SEP 11 1964

UCRL-7807

MASTER

University of California
Ernest O. Lawrence
Radiation Laboratory

THE AERODYNAMIC HEATING OF A
VEHICLE TRAVELING AT SUPERSONIC
VELOCITIES THROUGH A COMPRESSIBLE FLUID

NOT FOR PUBLIC RELEASE - OFFICIAL
DISTRIBUTION MAY BE MADE. OFFICIAL
REQUESTS MAY BE FILLED. REPORT
CONTAINS NOTHING OF PATENT INTEREST.
PROCEDURES ON FILE IN RECEIVING
SECTION.

Livermore, California

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This paper was submitted for publication in the open literature at least 6 months prior to the issuance date of this Microcard. Since the U.S.A.E.C. has no evidence that it has been published, the paper is being distributed in Microcard form as a preprint.

UCRL-7807

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Livermore, California

Contract No. W-7405-eng-48

THE AERODYNAMIC HEATING OF A VEHICLE TRAVELING AT
SUPERSONIC VELOCITIES THROUGH A COMPRESSIBLE FLUID

John Harri

July 23, 1964

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

	<u>Page No.</u>
Abstract	1
Nomenclature	1
Introduction	2
Theory	3
The 7094 Solution	7
Example Problem (HAD Rocket)	7
References	11
Bibliography	11
Appendices:	
A FORTRAN Statements for 7094 Solution	12
Laminar Program	12
Turbulent Program	15
Order of Deck	17
B HAD Data Input	18
Cylindrical Section (Flat Plate Data)	18
30° Cone Section	19
20° Cone Section	21
10° Cone Section	23
HAD Configuration Data Input	25
C Typical Data Output	26
Turbulent Approximation, T_w in °R	26
Laminar Approximation, T_w in °R	33

CONTENTS (Continued)

	<u>Page No.</u>
Illustrations:	
Fig. 1. Velocity profile for fluid flow along a wall	38
Fig. 2. Nose cone approximated by three conical segments.	39
Fig. 3. Temperature distribution along HAD nose cone. Wall thickness $1/8$ in., time 29 sec after launch	40
Fig. 4. Wall temperature 6 in. aft of nose as a function of time after launch. Wall thickness $1/8$ in.	41

THE AERODYNAMIC HEATING OF A VEHICLE TRAVELING AT SUPERSONIC VELOCITIES THROUGH A COMPRESSIBLE FLUID

John Harri

Lawrence Radiation Laboratory, University of California
Livermore, California

July 23, 1964

ABSTRACT

An equation is derived which describes the wall temperature of a vehicle traveling at supersonic velocities through a compressible fluid. A solution of this equation is obtained by the use of the 7094 computer for both laminar and turbulent boundary layers using the Van Driest boundary layer shear stresses. Example calculations pertaining to the Lawrence Radiation Laboratory High Altitude Diagnostics rocket are included to demonstrate the use of the theory.

NOMENCLATURE

C_p	Specific heat of air
C_{pw}	Specific heat of missile skin
e	Emissivity of skin material
$\tilde{F}$	External force term in Navier-Stokes equation
G	Incident solar radiation
h	Heat transfer film coefficient
k	Ratio of specific heats for air
P	Pressure
q	Heat flux
t	Time

T_w	Wall temperature
T_r	Recovery temperature
T_∞	Free stream temperature
U_∞	Free stream velocity
u, v, w	Velocity components in the x, y, z , directions, respectively
x, y, z	Linear coordinates
∇^2	Laplacian operator
δ_w	Skin thickness
δ_b	Boundary layer thickness
ρ_w	Skin density
ρ_∞	Free stream density
σ	Stefan-Boltzmann constant
μ	Dynamic viscosity
ν	Kinematic viscosity
τ_w	Fluid shear stress at the fluid-wall boundary

INTRODUCTION

Aerodynamic heating is a fundamental parameter in designing missile nose cones and in selecting materials for them. Early design philosophy involved designing for the stagnation temperature, a practice which places undue concern on the heating problem. It is of interest then to examine this problem and obtain more reasonable limits for the expected temperatures, which might lead to a relaxation of the design requirements. To accomplish this goal it is necessary to examine not only the flow characteristics about the missile in question but also the nature of the boundary layer at the missile surface.

THEORY

For the purpose of analysis, consider an increment of wall past which is flowing a compressible fluid as in Fig. 1. δ_b represents the boundary layer thickness, δ_w the wall thickness, and U_∞ the stream velocity at the edge of the boundary layer ($y = \delta_b$). The velocity profile shown is typical of that through the boundary layer.

Using the following assumptions, an energy balance may be written describing the transfer of energy from the fluid to the wall.

1. Negligible heating of the material on the side of the wall opposite the fluid.
2. Negligible heat transfer in the x direction.
3. The temperature gradient in the y direction through the wall is small.

The net heat transfer from the fluid to the wall is represented by an increase in internal energy of the wall. This stored energy per unit area may be represented by

$$\frac{dq}{dt} = C_{pw} \rho_w \delta_w \frac{dT_w}{dt} \quad (1)$$

where C_{pw} is the specific heat of the wall, ρ_w is the density of the wall, δ_w is the wall thickness, T_w is the wall temperature, and t is the time.

Two mechanisms govern the heating of the wall. First, the major energy source is the boundary layer in which the velocity gradient results in a fluid temperature increase. (The lost fluid kinetic energy now appears as fluid internal energy.) The average temperature of the boundary layer is usually termed the recovery temperature. The second mechanism is that of radiation which tends to cool the wall. The net heat transfer per unit area to a wall such as described in Fig. 1 which is in addition subjected to radiation from the sun is

$$\frac{dq}{dt} = h(T_r - T_w) - e(\sigma T_w^4 - G) \quad (2)$$

where h is the film coefficient, T_r is the recovery temperature, T_w is the wall temperature, e is the emissivity of the wall surface, σ is the Stefan-Boltzmann constant, and G is the radiation received from the sun.

Combining Eqs. (1) and (2) yields

$$C_{pw} \rho_w \delta_w \frac{dT_w}{dt} = h(T_r - T_w) - e(\sigma T_w^4 - G). \quad (3)$$

Equation (3) now represents an energy balance per unit area in terms of the wall temperature. The crux of the problem is to determine h , the film coefficient. To do this the boundary layer must be examined.

The Navier-Stokes equations which describe the motion of a compressible viscous fluid are

$$\rho \frac{DW}{Dt} = \underline{F} - \text{grad } P + \mu \nabla^2 \underline{W}, \quad (4)$$

where ∇^2 is the Laplace operator $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$, $\frac{DW}{Dt}$ represents the total derivative of W , $\underline{W}$ is the total velocity whose x , y , and z components are u , v , and w , $\underline{F}$ is the resultant external force, $\text{grad } P$ is the gradient of pressure, μ is the fluid viscosity, and ρ is the fluid density. The x component of (4) would be

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = F_x - \frac{\partial P}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right). \quad (5)$$

Considering flow only in the x direction, no slip between the fluid and the wall ($u = 0$ for $y = 0$); $u \approx U_\infty$ for $y = \delta_b$, no external forces, and a velocity profile across the boundary layer which does not change appreciably with x or time, Eq. (5) reduces to

$$\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = \mu \frac{\partial^2 u}{\partial y^2}. \quad (6)$$

From a consideration of continuity,

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0. \quad (7)$$

The general energy equation written with respect to the boundary layer yields

$$\rho v \frac{\partial(C_p T)}{\partial x} + \rho v \frac{\partial(C_p T)}{\partial y} = \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) + \mu \left(\frac{\partial u}{\partial y} \right)^2, \quad (8)$$

where the left-hand side of Eq. (8) represents the energy influx and the right-hand terms represent the energy stored and the work done by viscous shear.

In Eq. (8), ρ , C_p , T , and μ are the properties of the fluid in the boundary layer.

Equations (6), (7), and (8) constitute a set of equations which represent the flow of fluid in the boundary layer. Combining these equations in the usual manner¹ and recognizing the definitions of $\frac{dq}{dt}$ and τ_w , the shear stress in the boundary layer,

$$\frac{dq}{dt} = \frac{C_p \tau_w}{U_\infty} (T_r - T_w). \quad (9)$$

Equation (9) represents the net energy transferred through the boundary layer in the absence of radiation. Noting Eq. (2), then

$$h = \frac{C_p \tau_w}{U_\infty}. \quad (10)$$

Up to this point, no mention has been made as to whether the flow is laminar or turbulent. The equations presented are essentially for laminar flow. However, if turbulent flow is described by perturbation velocities where $U = U_{\text{laminar}} + U'$, etc., where U' is the turbulent perturbation velocity, the resulting boundary layer equations would be mathematically the same as Eqs. (6), (7), and (8). The solution of the resulting equations would have the same form as for the laminar case with one exception. That is, in Eq. (10), τ_w will have different values for the laminar and turbulent cases. In

fact, if Eq. (9) is used with the proper values of τ_w , the error which arises in using it for both laminar and turbulent flow is consistent with the approximations made in the derivation of Eq. (9).

Van Driest¹⁻³ has developed solutions for both laminar and turbulent flow which seem to be in reasonable agreement with experiment. Both of his τ_w 's are developed from the momentum integral

$$\tau_w = \frac{d}{dx} \int_0^{\delta_b} \rho u (U_\infty - u) dy, \quad (11)$$

which simply states that momentum is conserved across the boundary layer. Both of Van Driest's solutions are for a flat plate and indeed some of the assumptions made in obtaining Eq. (9) were peculiar to a flat plate. Combining Eqs. (3) and (10) gives an equation which represents an energy balance on a flat plate.

$$C_{pw} \delta_w \rho_w \frac{dT_w}{dt} = \frac{C_p \tau_w}{U_\infty} (T_r - T_w) - e(\sigma T_w^4 - G). \quad (12)$$

The fact that Eq. (12) is written for a flat plate would seem to impose severe restrictions on its use in the aerodynamic heating of a nonflat body. However, if the data used in the solution of Eq. (12) are properly chosen, the results are reasonably accurate. The essence of the previous statement is that the fluid conditions at $y = \delta_b$ and the value of δ_b must be taken as those which actually occur at the point on the body in question. If the flow properties about an aerodynamic body are known, the problem is one of approximating the body by a series of flat plates inclined at various angles to the flow. Inclining the flat plate to the direction of flow requires that the value of δ_b be adjusted accordingly. For example, the boundary layer at a given distance back from the forward edge of a cone is about 1/3 as thick as the boundary layer the same distance back from the forward edge of a flat plate subjected to the same free-stream velocity.

THE 7094 SOLUTION

Equation (12) is essentially a first-order nonlinear differential equation with nonconstant coefficients, τ_w , U_∞ , and G being time dependent. The solution must be obtained numerically. Consider that the nonconstant coefficients are tabulated with respect to time. A method of solution which will yield the desired time-vs- T_w data could proceed as follows:

1. Solve Eq. (12) for $\frac{dT_w}{dt}$.
2. Select an initial T_w for $t = 0$.
3. Guess T_w for $t = t_1$ using some arbitrary slope.
4. Obtain from the data tables the values of τ_w , U_∞ , and G for $t = t_1$.
5. Calculate $\frac{dT_w}{dt}$ using step 3 and step 4 information.
6. Compare 5 with the slope used in guessing T_w in step 3 and choose a new T_w using the slope calculated in step 5.
7. Repeat steps 3 to 6 until T_w and the calculated slope agree. Use this new T_w for $t = t_1$ and repeat the process by selecting T_w for $t = t_2$, etc.

The result of the above steps will be a curve of T_w vs t which represents a solution of the differential equation. The solution scheme just described has been programmed for the IBM 7094 computer, and the details of the program appear in Appendix A.

EXAMPLE PROBLEM (HAD Rocket)

To demonstrate the use of this program, a typical problem and the results will be presented. Consider the HAD (High Altitude Diagnostics rocket) two-calibre tangent ogive nose cone. The data available is the vehicle trajectory consisting of altitude and velocity vs time. To apply the theory just developed, the tangent ogive nose cone can be approximated by a series of

conical segments. (See Fig. 2.) The fluid properties over each of the conical segments must now be determined.

In the supersonic flow range the bow wave angle will be assumed to be the same as it would be if the whole nose cone had the initial cone segment angle. At each junction of the cone segments a Prandtl-Meyer expansion can be assumed. So, at point D the air velocity will be nearly the same as the free stream velocity. In reality, the air is slightly overexpanded at D and does not reach free stream velocity for about a calibre beyond D. However, the overexpansion is not large and will not cause an appreciable error. Referring to the velocity-vs-time data, at each time point the following calculations must be made.

1. Determine the bow wave angle and the air properties behind the shock wave.
2. Assuming that the stagnation temperature does not change throughout the shock-expansion process, use a Prandtl-Meyer expansion with the appropriate turning angle to progress from one cone segment to the next. The required fluid properties must be calculated step by step.
3. The appropriate air data vs altitude is determined from the ARDC standard atmosphere for each time point.

The maximum time interval consistent with an integration accuracy of $\pm 1^\circ\text{F}$ is 1 second. A typical list of time-dependent variables including the information necessary to use Van Driest's boundary layer solutions is shown in Appendix B. Also included is a list of constant data required for the solution.

The computer program uses the listed data to compute T_w vs time for eight locations specified by the values of x supplied in the input data. For

the cone segments which represent the tangent ogive nose, the values of x used must be modified to result in a realistic boundary layer thickness.

Since the boundary layer on the conical segments is about $1/3$ the thickness of the boundary layer on a similar flat plate, $1/3$ the actual values of x must be used for the computation.

On the cylindrical body of the payload the appropriate length to use would be $1/3$ the nose length plus the distance behind the nose cone-cylindrical body junction. On the cone segment joining the cylinder of the payload to the larger cylinder of the third stage, the appropriate x would be $1/3$ the nose length plus the cylinder length plus $1/3$ the distance aft of the junction between the cylindrical section of the cone segment. The values of C_{pw} , ρ_w , and δ_w must be the correct ones for the particular wall location.

Essentially, separate computer programs have been written for laminar and turbulent boundary layers. The complete solution of a given problem involves using both programs and making an estimate of the location of boundary layer transition. In general, experiment indicates⁴ that transition occurs at Reynolds number values of 3×10^6 to 8×10^6 along bodies of revolution as well as flat plates, so the exact location of transition cannot be accurately predicted. For uniform wall conditions (thickness, material, etc.) the maximum temperature along the wall occurs at the transition point, so it is of interest to at least make some estimate of the transition location.

The list of data which appears in Appendix B was prepared in the manner just described, approximating the HAD nose cone by 30° , 20° , and 10° cone segments, and using the theoretical trajectory data obtained from the IMPACT program.⁵ This data was used in the 7094 solution of Eq. (12) and the results are listed in Appendix C.

Figure 3 represents the time-temperature history of a given location on the nose cone surface. Figure 4 is a temperature profile along the payload at the time corresponding to the maximum temperature. The transition location indicated corresponds to a Reynolds number of 3×10^6 . The dashed curve areas in Fig. 4 indicate locations at which δ_w is very large for a short distance, thus violating some of the assumptions made in the derivation of Eq. (12).

The data shown in Figs. 3 and 4 not only are restricted by the assumptions contained in Eq. (12), but it is also assumed that the skin surface does not become charred or insulated in any other manner. No account is taken of the possible buildup of a laminar sublayer in the turbulent boundary layer region, or of the effect on the boundary layer due to vehicle spin.

It can then be said with some degree of sureness that this data represents an upper limit for the skin temperatures. Also shown in Figs. 3 and 4 are data pertaining to 100% laminar flow. It is not unreasonable to assume that this data constitutes the lower limit of the skin temperature.

Acknowledgment

The programs in the appendices which follow were written by Mr. Ira Morrison of the Lawrence Radiation Laboratory, Livermore, Computation Center. This work was performed under the auspices of the U. S. Atomic Energy Commission.

REFERENCES

- ¹E. R. Van Driest, "Turbulent Boundary Layer in Compressible Fluids," J. Aeron. Sci. 18, No. 3 (March 1951).
- ²E. R. Van Driest, "The Laminar Boundary Layer with Variable Fluid Properties," Heat Transfer and Fluid Mechanics Institute, Berkeley, L954.
- ³E. R. Van Driest, "The Problem of Aerodynamic Heating," Aeron. Eng. Rev. 5, No. 10 (October 1956).
- ⁴Carl Gazley, "Boundary Layer Stability and Transition in Subsonic and Supersonic Flow," J. Aeron. Sci. 20, No. 1 (1953).
- ⁵J. A. Hawkins, "Approximate Trajectory Equations for Unguided Thin-Stabilized Multistage Rockets," APGC-TN-60-27 (June 1960).

BIBLIOGRAPHY

- Knudsen, J. G., and Katz, D. L., Fluid Dynamics and Heat Transfer (McGraw-Hill Book Company, New York, 1958).
- Lee, D. B., and Faget, M. A., "Charts Adapted from Van Driest's Turbulent Flat-Plate Theory for Determining Values of Turbulent Aerodynamic Friction and Heat Transfer Coefficients," NACA-TN-3811, 1956.
- Lee, D. B., Rumsey, C. B., and Bond, A. C., "Heat Transfer Measured in Free Flight on a Slightly Blunted 25° Cone-Cylinder-Flare Configuration at Mach Numbers up to 9.89," NACA-RM-L58G21, 1958.
- Lin, C. C., Turbulent Flows and Heat Transfer (Princeton University Press, Princeton, New Jersey, 1959).
- Schlichting, Hermann, Boundary Layer Theory (McGraw-Hill Book Company, New York, 1960).
- Shapiro, Ascher H., The Dynamics and Thermodynamics of Compressible Fluid Flow (two volumes) (The Ronald Press, New York, 1953).

APPENDIX A

FORTRAN STATEMENTS FOR 7094 SOLUTION

Laminar Program

FORTRAN REORDER OUTPUT

```

CARDS COLUMN
LIST8
FORTRAN      IFLDL
C    TEMP CHANGE
      COMMON STERA , TER1, XMC, TRC
      DIMENSION TD(64), UINT(64), SMUE(64), ETA(64), TINT(64), SKRIPK(64),
1    G(64), ROEINT(64), X(8), TW(127), T(127), DELTA(4), ALI(64)
      DIMENSION SMALLA(8), Q1(1), FACT(16), QU(1)
      DIMENSION TER1(6,5), XMC(6), TRC(5), TIME(64)
      READ INPUT TAPE 2, 10, ((TIME(I), ALT(I), UINT(I), SMUE(I), ETA(I),
X    TINT(I), SKRIPK(I), G(I), ROEINT(I), I=1,62)
10    FORMAT (F5.2, F6.0, F5.0, E12.4, E11.5, F4.0, F5.4, F3.0, E11.3 )
      READ INPUT TAPE 2, 20, ((TER1(I,J), I=1,6), J=1,5)
20    FORMAT ( 6F5.3)
      READ INPUT TAPE 2, 30, ((TRC(K), K=1,5)
30    FORMAT (5F4.2)
      READ INPUT TAPE 2, 40, (XMC(J), J=1,6)
40    FORMAT (6F4.1)
      READ INPUT TAPE 2, 50, XPH, BET, (SMALLA(I), I=1,8)
50    FORMAT (5E14.6)
C    FORMAT 510 NEEDS 2 CARDS , FIRST 28 COLS. OF ONE ARE XPH AND BET ,
C    REST ARE SMALLA(S)
      READ INPUT TAPE 2 , 60, DELW, SIG, (X(J), J=1,8)
60    FORMAT ( F6.4, E11.3, 8F5.3)
C    TINITL = INITIAL TW , TIMIN = INITIAL T
      READ INPUT TAPE 2, 70, TINITL, TIMIN
70    FORMAT(2E15.8)
      READ INPUT TAPE 2, 80, KEY
80    FORMAT (I2)
      DO 90 J = 1, 64
90    TD(J) = TIME(J)
      FACT(C) = 1.
      DO 100 M = 1, 16
      XM = M
100    FACT(M) = XM* FACT(M-1)
      TW(1) = TINITL
      T(1) = TIMIN
      D1 = 1.4*1716.
      D2 = LOGF(40.)
      D3 = 0.3 * 118.56 * DELW
      D4 = 32.2 * 0.24 / D3
      D5 = 0.7 / (3600. * D3)
      DO 330 I37 = 1, 8
      I35 = 1
      CFA1 = 0
      CFA40 = 0
      CAPK = 0
      DO 280 I29 = 1, 61
      IF(SENSE SWITCH 1) 340, 110
110    CONTINUE

```

FORTRAN REORDER OUTPUT

```

DELTT = (TD(I29+1) - TD(I29)) / 2.
C7 = 0
C8 = 4.
DO 280 I30 = 1,4
  UINTC = UINT(I29) + C7 * (UINT(I29+1) - UINT(I29)) / C8
  SMUEC = SMUE(I29) + C7 * (SMUE(I29+1) - SMUE(I29)) / C8
  ETAC = ETA(I29) + C7 * (ETA(I29+1) - ETA(I29)) / C8
  TINTC = TINT(I29) + C7 * (TINT(I29+1) - TINT(I29)) / C8
  SKRPKC = SKRIPK(I29) + C7 * (SKRIPK(I29+1) - SKRIPK(I29)) / C8
  GC = G(I29) + C7 * (G(I29+1) - G(I29)) / C8
  ROINTC = ROEINT(I29) + C7 * (ROEINT(I29+1) - ROEINT(I29)) / C8
  IF(KEY) 120, 160, 120
120 DO 130 K = 1,8
    DO 130 LP = 1,8
      LPK = LP + K
130 PL3 = SMALLA(K) * SMALLA(LP) * FACT(LP) / (2. * BET) ** (LP + K + 1)
      PL2 = 0
      DO 140 LP5 = 1,8
        140 PL2 = SMALLA(LP5) * FACT(LP5) / (BET + XPH) ** (LP5 + 1) + PL2
      PL = 0
      DO 150 IP = 1,8
        150 PL = SMALLA(IP) * FACT(IP) / BET ** (IP + 1)
        YTER = 1. / XPH - PL + 2. * PL2 - PL3
        TAUW = SQRTF(ETAC / (UINTC * X(I37))) * YTER
        SKR = SQRTF(115920. * SMUEC * 0.24 / SKRPKC)
        GO TO 170
160 E1 = D1 * TINTC
      XM = UINTC / SQRTF(E1)
      TRATIO = TW(I35) / TINTC
      CALL TABLE3(XM, TRATIO)
      TAUW = SQRTF(ETAC / (UINTC * X(I37))) * UINTC * UINTC * ROINTC *
      1 STERA
      SKR = SQRTF(115920. * SMUEC * 0.24 / SKRPKC)
170 TOINT = TINTC * (1. + 2. * XM ** 2)
      TR = SKR * (TOINT - TINTC) + TINTC
C    FORTH ORDER RUNGE-KUTTA INTEGRATION
      IF(I30-2) 190, 210, 180
180 IF(I30-4) 190, 210, 190
190 C7 = C7 + 1.
200 DELTA(1) = (D4 * TAUW / UINTC * (TR - TW(I35)) - D5 * (SIG * TW(I35)
      1 ** 4 - GC)) * DELTT
      GO TO 280
210 DO 220 I38 = 2,3
220 DELTA(I38) = (D4 * TAUW / UINTC * (TR - (TW(I35) + .5 * DELTA(I38-1))))
      1 - D5 * (SIG * (TW(I35) + .5 * DELTA(I38-1)) ** 4 - GC)) * DELTT
      DELTA(4) = (D4 * TAUW / UINTC * (TR - (TW(I35) + DELTA(3)))) - D5
      1 * (SIG * (TW(I35) + DELTA(3)) ** 4 - GC)) * DELTT
      I35 = I35 + 1
      C7 = C7 + 1.

```

FORTTRAN REORDER OUTPUT

```
230 TW(I35) = .16666666 * (DELTA(1)+ 2.*DELTA(2)+ 2.*DELTA(3)+DELTA(4)
1 ) + TW(I35-1)
240 I(I35) = I(I35-1) + DELTT
WRITE OUTPUT TAPE 3,250, I35, C7 , DELTA, TW(I35)
250 FORMAT (1X,I4, 3X, F4.0,3X, 4E16.8,3X ,E16.8 )
IF(TW(I35)-10000.) 280,280,260
260 WRITE OUTPUT TAPE 3,270,I35,TW(I35)
270 FORMAT ( 26HTW OUT OF LIMITS AT I35 = ,I4,5X,9HTW(I35)= ,E16.8)
GO TO 340
280 CONTINUE
WRITE OUTPUT TAPE 3,290,DELW,X(I37)
290 FORMAT (1H1,5X,32HLAMINAR CASE SOLUTION FOR DELW = ,E11.3,8X,3HX=
X ,F5.3 )
WRITE OUTPUT TAPE 3,300
300 FORMAT ( 4(7X,2H1=,10X,3HTW=,8X))
310 WRITE OUTPUT TAPE 3,320,( T(J10),TW(J10),T(J10+1),TW(J10+1),T(J10
X +2),TW(J10+2),T(J10+3),TW(J10+3),T(J10+4),TW(J10+4),J10 =1,123,5)
320 FORMAT (4(2X,F7.3,2X,E16.8,3X))
330 CONTINUE
340 CALL DUMP
END
```

Turbulent Program

TEMP CHANGE

B09/2400/00

COMMON CF1,CF40,XMC,TRC,CFA1,CFA40,CAPK,CAPKT,B IGR	000001
DIMENSION TO(64), UIN(64), SMUE(64), ETA(64), TINT(64), SKRIPK(64),	000002
1 G(64), ROEINT(64), X(8), TW(127), T(127), DELTA(4), ALT(64)	000003
DIMENSION CF1(12,7), CF40(12,7), XMC(12), TRC(7), CFA1(1), CFA40(1),	000004
1CAPKT(9), BIGRT(9), CAPK(9), TIME(64)	000005
READ INPUT TAPE 2, 500, ((CF1(I,J), J=1,7), I=1,12)	000006
READ INPUT TAPE 2, 500, ((CF40(I,J), J=1,7), I=1,12)	000007
READ INPUT TAPE 2, 501, (XMC(K), K=1,12)	000008
READ INPUT TAPE 2, 502, (TRC(J), J=1,7)	000009
READ INPUT TAPE 20503, (BIGRT(M), M=1,9)	000010
READ INPUT TAPE 20504, (CAPKT(N), N=1,9)	000011
READ INPUT TAPE 2, 15, (TIME(I), ALT(I), UIN(I), SMUE(I), ETA(I),	000012
1 TINT(I), SKRIPK(I), G(I), ROEINT(I), I=1,62)	000013
15 FORMAT (F5.2, F6.0, F5.0, E12.4, E12.5, F3.0, F5.4, F3.0, E11.3)	000014
READ INPUT TAPE 2, 505, DELW, SIG, (X(J), J=1,8)	000015
500 FORMAT (7F7.6)	000016
501 FORMAT (12F4.1)	000017
502 FORMAT (7F4.1)	000018
503 FORMAT (9E8.2)	000019
504 FORMAT (9F5.3)	000020
505 FORMAT (F6.4, E11.3, 8F5.3)	000021
READ INPUT TAPE 2, 921, TINITL, TIMIN	000022
C TINITL = INITIAL TW, TIMIN = INITIAL T	000023
921 FORMAT(2F15.8)	000024
DO 301 J = 1,64	000025
301 TO(J) = TIME(J)	000026
TW(I) = TINITL	000027
T(I) = TIMIN	000028
D1 = 1.4 * 1716.	000029
D2 = LOGF(40.)	000030
D3 = 0.3 * 118.56 * DELW	000031
D4 = 32.2 * 0A24 / D3	000032
D5 = 0.7 / (3600. * D3)	000033
DO 209 I37 = 1,8	000034
I35 = 1	000035
CFA1 = 0	000036
CFA40 = 0	000037
CAPK = 0	000038
DO 2000 I29 = 1,61	000039
IF (SENSE SWITCH) 508.1	000040
1 CONTINUE	000041
DELTT = (TO(I29+1) - TO(I29)) / 2.	000042
C7 = 0	000043
C8 = 4.	000044
DO 2000 I30 = 1,4	000045
UINTC = UIN(I29) + C7 * (UIN(I29+1) - UIN(I29)) / C8	000046
SMUEC = SMUE(I29) + C7 * (SMUE(I29+1) - SMUE(I29)) / C8	000047
ETAC = ETA(I29) + C7 * (ETA(I29+1) - ETA(I29)) / C8	000048
TINTC = TINT(I29) + C7 * (TINT(I29+1) - TINT(I29)) / C8	000049
SKRPKC = SKRIPK(I29) + C7 * (SKRIPK(I29+1) - SKRIPK(I29)) / C8	000050
GC = G(I29) + C7 * (G(I29+1) - G(I29)) / C8	000051
ROINTC = ROEINT(I29) + C7 * (ROEINT(I29+1) - ROEINT(I29)) / C8	000052
BIGR = UINTC * X(I37) / ETAC	000053
CALL TABLE2 (BIGR)	000054
E1 = D1 * TINTC	000055
XM = UINTC / SQRTF(E1)	000056

TEMP CHANGE	809/2400/00
TRATIO = TW(I35) / TINTC	000057
CALL TABLE1(XM,TRATIO)	000058
CRAT = CFA1 / CFA40	000059
Z = LOGF(CRAT) / D2	000060
CF = CAPK * CFA1 / (BIGR / 1.0E+6) ** 2	000061
TAUW = 0.5 * ROINTC * (UINTC ** 2) * CF	000062
SKR = (115920. * SMUEC * 0.24 / SKRPKC) ** (0.33 333333)	000063
TPOINT = TINTC * (1. + 2 * XM ** 2)	000064
TR = SKR * (TPOINT - TINTC) + TINTC	000065
C FORTH ORDER RUNGE-KUTTA INTEGRATION	000066
IF(I30-2) 203,205,207	000067
207 IF(I30-4) 203,205,203	000068
203 C7 = C7 + 1.	000069
204 DELTA(1) = (D4 * TAUW / UINTC * (TR - TW(I35)) - D5 * (SIG * TW(I35) * 4 - GC)) * DELTT	000070
GO TO 2000	000071
205 DO 208 I38 = 2,3	000072
208 DELTA(I38) = (D4 * TAUW / UINTC * (TR - (TW(I35) + .5 * DELTA(I38-1))) - D5 * (SIG * (TW(I35) + .5 * DELTA(I38-1)) * 4 - GC)) * DELTT	000073
DELTA(4) = (D4 * TAUW / UINTC * (TR - (TW(I35) + DELTA(3))) - D5 * (SIG * (TW(I35) + DELTA(3)) * 4 - GC)) * DELTT	000074
I35 = I35 + 1	000075
C7 = C7 + 1.	000076
200 TW(I35) = .16666666 * (DELTA(1) + 2 * DELTA(2) + 2 * DELTA(3) + DELTA(4)) + TW(I35-1)	000077
T(I35) = T(I35-1) + DELTT	000078
WRITE OUTPUT TAPE 3,700, I35, C7, DELTA, TW(I35)	000079
700 FORMAT (1X,14, 3X, F4.0,3X, 4E16.8,3X, E16.8)	000080
IF(TW(I35)-10000.) 2000,2000,509	000081
509 WRITE OUTPUT TAPE 3,510,I35,TW(I35)	000082
510 FORMAT (26HTW OUT OF LIMITS AT I35 = ,14,5X,9HT W(I35) = ,E16.8)	000083
GO TO 508	000084
2000 CONTINUE	000085
WRITE OUTPUT TAPE 3,16,DELW,X(I37)	000086
16 FORMAT (1H1,5X,21HSOLUTIONS FOR DELW = ,E11.3, 8X,3HX= ,F5.3)	000087
WRITE OUTPUT TAPE 3,511	000088
511 FORMAT (4(7X,2HT=,10X,3HTW=,8X))	000089
210 WRITE OUTPUT TAPE 3,507,(T(J10),TW(J10),T(J10+1),TW(J10+1),T(J10+2),TW(J10+2),T(J10+3),TW(J10+3),T(J10+4),TW(J10+4),J10 = 1,123,5)	000090
507 FORMAT (4(2X,F7.3,2X,E16.8,3X))	000091
209 CONTINUE	000092
508 CALL DUMP	000093
END(0,1,0,1,0,0,0,1,0,0,0,0,0,0,0)	000094

Order of Deck

A. Turbulent Case

1. I.D. card.
2. Binary deck.
3. Tables for Van Driest turbulent τ_w .
4. 62 aerodynamic data cards.
5. δ_w , σ , and x values card.
6. Initial T_w and initial t card.

B. Laminar Case

1. I.D. card.
2. Binary deck.
3. 62 aerodynamic data cards.
4. Tables for Van Driest laminar τ_w (7 cards).
5. Values for Harri-Appl laminar τ_w (3 cards).
6. δ_w , σ , and x values card.
7. Initial T_w and initial t card.
8. Key card to select 4 or 5.

APPENDIX B HAD DATA INPUT

Cylindrical Section (Flat Plate Data)

Time from launch, sec	Altitude, ft	Velocity, ft/sec	Dynamic viscosity, 10^{-7} slugs/ft-sec	Kinematic viscosity, 10^{-4} ft ² /sec	Air temp, °R	Air thermal conductivity, Btu/h-ft-°F	Solar radiation, Btu/h-ft ²	Air density, 10^{-4} slugs/ft ³
2.00	877	711	3.719	1.602	518	0.01460	175	23.1
3.00	1773	1100	3.680	1.641	512	.01440	180	22.4
4.00	3058	1498	3.659	1.681	508	.01420	190	21.7
4.80	4253	1792	3.638	1.723	503	.01400	200	21.1
5.00	4721	1769	3.618	1.766	500	.01380	210	20.5
6.00	6429	1648	3.581	1.840	495	.01370	220	19.4
7.00	8057	1609	3.557	1.903	490	.01350	230	18.7
8.00	9610	1535	3.521	2.002	483	.01330	240	17.5
9.00	11091	1466	3.495	2.054	479	.01330	250	17.0
10.00	12418	1403	3.460	2.137	474	.01300	260	16.5
10.06	12505	1432	3.458	2.138	473	.01270	270	16.0
11.00	14154	1918	3.428	2.220	469	.01240	280	15.5
12.00	16303	2448	3.307	3.241	461	.01210	290	14.5
12.87	18448	2917	3.331	2.501	454	.01205	300	13.6
13.00	18986	2902	3.326	2.538	452	.0120	310	13.1
14.00	21809	2030	3.262	2.757	441	.01195	320	11.8
15.00	24562	2763	3.201	3.008	430	.01190	330	10.9
16.00	27251	2700	3.153	3.177	423	.01185	340	9.9
17.00	29880	2642	3.090	3.469	413	.01180	355	8.9
18.00	32452	2587	3.029	3.700	404	.01175	370	8.2
19.00	34970	2535	2.974	4.036	395	.0113	380	7.2
20.00	37285	2489	2.961	4.376	393	.0110	390	6.7
20.06	37440	2547	2.961	4.450	393	.0110	400	6.5
21.00	40427	3563	2.961	5.055	393	.0110	410	5.8
22.00	44512	4800	2.961	6.205	393	.0110	412	4.7
22.07	40822	4050	2.961	7.792	393	.0110	415	3.9
23.00	49935	6035	2.961	8.175	393	.0110	417	3.8
24.00	55821	5958	2.961	13.200	393	.0110	420	2.8
25.00	61636	5893	2.961	14.001	393	.0110	420	2.2
26.00	67392	5836	2.961	16.200	393	.0110	420	1.4
27.00	73093	5786	2.961	21.317	393	.0110	420	0.95
28.00	78748	5741	2.961	30.390	393	.0110	420	.91
29.00	83501	5700	2.961	34.390	393	.0110	420	.85
30.00	88400	5660	2.961	54.350	393	.0117	420	.53
31.00	94030	5620	2.961	74.150	400	.01185	420	.41
32.00	98950	5580	2.961	85.456	402	.0120	420	.33
33.00	104400	5540	2.961	113.4	406	.0122	420	.26
34.00	109650	5500	3.090	157.2	413	.0124	420	.21
35.00	114850	5460	3.240	220.5	424	.0127	420	.17
36.00	120400	5440	3.339	287.6	439	.0130	420	.11
37.00	126540	5420	3.510	498.9	460	.0133	420	.08
38.00	133178	5386	3.590	570.5	493	.0137	420	.07
39.00	136500	5350	3.809	690.5	510	.0141	420	.05
40.00	142100	5320	3.850	827.9	535	.0145	420	.04
41.00	147020	5290	3.880	1200	557	.0150	420	.035
42.00	152100	5260	4.032	1322	585	.0158	420	.03
43.00	157500	5230	4.101	1790	605	.0165	420	.025
44.00	163010	5200	4.332	2050	618	.0168	420	.02
45.00	168250	5170	4.332	2886	627	.0171	420	.015
46.00	174000	5140	4.332	3050	630	.0173	420	.010
47.00	180300	5109	4.332	3886	630	.0173	420	.0091
48.00	184287	5072	4.332	4230	630	.0173	420	.0085
49.00	189100	5040	4.332	5232	630	.0173	420	.008
50.00	193900	5010	4.332	5405	630	.0173	420	.0078
51.00	199100	4980	4.227	6844	621	.0173	420	.0074
52.00	203500	4950	4.177	6850	607	.0170	420	.006
53.00	207810	4920	4.099	7010	593	.0167	420	.0053
54.00	212600	4890	4.080	8467	575	.0163	420	.0048
55.00	217500	4860	4.001	10600	558	.0160	420	.0043
56.00	222500	4830	3.916	11300	543	.0157	420	.0037
57.00	227500	4800	3.727	13000	526	.0153	420	.003
58.00	232223	4765	3.695	13400	510	0.0150	420	0.002

HAD Data Input for 30° Cone Section

All the previous data remains the same except velocity, temperature, and density, whose new values are as listed below.

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
2.00	711	562	24.4
3.00	1100	612	27.9
(Normal shock)			
4.00	840	619	34.7
4.80	1057	649	39.3
5.00	1031	643	40.0
6.00	941	636	36.4
7.00	816	633	33.0
8.00	778	611	30.0
9.00	806	588	27.7
10.00	856	569	30.1
10.06	834	573	32.0
11.00	1179	622	34.5
12.00	1541	671	37.0
12.87	1785	733	45.2
13.00	1780	728	43.5
14.00	1755	689	37.3
15.00	1710	680	34.5
16.00	1672	666	30.6
17.00	1645	641	28.0
18.00	1610	625	26.0
19.00	1580	608	24.1
20.00	1550	602	19.8
20.06	1605	604	26.5
21.00	2050	775	34.9
22.00	2540	965	44.3
22.87	3010	1120	53.1
23.00	3000	1121	48.0

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
24.00	2970	1121	43.0
25.00	2950	1136	38.0
26.00	2930	1135	33.0
27.00	2910	1039	28.0
28.00	2880	1025	23.0
29.00	2870	1018	18.0
30.00	2860	1012	10.0
31.00	2855	1002	5.67
32.00	2850	1015	4.1
33.00	2845	1033	3.1
34.00	2840	1049	2.5
35.00	2830	1090	2.1
36.00	2825	1150	1.5
37.00	2820	1201	1.1
38.00	2810	1252	0.694
39.00	2809	1310	.600
40.00	2808	1369	.520
41.00	2807	1425	.470
42.00	2806	1437	.350
43.00	2805	1450	.270
44.00	2804	1462	.184
45.00	2803	1440	.130
46.00	2802	1410	.100
47.00	2801	1375	.070
48.00	2800	1351	.058
49.00	2780	1351	.051
50.00	2760	1351	.047
51.00	2740	1320	.042
52.00	2720	1300	.037
53.00	2700	1285	0.033

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
54.00	2680	1275	0.028
55.00	2660	1250	.024
56.00	2640	1225	.016
57.00	2620	1200	.015
58.00	2590	1170	0.0145

HAD Data Input for 20° Cone Section

All the previous data remained the same except velocity, temperature, and density, whose new values are as listed below.

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
2.00	711	562	23.8
3.00	1100	612	26.2
	(Normal shock)		
4.00	920	578	29.9
4.80	1395	584	30.1
5.00	1360	578	30.7
6.00	1305	568	27.5
7.00	1230	562	26.0
8.00	1155	552	24.8
9.00	1090	544	23.5
10.00	1043	535	24.0
10.06	1057	535	24.3
11.00	1500	555	24.9
12.00	1910	577	35.8
12.87	2240	605	28.2
13.00	2228	602	27.2
14.00	2175	584	23.8
15.00	2120	568	22.0
16.00	2085	556	19.5
17.00	2040	536	18.0

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10 ⁻⁴ slugs/ft ³
18.00	2005	526	16.0
19.00	1960	514	14.5
20.00	1930	509	13.0
20.06	1975	513	15.0
21.00	2620	596	17.0
22.00	3310	687	19.1
22.87	4030	738	19.5
23.00	4020	739	17.0
24.00	3980	743	15.0
25.00	3940	748	13.0
26.00	3910	738	11.0
27.00	3880	693	9.0
28.00	3840	684	7.1
29.00	3820	682	5.2
30.00	3800	680	3.3
31.00	3785	670	2.05
32.00	3770	682	1.7
33.00	3755	698	1.5
34.00	3740	713	1.3
35.00	3730	753	0.95
36.00	3720	790	.68
37.00	3710	831	.40
38.00	3700	878	.286
39.00	3699	911	.20
40.00	3698	960	.18
41.00	3697	1002	.16
42.00	3696	1011	.13
43.00	3695	1022	.10
44.00	3694	1035	.081
45.00	3693	1025	.061
46.00	3692	1015	.048
47.00	3691	1007	.035
48.00	3690	1005	.0275
49.00	3600	1005	0.025

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
50.00	3520	1005	0.023
51.00	3480	993	.021
52.00	3460	970	.019
53.00	3440	959	.017
54.00	3420	943	.015
55.00	3400	921	.013
56.00	3380	902	.011
57.00	3380	883	.009
58.00	3388	868	0.0069

HAD Data Input for 10° Cone Section

All the previous data remains the same except velocity, temperature, and density, whose new values are as listed below.

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
2.00	711	562	23.1
3.00	1100	612	23.8
4.00	1350	535	24.7
4.80	1650	520	23.7
5.00	1615	529	24.4
6.00	1545	522	22.2
7.00	1480	513	21.0
8.00	1405	499	20.0
9.00	1335	500	19.1
10.00	1276	496	18.9
10.06	1294	498	18.7
11.00	1760	502	18.5
12.00	2228	506	18.3
12.87	2645	510	18.2
13.00	2635	507	17.6
14.00	2560	495	15.8

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
15.00	2500	482	14.6
16.00	2459	472	12.9
17.00	2400	456	11.8
18.00	2350	438	10.7
19.00	2310	436	9.7
20.00	2265	435	8.76
20.06	2315	437	8.45
21.00	3170	469	8.11
22.00	4160	483	7.95
22.87	5180	456	7.03
23.00	5160	458	6.01
24.00	5110	456	5.02
25.00	5060	487	4.01
26.00	5000	520	3.00
27.00	4950	466	2.00
28.00	4930	463	1.9
29.00	4900	460	1.01
30.00	4870	457	0.91
31.00	4810	459	.75
32.00	4810	465	.62
33.00	4780	477	.58
34.00	4750	489	.51
35.00	4720	540	.42
36.00	4680	594	.31
37.00	4670	652	.20
38.00	4660	706	.115
39.00	4640	712	.090
40.00	4620	718	.081
41.00	4600	723	.075
42.00	4580	735	.059
43.00	4560	748	.045
44.00	4540	760	0.036

Time, sec	Velocity, ft/sec	Temperature, °R	Density, 10^{-4} slugs/ft ³
45.00	4520	763	0.028
46.00	4500	764	.024
47.00	4480	765	.020
48.00	4460	765	.0136
49.00	4430	765	.0121
50.00	4400	765	.0112
51.00	4370	745	.0093
52.00	4340	725	.0084
53.00	4310	704	.0075
54.00	4280	684	.0066
55.00	4250	677	.0057
56.00	4220	669	.0048
57.00	4190	659	.0040
58.00	4160	649	0.0034

HAD Configuration Data Input

$$C_{pw} = 0.3 \text{ Btu/lb}_m \text{ } ^\circ\text{F}$$

$$\rho_w = 118.56 \text{ lb}_m/\text{ft}^3$$

$$\delta_w = 0.0104 \text{ ft}$$

$$C_p = 0.24 \text{ Btu/lb}_m \text{ } ^\circ\text{R}$$

$$e = 0.7$$

$$\sigma = 0.173 \times 10^{-8} \text{ Btu/ft}^2 \text{ } ^\circ\text{R}$$

$$k = 1.4$$

x = Eight locations measured in feet from the forward end of the nose. Numerical values are adjusted to obtain the estimated correct boundary layer thickness.

APPENDIX C

TYPICAL DATA OUTPUT

Turbulent Approximation, T_w in °R

30° Cone, $x = 2$ in.

SOLUTIONS FOR DELW = 0.104E-01

X = 0.057

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.55999999E 03	2.500	0.56293501E 03	3.000	0.56969182E 03	3.500	0.57867745E 03
4.000	0.58595674E 03	4.435	0.59253532E 03	4.870	0.60205870E 03	4.935	0.60374613E 03
5.000	0.60534589E 03	5.500	0.61593339E 03	6.000	0.62389412E 03	6.500	0.62975182E 03
7.000	0.63393319E 03	7.500	0.63677058E 03	8.000	0.63844430E 03	8.500	0.63925124E 03
9.000	0.63943845E 03	9.500	0.63914035E 03	10.000	0.63845935E 03	10.030	0.63840521E 03
10.060	0.63835344E 03	10.530	0.63890968E 03	11.000	0.64367231E 03	11.500	0.65475329E 03
12.000	0.67328483E 03	12.435	0.69721394E 03	12.870	0.73022252E 03	12.935	0.73590582E 03
13.000	0.74127656E 03	13.500	0.77539762E 03	14.000	0.79854713E 03	14.500	0.81461076E 03
15.000	0.82652836E 03	15.500	0.83497749E 03	16.000	0.84049521E 03	16.500	0.84357368E 03
17.000	0.84449726E 03	17.500	0.84380338E 03	18.000	0.84196328E 03	18.500	0.83922672E 03
19.000	0.83580920E 03	19.500	0.83210620E 03	20.000	0.82856394E 03	20.030	0.82835660E 03
20.060	0.82815801E 03	20.530	0.83132713E 03	21.000	0.85458312E 03	21.500	0.90993097E 03
22.000	0.10048606E 04	22.435	0.11235996E 04	22.870	0.12759862E 04	22.935	0.13010129E 04
23.000	0.13236028E 04	23.500	0.14608509E 04	24.000	0.15527596E 04	24.500	0.16146481E 04
25.000	0.16575460E 04	25.500	0.16871770E 04	26.000	0.17068759E 04	26.500	0.17154042E 04
27.000	0.17107777E 04	27.500	0.17003057E 04	28.000	0.16897806E 04	28.500	0.16799276E 04
29.000	0.16713784E 04	29.500	0.16611773E 04	30.000	0.16486485E 04	30.500	0.16382383E 04
31.000	0.16317778E 04	31.500	0.16274571E 04	32.000	0.16236769E 04	32.500	0.16203386E 04
33.000	0.16173800E 04	33.500	0.16147619E 04	34.000	0.16124779E 04	34.500	0.16106012E 04
35.000	0.16092639E 04	35.500	0.16084183E 04	36.000	0.16079529E 04	36.500	0.16077512E 04
37.000	0.16077658E 04	37.500	0.16077472E 04	38.000	0.16074550E 04	38.500	0.16070302E 04
39.000	0.16067916E 04	39.500	0.16066917E 04	40.000	0.16066906E 04	40.500	0.16068069E 04
41.000	0.16070832E 04	41.500	0.16072876E 04	42.000	0.16071240E 04	42.500	0.16066603E 04
43.000	0.16059858E 04	43.500	0.16050696E 04	44.000	0.16038810E 04	44.500	0.16024361E 04
45.000	0.16007764E 04	45.500	0.15989297E 04	46.000	0.15969446E 04	46.500	0.15948337E 04
47.000	0.15926080E 04	47.500	0.15903012E 04	48.000	0.15879568E 04	48.500	0.15855899E 04
49.000	0.15832186E 04	49.500	0.15808448E 04	50.000	0.15784718E 04	50.500	0.15760940E 04
51.000	0.15737035E 04	51.500	0.15712816E 04	52.000	0.15688072E 04	52.500	0.15663242E 04
53.000	0.15638825E 04	53.500	0.15614630E 04	54.000	0.15590432E 04	54.500	0.15566228E 04
55.000	0.15542021E 04	55.500	0.15517768E 04	56.000	0.15493426E 04	56.500	0.15469081E 04
57.000	0.15444825E 04	57.500	0.15420660E 04	58.000	0.15396586E 04	0.	0.
0.	0.						

20° Cone, x = 4 in.

SOLUTIONS FOR DELW = 0.104E-01

X = 0.111

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.55999999E 03	2.500	0.56249168E 03	3.000	0.56811973E 03	3.500	0.57515539E 03
4.000	0.57995974E 03	4.435	0.58412082E 03	4.870	0.59142663E 03	4.935	0.59282918E 03
5.000	0.59415494E 03	5.500	0.60305724E 03	6.000	0.61001644E 03	6.500	0.61542723E 03
7.000	0.61961626E 03	7.500	0.62271996E 03	8.000	0.62483500E 03	8.500	0.62614816E 03
9.000	0.62683708E 03	9.500	0.62701661E 03	10.000	0.62676746E 03	10.030	0.62673992E 03
10.060	0.62671690E 03	10.530	0.62746941E 03	11.000	0.63154269E 03	11.500	0.64043144E 03
12.000	0.65469180E 03	12.435	0.67246819E 03	12.870	0.69619336E 03	12.935	0.70025131E 03
13.000	0.70414025E 03	13.500	0.73036169E 03	14.000	0.75063041E 03	14.500	0.76637424E 03
15.000	0.77872711E 03	15.500	0.78830859E 03	16.000	0.79569982E 03	16.500	0.80117146E 03
17.000	0.80488520E 03	17.500	0.80724153E 03	18.000	0.80864736E 03	18.500	0.80924662E 03
19.000	0.80914795E 03	19.500	0.80858266E 03	20.000	0.80778889E 03	20.030	0.80774306E 03
20.060	0.80772188E 03	20.530	0.81105214E 03	21.000	0.82515994E 03	21.500	0.85638107E 03
22.000	0.90933570E 03	22.435	0.97682333E 03	22.870	0.10662325E 04	22.935	0.10811433E 04
23.000	0.10948301E 04	23.500	0.11886919E 04	24.000	0.12685440E 04	24.500	0.13348951E 04
25.000	0.13889986E 04	25.500	0.14331175E 04	26.000	0.14689314E 04	26.500	0.14973944E 04
27.000	0.15191586E 04	27.500	0.15358879E 04	28.000	0.15490399E 04	28.500	0.15588956E 04
29.000	0.15657894E 04	29.500	0.15689360E 04	30.000	0.15682100E 04	30.500	0.15663404E 04
31.000	0.15651189E 04	31.500	0.15640505E 04	32.000	0.15626387E 04	32.500	0.15609675E 04
33.000	0.15591129E 04	33.500	0.15571290E 04	34.000	0.15550739E 04	34.500	0.15530179E 04
35.000	0.15510315E 04	35.500	0.15490615E 04	36.000	0.15470662E 04	36.500	0.15450592E 04
37.000	0.15430481E 04	37.500	0.15410156E 04	38.000	0.15389796E 04	38.500	0.15369707E 04
39.000	0.15350232E 04	39.500	0.15331368E 04	40.000	0.15313489E 04	40.500	0.15296533E 04
41.000	0.15280427E 04	41.500	0.15264719E 04	42.000	0.15248831E 04	42.500	0.15232731E 04
43.000	0.15216374E 04	43.500	0.15199771E 04	44.000	0.15183033E 04	44.500	0.15165996E 04
45.000	0.15148465E 04	45.500	0.15130498E 04	46.000	0.15112225E 04	46.500	0.15093663E 04
47.000	0.15074818E 04	47.500	0.15055776E 04	48.000	0.15036688E 04	48.500	0.15017503E 04
49.000	0.14998206E 04	49.500	0.14978804E 04	50.000	0.14959313E 04	50.500	0.14939770E 04
51.000	0.14920215E 04	51.500	0.14900630E 04	52.000	0.14881001E 04	52.500	0.14861353E 04
53.000	0.14841718E 04	53.500	0.14822078E 04	54.000	0.14802407E 04	54.500	0.14782737E 04
55.000	0.14763101E 04	55.500	0.14743495E 04	56.000	0.14723918E 04	56.500	0.14704366E 04
57.000	0.14684834E 04	57.500	0.14665331E 04	58.000	0.14645869E 04	0.	0.
0.	0.						

20° Cone, x = 6 in.

SOLUTIONS FOR DELW = 0.104E-01 X = 0.166							
T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	Q.55999999E 03	2.500	0.56227483E 03	3.000	0.56740087E 03	3.500	0.57385860E 03
4.000	0.57829693E 03	4.435	0.58216234E 03	4.870	0.58900788E 03	4.935	0.59033024E 03
5.000	0.59157954E 03	5.500	0.59998643E 03	6.000	0.60659605E 03	6.500	0.61177205E 03
7.000	0.61581705E 03	7.500	0.61885728E 03	8.000	0.62098587E 03	8.500	0.62237833E 03
9.000	0.62319107E 03	9.500	0.62352901E 03	10.000	0.62346770E 03	10.030	0.62345228E 03
10.060	0.62344106E 03	10.530	0.62428662E 03	11.000	0.62817422E 03	11.500	0.63656859E 03
12.000	0.65006705E 03	12.435	0.66697086E 03	12.870	0.68963271E 03	12.935	0.69351818E 03
13.000	0.69724243E 03	13.500	0.72240302E 03	14.000	0.74194308E 03	14.500	0.75721449E 03
15.000	0.76929431E 03	15.500	0.77876741E 03	16.000	0.78617372E 03	16.500	0.79176776E 03
17.000	0.79570881E 03	17.500	0.79837724E 03	18.000	0.80013594E 03	18.500	0.80111704E 03
19.000	0.80142231E 03	19.500	0.80126278E 03	20.000	0.80085808E 03	20.030	0.80083495E 03
20.060	0.80083593E 03	20.530	0.80423675E 03	21.000	0.81754714E 03	21.500	0.84665013E 03
22.000	0.89592030E 03	22.435	0.95881294E 03	22.870	0.10423972E 04	22.935	0.10563713E 04
23.000	0.10692299E 04	23.500	0.11562792E 04	24.000	0.12352882E 04	24.500	0.13000684E 04
25.000	0.13534077E 04	25.500	0.13973353E 04	26.000	0.14333696E 04	26.500	0.14623428E 04
27.000	0.14848422E 04	27.500	0.15024513E 04	28.000	0.15165295E 04	28.500	0.15273005E 04
29.000	0.15350594E 04	29.500	0.15391033E 04	30.000	0.15393236E 04	30.500	0.15382852E 04
31.000	0.15377026E 04	31.500	0.15371585E 04	32.000	0.15362480E 04	32.500	0.15350600E 04
33.000	0.15336776E 04	33.500	0.15321515E 04	34.000	0.15305366E 04	34.500	0.15288918E 04
35.000	0.15272737E 04	35.500	0.15256348E 04	36.000	0.15239416E 04	36.500	0.15222073E 04
37.000	0.15204324E 04	37.500	0.15186077E 04	38.000	0.15167645E 04	38.500	0.15149342E 04
39.000	0.15131506E 04	39.500	0.15114170E 04	40.000	0.15097730E 04	40.500	0.15082140E 04
41.000	0.15067343E 04	41.500	0.15052896E 04	42.000	0.15038237E 04	42.500	0.15023343E 04
43.000	0.15008178E 04	43.500	0.14992749E 04	44.000	0.14977164E 04	44.500	0.14961272E 04
45.000	0.14944893E 04	45.500	0.14928076E 04	46.000	0.14910948E 04	46.500	0.14893523E 04
47.000	0.14875811E 04	47.500	0.14857894E 04	48.000	0.14839917E 04	48.500	0.14821840E 04
49.000	0.14803652E 04	49.500	0.14785358E 04	50.000	0.14766975E 04	50.500	0.14748535E 04
51.000	0.14730078E 04	51.500	0.14711586E 04	52.000	0.14693043E 04	52.500	0.14674476E 04
53.000	0.14655912E 04	53.500	0.14637335E 04	54.000	0.14618725E 04	54.500	0.14600108E 04
55.000	0.14581516E 04	55.500	0.14562945E 04	56.000	0.14544395E 04	56.500	0.14525862E 04
57.000	0.14507341E 04	57.500	0.14488841E 04	58.000	0.14470372E 04	0.	0.
0.	0.						

20° Cone, x = 8 in.

SOLUTIONS FOR DELW = 0.104E-01

X= 0.222

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.55999999E 03	2.500	0.56213262E 03	3.000	0.56702875E 03	3.500	0.57321465E 03
4.000	0.57747152E 03	4.435	0.58119698E 03	4.870	0.58778604E 03	4.935	0.58905789E 03
5.000	0.59026065E 03	5.500	0.59837603E 03	6.000	0.60478774E 03	6.500	0.60983627E 03
7.000	0.61380708E 03	7.500	0.61681750E 03	8.000	0.61895177E 03	8.500	0.62037264E 03
9.000	0.62123421E 03	9.500	0.62164064E 03	10.000	0.62166776E 03	10.030	0.62165828E 03
10.060	0.62165278E 03	10.530	0.62253441E 03	11.000	0.62633875E 03	11.500	0.63447157E 03
12.000	0.64751022E 03	12.435	0.66382549E 03	12.870	0.68570652E 03	12.935	0.68945999E 03
13.000	0.69306065E 03	13.500	0.71746223E 03	14.000	0.73652953E 03	14.500	0.75152910E 03
15.000	0.76348029E 03	15.500	0.77292756E 03	16.000	0.78037615E 03	16.500	0.78606927E 03
17.000	0.79016151E 03	17.500	0.79300196E 03	18.000	0.79494303E 03	18.500	0.79611846E 03
19.000	0.79663280E 03	19.500	0.79669005E 03	20.000	0.79649952E 03	20.030	0.79648893E 03
20.060	0.79650166E 03	20.530	0.79987948E 03	21.000	0.81262212E 03	21.500	0.84041183E 03
22.000	0.88747045E 03	22.435	0.94758112E 03	22.870	0.10274784E 04	22.935	0.10408303E 04
23.000	0.10531028E 04	23.500	0.11379705E 04	24.000	0.12122871E 04	24.500	0.12754297E 04
25.000	0.13278036E 04	25.500	0.13712589E 04	26.000	0.14071867E 04	26.500	0.14363410E 04
27.000	0.14592078E 04	27.500	0.14773272E 04	28.000	0.14919792E 04	28.500	0.15033384E 04
29.000	0.15116661E 04	29.500	0.15163144E 04	30.000	0.15171844E 04	30.500	0.15167214E 04
31.000	0.15165845E 04	31.500	0.15164077E 04	32.000	0.15158495E 04	32.500	0.15150020E 04
33.000	0.15139537E 04	33.500	0.15127527E 04	34.000	0.15114512E 04	34.500	0.15101002E 04
35.000	0.15087469E 04	35.500	0.15073479E 04	36.000	0.15058742E 04	36.500	0.15043389E 04
37.000	0.15027421E 04	37.500	0.15010785E 04	38.000	0.14993847E 04	38.500	0.14976903E 04
39.000	0.14960292E 04	39.500	0.14944070E 04	40.000	0.14928680E 04	40.500	0.14914093E 04
41.000	0.14900264E 04	41.500	0.14886755E 04	42.000	0.14873014E 04	42.500	0.14859026E 04
43.000	0.14844760E 04	43.500	0.14830219E 04	44.000	0.14815510E 04	44.500	0.14800490E 04
45.000	0.14784988E 04	45.500	0.14769048E 04	46.000	0.14752792E 04	46.500	0.14736236E 04
47.000	0.14719389E 04	47.500	0.14702331E 04	48.000	0.14685204E 04	48.500	0.14667971E 04
49.000	0.14650627E 04	49.500	0.14633178E 04	50.000	0.14615636E 04	50.500	0.14598036E 04
51.000	0.14580415E 04	51.500	0.14562756E 04	52.000	0.14545043E 04	52.500	0.14527299E 04
53.000	0.14509553E 04	53.500	0.14491791E 04	54.000	0.14473989E 04	54.500	0.14456176E 04
55.000	0.14438381E 04	55.500	0.14420602E 04	56.000	0.14402837E 04	56.500	0.14385082E 04
57.000	0.14367333E 04	57.500	0.14349598E 04	58.000	0.14331889E 04	0.	0.
0.	0.						

10° Cone, x = 4 in.

SOLUTIONS FOR DELW = 0.104E-01

x = 0.389

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.55999999E 03	2.500	0.56186122E 03	3.000	0.56601053E 03	3.500	0.57164648E 03
4.000	0.57670221E 03	4.435	0.58126897E 03	4.870	0.58705157E 03	4.935	0.58803855E 03
5.000	0.58903311E 03	5.500	0.59605908E 03	6.000	0.60170415E 03	6.500	0.60621233E 03
7.000	0.60978734E 03	7.500	0.61248020E 03	8.000	0.61431452E 03	8.500	0.61557927E 03
9.000	0.61658361E 03	9.500	0.61727162E 03	10.000	0.61756262E 03	10.030	0.61757029E 03
10.060	0.61758526E 03	10.530	0.61867259E 03	11.000	0.62211929E 03	11.500	0.62901033E 03
12.000	0.63978967E 03	12.435	0.65292281E 03	12.870	0.66998961E 03	12.935	0.67287236E 03
13.000	0.67565846E 03	13.500	0.69508475E 03	14.000	0.71111327E 03	14.500	0.72446859E 03
15.000	0.73568384E 03	15.500	0.74505676E 03	16.000	0.75285301E 03	16.500	0.75924066E 03
17.000	0.76434270E 03	17.500	0.76831344E 03	18.000	0.77129307E 03	18.500	0.77358232E 03
19.000	0.77549133E 03	19.500	0.77706021E 03	20.000	0.77832505E 03	20.030	0.77839836E 03
20.060	0.77848499E 03	20.530	0.78186058E 03	21.000	0.79078472E 03	21.500	0.80780364E 03
22.000	0.83377951E 03	22.435	0.86522462E 03	22.870	0.90643106E 03	22.935	0.91320553E 03
23.000	0.91943832E 03	23.500	0.96341742E 03	24.000	0.10032649E 04	24.500	0.10387424E 04
25.000	0.10699102E 04	25.500	0.10970370E 04	26.000	0.11203405E 04	26.500	0.11394963E 04
27.000	0.11542655E 04	27.500	0.11667179E 04	28.000	0.11791070E 04	28.500	0.11900611E 04
29.000	0.11978593E 04	29.500	0.12034204E 04	30.000	0.12080563E 04	30.500	0.12122779E 04
31.000	0.12166508E 04	31.500	0.12209171E 04	32.000	0.12246948E 04	32.500	0.12281615E 04
33.000	0.12315486E 04	33.500	0.12348342E 04	34.000	0.12379839E 04	34.500	0.12410070E 04
35.000	0.12439108E 04	35.500	0.12465899E 04	36.000	0.12489203E 04	36.500	0.12509200E 04
37.000	0.12525824E 04	37.500	0.12538188E 04	38.000	0.12546067E 04	38.500	0.12550560E 04
39.000	0.12553642E 04	39.500	0.12555646E 04	40.000	0.12557113E 04	40.500	0.12558201E 04
41.000	0.12559094E 04	41.500	0.12559381E 04	42.000	0.12558551E 04	42.500	0.12556718E 04
43.000	0.12554004E 04	43.500	0.12550549E 04	44.000	0.12546572E 04	44.500	0.12542090E 04
45.000	0.12537117E 04	45.500	0.12531684E 04	46.000	0.12525911E 04	46.500	0.12519845E 04
47.000	0.12513525E 04	47.500	0.12506821E 04	48.000	0.12499577E 04	48.500	0.12491982E 04
49.000	0.12484304E 04	49.500	0.12476530E 04	50.000	0.12468656E 04	50.500	0.12460668E 04
51.000	0.12452535E 04	51.500	0.12444278E 04	52.000	0.12435929E 04	52.500	0.12427499E 04
53.000	0.12419000E 04	53.500	0.12410443E 04	54.000	0.12401842E 04	54.500	0.12393200E 04
55.000	0.12384517E 04	55.500	0.12375789E 04	56.000	0.12367009E 04	56.500	0.12358185E 04
57.000	0.12349327E 04	57.500	0.12340438E 04	58.000	0.12331528E 04	0.	0.
0.	0.						

0° Cone, x = 18 in.

SOLUTIONS FOR CELW = 0.104E-01

 $x = 0.501$

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.55999999E 03	2.500	0.56010437E 03	3.000	0.56099148E 03	3.500	0.56307659E 03
4.000	0.56681015E 03	4.435	0.57160635E 03	4.870	0.57782918E 03	4.935	0.57887585E 03
5.000	0.57987064E 03	5.500	0.58674154E 03	6.000	0.59242570E 03	6.500	0.59710965E 03
7.000	0.60096180E 03	7.500	0.60404517E 03	8.000	0.60641500E 03	8.500	0.60821102E 03
9.000	0.60956340E 03	9.500	0.61051918E 03	10.000	0.61112007E 03	10.030	0.61114721E 03
10.060	0.61118045E 03	10.530	0.61248649E 03	11.000	0.61593202E 03	11.500	0.62248533E 03
12.000	0.63244285E 03	12.435	0.64425687E 03	12.870	0.65922557E 03	12.935	0.66171406E 03
13.000	0.66411819E 03	13.500	0.68107752E 03	14.000	0.69548617E 03	14.500	0.70778187E 03
15.000	0.71838060E 03	15.500	0.72747425E 03	16.000	0.73524381E 03	16.500	0.74184040E 03
17.000	0.74739742E 03	17.500	0.75266308E 03	18.000	0.75597718E 03	18.500	0.75922815E 03
19.000	0.76190399E 03	19.500	0.76414939E 03	20.000	0.76611219E 03	20.030	0.76622575E 03
20.060	0.76635130E 03	20.530	0.77006659E 03	21.000	0.77834152E 03	21.500	0.79317246E 03
22.000	0.81494857E 03	22.435	0.84006684E 03	22.870	0.87153072E 03	22.935	0.87571020E 03
23.000	0.88181382E 03	23.500	0.91884793E 03	24.000	0.95090244E 03	24.500	0.97827213E 03
25.000	0.10018624E 04	25.500	0.10215671E 04	26.000	0.10370953E 04	26.500	0.10493594E 04
27.000	0.10594729E 04	27.500	0.10683002E 04	28.000	0.10770524E 04	28.500	0.10856665E 04
29.000	0.10939778E 04	29.500	0.11012154E 04	30.000	0.11064731E 04	30.500	0.11106572E 04
31.000	0.11147619E 04	31.500	0.11186115E 04	32.000	0.11219949E 04	32.500	0.11249658E 04
33.000	0.11275815E 04	33.500	0.11298999E 04	34.000	0.11320035E 04	34.500	0.11339040E 04
35.000	0.11356285E 04	35.500	0.11371065E 04	36.000	0.11382207E 04	36.500	0.11390838E 04
37.000	0.11398169E 04	37.500	0.11404339E 04	38.000	0.11409963E 04	38.500	0.11414658E 04
39.000	0.11417873E 04	39.500	0.11419880E 04	40.000	0.11421139E 04	40.500	0.11421858E 04
41.000	0.11422330E 04	41.500	0.11422463E 04	42.000	0.11422187E 04	42.500	0.11421523E 04
43.000	0.11420480E 04	43.500	0.11419019E 04	44.000	0.11417113E 04	44.500	0.11414755E 04
45.000	0.11411933E 04	45.500	0.11408597E 04	46.000	0.11404679E 04	46.500	0.11400405E 04
47.000	0.11396080E 04	47.500	0.11391693E 04	48.000	0.11387242E 04	48.500	0.11382747E 04
49.000	0.11378230E 04	49.500	0.11373688E 04	50.000	0.11369122E 04	50.500	0.11364603E 04
51.000	0.11360254E 04	51.500	0.11355832E 04	52.000	0.11351019E 04	52.500	0.11345979E 04
53.000	0.11340854E 04	53.500	0.11335658E 04	54.000	0.11330412E 04	54.500	0.11325117E 04
55.000	0.11319779E 04	55.500	0.11314385E 04	56.000	0.11308923E 04	56.500	0.11303391E 04
57.000	0.11297785E 04	57.500	0.11292092E 04	58.000	0.11286296E 04	0.	0.

0° Cone, x = 22 in.

SOLUTIONS FOR CELW = 0.104E-01

X = 0.612

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.55999999E 03	2.500	0.56010000E 03	3.000	0.56095789E 03	3.500	0.56297201E 03
4.000	0.56658034E 03	4.435	0.57122897E 03	4.870	0.57727484E 03	4.935	0.57829224E 03
5.000	0.57925949E 03	5.500	0.58594482E 03	6.000	0.59148139E 03	6.500	0.59604991E 03
7.000	0.59981415E 03	7.500	0.60283454E 03	8.000	0.60516613E 03	8.500	0.60694372E 03
9.000	0.60829277E 03	9.500	0.60925780E 03	10.000	0.60987851E 03	10.030	0.60990750E 03
10.060	0.60994196E 03	10.530	0.61124085E 03	11.000	0.61460652E 03	11.500	0.62099412E 03
12.000	0.63070260E 03	12.435	0.64221340E 03	12.870	0.65679252E 03	12.935	0.65921660E 03
13.000	0.66155856E 03	13.500	0.67809522E 03	14.000	0.69216906E 03	14.500	0.70429266E 03
15.000	0.71458147E 03	15.500	0.72349434E 03	16.000	0.73111936E 03	16.500	0.73760235E 03
17.000	0.74307755E 03	17.500	0.74768967E 03	18.000	0.75157334E 03	18.500	0.75481246E 03
19.000	0.75749046E 03	19.500	0.75974803E 03	20.000	0.76172961E 03	20.030	0.76184439E 03
20.060	0.76197064E 03	20.530	0.76563770E 03	21.000	0.77370617E 03	21.500	0.78810173E 03
22.000	0.80917820E 03	22.435	0.83345842E 03	22.870	0.86384887E 03	22.935	0.86885026E 03
23.000	0.87377950E 03	23.500	0.90958302E 03	24.000	0.94062280E 03	24.500	0.96715607E 03
25.000	0.99004347E 03	25.500	0.10091766E 04	26.000	0.10242672E 04	26.500	0.10361964E 04
27.000	0.10460427E 04	27.500	0.10546438E 04	28.000	0.10631767E 04	28.500	0.10715049E 04
29.000	0.10794920E 04	29.500	0.10864399E 04	30.000	0.10915183E 04	30.500	0.10955773E 04
31.000	0.10995640E 04	31.500	0.11033092E 04	32.000	0.11066059E 04	32.500	0.11095070E 04
33.000	0.11120676E 04	33.500	0.11143426E 04	34.000	0.11164115E 04	34.500	0.11182848E 04
35.000	0.11199882E 04	35.500	0.11214472E 04	36.000	0.11225639E 04	36.500	0.11234295E 04
37.000	0.11241690E 04	37.500	0.11247958E 04	38.000	0.11253695E 04	38.500	0.11258529E 04
39.000	0.11261919E 04	39.500	0.11264133E 04	40.000	0.11265616E 04	40.500	0.11266574E 04
41.000	0.11267292E 04	41.500	0.11267679E 04	42.000	0.11267659E 04	42.500	0.11267281E 04
43.000	0.11266521E 04	43.500	0.11265353E 04	44.000	0.11263750E 04	44.500	0.11261702E 04
45.000	0.11259194E 04	45.500	0.11256161E 04	46.000	0.11252556E 04	46.500	0.11248602E 04
47.000	0.11244600E 04	47.500	0.11240541E 04	48.000	0.11236420E 04	48.500	0.11232258E 04
49.000	0.11228075E 04	49.500	0.11223860E 04	50.000	0.11219636E 04	50.500	0.11215451E 04
51.000	0.11211430E 04	51.500	0.11207330E 04	52.000	0.11202867E 04	52.500	0.11198175E 04
53.000	0.11193390E 04	53.500	0.11188553E 04	54.000	0.11183659E 04	54.500	0.11178717E 04
55.000	0.11173732E 04	55.500	0.11168692E 04	56.000	0.11163584E 04	56.500	0.11158407E 04
57.000	0.11153157E 04	57.500	0.11147822E 04	58.000	0.11142305E 04	0.	0.
0.	0.						

Laminar Approximation, T_w in $^{\circ}R$

30° Cone, $x = 2$ in.

LAMINAR CASE SOLUTION FOR DELW = 0.04E-01 X = 0.057

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.58800000E 03	2.500	0.58844221E 03	3.000	0.58989119E 03	3.500	0.59200841E 03
4.000	0.59386880E 03	4.435	0.59567663E 03	4.870	0.59838352E 03	4.935	0.59887364E 03
5.000	0.59934781E 03	5.500	0.60266788E 03	6.000	0.60543866E 03	6.500	0.60771711E 03
7.000	0.60955871E 03	7.500	0.61100832E 03	8.000	0.61208419E 03	8.500	0.61285980E 03
9.000	0.61340828E 03	9.500	0.61378559E 03	10.000	0.61404509E 03	10.030	0.61405689E 03
10.060	0.61407036E 03	10.530	0.61477263E 03	11.000	0.61689286E 03	11.500	0.62113392E 03
12.000	0.62789387E 03	12.435	0.63656505E 03	12.870	0.64879605E 03	12.935	0.65095756E 03
13.000	0.65305110E 03	13.500	0.66762941E 03	14.000	0.67959157E 03	14.500	0.68966378E 03
15.000	0.69859986E 03	15.500	0.70637608E 03	16.000	0.71296139E 03	16.500	0.71849125E 03
17.000	0.72306848E 03	17.500	0.72682115E 03	18.000	0.72989026E 03	18.500	0.73236421E 03
19.000	0.73433106E 03	19.500	0.73587034E 03	20.000	0.73708457E 03	20.030	0.73715767E 03
20.060	0.73725916E 03	20.530	0.74168922E 03	21.000	0.75428639E 03	21.500	0.78068598E 03
22.000	0.82589453E 03	22.435	0.88557699E 03	22.870	0.96888827E 03	22.935	0.98341246E 03
23.000	0.99709312E 03	23.500	0.10951959E 04	24.000	0.11846660E 04	24.500	0.12616452E 04
25.000	0.13252310E 04	25.500	0.13780177E 04	26.000	0.14218405E 04	26.500	0.14562859E 04
27.000	0.14800170E 04	27.500	0.14965315E 04	28.000	0.15094249E 04	28.500	0.15190954E 04
29.000	0.15262327E 04	29.500	0.15286282E 04	30.000	0.15253801E 04	30.500	0.15215192E 04
31.000	0.15201587E 04	31.500	0.15199888E 04	32.000	0.15196973E 04	32.500	0.15193593E 04
33.000	0.15190881E 04	33.500	0.15189521E 04	34.000	0.15190791E 04	34.500	0.15195933E 04
35.000	0.15207054E 04	35.500	0.15223303E 04	36.000	0.15242864E 04	36.500	0.15266214E 04
37.000	0.15294793E 04	37.500	0.15323099E 04	38.000	0.15345728E 04	38.500	0.15365692E 04
39.000	0.15389079E 04	39.500	0.15415131E 04	40.000	0.15443177E 04	40.500	0.15474579E 04
41.000	0.15511346E 04	41.500	0.15547956E 04	42.000	0.15577383E 04	42.500	0.15601719E 04
43.000	0.15623425E 04	43.500	0.15641022E 04	44.000	0.15653130E 04	44.500	0.15660424E 04
45.000	0.15663990E 04	45.500	0.15663412E 04	46.000	0.15659129E 04	46.500	0.15651710E 04
47.000	0.15641588E 04	47.500	0.15629274E 04	48.000	0.15615693E 04	48.500	0.15601362E 04
49.000	0.15586907E 04	49.500	0.15572190E 04	50.000	0.15557130E 04	50.500	0.15541714E 04
51.000	0.15525854E 04	51.500	0.15508696E 04	52.000	0.15489327E 04	52.500	0.15469237E 04
53.000	0.15450141E 04	53.500	0.15431460E 04	54.000	0.15412495E 04	54.500	0.15393230E 04
55.000	0.15373655E 04	55.500	0.15353525E 04	56.000	0.15332595E 04	56.500	0.15311192E 04
57.000	0.15289675E 04	57.500	0.15268031E 04	58.000	0.15246248E 04	0.	0.
0.	0.						

20° Cone, x = 4 in.

LAMINAR CASE SOLUTION FOR DELW = 0.104E-01

X = 0.111

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.58800000E 03	2.500	0.58830424E 03	3.000	0.58929107E 03	3.500	0.59062286E 03
4.000	0.59154214E 03	4.435	0.59236398E 03	4.870	0.59389807E 03	4.935	0.59420030E 03
5.000	0.59448989E 03	5.500	0.59651484E 03	6.000	0.59821865E 03	6.500	0.59965071E 03
7.000	0.60085992E 03	7.500	0.60185539E 03	8.000	0.60264065E 03	8.500	0.60324244E 03
9.000	0.60369077E 03	9.500	0.60400945E 03	10.000	0.60421775E 03	10.030	0.60422700E 03
10.060	0.60423773E 03	10.530	0.60470503E 03	11.000	0.60603677E 03	11.500	0.60863681E 03
12.000	0.61267944E 03	12.435	0.61770507E 03	12.870	0.62451445E 03	12.935	0.62569769E 03
13.000	0.62685105E 03	13.500	0.63510270E 03	14.000	0.64227108E 03	14.500	0.64855345E 03
15.000	0.65415988E 03	15.500	0.65512468E 03	16.000	0.66348936E 03	16.500	0.66731213E 03
17.000	0.67063875E 03	17.500	0.67352019E 03	18.000	0.67601933E 03	18.500	0.67818410E 03
19.000	0.68006216E 03	19.500	0.68171018E 03	20.000	0.68319509E 03	20.030	0.68328499E 03
20.060	0.68339083E 03	20.530	0.68634611E 03	21.000	0.69281285E 03	21.500	0.70507877E 03
22.000	0.72503071E 03	22.435	0.75064916E 03	22.870	0.78576448E 03	22.935	0.79181337E 03
23.000	0.79748377E 03	23.500	0.83983838E 03	24.000	0.88234295E 03	24.500	0.92248373E 03
25.000	0.95837490E 03	25.500	0.99058843E 03	26.000	0.10196140E 04	26.500	0.10457265E 04
27.000	0.10690524E 04	27.500	0.10900655E 04	28.000	0.11092793E 04	28.500	0.11260142E 04
29.000	0.11398437E 04	29.500	0.11503059E 04	30.000	0.11571445E 04	30.500	0.11622347E 04
31.000	0.11672301E 04	31.500	0.11718284E 04	32.000	0.11758625E 04	32.500	0.11795153E 04
33.000	0.11829952E 04	33.500	0.11863490E 04	34.000	0.11896413E 04	34.500	0.11928212E 04
35.000	0.11957990E 04	35.500	0.11984829E 04	36.000	0.12008328E 04	36.500	0.12029196E 04
37.000	0.12047407E 04	37.500	0.12061968E 04	38.000	0.12073984E 04	38.500	0.12084199E 04
39.000	0.12093547E 04	39.500	0.12102569E 04	40.000	0.12112717E 04	40.500	0.12124314E 04
41.000	0.12137732E 04	41.500	0.12151604E 04	42.000	0.12164246E 04	42.500	0.12175959E 04
43.000	0.12186997E 04	43.500	0.12197155E 04	44.000	0.12206565E 04	44.500	0.12215169E 04
45.000	0.12222768E 04	45.500	0.12228993E 04	46.000	0.12233814E 04	46.500	0.12237462E 04
47.000	0.12240132E 04	47.500	0.12241862E 04	48.000	0.12242944E 04	48.500	0.12243486E 04
49.000	0.12243722E 04	49.500	0.12243500E 04	50.000	0.12242690E 04	50.500	0.12241527E 04
51.000	0.12240259E 04	51.500	0.12238649E 04	52.000	0.12236462E 04	52.500	0.12233788E 04
53.000	0.12230736E 04	53.500	0.12227334E 04	54.000	0.12223592E 04	54.500	0.12219585E 04
55.000	0.12215409E 04	55.500	0.12210962E 04	56.000	0.1220649E 04	56.500	0.12200973E 04
57.000	0.12195431E 04	57.500	0.12189514E 04	58.000	0.12183219E 04	0.	0.
0.	0.						

20° Cone, x = 6 in.

LAMINAR CASE SOLUTION FOR DELW = 0.104E-01

x = 0.166

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.58800000E 03	2.500	0.58824753E 03	3.000	0.58905463E 03	3.500	0.59014668E 03
4.000	0.59090417E 03	4.435	0.59158347E 03	4.870	0.59284893E 03	4.935	0.59309818E 03
5.000	0.59333725E 03	5.500	0.59501358E 03	6.000	0.59643100E 03	6.500	0.59762888E 03
7.000	0.59864669E 03	7.500	0.59949125E 03	8.000	0.60016496E 03	8.500	0.60068910E 03
9.000	0.60108763E 03	9.500	0.60138027E 03	10.000	0.60158333E 03	10.030	0.60159289E 03
10.060	0.60160369E 03	10.530	0.60202060E 03	11.000	0.60314835E 03	11.500	0.60532583E 03
12.000	0.60869728E 03	12.435	0.61288296E 03	12.870	0.61855174E 03	12.935	0.61953724E 03
13.000	0.62049864E 03	13.500	0.62739919E 03	14.000	0.63343095E 03	14.500	0.63875115E 03
15.000	0.64353091E 03	15.500	0.64779300E 03	16.000	0.65156608E 03	16.500	0.65489596E 03
17.000	0.65782300E 03	17.500	0.66038489E 03	18.000	0.66262928E 03	19.500	0.66459545E 03
19.000	0.66632330E 03	19.500	0.66785829E 03	20.000	0.66925452E 03	20.030	0.66933912E 03
20.060	0.66943769E 03	20.530	0.67206918E 03	21.000	0.67762308E 03	21.500	0.68801893E 03
22.000	0.70483471E 03	22.435	0.72638497E 03	22.370	0.75592412E 03	22.935	0.76101539E 03
23.000	0.76579335E 03	23.500	0.80163400E 03	24.000	0.83789415E 03	24.500	0.87242676E 03
25.000	0.90356077E 03	25.500	0.93173251E 03	26.000	0.95732361E 03	26.500	0.98054846E 03
27.000	0.10015044E 04	27.500	0.10205655E 04	28.000	0.10381446E 04	28.500	0.10535961E 04
29.000	0.10664911E 04	29.500	0.10764793E 04	30.000	0.10833565E 04	30.500	0.10886307E 04
31.000	0.10936768E 04	31.500	0.10982758E 04	32.000	0.11023653E 04	32.500	0.11061162E 04
33.000	0.11097269E 04	33.500	0.11132360E 04	34.000	0.11166974E 04	34.500	0.11200488E 04
35.000	0.11231854E 04	35.500	0.11260238E 04	36.000	0.11285314E 04	36.500	0.11307731E 04
37.000	0.11327423E 04	37.500	0.11343464E 04	38.000	0.11356964E 04	38.500	0.11368590E 04
39.000	0.11379185E 04	39.500	0.11389308E 04	40.000	0.11400343E 04	40.500	0.11412602E 04
41.000	0.11426439E 04	41.500	0.11440615E 04	42.000	0.11453617E 04	42.500	0.11465728E 04
43.000	0.11477190E 04	43.500	0.11487804E 04	44.000	0.11497688E 04	44.500	0.11506815E 04
45.000	0.11515037E 04	45.500	0.11522011E 04	46.000	0.11527701E 04	46.500	0.11532313E 04
47.000	0.11536024E 04	47.500	0.11538860E 04	48.000	0.11541082E 04	48.500	0.11542810E 04
49.000	0.11544282E 04	49.500	0.11545358E 04	50.000	0.11545920E 04	50.500	0.11546174E 04
51.000	0.11546344E 04	51.500	0.11546217E 04	52.000	0.11545573E 04	52.500	0.11544493E 04
53.000	0.11543065E 04	53.500	0.11541321E 04	54.000	0.11539283E 04	54.500	0.11537009E 04
55.000	0.11534585E 04	55.500	0.11531910E 04	56.000	0.11528895E 04	56.500	0.11525545E 04
57.000	0.11521861E 04	57.500	0.11517826E 04	58.000	0.11513429E 04	0.	0.
0.	0.						

20° Cone, x = 8 in.

LAMINAR CASE SOLUTION FOR DELW = 0.104E-01

x = 0.222

T=	TW=	T=	TW=	T=	TW=	T=	TW=
2.000	0.58800000E 03	2.500	0.58821307E 03	3.000	0.58891077E 03	3.500	0.58985642E 03
4.000	0.59051429E 03	4.435	0.59110540E 03	4.870	0.59220542E 03	4.935	0.59242207E 03
5.000	0.59263001E 03	5.500	0.59409051E 03	6.000	0.59532916E 03	6.500	0.59637949E 03
7.000	0.59727533E 03	7.500	0.59802227E 03	8.000	0.59862216E 03	8.500	0.59909302E 03
9.000	0.59945532E 03	9.500	0.59972622E 03	10.000	0.59992012E 03	10.030	0.59992951E 03
10.060	0.59993999E 03	10.530	0.60031965E 03	11.000	0.60131717E 03	11.500	0.60322893E 03
12.000	0.60618100E 03	12.435	0.60984226E 03	12.870	0.61480018E 03	12.935	0.61566225E 03
13.000	0.61650366E 03	13.500	0.62255496E 03	14.000	0.62786439E 03	14.500	0.63256580E 03
15.000	0.63680688E 03	15.500	0.64066452E 03	16.000	0.64398C32E 03	16.500	0.64697379E 03
17.000	0.64962061E 03	17.500	0.65195151E 03	18.000	0.65400556E 03	18.500	0.65581675E 03
19.000	0.65742007E 03	19.500	0.65885429E 03	20.000	0.66016586E 03	20.030	0.66024537E 03
20.060	0.66033750E 03	20.530	0.66273616E 03	21.000	0.66769C97E 03	21.500	0.67688917E 03
22.000	0.69171424E 03	22.435	0.71066673E 03	22.870	0.73668E56E 03	22.935	0.74117225E 03
23.000	0.74538295E 03	23.500	0.77705032E 03	24.000	0.80924E95E 03	24.500	0.84006719E 03
25.000	0.86799520E 03	25.500	0.89339134E 03	26.000	0.91657545E 03	26.500	0.93772740E 03
27.000	0.95692820E 03	27.500	0.97449360E 03	28.000	0.99077E73E 03	28.500	0.10051665E 04
29.000	0.10172451E 04	29.500	0.10267240E 04	30.000	0.10334293E 04	30.500	0.10386492E 04
31.000	0.10435849E 04	31.500	0.10480630E 04	32.000	0.10520734E 04	32.500	0.10557759E 04
33.000	0.10593592E 04	33.500	0.10528568E 04	34.000	0.10663159E 04	34.500	0.10696701E 04
35.000	0.10728100E 04	35.500	0.10756578E 04	36.000	0.10781854E 04	36.500	0.10804531E 04
37.000	0.10824522E 04	37.500	0.10840954E 04	38.000	0.10854913E 04	38.500	0.10867010E 04
39.000	0.10878024E 04	39.500	0.10888503E 04	40.000	0.10899769E 04	40.500	0.10912119E 04
41.000	0.10925890E 04	41.500	0.10939936E 04	42.000	0.10952865E 04	42.500	0.10964946E 04
43.000	0.10976405E 04	43.500	0.10987057E 04	44.000	0.10997004E 04	44.500	0.11006239E 04
45.000	0.11014641E 04	45.500	0.11021888E 04	46.000	0.11027942E 04	46.500	0.11032993E 04
47.000	0.11037201E 04	47.500	0.11040591E 04	48.000	0.11043397E 04	48.500	0.11045745E 04
49.000	0.11047868E 04	49.500	0.11049637E 04	50.000	0.11050941E 04	50.500	0.11051968E 04
51.000	0.11052924E 04	51.500	0.11053613E 04	52.000	0.11053830E 04	52.500	0.11053643E 04
53.000	0.11053134E 04	53.500	0.11052335E 04	54.000	0.11051270E 04	54.500	0.11049993E 04
55.000	0.11048576E 04	55.500	0.11046927E 04	56.000	0.11044958E 04	56.500	0.11042677E 04
57.000	0.11040085E 04	57.500	0.11037162E 04	58.000	0.11033896E 04	0.	0.
0.	0.						

10° Cone, x = 14 in.

LAMINAR CASE SOLUTION FOR DELW = 0.104E-01

9,360

Tz	TWz	Tz	TWz	Tz	TWz	Tz	TWz
2.000	0.58800000E 03	2.500	0.58815785E 03	3.000	0.58866335E 03	3.500	0.58938803E 03
4.000	0.59003083E 03	4.435	0.59062232E 03	4.870	0.59141298E 03	4.935	0.59155203E 03
5.000	0.59169432E 03	5.500	0.59273533E 03	6.000	0.59362295E 03	6.500	0.59437682E 03
7.000	0.59501582E 03	7.500	0.59553745E 03	8.000	0.59593537E 03	8.500	0.59624876E 03
9.000	0.59652571E 03	9.500	0.59675450E 03	10.000	0.59691831E 03	10.030	0.59692654E 03
10.060	0.59693623E 03	10.530	0.59724261E 03	11.000	0.59796288E 03	11.500	0.59929059E 03
12.000	0.60130481E 03	12.435	0.60374273E 03	12.370	0.60693684E 03	12.935	0.60748270E 03
13.000	0.60801703E 03	13.500	0.61190117E 03	14.000	0.61538458E 03	14.500	0.61853011E 03
15.000	0.62140931E 03	15.500	0.62402205E 03	16.000	0.62636909E 03	16.500	0.62847333E 03
17.000	0.63035719E 03	17.500	0.63202631E 03	18.000	0.63348731E 03	18.500	0.63479607E 03
19.000	0.63601848E 03	19.500	0.63715758E 03	20.000	0.63821726E 03	20.030	0.63827931E 03
20.060	0.63834415E 03	20.530	0.63982060E 03	21.000	0.64255668E 03	21.500	0.64720894E 03
22.000	0.65404350E 03	22.435	0.66242614E 03	22.870	0.67400272E 03	22.935	0.67598685E 03
23.000	0.67783453E 03	23.500	0.69162614E 03	24.000	0.70552322E 03	24.500	0.71872701E 03
25.000	0.73060998E 03	25.500	0.74125727E 03	26.000	0.75073925E 03	26.500	0.75899850E 03
27.000	0.76593985E 03	27.500	0.77221886E 03	28.000	0.77882820E 03	28.500	0.78496755E 03
29.000	0.78956972E 03	29.500	0.79311582E 03	30.000	0.79634640E 03	30.500	0.79952054E 03
31.000	0.80299061E 03	31.500	0.80654172E 03	32.000	0.80983221E 03	32.500	0.81300844E 03
33.000	0.81627119E 03	33.500	0.81961637E 03	34.000	0.82303102E 03	34.500	0.82650048E 03
35.000	0.83000515E 03	35.500	0.83341956E 03	36.000	0.83659676E 03	36.500	0.83960871E 03
37.000	0.84247761E 03	37.500	0.84496115E 03	38.000	0.84693696E 03	38.500	0.84854755E 03
39.000	0.85004087E 03	39.500	0.85144721E 03	40.000	0.85282785E 03	40.500	0.85422458E 03
41.000	0.85568717E 03	41.500	0.85711686E 03	42.000	0.85839676E 03	42.500	0.85956040E 03
43.000	0.86064048E 03	43.500	0.86163058E 03	44.000	0.86254570E 03	44.500	0.86340041E 03
45.000	0.86420782E 03	45.500	0.86495066E 03	46.000	0.86563134E 03	46.500	0.86626697E 03
47.000	0.86687481E 03	47.500	0.86741702E 03	48.000	0.86784922E 03	48.500	0.86821377E 03
49.000	0.86857091E 03	49.500	0.86891187E 03	50.000	0.86922920E 03	50.500	0.86952511E 03
51.000	0.86979839E 03	51.500	0.87004424E 03	52.000	0.87026226E 03	52.500	0.87045523E 03
53.000	0.87062629E 03	53.500	0.87078120E 03	54.000	0.87092606E 03	54.500	0.87106128E 03
55.000	0.87118766E 03	55.500	0.87129861E 03	56.000	0.87138792E 03	56.500	0.87145840E 03
57.000	0.87151324E 03	57.500	0.87155189E 03	58.000	0.87157483E 03	0.	0.
0.	0.

Fig. 1. Velocity profile for fluid flow along a wall.

GLL-648-2466

Fig. 2. Nose cone approximated by three conical segments.

GLL-648-2467

Fig. 3. Temperature distribution along HAD nose cone. Wall thickness 1/8 in., time 29 sec after launch.

GLL-648-2468

Fig. 4. Wall temperature 6 in. aft of nose as a function of time after launch. Wall thickness 1/8 in.

— LEGAL NOTICE —

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission " includes any employee or contractor of the commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.