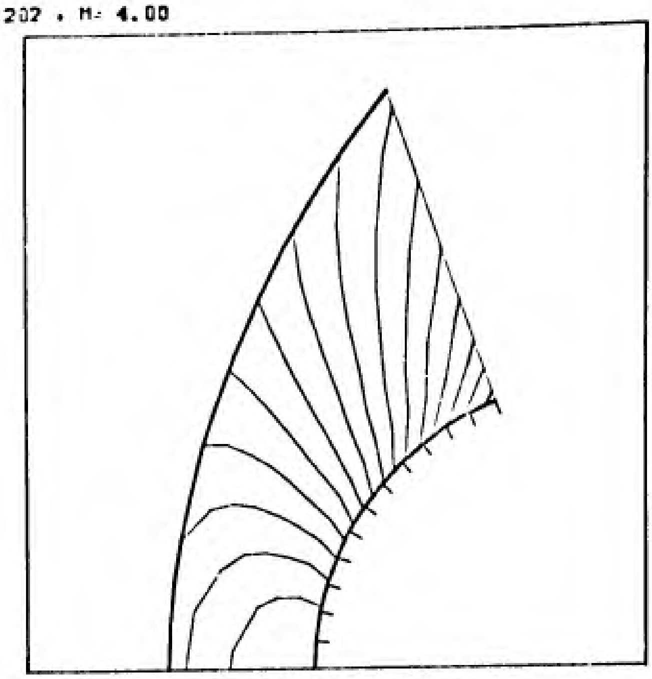


TEMPERATURE DISTRIBUTION ON THE BODY

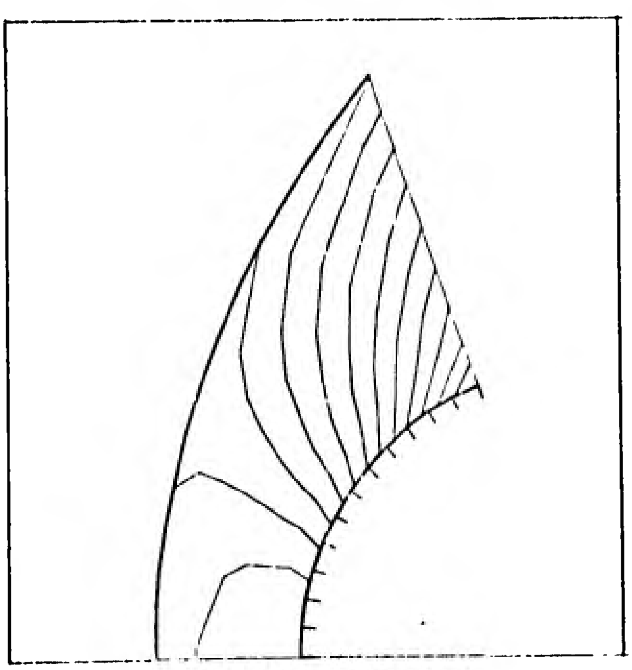
PROGRAM 2E, RUN NO 202 , M= 4.00



CONSTANT MACH NUMBER LINES



ISOBARS



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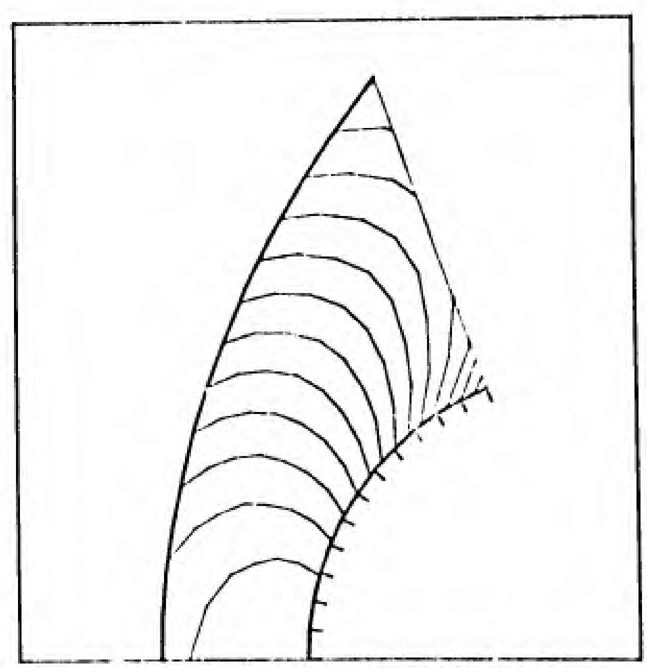


ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 203

10 BY 16 MESH, 800 STEPS   TOLERANCE=0.000010

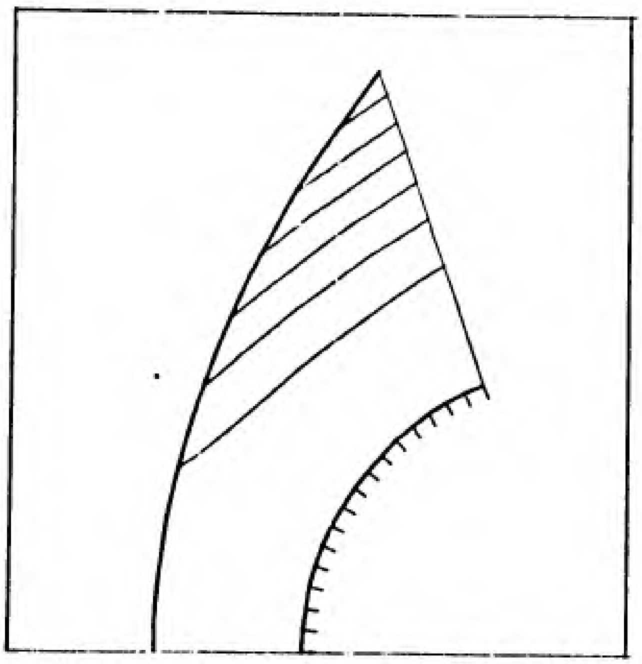
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.0[illegible]
COMP. STAGNATION PRESSURE= 21.072
RELATIVE ERROR= 0.00017

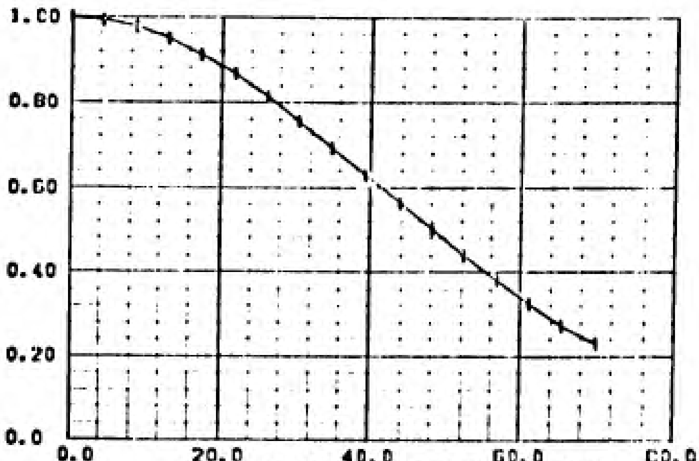
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00005

CRITICAL PRESSURE RATIO=0.52[illegible] (REL. ERROR= 0.0007)
CRITICAL DENSITY RATIO=0.6340 (REL. ERROR= 0.0001)
CRITICAL TEMPERAT.RATIO=0.8333 (REL. ERROR= 0.0006)

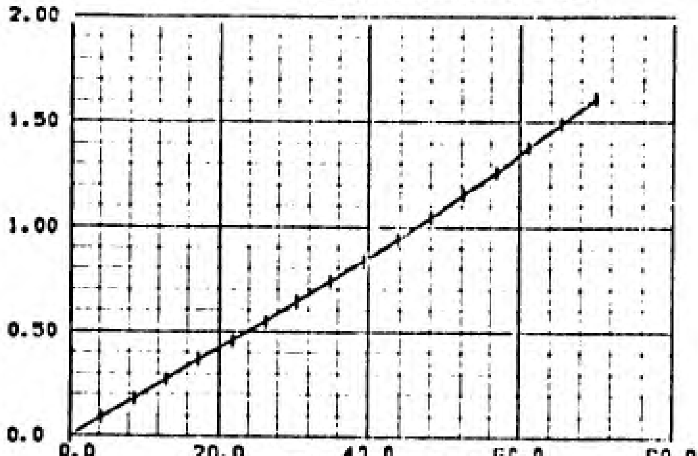
STANDOFF DISTANCE=0.5410
ABSCISSA OF STAGNATION POINT= -1.00000



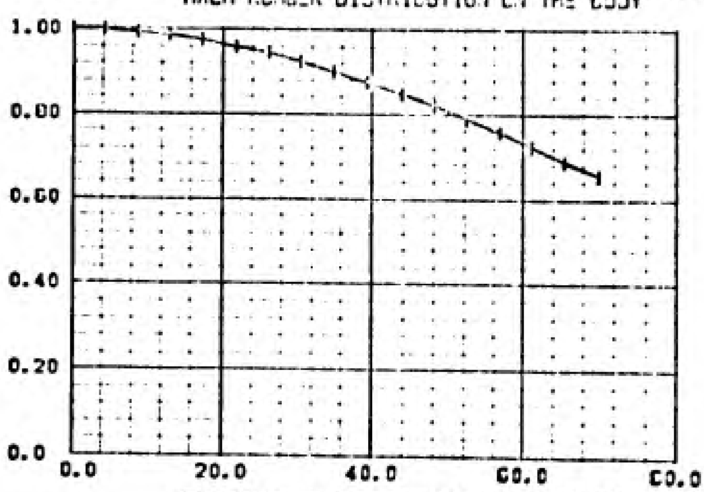
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



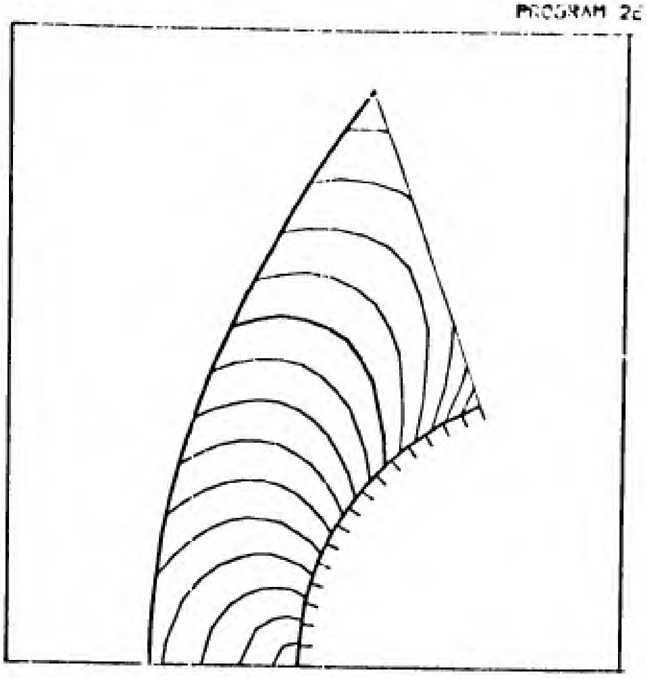
MACH NUMBER DISTRIBUTION ON THE BODY



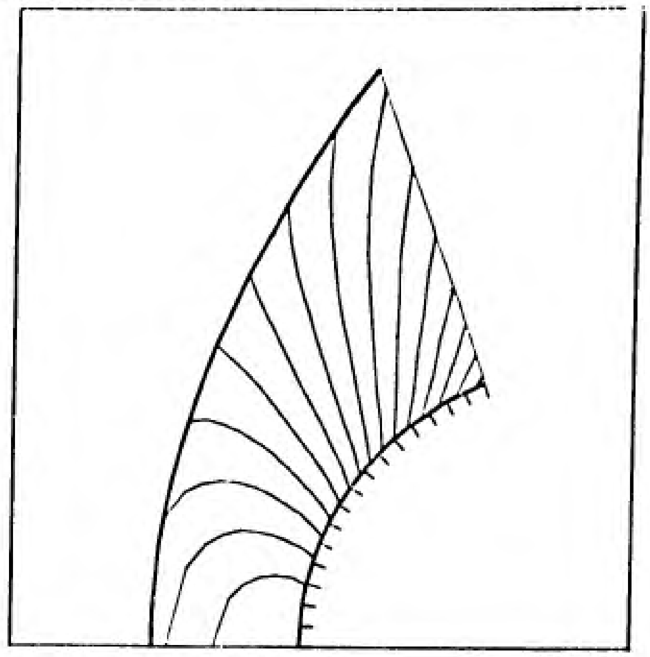
TEMPERATURE DISTRIBUTION ON THE BODY

A5

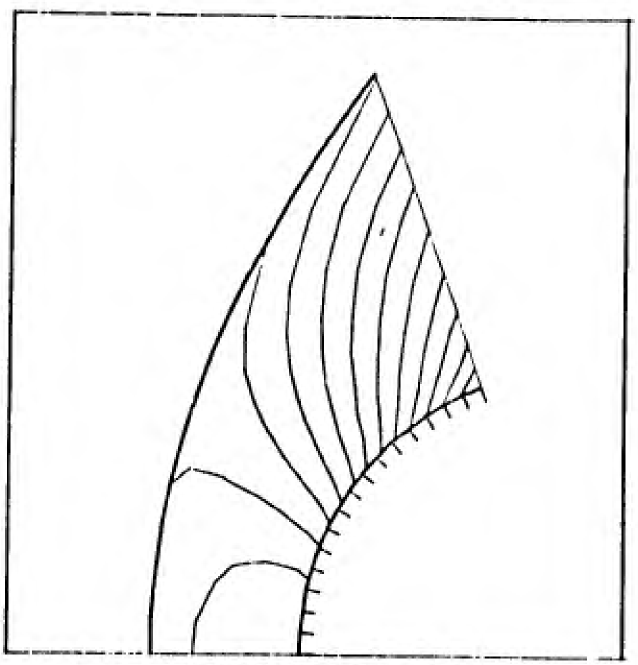
PROGRAM 2E. RUN NO 203 . M= 4.00



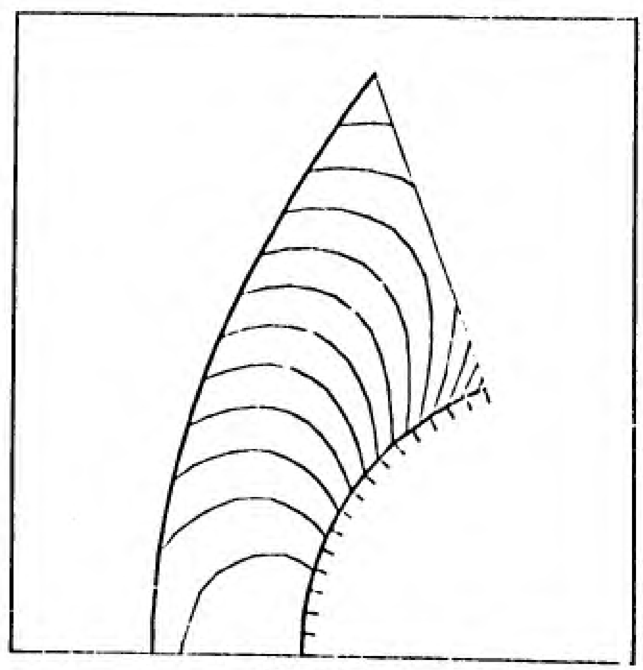
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 169

5 BY 8 MESH, 400 STEPS   TOLERANCE=0.000010

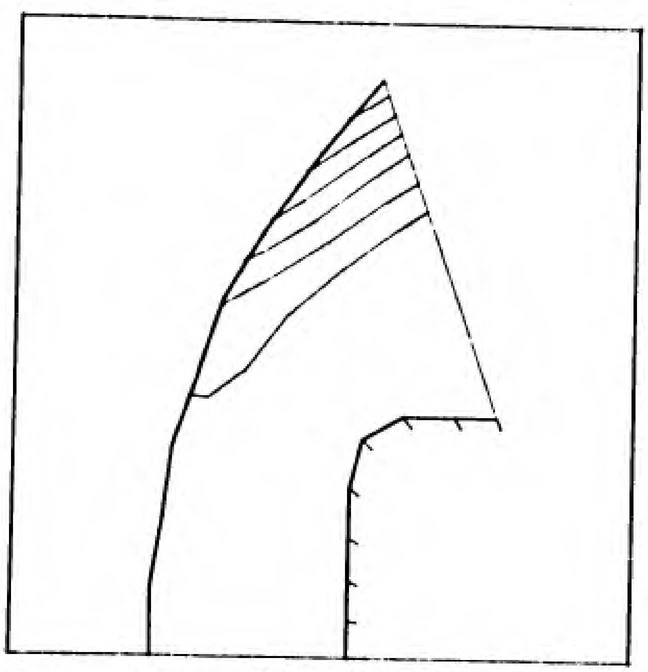
FREE STREAM MACH NUMBER= 6.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 46.815
COMP. STAGNATION PRESSURE= 46.831
RELATIVE ERROR= 0.00034

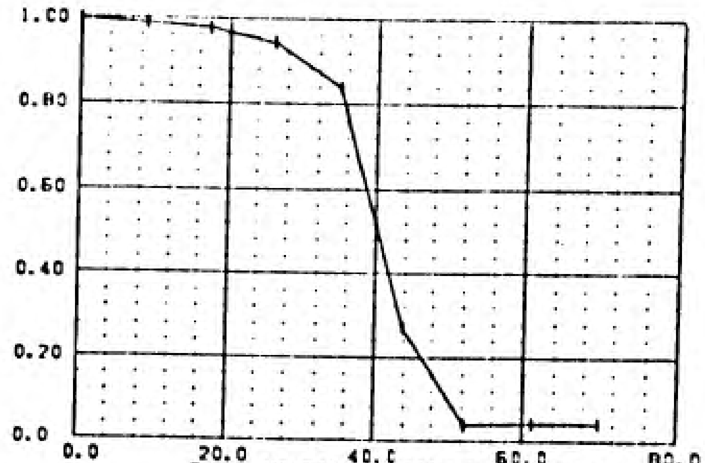
THEOR. STAGNATION TEMPERATURE= 8.200
COMP. STAGNATION TEMPERATURE= 8.201
RELATIVE ERROR= 0.00010

CRITICAL PRESSURE RATIO=0.7115   (REL. ERROR= 0.3467)
CRITICAL DENSITY RATIO=0.7723   (REL. ERROR= 0.2183)
CRITICAL TEMPERAT.RATIO=0.9212   (REL. ERROR= 0.1054)

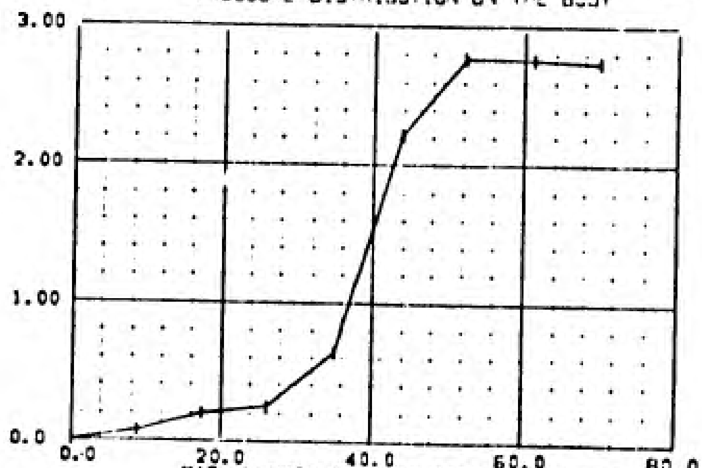
STANDOFF DISTANCE=0.8394
ABSCISSA OF STAGNATION POINT= -1.8394



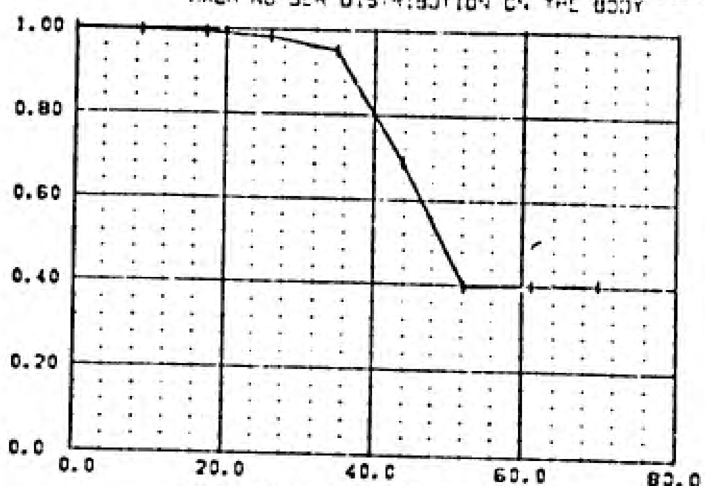
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



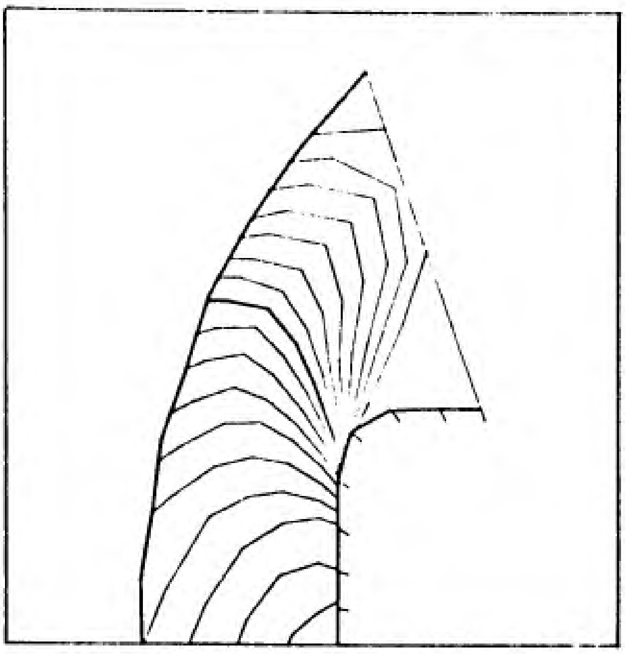
MACH NUMBER DISTRIBUTION ON THE BODY



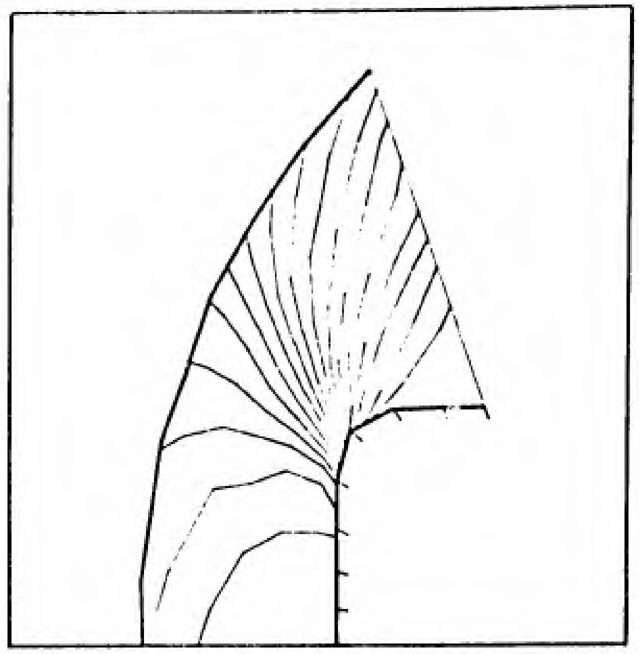
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 169 . M= 6.00

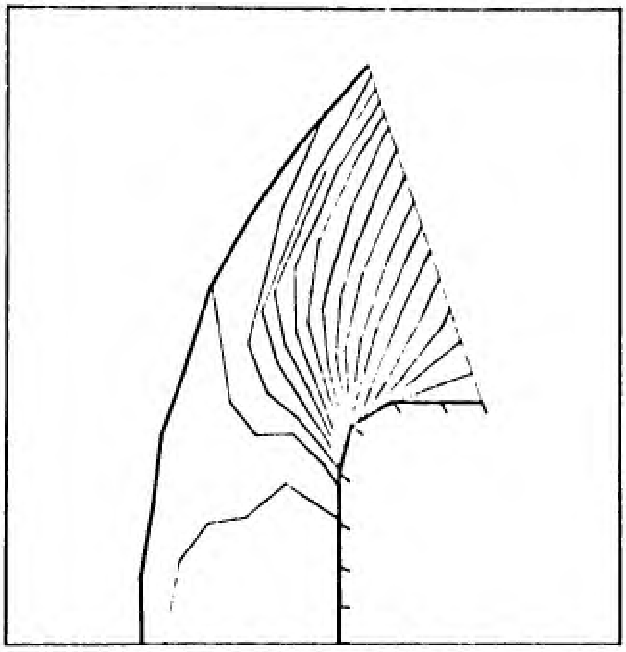
A6



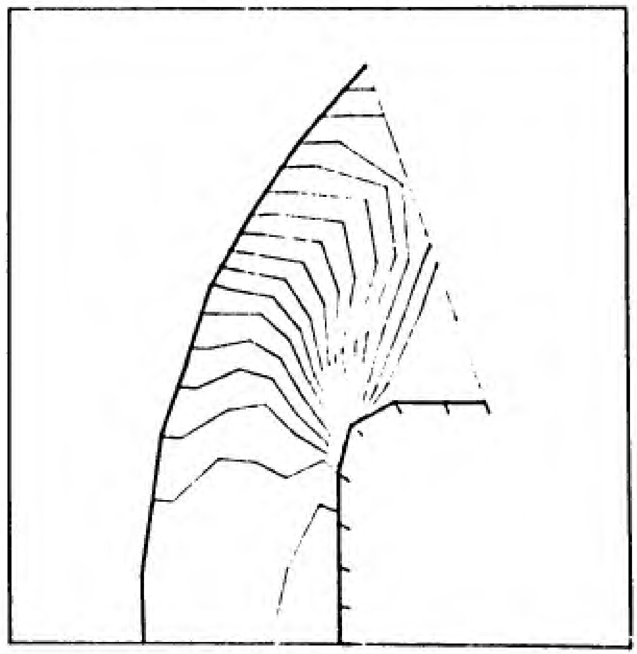
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 270

10 BY 16 MESH, 800 STEPS TOLERANCE=0.000010

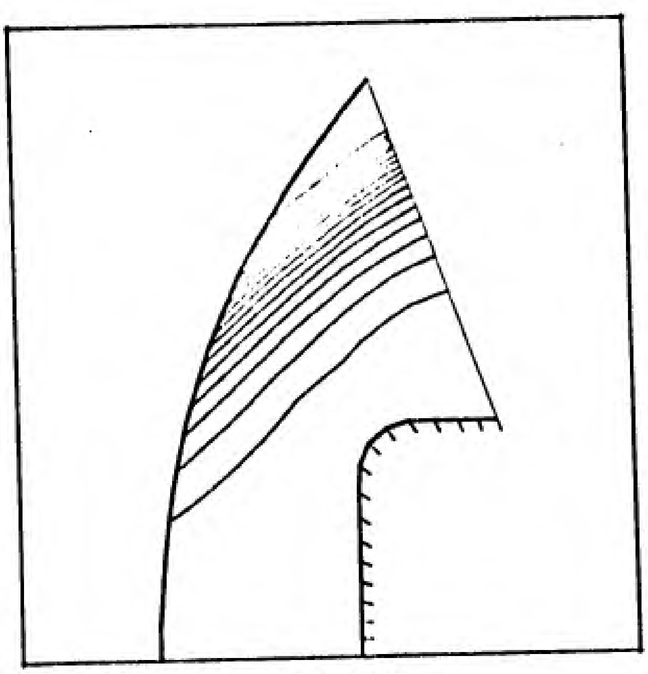
FREE STREAM MACH NUMBER= 6.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 46.815
COMP. STAGNATION PRESSURE= 46.790
RELATIVE ERROR= 0.00053

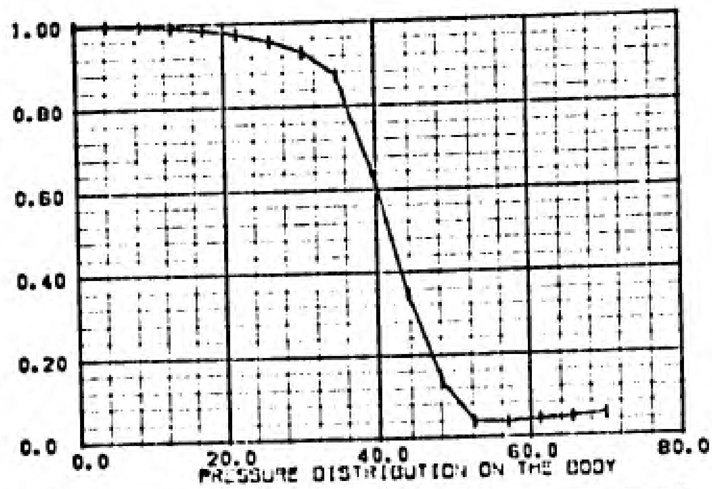
THEOR. STAGNATION TEMPERATURE= 8.200
COMP. STAGNATION TEMPERATURE= 8.199
RELATIVE ERROR= 0.00015

CRITICAL PRESSURE RATIO=0.6058 (REL. ERROR= 0.1467)
CRITICAL DENSITY RATIO=0.6975 (REL. ERROR= 0.1003)
CRITICAL TEMPERAT.RATIO=0.8700 (REL. ERROR= 0.0440)

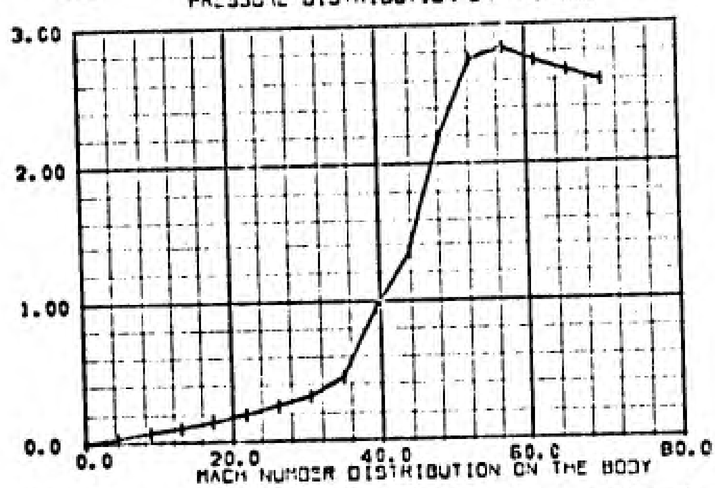
STANDOFF DISTANCE=0.6777
ABSCISSA OF STAGNATION POINT= -1.00000



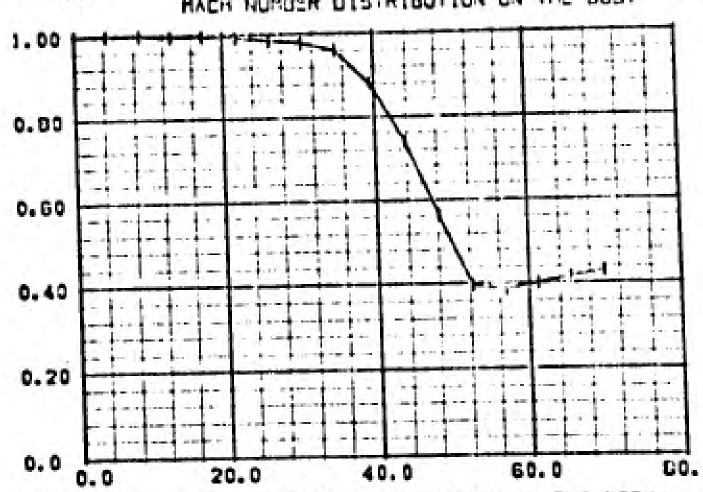
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



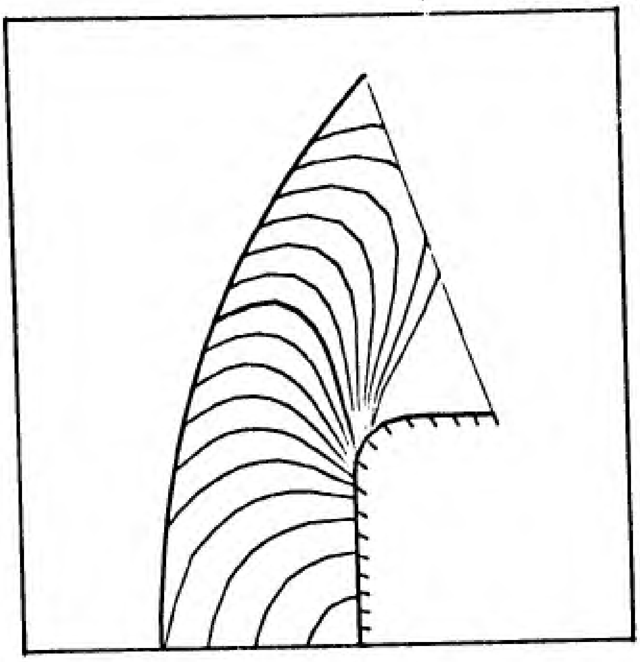
MACH NUMBER DISTRIBUTION ON THE BODY



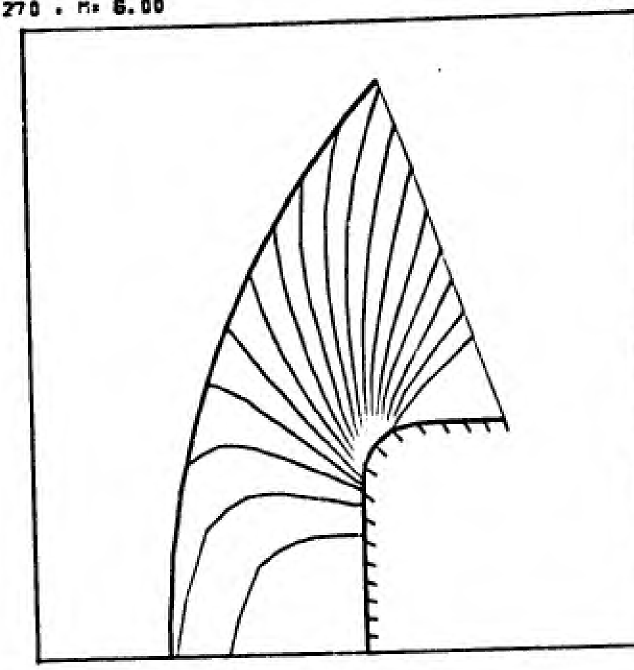
TEMPERATURE DISTRIBUTION ON THE BODY

A7

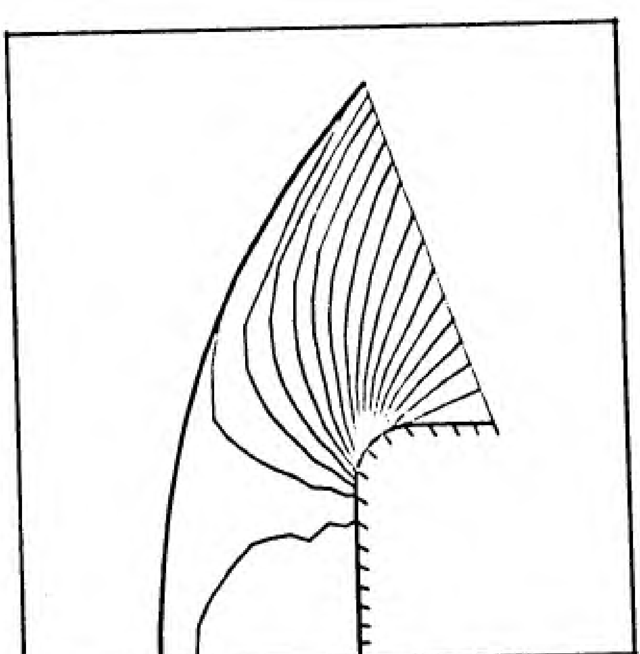
PROGRAM 2E. RUN NO 270 . M= 6.00



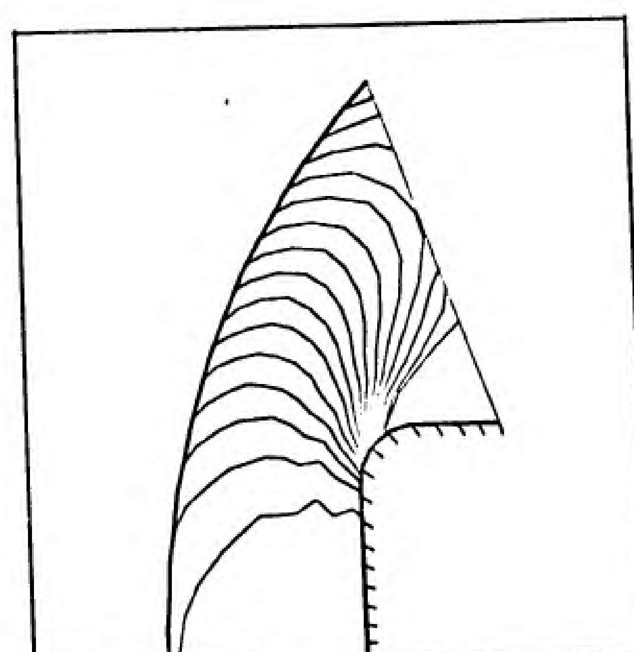
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 320

10 BY 12 MESH, 800 STEPS   TOLERANCE= 0.000010

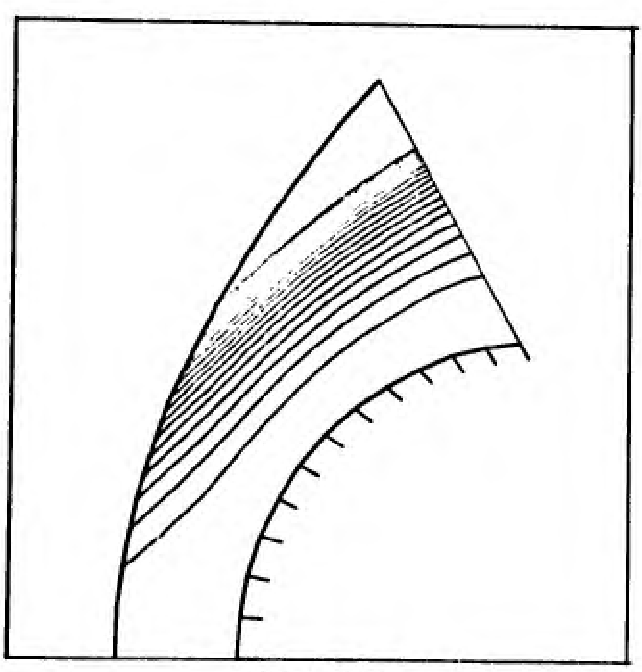
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.661
RELATIVE ERROR= 0.00034

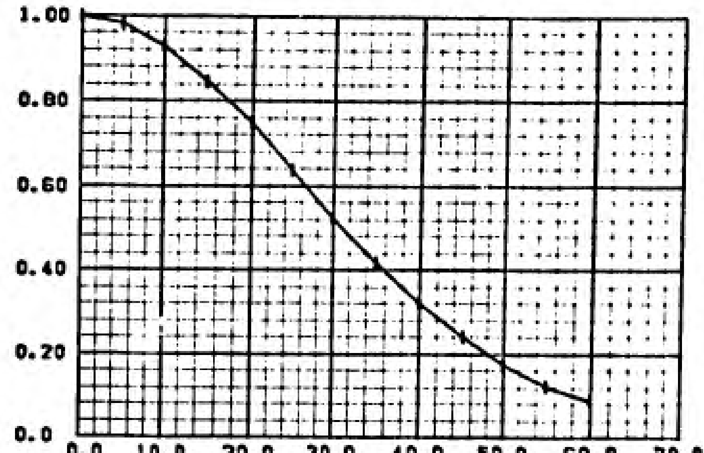
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 81.008
RELATIVE ERROR= 0.00010

CRITICAL PRESSURE RATIO= 0.5302 (REL. ERROR= 0.0036)
CRITICAL DENSITY RATIO= 0.6354 (REL. ERROR= 0.0023)
CRITICAL TEMPERAT. RATIO= 0.8344 (REL. ERROR= 0.0012)

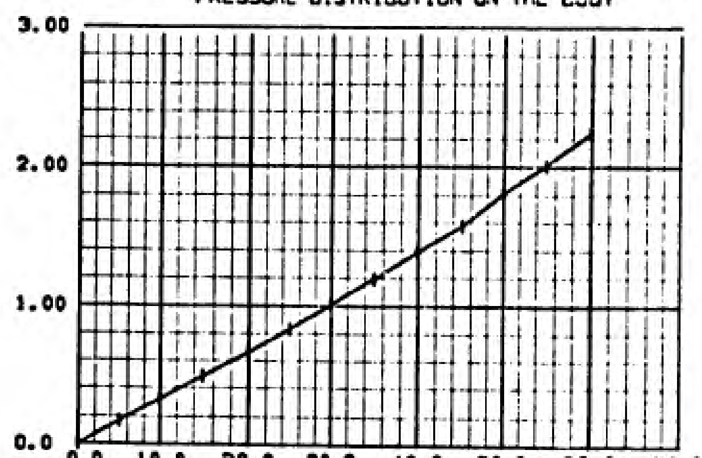
STANDOFF DISTANCE=0.3821
ABSCISSA OF STAGNATION POINT= -1.50000



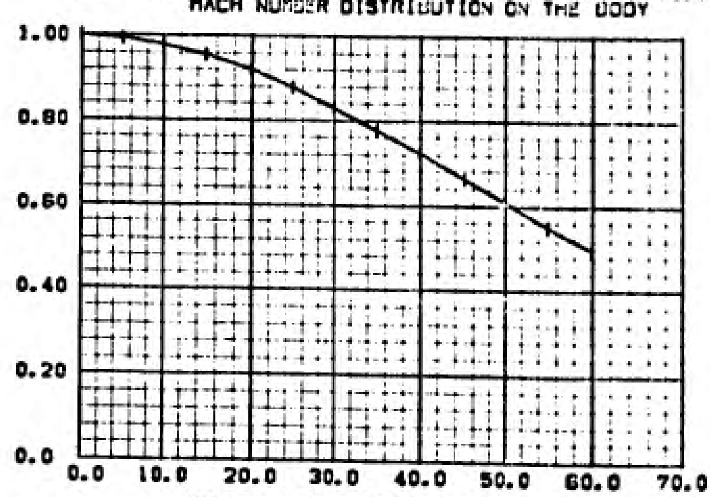
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

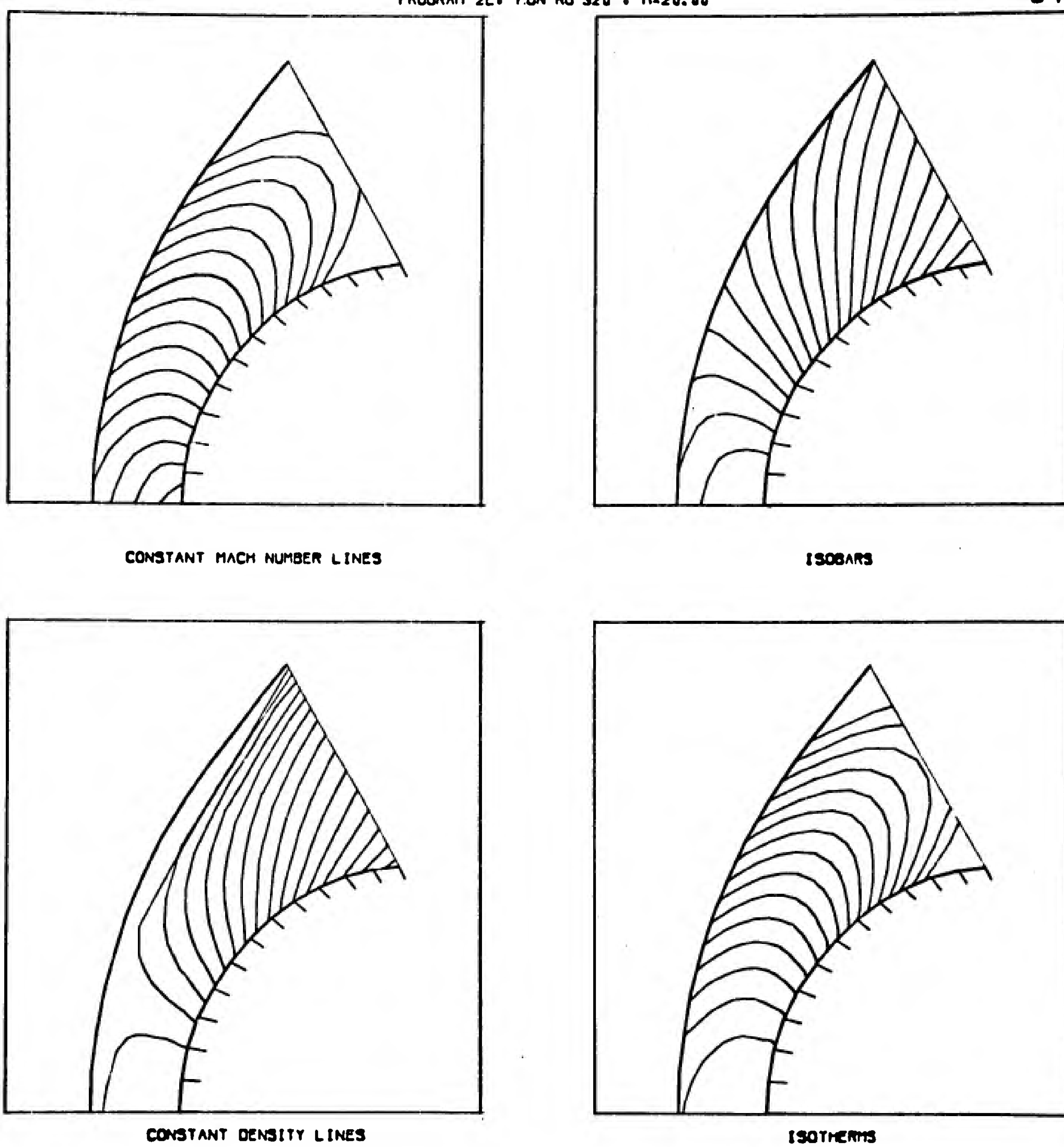


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 320 . M=20.00 B1



TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 221

10 BY 12 MESH, 600 STEPS TOLERANCE= 0.000010

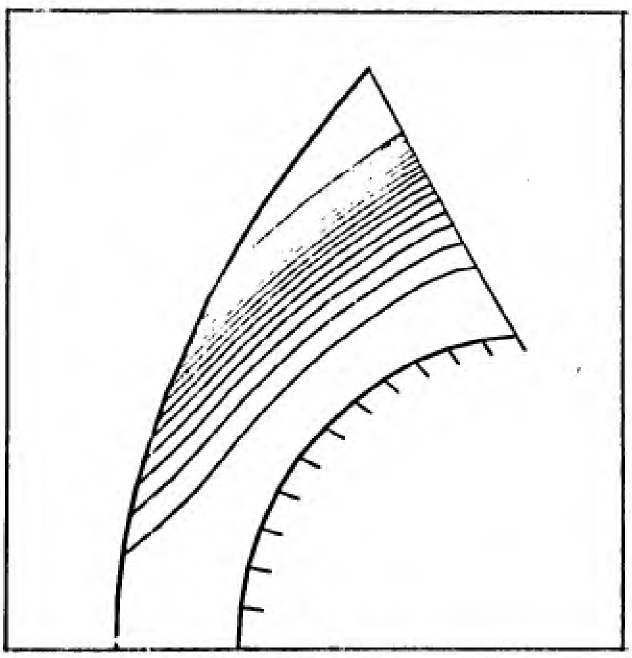
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.237
RELATIVE ERROR= 0.00016

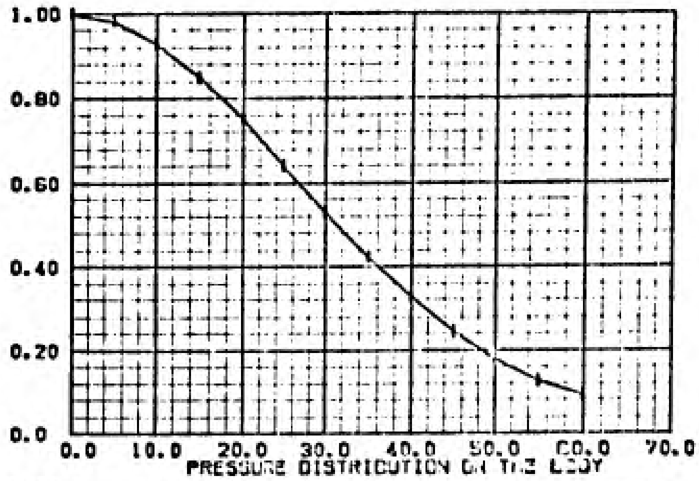
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.001
RELATIVE ERROR= 0.00005

CRITICAL PRESSURE RATIO= 0.5301 (REL. ERROR= 0.0035)
CRITICAL DENSITY RATIO= 0.6355 (REL. ERROR= 0.0024)
CRITICAL TEMPERAT.RATIO= 0.8342 (REL. ERROR= 0.0011)

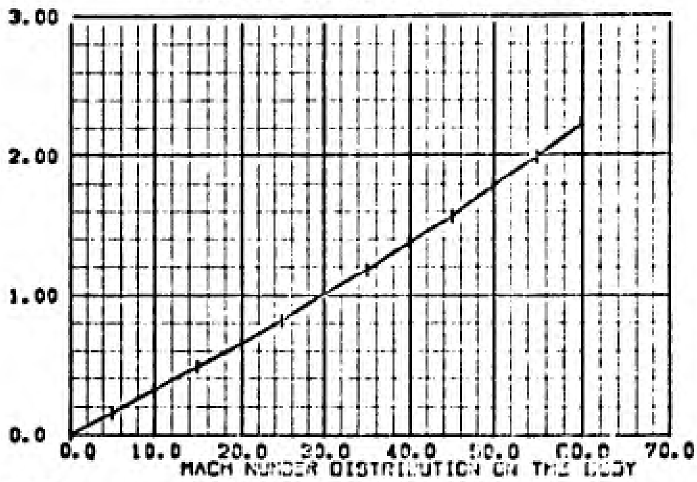
STANDOFF DISTANCE=0.4005
ABSCISSA OF STAGNATION POINT= -1.50000



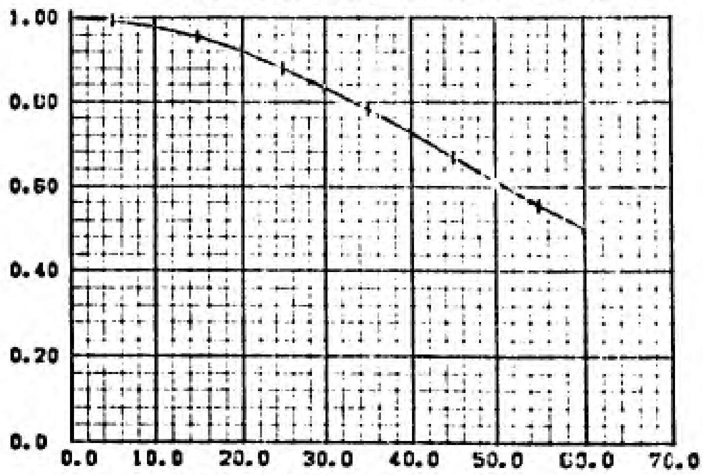
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

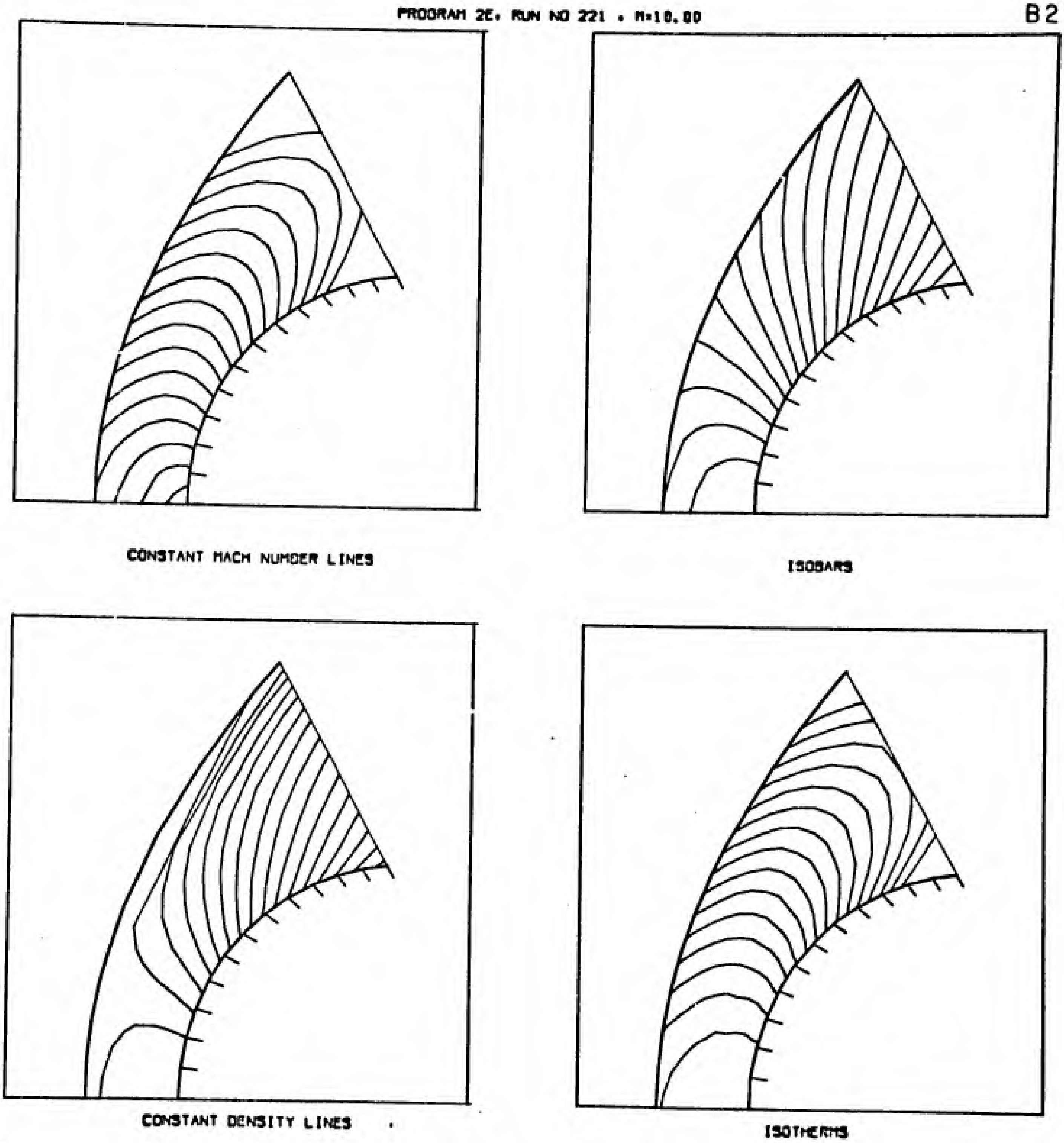


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 221 . M=10.00 B2



TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 222

10 BY 12 MESH, 600 STEPS   TOLERANCE=0.000010

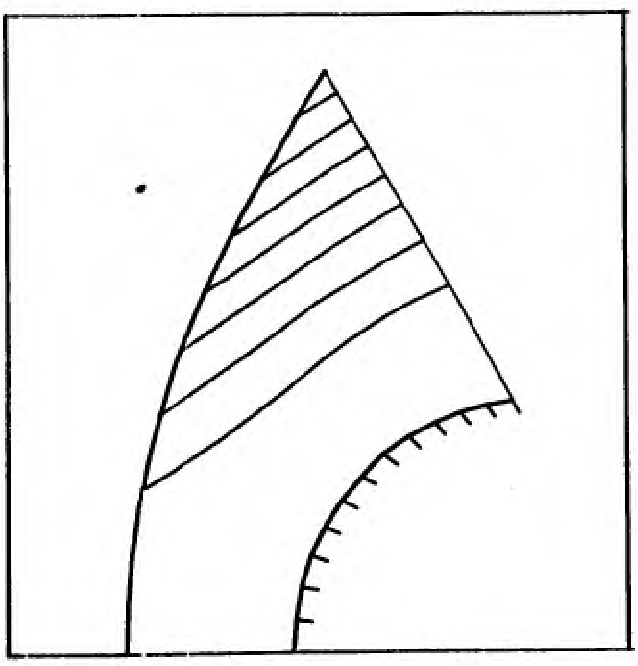
FREE STREAM MACH NUMBER= 3.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 12.061
COMP. STAGNATION PRESSURE= 12.062
RELATIVE ERROR= 0.00008

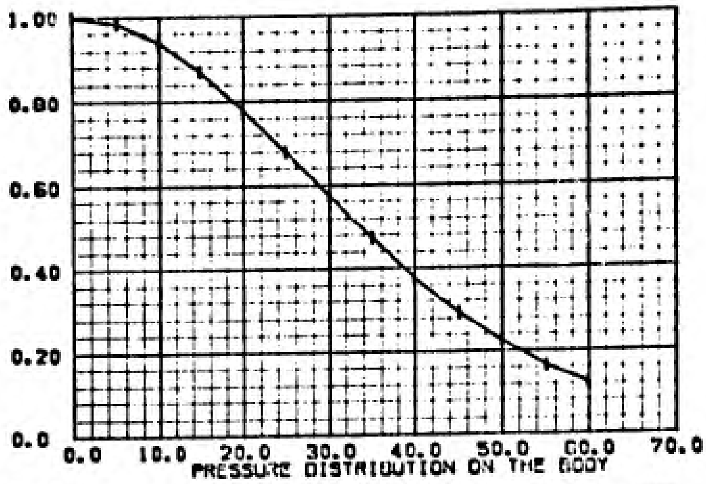
THEOR. STAGNATION TEMPERATURE= 2.800
COMP. STAGNATION TEMPERATURE= 2.800
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5287 (REL. ERROR= 0.0026)
CRITICAL DENSITY RATIO=0.6345 (REL. ERROR= 0.0009)
CRITICAL TEMPERAT.RATIO=0.8348 (REL. ERROR= 0.0017)

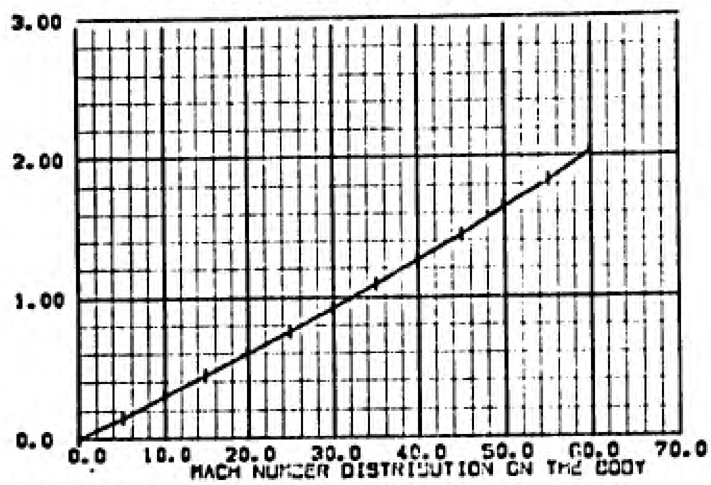
STANDOFF DISTANCE=0.6940
ABSCISSA OF STAGNATION POINT= -1.50000



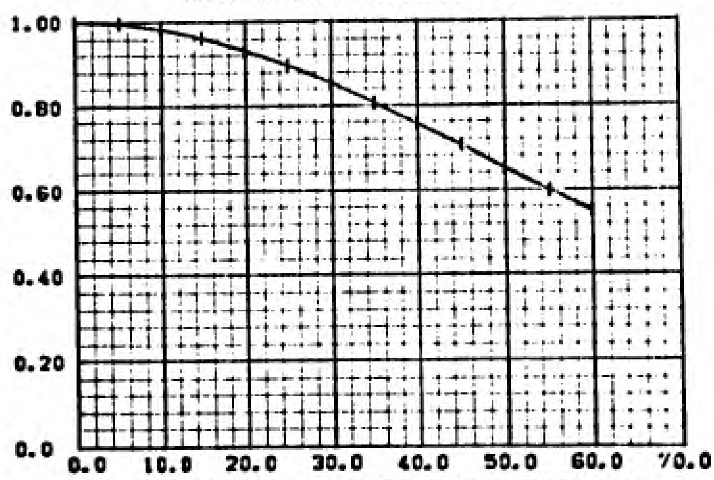
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



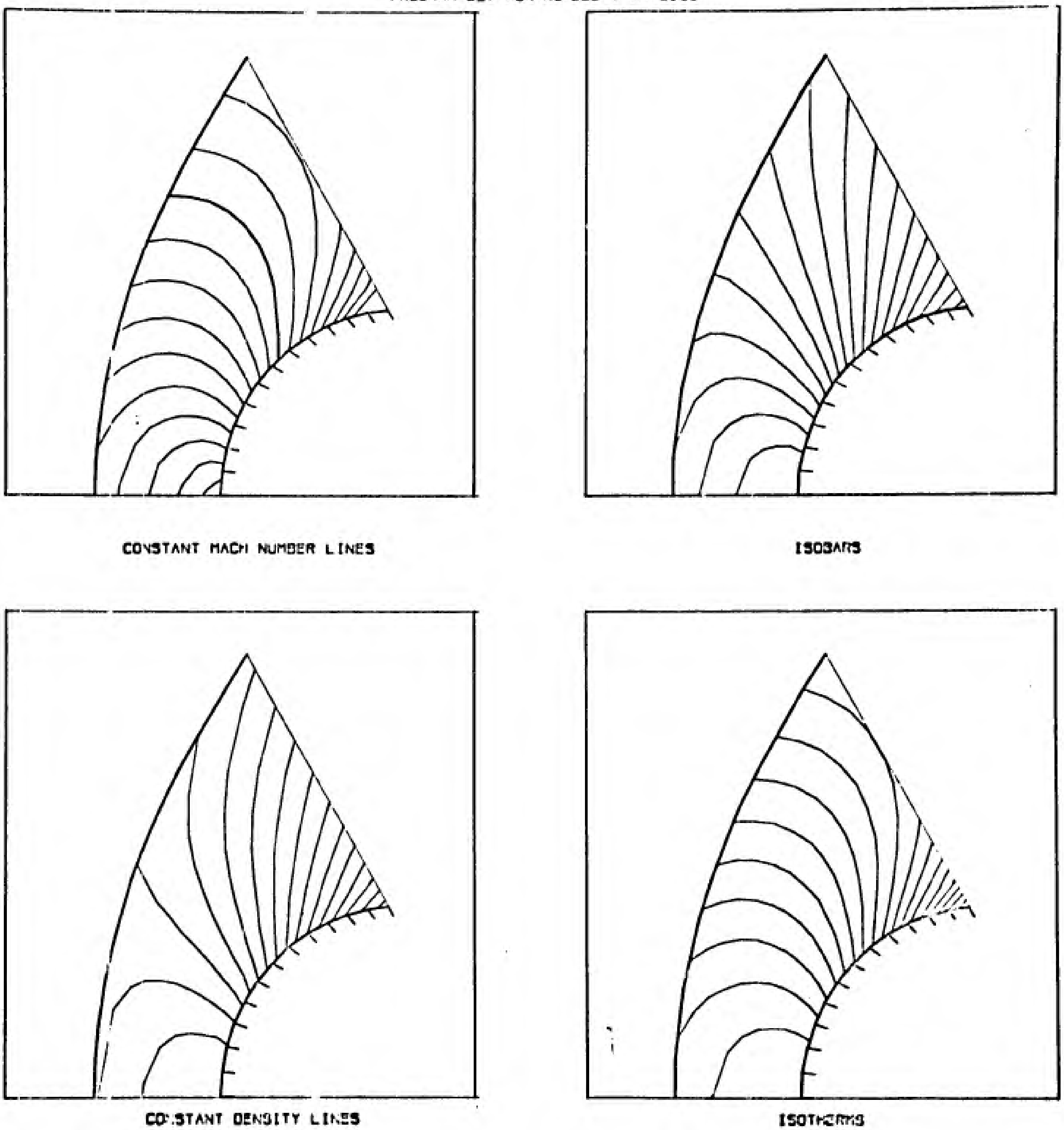
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

B4

PROGRAM 2E. RUN NO 222 . M= 3.00



TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 423

10 BY 12 MESH, 800 STEPS   TOLERANCE=0.000010

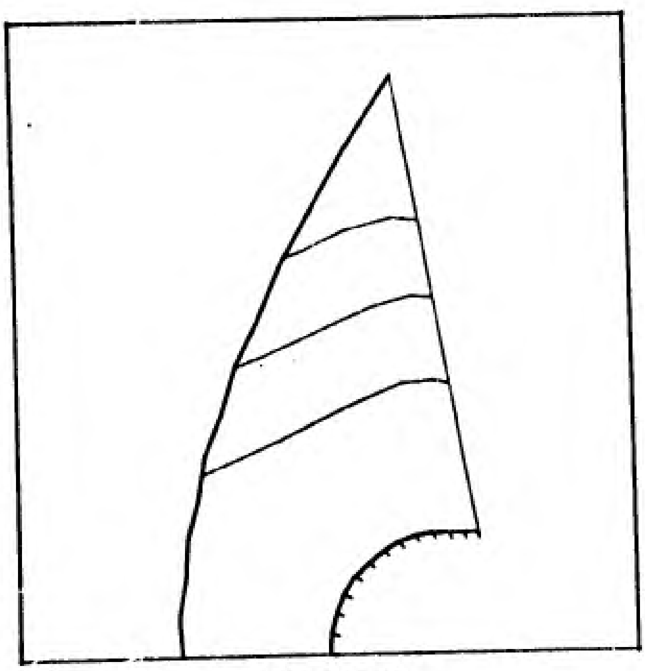
FREE STREAM MACH NUMBER= 2.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 5.640
COMP. STAGNATION PRESSURE= 5.619
RELATIVE ERROR= 0.00334

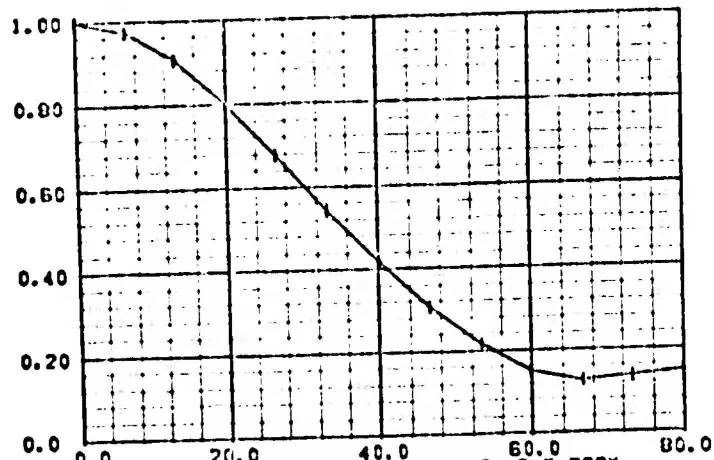
THEOR. STAGNATION TEMPERATURE= 1.800
COMP. STAGNATION TEMPERATURE= 1.798
RELATIVE ERROR= 0.00110

CRITICAL PRESSURE RATIO=0.5274 (REL. ERROR= 0.0017)
CRITICAL DENSITY RATIO=0.6327 (REL. ERROR= 0.0019)
CRITICAL TEMPERAT.RATIO=0.8335 (REL. ERROR= 0.0002)

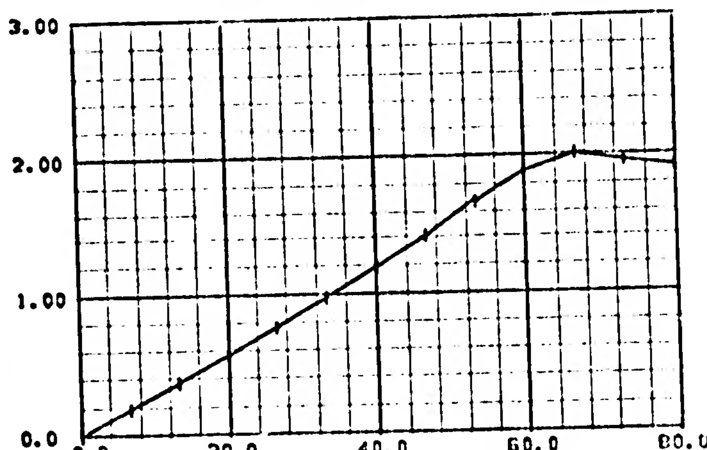
STANDOFF DISTANCE=1.2748
ABSCISSA OF STAGNATION POINT= -1.50000



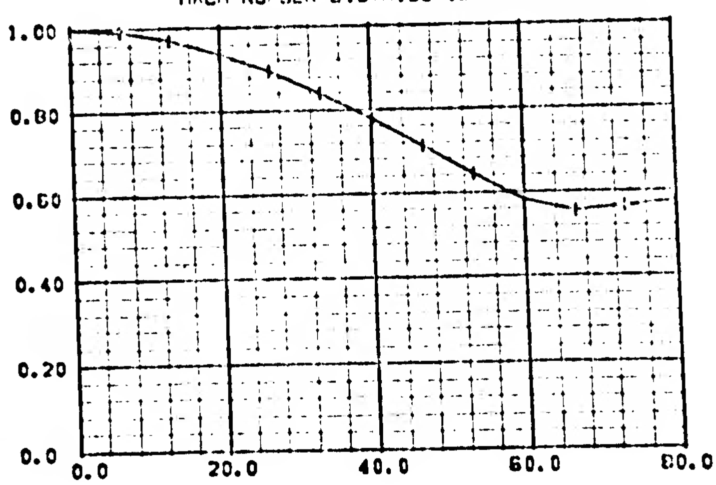
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



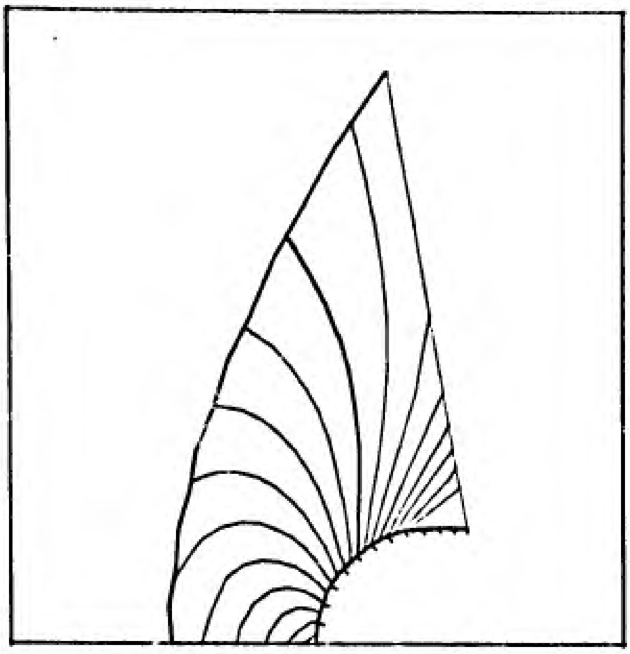
MACH NUMBER DISTRIBUTION ON THE BODY



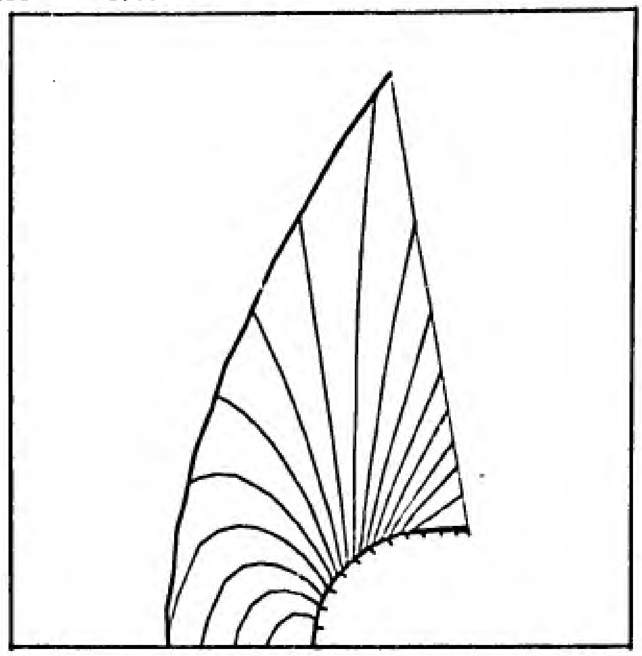
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 423 . M= 2.00

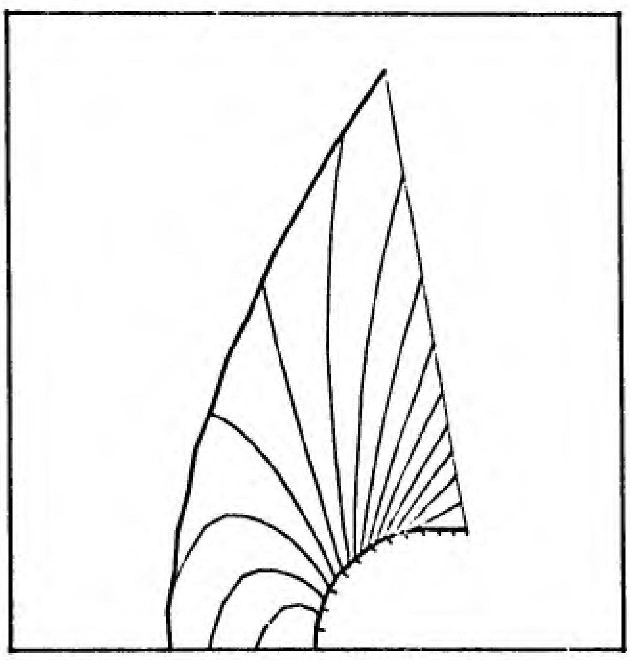
B 5



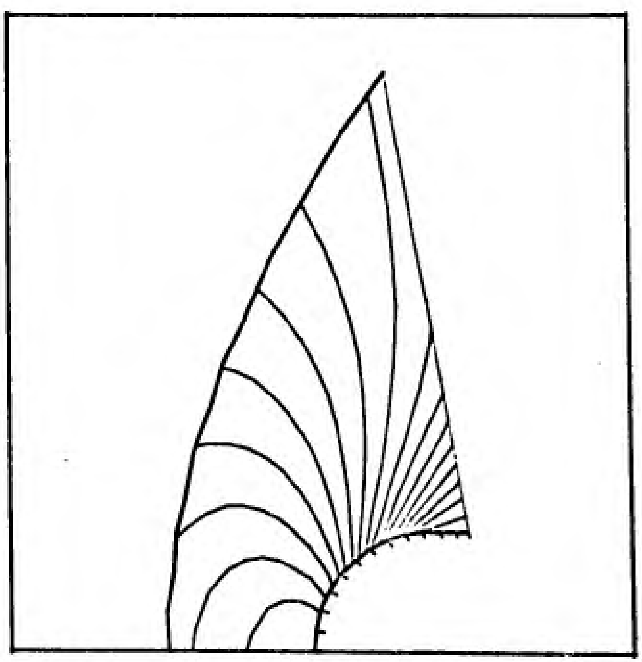
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 324

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

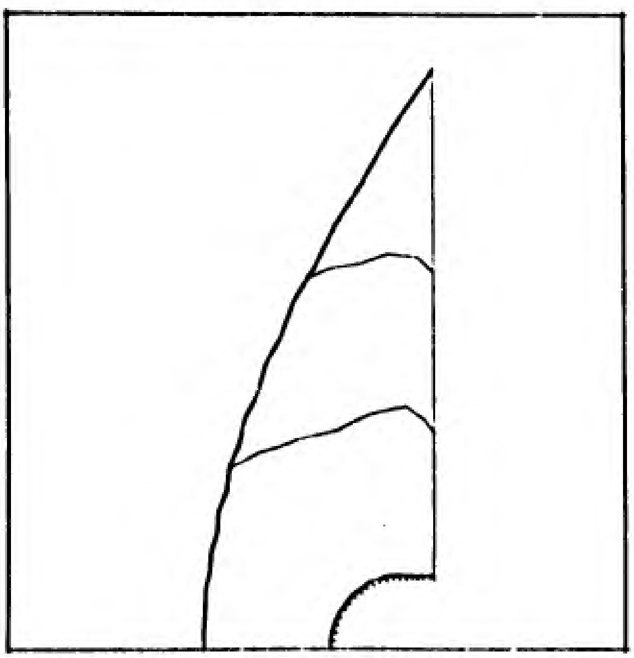
FREE STREAM MACH NUMBER= 1.70, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 4.224
COMP. STAGNATION PRESSURE= 4.175
RELATIVE ERROR= 0.01163

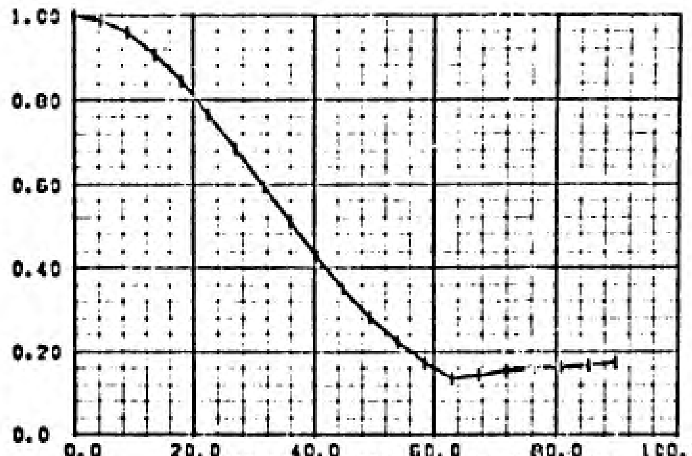
THEOR. STAGNATION TEMPERATURE= 1.578
COMP. STAGNATION TEMPERATURE= 1.573
RELATIVE ERROR= 0.00335

CRITICAL PRESSURE RATIO= 0.5291   (REL. ERROR= 0.0016)
CRITICAL DENSITY RATIO= 0.6344   (REL. ERROR= 0.0008)
CRITICAL TEMPERAT.RATIO= 0.8341   (REL. ERROR= 0.0009)

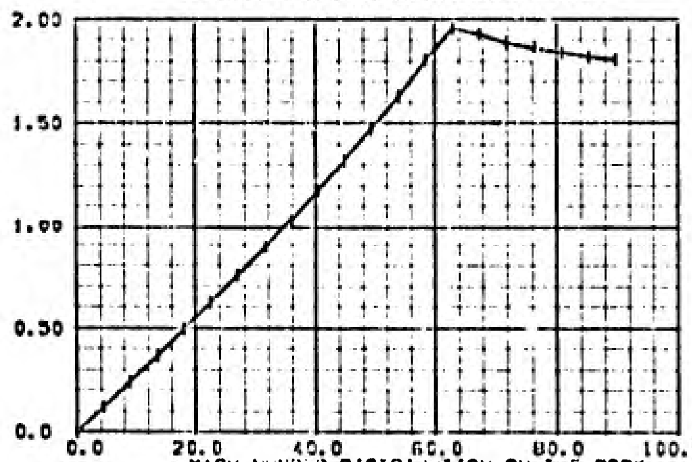
STANDOFF DISTANCE=1.8300
ABSCISSA OF STAGNATION POINT= -1.50000



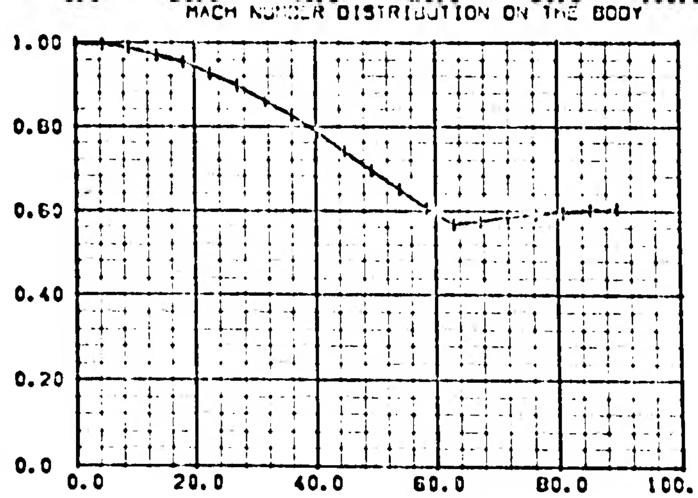
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

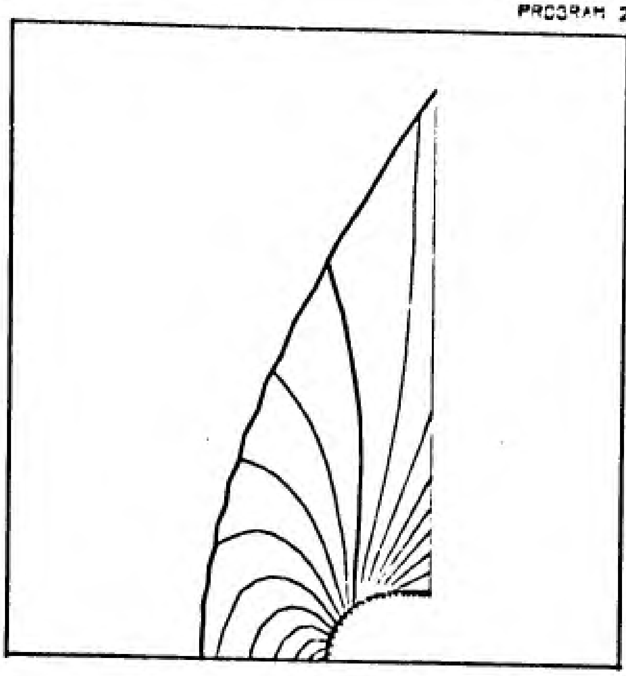


MACH NUMBER DISTRIBUTION ON THE BODY

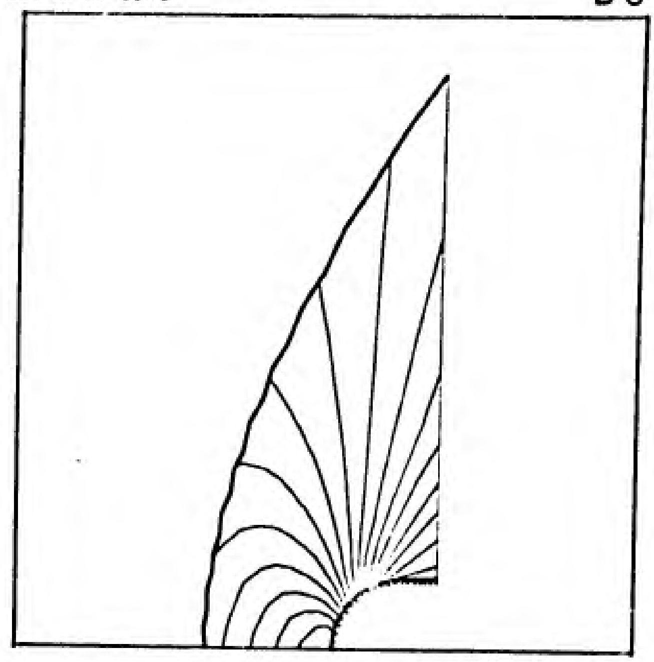


TEMPERATURE DISTRIBUTION ON THE BODY

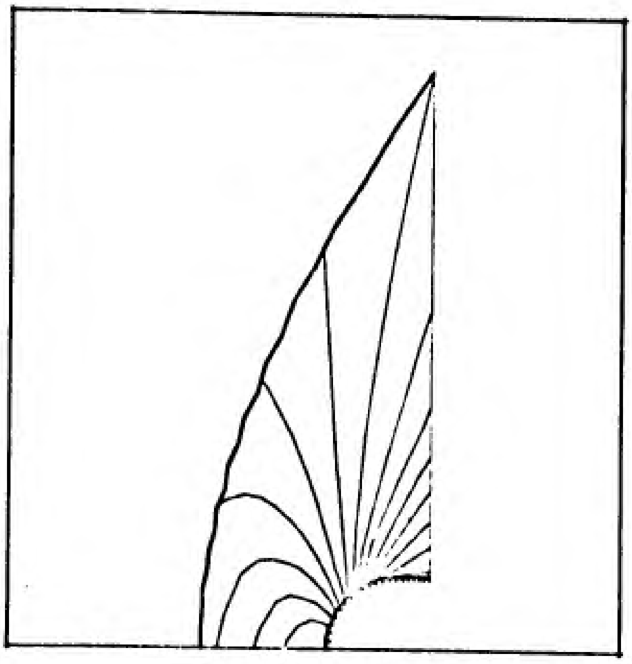
PROGRAM 22, RUN NO 324 , M= 1.70 B6



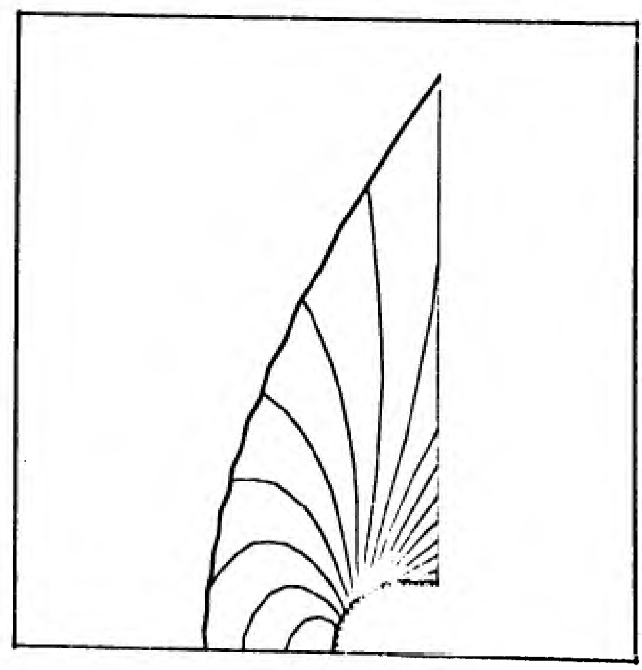
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 325

10 BY 20 MESH, 1100 STEPS   TOLERANCE=0.000010

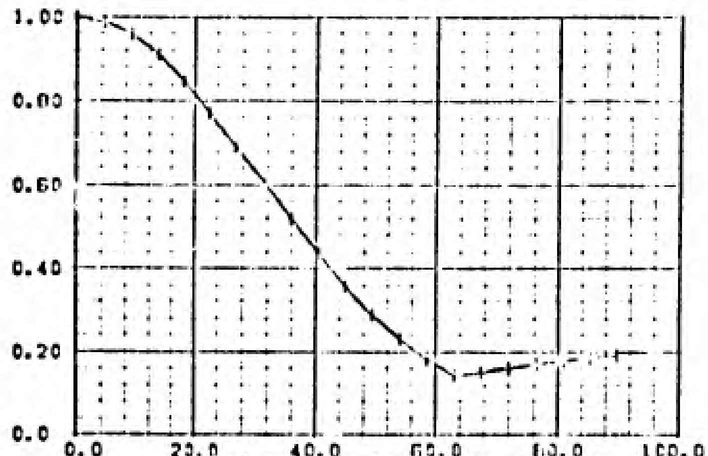
FREE STREAM MACH NUMBER= 1.50, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 3.413
COMP. STAGNATION PRESSURE= 3.310
RELATIVE ERROR= 0.02143

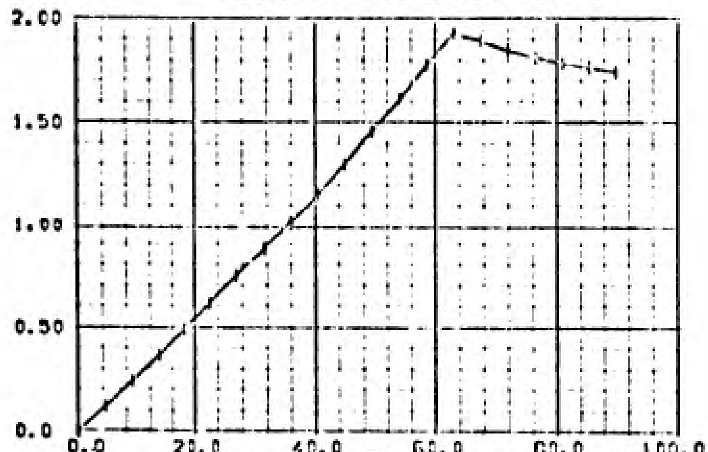
THEOR. STAGNATION TEMPERATURE= 1.450
COMP. STAGNATION TEMPERATURE= 1.441
RELATIVE ERROR= 0.00317

CRITICAL PRESSURE RATIO=0.5230 (REL. ERROR= 0.0013)
CRITICAL DENSITY RATIO=0.6344 (REL. ERROR= 0.0007)
CRITICAL TEMPERAT.RATIO=0.8339 (REL. ERROR= 0.0003)

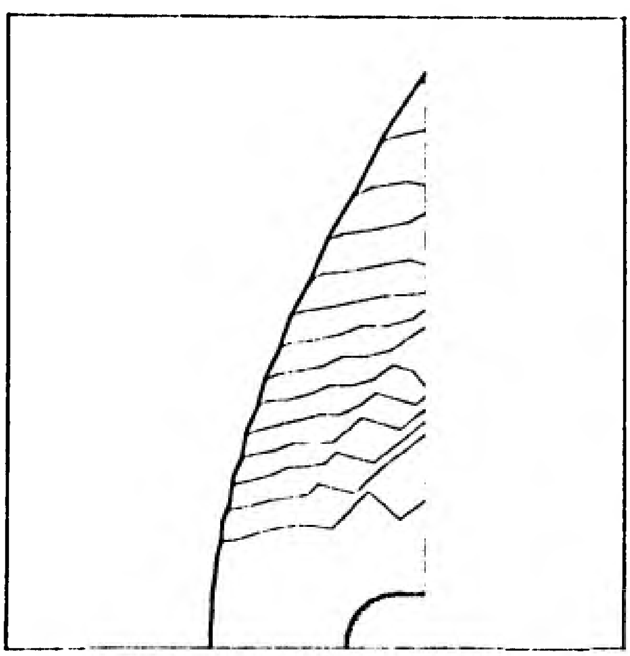
STANDOFF DISTANCE=2.5755
ABSCISSA OF STAGNATION POINT= -1.50000



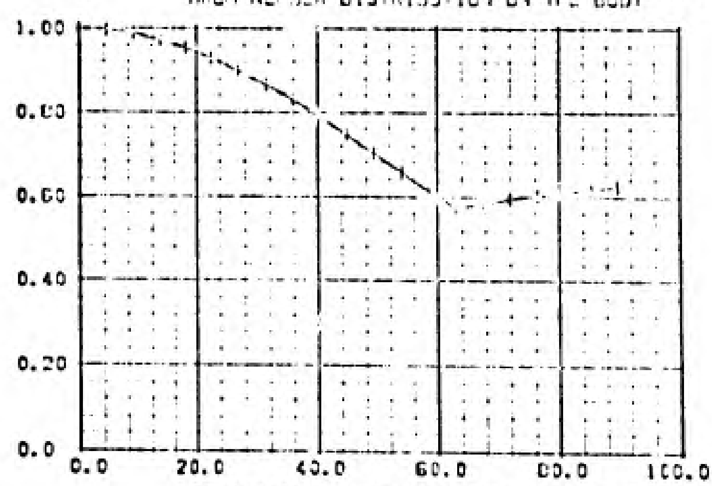
PRESSURE DISTRIBUTION ON THE BODY



MACH NUMBER DISTRIBUTION ON THE BODY



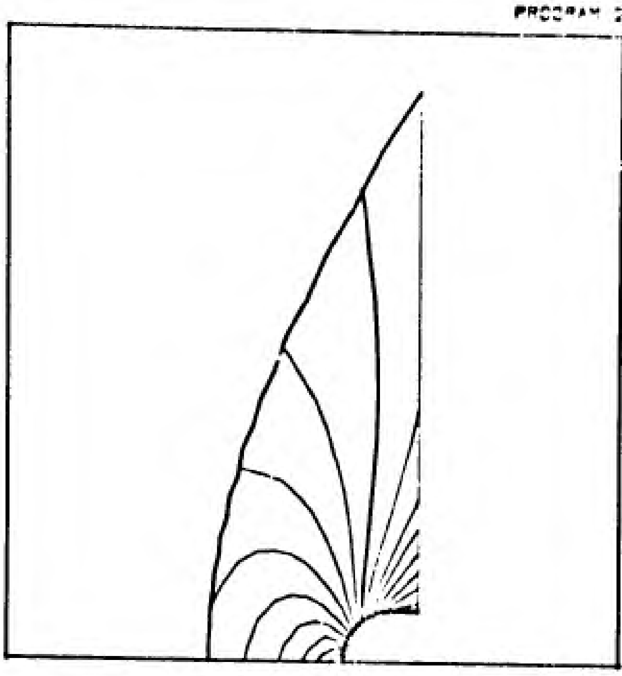
STREAMLINES



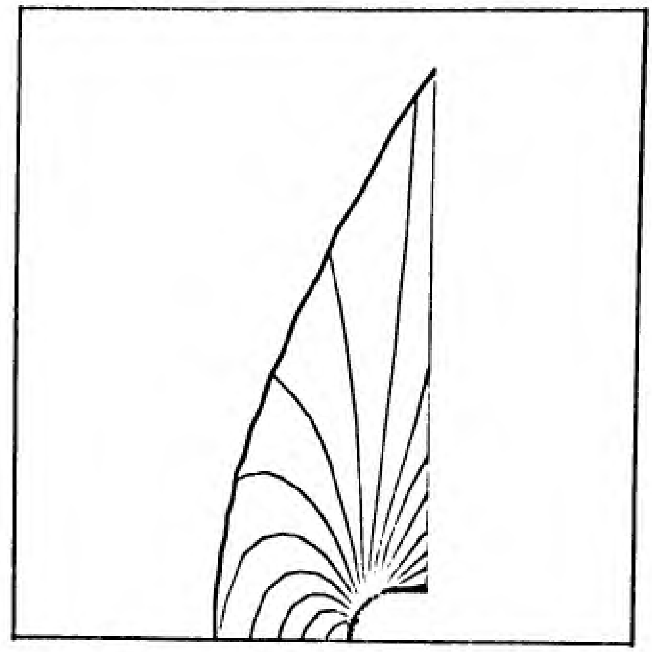
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2C, RUN NO 325 , M= 1.50

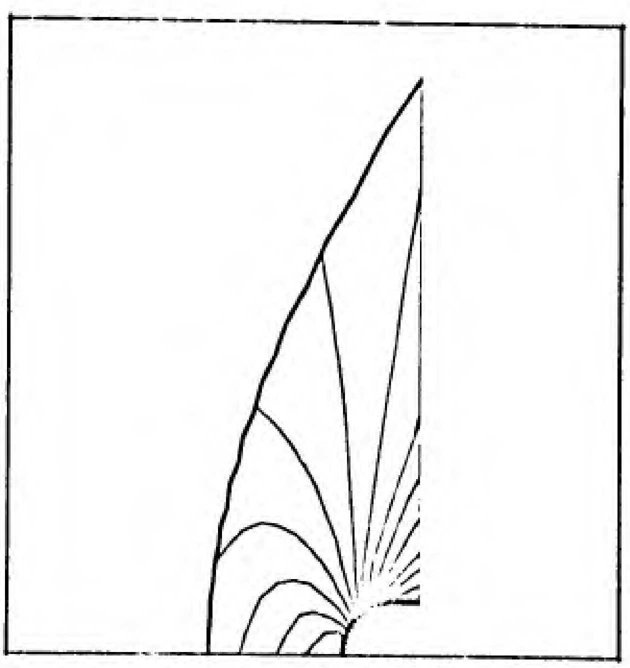
B 7



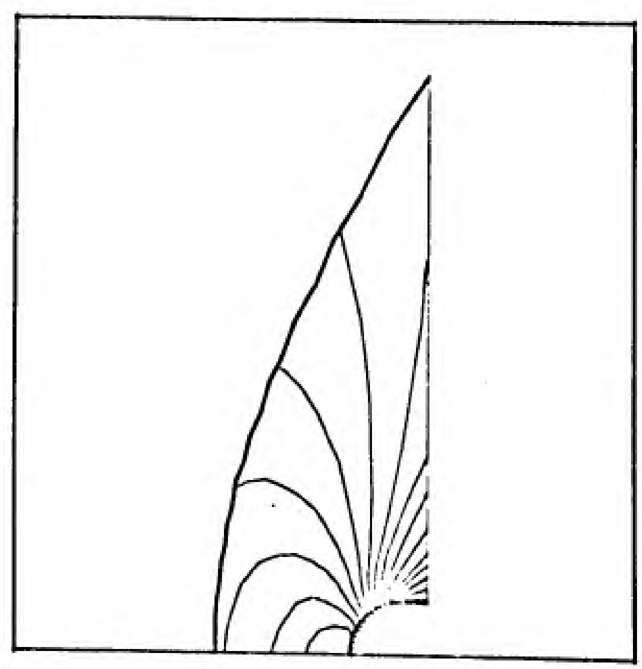
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 215

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

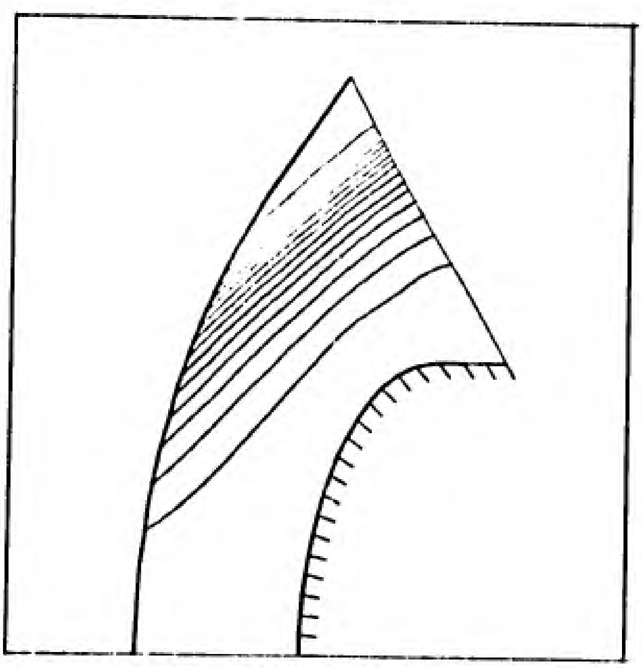
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.524
RELATIVE ERROR= 0.00008

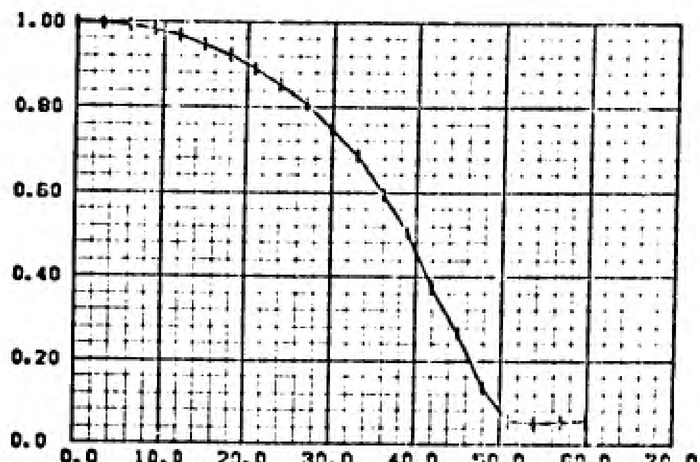
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 81.002
RELATIVE ERROR= 0.00002

CRITICAL PRESSURE RATIO=0.5242 (REL. ERROR= 0.0077)
CRITICAL DENSITY RATIO=0.6301 (REL. ERROR= 0.0030)
CRITICAL TEMPERAT.RATIO=0.8319 (REL. ERROR= 0.0017)

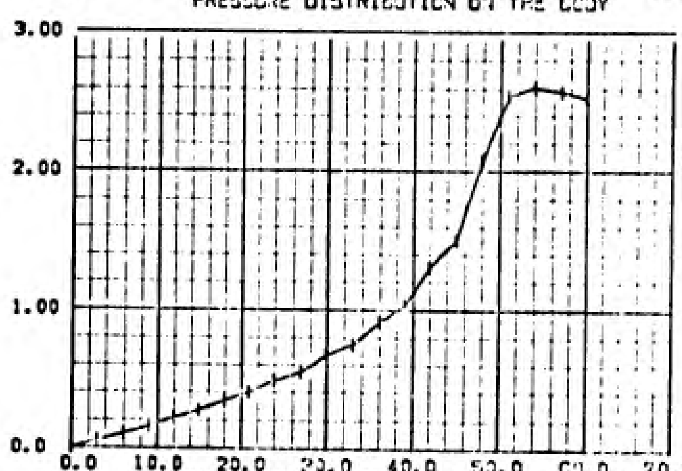
STANDOFF DISTANCE=0.5890
ABSCISSA OF STAGNATION POINT= -1.30000



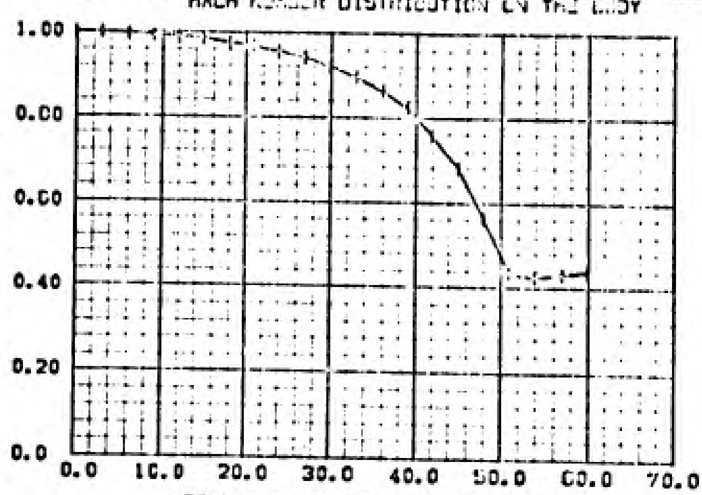
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



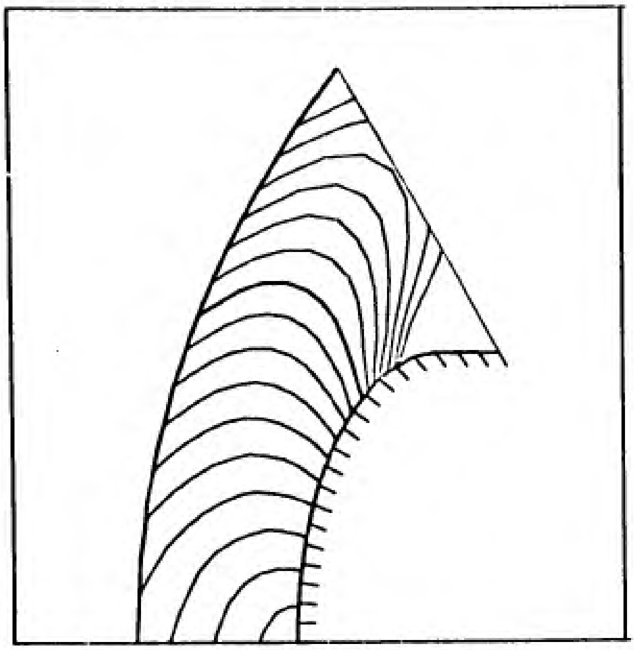
MACH NUMBER DISTRIBUTION ON THE BODY



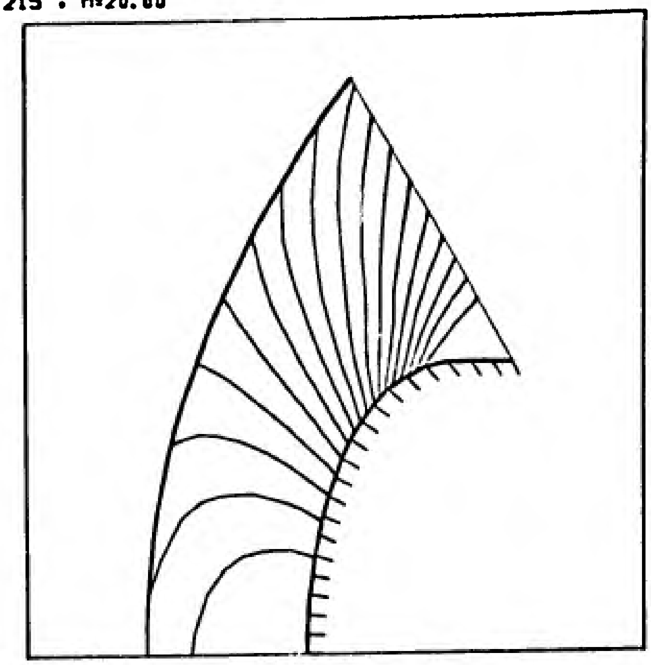
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 215 . M=20.80

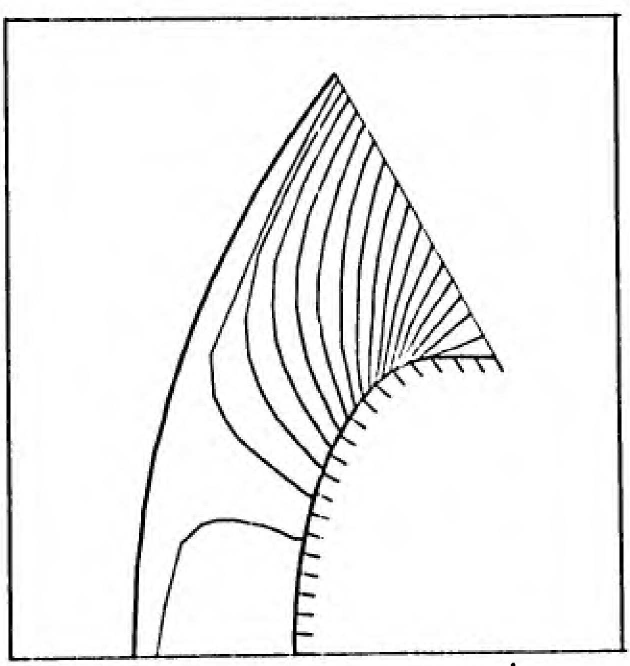
C2



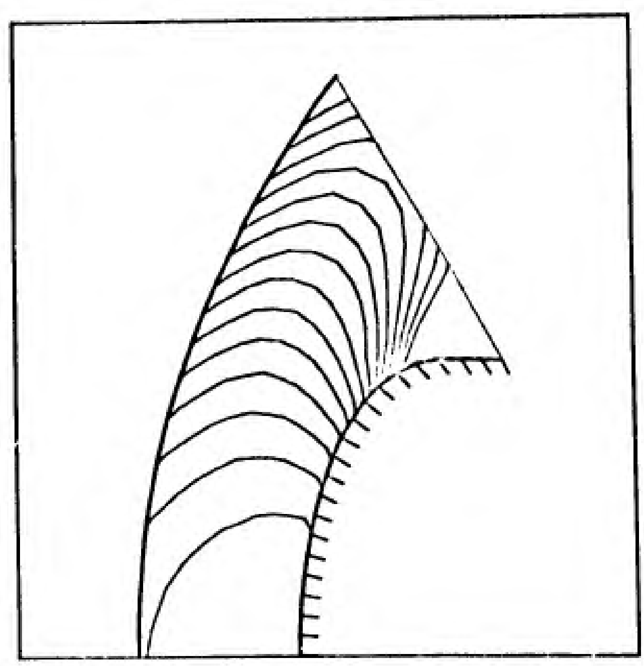
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 319

10 BY 20 MESH, 2000 STEPS TOLERANCE=0.000010

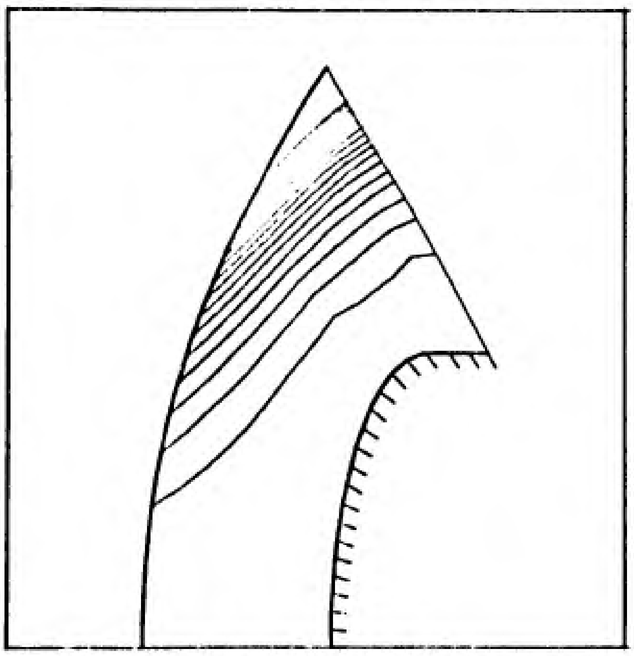
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.494
COMP. STAGNATION PRESSURE=515.370
RELATIVE ERROR= 0.00022

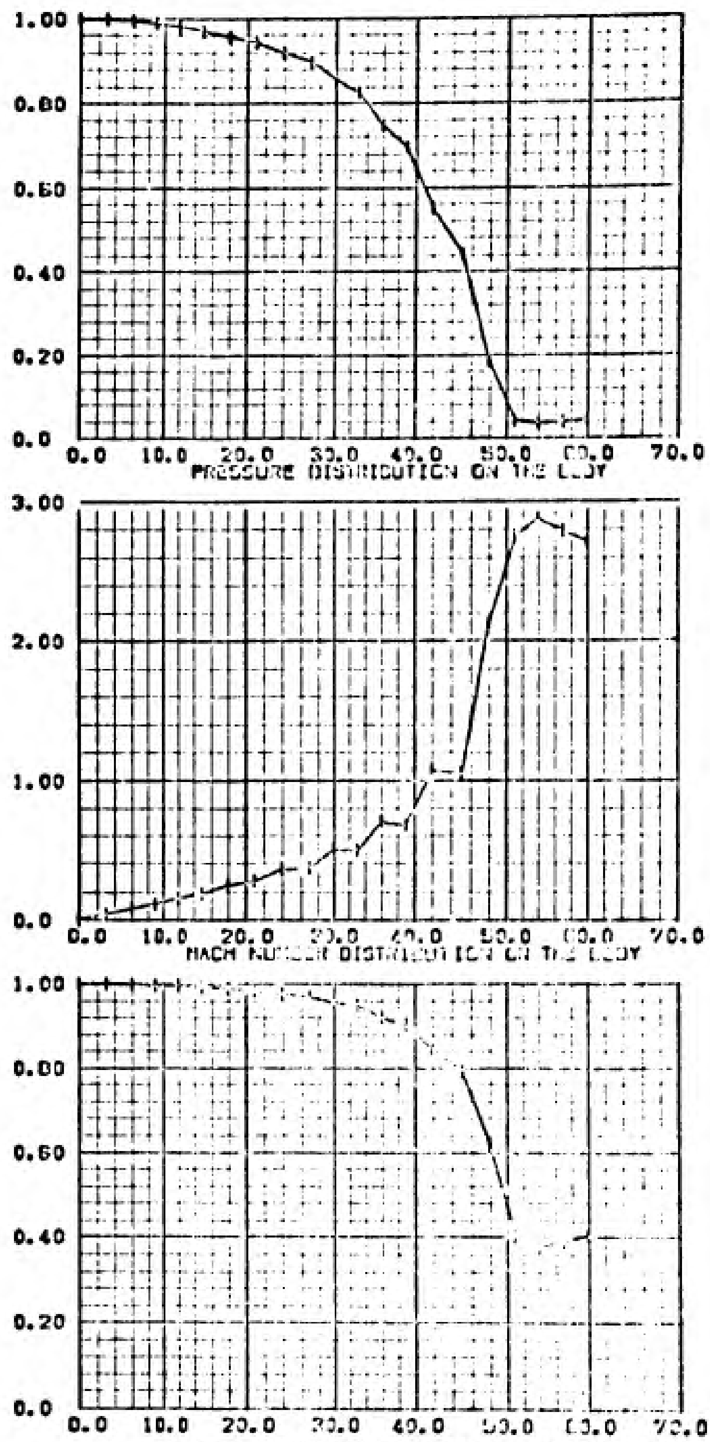
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.995
RELATIVE ERROR= 0.00006

CRITICAL PRESSURE RATIO=0.5779 (REL. ERROR= 0.0340)
CRITICAL DENSITY RATIO=0.6753 (REL. ERROR= 0.0053)
CRITICAL TEMPERAT.RATIO=0.8559 (REL. ERROR= 0.0203)

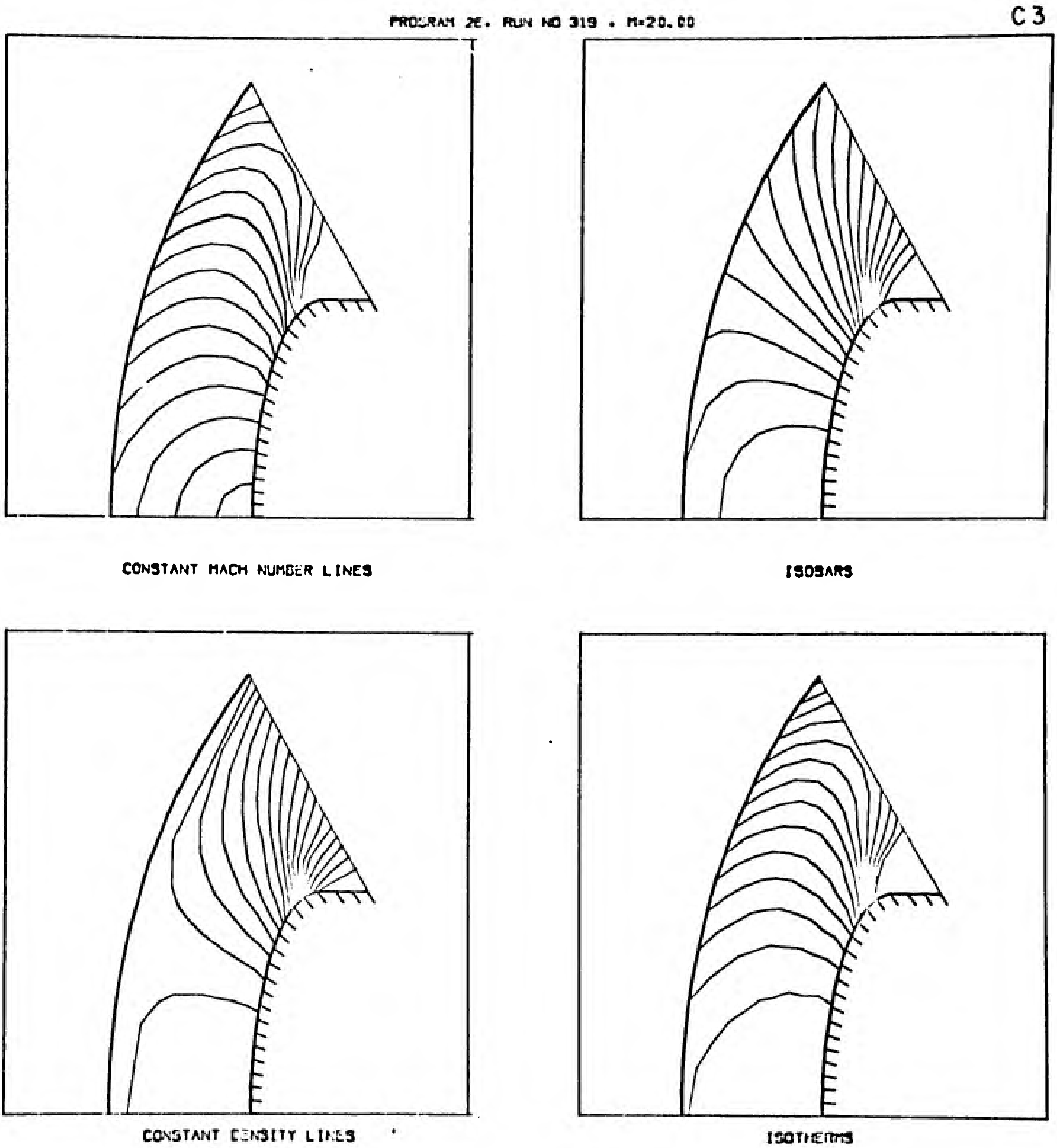
STANDOFF DISTANCE=0.6 32
ABSCISSA OF STAGNATION POINT= -1.13333



STREAMLINES



TEMPERATURE DISTRIBUTION ON THE BODY


PROGRAM 2E. RUN NO 319 . M=20.00
C3
CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 316

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

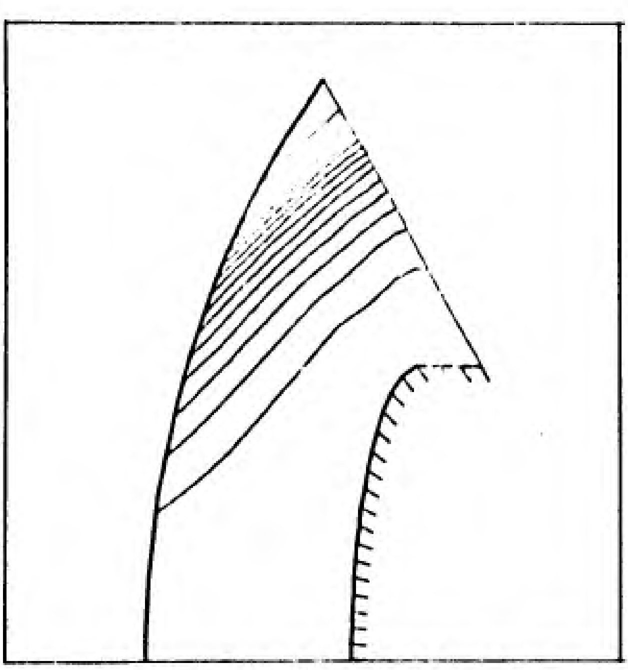
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.401
COMP. STAGNATION PRESSURE=515.332
RELATIVE ERROR= 0.00018

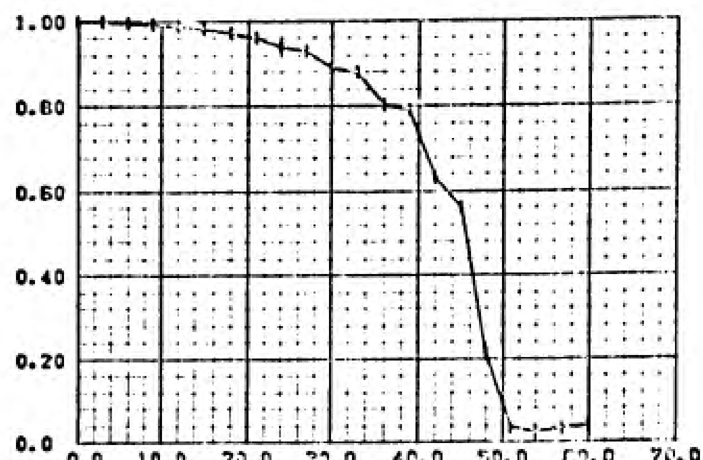
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.996
RELATIVE ERROR= 0.00005

CRITICAL PRESSURE RATIO= 0.5161   (REL. ERROR= 0.0230)
CRITICAL DENSITY RATIO= 0.6191   (REL. ERROR= 0.0234)
CRITICAL TEMPERAT.RATIO= 0.8337   (REL. ERROR= 0.0004)

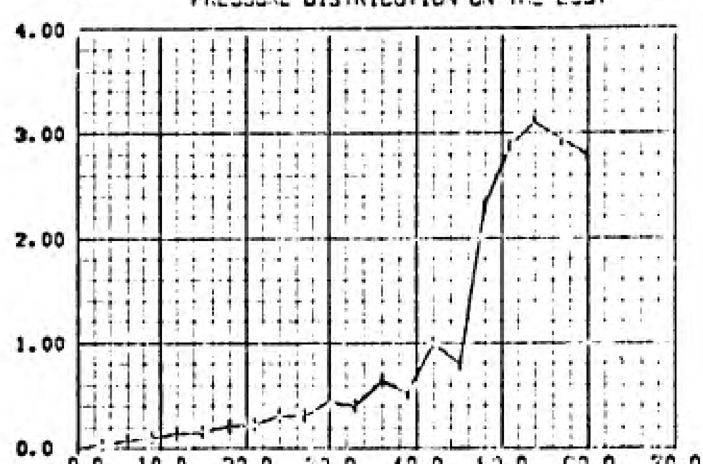
STANDOFF DISTANCE=0.7200
ABSCISSA OF STAGNATION POINT= -1.05000



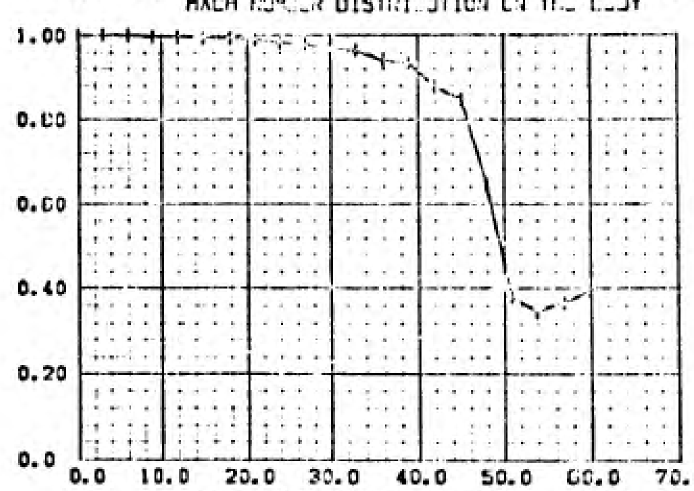
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

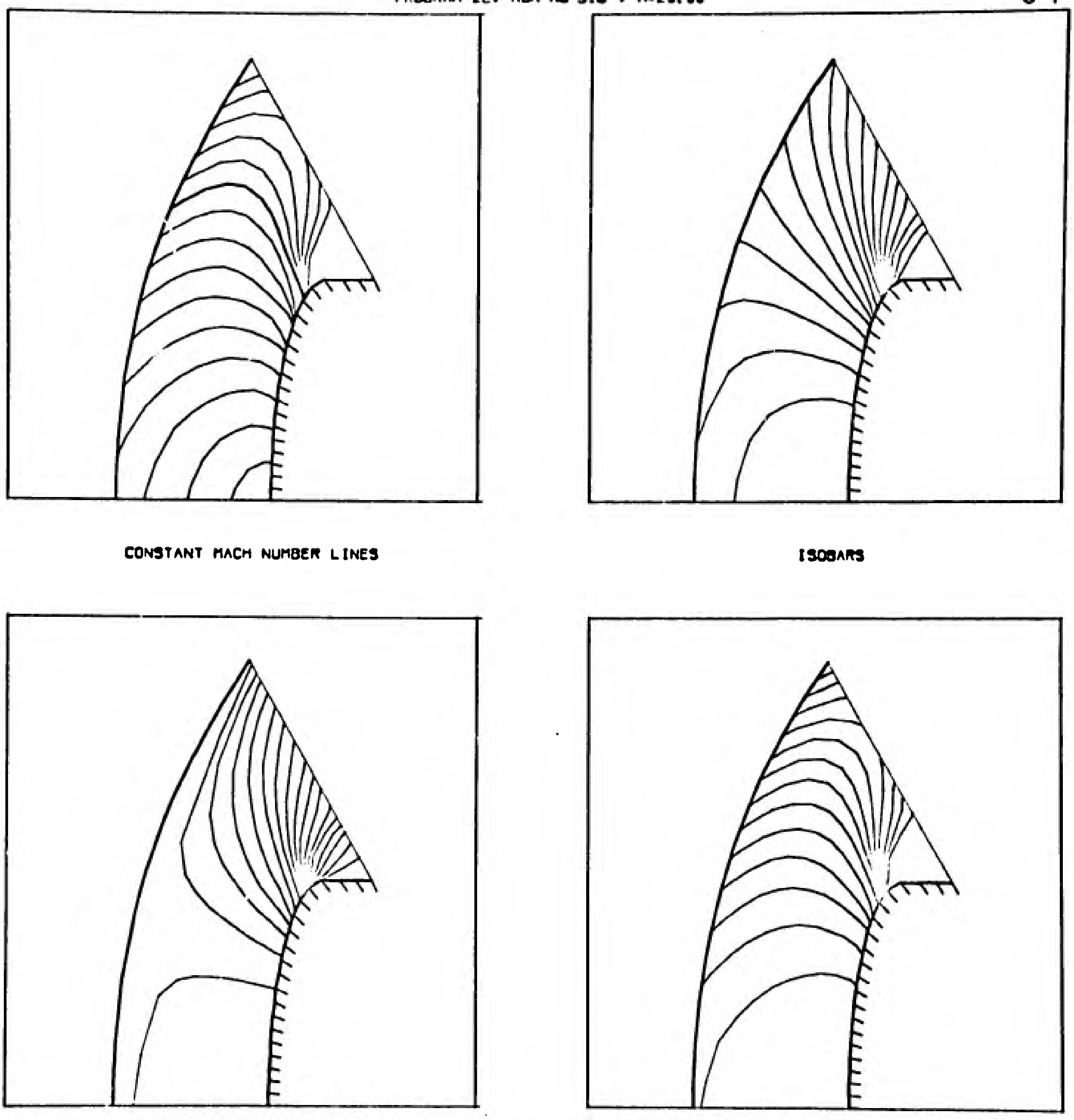


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 316 . M=20.00 C4



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 317

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

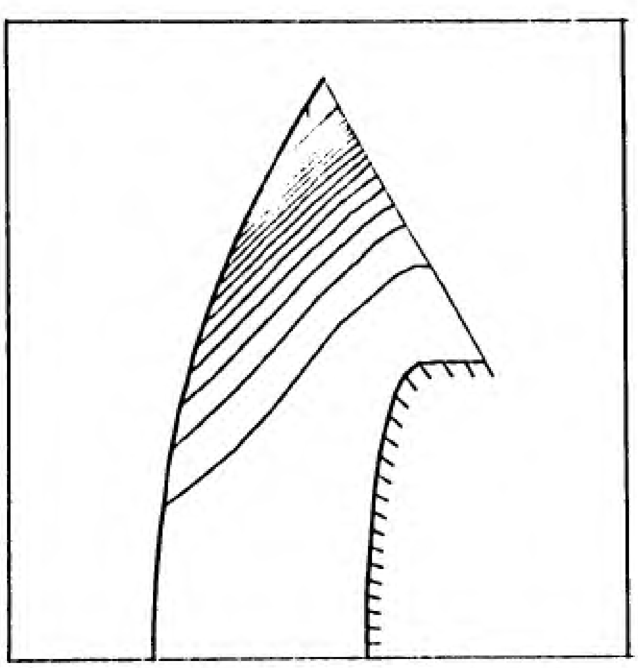
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.494
COMP. STAGNATION PRESSURE=515.332
RELATIVE ERROR= 0.00030

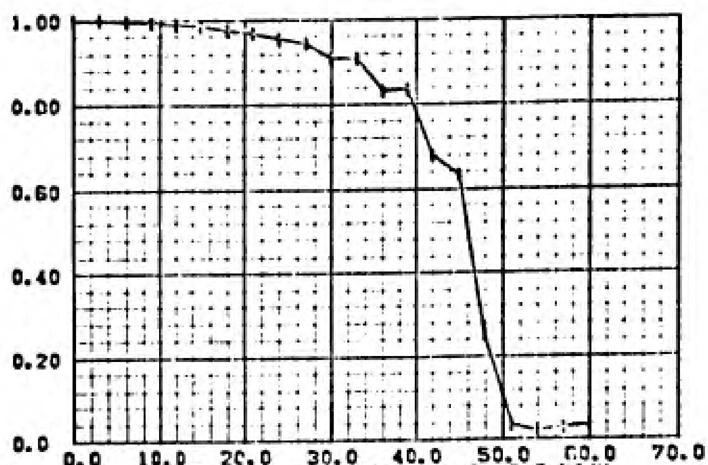
THEOR. STAGNATION TEMPERATURE= 01.000
COMP. STAGNATION TEMPERATURE= 00.993
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5530 (REL. ERROR= 0.0562)
CRITICAL DENSITY RATIO=0.6527 (REL. ERROR= 0.0297)
CRITICAL TEMPERAT.RATIO=0.8548 (REL. ERROR= 0.0257)

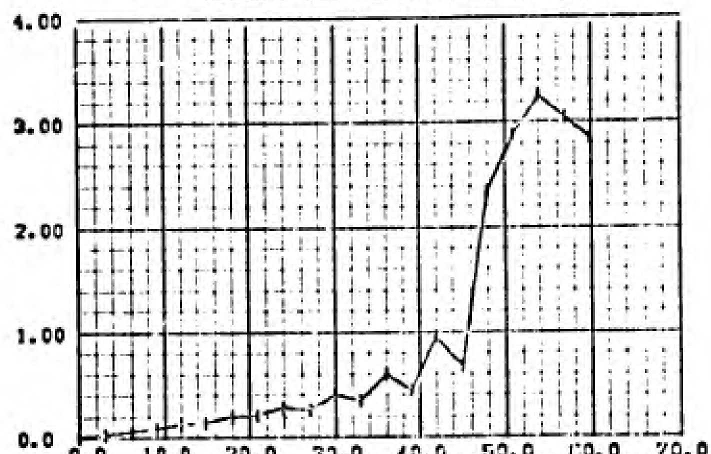
STANDOFF DISTANCE=0.7529
ABSCISSA OF STAGNATION POINT=-1.00000



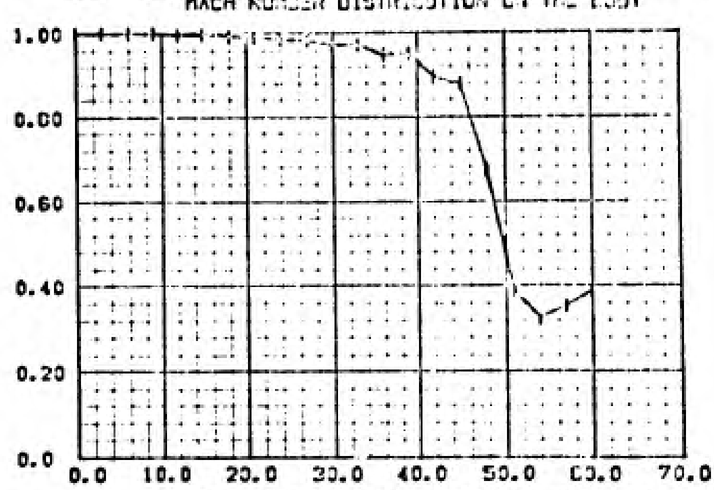
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



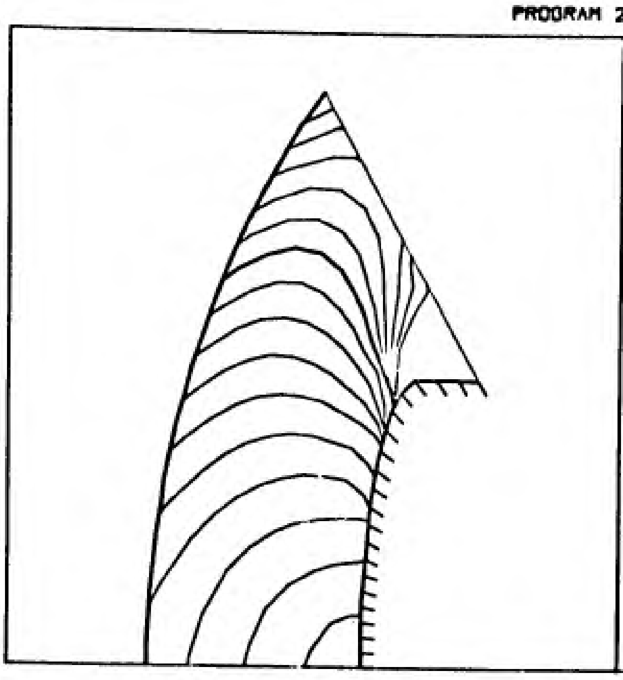
MACH NUMBER DISTRIBUTION ON THE BODY



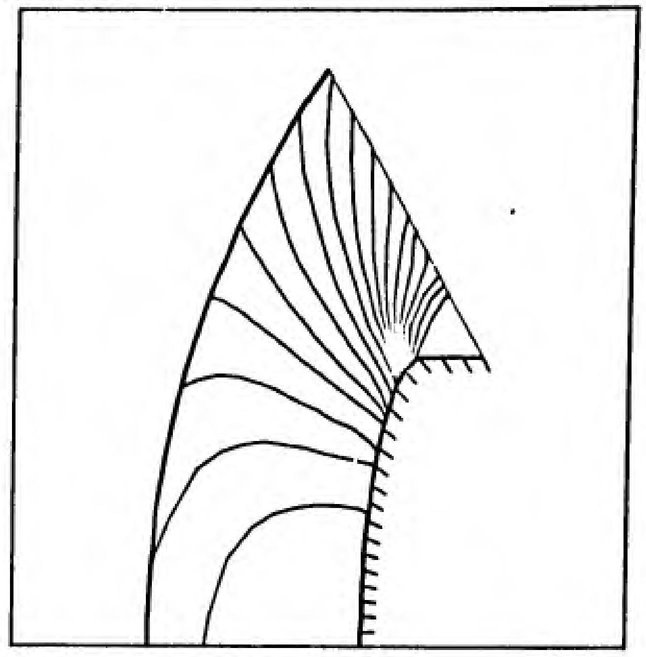
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 317 . M=20.00

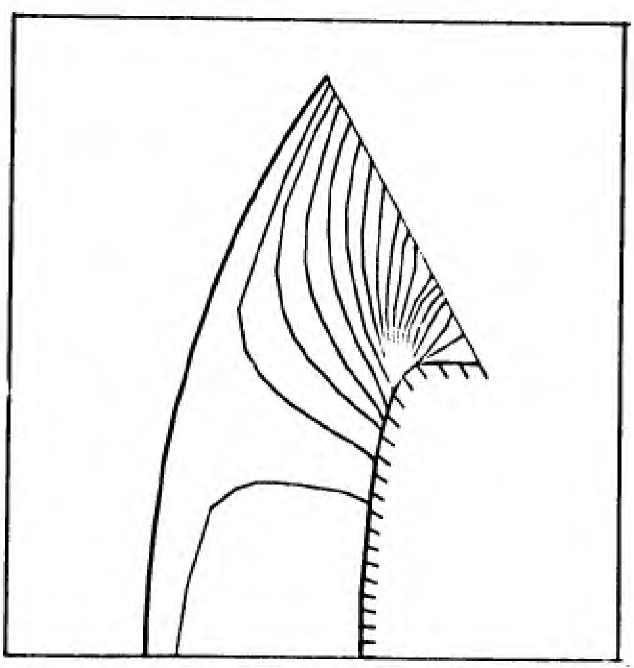
C5



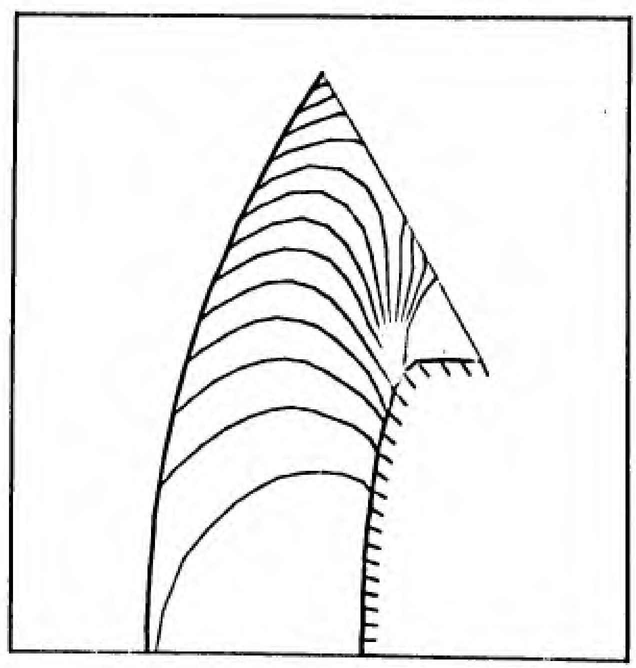
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 310

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

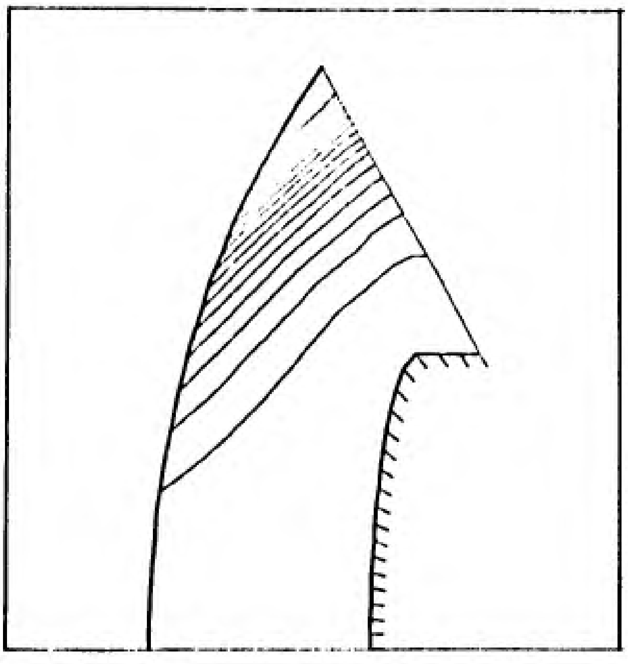
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.404
COMP. STAGNATION PRESSURE=515.302
RELATIVE ERROR= 0.00035

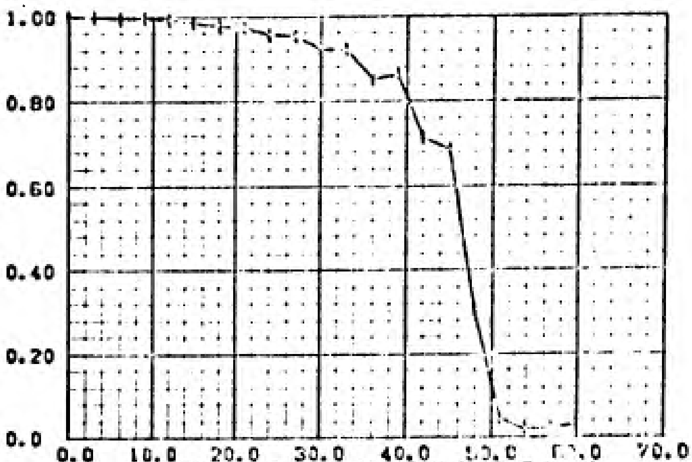
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.992
RELATIVE ERROR= 0.00010

CRITICAL PRESSURE RATIO=0.5[illegible]94   (REL. ERROR= 0.1153)
CRITICAL DENSITY RATIO=0.6787   (REL. ERROR= 0.0706)
CRITICAL TEMPERAT.RATIO=0.[illegible]   (REL. ERROR= 0.0422)

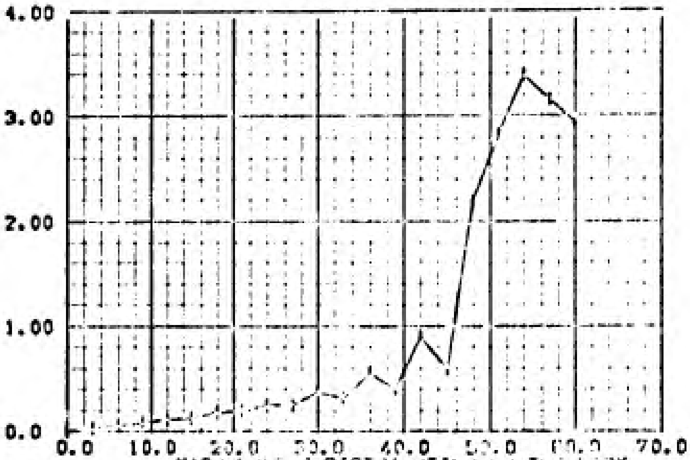
STANDOFF DISTANCE=0.7764
ABSCISSA OF STAGNATION POINT= 0.[illegible]



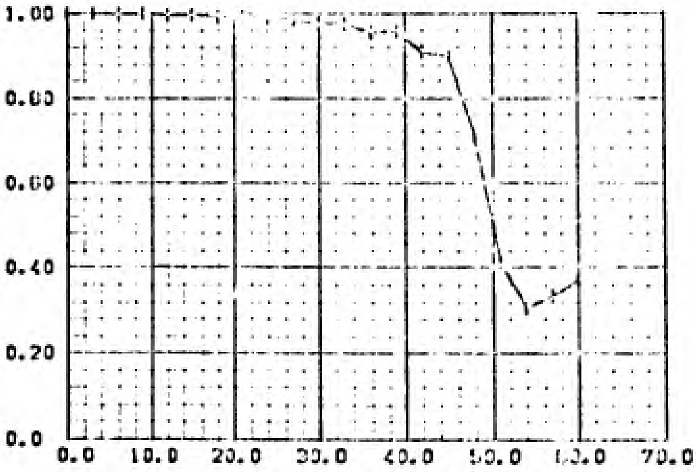
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

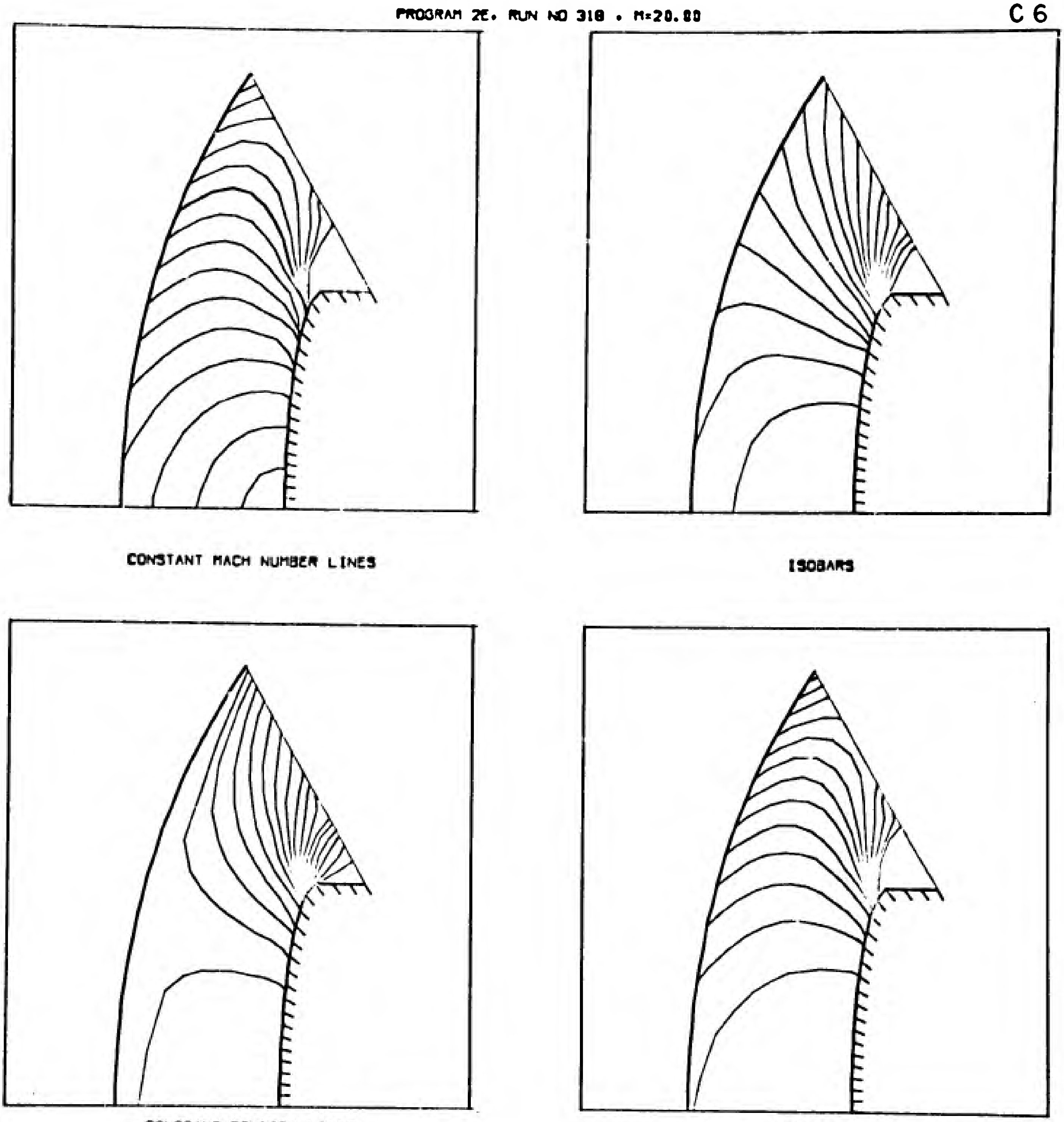


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 318 . M=20.00 C 6



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 230

10 BY 20 MESH, 1000 STEPS TOLERANCE=0.000010

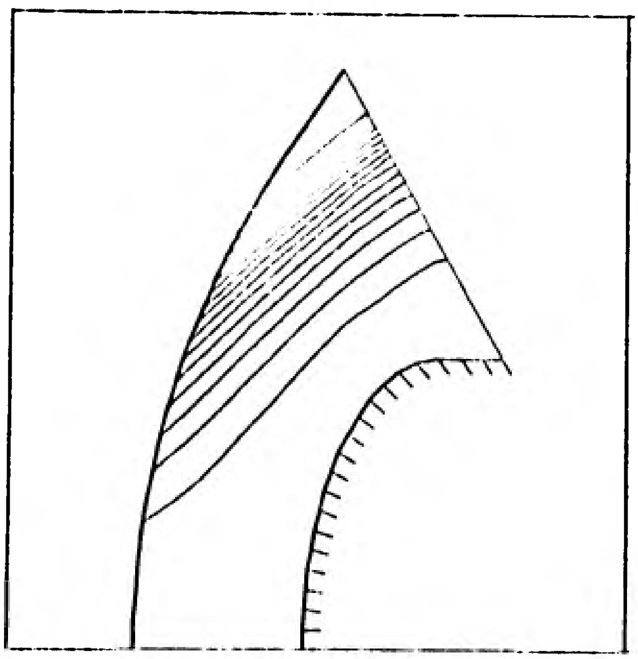
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.217
RELATIVE ERROR= 0.00000

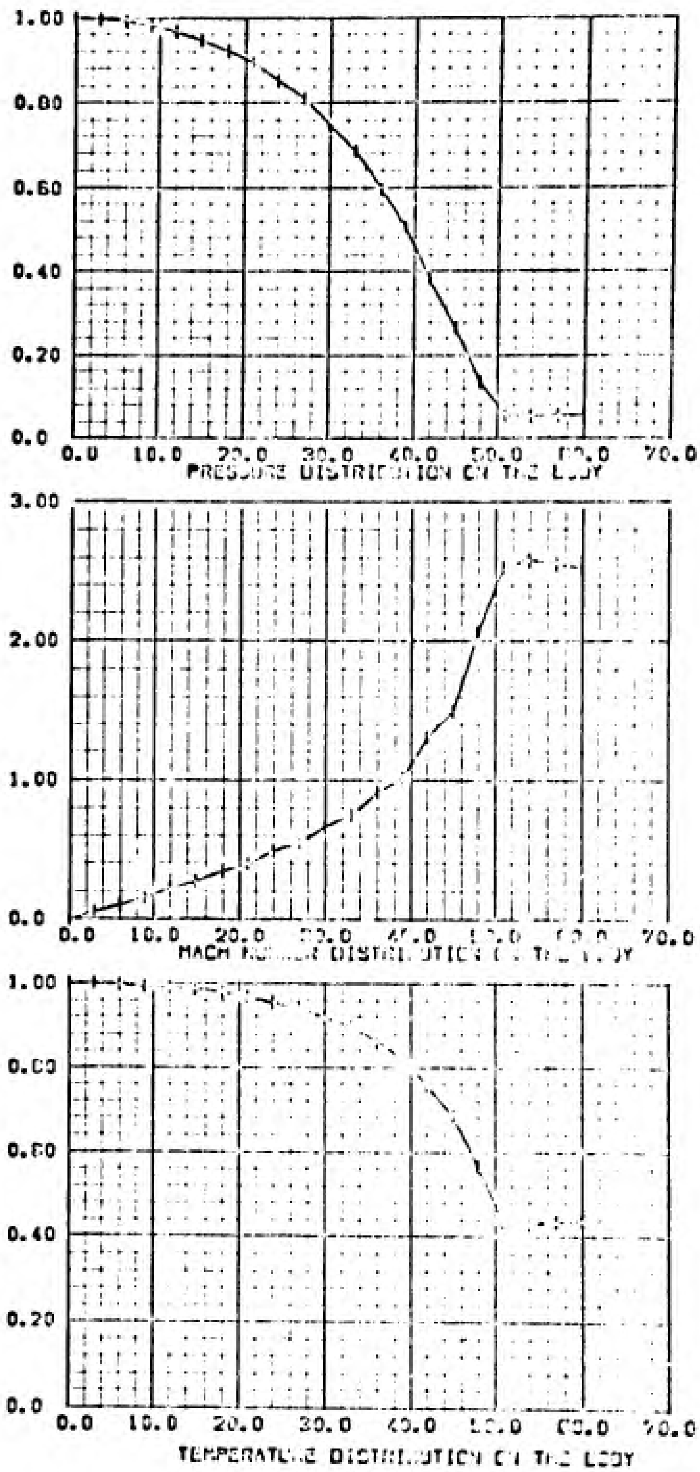
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.000
RELATIVE ERROR= 0.00000

CRITICAL PRESSURE RATIO=0.5237 (REL. ERROR= 0.0037)
CRITICAL DENSITY RATIO=0.6337 (REL. ERROR= 0.0037)
CRITICAL TEMPERAT.RATIO=0.0317 (REL. ERROR= 0.0020)

STANDOFF DISTANCE=0.5312
ABSCISSA OF STAGNATION POINT= -1.30000

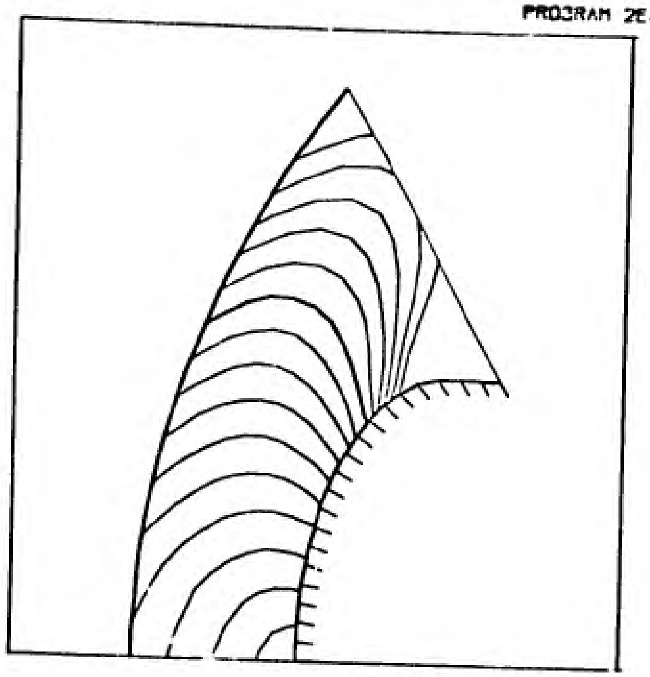


STREAMLINES

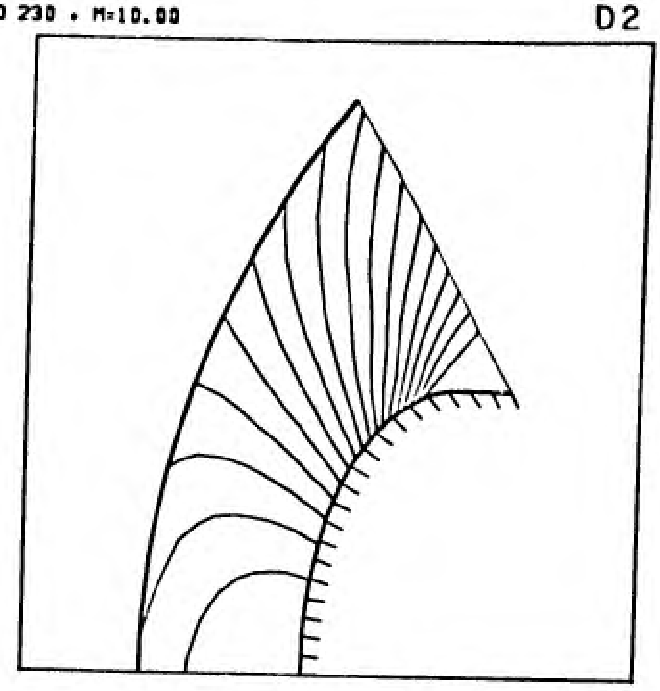


PROGRAM 2E. RUN NO 230 . M=10.00

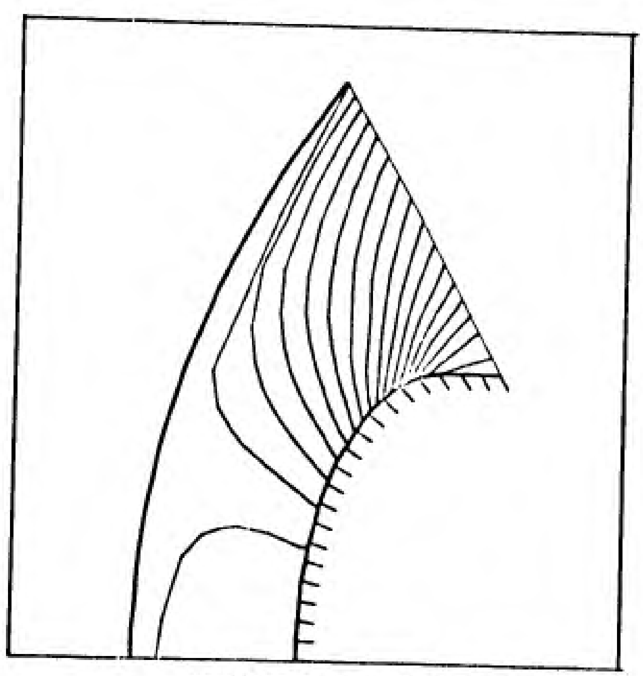
D2



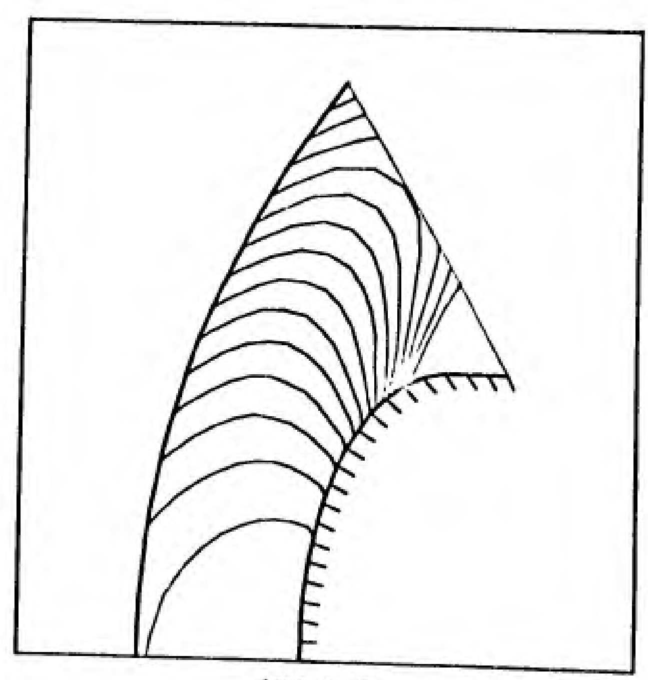
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 331

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

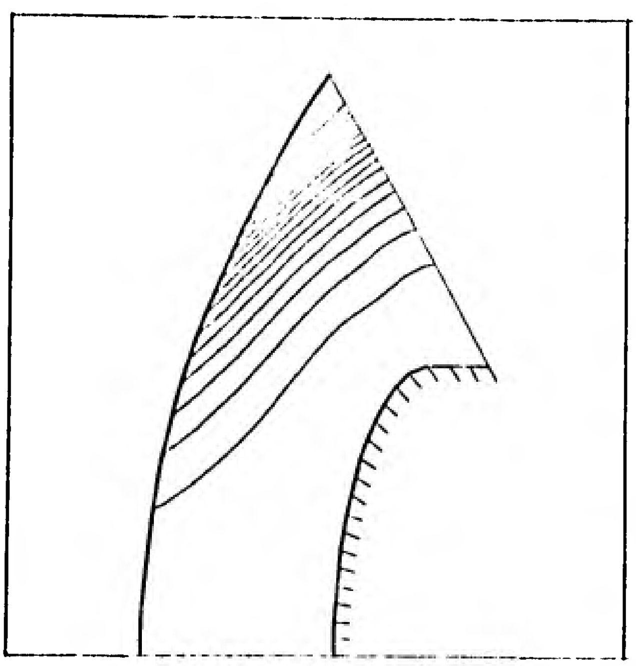
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.197
RELATIVE ERROR= 0.00015

THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 20.999
RELATIVE ERROR= 0.00004

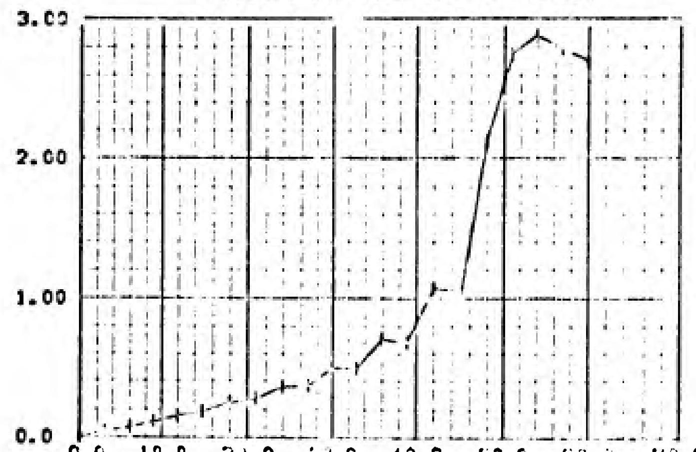
CRITICAL PRESSURE RATIO=0.5777 (REL. ERROR= 0.0935)
CRITICAL DENSITY RATIO=0.6751 (REL. ERROR= 0.0650)
CRITICAL TEMPERAT.RATIO=0.8557 (REL. ERROR= 0.0269)

STANDOFF DISTANCE=0.6915
ABSCISSA OF STAGNATION POINT= -1.13[illegible]3

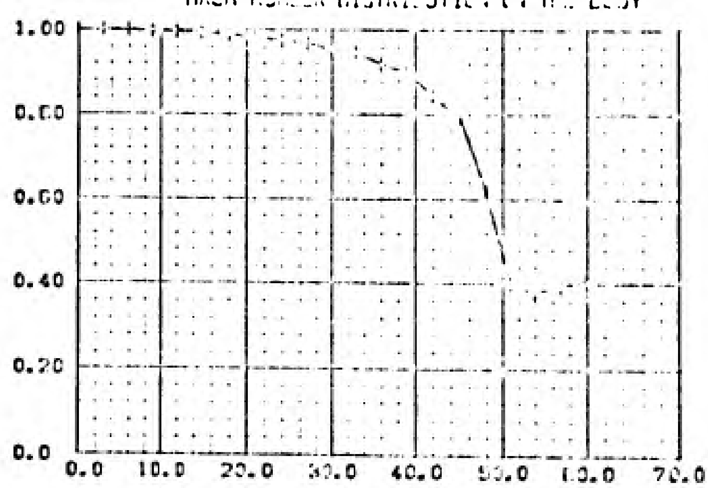


STREAMLINES

PRESSURE DISTRIBUTION ON THE BODY

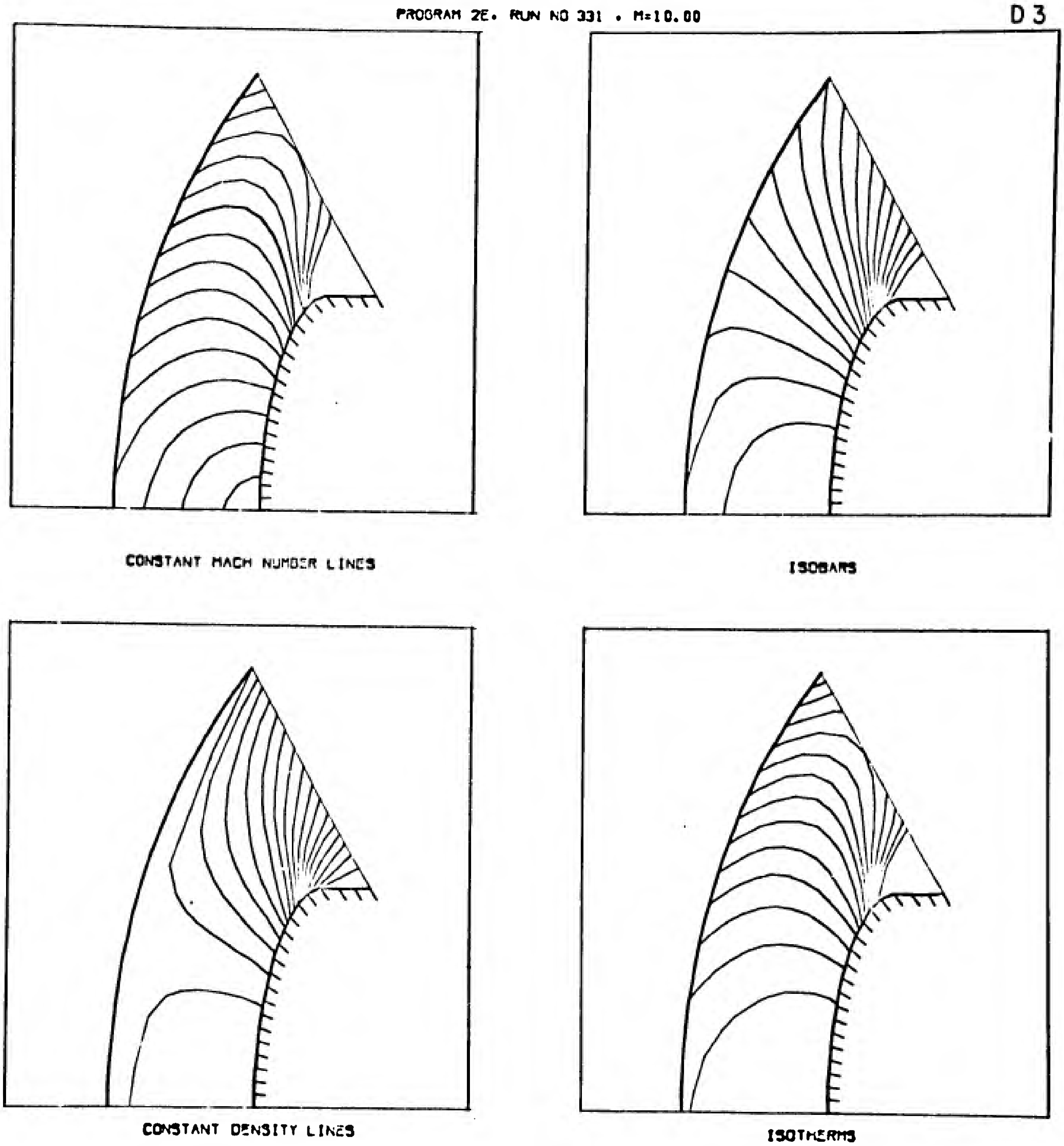


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 331 . M=10.00 D 3



TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 332

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

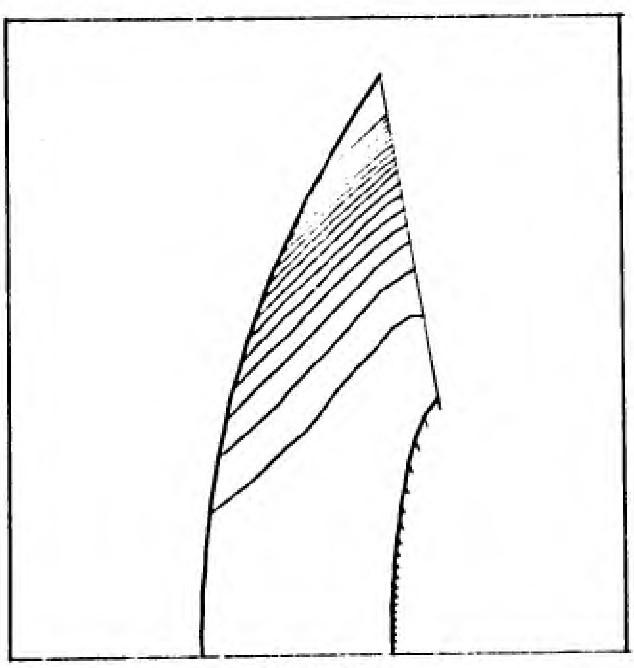
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.152
RELATIVE ERROR= 0.00050

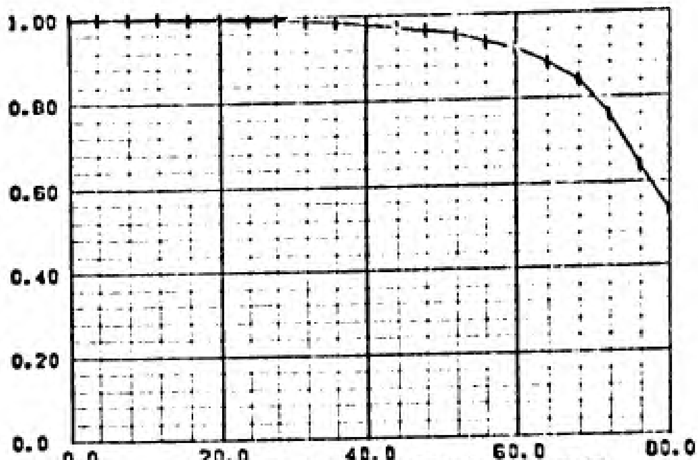
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 20.997
RELATIVE ERROR= 0.00014

CRITICAL PRESSURE RATIO=0.5539   (REL. ERROR= 0.0485)
CRITICAL DENSITY RATIO=0.6554   (REL. ERROR= 0.0339)
CRITICAL TEMPERAT.RATIO=0.8452   (REL. ERROR= 0.0142)

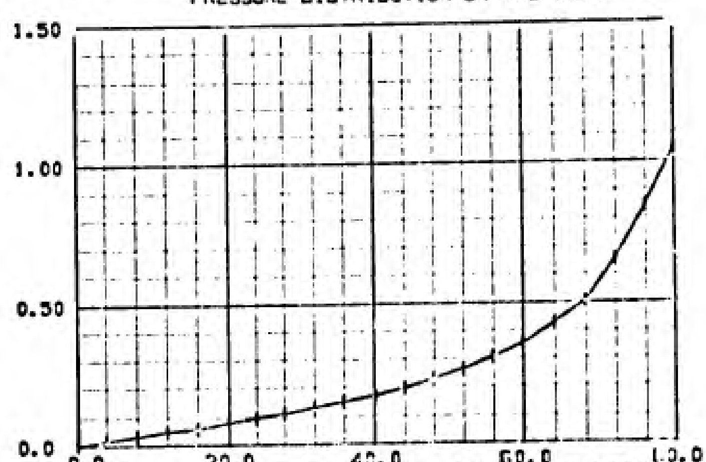
STANDOFF DISTANCE=0.7613
ABSCISSA OF STAGNATION POINT= -0.37000



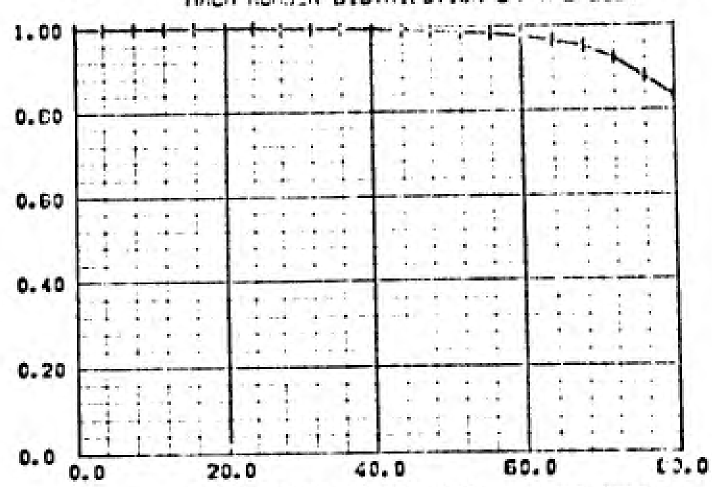
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



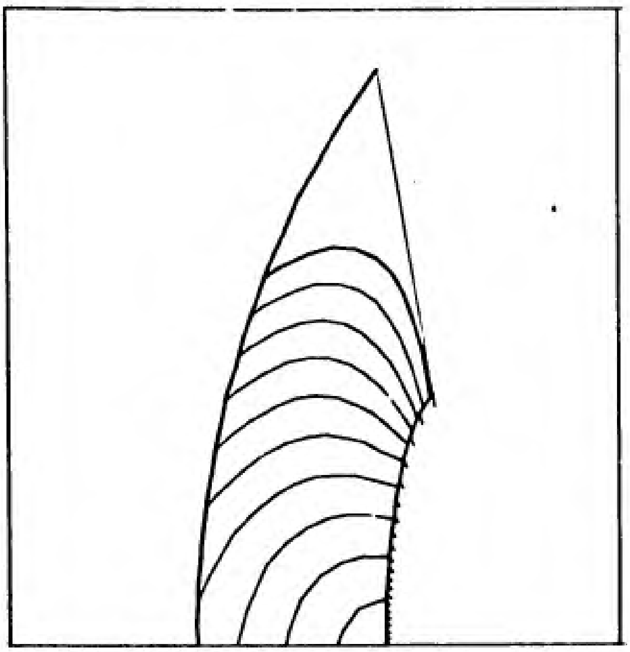
MACH NUMBER DISTRIBUTION ON THE BODY



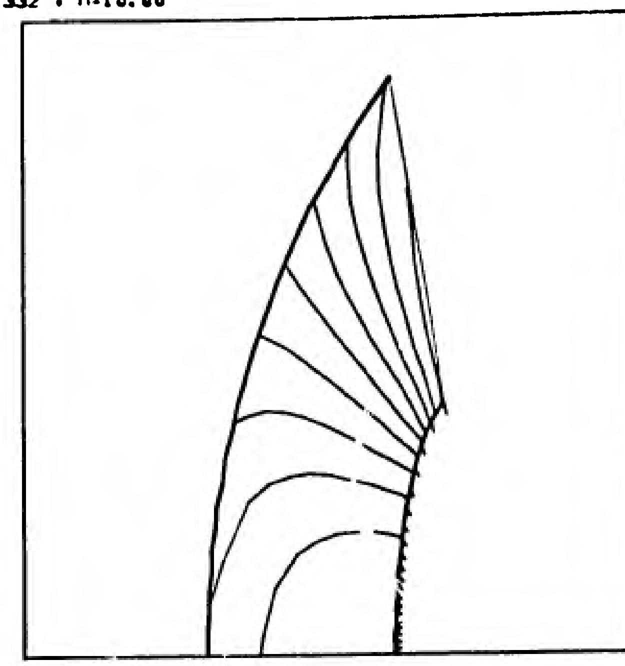
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 332 . M=10.80

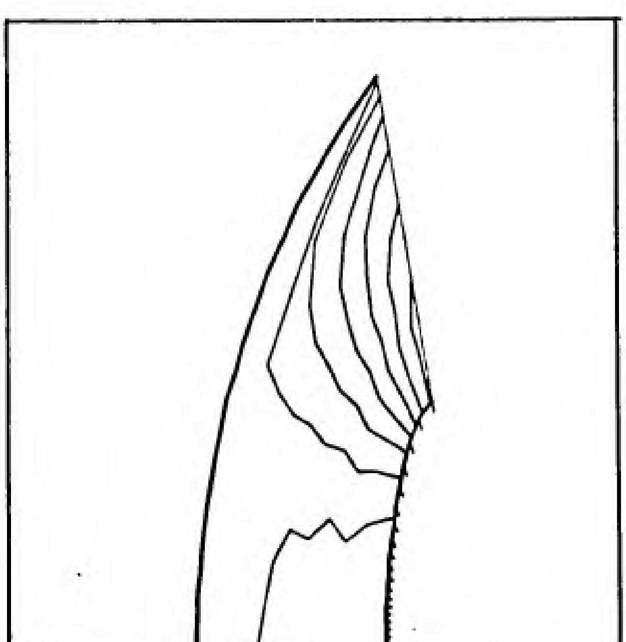
D4



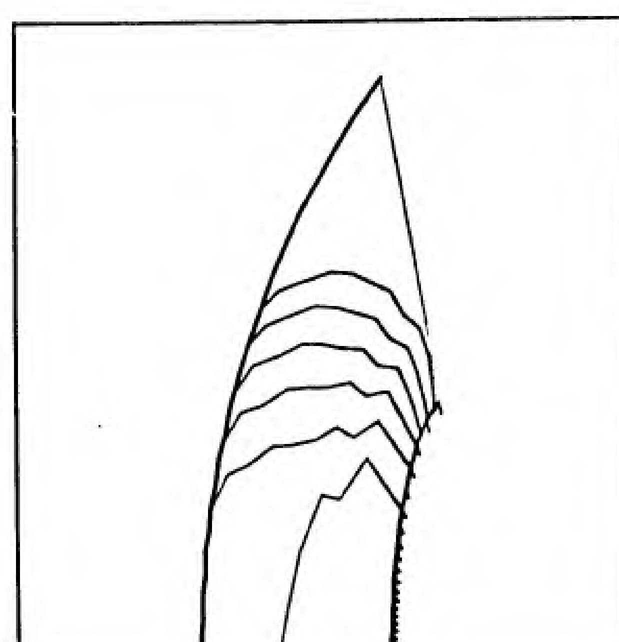
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 233

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

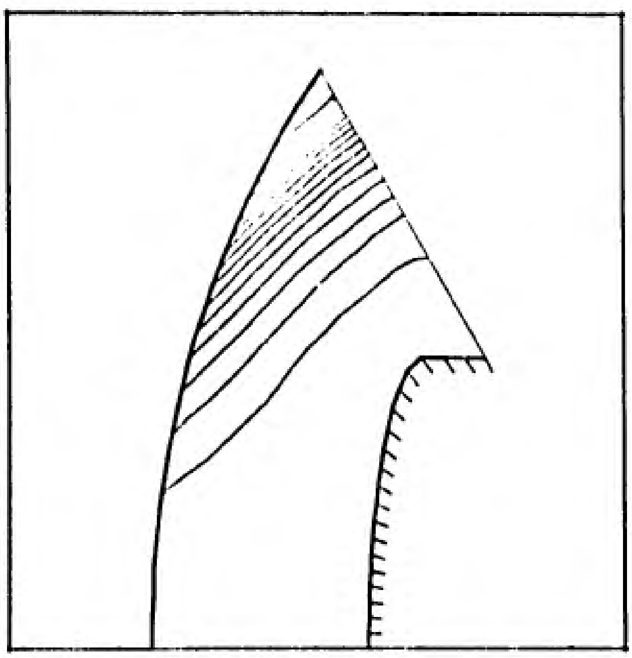
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.073
RELATIVE ERROR= 0.00112

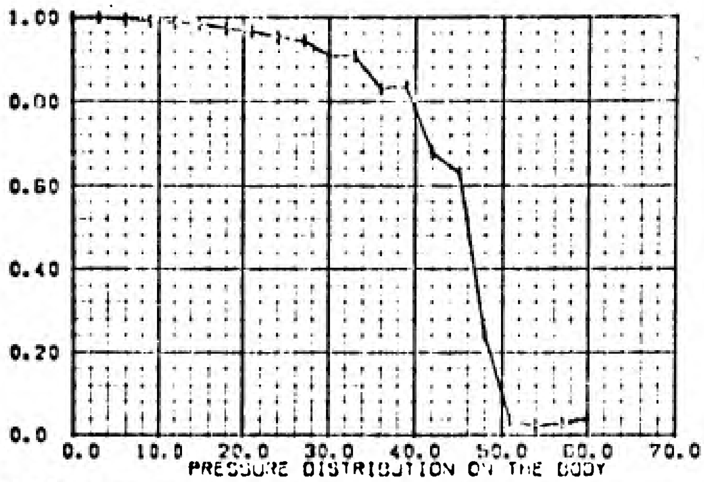
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 20.993
RELATIVE ERROR= 0.00032

CRITICAL PRESSURE RATIO=0.5534   (REL. ERROR= 0.0332)
CRITICAL DENSITY RATIO=0.6514   (REL. ERROR= 0.0275)
CRITICAL TEMPERAT.RATIO=0.8341   (REL. ERROR= 0.0249)

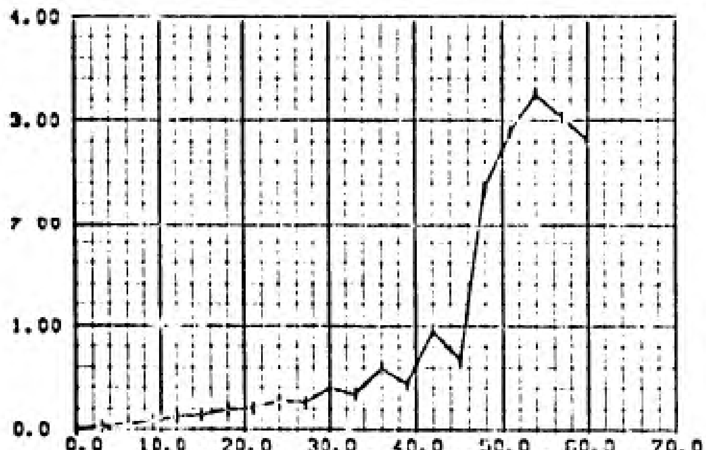
STANDOFF DISTANCE=0.7759
ABSCISSA OF STAGNATION POINT= -1.00000



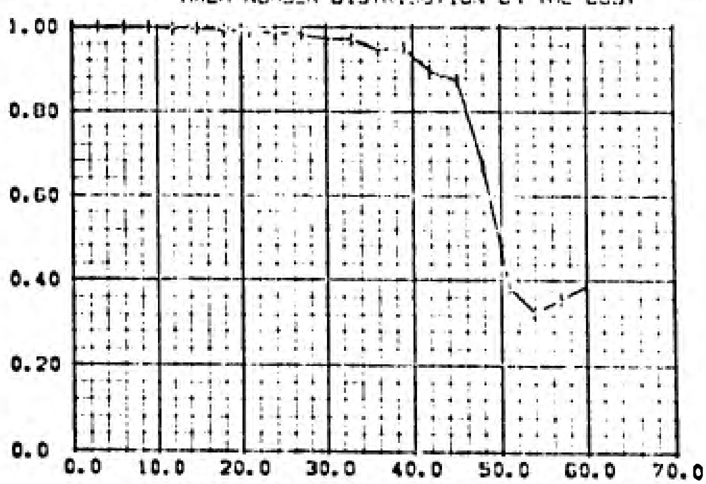
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



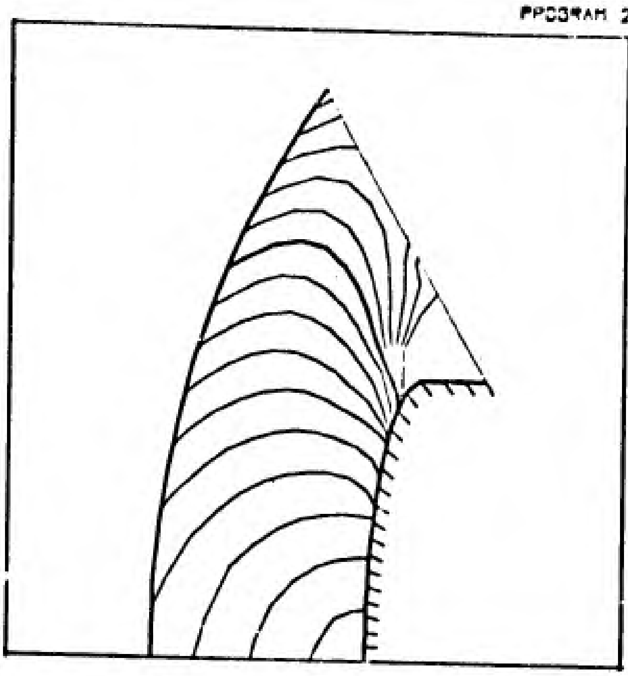
MACH NUMBER DISTRIBUTION ON THE BODY



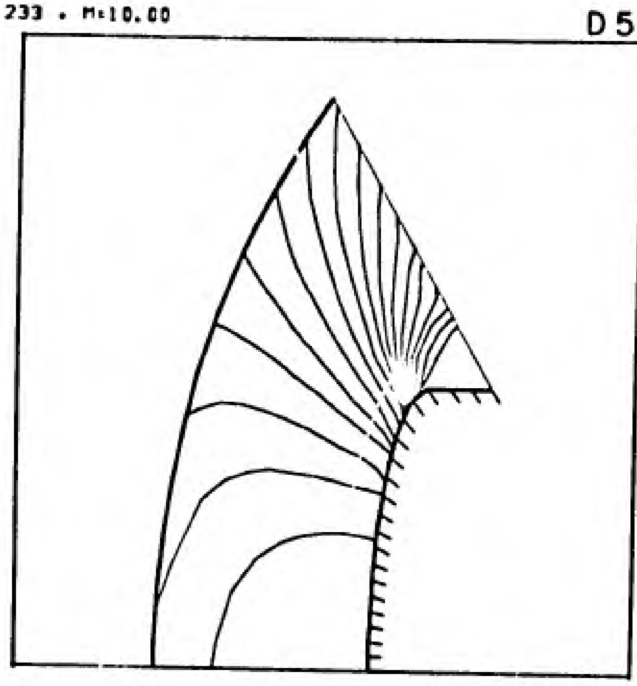
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E, RUN NO 233 , M=10.00

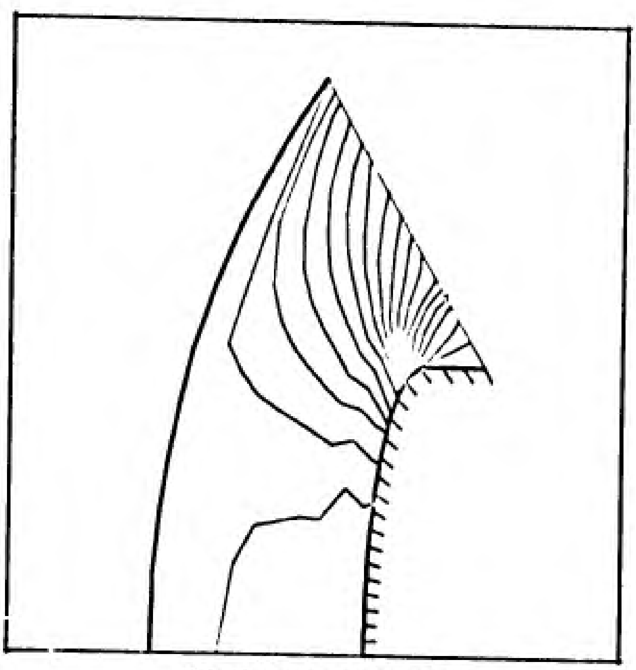
D5



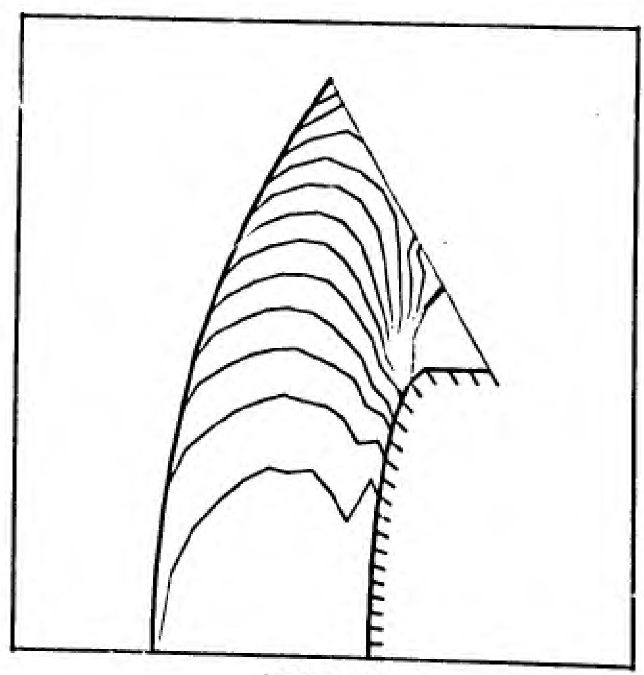
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 234

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

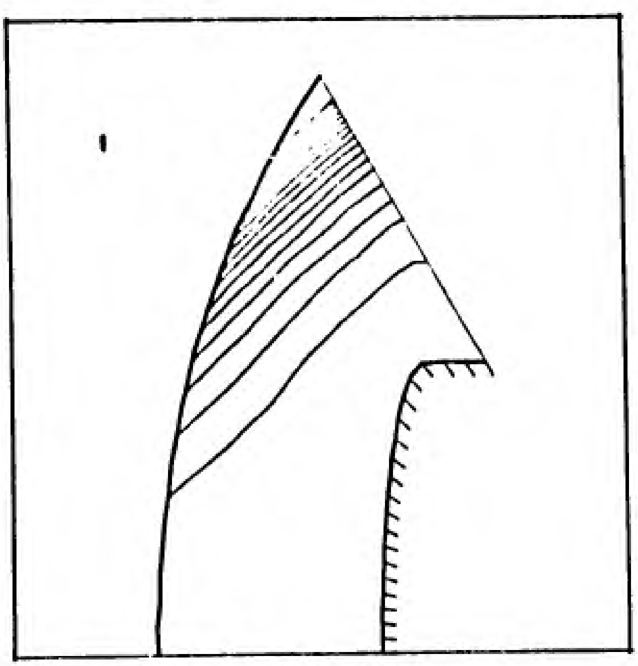
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.045
RELATIVE ERROR= 0.00133

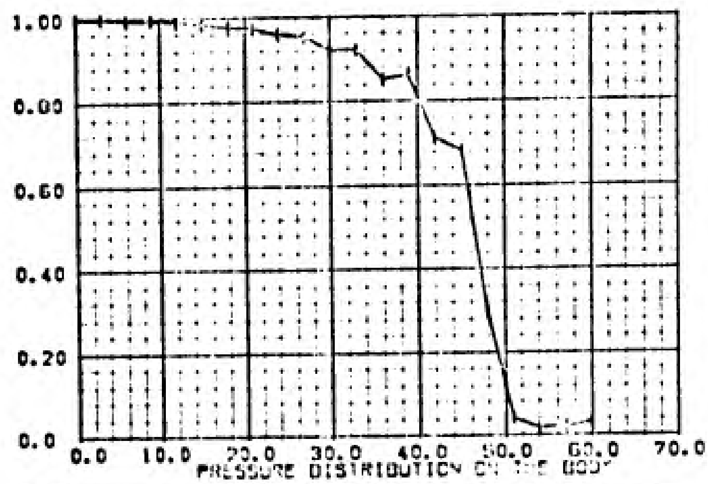
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 20.992
RELATIVE ERROR= 0.00038

CRITICAL PRESSURE RATIO=0.5877 (REL. ERROR= 0.1125)
CRITICAL DENSITY RATIO=0.6772 (REL. ERROR= 0.0002)
CRITICAL TEMPERAT.RATIO=0.8378 (REL. ERROR= 0.0414)

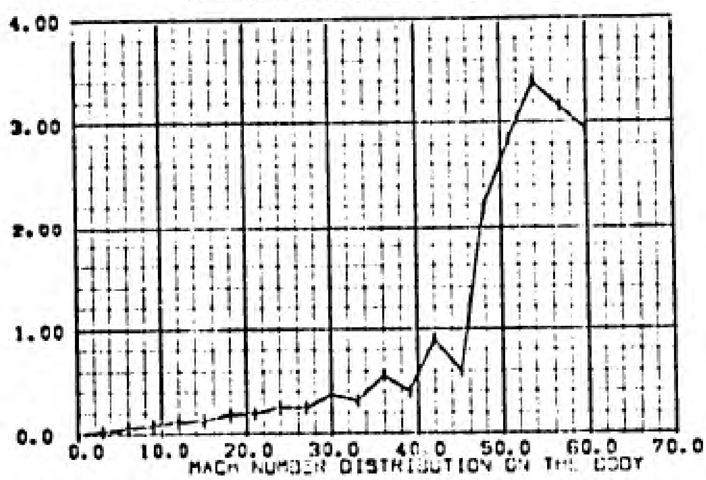
STANDOFF DISTANCE=0.7007
ABSCISSA OF STAGNATION POINT=-0.00087



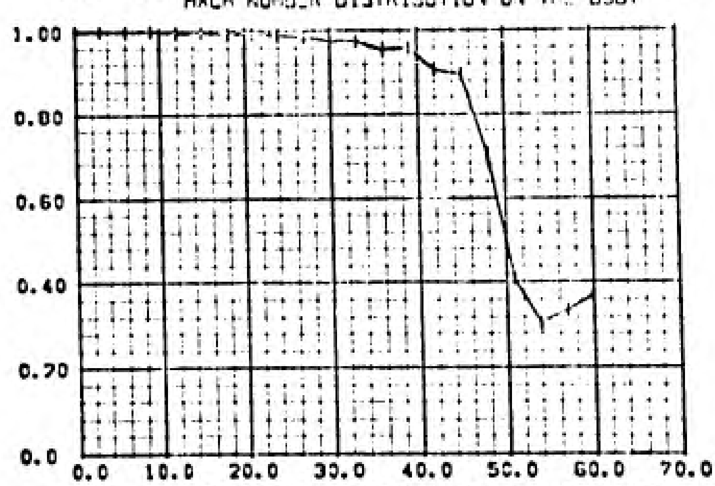
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

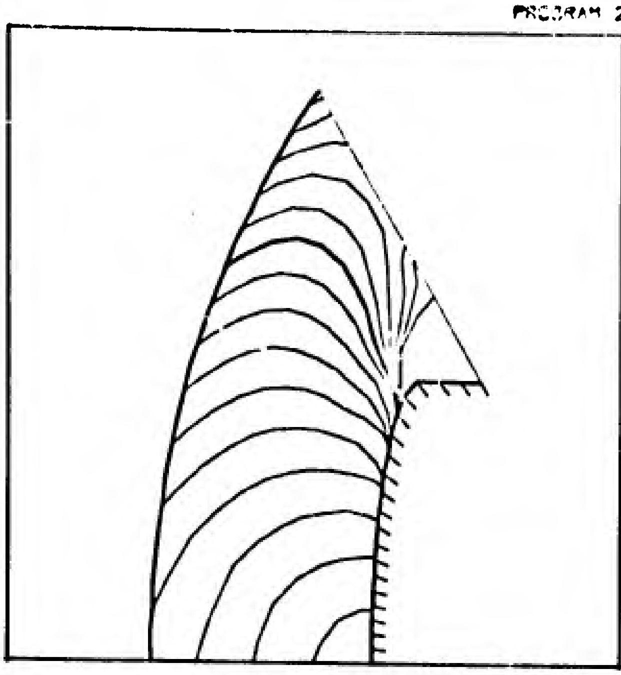


MACH NUMBER DISTRIBUTION ON THE BODY

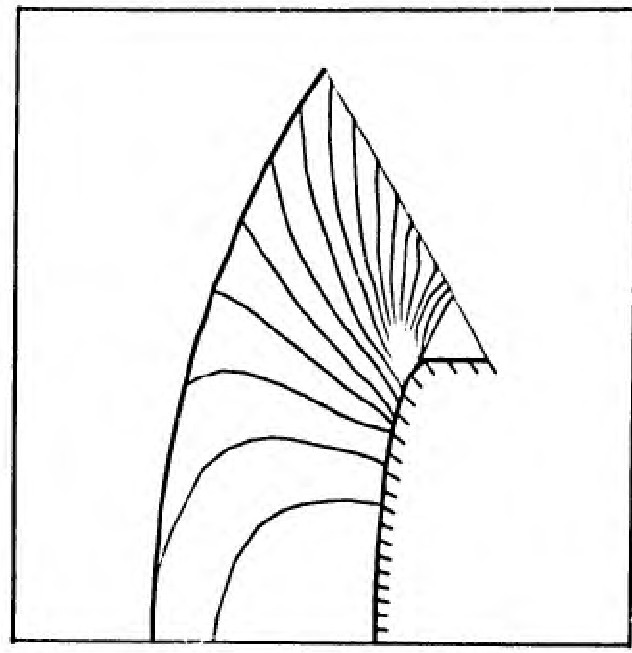


TEMPERATURE DISTRIBUTION ON THE BODY

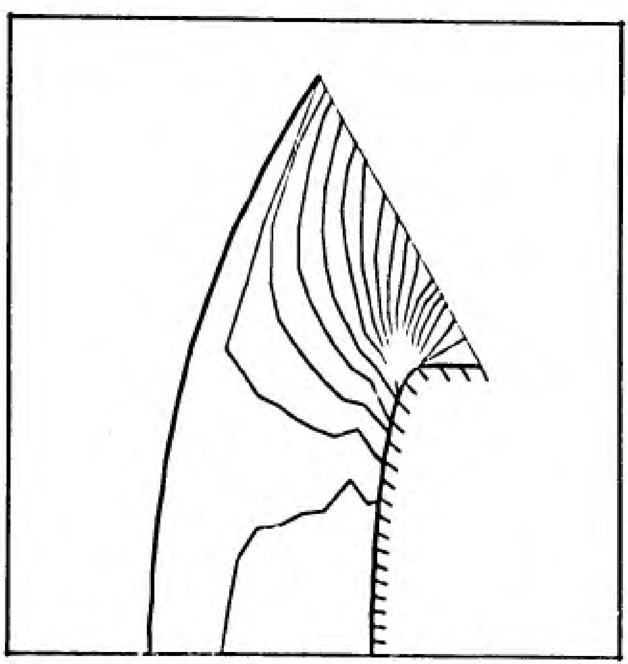
PROGRAM 2E, RUN NO 234 . M=10.00 **D6**



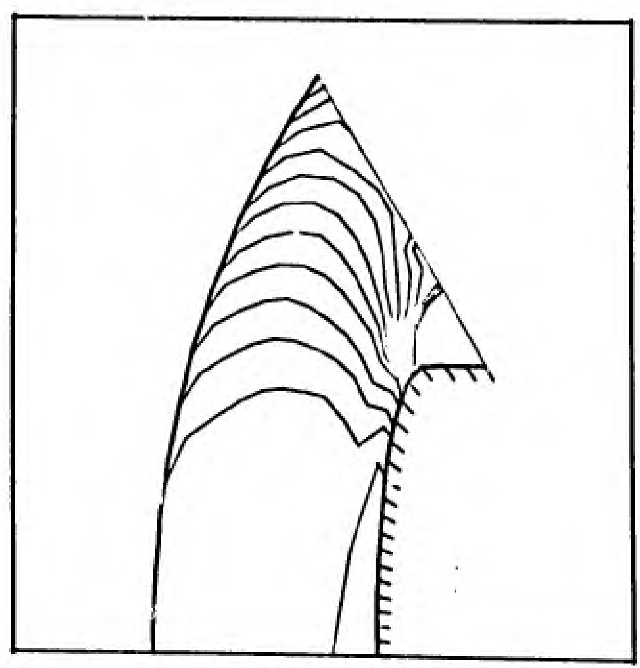
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 210

10 BY 20 MESH. 1000 STEPS   TOLERANCE=0.000010

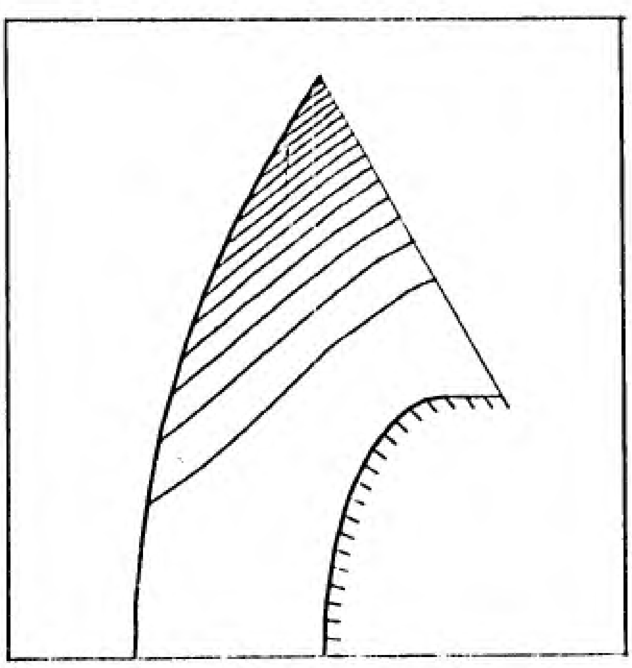
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.063
COMP. STAGNATION PRESSURE= 21.055
RELATIVE ERROR= 0.00034

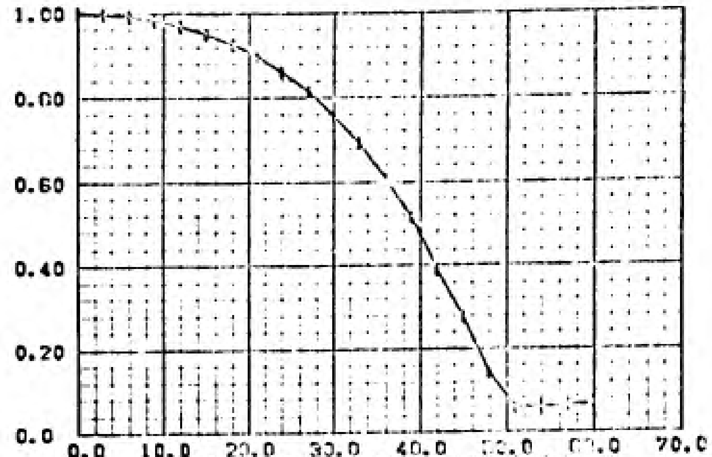
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.199
RELATIVE ERROR= 0.00018

CRITICAL PRESSURE RATIO=0.5203 (REL. ERROR= 0.0141)
CRITICAL DENSITY RATIO=0.6274 (REL. ERROR= 0.0103)
CRITICAL TEMPERAT.RATIO=0.8301 (REL. ERROR= 0.0039)

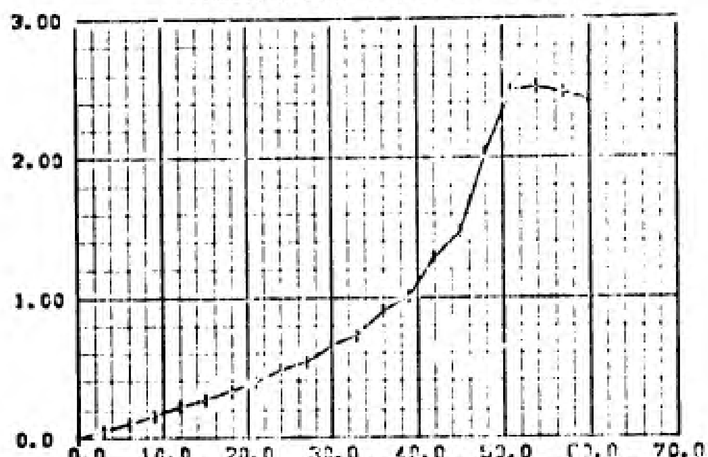
STANDOFF DISTANCE=0.7643
ABSCISSA OF STAGNATION POINT= -1.30000



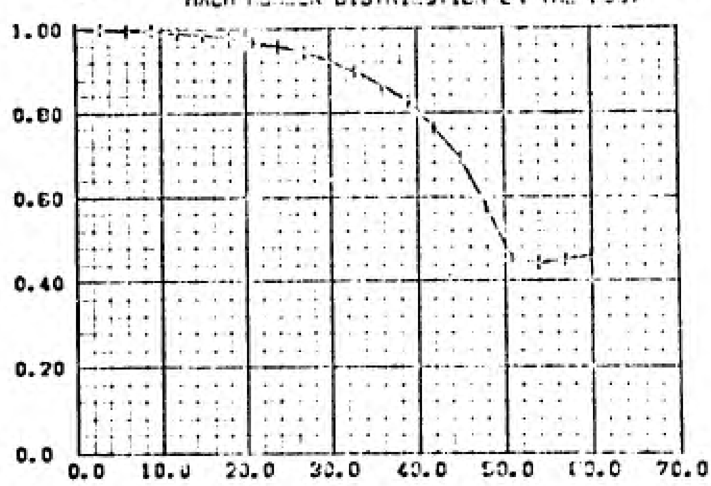
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

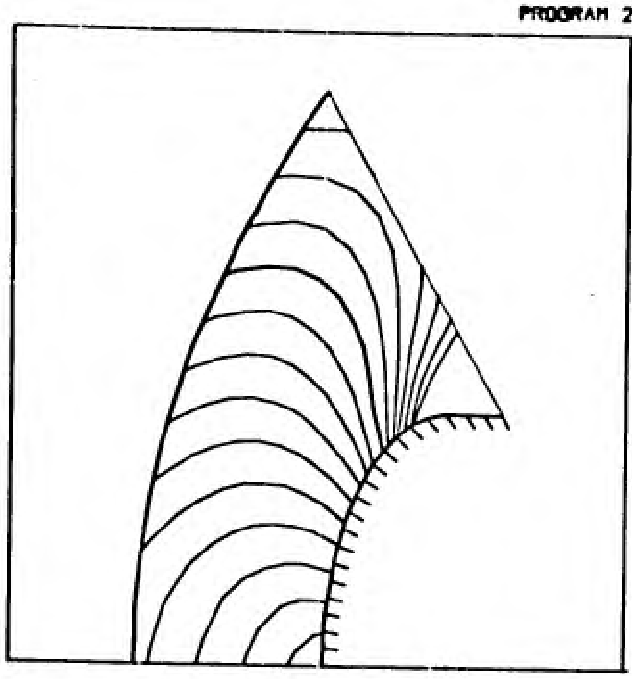


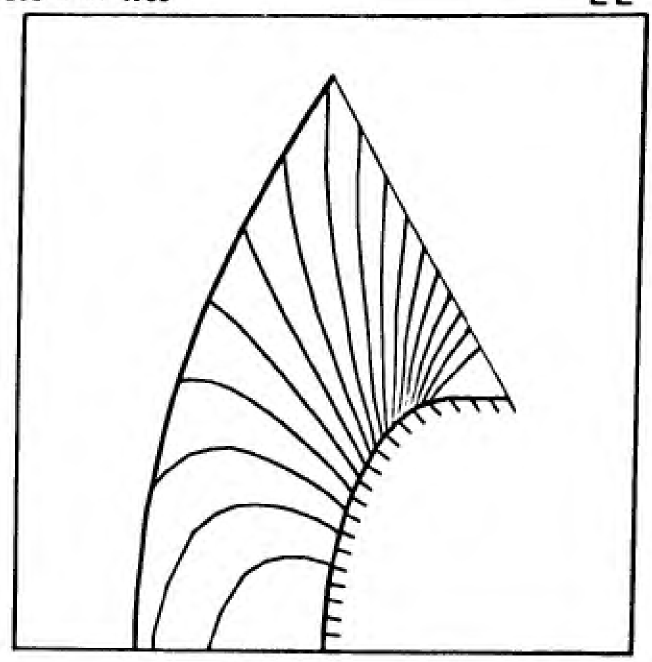
MACH NUMBER DISTRIBUTION ON THE BODY

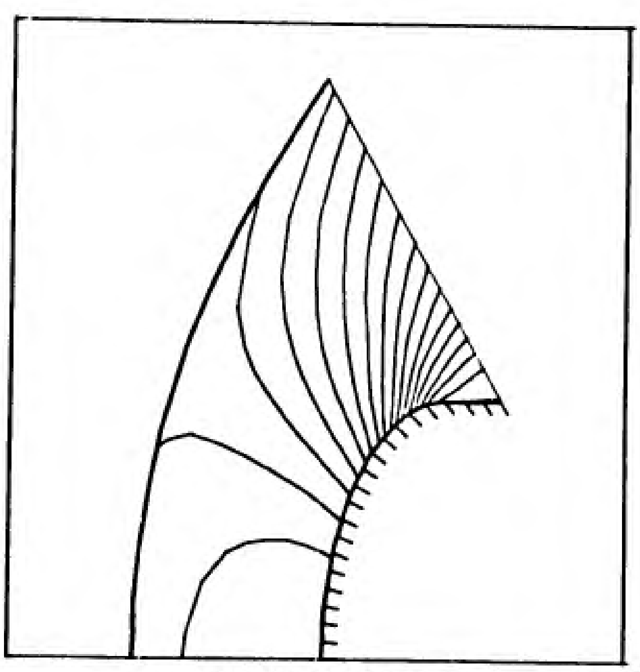


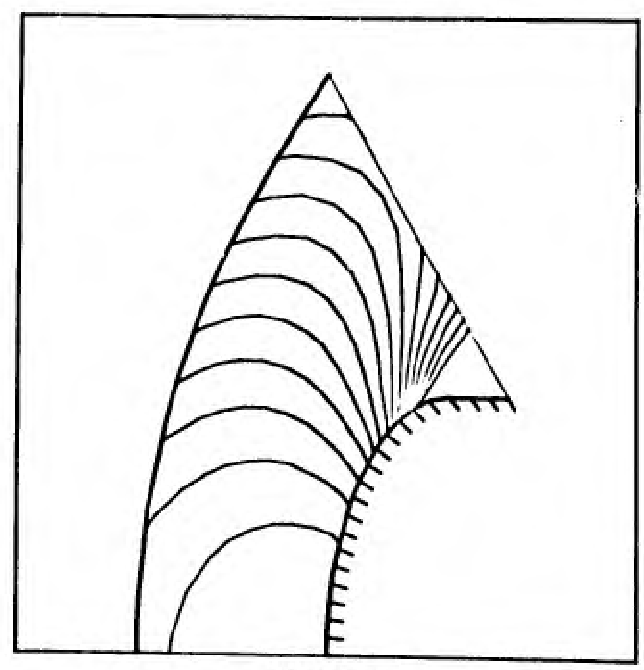
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 210 . M= 4.00 E2


CONSTANT MACH NUMBER LINES


ISOBARS


CONSTANT DENSITY LINES


ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 211

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

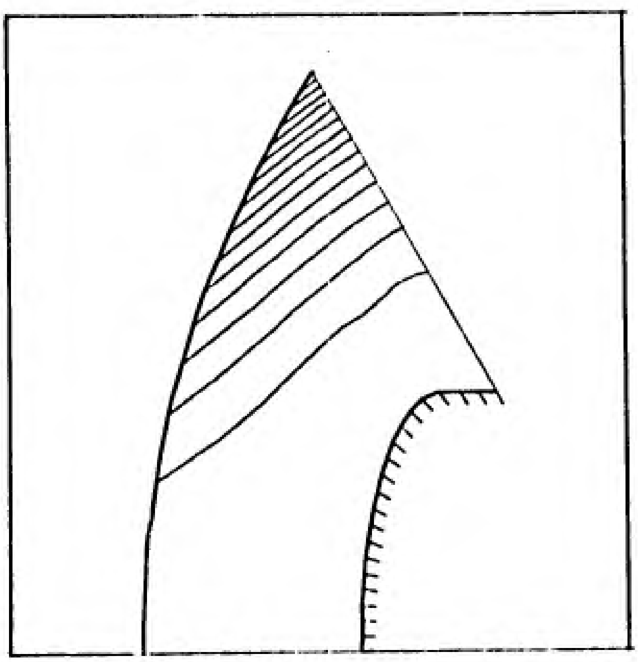
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.058
RELATIVE ERROR= 0.00048

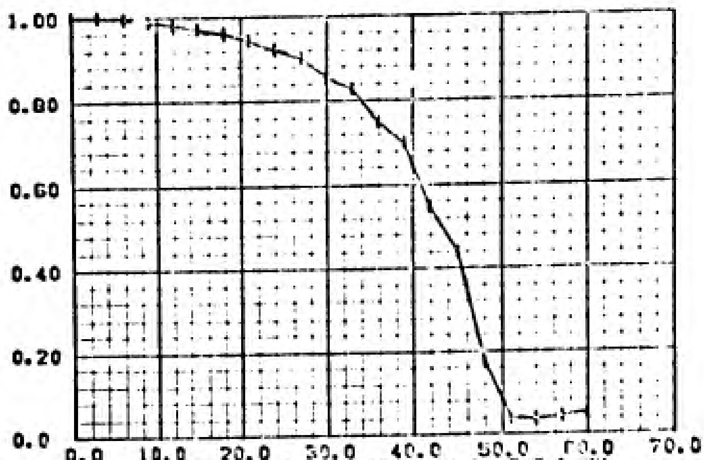
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.199
RELATIVE ERROR= 0.00014

CRITICAL PRESSURE RATIO= 0.5759 (REL. ERROR= 0.0902)
CRITICAL DENSITY RATIO= 0.6736 (REL. ERROR= 0.0625)
CRITICAL TEMPERAT.RATIO= 0.8550 (REL. ERROR= 0.0260)

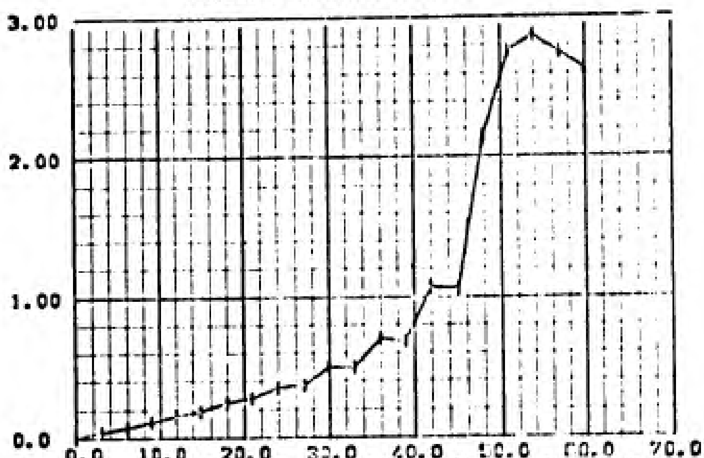
STANDOFF DISTANCE=0.0741
ABSCISSA OF STAGNATION POINT= -1.13333



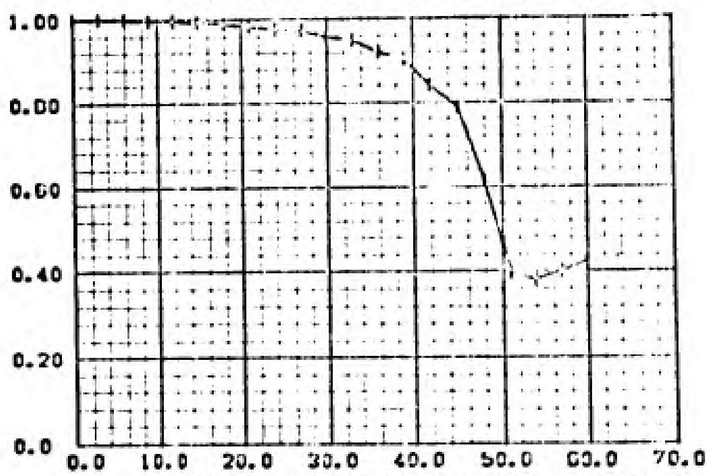
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

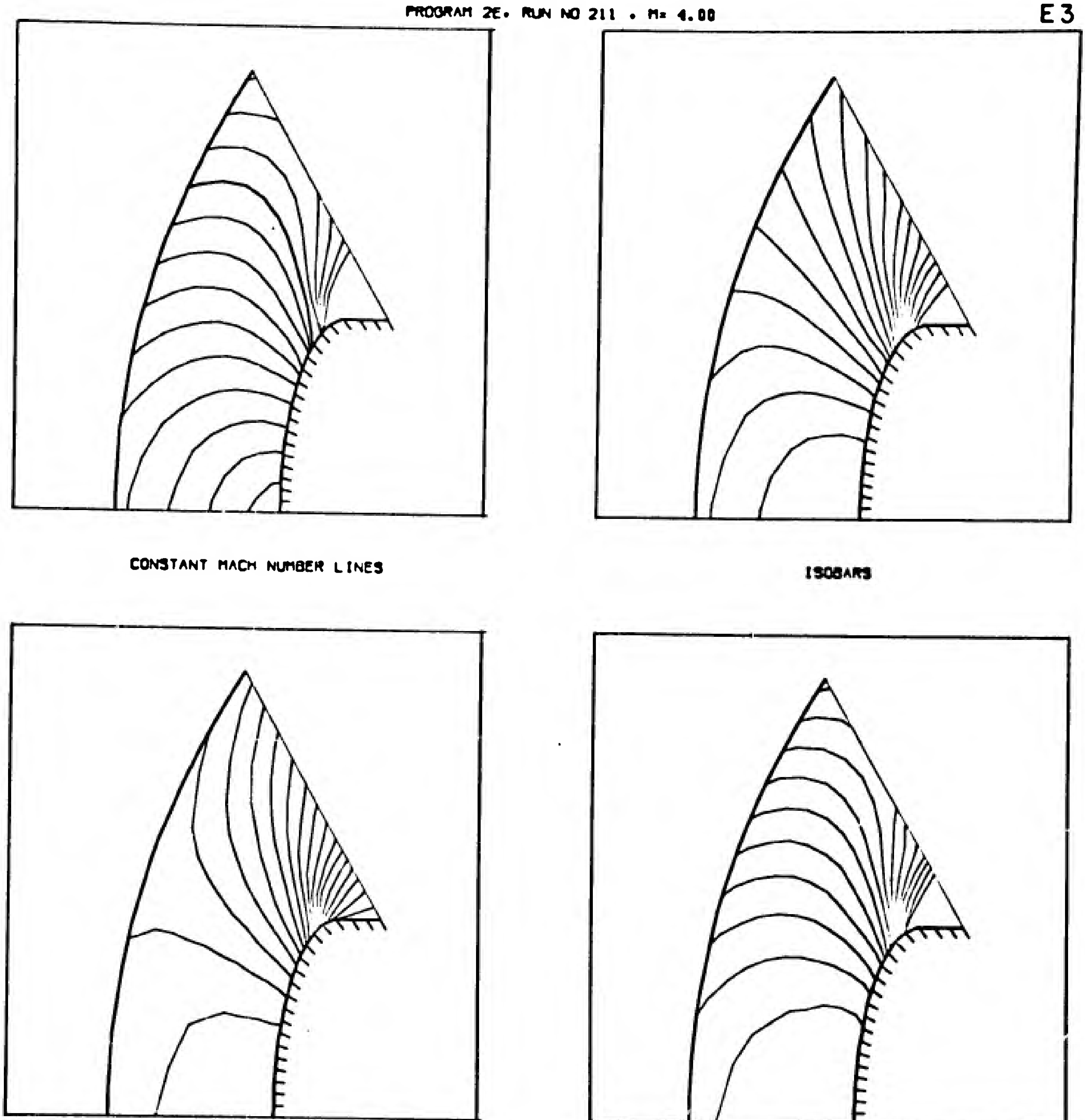


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 211 . M= 4.00 E3



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 212

10 BY 20 MESH, 1000 STEPS   TOLERANCE=0.000010

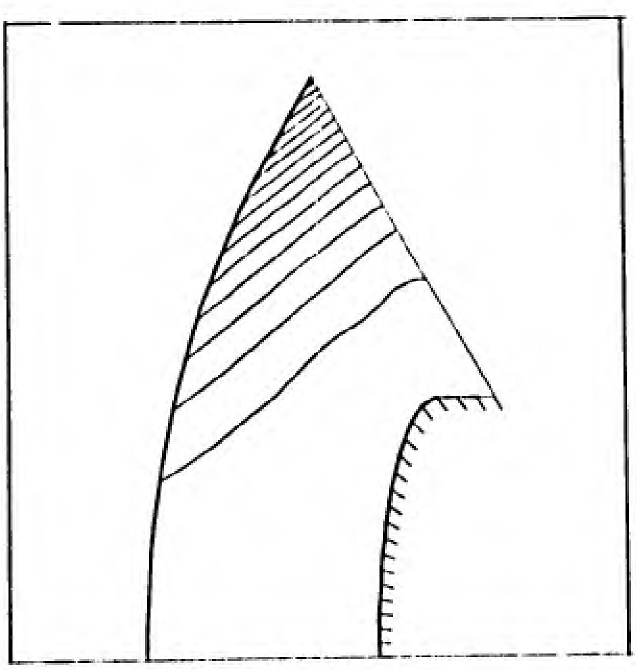
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.0[illegible]3
COMP. STAGNATION PRESSURE= 21.034
RELATIVE ERROR= 0.000[illegible]3

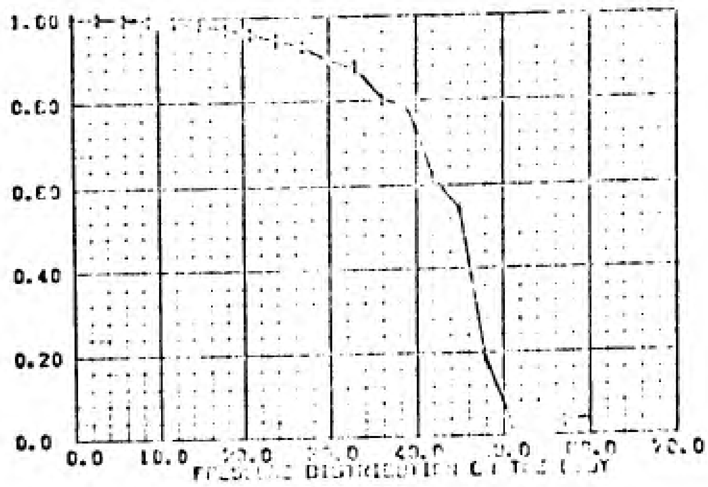
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.1[illegible]3
RELATIVE ERROR= 0.00019

CRITICAL PRESSURE RATIO= 0.6229 (REL. ERROR= 0.1731)
CRITICAL DENSITY RATIO 0.7131 (REL. ERROR= 0.12[illegible])
CRITICAL TEMPERAT.RATIO= 0.[illegible] (REL. ERROR= 0.04[illegible])

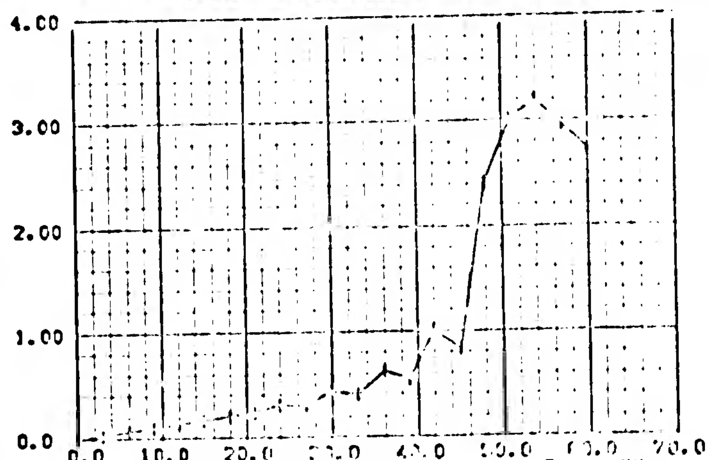
STANDOFF DISTANCE=0.[illegible]15
ABSCISSA OF STAGNATION POINT= -1.05000



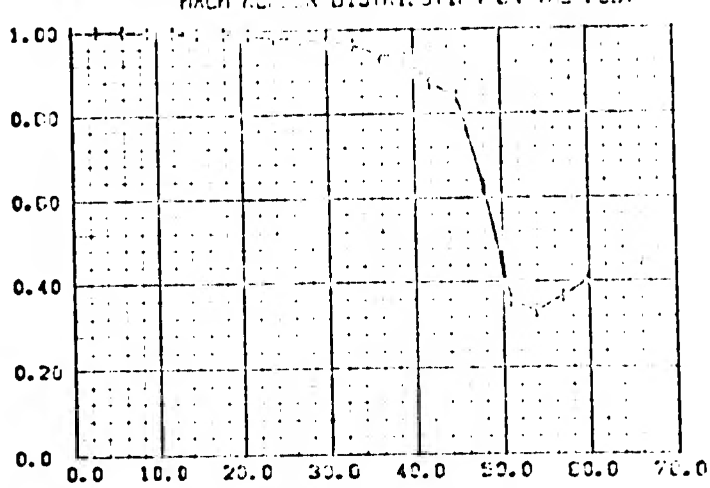
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



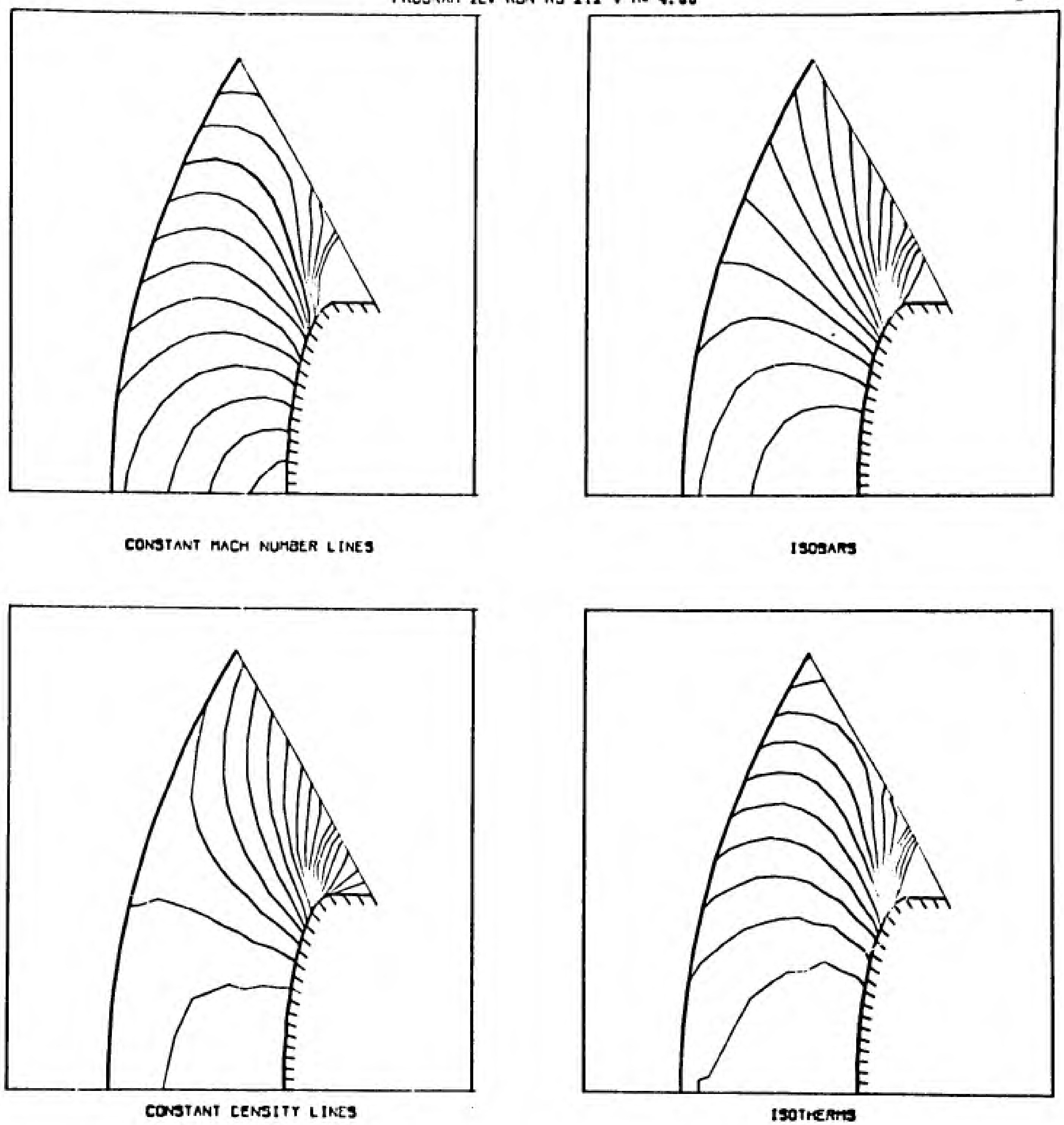
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E. RUN NO 212 . M= 4.00

E 4



TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 313

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

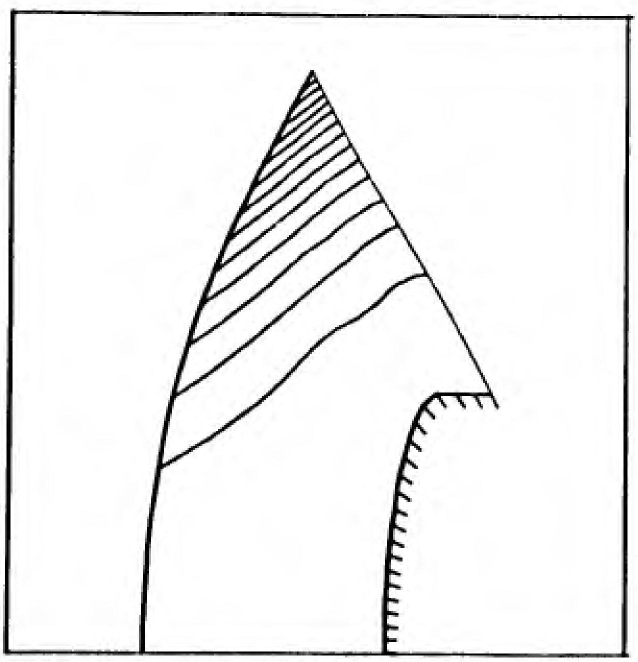
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.048
COMP. STAGNATION PRESSURE= 21.032
RELATIVE ERROR= 0.00077

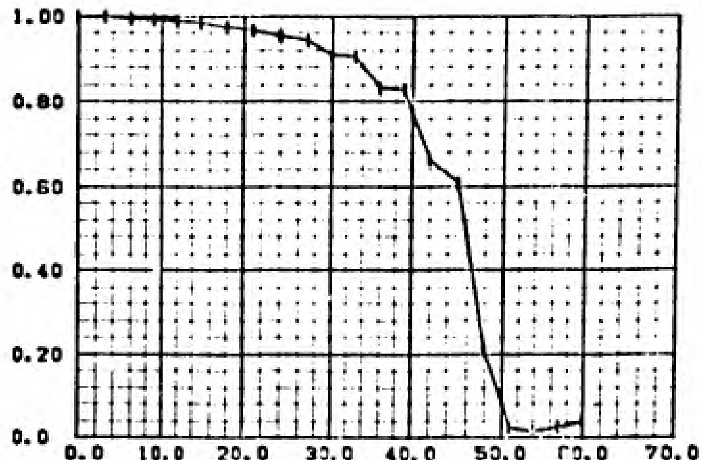
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.199
RELATIVE ERROR= 0.00022

CRITICAL PRESSURE RATIO=0.5439 (REL. ERROR= 0.0295)
CRITICAL DENSITY RATIO=0.6409 (REL. ERROR= 0.0110)
CRITICAL TEMPERAT.RATIO=0.8486 (REL. ERROR= 0.0184)

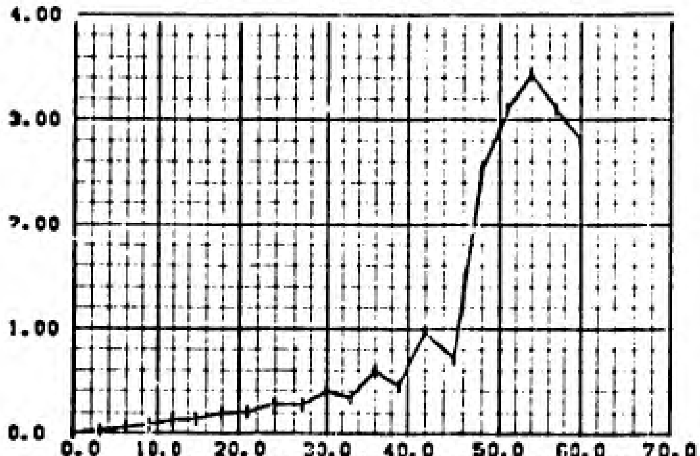
STANDOFF DISTANCE=0.9718
ABSCISSA OF STAGNATION POINT= -1.00000



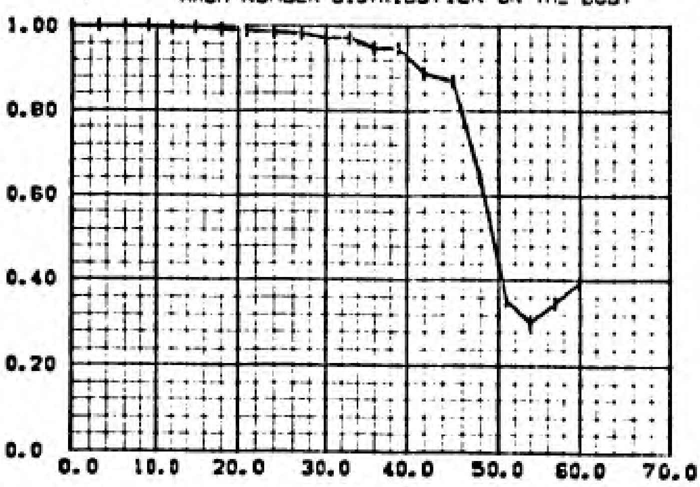
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



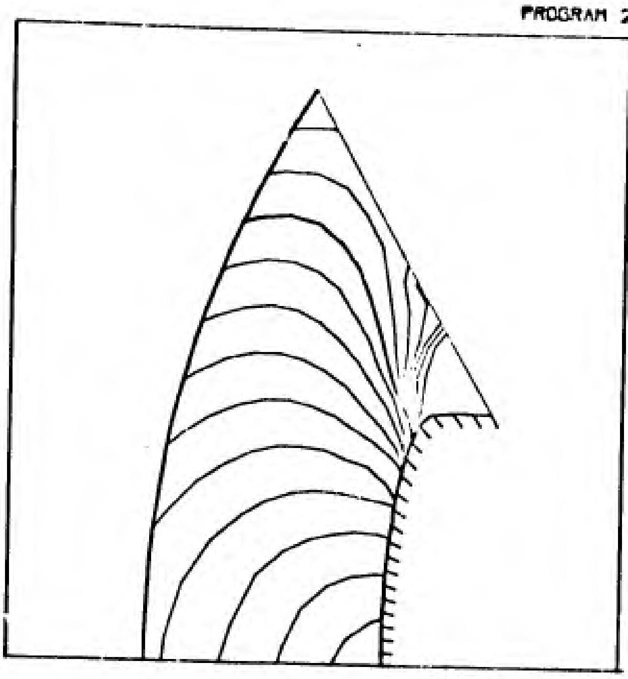
MACH NUMBER DISTRIBUTION ON THE BODY



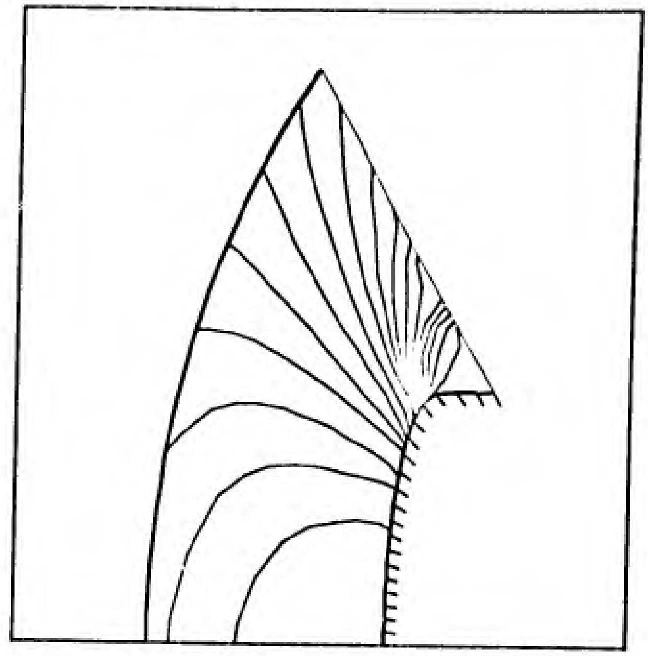
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2E, RUN NO 313 . M= 4.00

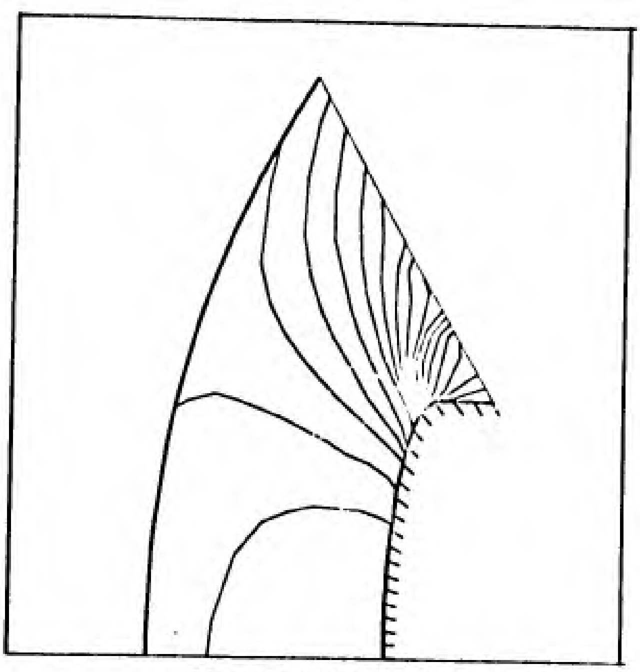
E5



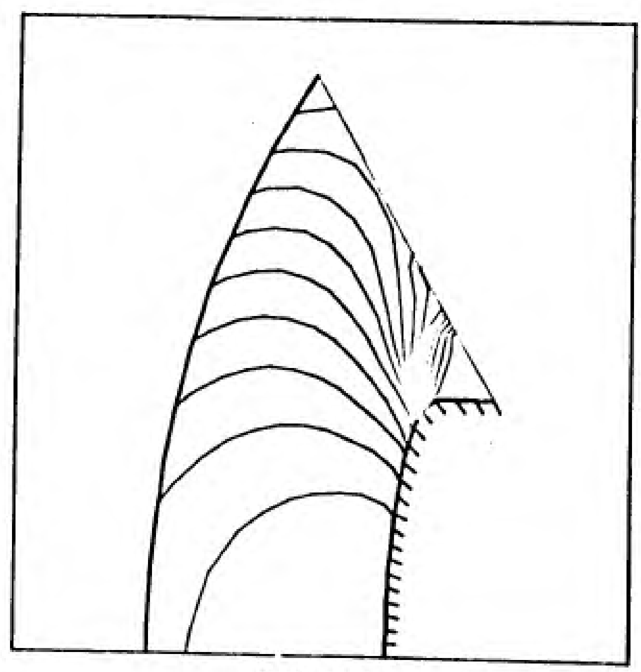
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 340

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

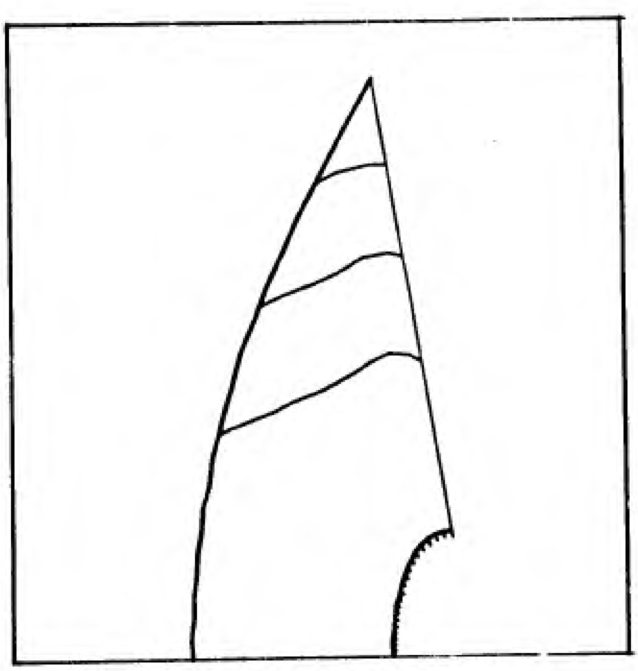
FREE STREAM MACH NUMBER= 2.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 5.640
COMP. STAGNATION PRESSURE= 5.607
RELATIVE ERROR= 0.00599

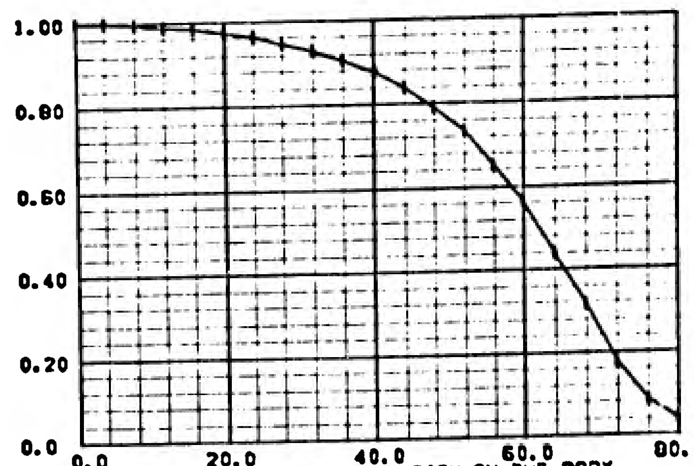
THEOR. STAGNATION TEMPERATURE= 1.800
COMP. STAGNATION TEMPERATURE= 1.797
RELATIVE ERROR= 0.00171

CRITICAL PRESSURE RATIO=0.5332 (REL. ERROR= 0.0094)
CRITICAL DENSITY RATIO=0.6375 (REL. ERROR= 0.0055)
CRITICAL TEMPERAT.RATIO=0.8365 (REL. ERROR= 0.0030)

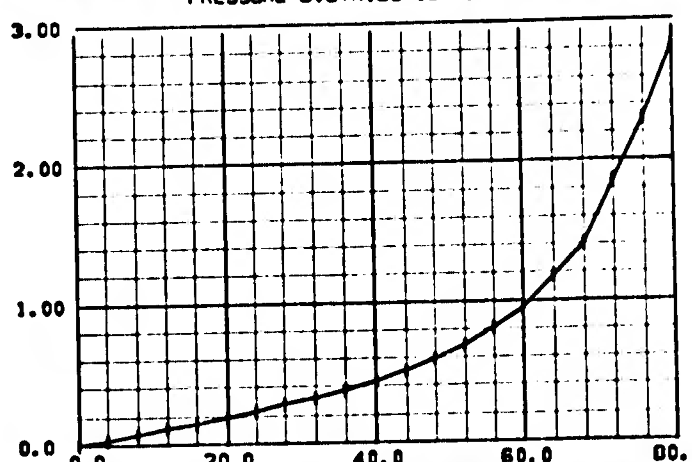
STANDOFF DISTANCE=1.6597
ABSCISSA OF STAGNATION POINT= - 0.70000



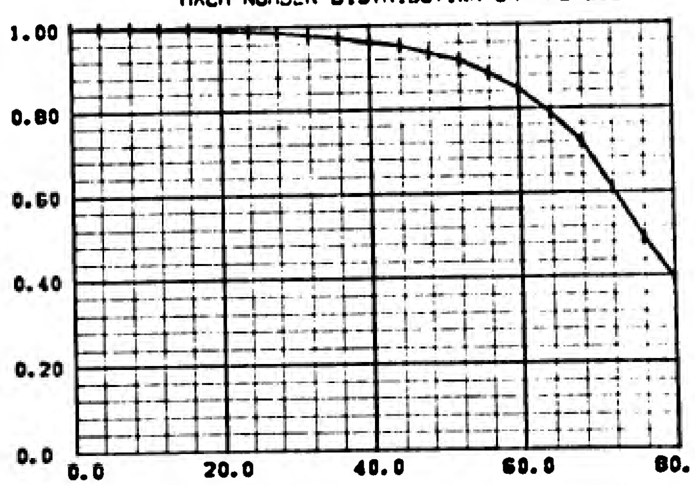
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



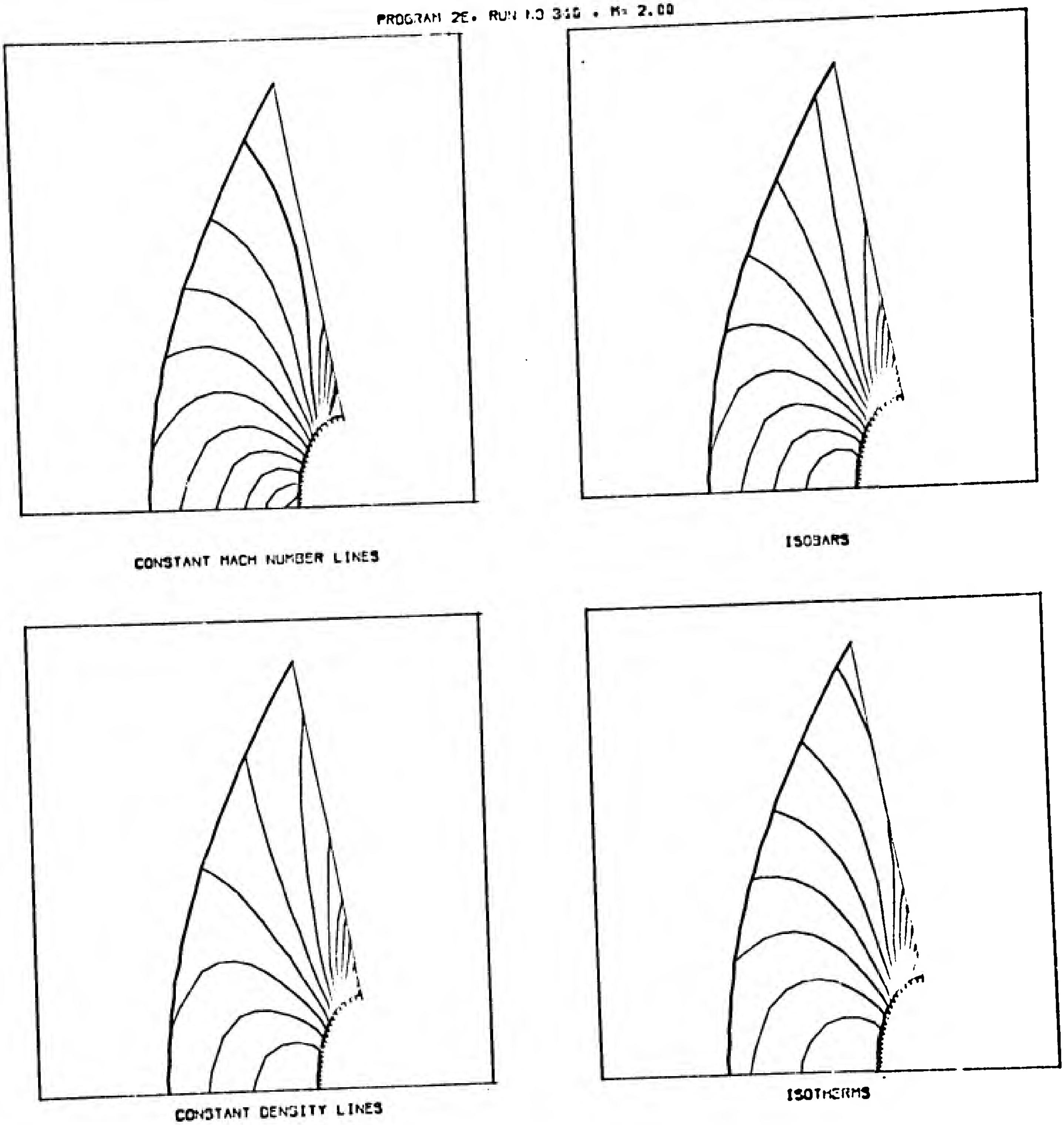
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

F2

PROGRAM 2E. RUN NO 3[illegible]0 . M= 2.00



TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 341

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

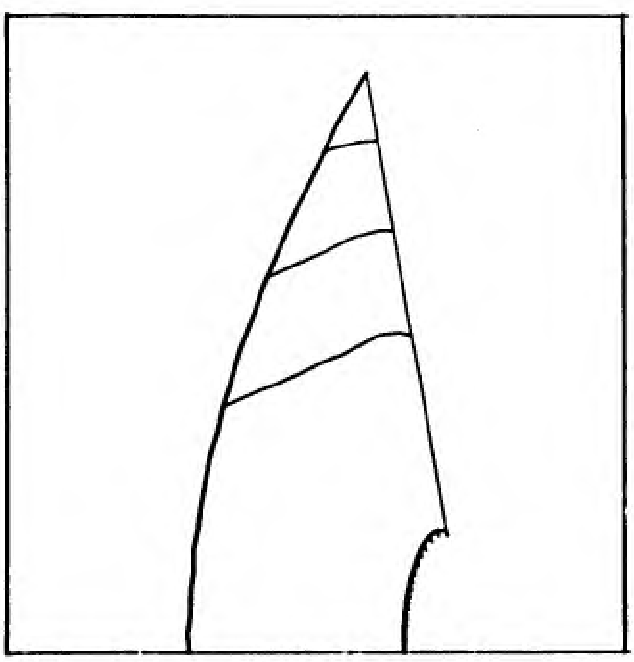
FREE STREAM MACH NUMBER= 2.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 5.640
COMP. STAGNATION PRESSURE= 5.629
RELATIVE ERROR= 0.00202

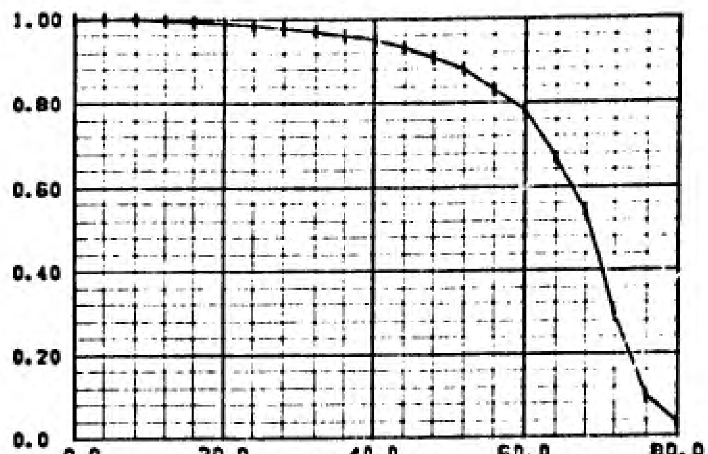
THEOR. STAGNATION TEMPERATURE= 1.800
COMP. STAGNATION TEMPERATURE= 1.799
RELATIVE ERROR= 0.00058

CRITICAL PRESSURE RATIO=0.5290 (REL. ERROR= 0.0014)
CRITICAL DENSITY RATIO=0.6335 (REL. ERROR= 0.0007)
CRITICAL TEMPERAT.RATIO=0.8351 (REL. ERROR= 0.0021)

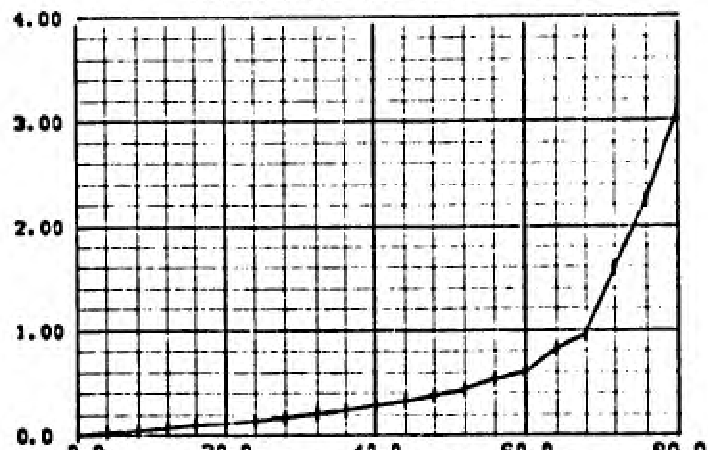
STANDOFF DISTANCE=1.8356
ABSCISSA OF STAGNATION POINT= -0.53333



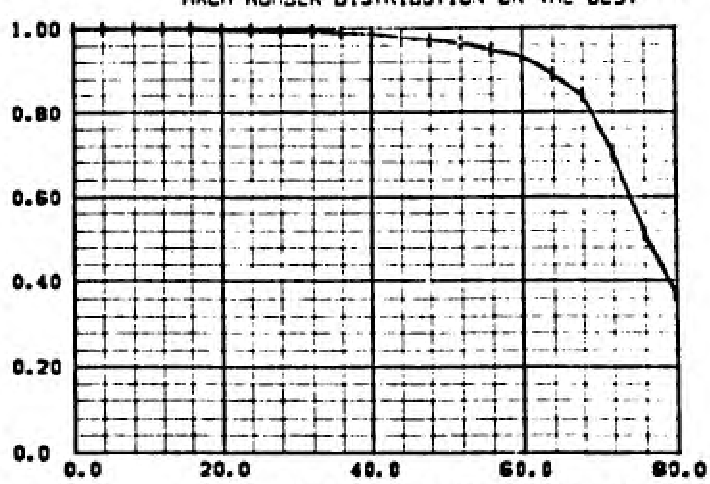
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



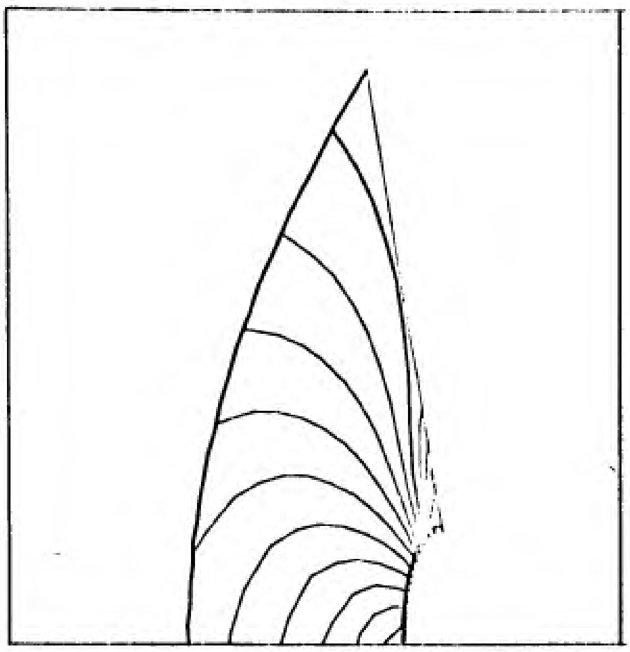
MACH NUMBER DISTRIBUTION ON THE BODY



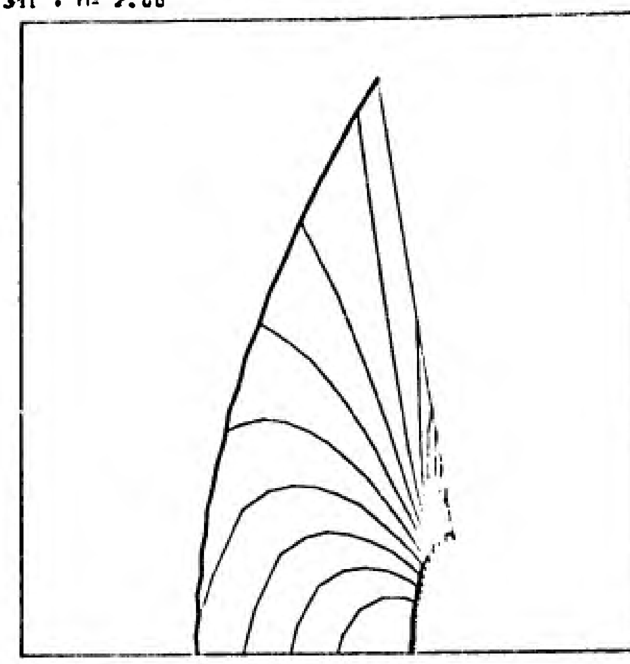
TEMPERATURE DISTRIBUTION ON THE BODY

F3

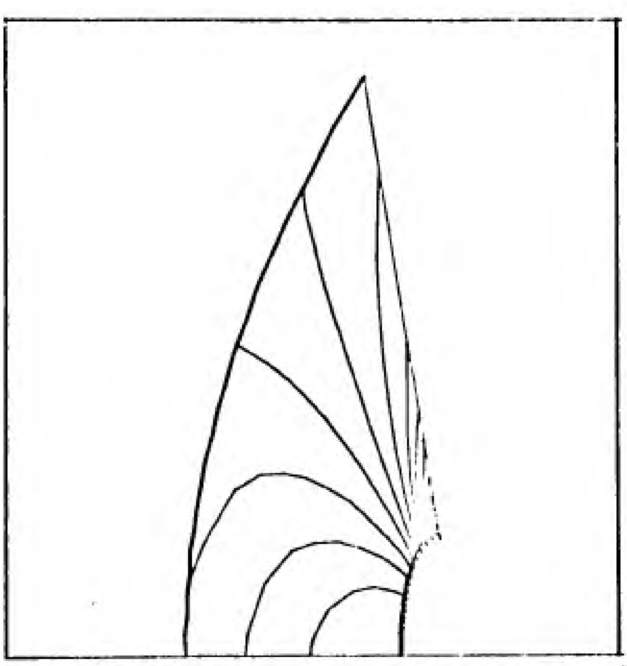
PROGRAM 2E. RUN NO 341 . M= 2.00



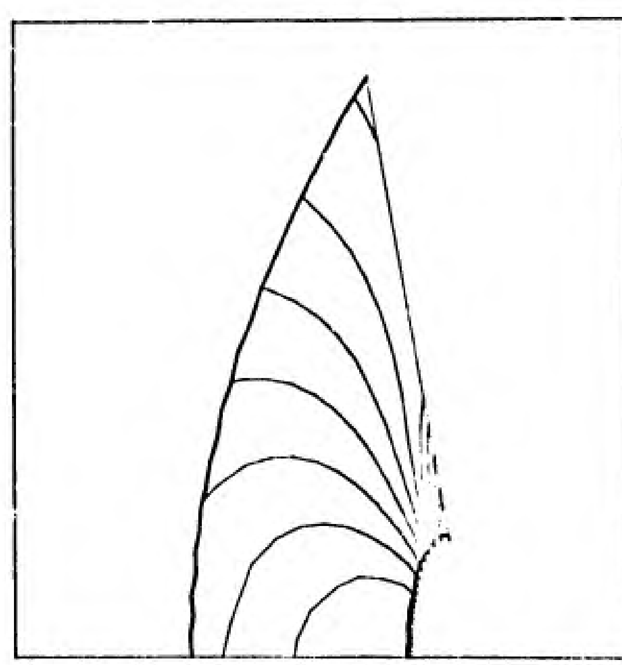
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 450

8 BY 13 MESH, 800 STEPS TOLERANCE=0.000010

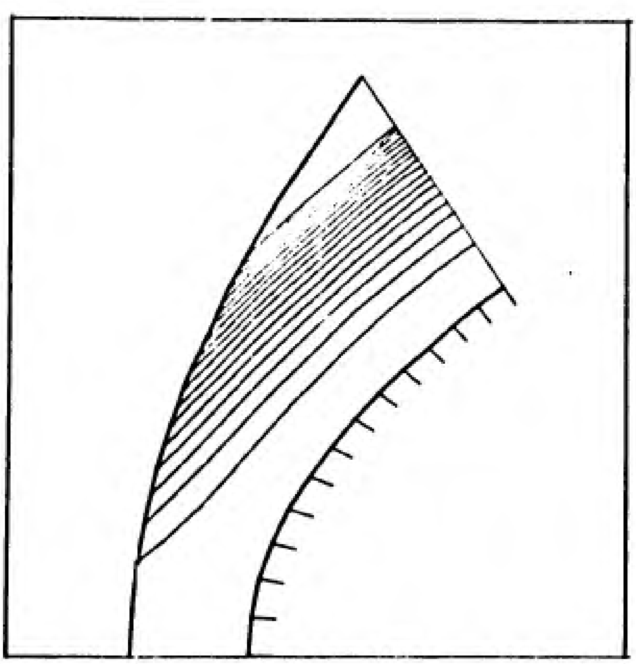
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.757
RELATIVE ERROR= 0.00053

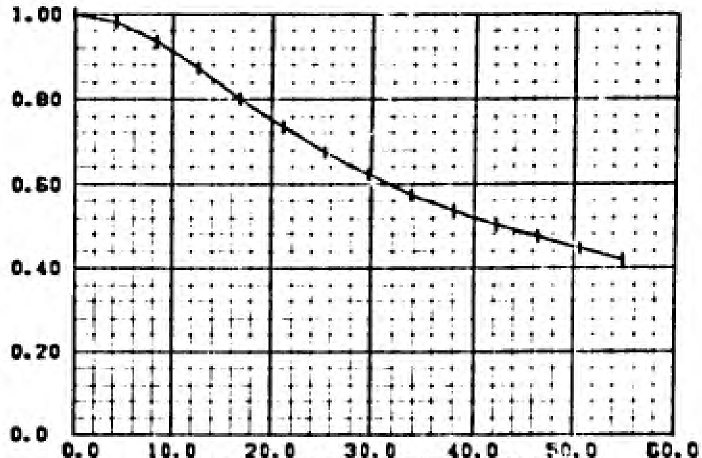
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 81.012
RELATIVE ERROR= 0.00015

CRITICAL PRESSURE RATIO=0.5247 (REL. ERROR= 0.0003)
CRITICAL DENSITY RATIO=0.6308 (REL. ERROR= 0.0050)
CRITICAL TEMPERAT.RATIO=0.8318 (REL. ERROR= 0.0019)

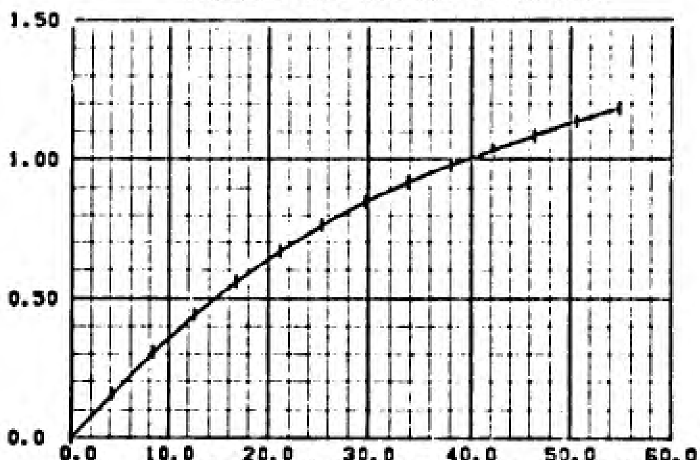
STANDOFF DISTANCE=0.4644
ABSCISSA OF STAGNATION POINT= -2.00000



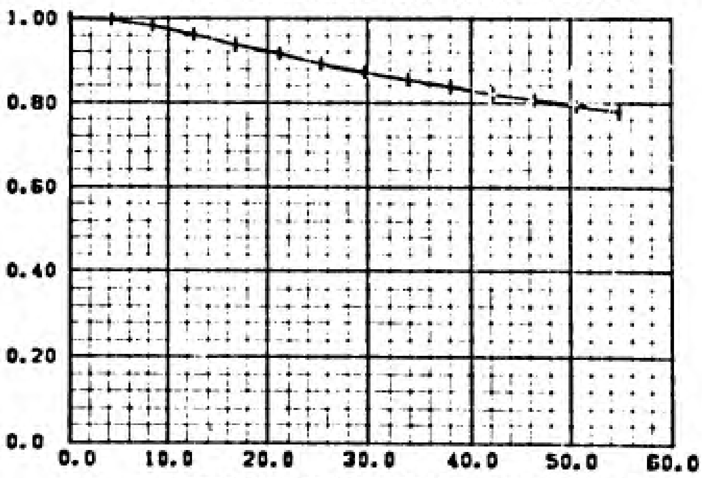
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



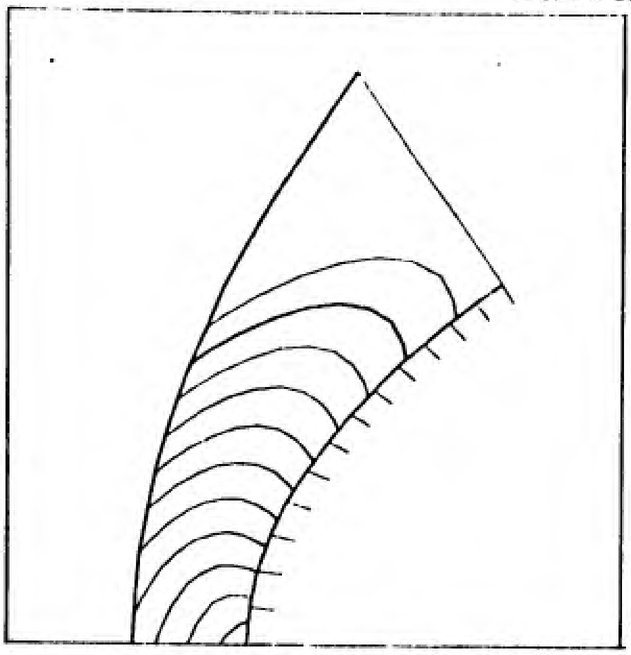
MACH NUMBER DISTRIBUTION ON THE BODY



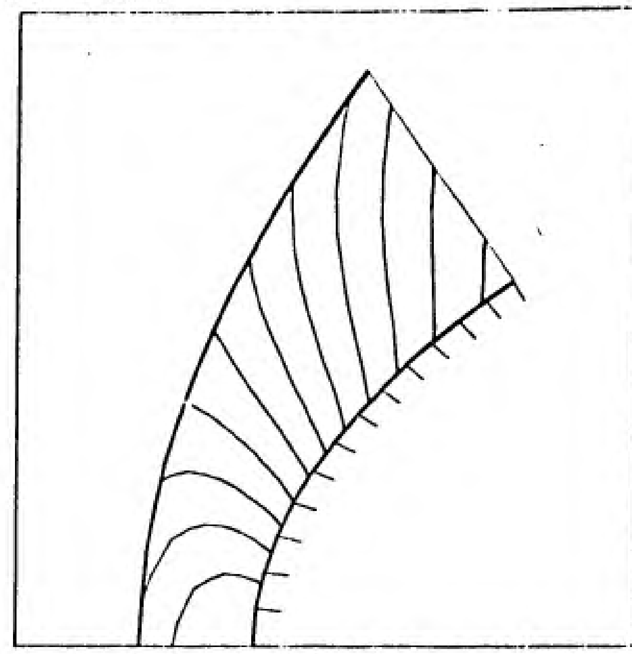
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2[illegible] RUN NO [illegible] . M=20.00

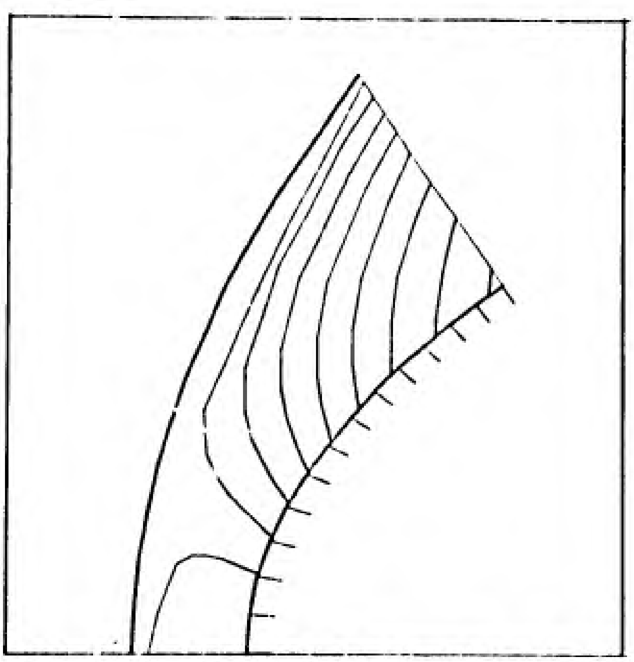
G I



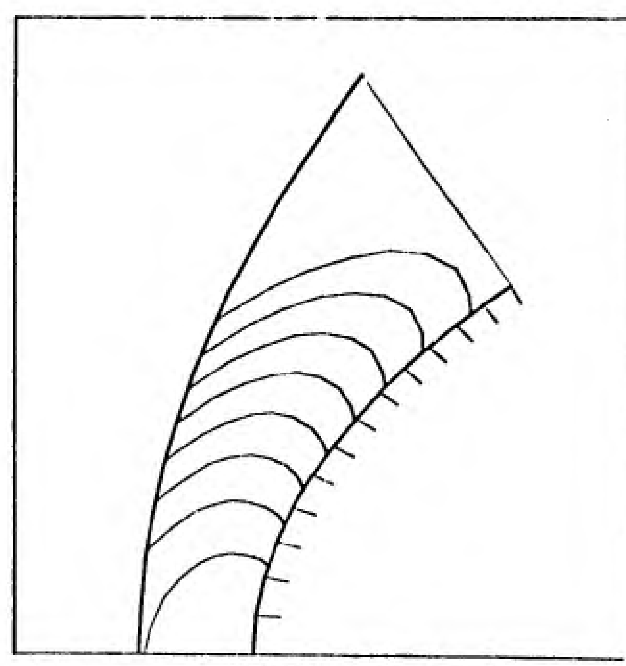
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY   RUN NO 451

8 BY 13 MESH, 800 STEPS   TOLERANCE=0.000010

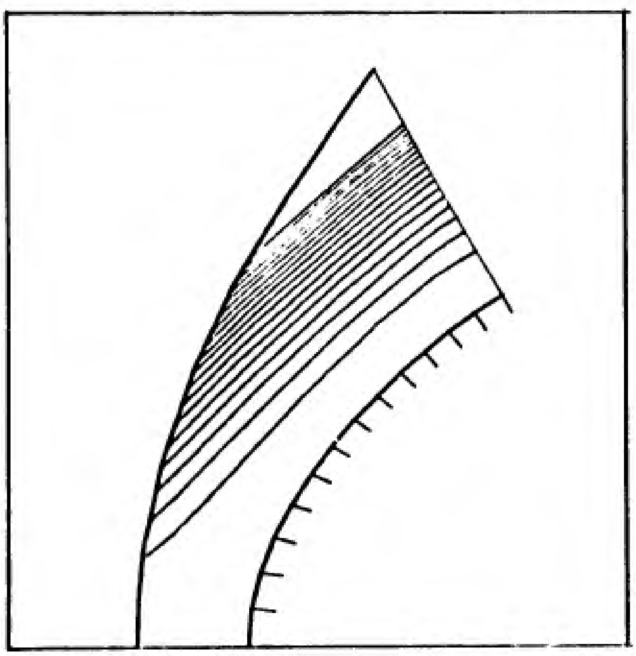
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.287
RELATIVE ERROR= 0.00055

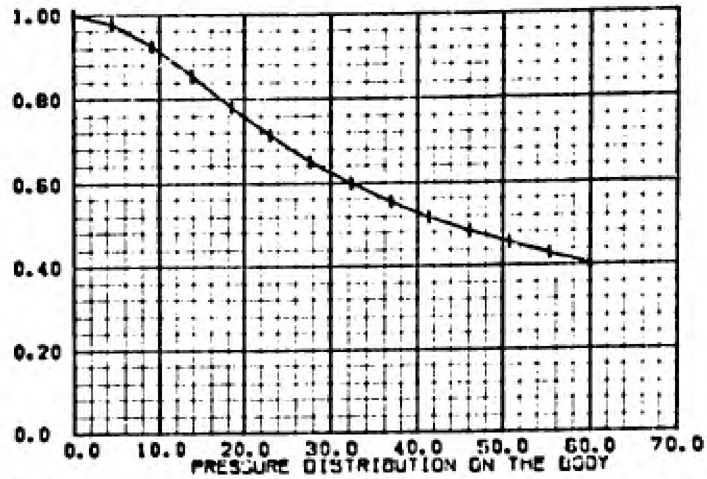
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.003
RELATIVE ERROR= 0.00015

CRITICAL PRESSURE RATIO=0.5241 (REL. ERROR= 0.0070)
CRITICAL DENSITY RATIO=0.6303 (REL. ERROR= 0.0057)
CRITICAL TEMPERAT.RATIO=0.8315 (REL. ERROR= 0.0022)

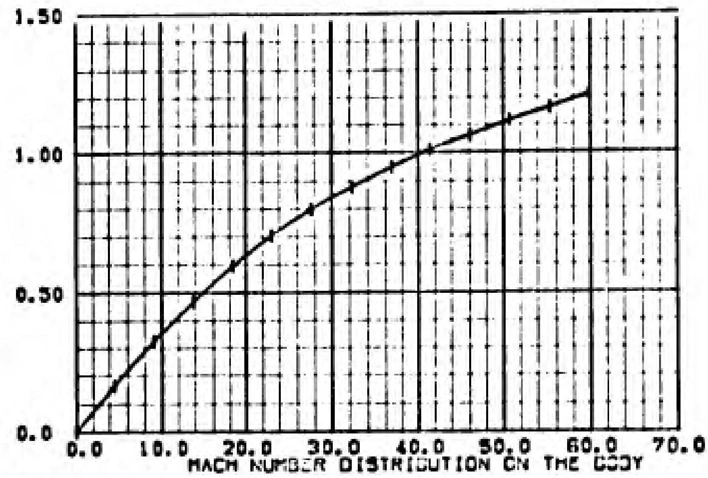
STANDOFF DISTANCE=0.4914
ABSCISSA OF STAGNATION POINT= -2.00000



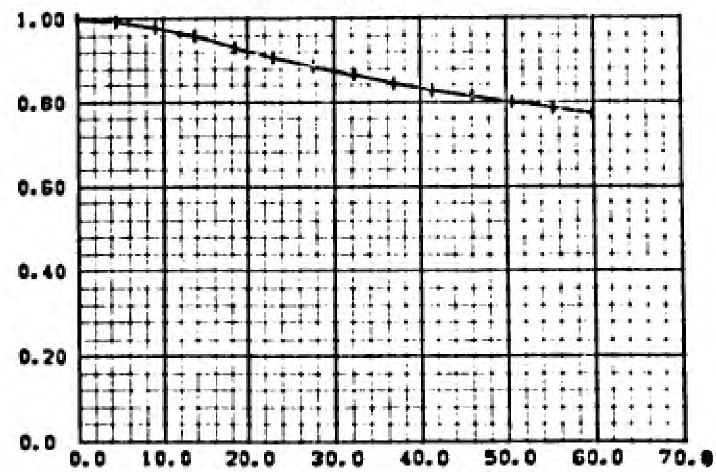
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

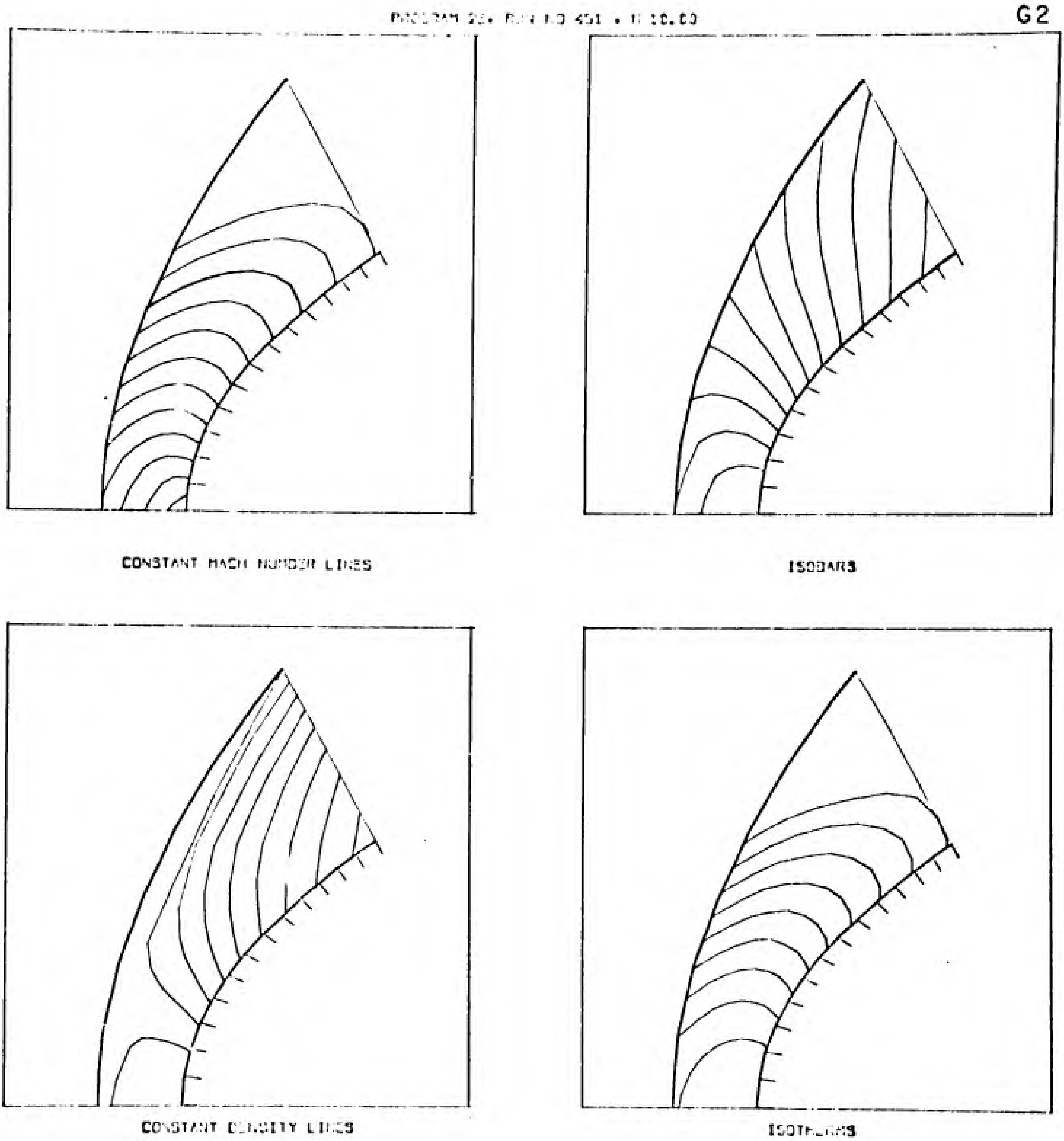


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

G2


CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

TWO DIMENSIONAL SYMMETRIC BLUNT BODY RUN NO 352

8 BY 13 MESH, 1400 STEPS TOLERANCE=0.000010

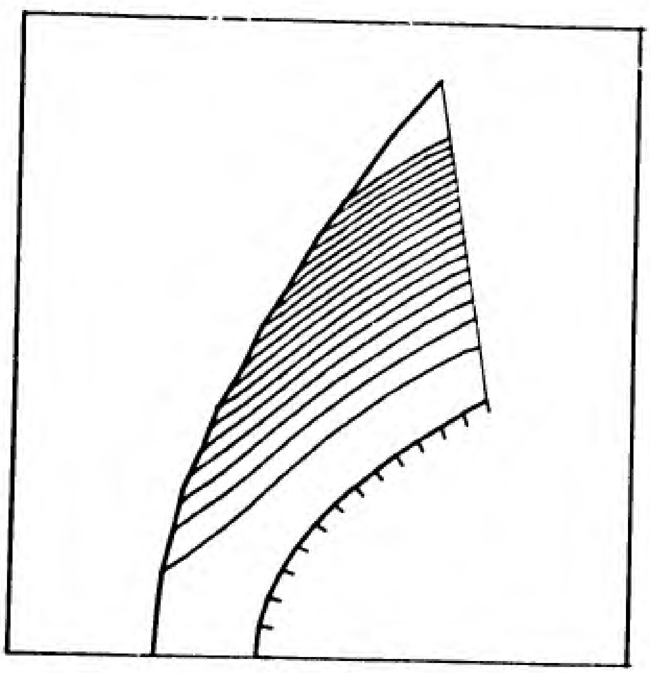
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.079
RELATIVE ERROR= 0.00052

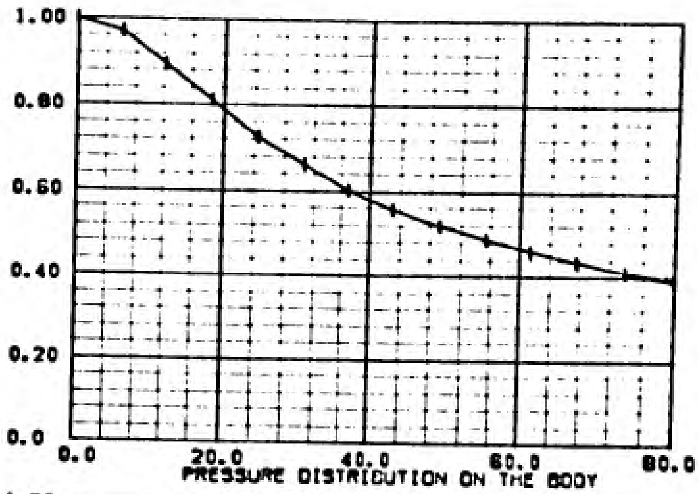
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.201
RELATIVE ERROR= 0.00015

CRITICAL PRESSURE RATIO=0.5218 (REL. ERROR= 0.0123)
CRITICAL DENSITY RATIO=0.6283 (REL. ERROR= 0.0089)
CRITICAL TEMPERAT.RATIO=0.8304 (REL. ERROR= 0.0035)

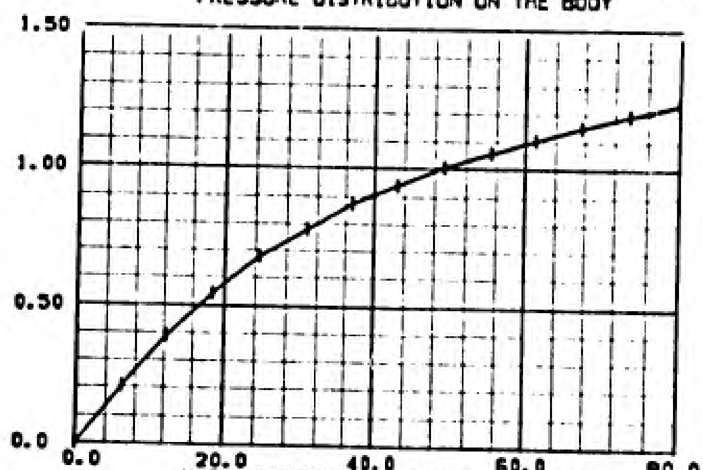
STANDOFF DISTANCE=0.7130
ABSCISSA OF STAGNATION POINT= -2.00000



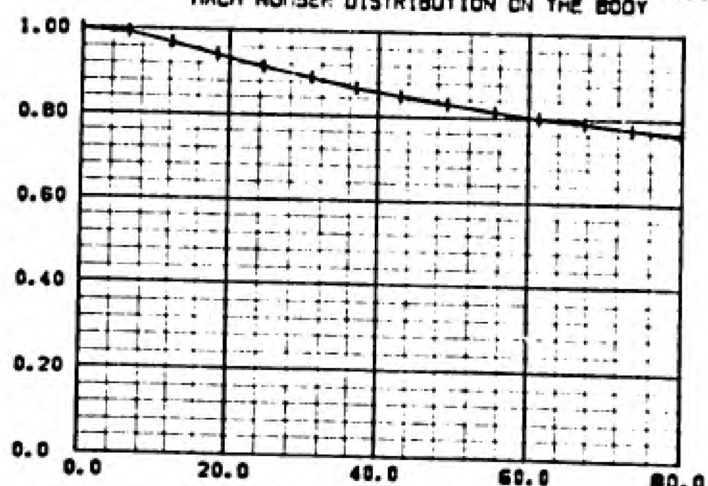
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



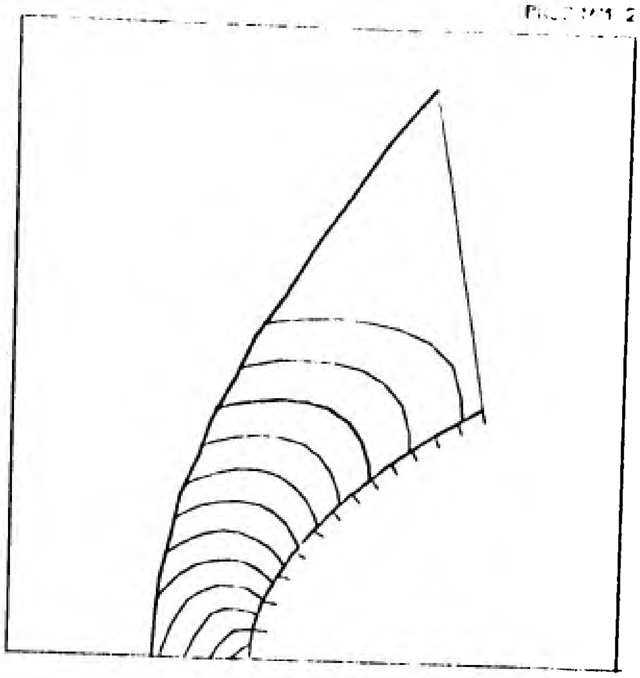
MACH NUMBER DISTRIBUTION ON THE BODY



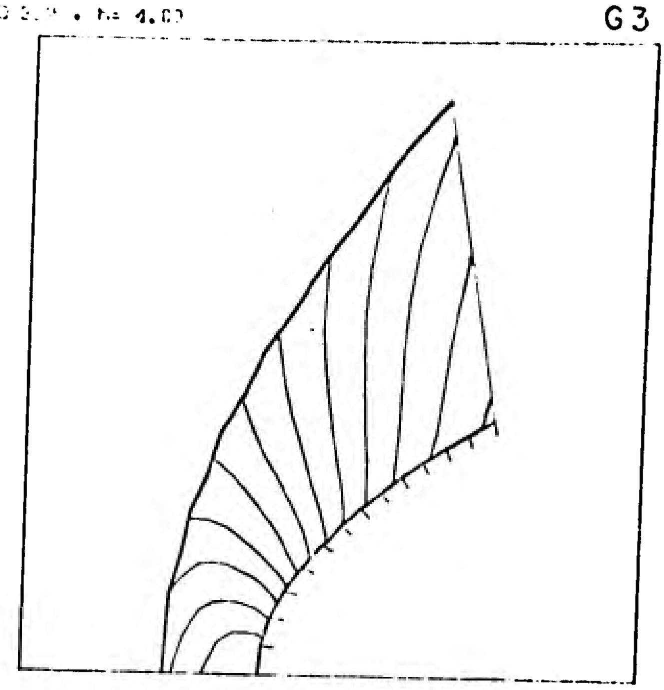
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 25, RUN NO 3.?, M= 4.00

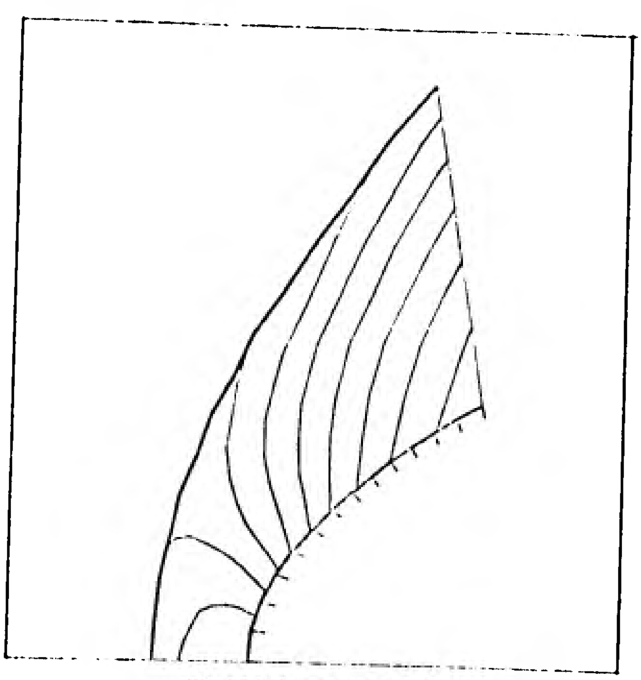
G3



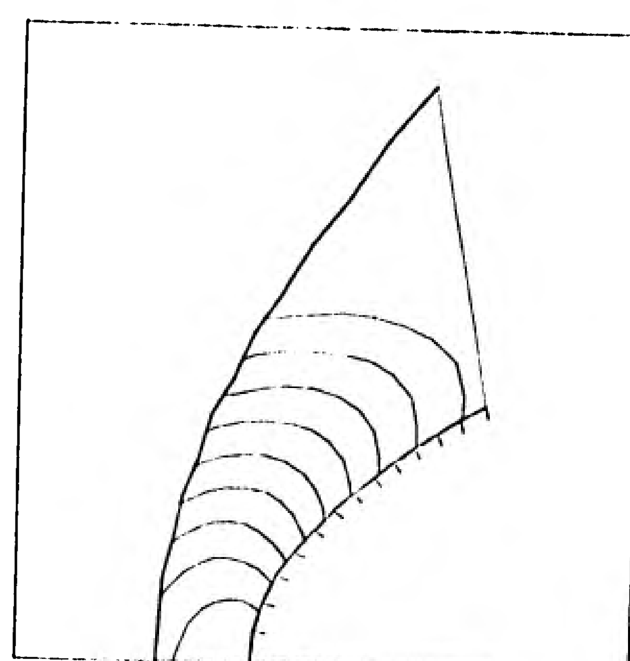
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

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AXISYMMETRIC CASES

AXISYMMETRIC BLUNT BODY RUN NO 120

10 BY 7 MESH, 600 STEPS TOLERANCE=0.000010

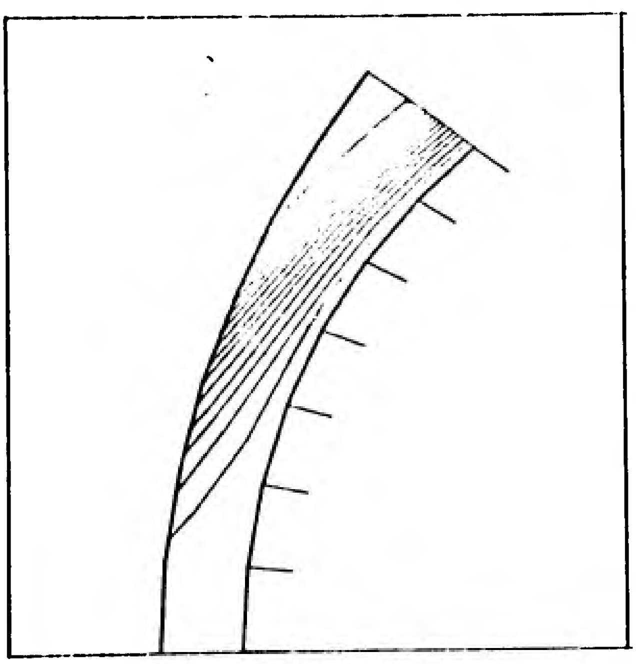
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.556
RELATIVE ERROR= 0.00014

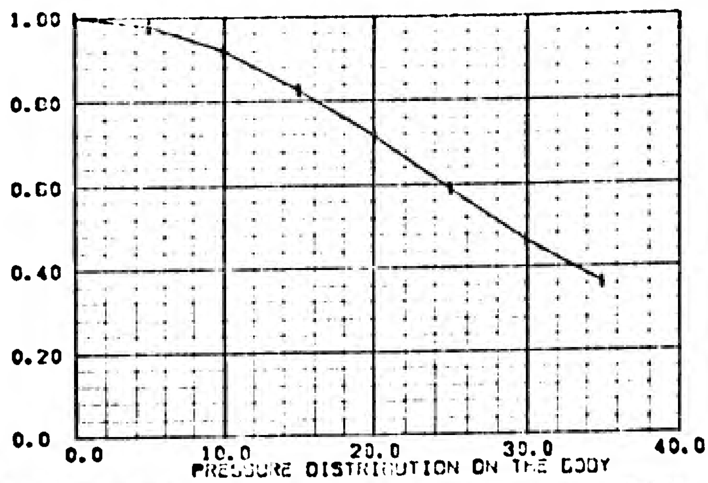
THEOR. STAGNATION TEMPERATURE= 01.000
COMP. STAGNATION TEMPERATURE= 01.003
RELATIVE ERROR= 0.00004

CRITICAL PRESSURE RATIO=0.5311 (REL. ERROR= 0.0054)
CRITICAL DENSITY RATIO=0.6305 (REL. ERROR= 0.0024)
CRITICAL TEMPERAT.RATIO=0.8358 (REL. ERROR= 0.0030)

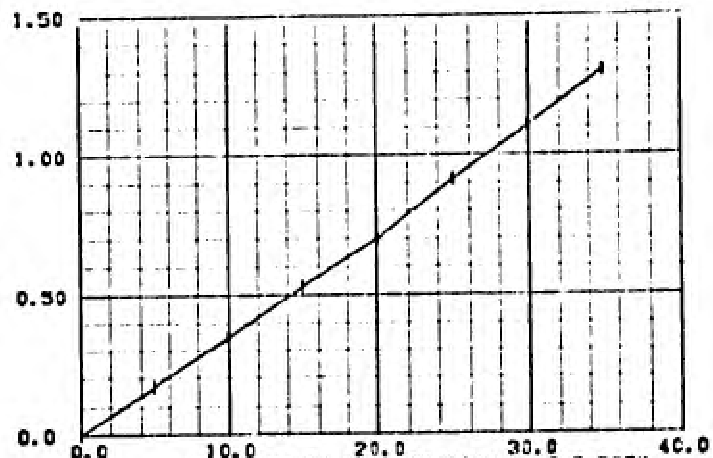
STANDOFF DISTANCE=0.1304
ABSCISSA OF STAGNATION POINT= -1.50000



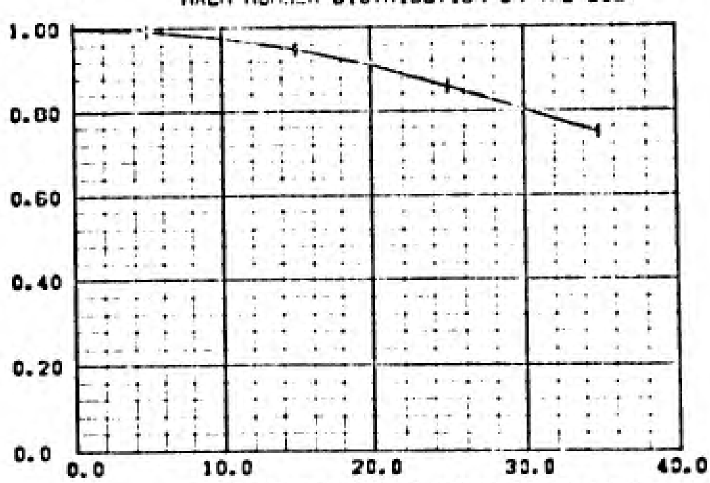
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

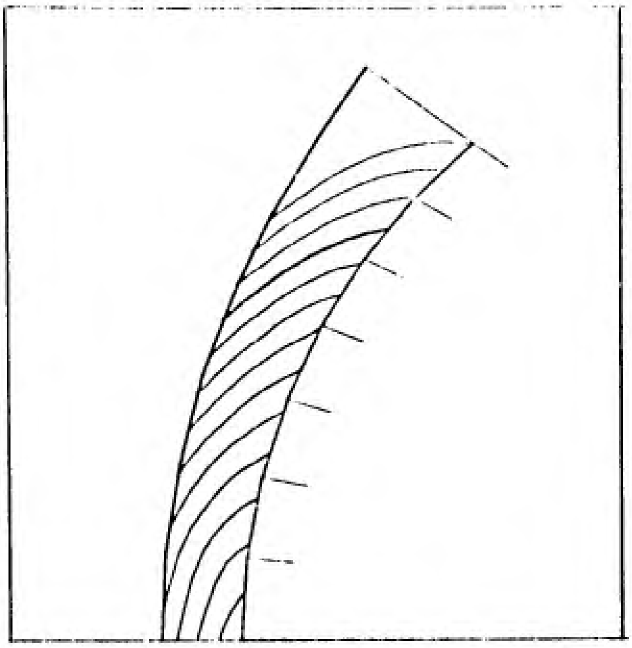


MACH NUMBER DISTRIBUTION ON THE BODY

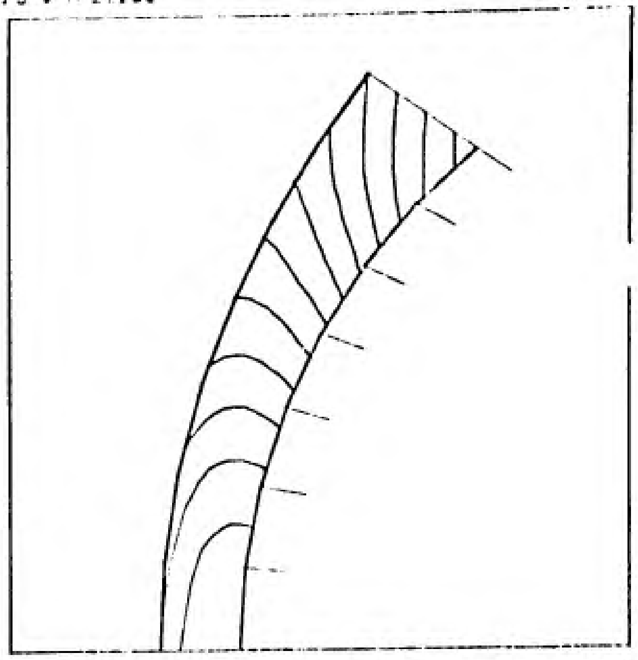


TEMPERATURE DISTRIBUTION ON THE BODY

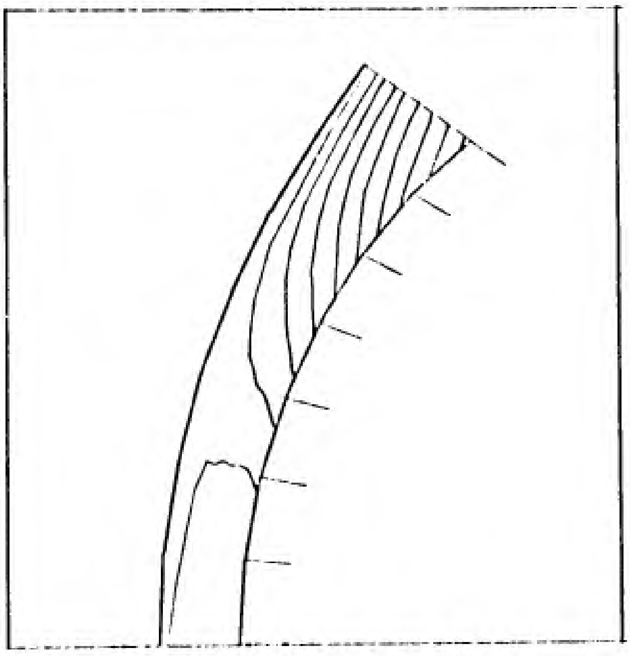
B I



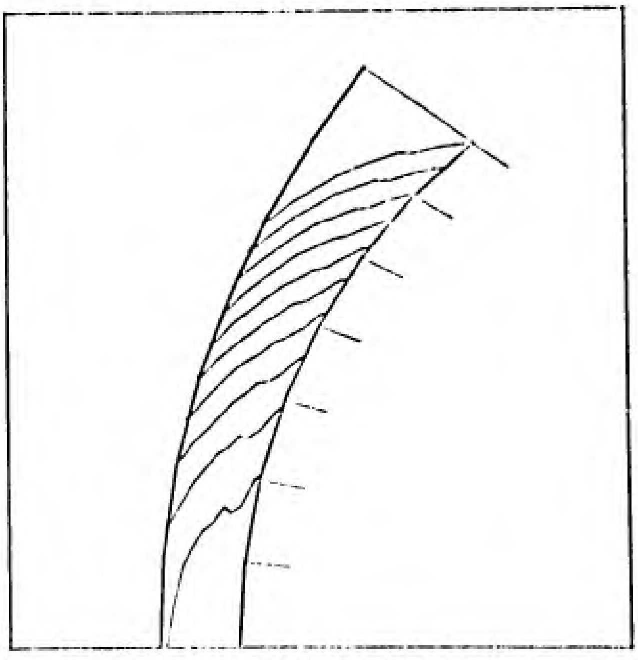
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 121

10 BY [illegible] MESH, 600 STEPS TOLERANCE=0.000010

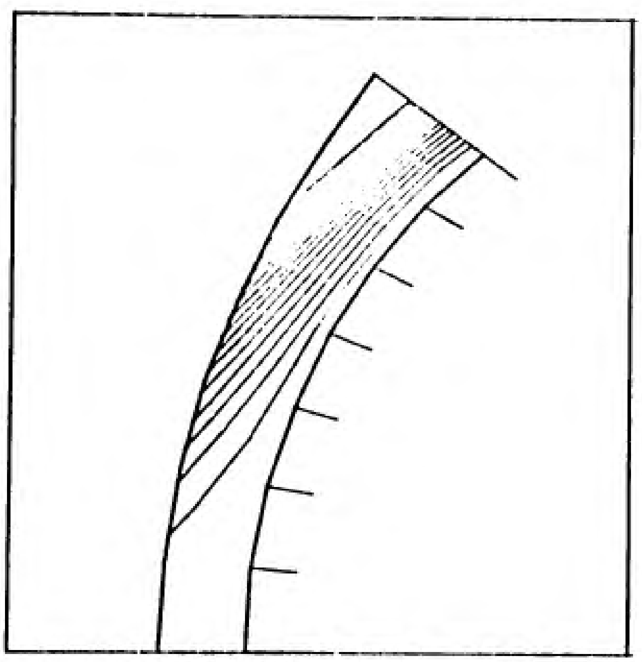
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.240
RELATIVE ERROR= 0.00010

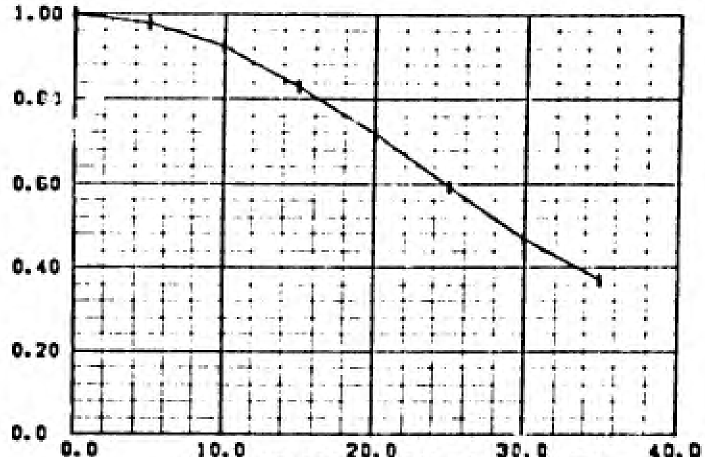
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.001
RELATIVE ERROR= 0.00005

CRITICAL PRESSURE RATIO=0.5305 (REL. ERROR= 0.0042)
CRITICAL DENSITY RATIO=0.6340 (REL. ERROR= 0.0016)
CRITICAL TEMPERAT.RATIO=0.8355 (REL. ERROR= 0.0026)

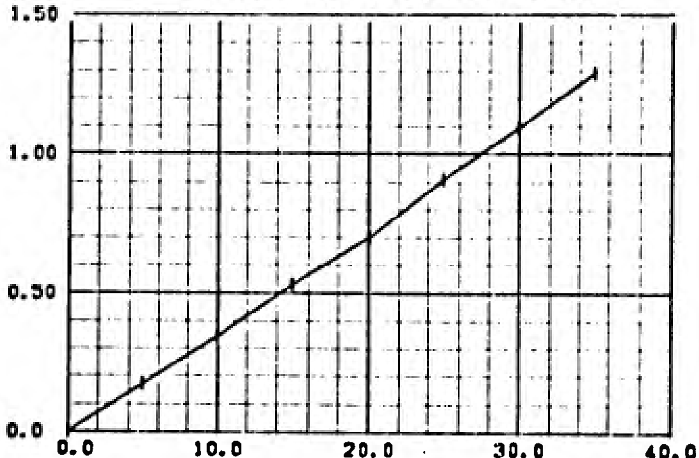
STANDOFF DISTANCE=0.1359
ABSCISSA OF STAGNATION POINT=-1.50000



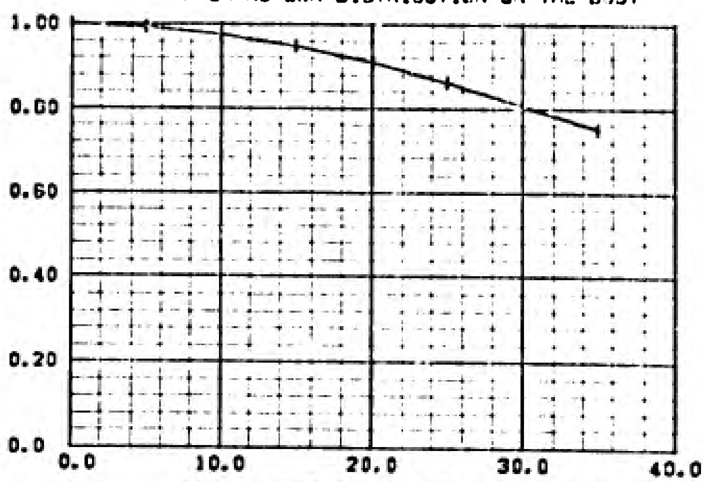
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

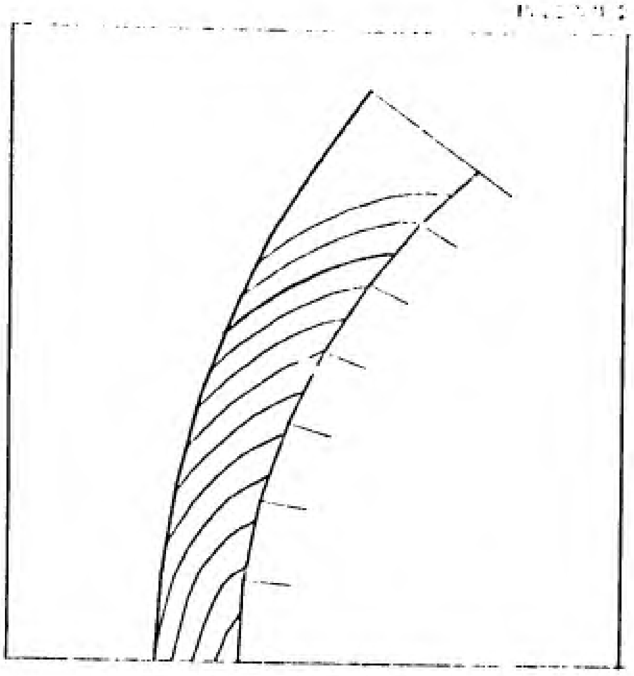


MACH NUMBER DISTRIBUTION ON THE BODY

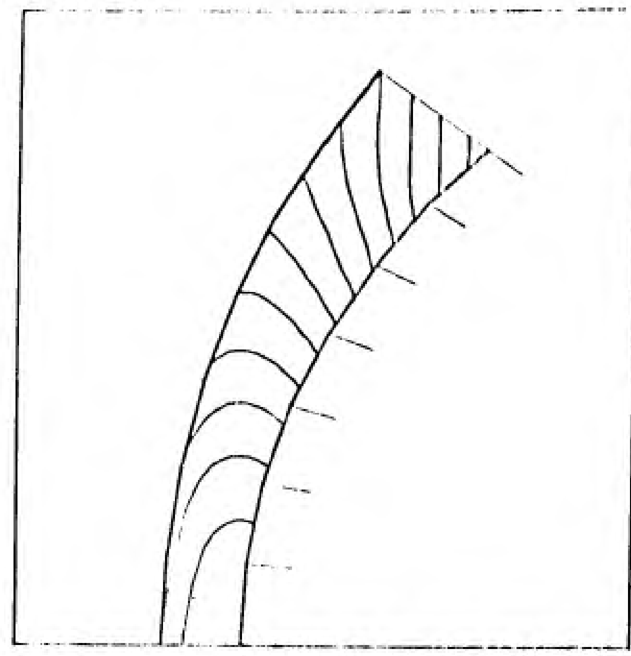


TEMPERATURE DISTRIBUTION ON THE BODY

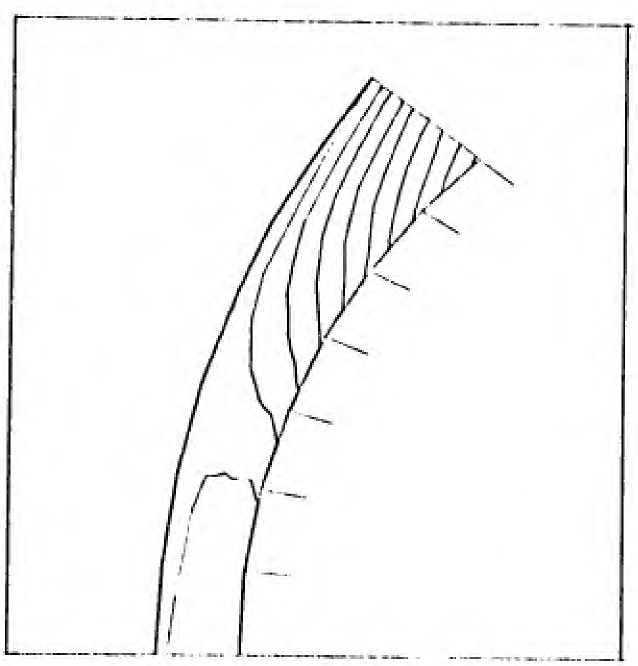
B2



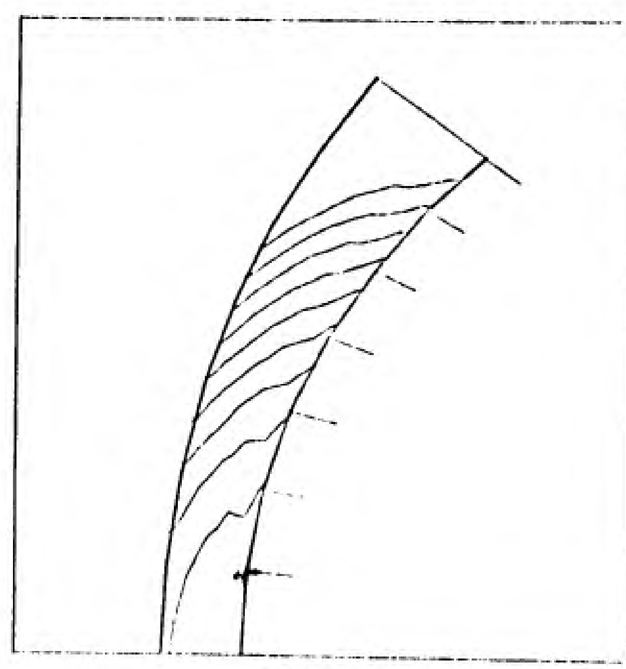
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 103

10 BY 13 MESH, 800 STEPS TOLERANCE=0.000010

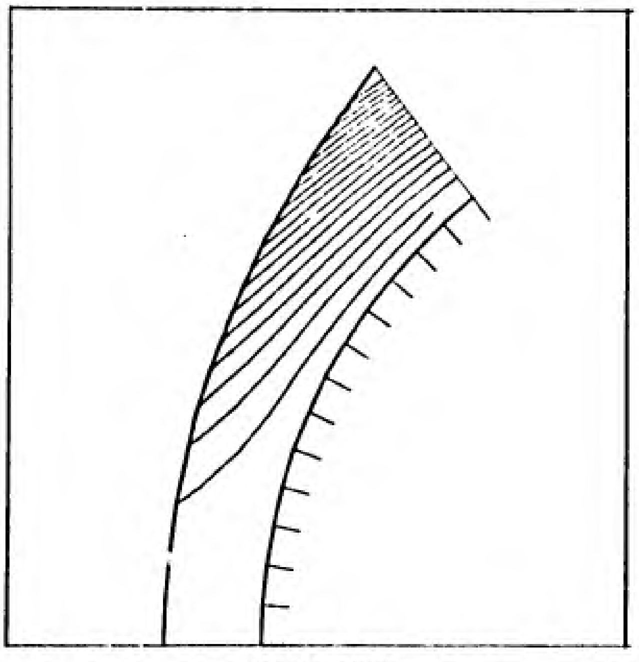
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.072
RELATIVE ERROR= 0.00019

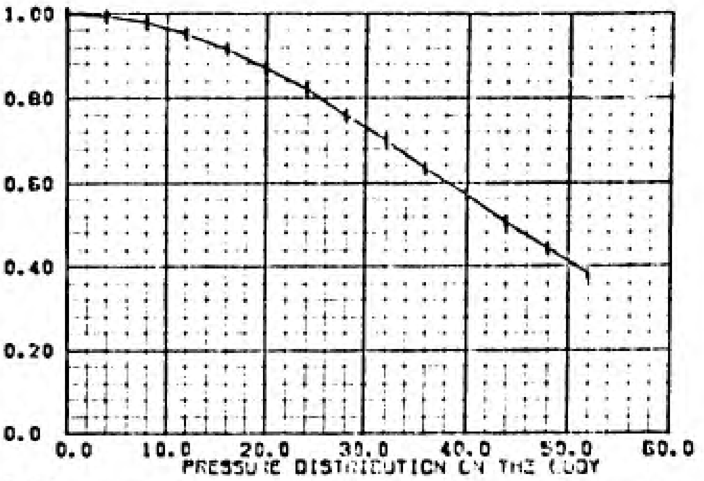
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00006

CRITICAL PRESSURE RATIO=0.5294 (REL. ERROR= 0.0021)
CRITICAL DENSITY RATIO=0.6347 (REL. ERROR= 0.0012)
CRITICAL TEMPERAT.RATIO=0.8341 (REL. ERROR= 0.0010)

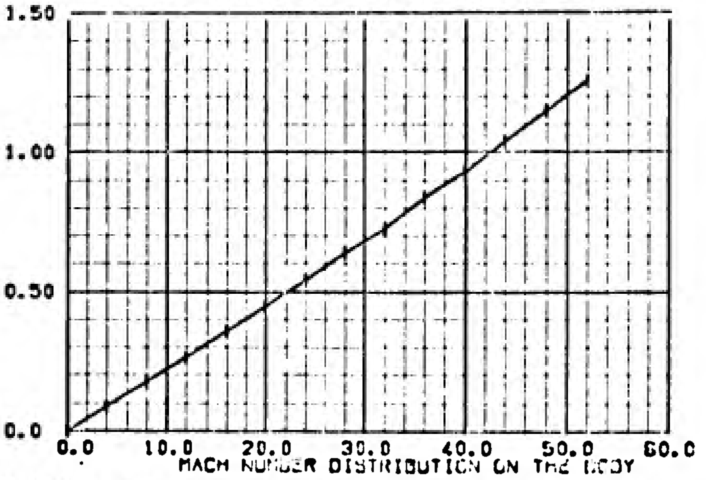
STANDOFF DISTANCE=0.1752
ABSCISSA OF STAGNATION POINT= 1.00000



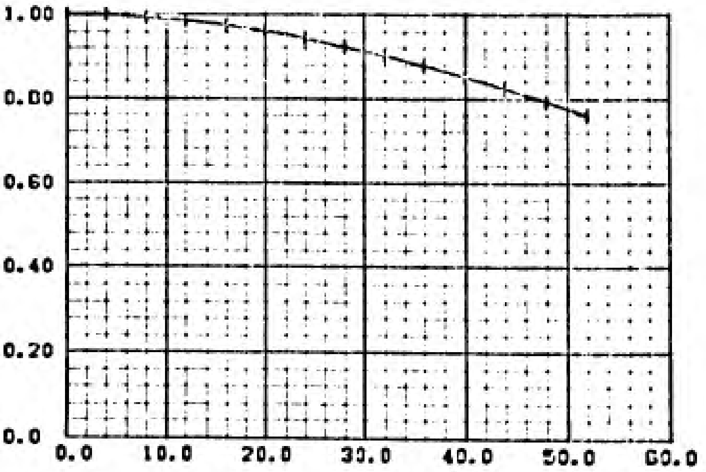
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

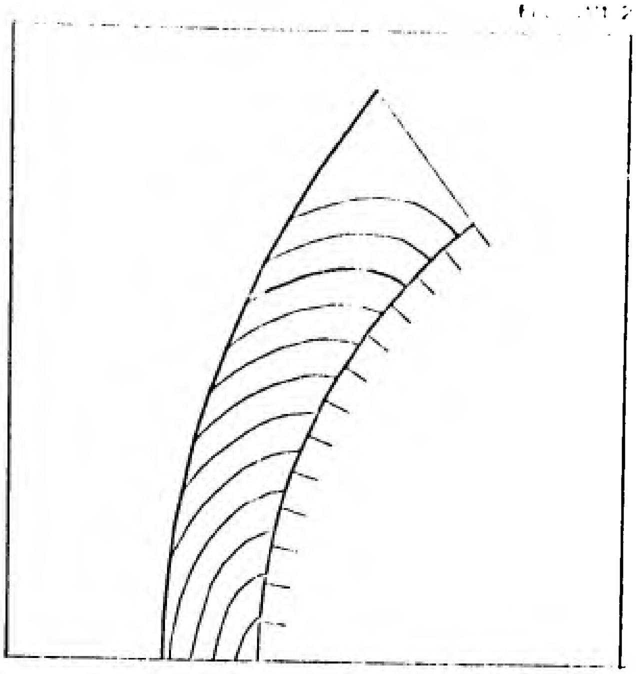


MACH NUMBER DISTRIBUTION ON THE BODY

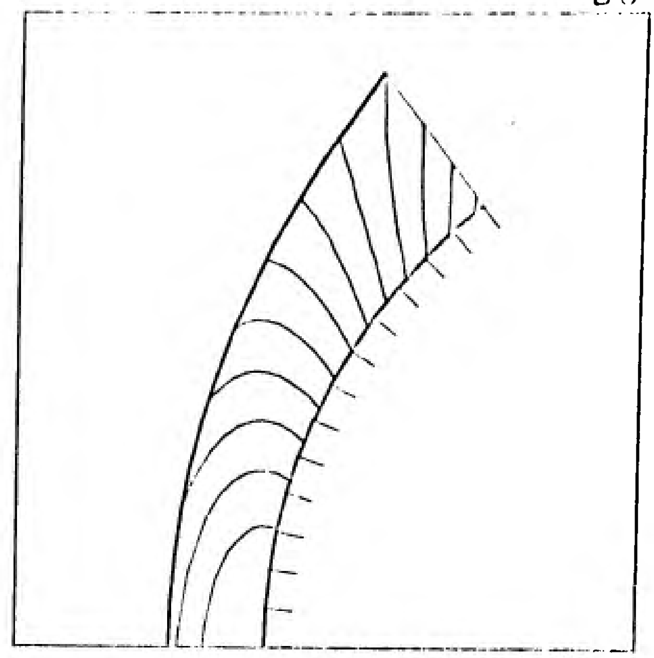


TEMPERATURE DISTRIBUTION ON THE BODY

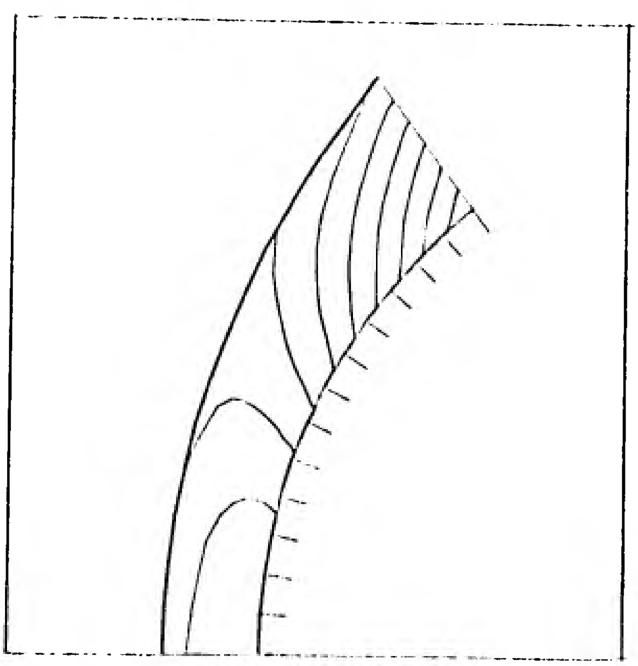
[illegible] M= 4.00 B 3



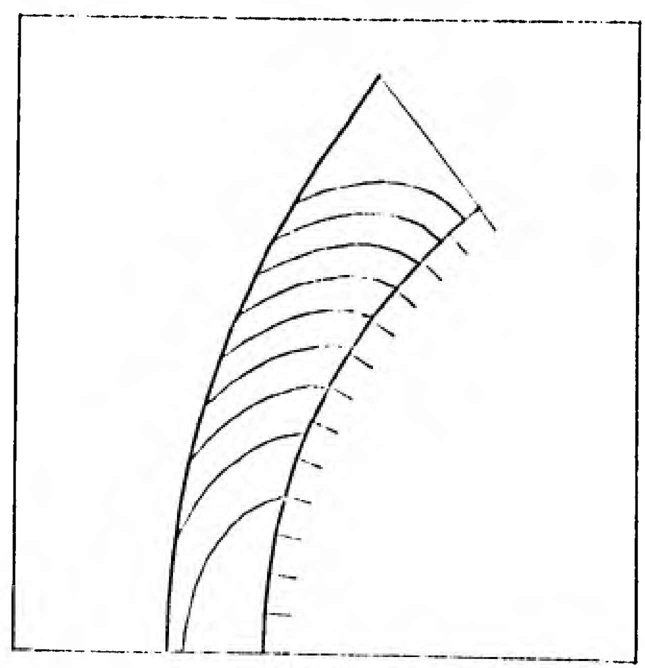
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY　　　　RUN NO 122

10 BY 8 MESH, 600 STEPS　　TOLERANCE=0.000010

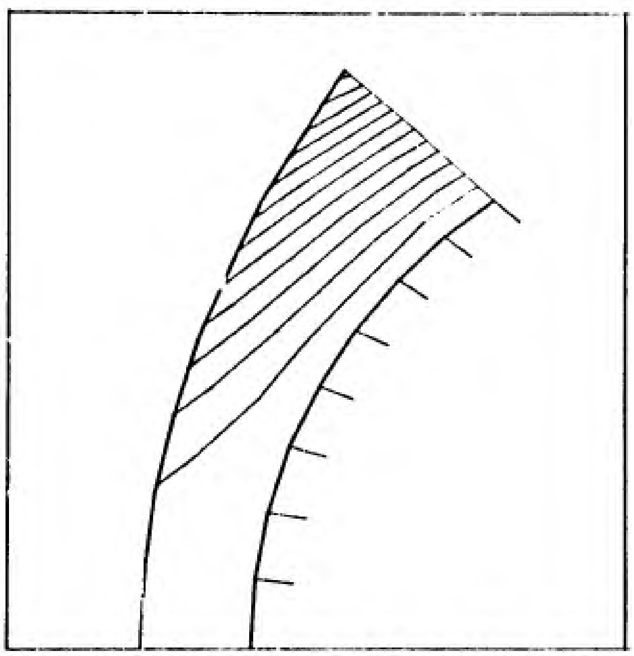
FREE STREAM MACH NUMBER= 3.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 12.061
COMP. STAGNATION PRESSURE= 12.062
RELATIVE ERROR= 0.00005

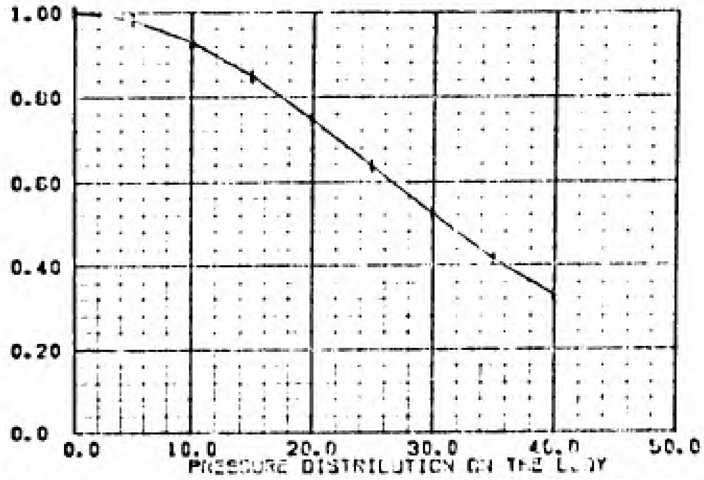
THEOR. STAGNATION TEMPERATURE= 2.800
COMP. STAGNATION TEMPERATURE= 2.800
RELATIVE ERROR= 0.00002

CRITICAL PRESSURE RATIO=0.5022 (REL. ERROR= 0.0075)
CRITICAL DENSITY RATIO=0.6371 (REL. ERROR= 0.0049)
CRITICAL TEMPERAT.RATIO=0.8354 (REL. ERROR= 0.0025)

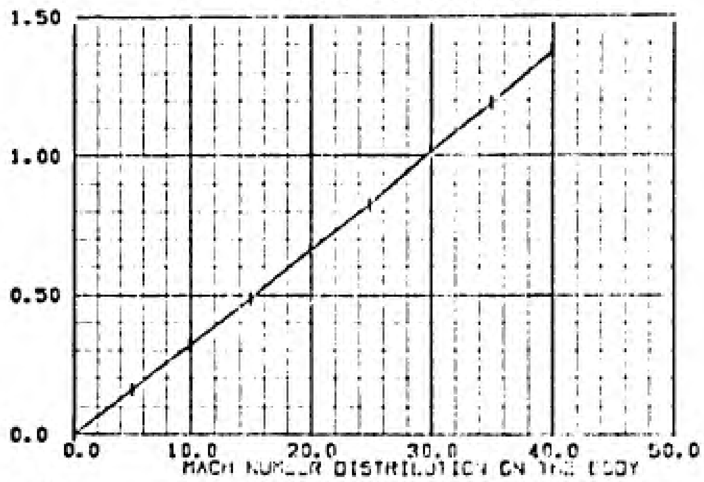
STANDOFF DISTANCE=0.2160
ABSCISSA OF STAGNATION POINT= -1.50000



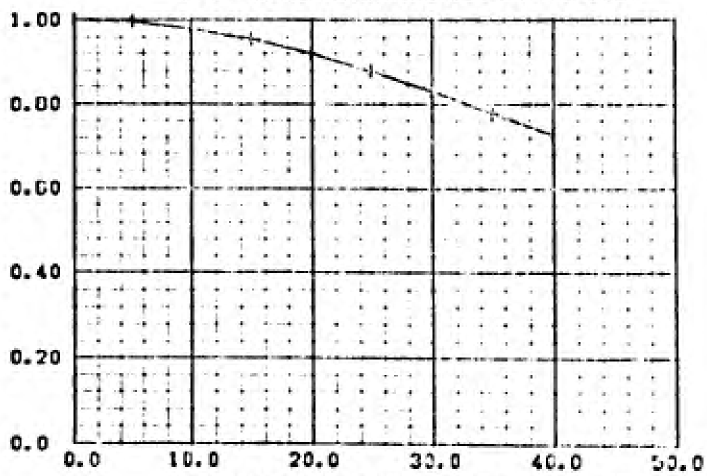
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

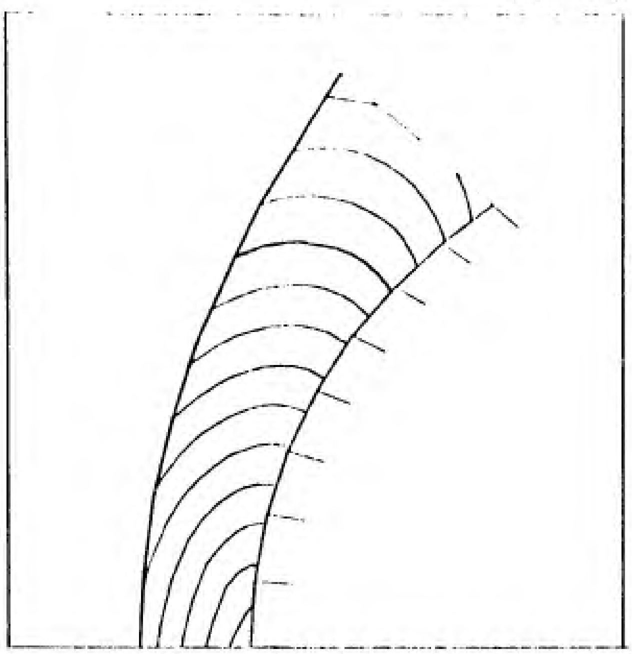


MACH NUMBER DISTRIBUTION ON THE BODY

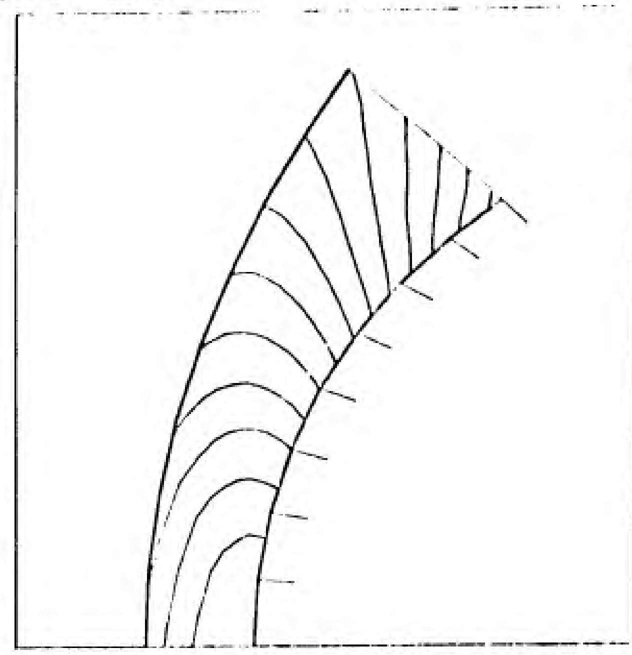


TEMPERATURE DISTRIBUTION ON THE BODY

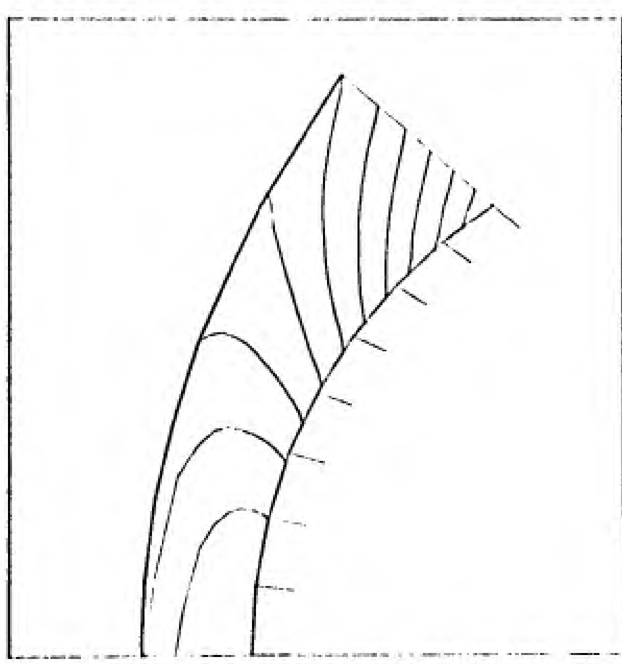
B4



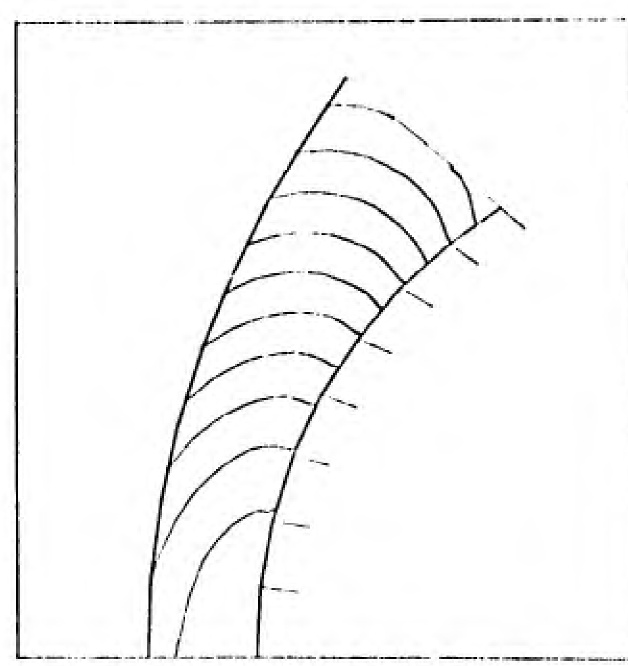
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY   RUN NO 223

10 BY 12 MESH, 600 STEPS   TOLERANCE=0.000010

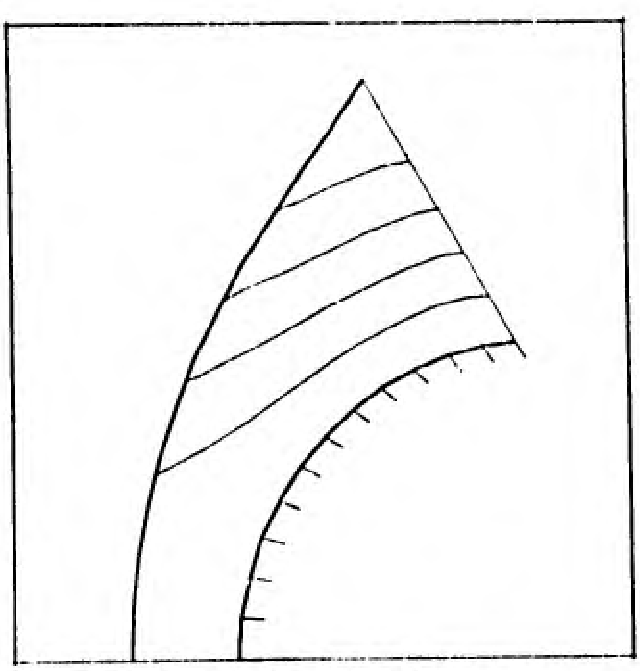
FREE STREAM MACH NUMBER= 2.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 5.640
COMP. STAGNATION PRESSURE= 5.640
RELATIVE ERROR= 0.00004

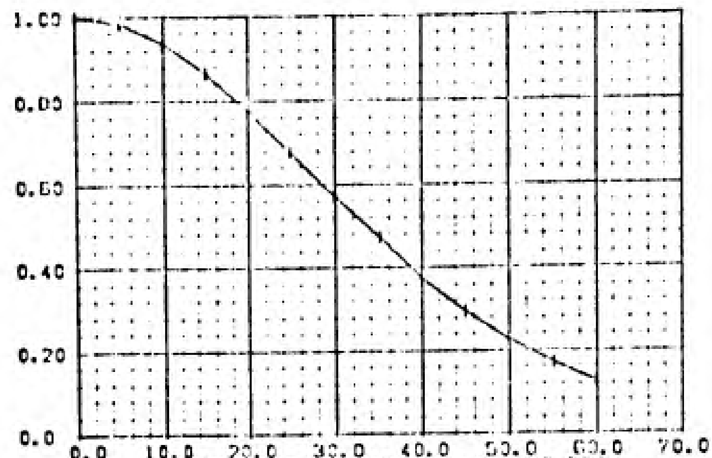
THEOR. STAGNATION TEMPERATURE= 1.000
COMP. STAGNATION TEMPERATURE= 1.000
RELATIVE ERROR= 0.00001

CRITICAL PRESSURE RATIO=0.5231 (REL. ERROR= 0.0015)
CRITICAL DENSITY RATIO=0.6341 (REL. ERROR= 0.0002)
CRITICAL TEMPERAT.RATIO=0.8344 (REL. ERROR= 0.0013)

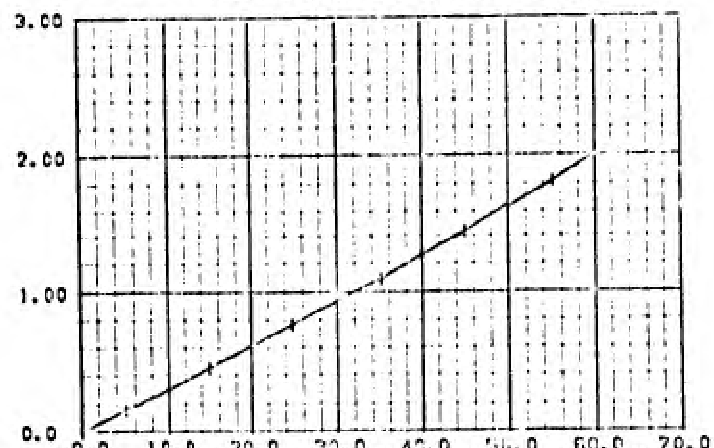
STANDOFF DISTANCE=0.3514
ABSCISSA OF STAGNATION POINT= 1.50000



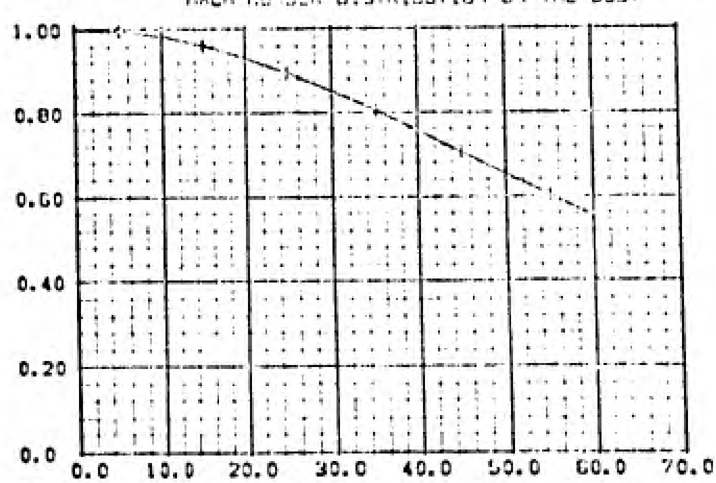
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

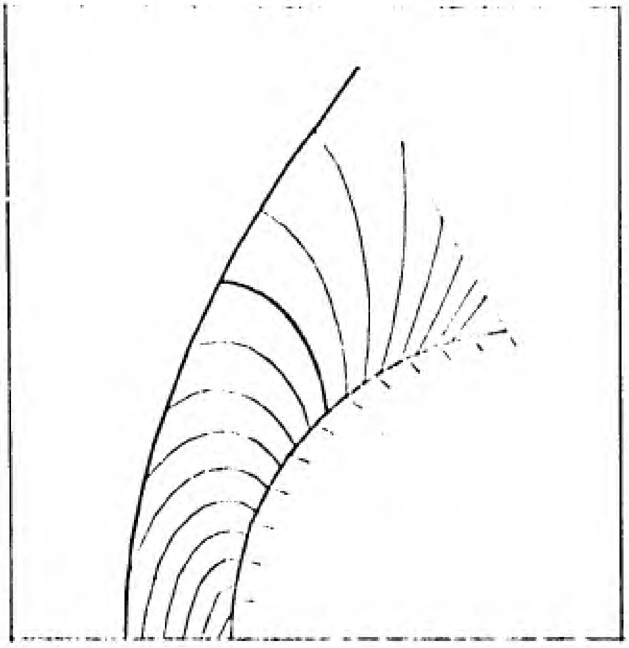


MACH NUMBER DISTRIBUTION ON THE BODY

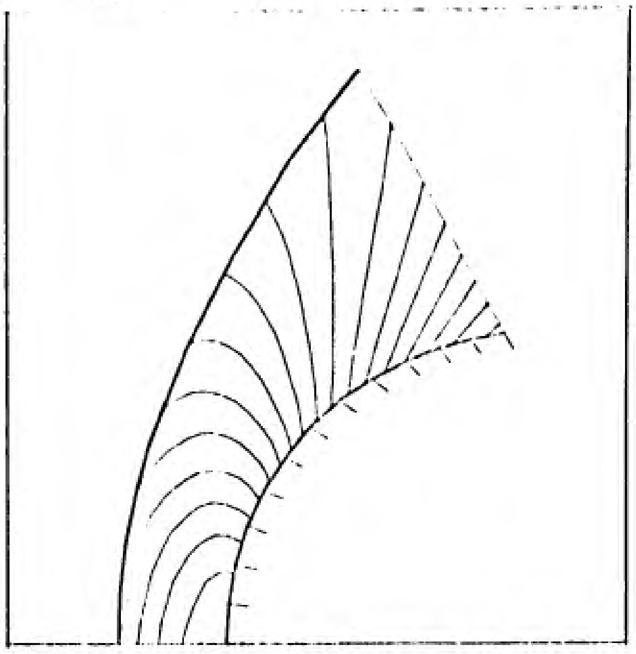


TEMPERATURE DISTRIBUTION ON THE BODY

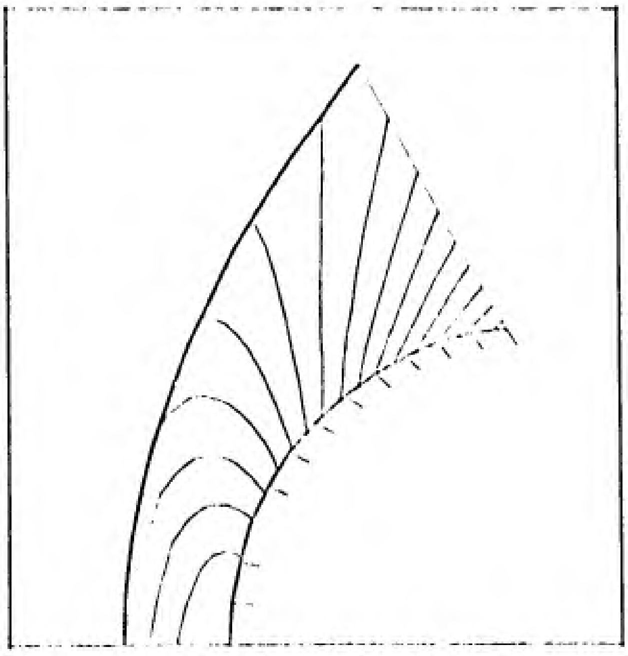
B5



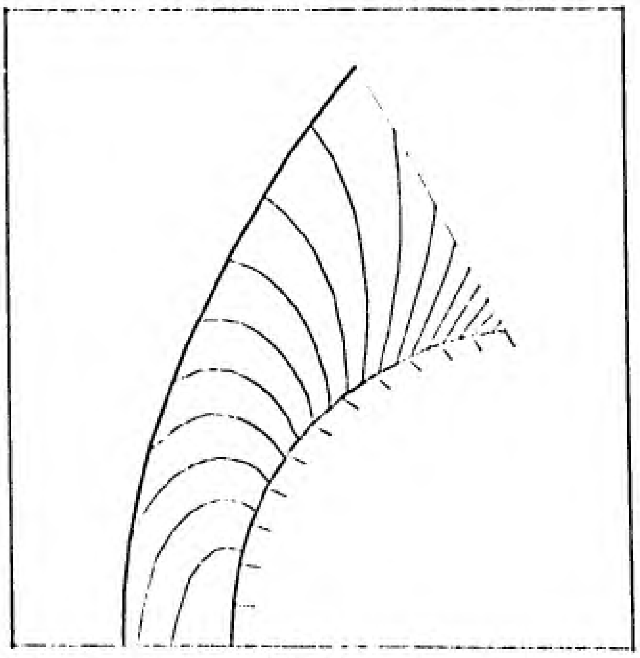
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 124

10 BY 15 MESH, 800 STEPS TOLERANCE=0.000010

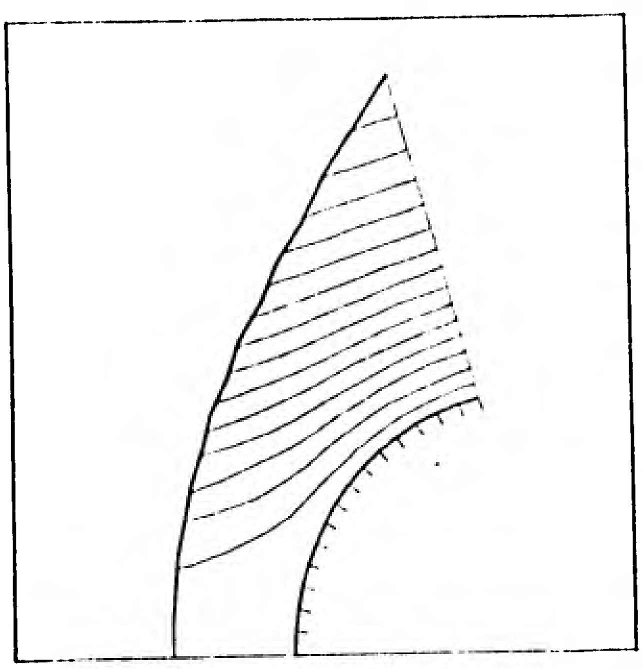
FREE STREAM MACH NUMBER= 1.70, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 4.224
COMP. STAGNATION PRESSURE= 4.226
RELATIVE ERROR= 0.00050

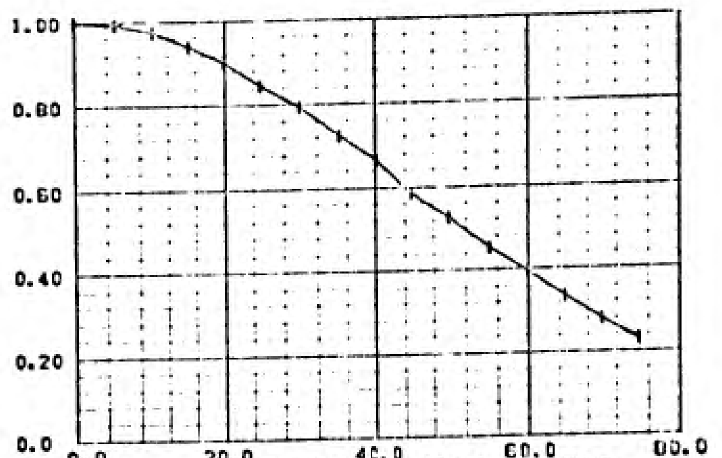
THEOR. STAGNATION TEMPERATURE= 1.578
COMP. STAGNATION TEMPERATURE= 1.578
RELATIVE ERROR= 0.00014

CRITICAL PRESSURE RATIO=0.5282 (REL. ERROR= 0.0002)
CRITICAL DENSITY RATIO=0.6323 (REL. ERROR= 0.0002)
CRITICAL TEMPERAT.RATIO=0.8333 (REL. ERROR= 0.0000)

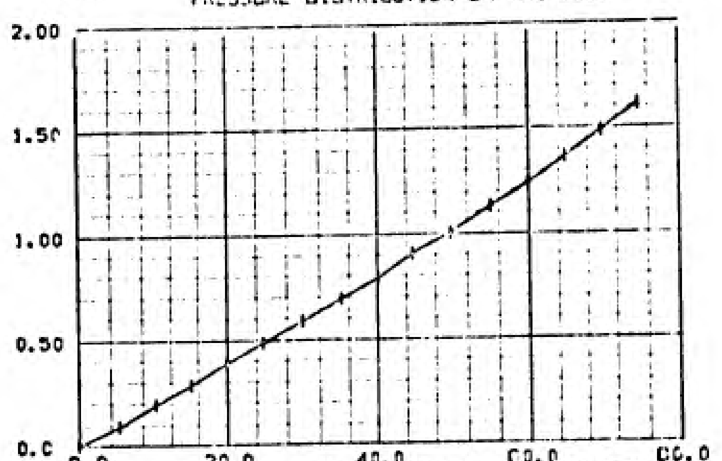
STANDOFF DISTANCE=0.4653
ABSCISSA OF STAGNATION POINT= -1.00000



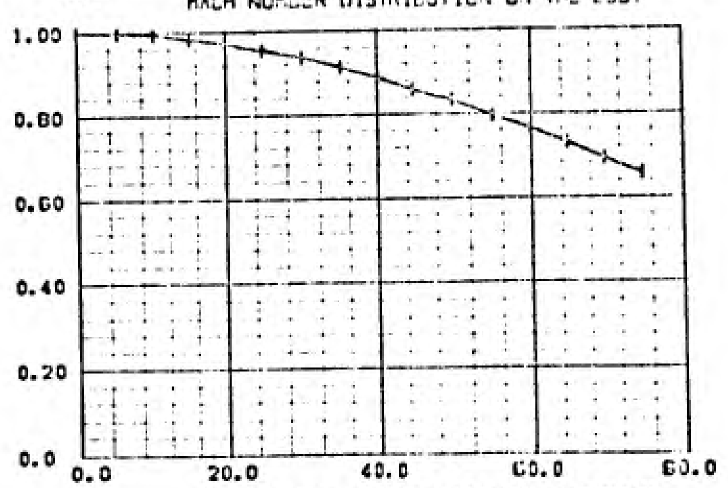
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



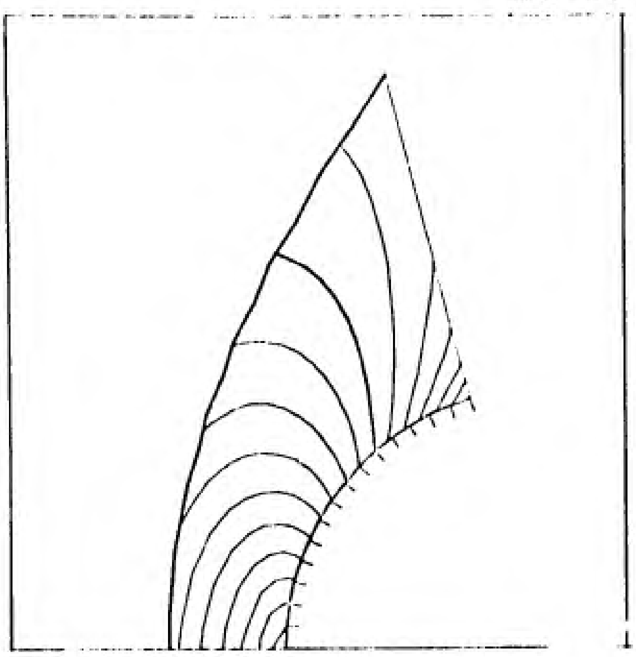
MACH NUMBER DISTRIBUTION ON THE BODY



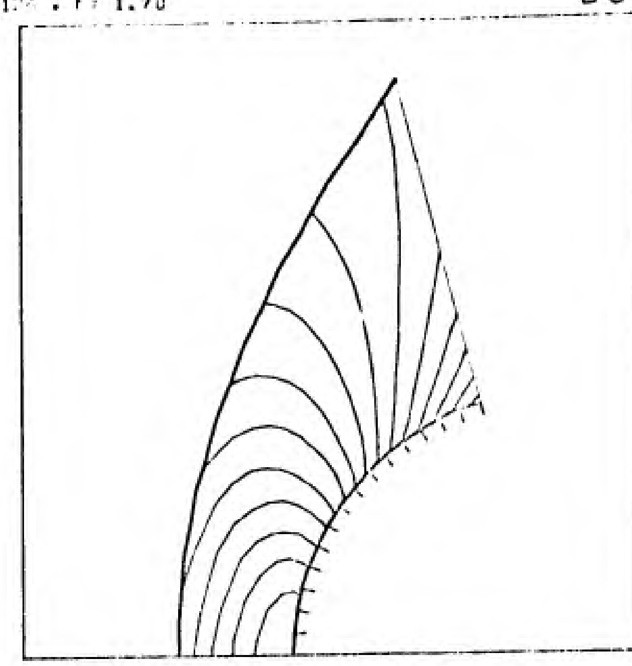
TEMPERATURE DISTRIBUTION ON THE BODY

B6

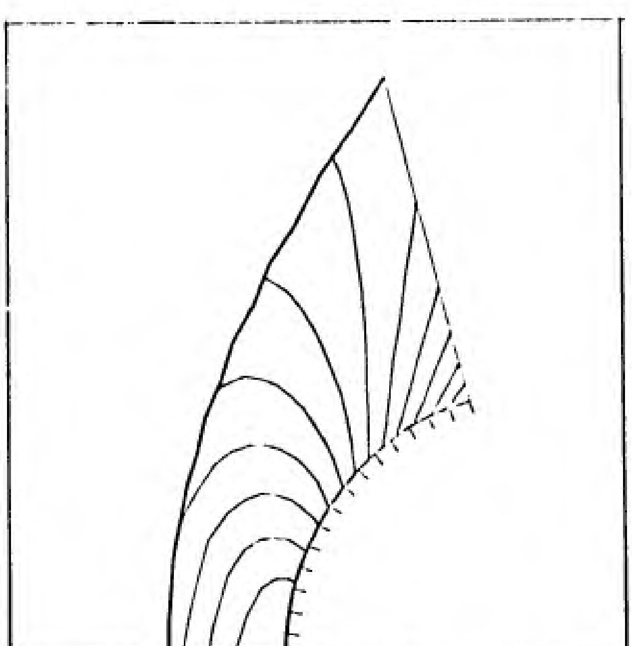
[illegible] 1.70



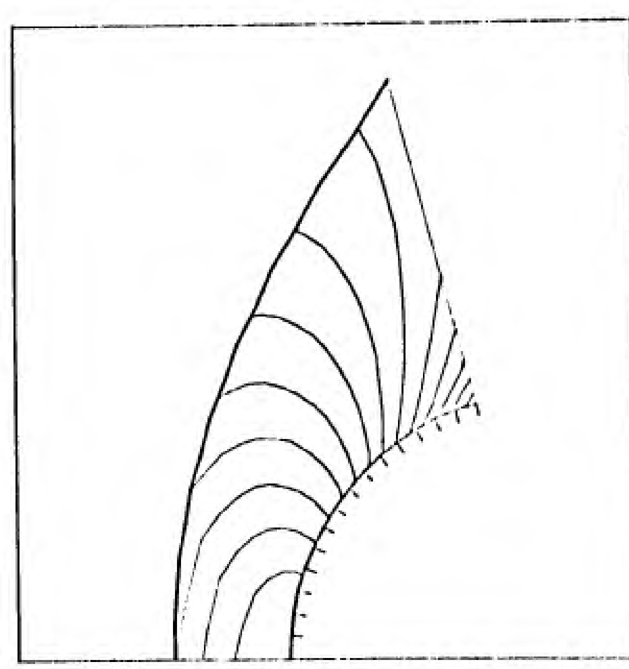
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 125

10 BY 16 MESH, 800 STEPS TOLERANCE=0.000010

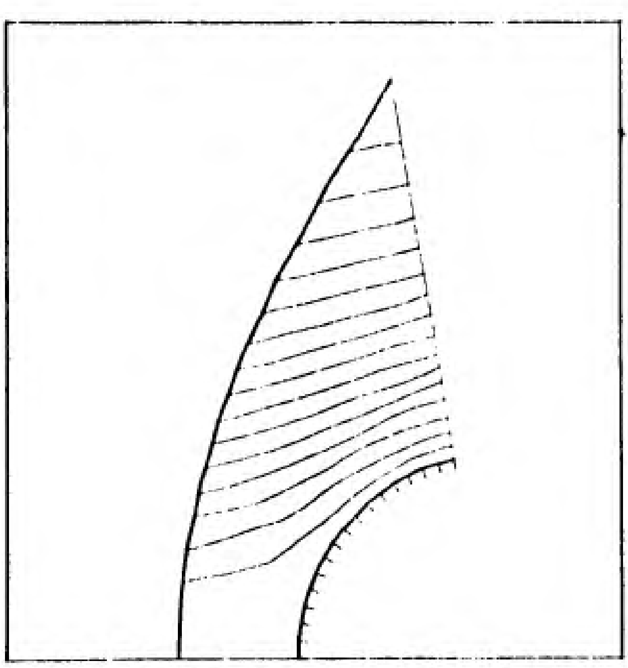
FREE STREAM MACH NUMBER= 1.50, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 3.413
COMP. STAGNATION PRESSURE= 3.414
RELATIVE ERROR= 0.00013

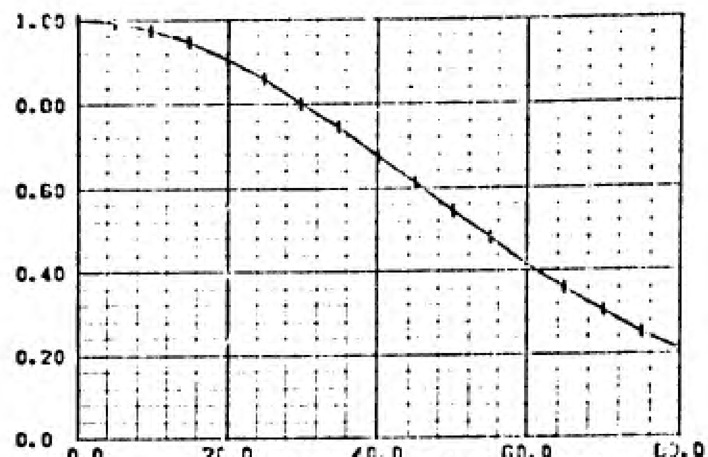
THEOR. STAGNATION TEMPERATURE= 1.450
COMP. STAGNATION TEMPERATURE= 1.450
RELATIVE ERROR= 0.00004

CRITICAL PRESSURE RATIO=0.5287 (REL. ERROR= 0.0008)
CRITICAL DENSITY RATIO=0.6342 (REL. ERROR= 0.0003)
CRITICAL TEMPERAT.RATIO=0.8337 (REL. ERROR= 0.0005)

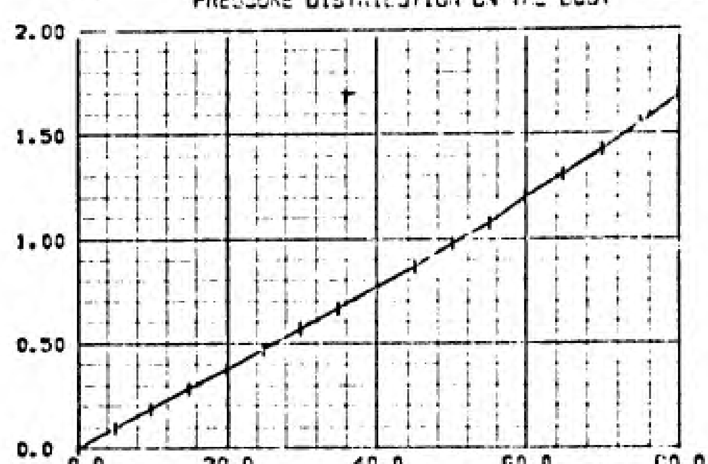
STANDOFF DISTANCE=0.6210
ABSCISSA OF STAGNATION POINT= -1.00000



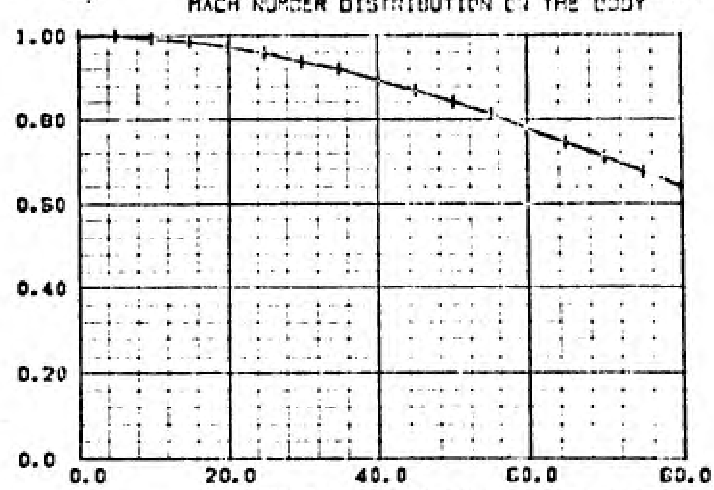
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

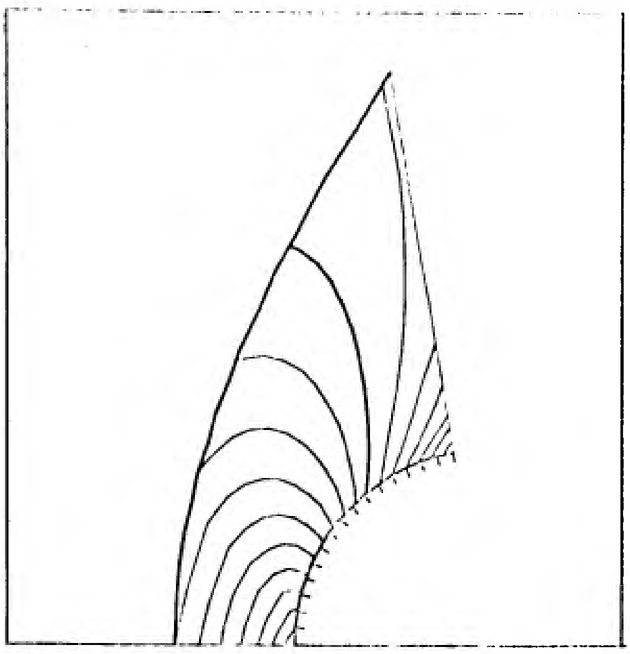


MACH NUMBER DISTRIBUTION ON THE BODY

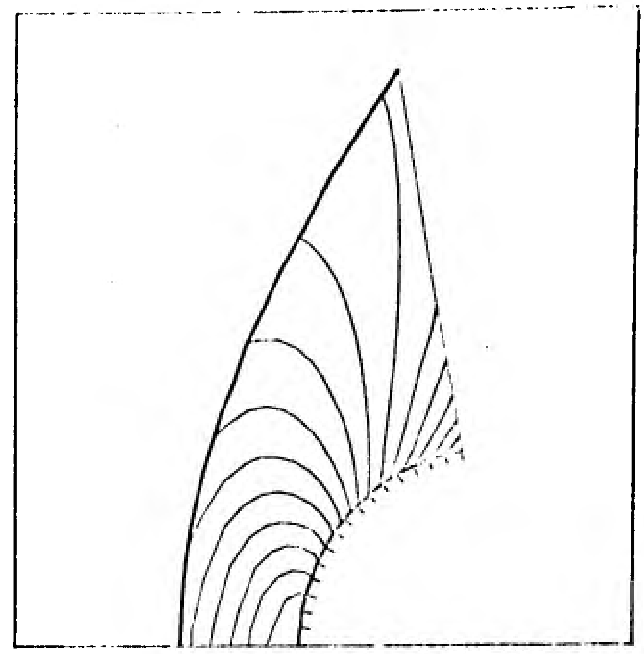


TEMPERATURE DISTRIBUTION ON THE BODY

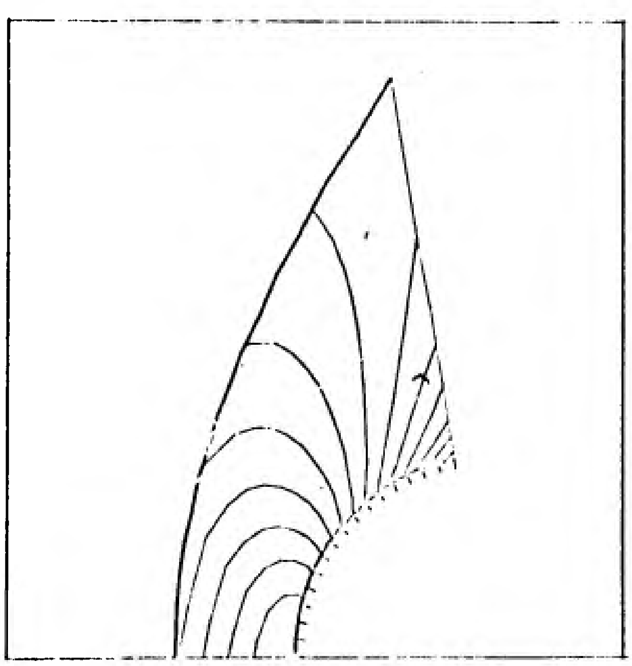
B7



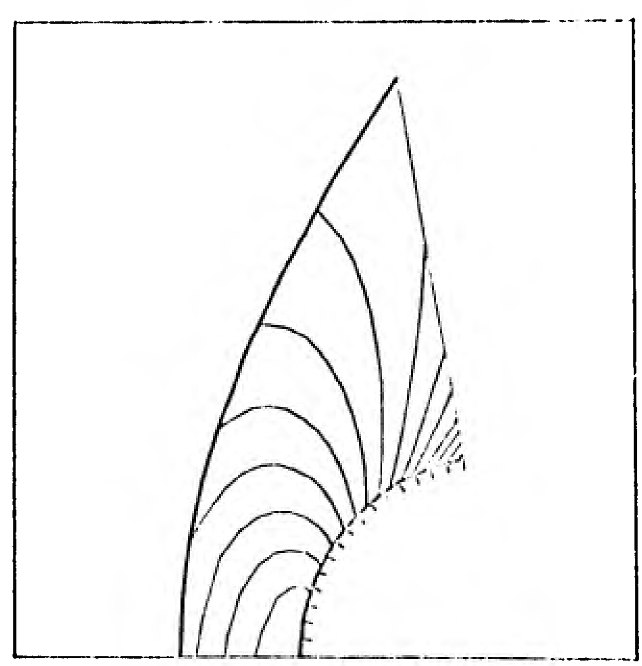
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 115

10 BY 15 MESH, 050 STEPS TOLERANCE=0.000010

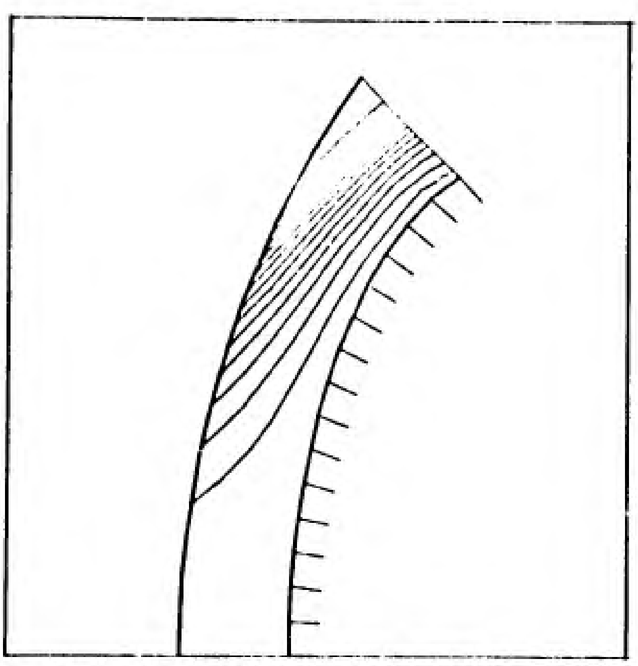
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.356
RELATIVE ERROR= 0.00025

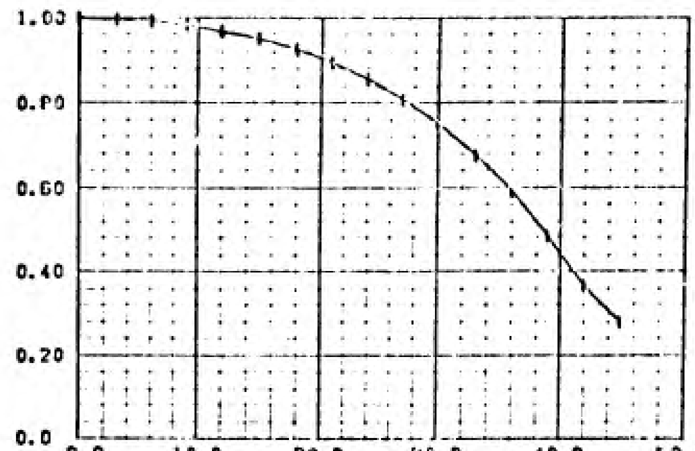
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.994
RELATIVE ERROR= 0.00007

CRITICAL PRESSURE RATIO=0.5346 (REL. ERROR= 0.0120)
CRITICAL DENSITY RATIO=0.6387 (REL. ERROR= 0.0075)
CRITICAL TEMPERAT. RATIO=0.8370 (REL. ERROR= 0.0044)

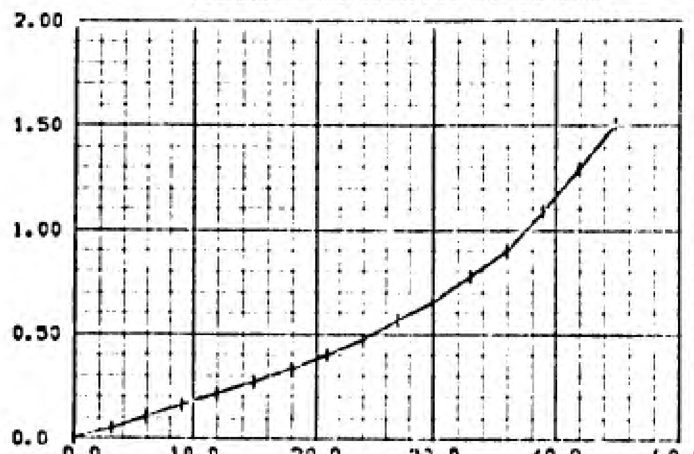
STANDOFF DISTANCE=0.2190
ABSCISSA OF STAGNATION POINT= -1.30000



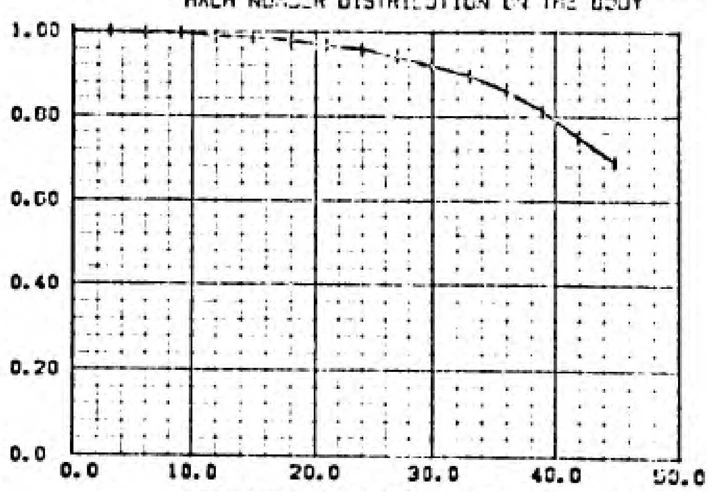
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

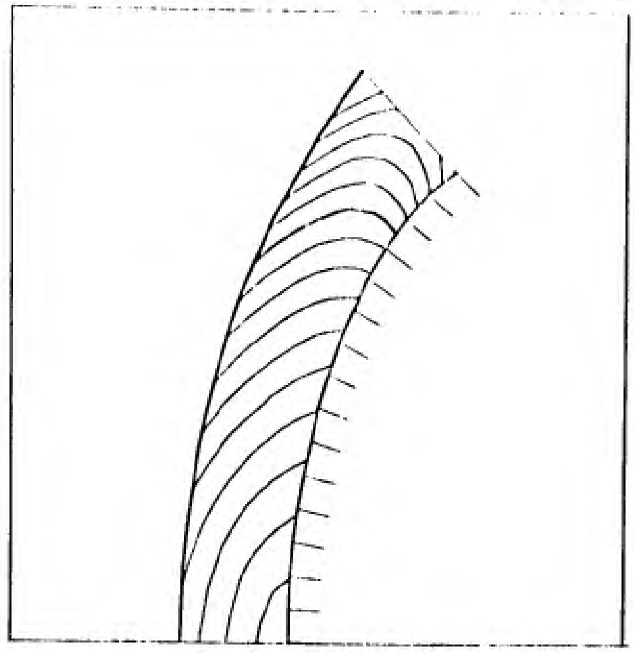


MACH NUMBER DISTRIBUTION ON THE BODY

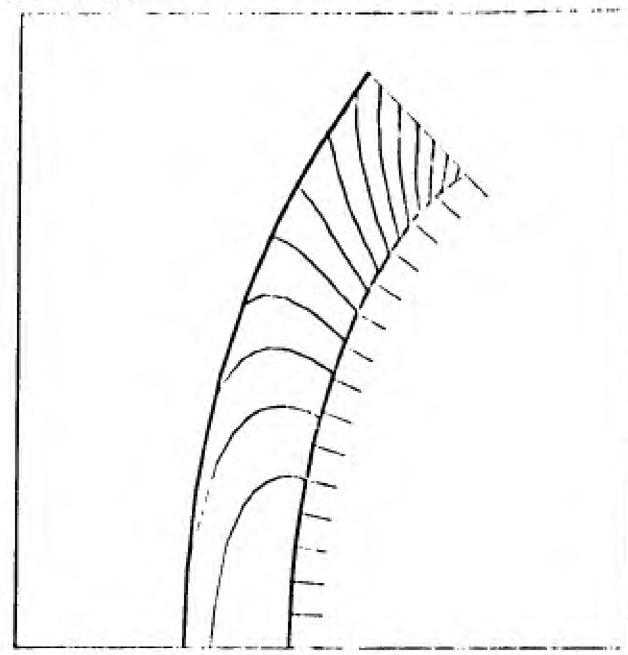


TEMPERATURE DISTRIBUTION ON THE BODY

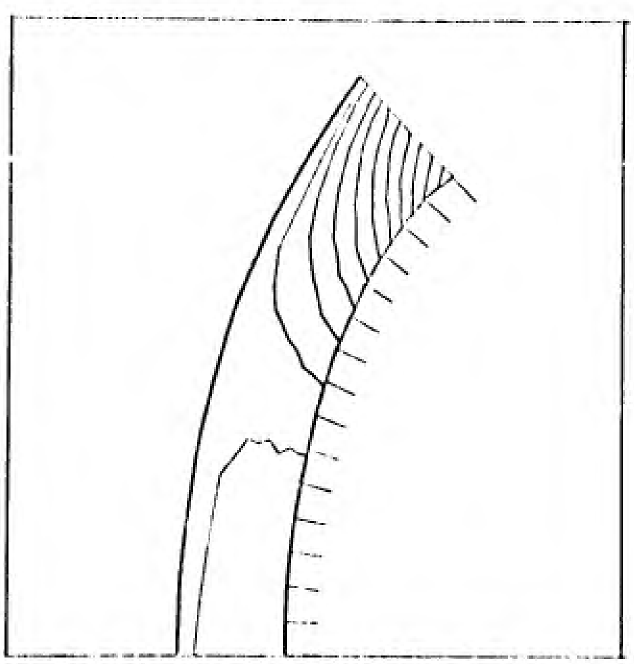
C2



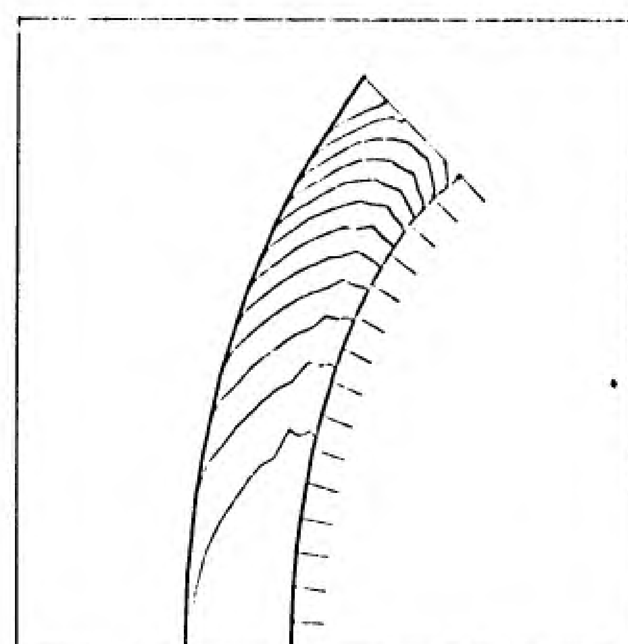
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 119

10 BY 16 MESH, 1000 STEPS TOLERANCE=0.000010

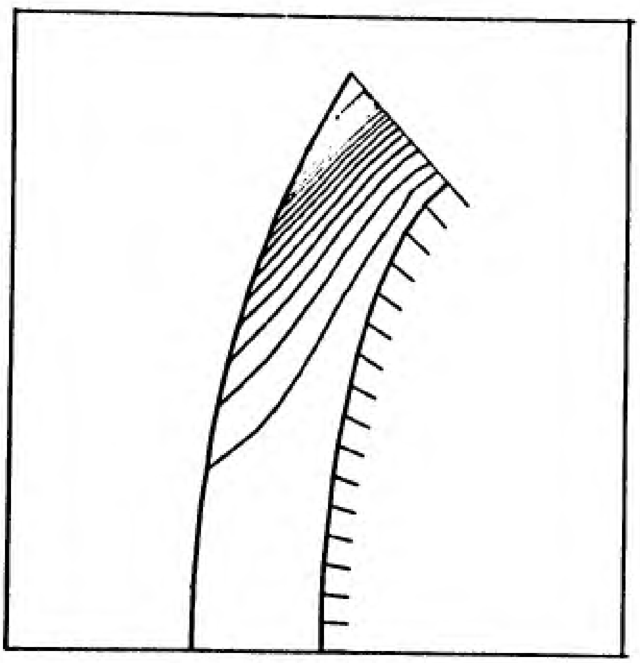
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.589
RELATIVE ERROR= 0.00020

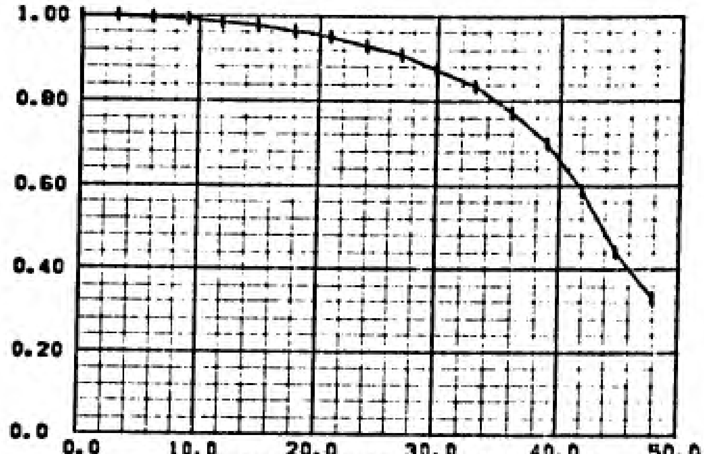
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 81.005
RELATIVE ERROR= 0.00006

CRITICAL PRESSURE RATIO=0.5414 (REL. ERROR= 0.0248)
CRITICAL DENSITY RATIO=0.6440 (REL. ERROR= 0.0159)
CRITICAL TEMPERAT.RATIO=0.8406 (REL. ERROR= 0.0090)

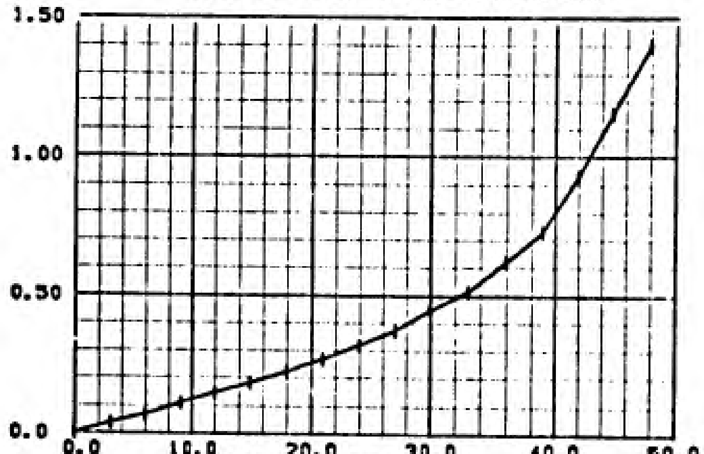
STANDOFF DISTANCE=0.2754
ABSCISSA OF STAGNATION POINT= -1.13333



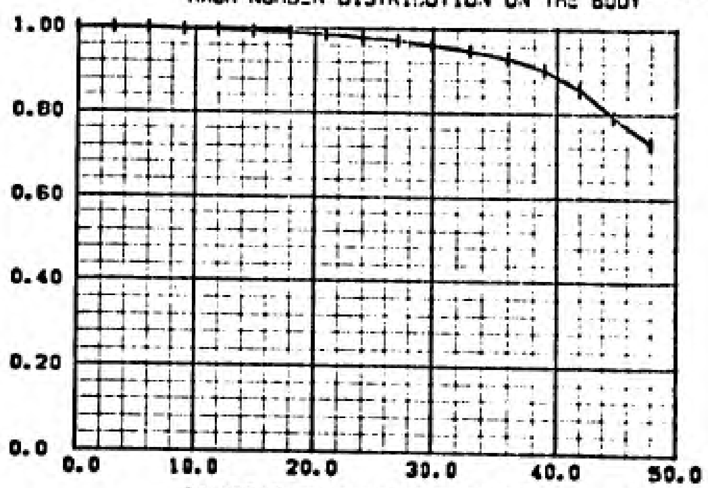
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



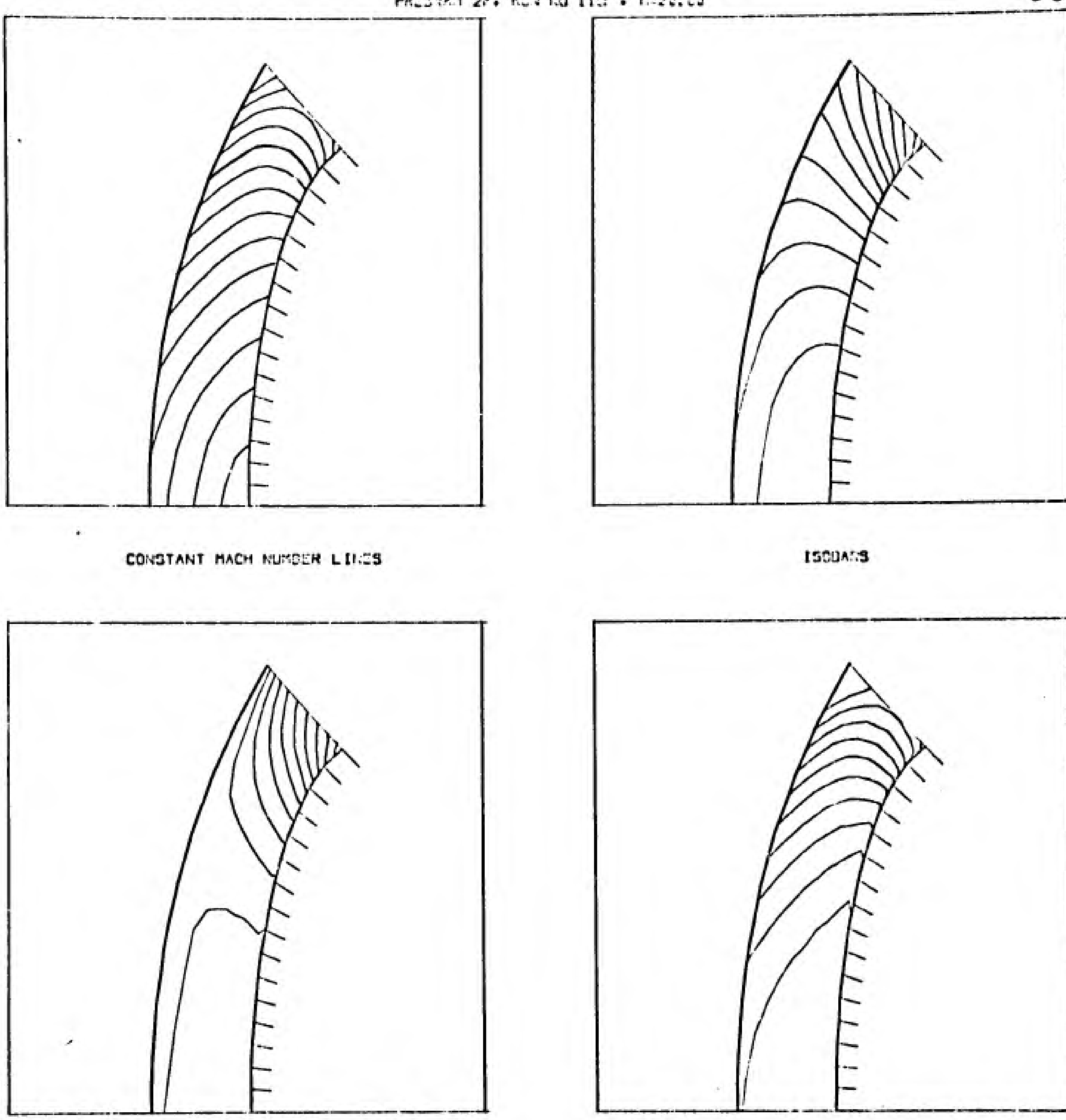
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 27, RUN NO 110 • M=20.00

C 3



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 116

10 BY 17 MESH, 1000 STEPS TOLERANCE=0.000010

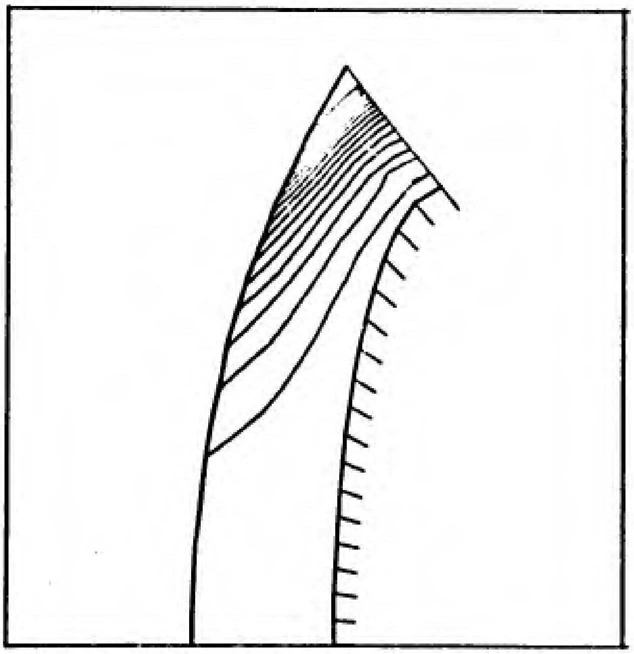
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.450
RELATIVE ERROR= 0.00007

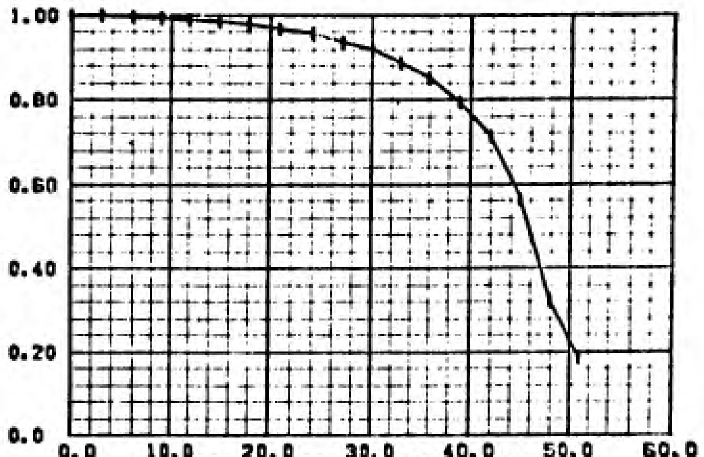
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.998
RELATIVE ERROR= 0.00002

CRITICAL PRESSURE RATIO=0.5437 (REL. ERROR= 0.0291)
CRITICAL DENSITY RATIO=0.6459 (REL. ERROR= 0.0160)
CRITICAL TEMPERAT.RATIO=0.8418 (REL. ERROR= 0.0101)

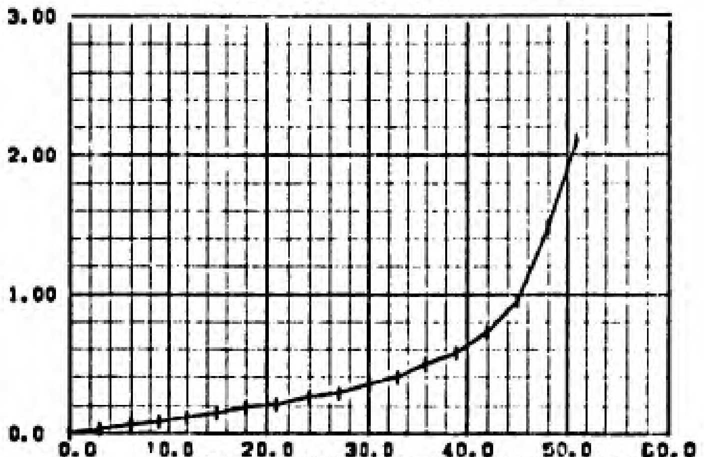
STANDOFF DISTANCE=0.3111
ABSCISSA OF STAGNATION POINT=-1.05000



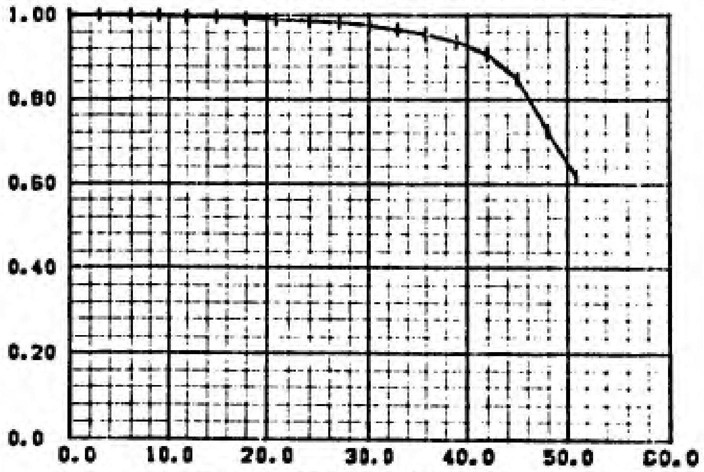
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

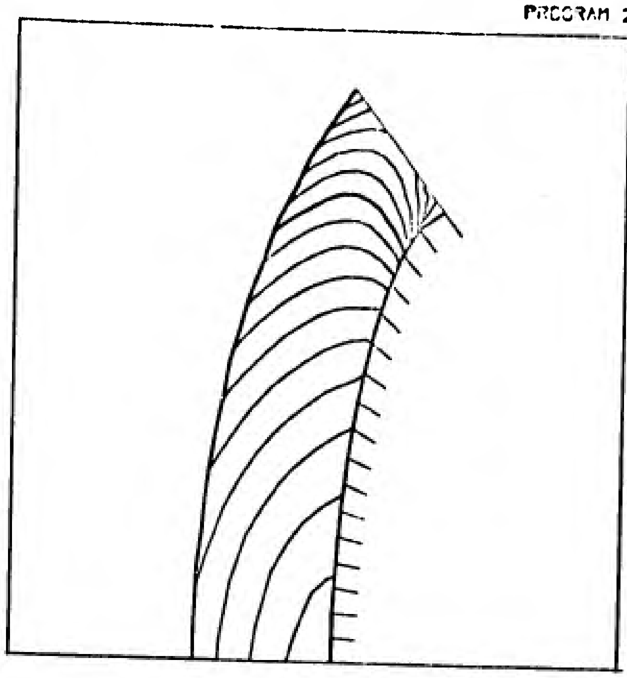


MACH NUMBER DISTRIBUTION ON THE BODY

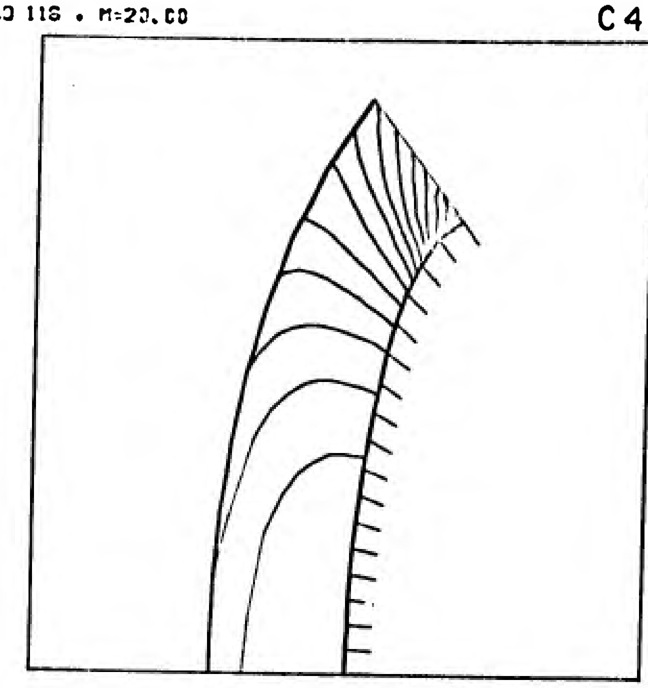


TEMPERATURE DISTRIBUTION ON THE BODY

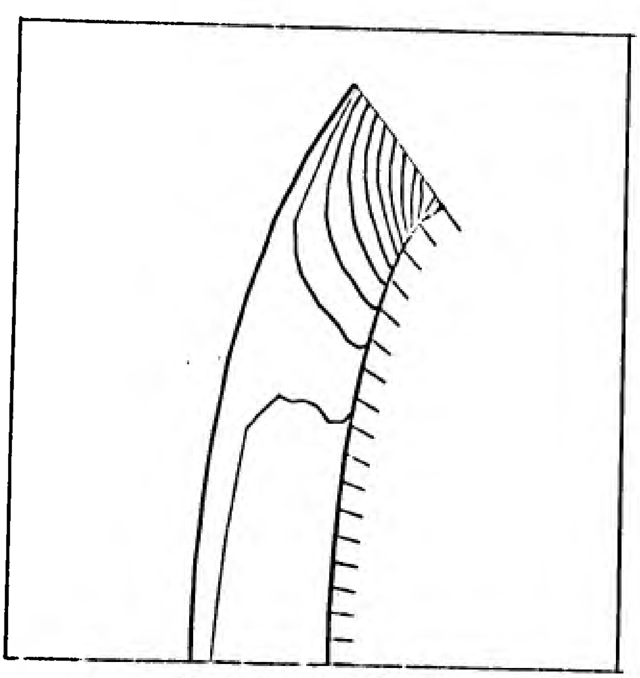
PROGRAM 2F. RUN NO 118 . M=20.00 C4



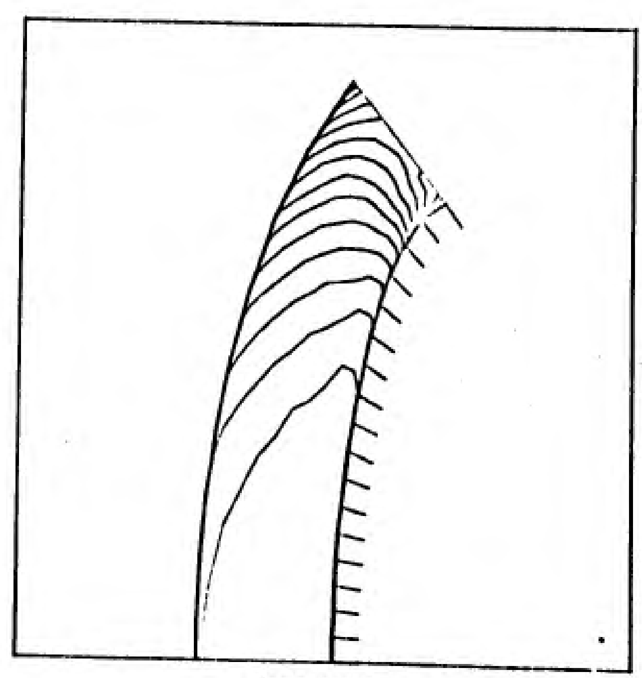
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 117

10 BY 17 MESH, 1000 STEPS TOLERANCE=0.000010

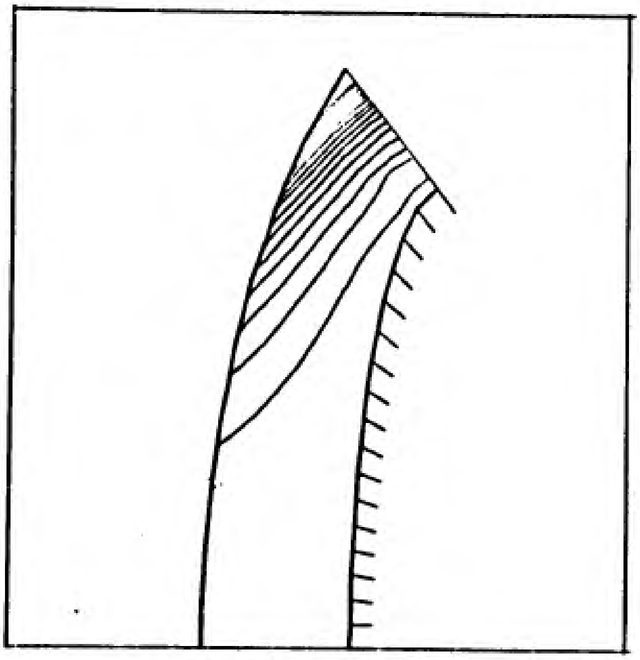
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.323
RELATIVE ERROR= 0.00031

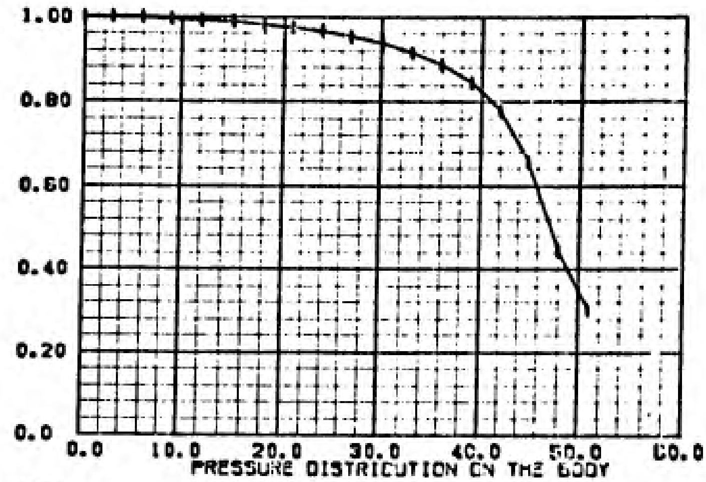
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.893
RELATIVE ERROR= 0.00009

CRITICAL PRESSURE RATIO=0.5563 (REL. ERROR= 0.0533)
CRITICAL DENSITY RATIO=0.6331 (REL. ERROR= 0.0331)
CRITICAL TEMPERAT.RATIO=0.6304 (REL. ERROR= 0.0205)

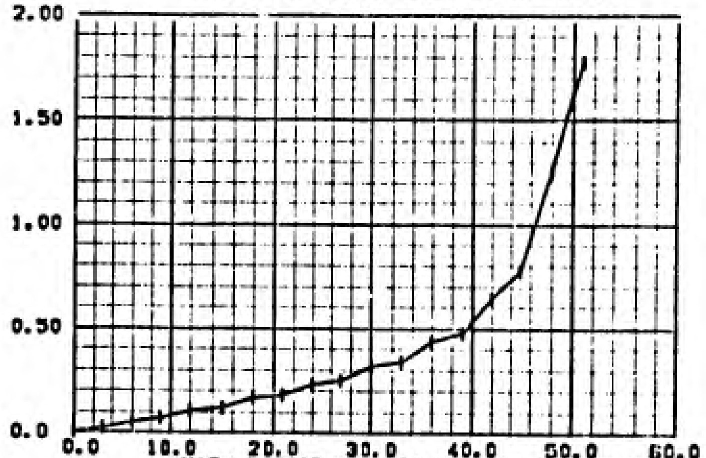
STANDOFF DISTANCE=0.3364
ABSCISSA OF STAGNATION POINT= -1.00000



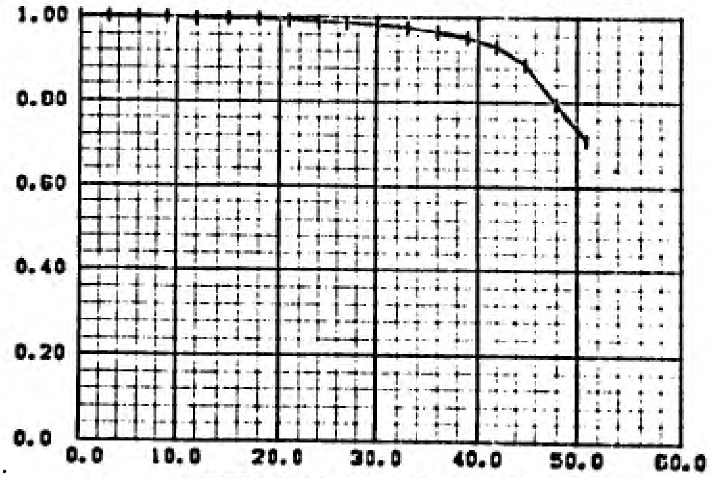
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

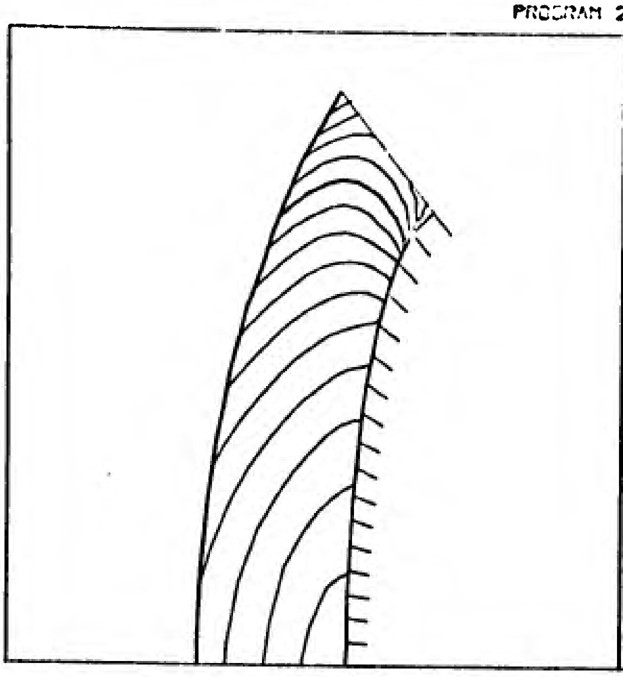


MACH NUMBER DISTRIBUTION ON THE BODY

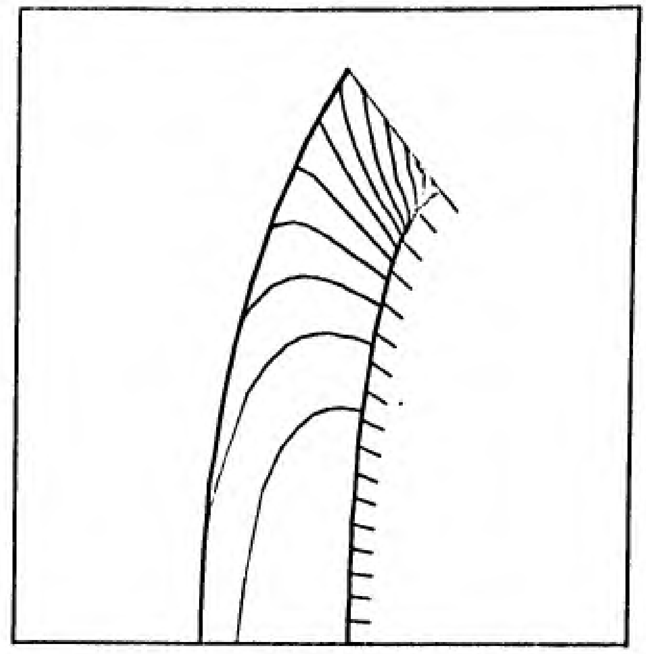


TEMPERATURE DISTRIBUTION ON THE BODY

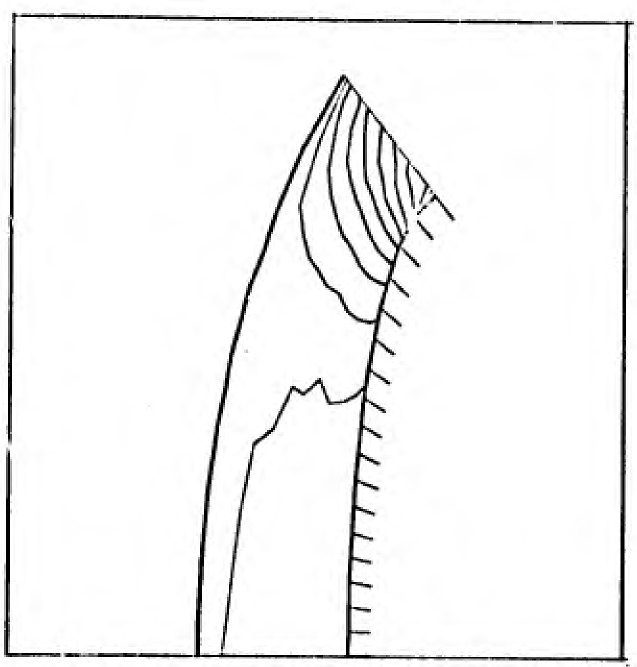
PROGRAM 2F. RUN NO 117 . M=22.00 C5



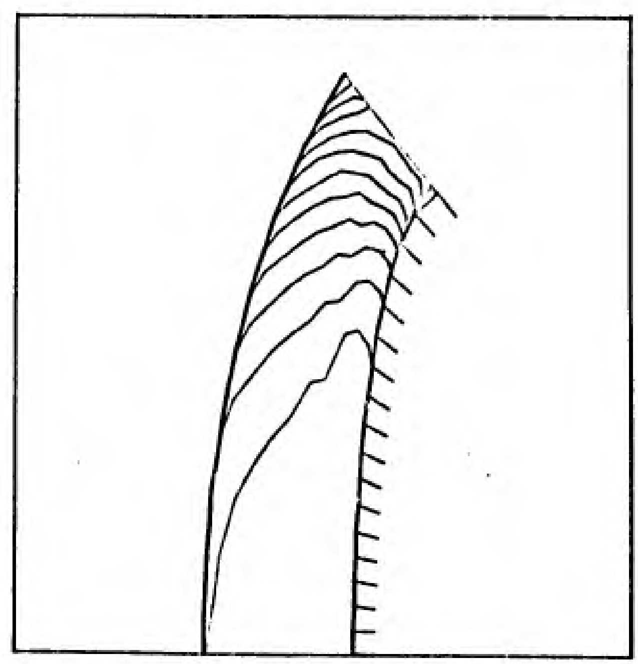
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 118

18 BY 17 MESH. 1000 STEPS TOLERANCE=0.000010

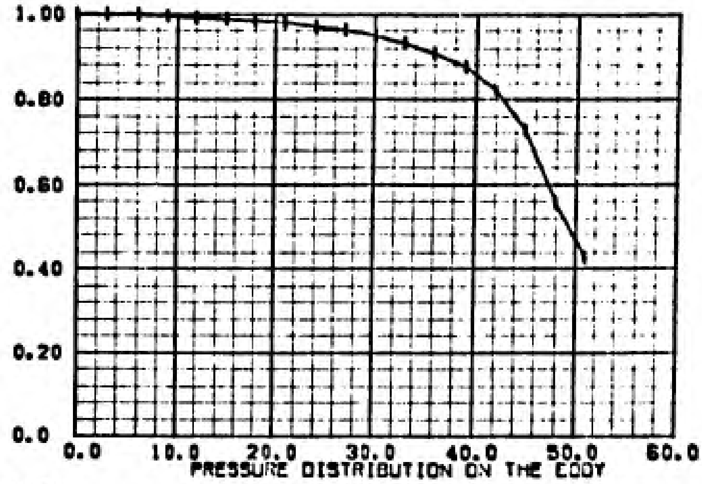
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.260
RELATIVE ERROR= 0.00042

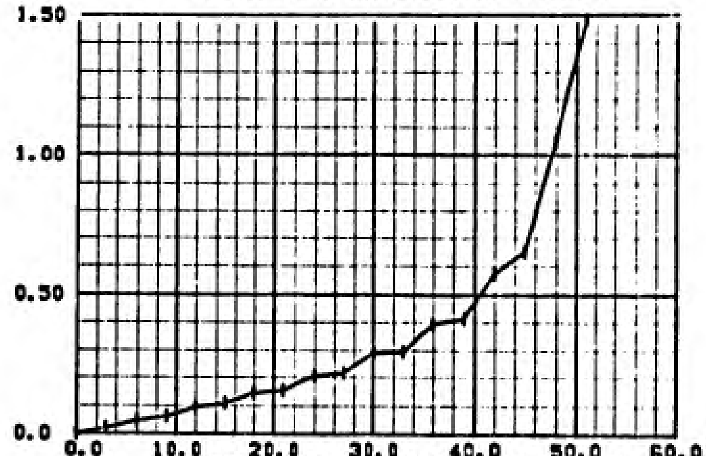
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 80.990
RELATIVE ERROR= 0.00012

CRITICAL PRESSURE RATIO=0.5819 (REL. ERROR= 0.1014)
CRITICAL DENSITY RATIO=0.6783 (REL. ERROR= 0.0704)
CRITICAL TEMPERAT.RATIO=0.8575 (REL. ERROR= 0.0290)

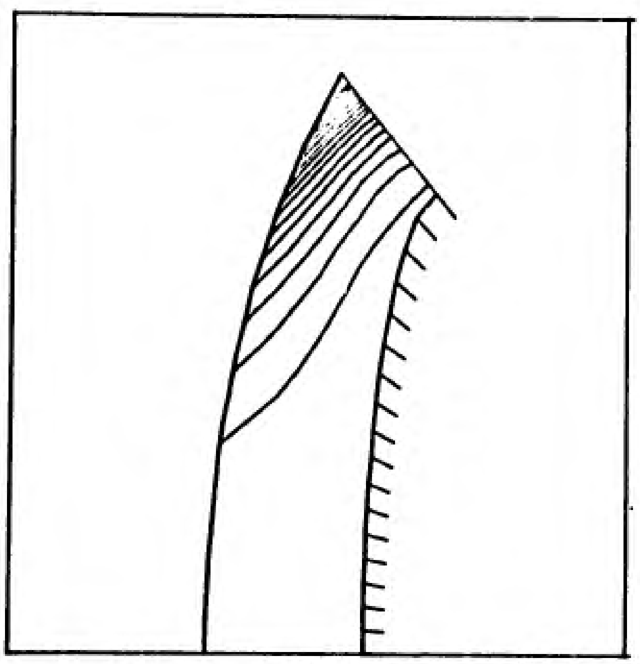
STANDOFF DISTANCE=0.3565
ABSCISSA OF STAGNATION POINT= -0.96667

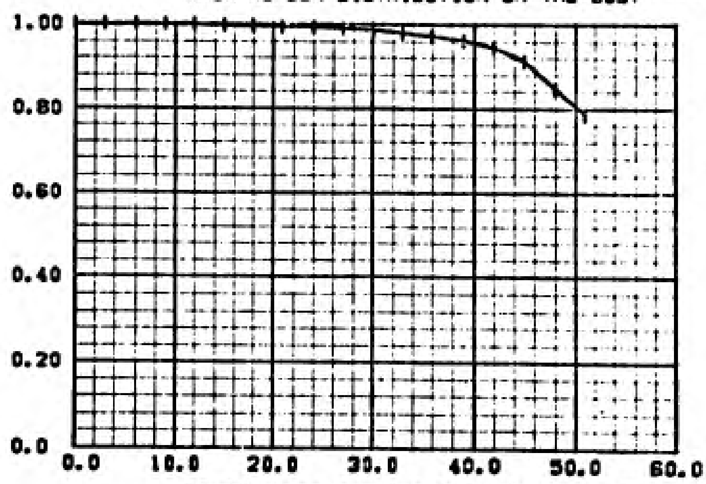


PRESSURE DISTRIBUTION ON THE BODY



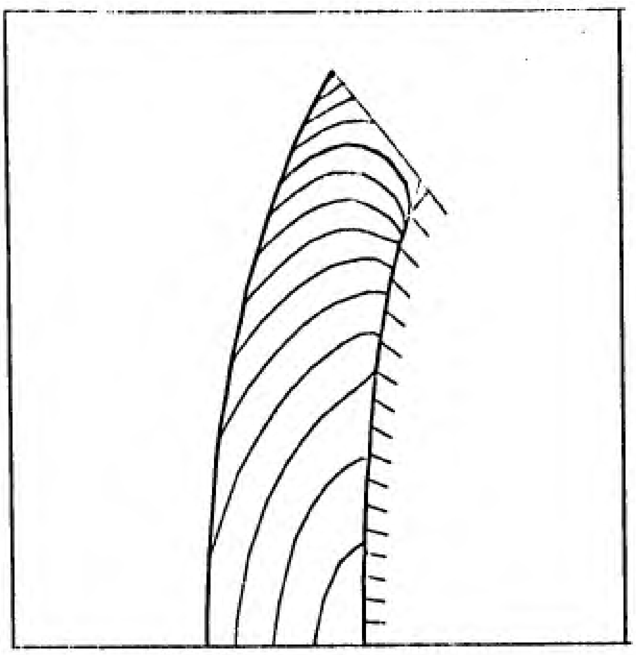
MACH NUMBER DISTRIBUTION ON THE BODY


STREAMLINES

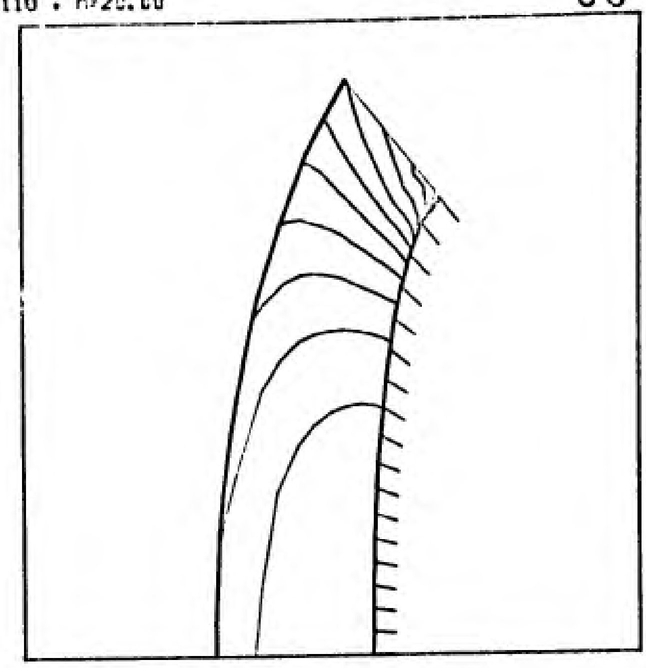


TEMPERATURE DISTRIBUTION ON THE BODY

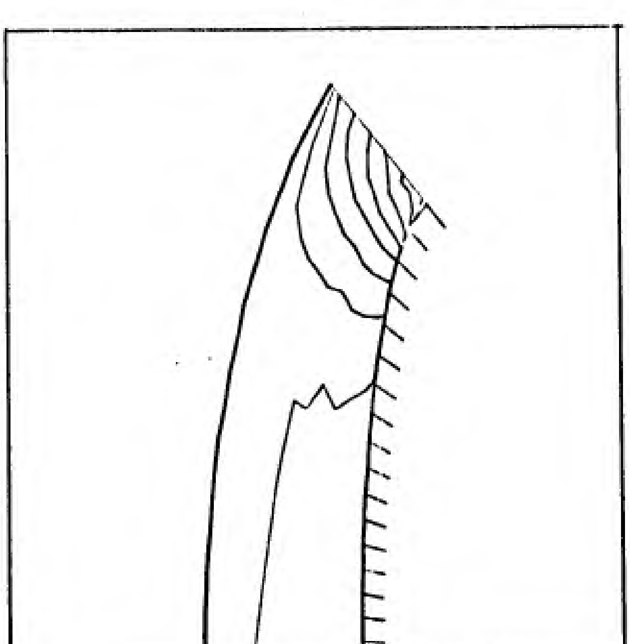
PROGRAM 2F, RUN NO 110 . M=20.00 C6



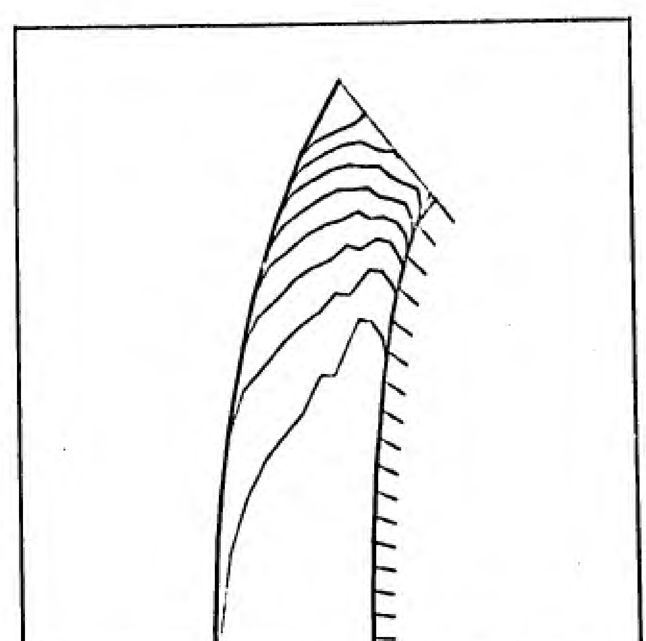
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 130

10 BY 15 MESH, 1000 STEPS TOLERANCE=0.000010

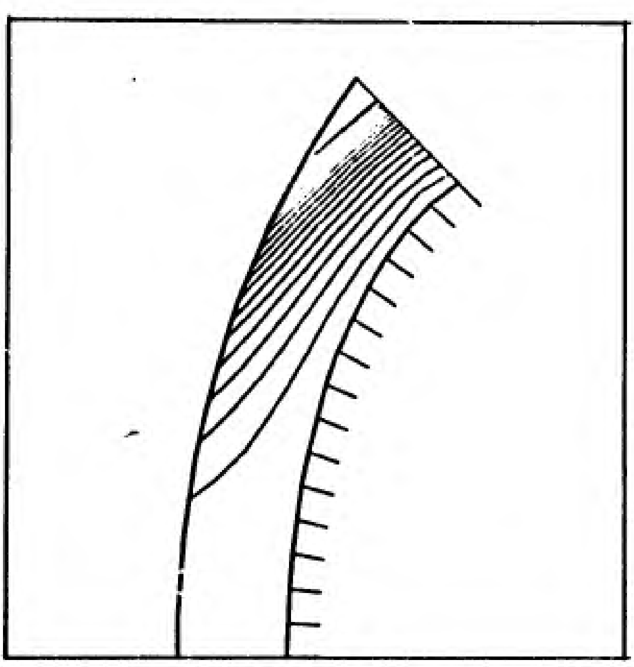
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.256
RELATIVE ERROR= 0.00030

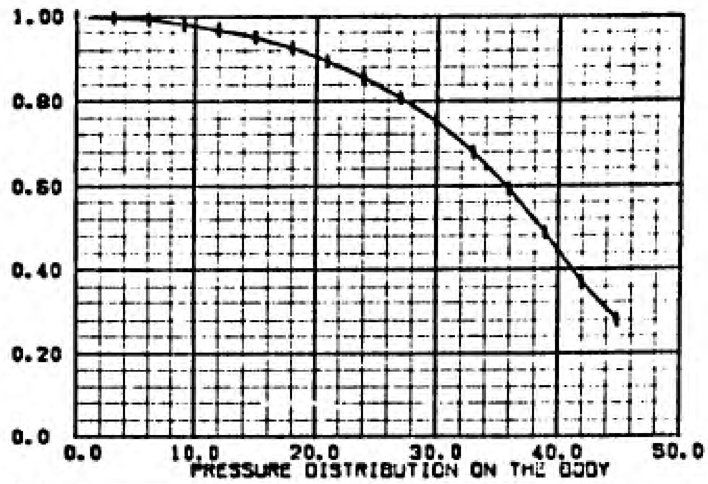
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.002
RELATIVE ERROR= 0.00009

CRITICAL PRESSURE RATIO=0.5348 (REL. ERROR= 0.0124)
CRITICAL DENSITY RATIO=0.6399 (REL. ERROR= 0.0079)
CRITICAL TEMPERAT.RATIO=0.8371 (REL. ERROR= 0.0045)

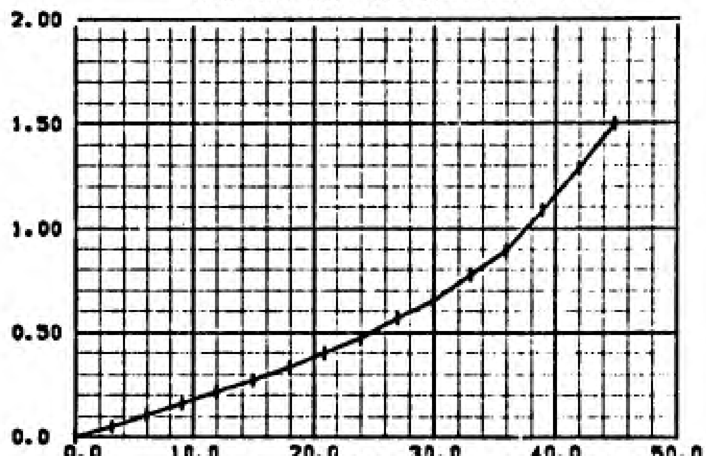
STANDOFF DISTANCE=0.2272
ABSCISSA OF STAGNATION POINT=-1.30000



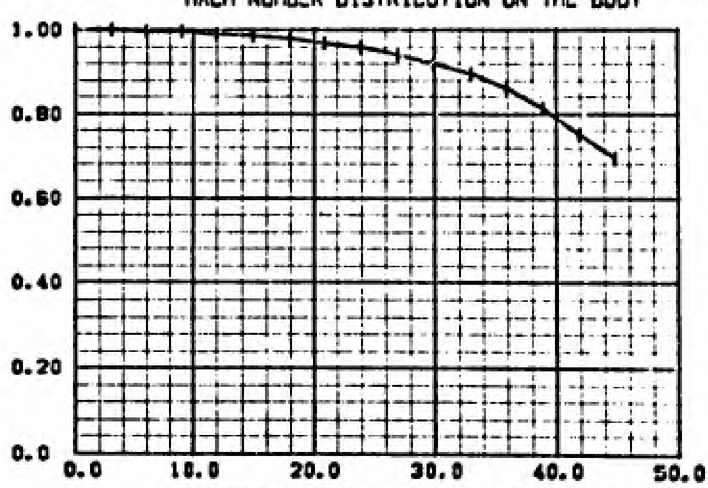
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

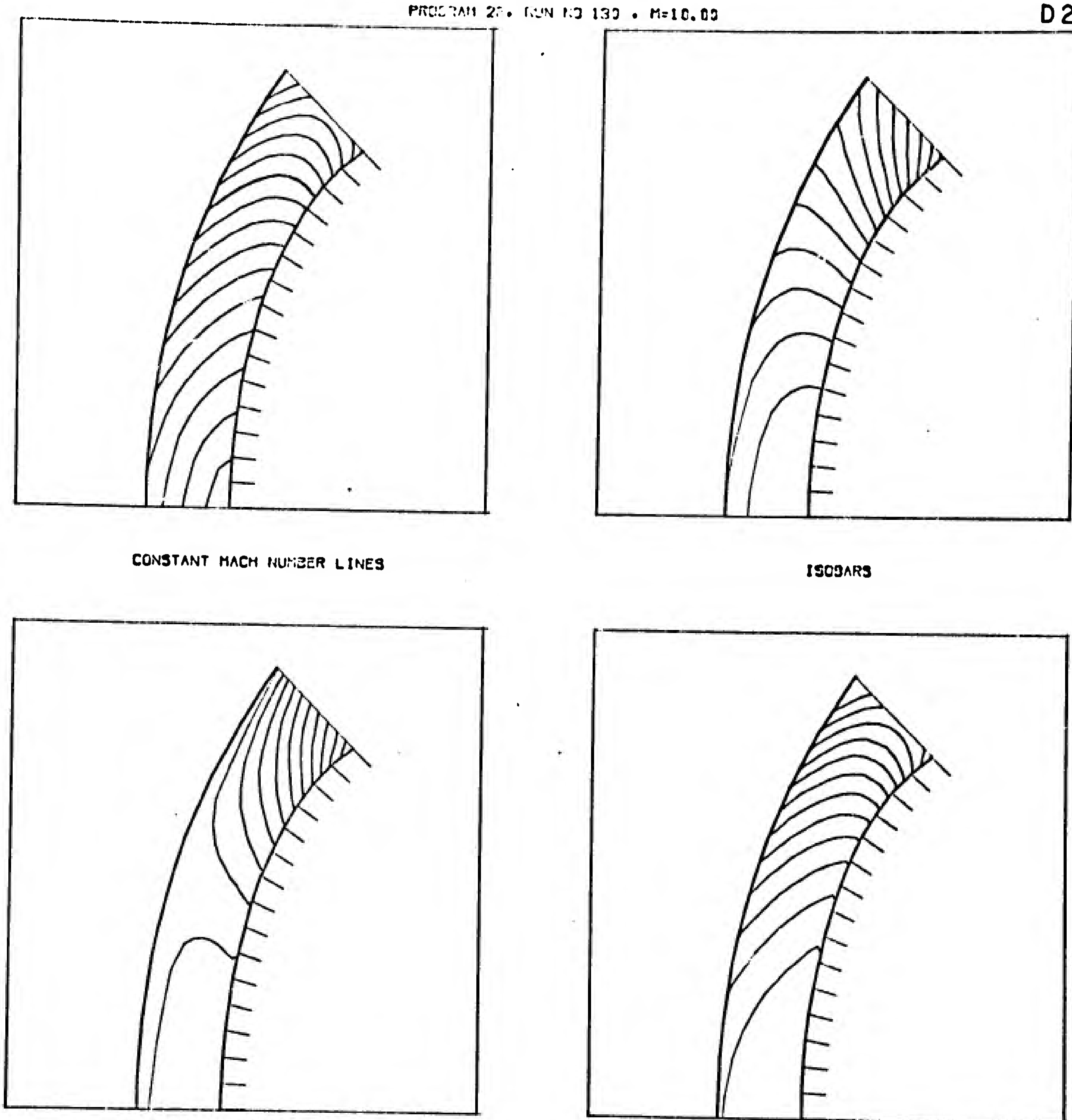


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2?. RUN NO 130 . M=10.00 **D2**



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 131

18 BY 18 MESH, 1000 STEPS TOLERANCE=0.000010

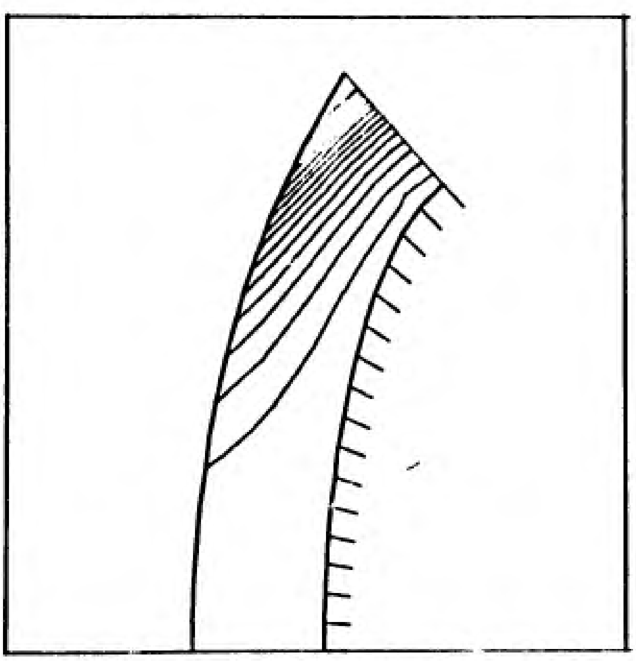
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.256
RELATIVE ERROR= 0.00030

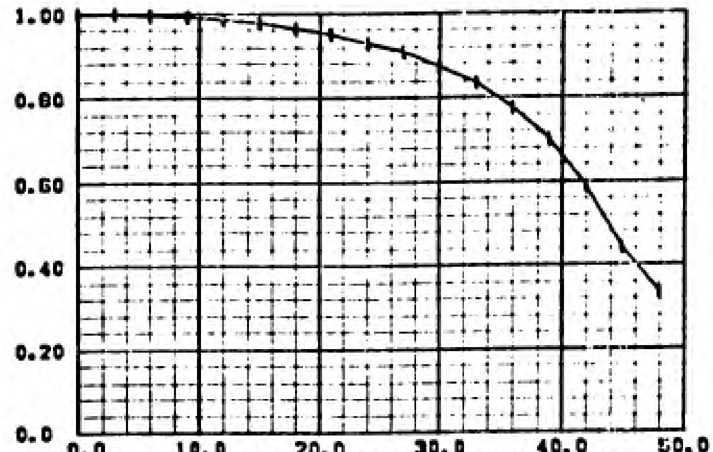
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.002
RELATIVE ERROR= 0.00009

CRITICAL PRESSURE RATIO=0.5413 (REL. ERROR= 0.0246)
CRITICAL DENSITY RATIO=0.6439 (REL. ERROR= 0.0157)
CRITICAL TEMPERAT.RATIO=0.8408 (REL. ERROR= 0.0087)

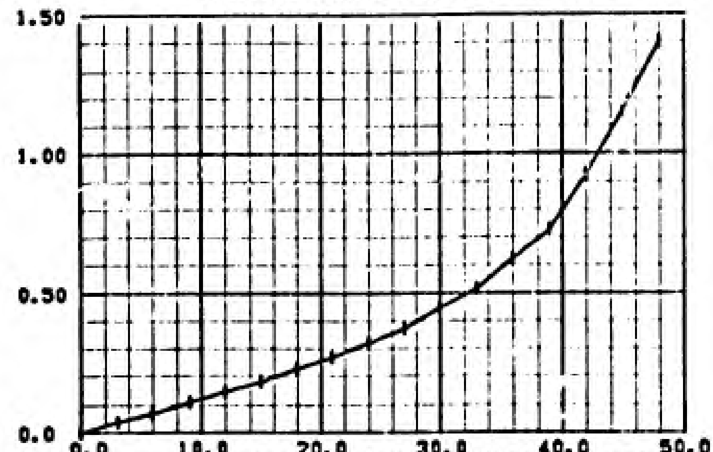
STANDOFF DISTANCE=0.2847
ABSCISSA OF STAGNATION POINT=-1.13333



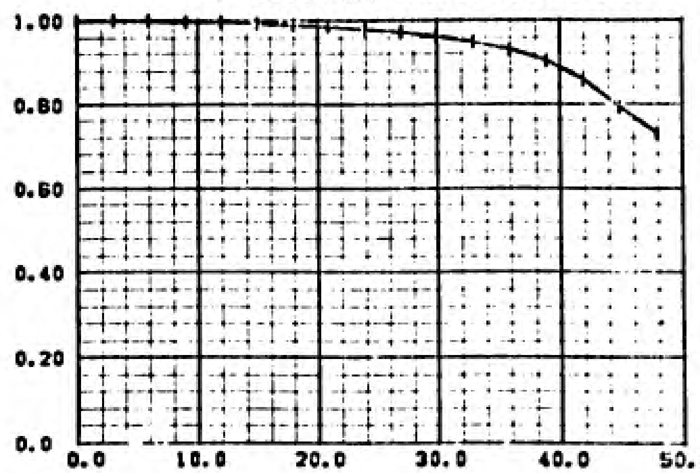
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



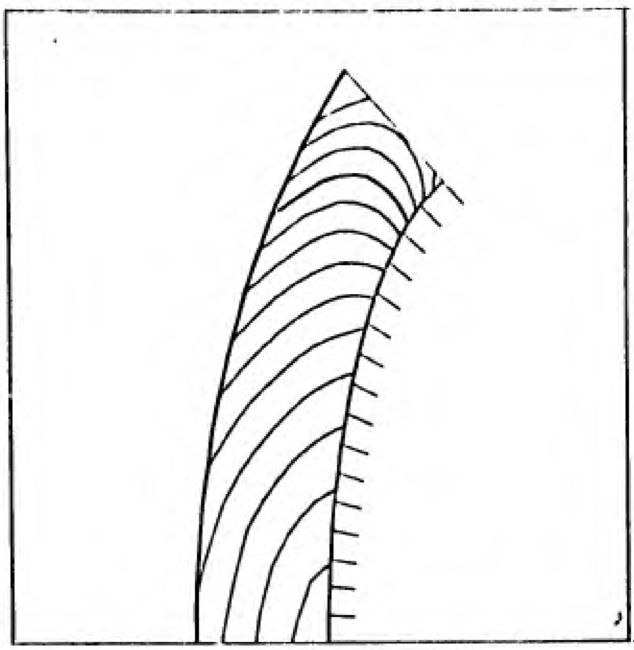
MACH NUMBER DISTRIBUTION ON THE BODY



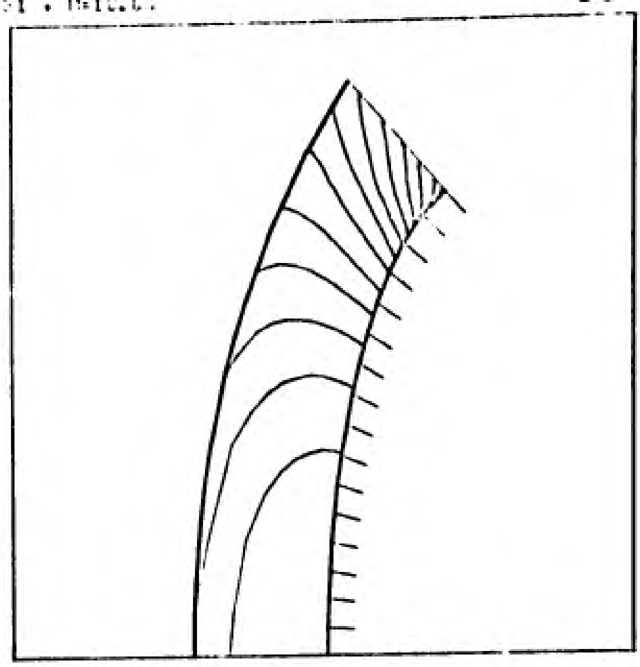
TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2F. RUN NO 1[illegible]1 . M=10.[illegible]

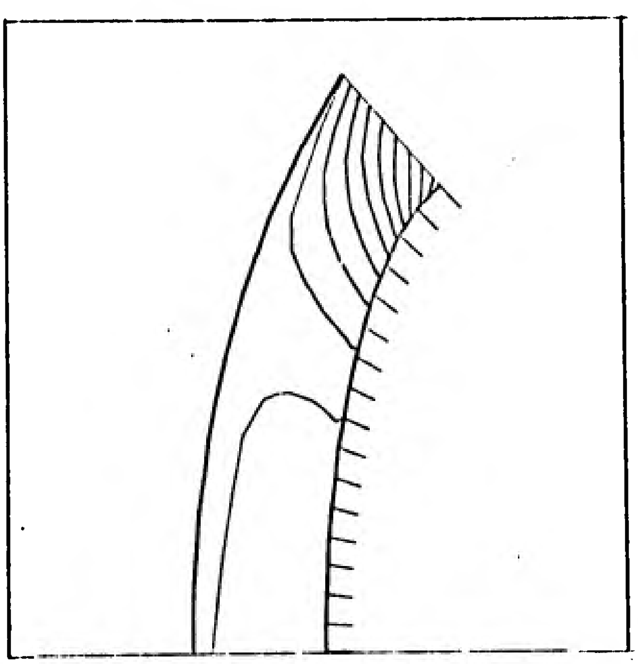
D3



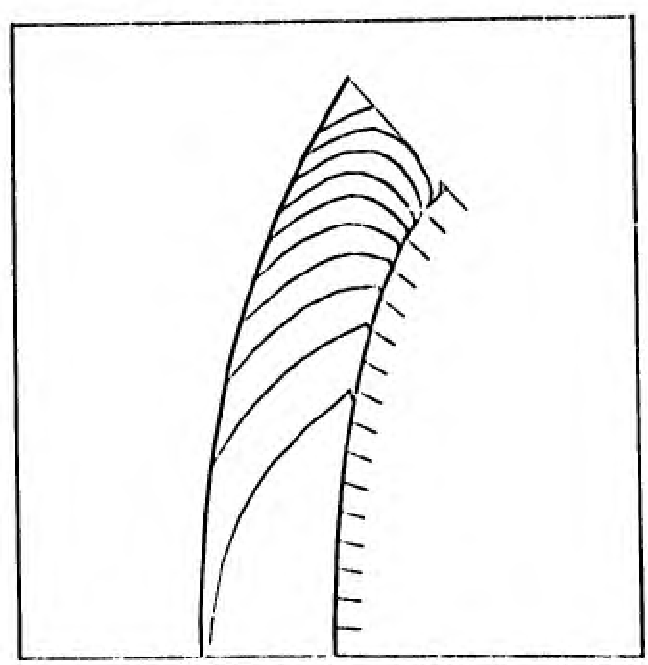
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 132

10 BY 17 MESH, 1000 STEPS TOLERANCE=0.000010

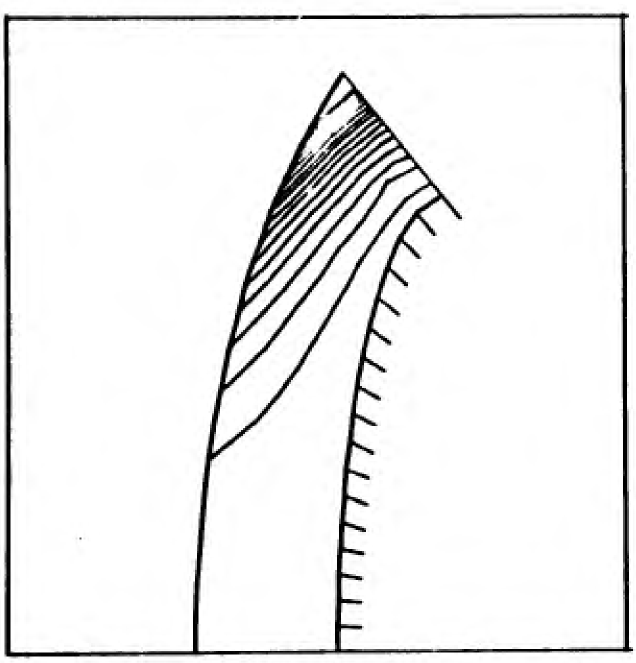
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.231
RELATIVE ERROR= 0.00013

THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.001
RELATIVE ERROR= 0.00004

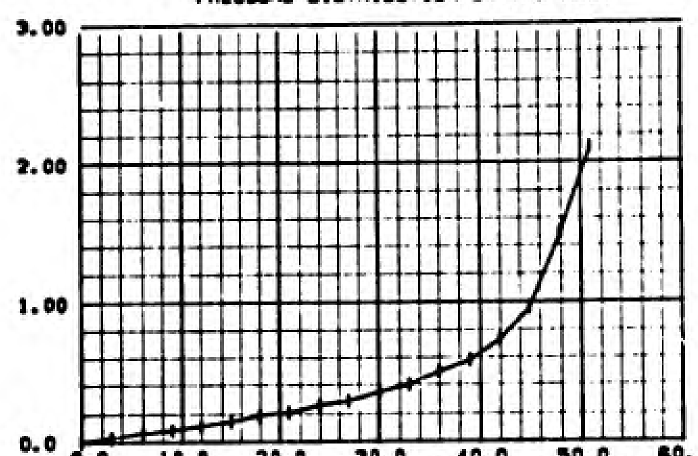
CRITICAL PRESSURE RATIO=0.5439 (REL. ERROR= 0.0296)
CRITICAL DENSITY RATIO=0.6461 (REL. ERROR= 0.0191)
CRITICAL TEMPERAT.RATIO=0.8419 (REL. ERROR= 0.0103)

STANDOFF DISTANCE=0.3210
ABSCISSA OF STAGNATION POINT= -1.05000

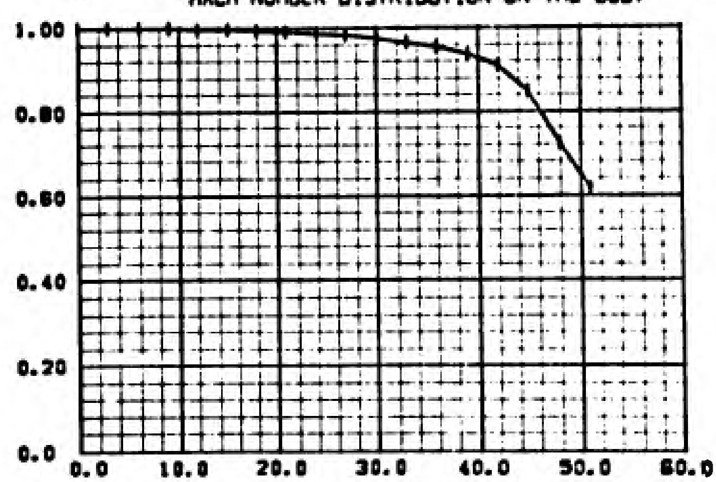


STREAMLINES

PRESSURE DISTRIBUTION ON THE BODY

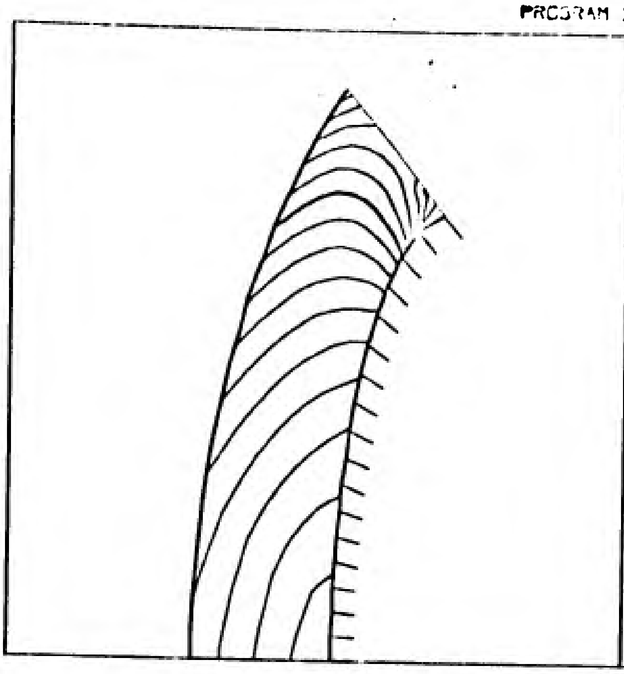


MACH NUMBER DISTRIBUTION ON THE BODY

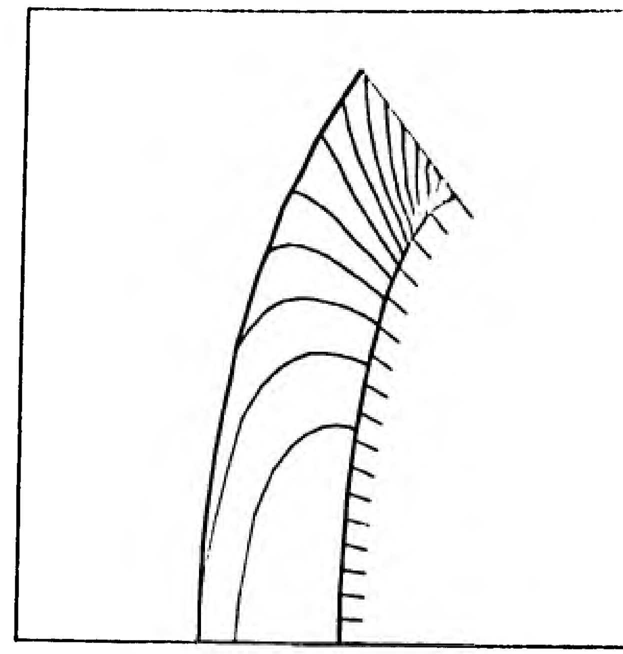


TEMPERATURE DISTRIBUTION ON THE BODY

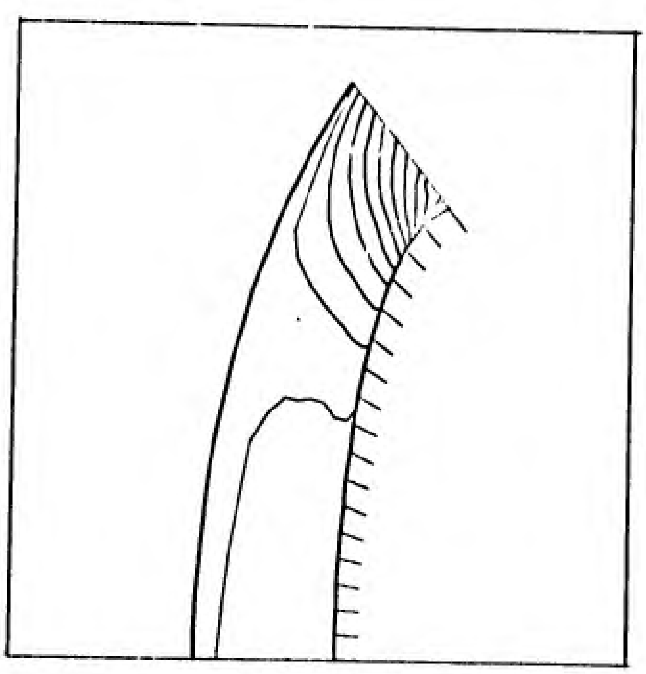
PROGRAM 2F, RUN NO 132 . M=10.00 D4



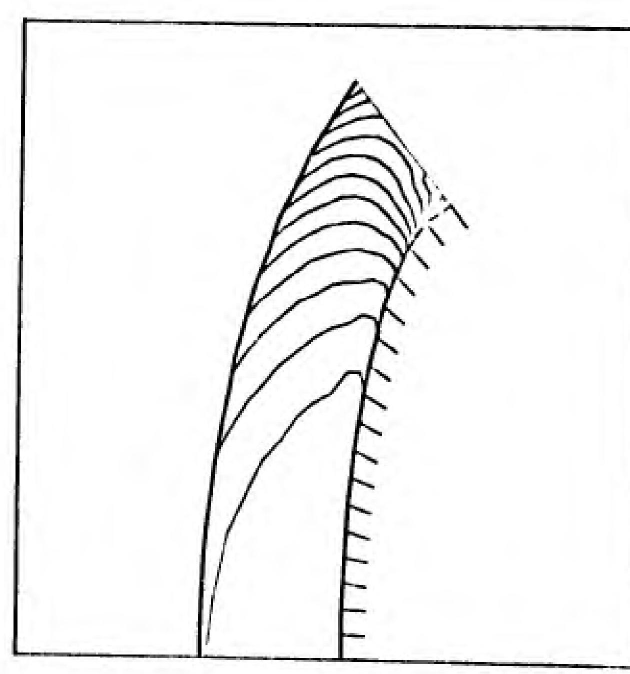
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 133

18 BY 17 MESH, 1000 STEPS TOLERANCE=0.000010

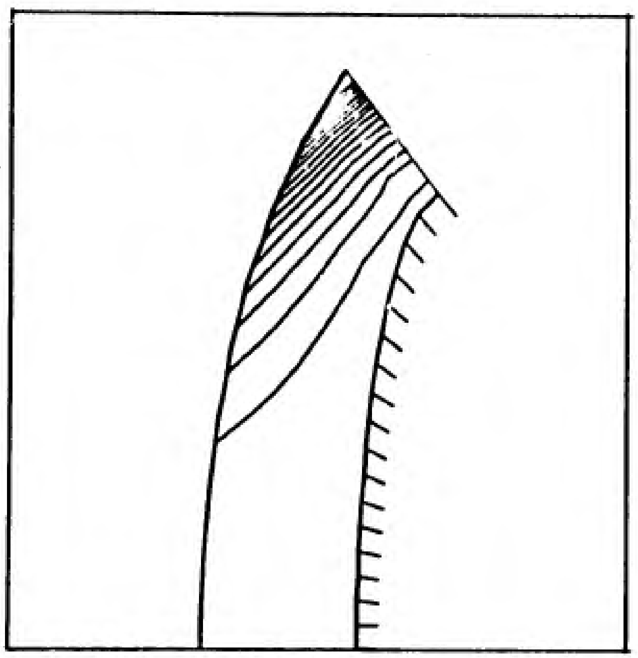
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.202
RELATIVE ERROR= 0.00011

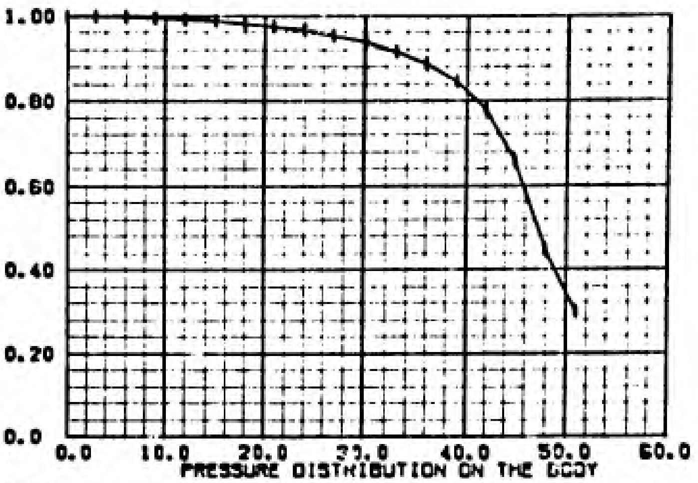
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 20.999
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5595 (REL. ERROR= 0.0590)
CRITICAL DENSITY RATIO=0.6580 (REL. ERROR= 0.0379)
CRITICAL TEMPERAT.RATIO=0.8503 (REL. ERROR= 0.0204)

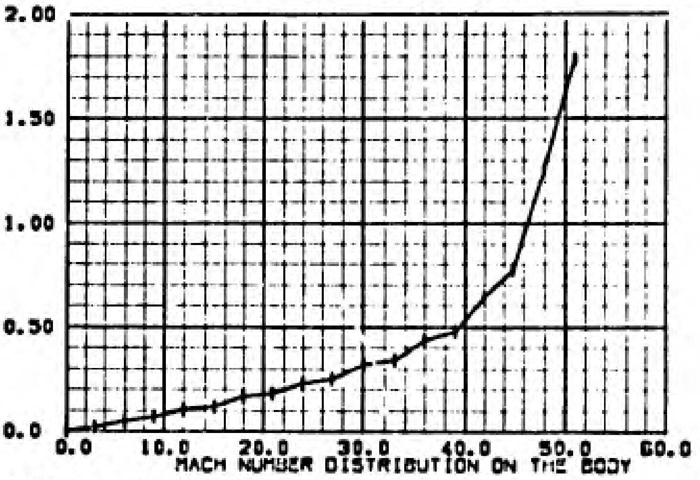
STANDOFF DISTANCE=0.3467
ABSCISSA OF STAGNATION POINT= -1.00000



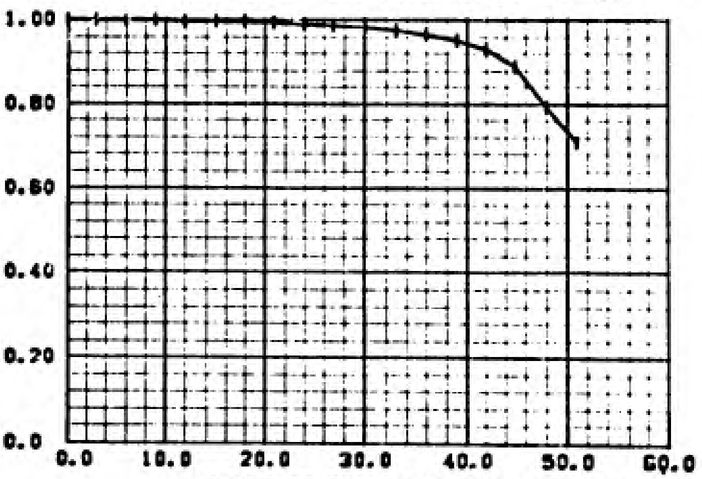
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



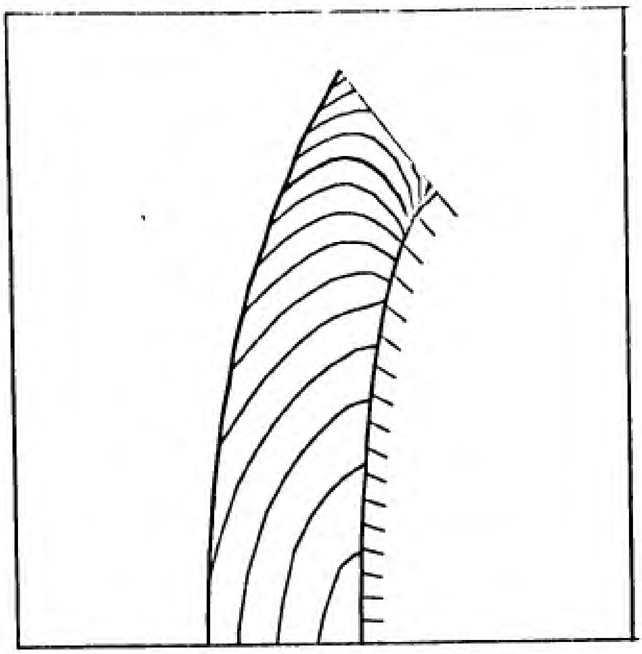
MACH NUMBER DISTRIBUTION ON THE BODY



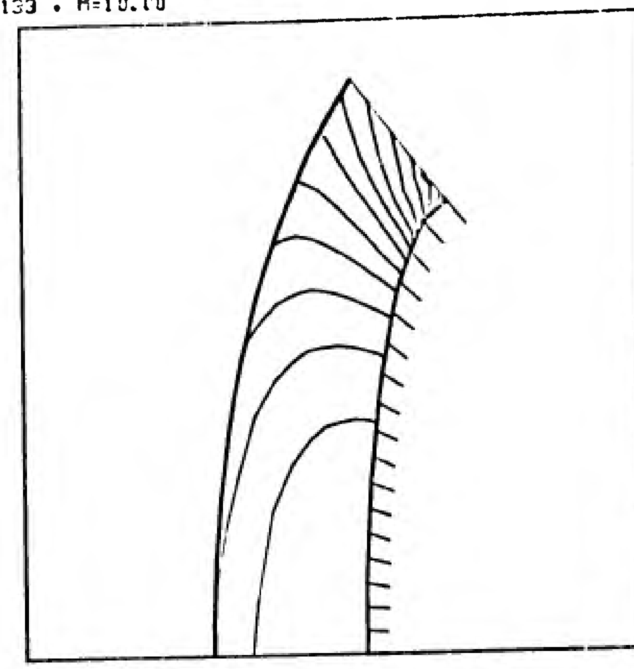
TEMPERATURE DISTRIBUTION ON THE BODY

D5

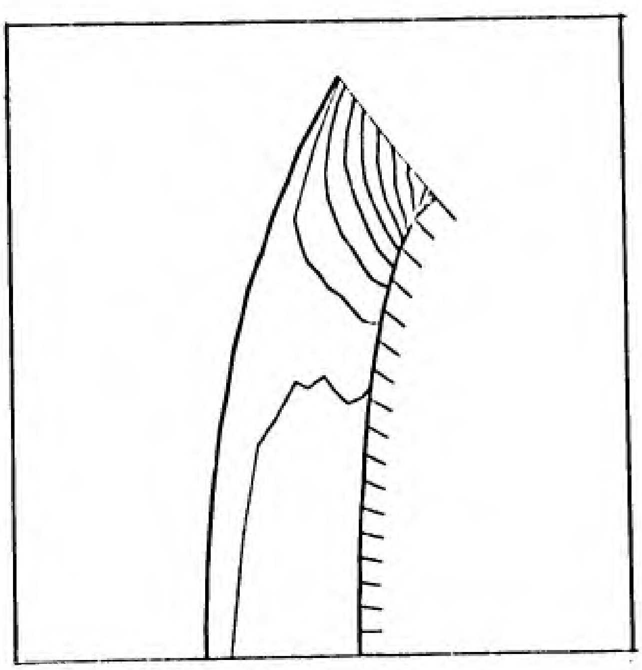
PROGRAM 2F, RUN NO 133 . M=10.00



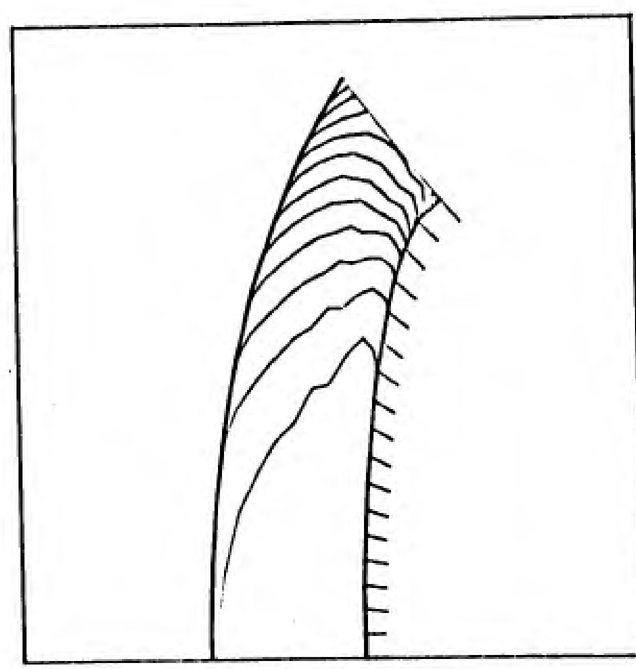
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 134

10 BY 10 MESH, 1000 STEPS TOLERANCE=0.000010

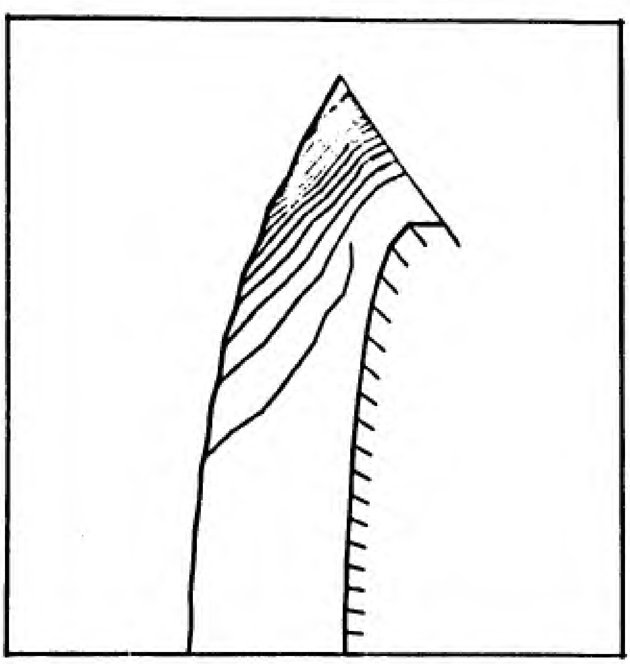
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR, STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=128.902
RELATIVE ERROR= 0.00244

THEOR, STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 20.985
RELATIVE ERROR= 0.00070

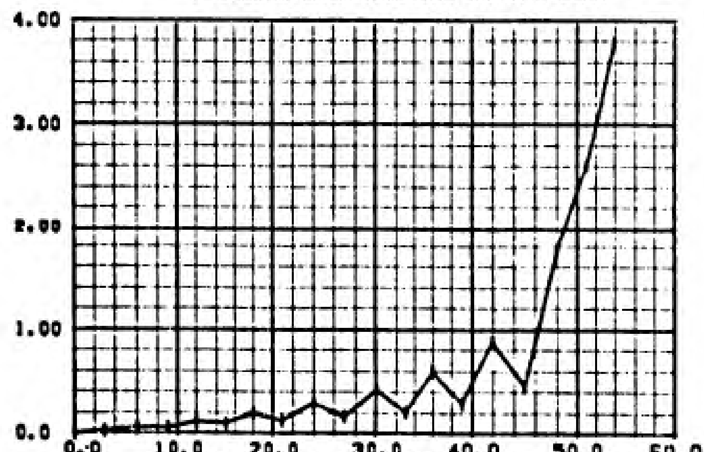
CRITICAL PRESSURE RATIO=0.6268 (REL. ERROR= 0.1881)
CRITICAL DENSITY RATIO=0.7134 (REL. ERROR= 0.1254)
CRITICAL TEMPERAT,RATIO=0.8783 (REL. ERROR= 0.0539)

STANDOFF DISTANCE=0.3663
ABSCISSA OF STAGNATION POINT= -0.08687

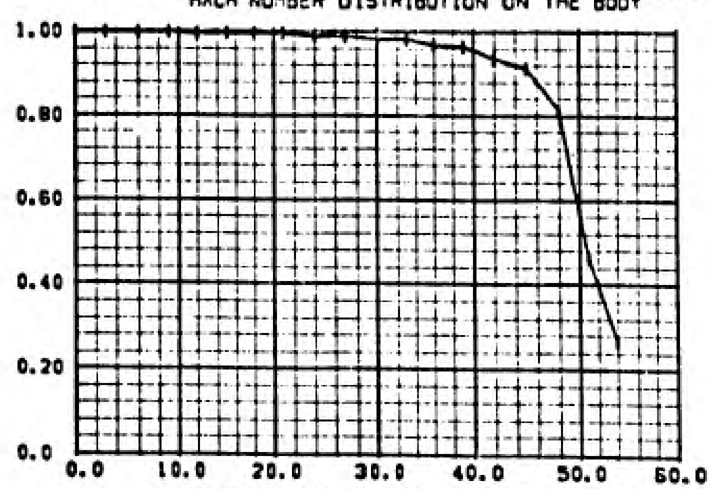


STREAMLINES

PRESSURE DISTRIBUTION ON THE BODY

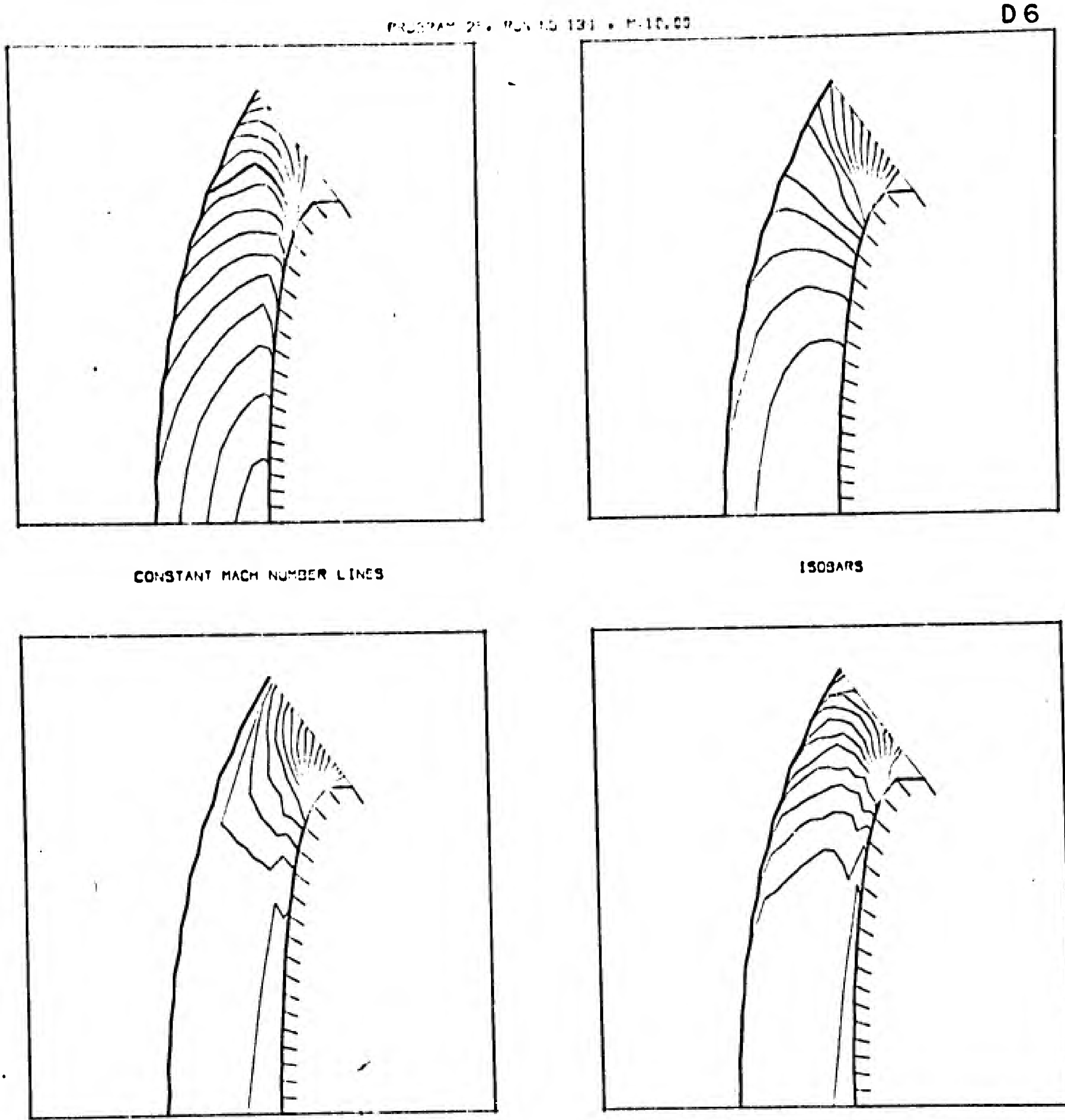


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

D6


PROGRAM 2?, RUN NO 131, M=10.00
CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 110

10 BY 10 MESH, 1000 STEPS TOLERANCE=0.000010

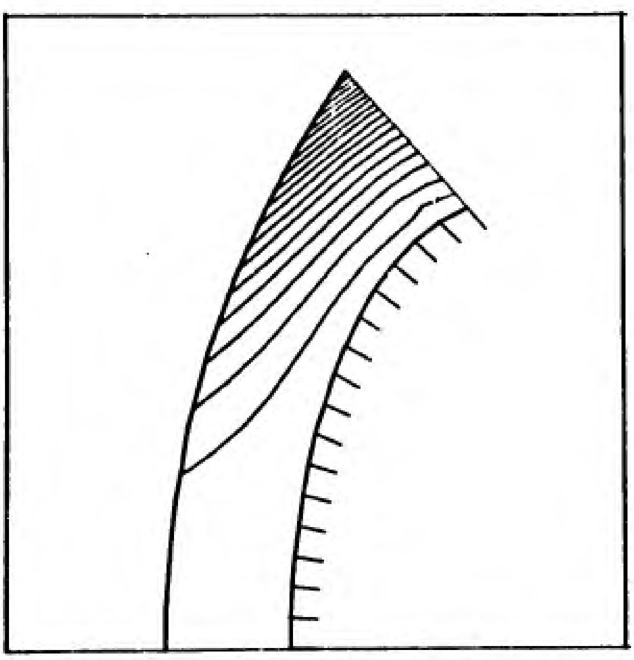
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.058
COMP. STAGNATION PRESSURE= 21.070
RELATIVE ERROR= 0.00011

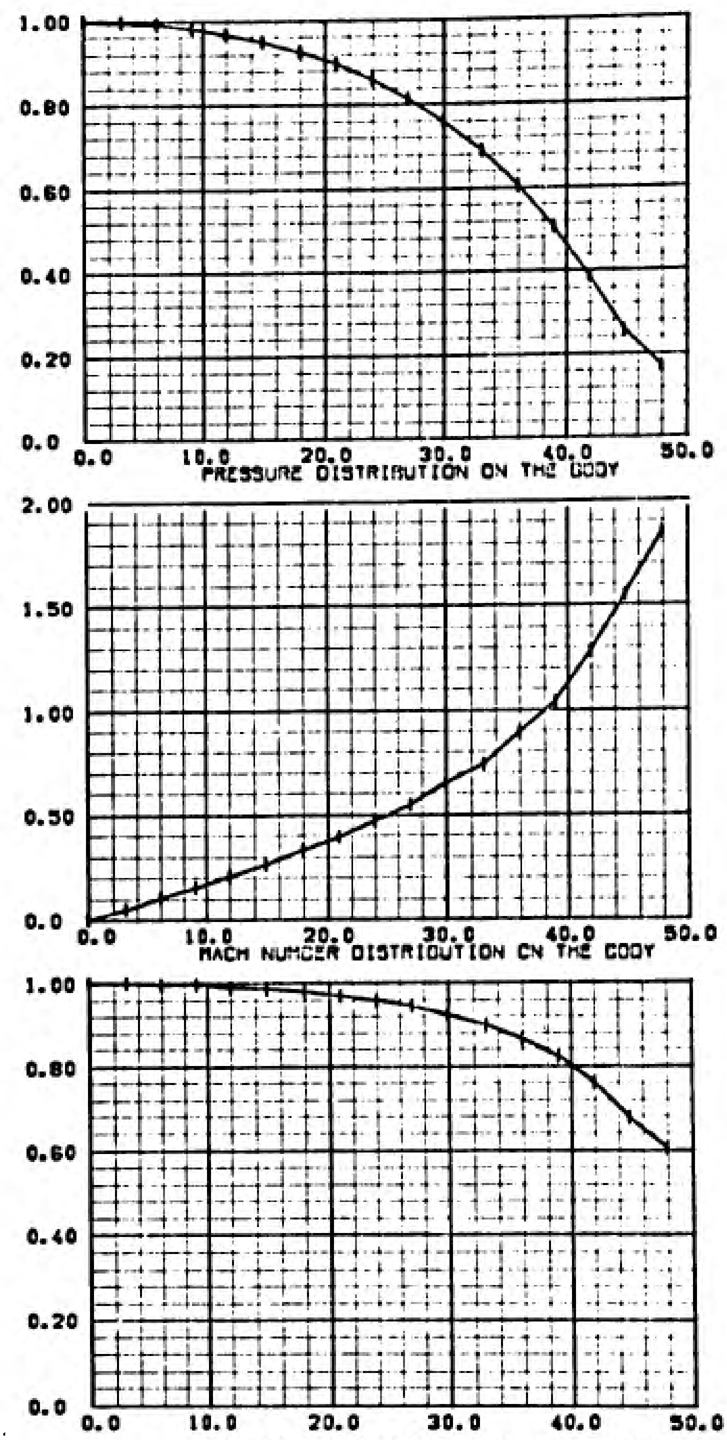
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5301 (REL. ERROR= 0.0035)
CRITICAL DENSITY RATIO=0.6331 (REL. ERROR= 0.0019)
CRITICAL TEMPERAT.RATIO=0.8347 (REL. ERROR= 0.0016)

STANDOFF DISTANCE=0.2849
ABSCISSA OF STAGNATION POINT= -1.30000



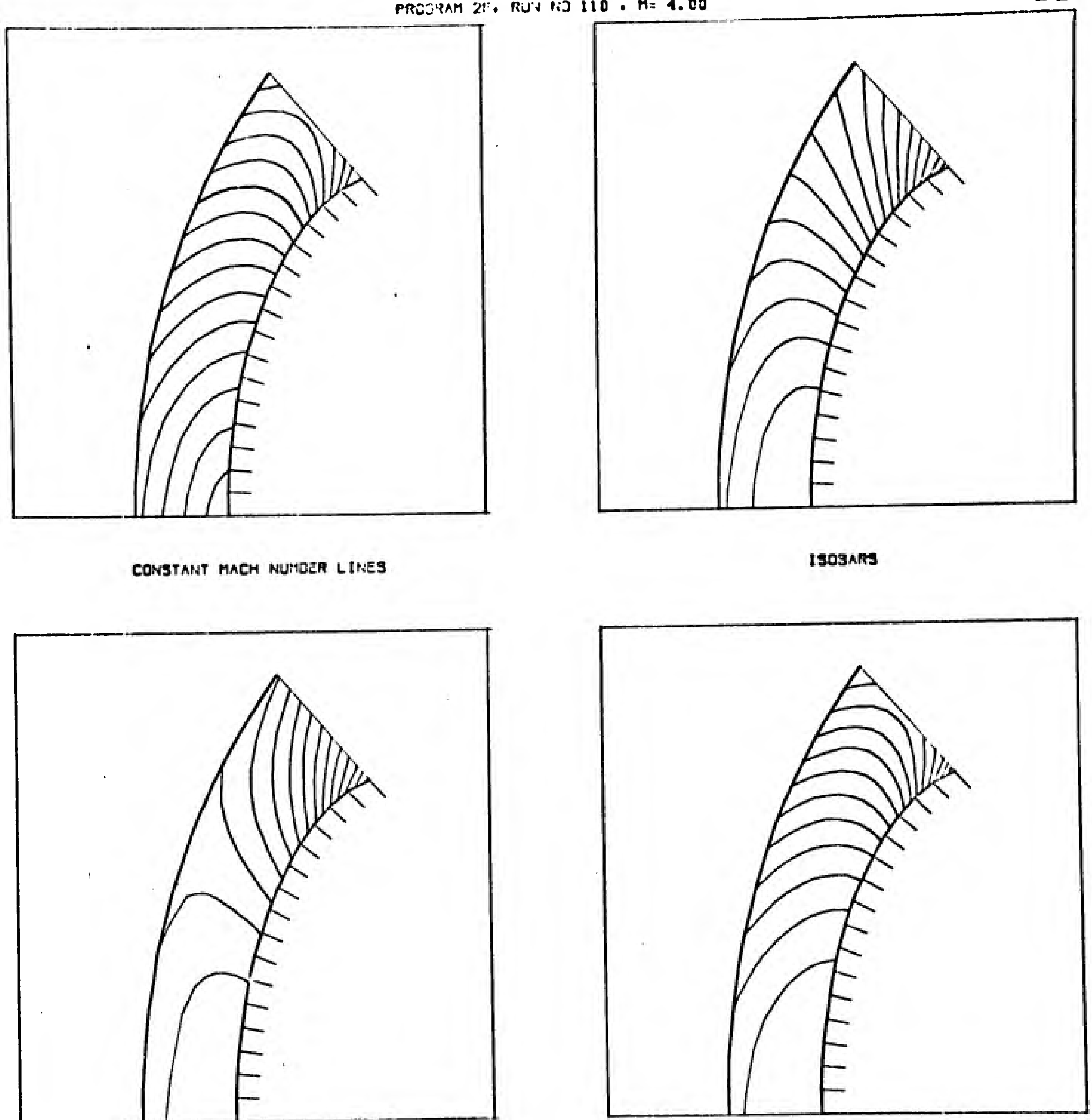
STREAMLINES



TEMPERATURE DISTRIBUTION ON THE BODY

E2

PROGRAM 2F, RUN NO 110 , M= 4.00



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 111

10 BY 17 MESH, 1000 STEPS TOLERANCE=0.000010

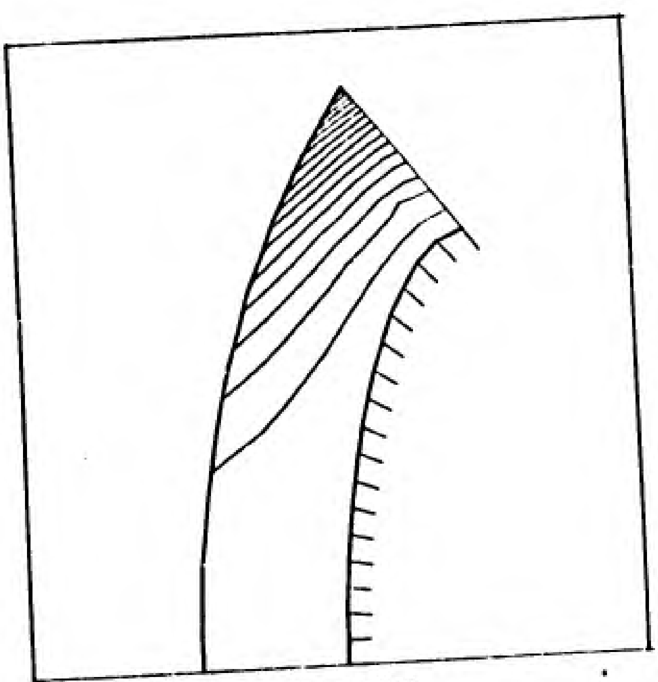
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.070
RELATIVE ERROR= 0.00010

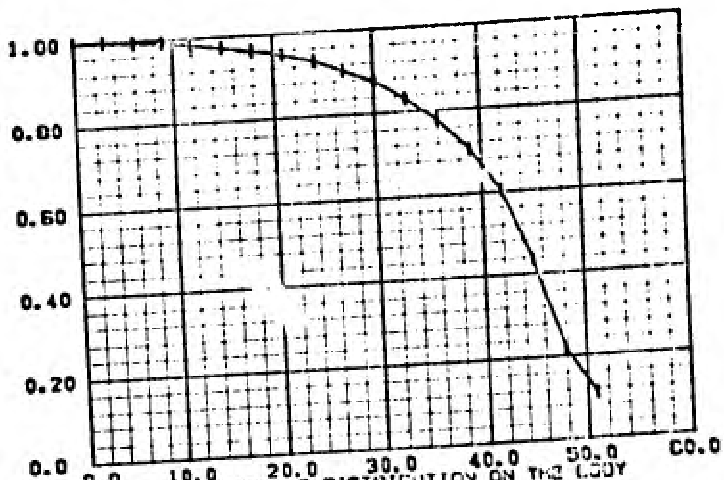
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00003

CRITICAL PRESSURE RATIO=0.5414 (REL. ERROR= 0.0249)
CRITICAL DENSITY RATIO=0.6437 (REL. ERROR= 0.0153)
CRITICAL TEMPERAT.RATIO=0.8412 (REL. ERROR= 0.0094)

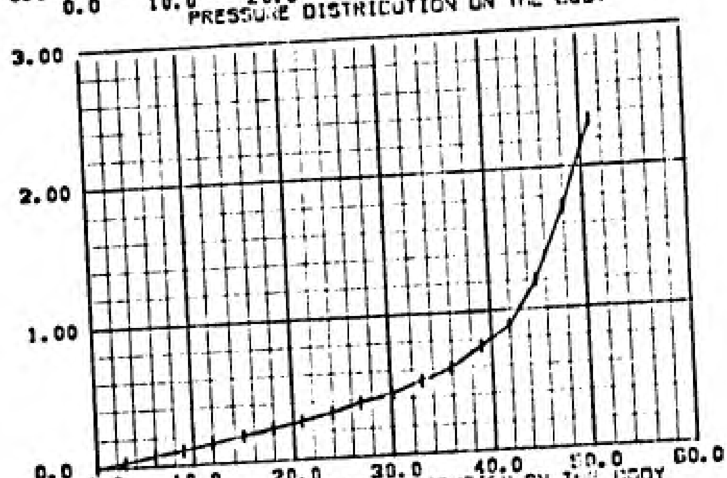
STANDOFF DISTANCE=0.3492
ABSCISSA OF STAGNATION POINT= -1.13333



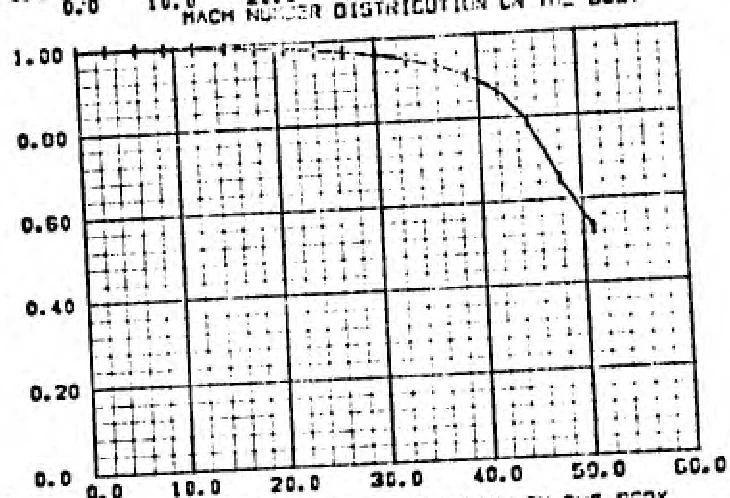
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

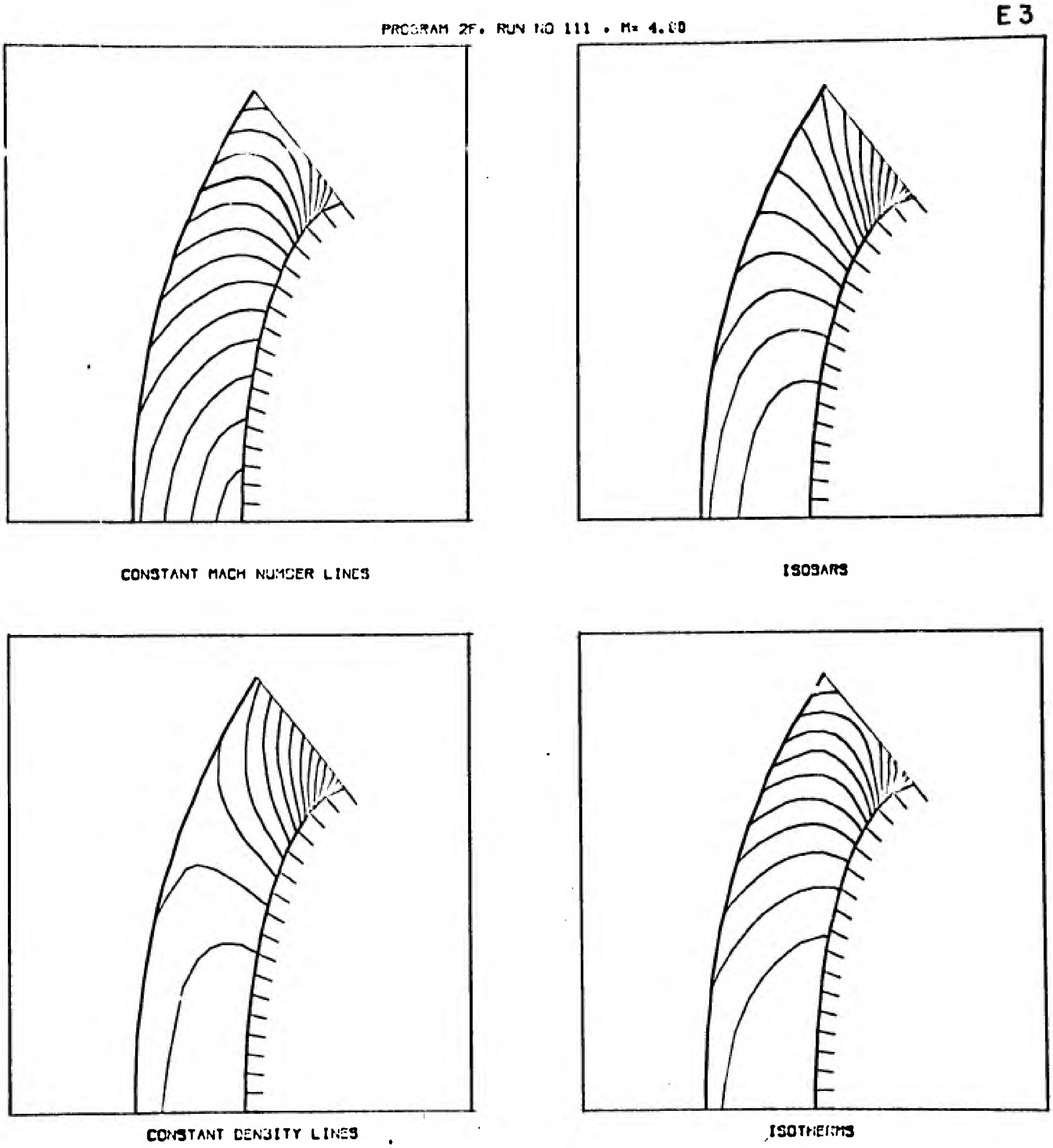


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

E3


PROGRAM 2F. RUN NO 111 . M= 4.00
CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 112

10 BY 17 MESH, 1000 STEPS TOLERANCE=0.000010

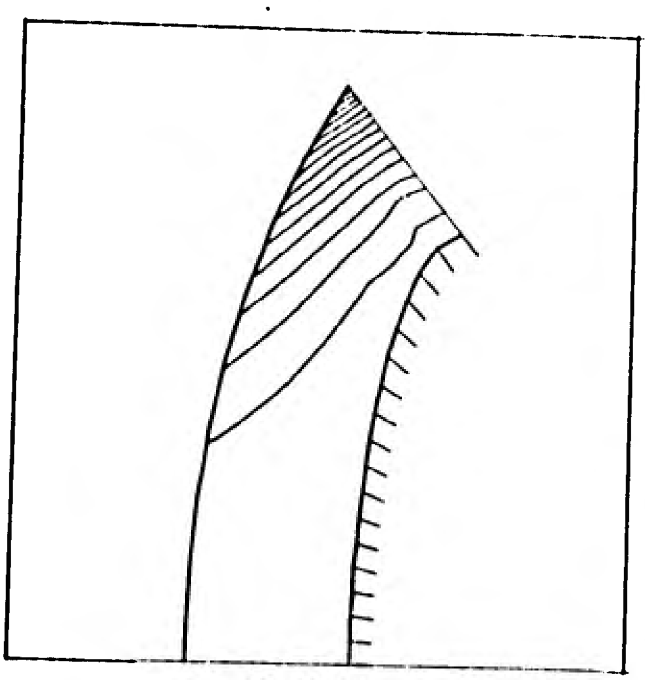
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.074
RELATIVE ERROR= 0.00027

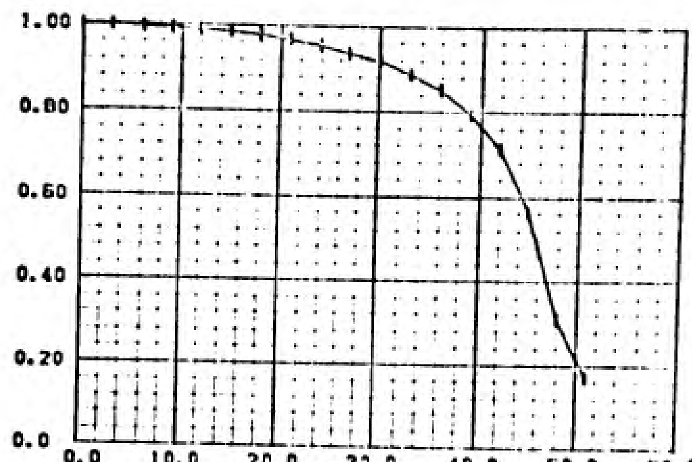
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00008

CRITICAL PRESSURE RATIO= 0.5457 (REL. ERROR= 0.0331)
CRITICAL DENSITY RATIO= 0.6477 (REL. ERROR= 0.0217)
CRITICAL TEMPERAT.RATIO= 0.8428 (REL. ERROR= 0.0111)

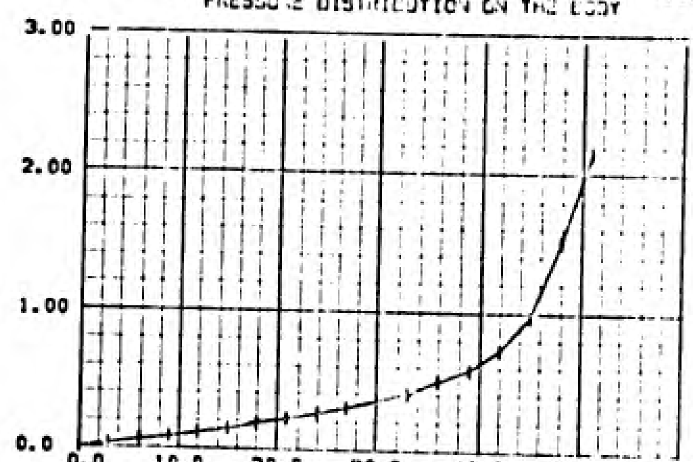
STANDOFF DISTANCE=0.3333
ABSCISSA OF STAGNATION POINT= -1.05000



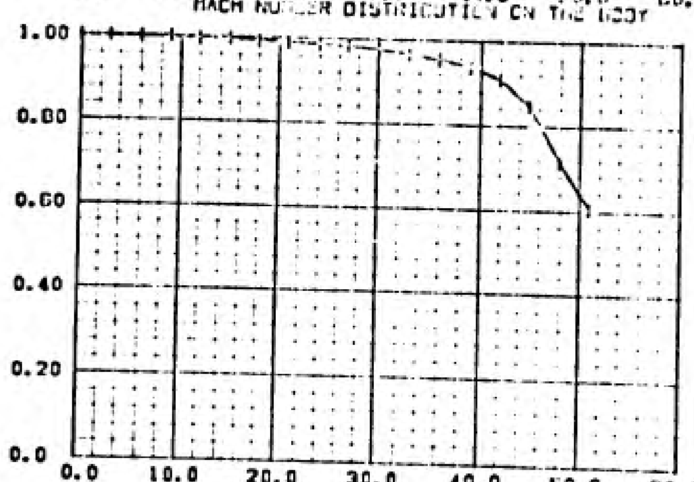
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

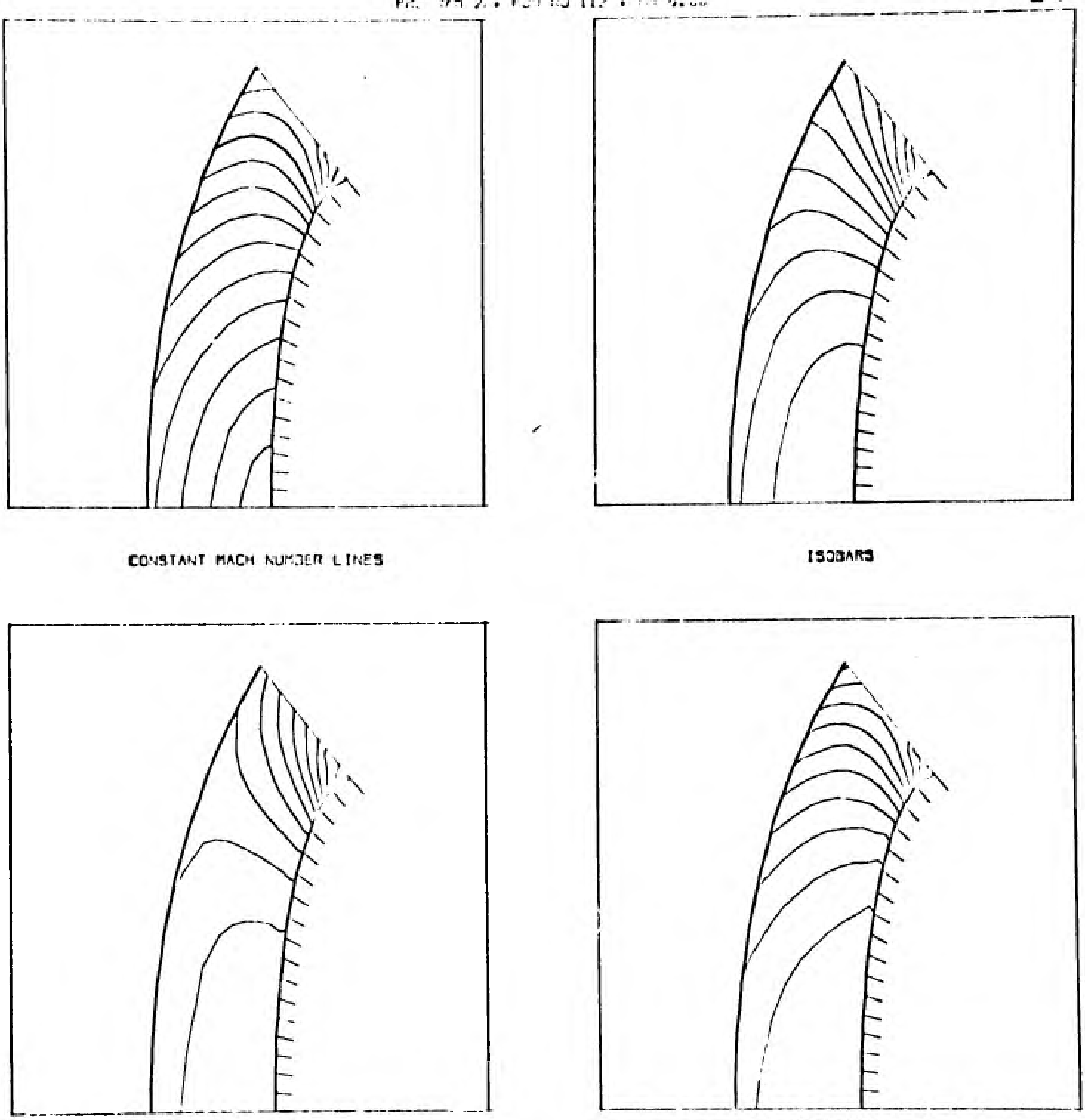


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

E4



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

AXISYMMETRIC BLUNT BODY   RUN NO 113

10 BY 17 MESH, 1000 STEPS   TOLERANCE=0.000010

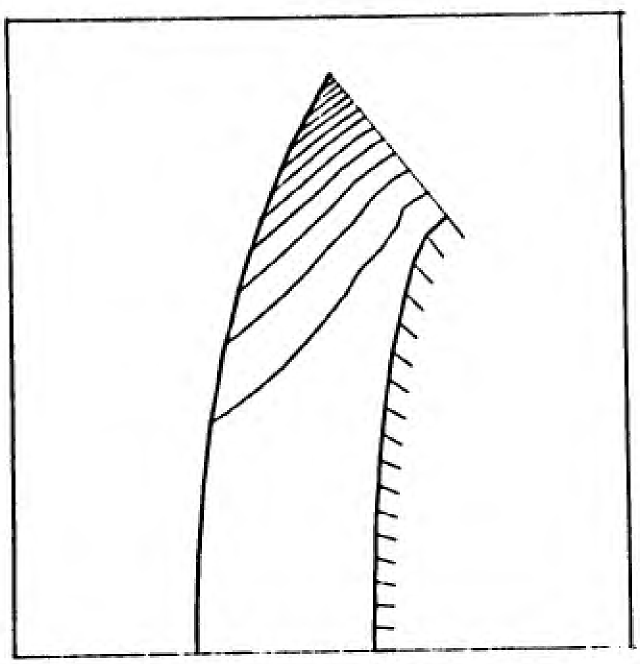
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.068
COMP. STAGNATION PRESSURE= 21.076
RELATIVE ERROR= 0.00039

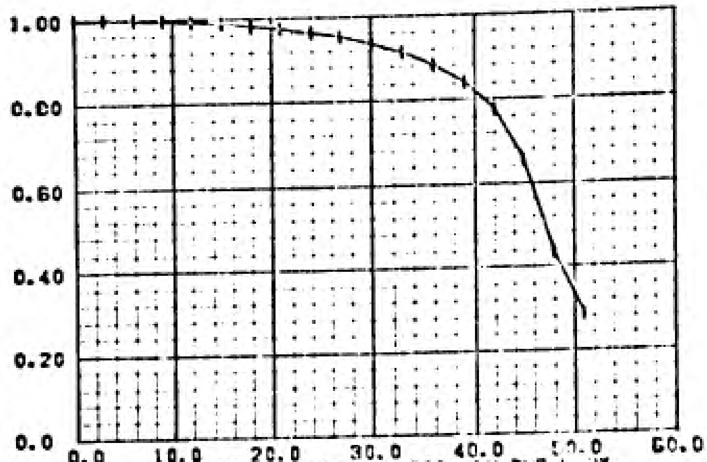
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00011

CRITICAL PRESSURE RATIO=0.5594 (REL. ERROR= 0.0509)
CRITICAL DENSITY RATIO=0.6576 (REL. ERROR= 0.0374)
CRITICAL TEMPERAT.RATIO=0.8508 (REL. ERROR= 0.0207)

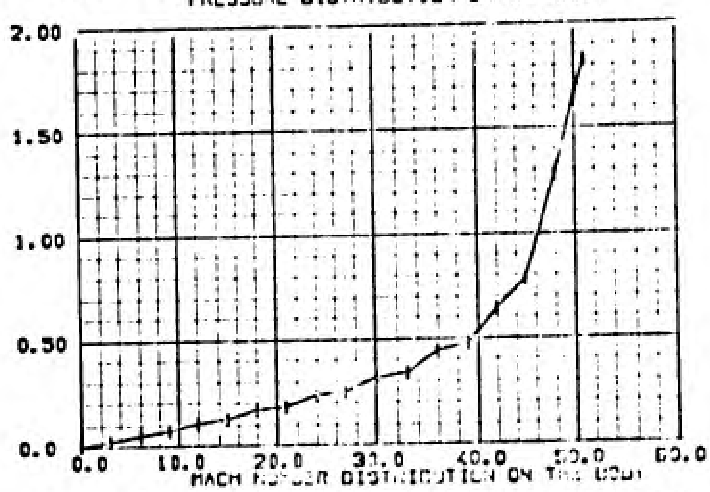
STANDOFF DISTANCE=0.4178
ABSCISSA OF STAGNATION POINT= -1.00000



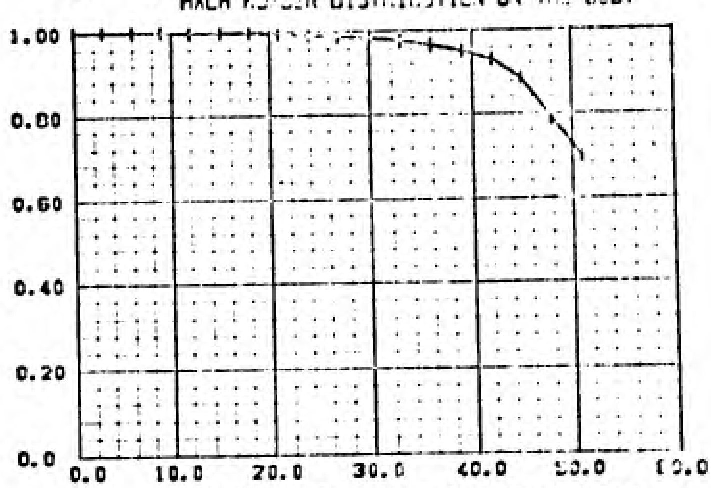
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

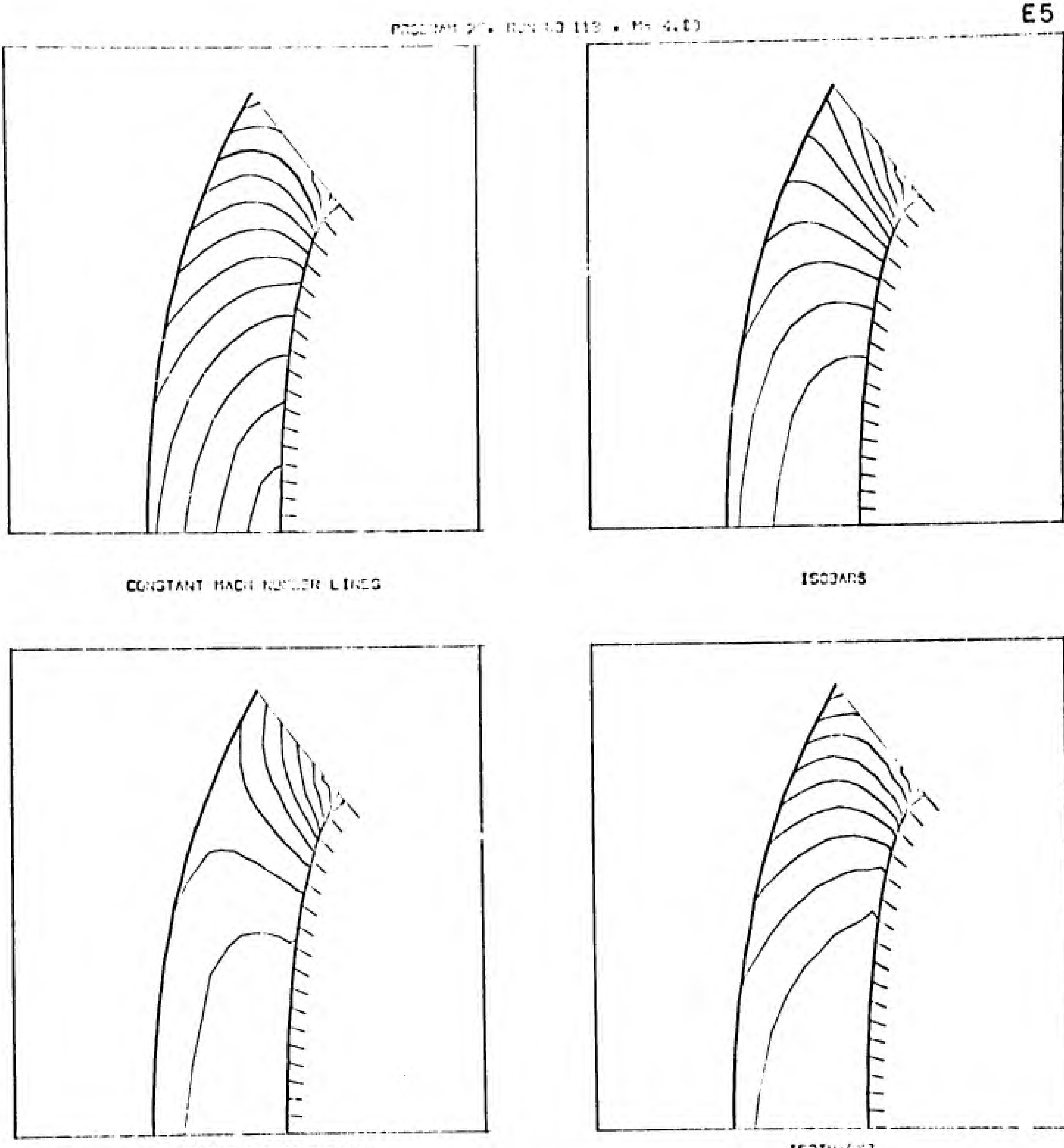


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

E5



CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

AXISYMMETRIC BLUNT BODY   RUN NO 140

10 BY 20 MESH, 2000 STEPS   TOLERANCE=0.000010

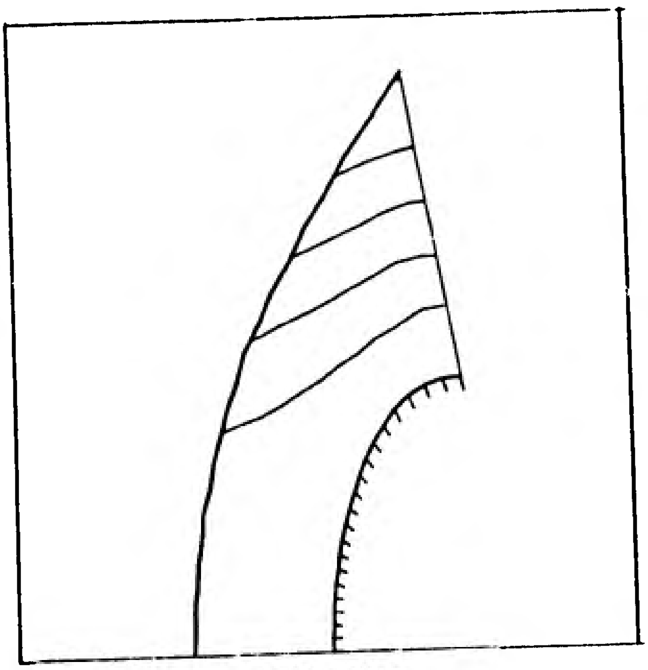
FREE STREAM MACH NUMBER= 2.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 5.640
COMP. STAGNATION PRESSURE= 5.639
RELATIVE ERROR= 0.00033

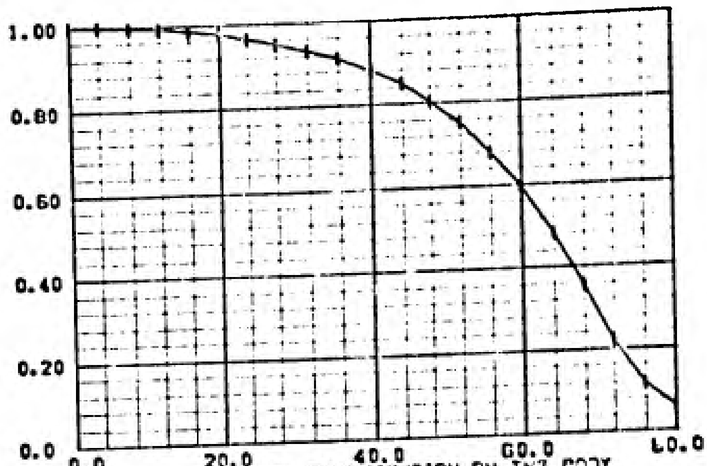
THEOR. STAGNATION TEMPERATURE= 1.800
COMP. STAGNATION TEMPERATURE= 1.800
RELATIVE ERROR= 0.00011

CRITICAL PRESSURE RATIO=0.5331 (REL. ERROR= 0.0148)
CRITICAL DENSITY RATIO=0.6329 (REL. ERROR= 0.0034)
CRITICAL TEMPERAT.RATIO=0.8378 (REL. ERROR= 0.0053)

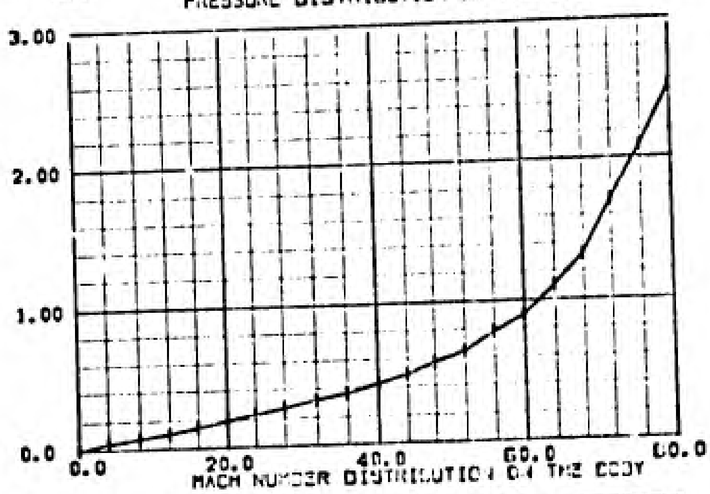
STANDOFF DISTANCE=0.5201
ABSCISSA OF STAGNATION POINT= -0.70000



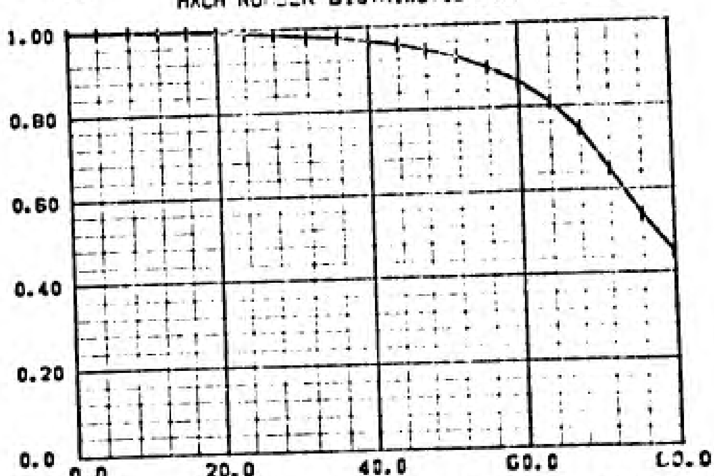
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



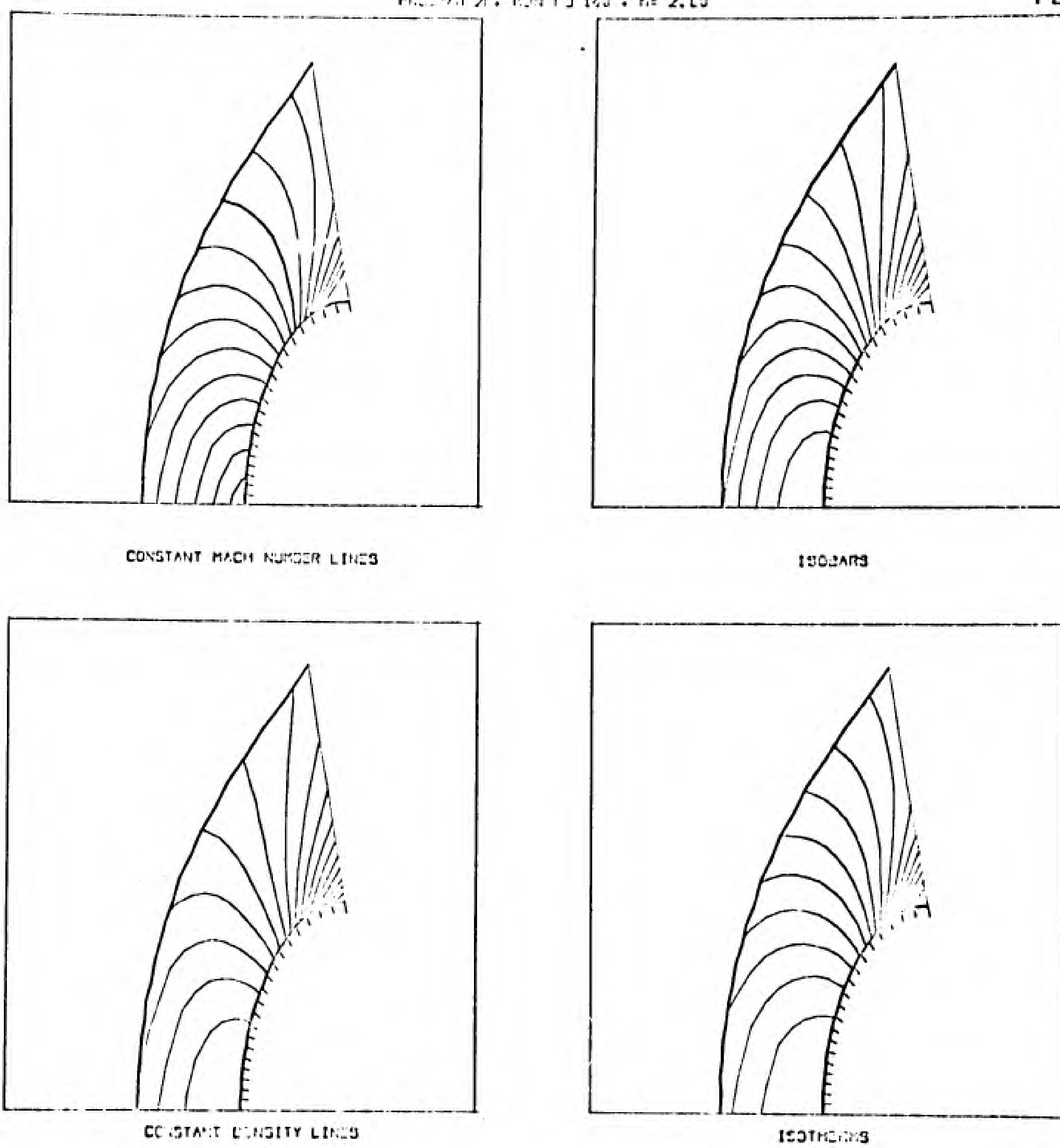
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2 , RUN NO 140 , M= 2.00

F2



AXISYMMETRIC BLUNT BODY RUN NO 141

10 BY 20 MESH, 2000 STEPS TOLERANCE=0.000010

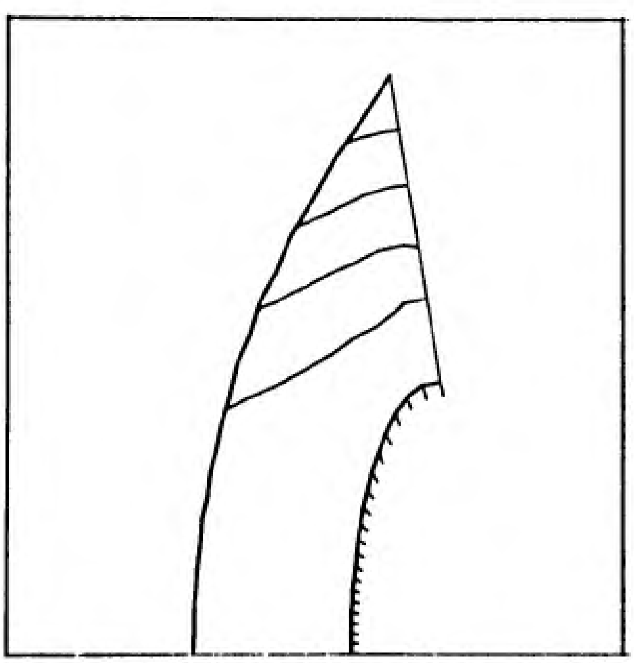
FREE STREAM MACH NUMBER= 2.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 5.640
COMP. STAGNATION PRESSURE= 5.637
RELATIVE ERROR= 0.00059

THEOR. STAGNATION TEMPERATURE= 1.800
COMP. STAGNATION TEMPERATURE= 1.000
RELATIVE ERROR= 0.00017

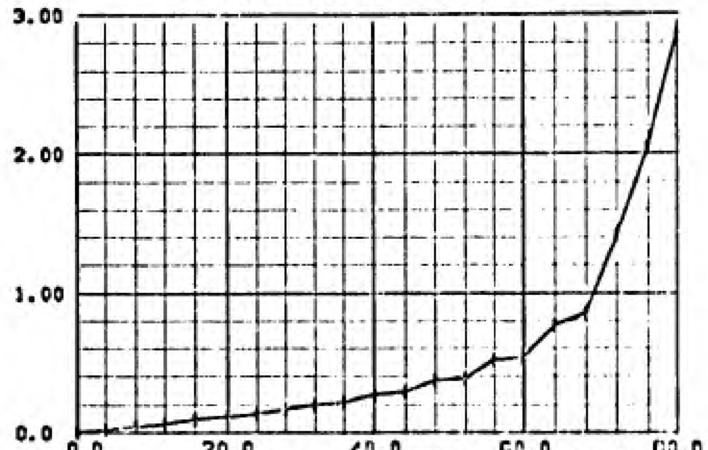
CRITICAL PRESSURE RATIO=0.5401 (REL. ERROR= 0.0223)
CRITICAL DENSITY RATIO=0.6417 (REL. ERROR= 0.0123)
CRITICAL TEMPERAT.RATIO=0.8416 (REL. ERROR= 0.0039)

STANDOFF DISTANCE=0.6035
ABSCISSA OF STAGNATION POINT= -0.53333

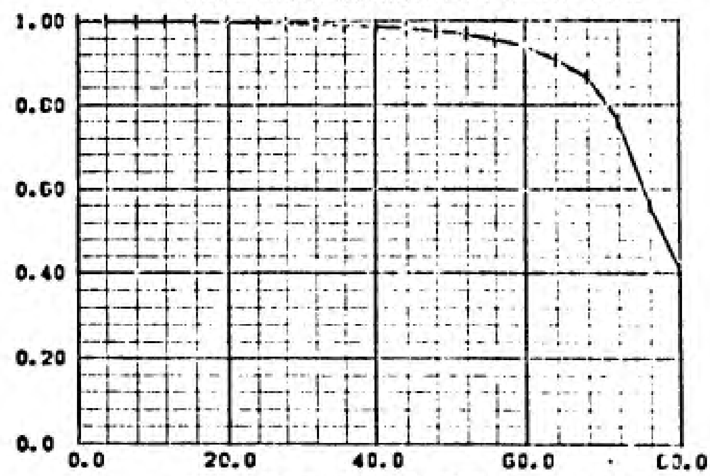


STREAMLINES

PRESSURE DISTRIBUTION ON THE BODY

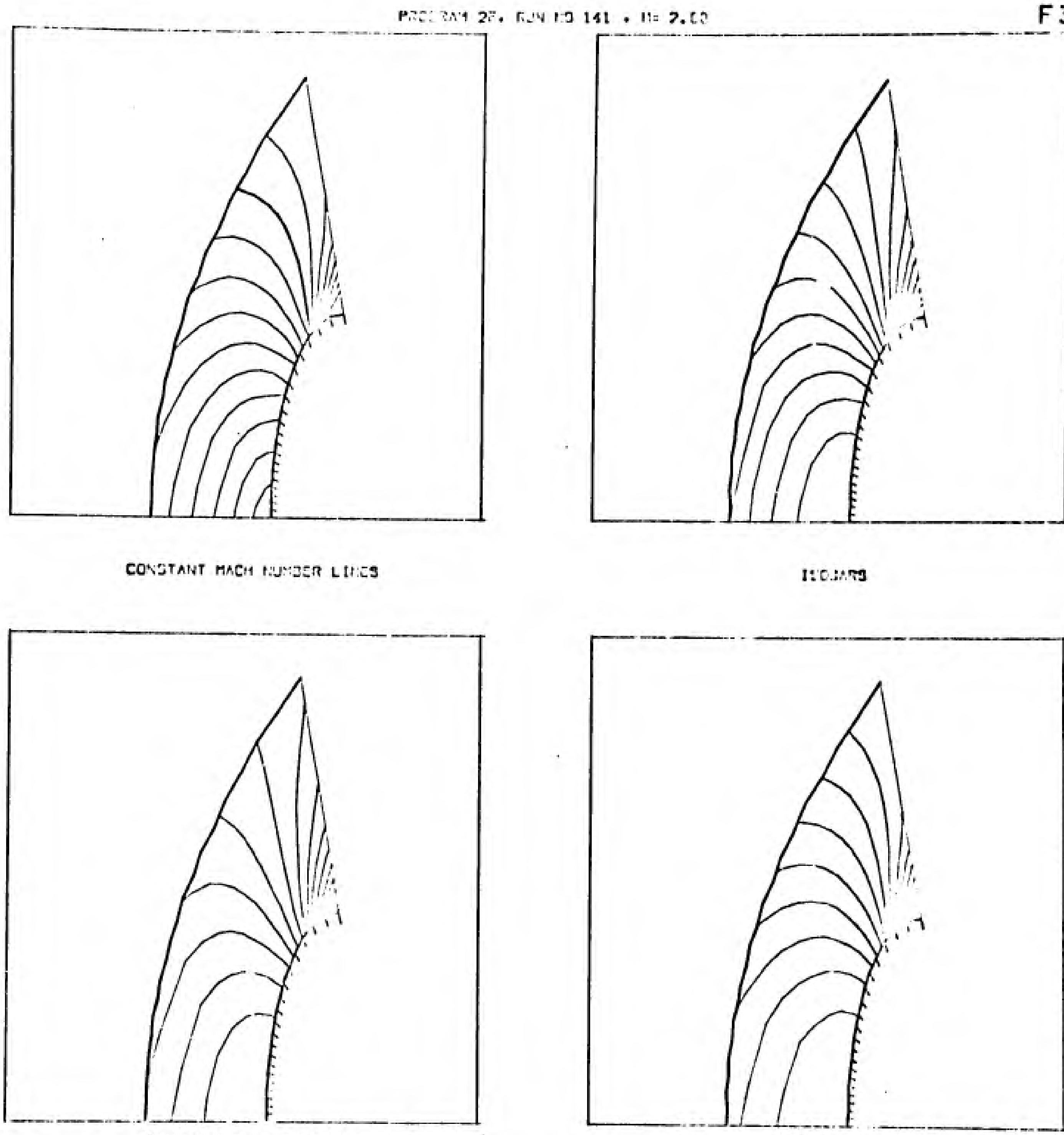


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

PROGRAM 2F, RUN NO 141, M= 2.00 **F3**



AXISYMMETRIC BLUNT BODY RUN NO 150

8 BY 13 MESH, 1000 STEPS TOLERANCE=0.000010

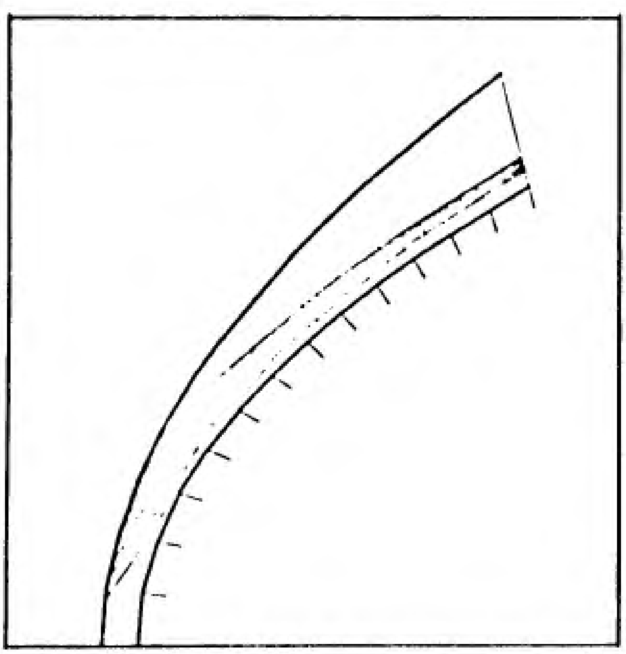
FREE STREAM MACH NUMBER=20.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=515.484
COMP. STAGNATION PRESSURE=515.519
RELATIVE ERROR= 0.00007

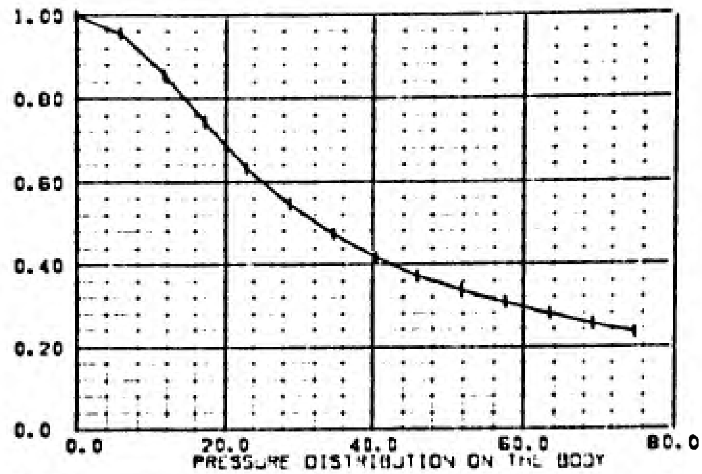
THEOR. STAGNATION TEMPERATURE= 81.000
COMP. STAGNATION TEMPERATURE= 81.002
RELATIVE ERROR= 0.00002

CRITICAL PRESSURE RATIO=0.5205 (REL. ERROR= -.0148)
CRITICAL DENSITY RATIO=0.6269 (REL. ERROR= -.0111)
CRITICAL TEMPERAT.RATIO=0.8302 (REL. ERROR= -.0038)

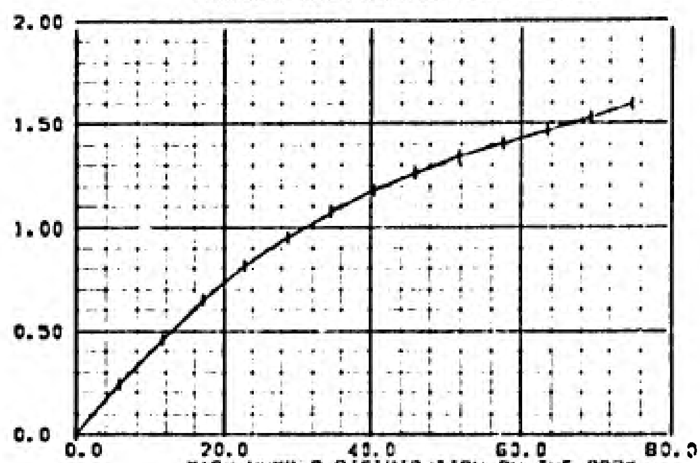
STANDOFF DISTANCE=0.1435
ABSCISSA OF STAGNATION POINT= -2.00000



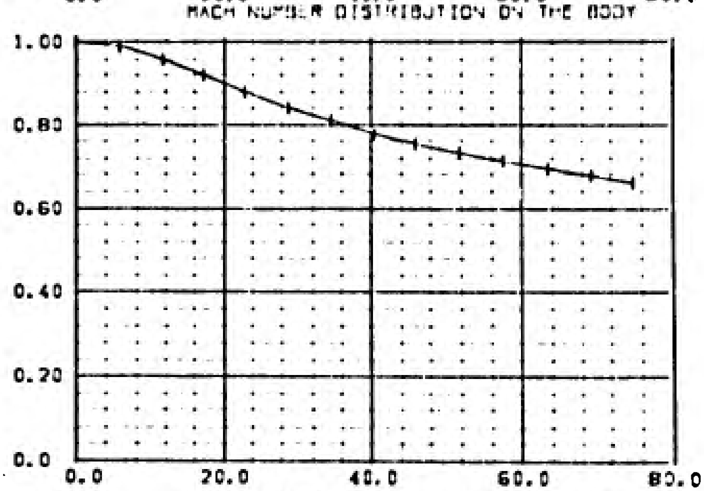
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

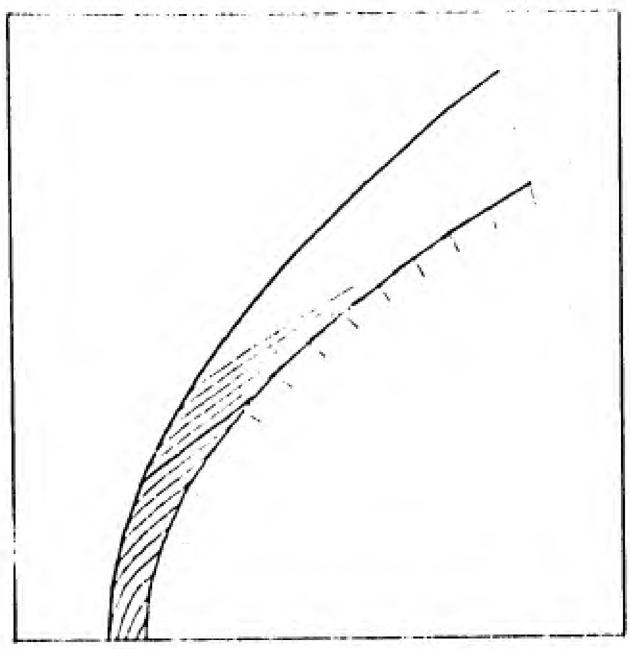


MACH NUMBER DISTRIBUTION ON THE BODY

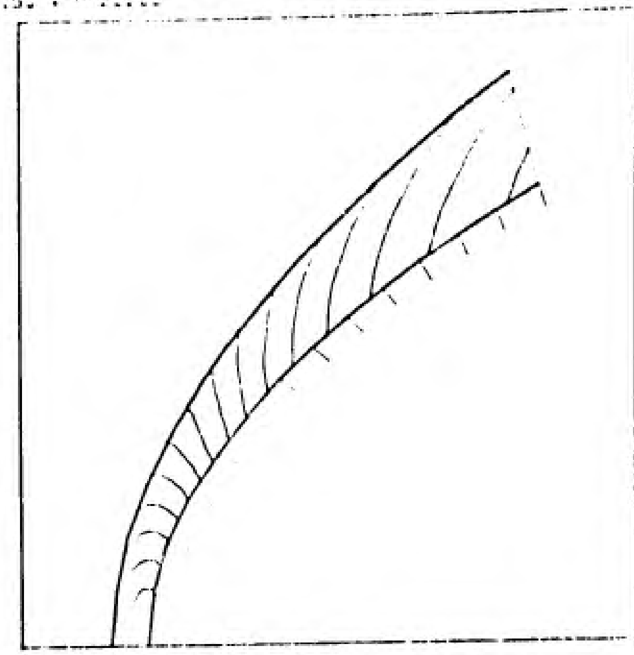


TEMPERATURE DISTRIBUTION ON THE BODY

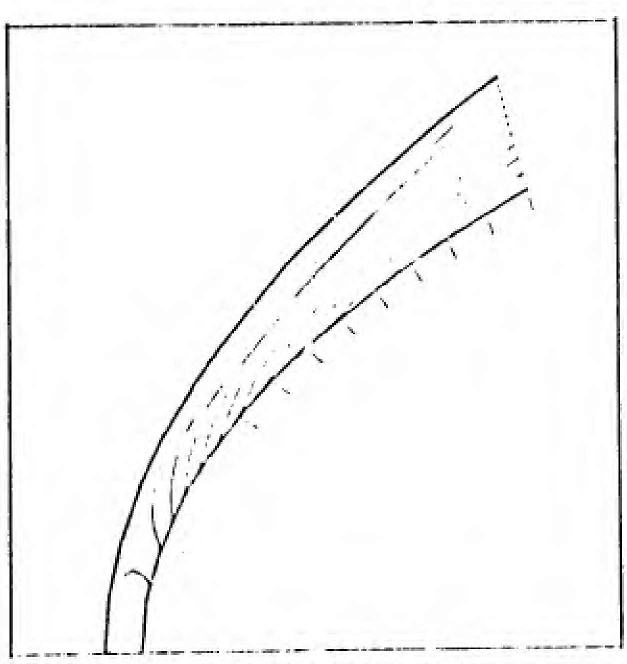
G I



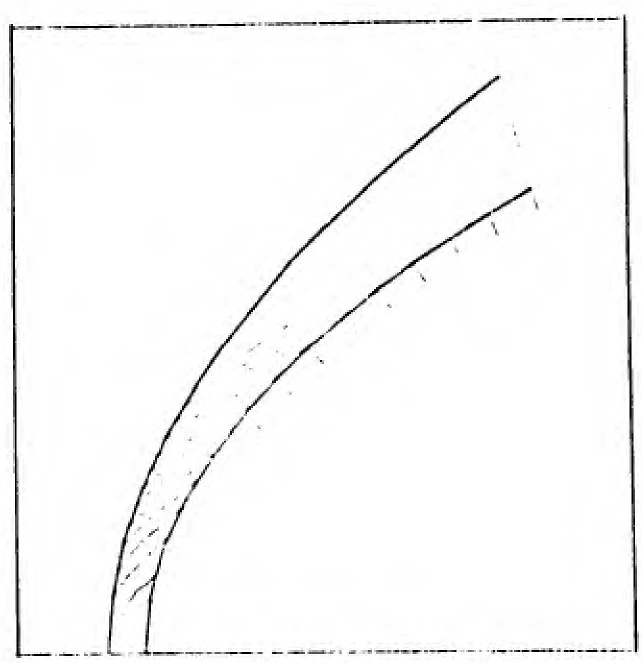
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 151

8 BY 13 MESH, 1000 STEPS TOLERANCE=0.000010

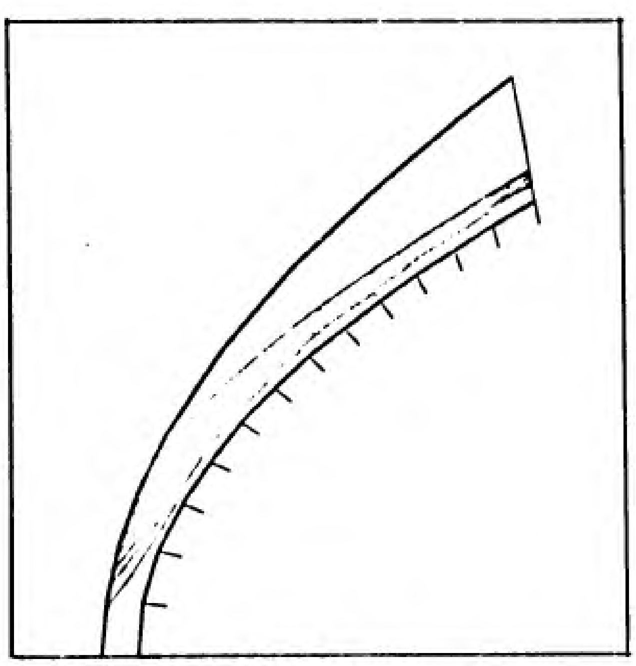
FREE STREAM MACH NUMBER=10.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=129.217
COMP. STAGNATION PRESSURE=129.253
RELATIVE ERROR= 0.00028

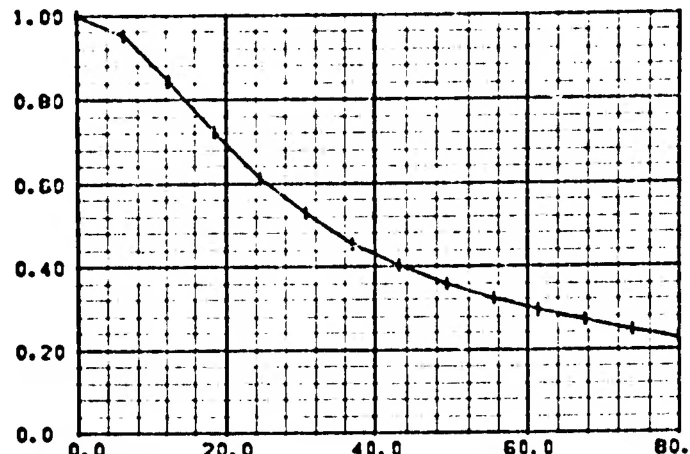
THEOR. STAGNATION TEMPERATURE= 21.000
COMP. STAGNATION TEMPERATURE= 21.002
RELATIVE ERROR= 0.00008

CRITICAL PRESSURE RATIO=0.5194 (REL. ERROR= 0.0100)
CRITICAL DENSITY RATIO=0.6[illegible]2 (REL. ERROR= 0.0122)
CRITICAL TEMPERAT.RATIO=0.8[illegible]35 (REL. ERROR= 0.0048)

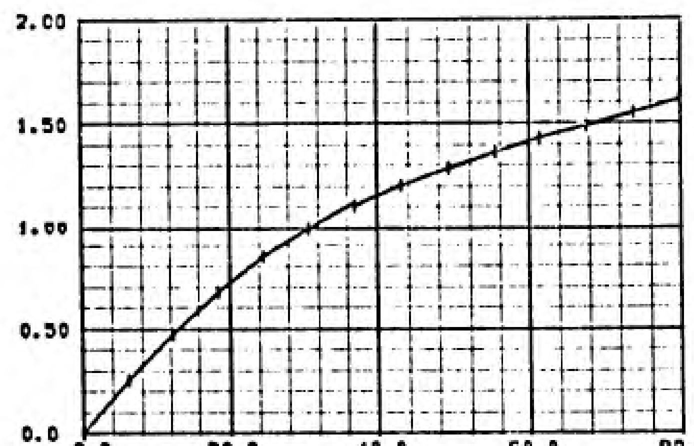
STANDOFF DISTANCE=0.1504
ABSCISSA OF STAGNATION POINT=-2.00000



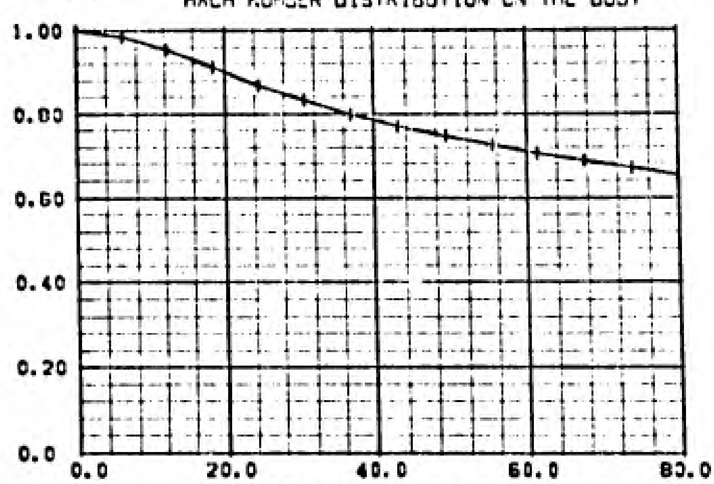
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

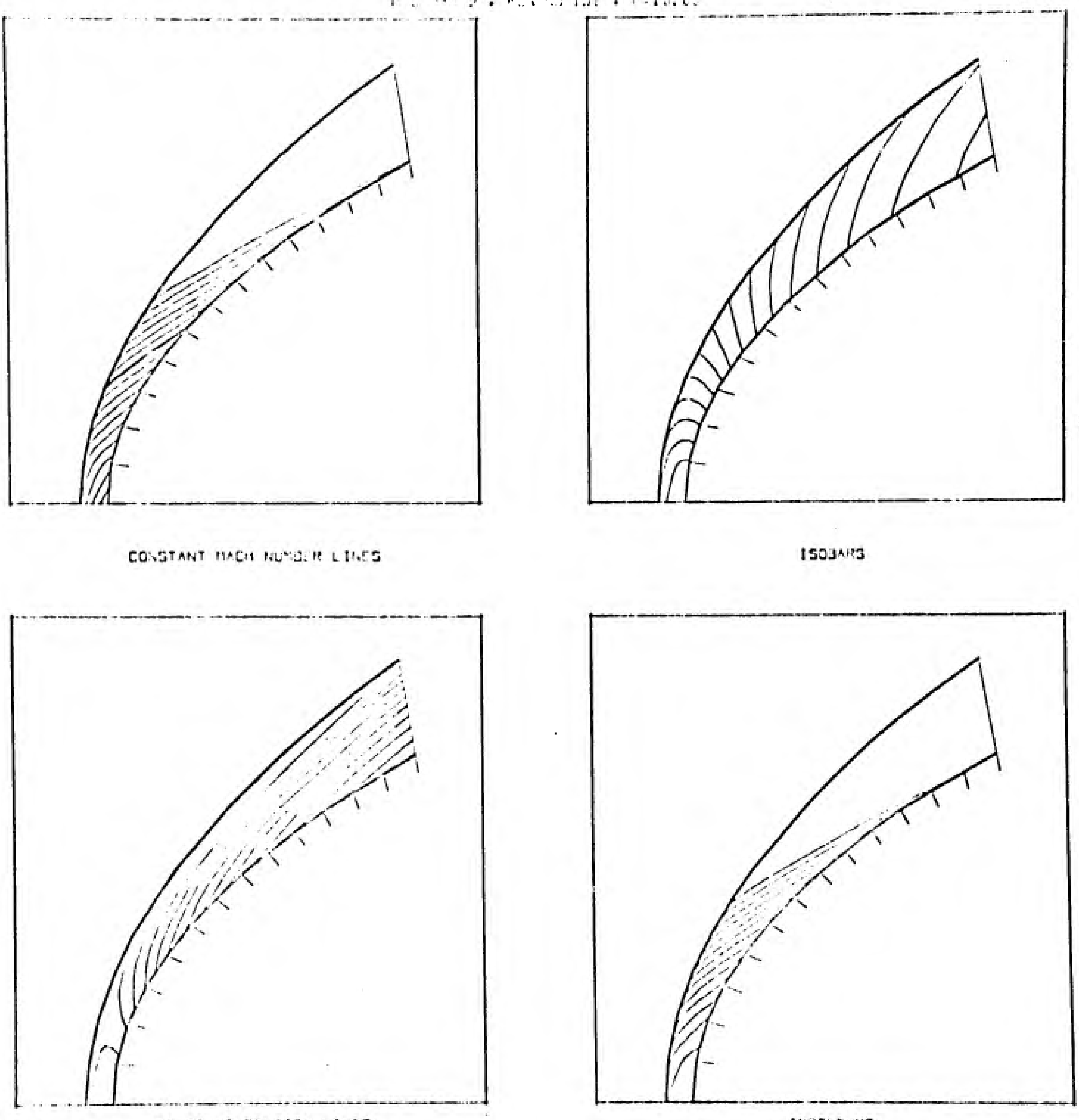


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

G2


CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 152

8 BY 13 MESH, 1400 STEPS TOLERANCE=0.000010

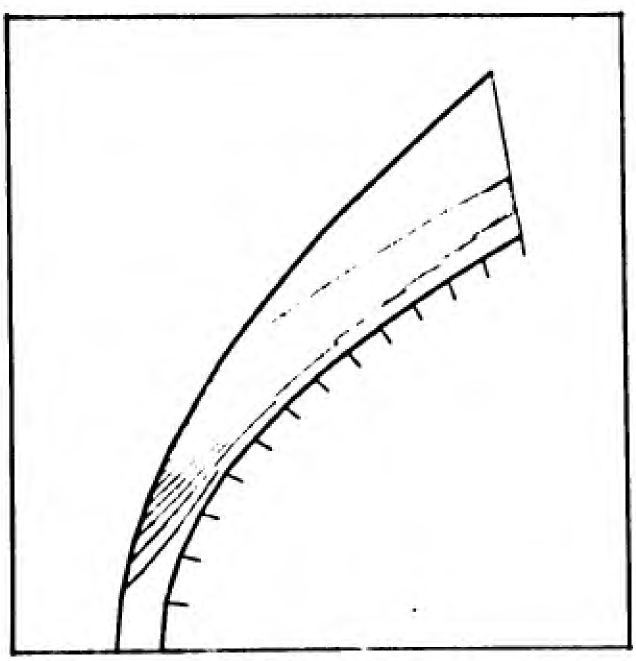
FREE STREAM MACH NUMBER= 4.00, GAMMA= 1.40

THEOR. STAGNATION PRESSURE= 21.070
COMP. STAGNATION PRESSURE= 21.078
RELATIVE ERROR= 0.00038

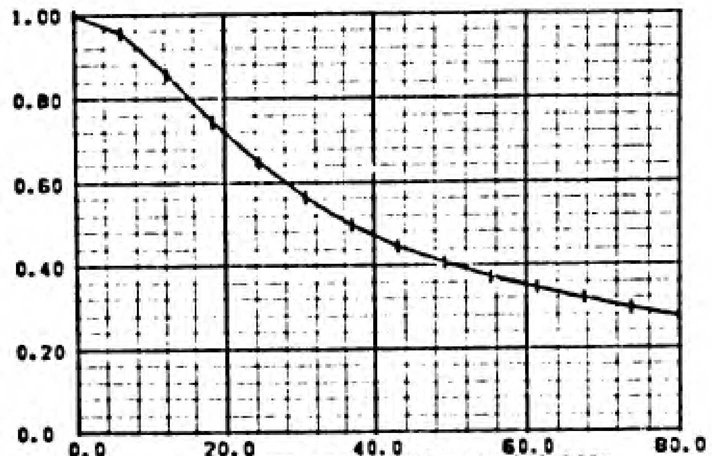
THEOR. STAGNATION TEMPERATURE= 4.200
COMP. STAGNATION TEMPERATURE= 4.200
RELATIVE ERROR= 0.00010

CRITICAL PRESSURE RATIO=0.5194 (REL. ERROR= 0.0168)
CRITICAL DENSITY RATIO=0.6261 (REL. ERROR= 0.0124)
CRITICAL TEMPERAT.RATIO=0.8293 (REL. ERROR= 0.0045)

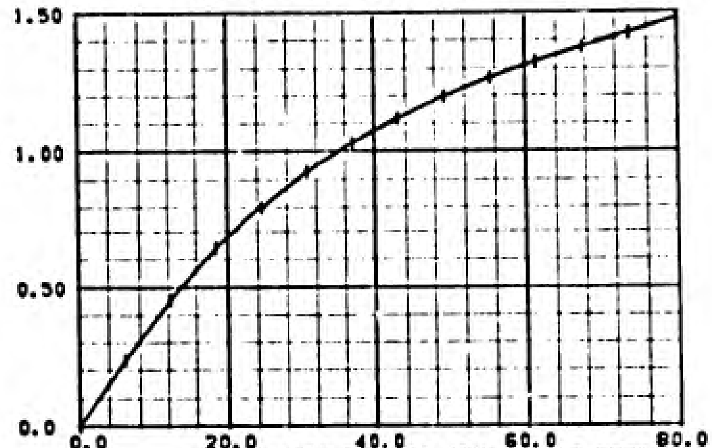
STANDOFF DISTANCE=0.1982
ABSCISSA OF STAGNATION POINT=-2.00000



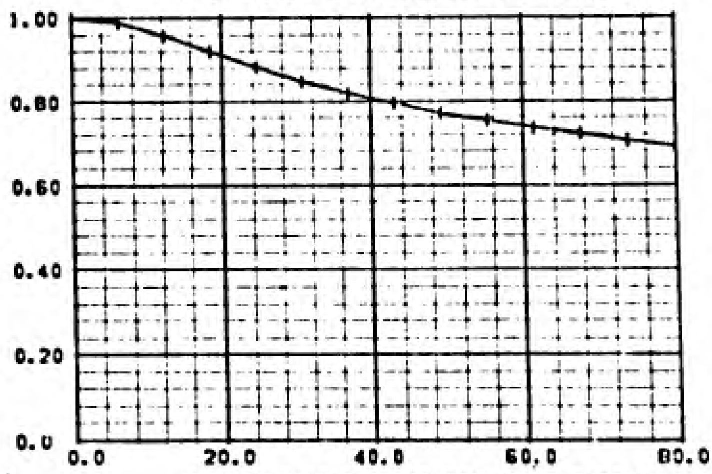
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

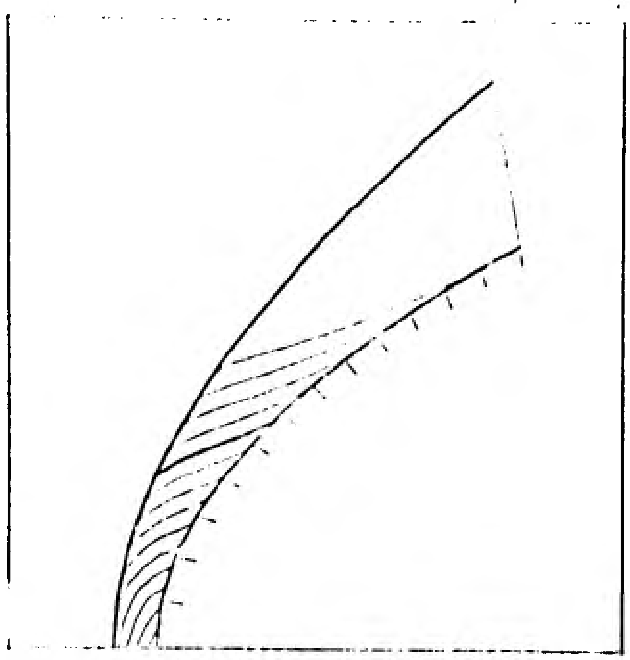


MACH NUMBER DISTRIBUTION ON THE BODY

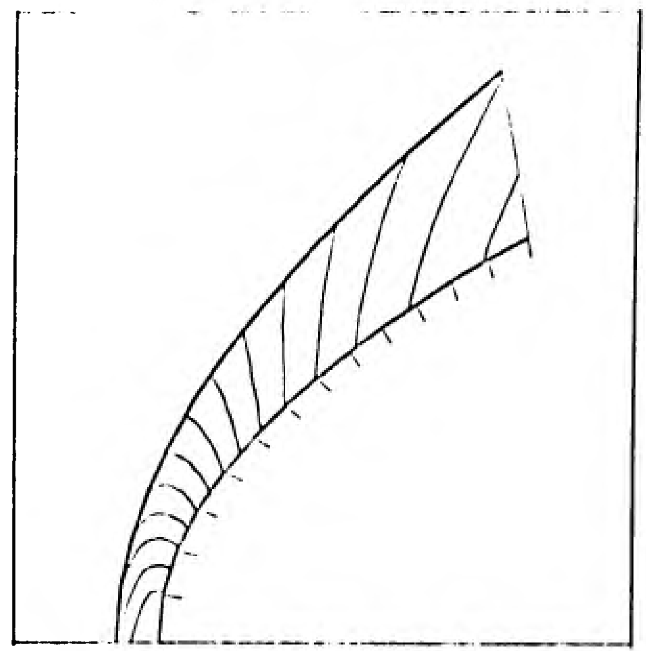


TEMPERATURE DISTRIBUTION ON THE BODY

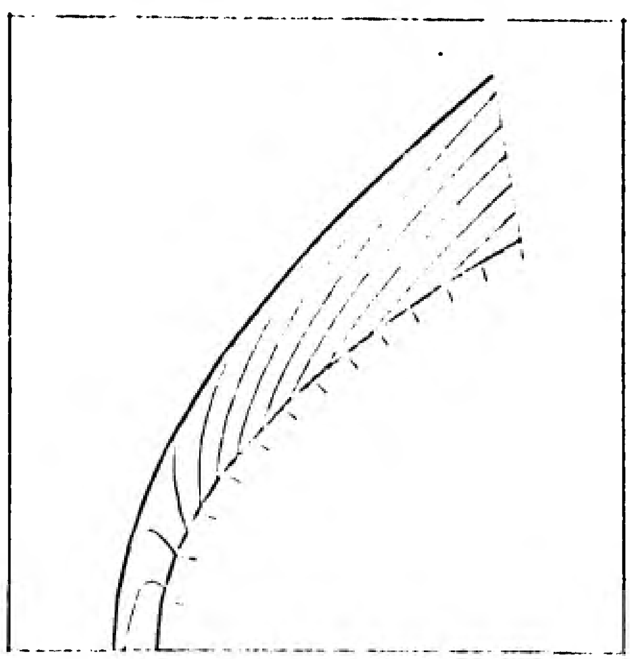
G3



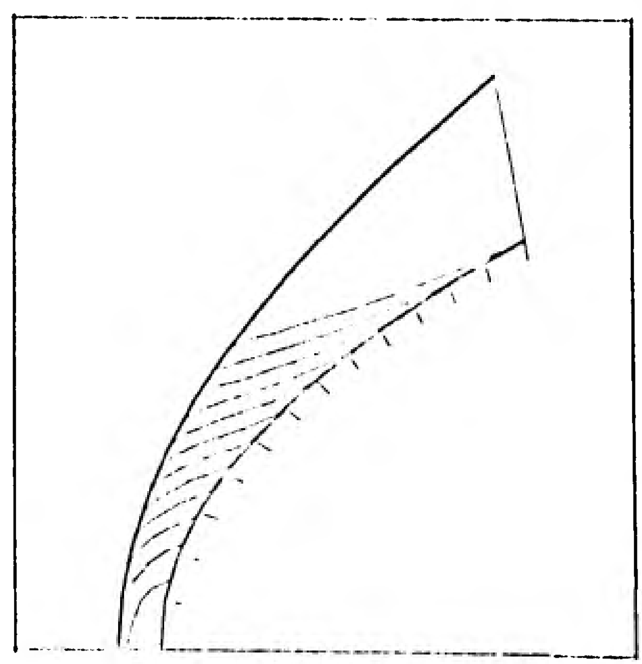
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 80

10 BY 11 MESH, 1000 STEPS TOLERANCE=0.000010

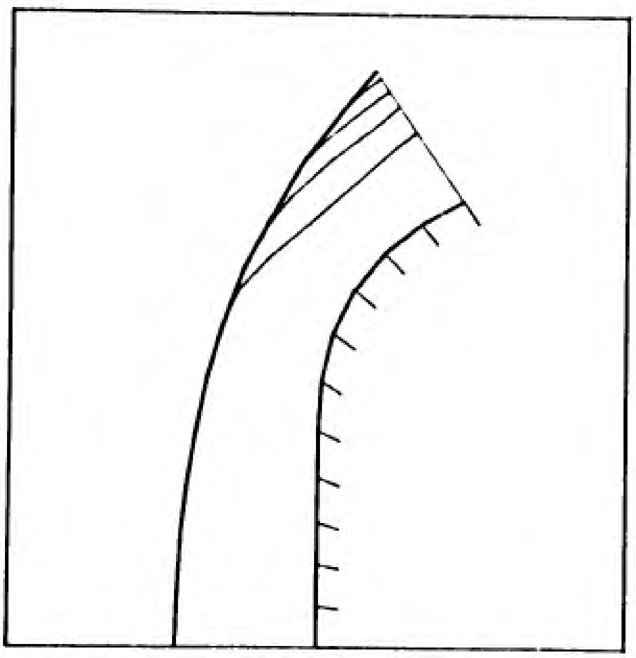
FREE STREAM MACH NUMBER=10.50, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=142.414
COMP. STAGNATION PRESSURE=142.350
RELATIVE ERROR= 0.00045

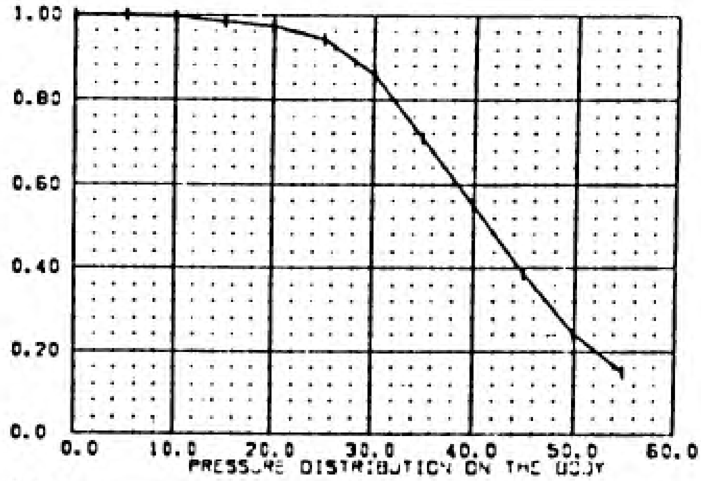
THEOR. STAGNATION TEMPERATURE= 23.050
COMP. STAGNATION TEMPERATURE= 23.047
RELATIVE ERROR= 0.00013

CRITICAL PRESSURE RATIO=0.5373 (REL. ERROR= 0.0171)
CRITICAL DENSITY RATIO=0.6411 (REL. ERROR= 0.0113)
CRITICAL TEMPERAT.RATIO=0.8381 (REL. ERROR= 0.0057)

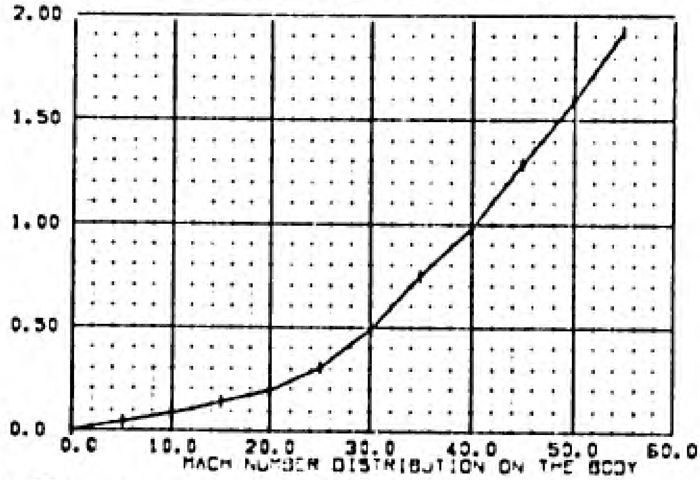
STANDOFF DISTANCE=0.3119
ABSCISSA OF STAGNATION POINT=-1.3119



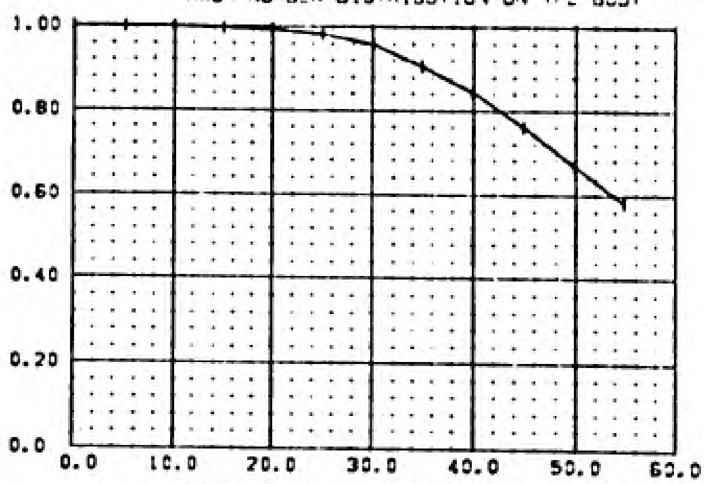
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



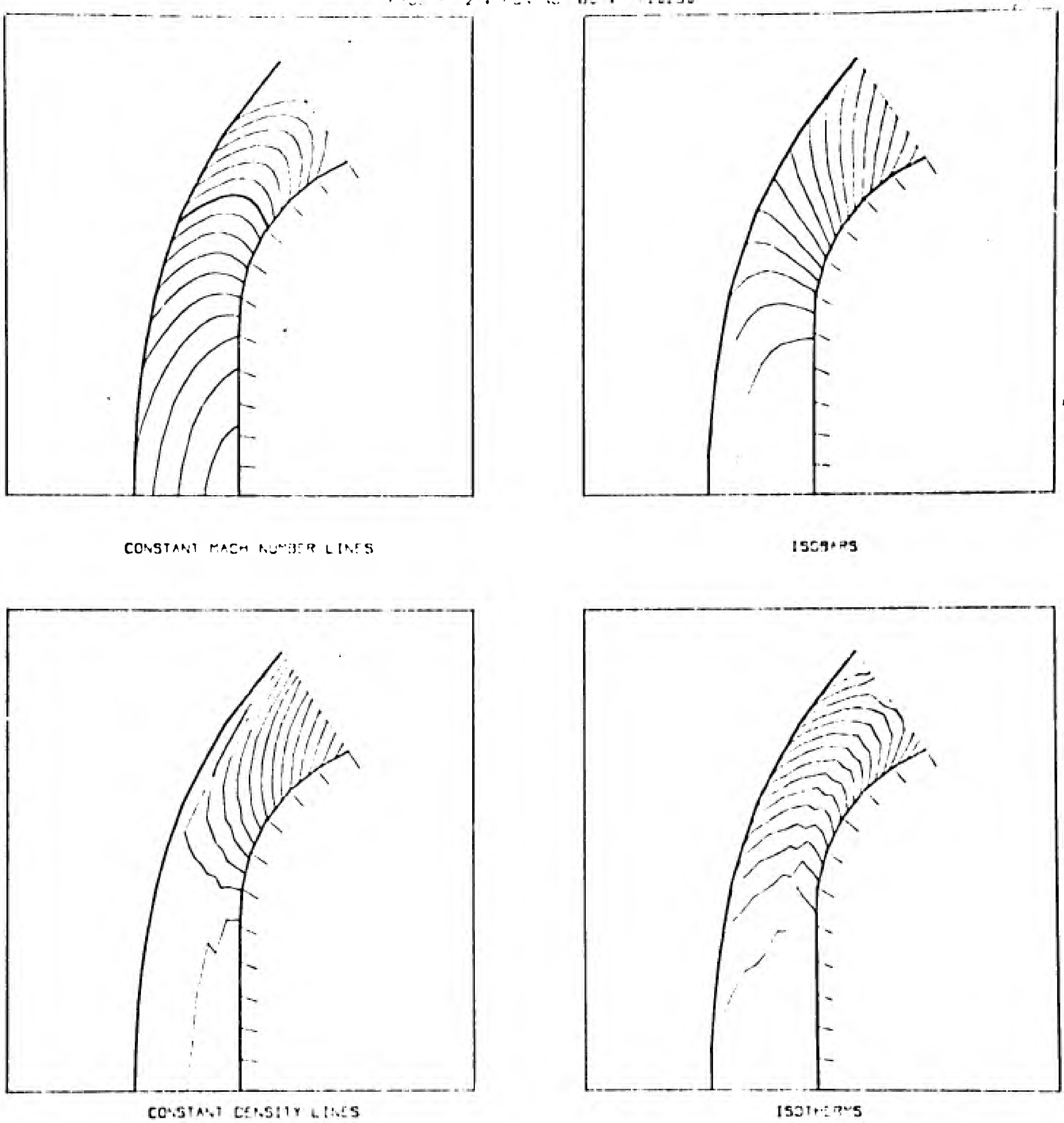
MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

H I

[illegible]



CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 81

10 BY 16 MESH, 1000 STEPS TOLERANCE=0.000010

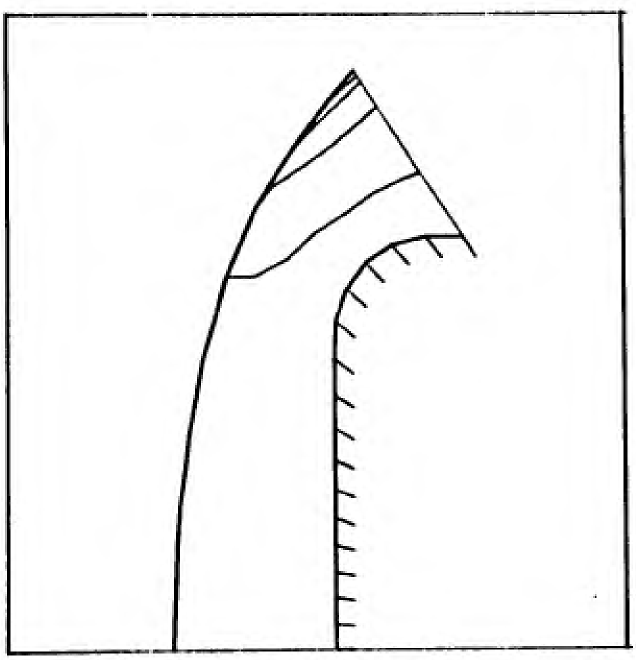
FREE STREAM MACH NUMBER=10.50, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=142.414
COMP. STAGNATION PRESSURE=141.930
RELATIVE ERROR= 0.00340

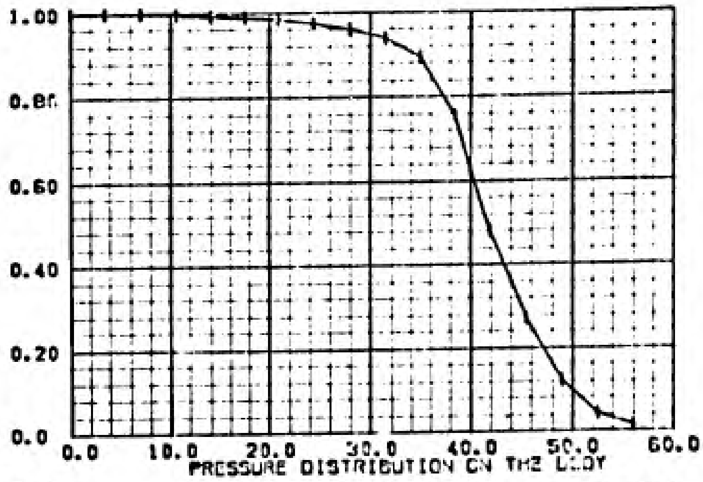
THEOR. STAGNATION TEMPERATURE= 23.050
COMP. STAGNATION TEMPERATURE= 23.028
RELATIVE ERROR= 0.00097

CRITICAL PRESSURE RATIO=0.5774 (REL. ERROR= 0.0331)
CRITICAL DENSITY RATIO=0.6721 (REL. ERROR= 0.0302)
CRITICAL TEMPERAT.RATIO=0.8591 (REL. ERROR= 0.0310)

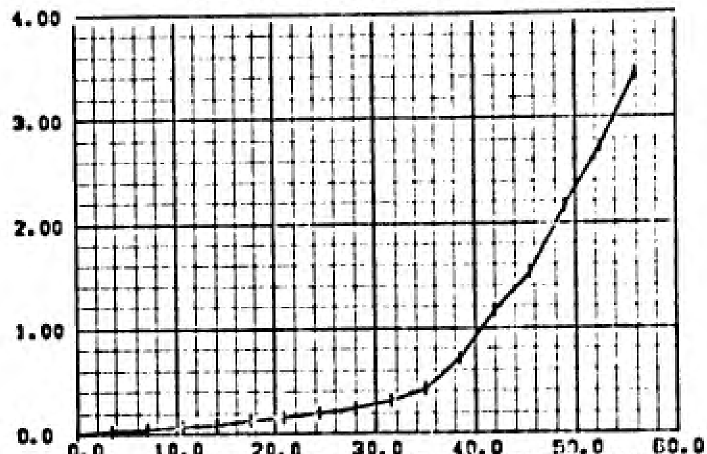
STANDOFF DISTANCE=0.4010
ABSCISSA OF STAGNATION POINT=-1.00000



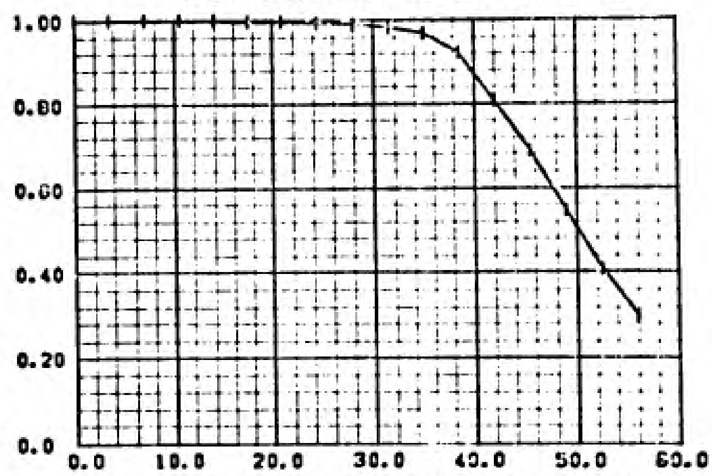
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY



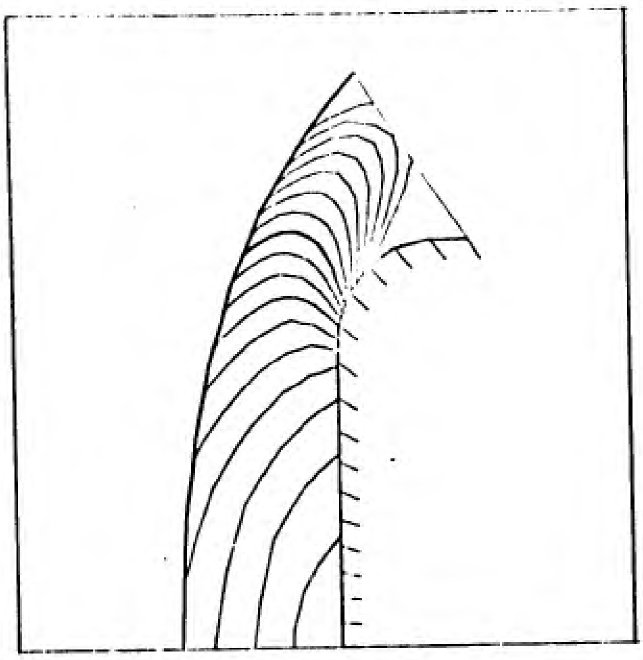
MACH NUMBER DISTRIBUTION ON THE BODY



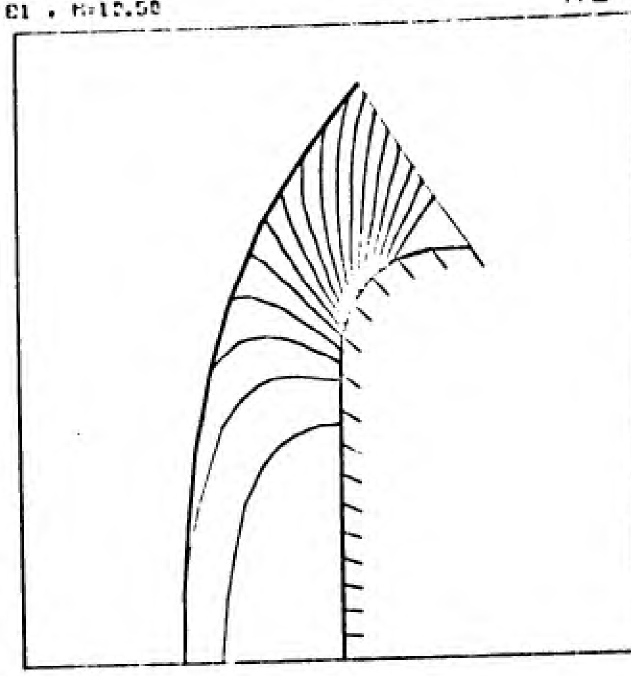
TEMPERATURE DISTRIBUTION ON THE BODY

H2

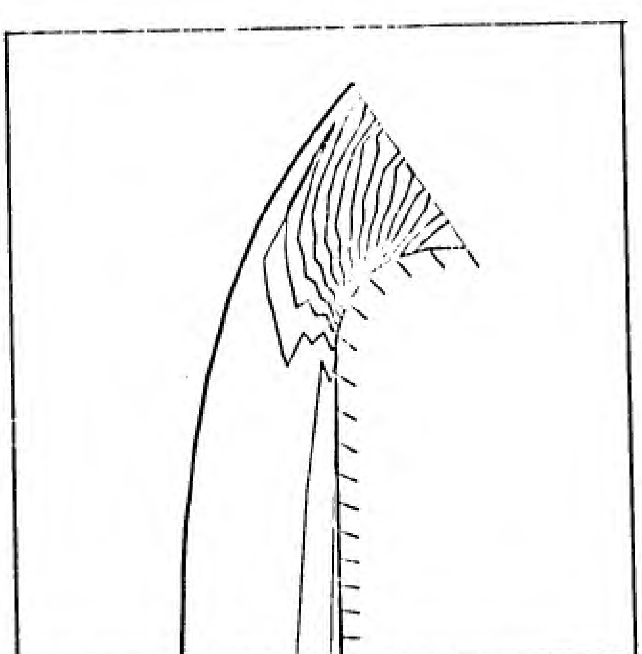
01 . M=10.50



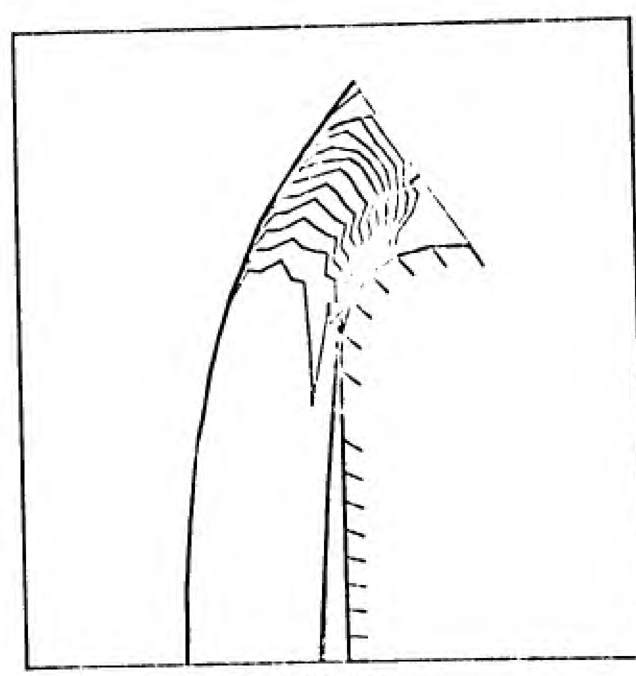
CONSTANT MACH NUMBER LINES



ISOBARS



CONSTANT DENSITY LINES



ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 82

10 BY 20 MESH, 1000 STEPS TOLERANCE=0.000010

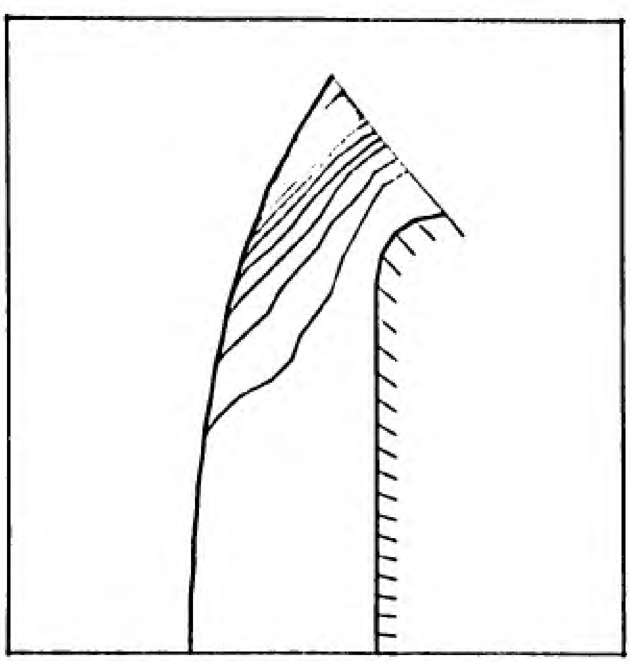
FREE STREAM MACH NUMBER=10.50, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=142.414
COMP. STAGNATION PRESSURE=141.836
RELATIVE ERROR= 0.00403

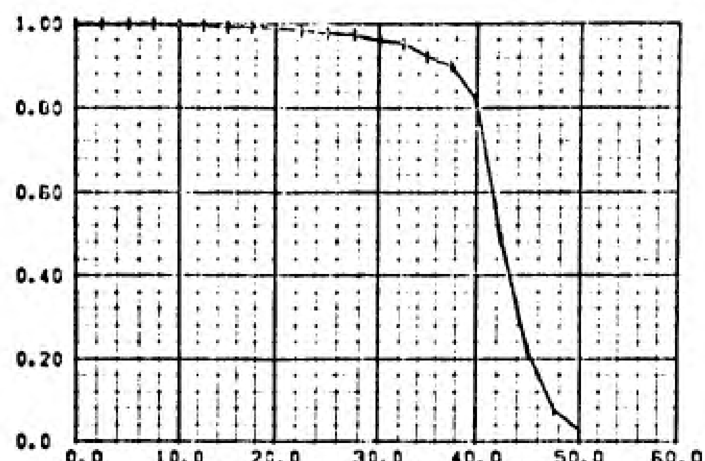
THEOR. STAGNATION TEMPERATURE= 23.050
COMP. STAGNATION TEMPERATURE= 23.023
RELATIVE ERROR= 0.00118

CRITICAL PRESSURE RATIO=0.5862 (REL. ERROR= 0.1097)
CRITICAL DENSITY RATIO=0.6705 (REL. ERROR= 0.0704)
CRITICAL TEMPERAT.RATIO=0.8839 (REL. ERROR= 0.0337)

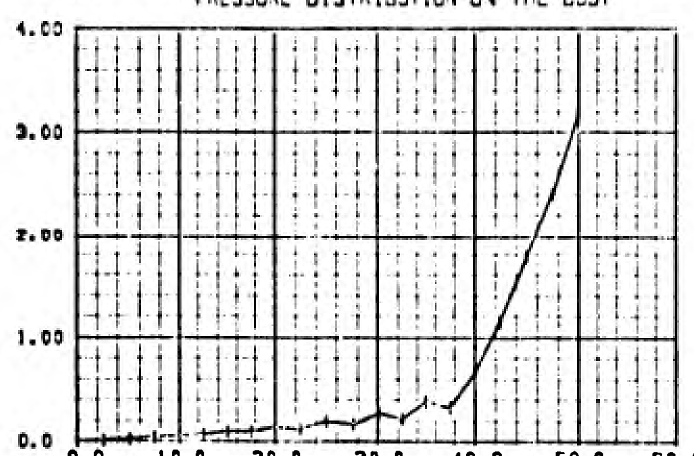
STANDOFF DISTANCE=0.4393
ABSCISSA OF STAGNATION POINT=-1.00000



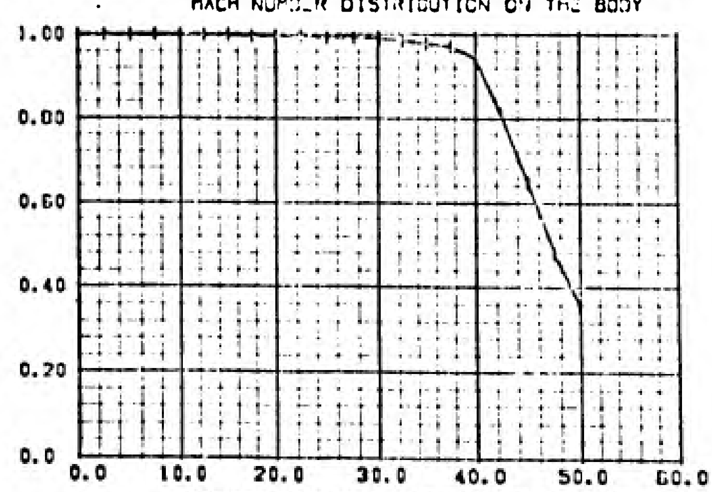
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

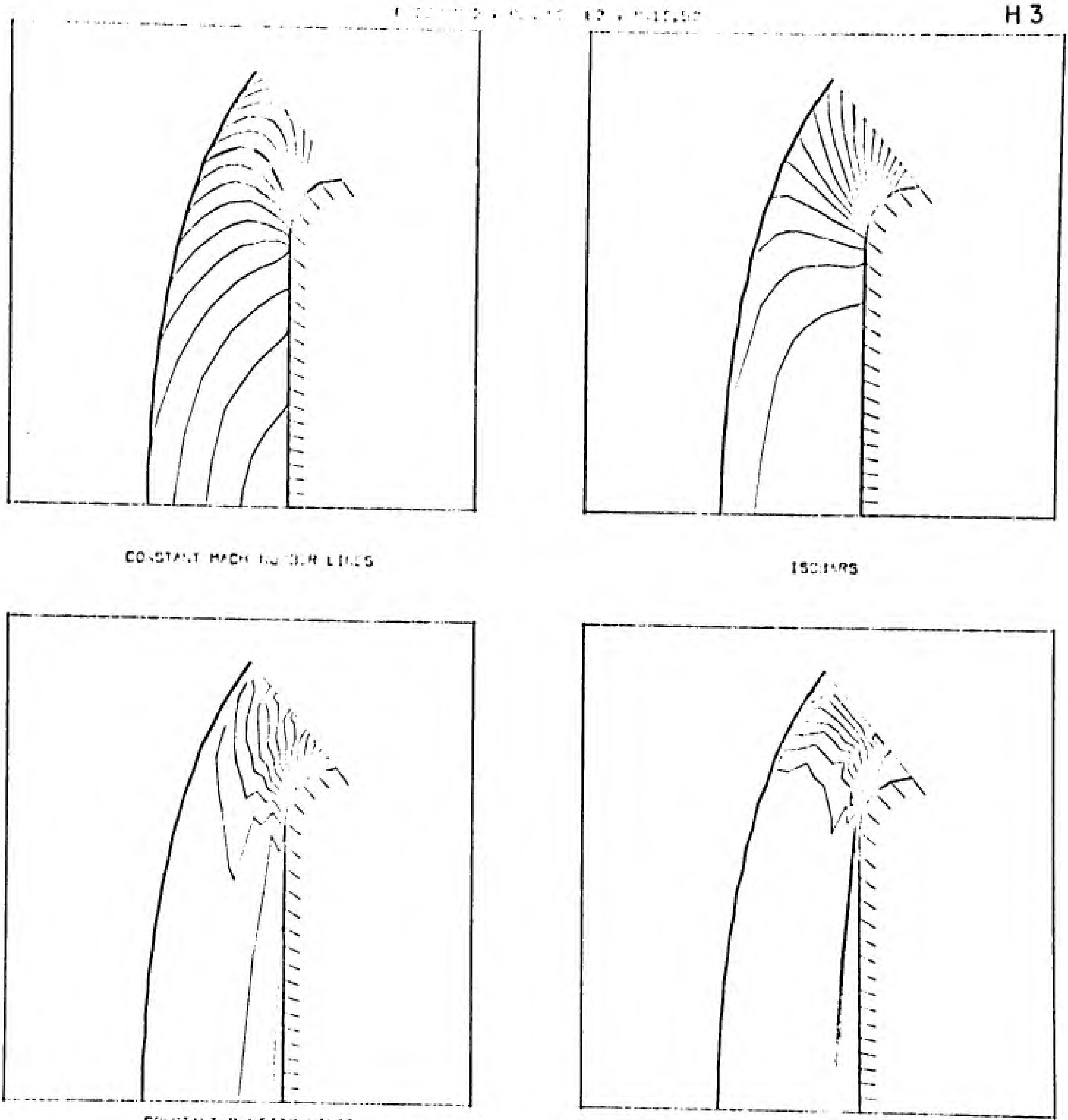


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

H3



CONSTANT MACH NUMBER LINES

ISOBARS

CONSTANT DENSITY LINES

ISOTHERMS

AXISYMMETRIC BLUNT BODY RUN NO 83

10 BY 20 MESH, 1000 STEPS TOLERANCE=0.000010

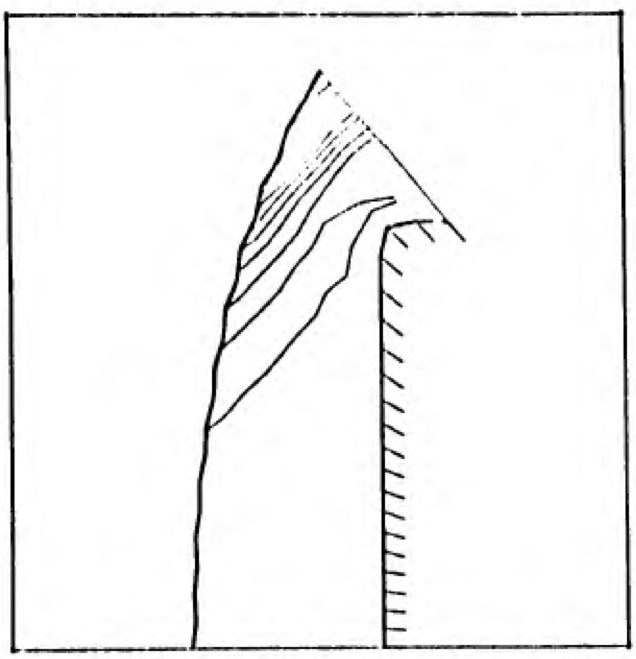
FREE STREAM MACH NUMBER=10.50, GAMMA= 1.40

THEOR. STAGNATION PRESSURE=142.414
COMP. STAGNATION PRESSURE=142.034
RELATIVE ERROR= 0.00267

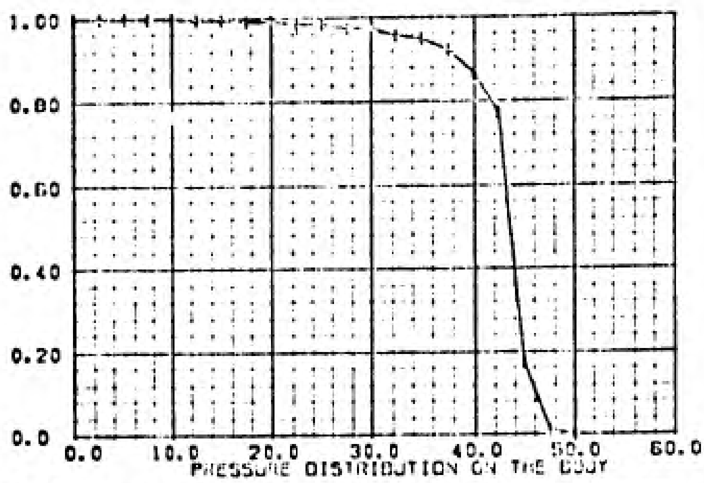
THEOR. STAGNATION TEMPERATURE= 23.050
COMP. STAGNATION TEMPERATURE= 23.032
RELATIVE ERROR= 0.00077

CRITICAL PRESSURE RATIO=0.7438 (REL. ERROR= 0.4079)
CRITICAL DENSITY RATIO=0.0034 (REL. ERROR= 0.2705)
CRITICAL TEMPERAT.RATIO=0.9235 (REL. ERROR= 0.1002)

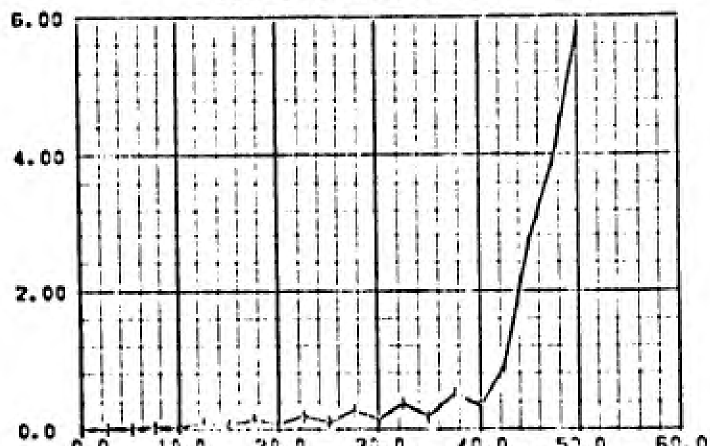
STANDOFF DISTANCE=0.4618
ABSCISSA OF STAGNATION POINT= -1.00000



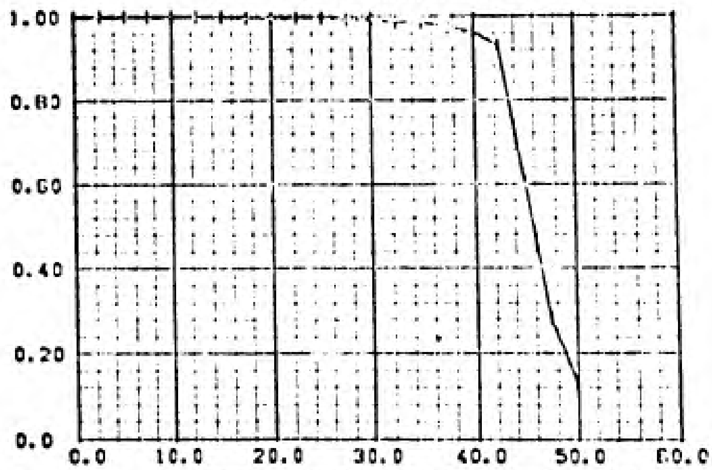
STREAMLINES



PRESSURE DISTRIBUTION ON THE BODY

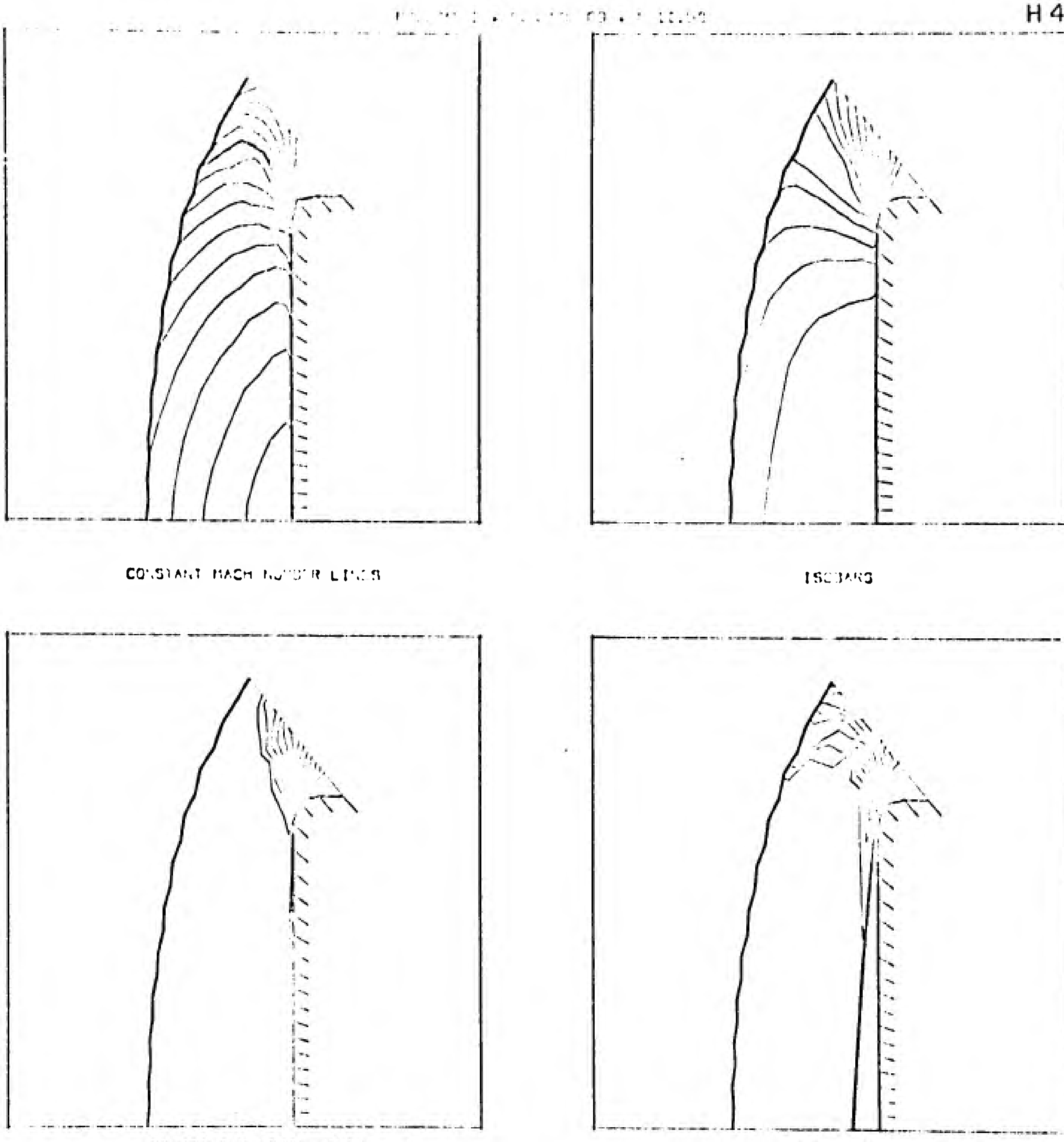


MACH NUMBER DISTRIBUTION ON THE BODY



TEMPERATURE DISTRIBUTION ON THE BODY

H 4



CONSTANT MACH NUMBER LINES
ISOBARS
CONSTANT DENSITY LINES
ISOTHERMS

Unclassified

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13. ABSTRACT

The results of a time-dependent computation of blunt body shock layers for two-dimensional symmetric and axisymmetric flows are presented in a systematic form for a range of values of the free stream Mach number and bodies of different shapes and variable bluntness.

A brief discussion of the relevant features of the computational technique is given. The results are presented in a graphical form; the graphs have been produced by the computer.

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Transonic flow						
Hypersonic flow						

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