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ON COMPRESSIBLE LAMINAR BOUNDARY LAYER FLOW OVER A SEMI-INFINITE FLAT PLATE WITH VARIABLE FLUID PROPERTIES

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ABSTRACT

We have considered the effect of the variation of fluid properties, such as temperature dependence of the viscosity coefficient, on the bonndary layer solution. To get over the difficulty of large computational work we have developed a series solution by splitting up the flow variables into sets of universal functions which are independent of the law governing the viscosity-temperature relation and also of the surface and free stream conditions. We have also given tables for the universal functions and have considered some examples.

1. INTRODUCTION

In this paper we have made a study of the effect of the variation of fluid properties on the boundary layer solution, taking the flow over a semi-infinite flat plate at zero angle of incidence. The surface temperature of the plate has been assumed to be constant and the effect of pressure-gradient is neglected.

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If the product of viscosity and density $(\bar{\mu} \cdot \bar{\rho})$ is not constant, the velocity and temperature fields are coupled and the solutions of the equations governing the flow depend on the prescribed free-stream and surface conditions and on the parameter occurring in the viscosity-temperature relation. Hence, under such conditions, a large number of numerical solutions are required to study the characteristics of the flow.

In order to get over this difficulty of large computational work, we have developed a Görtler type series solution by splitting up the normalised stream function f and the normalised temperature θ into sets of universal functions which are independent of the law governing the viscosity-temperature relation and also of the surface and free stream conditions. The surface and free-stream parameters, and the parameter associated with the viscosity-temperature relation appear as coefficients of the universal functions into which f and θ have been split up. The equations for universal functions have been integrated for Prandtl number 0.7 and the flow characteristics can be easily computed for a fairly good range of surface and free-stream conditions and for the parameter occuring in the viscosity temperature relation from these solutions. To illustrate the procedure we have drawn graphs corresponding to a few sets of parameters. The tables of the universal functions are given so that they might be used for computing the flow characteristics corresponding to other sets of parameters.

2. Equations of Motion and Boundary Conditions

The non-dimensionalised equations governing the two-dimensional compressible steady boundary layer flow are

$$\frac{\partial}{\partial \bar{x}}(\bar{\rho}\,\bar{u}) + \frac{\partial}{\partial \bar{y}}(\bar{\rho}\,\bar{v}) = 0\,, \qquad [2.1]$$

$$\bar{\rho}\,\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{\rho}\,\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \frac{\partial}{\partial \bar{y}}\left(\bar{\mu}\frac{\partial \bar{u}}{\partial \bar{y}}\right), \qquad [2.2]$$

$$\bar{\rho}\,\bar{u}\frac{\partial \bar{T}}{\partial \bar{x}} + \bar{\rho}\,\bar{v}\frac{\partial \bar{T}}{\partial \bar{y}} = (\gamma - 1)\,M_\infty^2\,\bar{\mu}\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 + \frac{\partial}{\partial \bar{y}}\left(\frac{\bar{\mu}}{\sigma}\frac{\partial \bar{T}}{\partial \bar{y}}\right), \qquad [2.3]$$

and the equation of state for air obeying the perfect gas law is

$$\bar{p} = \bar{\rho}\,\bar{T} \qquad [2.4]$$

where

$$\bar{x} = (x/L), \quad \bar{y} = (y/L)\sqrt{R_\infty}, \quad \bar{u} = (u/U_\infty), \quad \bar{v} = (\bar{v}/U_\infty)\sqrt{R_\infty},$$

$\bar{\rho}=(\rho/\rho_\infty)$, $\bar{p}=(p/p_\infty)$, $\bar{\mu}=(\mu/\mu_\infty)$, $\bar{T}=(T/T_\infty)$,

$c_p/c_v=\gamma=$constant, $M_\infty=$free stream Mach number,

$R_\infty=$free stream Reynolds number, $\sigma=$Prandtl number,

$L=$characteristic length ; and the variable with suffix ∞ denotes its value in free stream.

The boundary conditions are

(i) at $\bar{y}=0$; $\bar{u}=0$, $\bar{v}=0$, and $\bar{T}=\bar{T}_w=$constant

(ii) at $\bar{y}=\infty$, $\bar{u}=1$, $\bar{T}=1$ [2.5]

In terms of the similarity variables defined by

$$\xi=\bar{x},\quad \eta=\frac{1}{\sqrt{(2\xi)}}\int_0^{\bar{y}}\bar{\rho}\,d\bar{y},$$

$$\psi=\sqrt{(2\xi)}\,f(\eta),\quad \bar{T}=\bar{T}(\eta) \qquad [2.6]$$

where the stream function ψ is such that

$$\bar{\rho}\,\bar{u}=\frac{\partial\psi}{\partial\bar{y}},\quad \bar{\rho}\,\bar{u}=-\frac{\partial\psi}{\partial\bar{x}},$$

the equations [2.2] and [2.3] reduce to

$$(\bar{\rho}\,\bar{\mu}\,f'')'+ff''=0 \qquad [2.7]$$

$$\left(\frac{\bar{\rho}\,\bar{\mu}}{\sigma}\bar{T}'\right)'+f\bar{T}'+(\gamma-1)\,M_\infty^2\,\bar{\rho}\,\bar{\mu}\,f''^2=0 \qquad [2.8]$$

where dash denotes differentiation with respect to η.

In terms of the normalised temperature θ defined by

$$\theta=\frac{\bar{T}-1}{\bar{T}_w-1},\quad i.e.,\quad \bar{T}=(\bar{T}_w-1)\,\theta+1=\epsilon\,\theta+1,$$

where $$\epsilon=(\bar{T}_w-1)\neq 0, \qquad [2.9]$$

the equation [2.8] reduces to

$$\left(\frac{\bar{\rho}\,\bar{\mu}}{\sigma}\,\theta'\right)'+f\theta'+\frac{(\gamma-1)\,M_\infty^2}{\bar{T}_w-1}\,(\bar{\rho}\,\bar{\mu})\,f''^2=0 \qquad [2.10]$$

and the boundary conditions [2.5] now reduce to

$$\text{(i) } f(0)=f'(0)=0\,; \quad \theta(0)=1, \quad \text{(ii) } f'(\infty)=1\,; \quad \theta(\infty) \;\; 0 \qquad [2.11]$$

We assume that
$$\bar{\rho}\,\bar{\mu}=1+a_1\,\bar{T}+a_2\,\bar{T}^2$$
$$=A+\epsilon\,B\,\theta+\epsilon^2\,a_2\,\theta^2, \qquad [2.12]$$

where
$$A=1+a_1+a_2, \quad B=a_1+2a_2,$$

and the constants a_1 and a_2 can be determined by fitting the quadratic expression [2.12] with either the power-law for viscosity-temperature relation or with the Sutherland viscosity law.

We expand f and θ in powers of ϵ as follows:

$$f=f_0+\epsilon\,f_1+\epsilon^2 f_2+\;\cdots, \qquad [2.13]$$

$$\theta=\theta_0+\epsilon\,\theta_1+\epsilon^2\,\theta_2+\;\cdots. \qquad [2.14]$$

Substituting [2.12], [2.13] and [2.14] in [2.7] and [2.10] and by comparison of coefficients of equal powers of ϵ, we obtain the following recursive system of equations, of which all but the first are linear:

$$A\,f_0''' + f_0 f_0''=0, \qquad [2.15]$$

$$\frac{A}{\sigma}\,\theta_0'' + f_0\,\theta_0' + \frac{A(\gamma-1)\,M_\infty^2}{\bar{T}_w-1}\,f_0''^2=0, \qquad [2.16]$$

$$A\,f_1''' + f_0 f_1'' + f_0'' f_1 = -B\,(f_0'''\,\theta_0 + f_0''\,\theta_0'), \qquad [2.17]$$

$$\frac{A}{\sigma}\,\theta_1'' + f_0\,\theta_1' = -\frac{B}{\sigma}\,(\theta_0'^2+\theta_0\,\theta_0'') - \theta_0' f_1 - \frac{(\gamma-1)\,M_\infty^2}{\bar{T}_w-1}\,(B\,\theta_0\,f_0''^2 + 2A\,f_0''\,f_1''), \qquad [2.18]$$

$$A\,f_2''' + f_0 f_2'' + f_0'' f_2 = -f_1 f_1'' - (B\,\theta_1' + 2\,a_2\,\theta_0\,\theta_0'\;f_0''$$
$$-B\,(\theta_0' f_1'' + \theta_0\,f_1''') - (B\,\theta_1 + a_2\,\theta_0^2\;f_0'''. \qquad [2.19]$$

$$\frac{A}{\sigma}\,\theta_2'' + f_0\,\theta_2' = -\frac{B}{\sigma}\,(2\,\theta_1'\,\theta_0' + \theta_0\,\theta_1'' + \theta_1\,\theta_0'') - \frac{a_2}{\sigma}\,(2\,\theta_0\,\theta_0'^2 + \theta_0^2\,\theta_0''$$
$$-\theta_1' f_1 - \theta_0' f_2 - \frac{(\gamma-1)\,M_\infty^2}{\bar{T}_w-1}\,[(B\,\theta_1 + a_2\,\theta_0^2)\,f_0''^2 + 2\,B\,f_0''\,f_1''\,\theta_0$$
$$+A\,(f_1''^2 + 2 f_0''\,f_2'')], \qquad [2.20]$$

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The boundary conditions [2.11] reduce to

$$
\begin{aligned}
& f_j(0) = f_j'(0) = 0, \quad (j = 0, 1, 2, \cdots) \\
& \quad \theta_0(0) = 1; \quad \theta_j(0) = 0, \quad (j = 1, 2, \cdots) \\
& f_0'(\infty) = 1, \quad f_j'(\infty) = 0 \ (j = 1, 2, \cdots) \\
& \qquad\qquad \theta_j(\infty) = 0 \ (j = 0, 1, 2, \cdots).
\end{aligned}
\qquad [2.21]
$$

3. Splitting of f and θ into Universal Functions

We find that the equations [2.15] to [2.20] contain coefficients which are dependent on the free stream and plate conditions and on the fluid properties. We split them into a set of recursive system of equations determining the universal functions which are independent of the surface and free-stream conditions and also of the law governing the viscosity-temperature relation.

We set

$$\bar{\eta} = \eta/\sqrt{A}, \qquad [3.1]$$

$$F_i = (f_i/\sqrt{A}), \quad (i = 0, 1, 2, \cdots) \qquad [3.2]$$

$$\theta_0 = \theta_{00} + [(\gamma - 1) M_\infty^2/\bar{T}_w - 1]\, \theta_{01}, \qquad [3.3]$$

$$F_1 = (B/A) F_{10} + (B/A) [(\gamma - 1) M_\infty^2/\bar{T}_w - 1] F_{11}, \qquad [3.4]$$

$$\theta_1 = \frac{B}{A}\theta_{10} + \frac{B}{A}\frac{(\gamma-1)M_\infty^2}{\bar{T}_w - 1}\theta_{11} + \frac{B}{A}\left\{\frac{(\gamma-1)M_\infty^2}{\bar{T}_w - 1}\right\}^2\theta_{12}, \qquad [3.5]$$

The equations [2.15] and [2.16] under the transformations [3.1] to [3.3] reduce to

$$F_0''' + F_0 F_0'' = 0, \qquad [3.6]$$

$$(1/\sigma)\, \theta_{00}'' + F_0 \theta_{00}' = 0, \qquad [3.7]$$

$$(1/\sigma)\, \theta_{01}'' + F_0 \theta_{01}' = -F_0''^{\,2}, \qquad [3.8]$$

where $\quad ' \equiv d/d\bar{\eta}$,

and the corresponding boundary conditions [2.21] become

(i) $F_0(0) = F_0'(0) = 0; \quad \theta_{00}(0) = 1, \quad \theta_{01}(0) = 0,$

(ii) $F_0'(\infty) = 1; \quad \theta_{00}(\infty) = \theta_{01}(\infty) = 0.$ [3.9]

The equations [2.17] and [2.18] under the transformations [3.1] to [3.5] reduce to

$$F_{10}''' + F_0 F_{10}'' + F_0'' F_{10} = -(F_0''' \theta_{00} + F_0'' \theta_{00}'), \tag{3.10}$$

$$F_{11}''' + F_0 F_{11}'' + F_0'' F_{11} = -(F_0''' \theta_{01} + F_0'' \theta_{01}'), \tag{3.11}$$

$$(1/\sigma)\theta_{10}'' + F_0 \theta_{10}' = -(1/\sigma)(\theta_{00}'^2 + \theta_{00}\theta_{00}'') - F_{10}\theta_{00}', \tag{3.12}$$

$$(1/\sigma)\theta_{11}'' + F_0 \theta_{11}' = -(1/\sigma)(2\theta_{00}\theta_{01} + \theta_{00}\theta_{01}'' + \theta_{01}\theta_{00}'')$$
$$-(\theta_{00}' F_{11} + \theta_{01}' F_{10} + \theta_{00} F_{00}''^2 + 2F_0'' F_{10}''), \tag{3.13}$$

$$(1/\sigma)\theta_{12}'' + F_0 \theta_{12}' = -(1/\sigma)(\theta_{01}'^2 + \theta_{01}\theta_{01}'') - (\theta_{01}' F_{11} + \theta_{01} F_0''^2 + 2F_0'' F_{11}''), \tag{3.14}$$

and the corresponding boundary conditions [2.21] become

$$\left.\begin{array}{ll} \text{(i)} & F_{1j}(0) = F_{1j}'(0) = 0, \\ \text{(ii)} & F_{1j}'(\infty) = 0, \end{array}\right\} \quad (j = 0, 1) \tag{3.15}$$

$$\left.\begin{array}{ll} \text{(iii)} & \theta_{1j}(0) = 0 \\ \text{(iv)} & \theta_{1j}(\infty) = 0 \end{array}\right\} \quad (j = 0, 1, 2) \tag{3.16}$$

The equations [2.19] and [2.20], with the help of the relations [3.1] to [3.5] and the relations

$$F_2 = \left(\frac{B}{A}\right)^2 F_{20} + \left(\frac{B}{A}\right)^2 \frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)} F_{21} + \left(\frac{B}{A}\right)^2 \left\{\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\right\}^2 F_{22} + \frac{a_2}{A} F_{23}$$
$$+ \frac{a_2}{A}\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)} F_{24} + \frac{a_2}{A}\left\{\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\right\}^2 F_{25}, \tag{3.17}$$

and

$$\theta_2 = \left(\frac{B}{A}\right)^2 \theta_{20} + \left(\frac{B}{A}\right)^2 \frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)} \theta_{21} + \left(\frac{B}{A}\right)^2 \left\{\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\right\}^2 \theta_{22}$$
$$+ \left(\frac{B}{A}\right)^2 \left\{\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\right\}^3 \theta_{23} + \frac{a_2}{A}\theta_{24} + \frac{a_2}{A}\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\theta_{25}$$
$$+ \frac{a_2}{A}\left\{\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\right\}^2 \theta_{26} + \frac{a_2}{A}\left\{\frac{(\gamma-1)M_\infty^2}{(\bar{T}_w - 1)}\right\}^3 \theta_{27}, \tag{3.18}$$

reduce to

$$F'''_{20} + F_0 F''_{20} + F''_0 F_{20} = -F_{10} F''_{10} - \theta_{10} F'''_0 - \theta'_{10} F''_0 - \theta'_{00} F''_{10} - \theta_{00} F'''_{10}, \quad [3.19]$$

$$\begin{aligned} F'''_{21} + F_0 F''_{21} + F''_0 F''_{21} &= -F_{10} F''_{11} - F_{11} F''_{10} - \theta'_{11} F''_0 - \theta_{11} F'''_0 \\ &\quad - \theta'_{01} F''_{10} - \theta'_{00} F''_{11} - \theta_{00} F'''_{11} - \theta_{01} F'''_{10}, \end{aligned} \quad [3.20]$$

$$F'''_{22} + F_0 F''_{22} + F''_0 F_{22} = -F_{11} F''_{11} - \theta'_{12} F''_0 - \theta_{12} F'''_0 - \theta'_{01} F''_{11} - \theta_{01} F'''_{11}, \quad [3.21]$$

$$F'''_{23} + F_0 F''_{23} + F''_0 F_{23} = -\theta^2_{00} F'''_0 - 2\,\theta_{00}\,\theta'_{00}\, F''_0, \quad [3.22]$$

$$F'''_{24} + F_0 F''_{24} + F''_0 F_{24} = -2\,\theta_{00}\,\theta_{01}\, F'''_0 - 2(\theta_{00}\,\theta'_{01} + \theta_{01}\,\theta'_{00}) F''_0, \quad [3.23]$$

$$F'''_{25} + F_0 F''_{25} + F''_0 F_{25} = -\theta^2_{01} F'''_0 - 2\,\theta_{01}\,\theta'_{01}\, F''_0, \quad [3.24]$$

$$\begin{aligned} (1/\sigma)\,\theta''_{20} + F_0\,\theta'_{20} &= -(2/\sigma)\,\theta'_{10}\,\theta'_{00} - (1/\sigma)\,\theta''_{10}\,\theta_{00} - (1/\sigma)\,\theta_{10}\,\theta''_{00} \\ &\quad - \theta'_{10} F_{10} - \theta'_{00} F_{20}, \end{aligned} \quad [3.25]$$

$$\begin{aligned} (1/\sigma)\,\theta''_{21} + F_0\,\theta'_{21} &= -(2/\sigma)(\theta'_{10}\,\theta'_{01} + \theta'_{11}\,\theta'_{00}) - (1/\sigma)(\theta''_{10}\,\theta_{01} + \theta''_{11}\,\theta_{00}) \\ &\quad - (1/\sigma)(\theta_{10}\,\theta''_{01} + \theta_{11}\,\theta''_{00}) - (\theta'_{10} F_{11} + \theta'_{11} F_{10}) \\ &\quad - (\theta'_{00} F_{21} + \theta'_{01} F_{20}) - \theta_{10} F''^2_0 - 2 F''_0 F''_{10}\,\theta_{00} \\ &\quad - F''^2_{10} - 2 F''_0 F''_{20}, \end{aligned} \quad [3.26]$$

$$\begin{aligned} (1/\sigma)\,\theta''_{22} + F_0\,\theta'_{22} &= -(2/\sigma)\,\theta'_{11}\,\theta'_{01} - (2/\sigma)\,\theta'_{12}\,\theta'_{00} \\ &\quad - (1/\sigma)(\theta''_{11}\,\theta_{01} + \theta''_{12}\,\theta_{00}) - (1/\sigma)(\theta_{11}\,\theta''_{01} + \theta_{12}\,\theta''_{00}) - \theta'_{11} F_{11} \\ &\quad - \theta'_{12} F_{10} - \theta'_{00} F_{22} - \theta'_{01} F_{21} - \theta_{11} F''^2_0 - 2 F'_{10} F''_{11} \\ &\quad - 2(F''_{10}\,\theta_{01} + F''_{11}\,\theta_{00}) F''_0 - 2 F''_0 F''_{21}, \end{aligned} \quad [3.27]$$

$$\begin{aligned} (1/\sigma)\,\theta''_{23} + F_0\,\theta'_{23} &= -(2/\sigma)\,\theta'_{12}\,\theta'_{01} - (1/\sigma)\,\theta''_{12}\,\theta_{01} - (1/\sigma)\,\theta_{12}\,\theta''_{01} \\ &\quad - \theta'_{12} F_{11} - \theta'_{01} F_{22} - \theta_{12} F''^2_0 - 2 F''_0 F''_{11}\,\theta_{01} - F''^2_{11} - 2 F''_0 F''_{22}, \end{aligned} \quad [3.28]$$

$$(1/\sigma)\,\theta''_{24} + F_0\,\theta'_{24} = -(2/\sigma)\,\theta_{00}\,\theta'^2_{00} - (1/\sigma)\,\theta^2_{00}\,\theta''_{00} - \theta'_{00} F_{23}, \quad [3.29]$$

$$\begin{aligned} (1/\sigma)\,\theta''_{25} + F_0\,\theta'_{25} &= -(2/\sigma)(\theta_{01}\,\theta'^2_{00} + 2\,\theta_{00}\,\theta'_{00}\,\theta'_{01}) \\ &\quad - (1/\sigma)(2\,\theta_{00}\,\theta''_{00}\,\theta_{01} + \theta^2_{00}\,\theta''_{01}) - \theta'_{00} F_{24} \\ &\quad - \theta'_{01} F_{23} - \theta^2_{00} F''^2_0 - 2 F''_0 F''_{23}, \end{aligned} \quad [3.30]$$

$$(1/\sigma)\,\theta''_{26} + F_0\,\theta'_{26} = -(2/\sigma)\,(2\,\theta_{01}\,\theta'_{00}\,\theta'_{01} + \theta_{00}\,\theta'^{2}_{01})$$
$$-(1/\sigma)\,(\theta^2_{01}\,\theta''_{00} + 2\,\theta_{00}\,\theta_{01}\,\theta''_{01})$$
$$-\theta'_{01}\,F_{24} - \theta'_{00}\,F_{25} - 2\,\theta_{00}\,\theta_{01}\,F''^{2}_{0} - 2\,F''_0\,F'_{24}, \qquad [3.31]$$

$$(1/\sigma)\,\theta''_{27} + F_0\,\theta'_{27} = -(2/\sigma)\,\theta_{01}\,\theta'^{2}_{01} - (1/\sigma)\,\theta^2_{01}\,\theta''_{01} - \theta'_{01}\,F_{25}$$
$$-\theta^2_{01}\,F''^{2}_{0} - 2\,F''_0\,F''_{25}, \qquad [3.32]$$

and the corresponding boundary conditions [2.21] become

$$\left.\begin{array}{ll} \text{(i)} & F_{2j}(0) = 0, \quad F'_{2j}(0) = 0 \\ \text{(ii)} & F'_{2j}(\infty) = 0 \end{array}\right\} j = 0,\ 1,\ 2,\ 3,\ 4,\ 5$$

$$\left.\begin{array}{ll} \text{(iii)} & \theta_{2j}(0) = 0 \\ \text{(iv)} & \theta_{2j}(\infty) = 0 \end{array}\right\} j = 0,\ 1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7 \qquad [3.33]$$

4. DISCUSSION AND RESULTS

Using the solution of the equation [3.6] from [3], we have integrated the equations [3.7], [3.8], [3.10] to [3.14] under the boundary conditions [3.9], [3.15] and [3.16] for $\sigma = 0.7$ on the Elliott 803 computer at Hindustan Aeronautics Ltd., Bangalore. In order to illustrate the application of the universal functions given in tables 1 to 7, we have determined the coefficients a_1 and a_2 occuring in the relation [2.12] by fitting it with the power-law connecting the viscosity and temperature for the exponent $\omega = 0.5$ and the values for a_1 and a_2 so obtained are

$$a_1 = 0.635296$$
$$a_2 = -0.561750\,. \qquad [4.1]$$

Using [4.1] we have drawn the profiles for different surface and free-stream conditions indicated in the figures 1 to 4. Figure 1 shows the velocity distribution for two sets of parameters

$$\text{(i)}\ \frac{T_w - T_\infty}{T_\infty} = 0.1\,, \quad (\gamma - 1)\,M^2_\infty = 0.9$$

$$\text{(ii)}\ \frac{T_w - T_\infty}{T_\infty} = 0.2\,, \quad (\gamma - 1)\,M^2_\infty = 1.6 \qquad [4.2]$$

We observe that the velocity corresponding to the set (ii) of [4.2] is greater than that corresponding to the set (i) of [4.2] at all points. We also find that the velocity corresponding to each of the set (i) and (ii) of [4.2] is greater than that corresponding to Blasius solution.

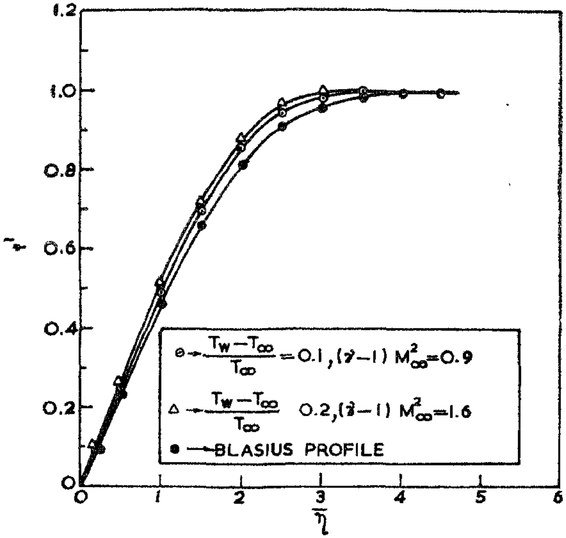

FIG. 1

Velocity Profiles

Figure 2 shows the distribution of $f''(\bar{\eta})$ for the parameters

$$\frac{T_w - T_\infty}{T_\infty} = 0.1\,,\quad (\gamma - 1)\, M_\infty^2 = 0.9 \qquad [4.3]$$

The profile for $f''(\bar{\eta})$ corresponding to the Blasius equation is also drawn for sake of comparison. We observe that corresponding to the set of parameters [4.3], $f''(\bar{\eta})$ attains its maximum value at a point close to the plate and not on the plate itself as in case of Blasius profile. This difference is attributed to the dependence of $f''(\bar{\eta})$ on free-stream Mach number, free-stream temperature, plate temperature and coefficients occuring in viscosity-temperature relation.

In Figure 3 we observe that the temperature θ first rises, attains a maximum value close to the plate and then asymptotically attains its free stream value near the baundary layer edge.

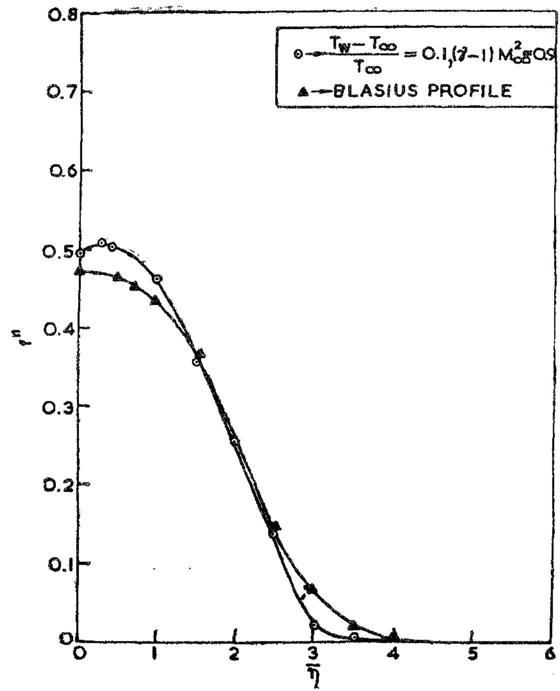
Tw − T∞ / T∞ = 0.1, (γ−1) M∞² = 0.5
BLASIUS PROFILE
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
f''
0
1
2
3
4
5
6
η̄

FIG. 2

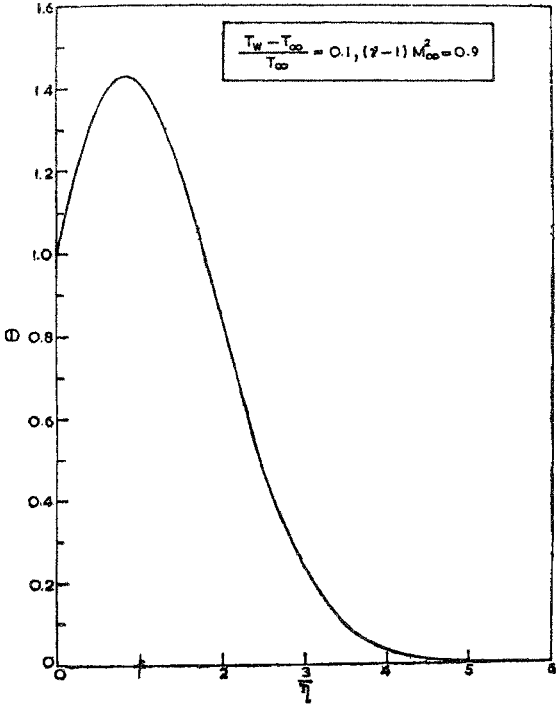

FIG. 3

Temperature Distribution

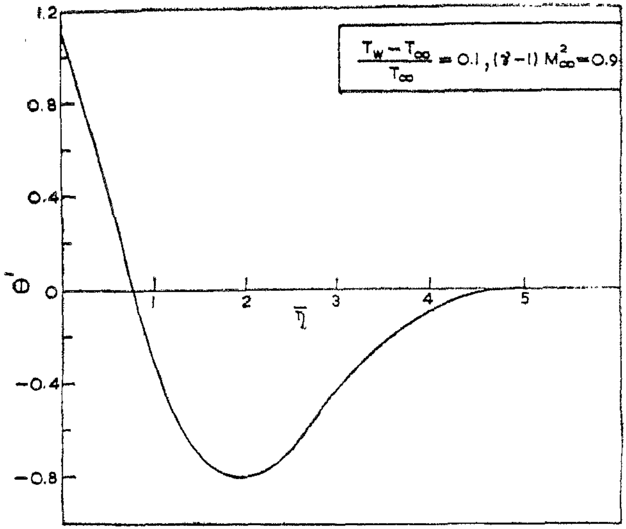

FIG. 4

Temperature Gradient

Figure IV shows the distribution of temperature gradient $\theta'(\bar{\eta})$ across the boundary layer. We find that $\theta'(\bar{\eta})$ is equal to zero at $\bar{\eta} = 0.8$ which is in conformity with the occurrence of the maximum value of $\theta(\bar{\eta})$ at $\bar{\eta} = 0.8$ as shown in figure 3. $\theta'(\bar{\eta})$ with its greatest positive value on the plate $\bar{\eta} = 0$, gradually decreases, changes its sign on crossing $\bar{\eta} = 0.8$, attains minimum value at $\bar{\eta} = 2$ and finally asymptotically approaches zero near the boun'ary layer edge.

The tables 1 to 7 for the universal functions θ_{00}, θ_{01}, F_{10}, F_{11}, θ_{10}, θ_{11}, θ_{12} can be easily utilised for computing the flow characteristics upto first order approximation for a fairly good range of free-stream and surface conditions and for laws governing viscosity-temperature relation to which the quadratic expression [2.12] can be fitted with.

TABLE 1

$\bar{\eta}$	θ_{00}	θ'_{00}	θ''_{00}
0	1	−.41393019	0
.1	.95860755	−.41390752	.00068001
.2	.91722303	−.41374884	.00271986
.3	.87586692	−.41331844	.00611252
.4	.83457289	−.41248176	.01084179
.5	.79338844	−.41110657	.01687568
.6	.75237380	−.40906480	.02416326
.7	.71160177	−.40623462	.03262909
.8	.67115694	−.40250308	.04217097
.9	.63113460	−.39776892	.05265685
1.0	.59163948	−.39194566	.06392359
1.1	.55278407	−.38496458	.07577831
1.2	.51468681	−.37677772	.08800017
1.3	.47746960	−.36736046	.10034366
1.4	.44125571	−.35671370	.11254560
1.5	.40616693	−.34486522	.12433164
1.6	.37232094	−.33187044	.13542610
1.7	.33982837	−.31781196	.14556217
1.8	.30679039	−.30279827	.15449104
1.9	.27929617	−.28696138	.16199280
2.0	.25142054	−.27045339	.16788608
2.1	.22522228	−.25344235	.17203538
2.2	.20074285	−.23610731	.17435665
2.3	.17800547	−.21863301	.17482023
2.4	.15701474	−.20120438	.17345218
2.5	.13775709	−.18400107	.17033114
2.6	.12020136	−.16719243	.16558362
2.7	.10430027	−.15093302	.15937762
2.8	.08999191	−.13535892	.15191325
2.9	.07720183	−.12058495	.14341362

TABLE 1—(*contd*)

$\bar{\eta}$	θ_{00}	θ'_{00}	θ''_{00}
3.0	.06584520	−.10670289	.13411468
3.1	.05582925	−.09378074	.12425534
3.2	.04705559	−.08186281	.11406824
3.3	.03942251	−.07097077	.10377241
3.4	.03282723	−.06110539	.09356631
3.5	.02716782	−.05224880	.08362345
3.6	.02234499	−.04436714	.07408934
3.7	.01826352	−.03741351	.06508002
3.8	.01483332	−.03133084	.05668221
3.9	.01197049	−.02605482	.04895452
4.0	.00959780	−.02151659	.04192986
4.1	.00764501	−.01764517	.03561833
4.2	.00604897	−.01436956	.03001069
4.3	.00475358	−.01162050	.02508193
4.4	.00370956	−.00933188	.02079488
4.5	.00287396	−.00744176	.01710365
4.6	.00220989	−.00589310	.01395669
4.7	.00168574	−.00463419	.01129950
4.8	.00127495	−.00361880	.00907696
4.9	.00095527	−.00280618	.00723510
5.0	.00070820	−.00216087	.00572256
5.1	.00051853	−.00165235	.00449152
5.2	.00037403	−.00125469	.00349840
5.3	.00026467	−.00094609	.00270417
5.4	.00018246	−.00070842	.00207443
5.5	.00012142	−.00052675	.00157934
5.6	.00007567	−.00038894	.00119338
5.7	.00004222	−.00028519	.00089498
5.8	.00001776	−.00020765	.00066619
5.9	.00000000	−.00015014	.00049219

TABLE 2

$\bar{\eta}$	θ_{01}	θ'_{01}	θ''_{01}
0	0	.17295104	−.15436691
.1	.01652305	.15750614	−.15460136
2.	0.3149987	.14202171	−.15510729
.3	.04492563	.12648556	−.15558666
.4	.05679580	.11091515	−.15574374
.5	.06710904	.09535713	−.15529138
.6	.07587009	.07988623	−.15395764
.7	.08309251	.06460316	−.15149654
.8	.08880107	.04963143	−.14770066
.9	.09303388	.03511283	−.14241232
1.0	.09584389	.02120191	−.13553746
1.1	.09729987	.00805901	−.12705529
1.2	.09748657	−.00415737	−.11702354
1.3	.09650424	−.01529867	−.10558353
1.4	.09446707	−.02523439	−.09295459
1.5	.09150110	−.03385948	−.07942439
1.6	.08774134	−.04110063	−.06533624
1 7	.08332838	−.04692064	−.05106643
1.8	.07840460	−.05132076	−.03700262
1.9	.07311029	−.95434060	−.02352068
2,0	.06757999	−.05605555	−.01095966
2.1	.06193912	−.05657276	+.00039507
2.2	.05630100	−.05602388	.01033114
2.3	.05076490	−.05455860	.01870712
2.4	.04541451	−.05233649	.02546425
2.5	.04031742	−.04951931	.03061638
2.6	.03552524	−.04626421	.03424030
2.7	.03107427	−.04271797	.03646483
2.8	.02698692	−.03901264	.03745133
2.9	.02327320	−.03526276	.03738595
3.0	.01993265	−.03156389	.03646335

TABLE 2—(*conctd*)

η	θ_{01}	θ'_{01}	θ''_{01}
3.1	.01695616	−.02799243	.03486940
3.2	.01432796	−.02460646	.03278170
3.3	.01202731	−.02144725	.03035893
3.4	.01003007	−.01854127	.02773825
3.5	.00831016	−.01580238	.02503430
3.6	.00684059	−.01353412	.02233932
3.7	.00559447	−.01143185	.01972479
3.8	.00454572	−.00958474	.01724346
3.9	.00366954	−.00797752	.01493185
4.0	.00294284	−.00659197	.01281284
4.1	.05234444	−.00540817	.01039810
4.2	.00185518	−.00440548	.00939036
4.3	.00145801	−.00356336	.00763554
4.4	.00113784	−.00286194	.00637442
4.5	.00088157	−.00228247	.00524429
4.6	.00067786	−.00180758	.00428009
4.7	.00051710	−.00142149	.00346559
4.8	.00039109	−.00111005	.00278412
4.9	.00029302	−.00086080	.00221928
5.0	.00021722	−.00066286	.00175537
5.1	.00015906	−.00050687	.00137778
5.2	.00011473	−.00038488	.00107315
5.3	.00008117	−.00029022	.00082952
5.4	.00005596	−.00021731	.00063634
5.5	.00003715	−.00016169	.00048447
5.6	.00002320	−.00011931	.00036608
5.7	.00001293	−.00008748	.00027454
5.8	.00000544	−.00006370	.00020436
5.9	.00000000	−.00004606	.00015098

TABLE 3

$\bar{\eta}$	F_{10}	F'_{10}	F''_{10}	F'''_{10}
0	0	0	−.35029192	.19438162
.1	−.00171902	−.03405505	−.33076556	.19699554
.2	−.00674528	−.06613622	−.31073626	.20430074
.3	−.01487812	−.09617115	−.28977627	.21544995
.4	−.02590766	−.12404899	−.26754481	.22952782
.5	−.03961138	−.14962950	−.24379563	.24552973
.6	−.05575168	−.17275293	−.21838557	.26236478
.7	−.07407447	−.19325073	−.19128270	.27886401
.8	−.09430880	−.21095703	−.16257242	.29381331
.9	−.11616779	−.22572053	−.13245988	.30599653
1.0	−.13935065	−.23741640	−.10126783	.31425581
1.1	−.16354590	−.24595763	−.06942783	.51755709
1.2	−.18843570	−.25130524	−.03746529	.31506331
1.3	−.21370105	−.25347557	−.00597730	.30520064
1.4	−.23902777	−.25255108	.03439520	.29071751
1.5	−.26411285	−.24867317	.05300044	.26871933
1.6	−.28867095	−.24205130	.07921116	.24068646
1.7	−.31244058	−.23295395	.10246036	.20745632
1.8	−.33518991	−.22170174	.12227415	.17017881
1.9	−.35672122	−.20865668	.13829954	.13024687
2.0	−.37687454	−.19420918	.15032408	.08919831
2.1	−.39552979	−.17876315	.15828656	.04861396
2.2	−.41260731	−.16272105	.86227710	.01000681
2.3	−.42806704	−.14646895	.16252736	−.02527528
2.4	−.44190601	−.13036347	.15939216	−.05613556
2.5	−.45415517	−.11472074	.15332358	−.08178341
2.6	−.46487451	−.09980802	.14484115	−.10176117
2.7	−.47414818	−.08583872	.13449996	−.11594757
2.8	−.48207891	−.07297042	.12285945	−.12452922
2.9	−.48878232	−.06130580	.11045564	−.12795217

TABLE 3—(*contd*)

$\bar{\eta}$	F_{10}	F'_{10}	F''_{10}	F'''_{10}
3.0	−.49438185	−.05089633	.09777780	−.12686201
3.1	−.49900357	−.04174766	.08525121	−.12203491
3.2	−.50277221	−.03382684	.07322606	−.11430952
3.3	−.50580765	−.02706984	.06197259	−.10452638
3.4	−.50822204	−.02138978	.05168188	−.09347545
3.5	−.51011801	−.01668435	.04247674	−.08185926
3.6	−.51158763	−.01284295	.03439042	−.07026568
3.7	−.51271160	−.00975273	.02743714	−.05915847
3.8	−.51355945	−.00730329	.02156382	−.04887412
3.9	−.51419014	−.00539068	.01669177	−.03963178
4.0	−.51465228	−.00391984	.01272163	−.03154632
4.1	−.51498593	−.00280615	.00954307	−.02464774
4.2	−.51522299	−.00197624	.00704263	−.01889764
4.3	−.51938850	−.00136784	.00511019	−.01421329
4.4	−.51550221	−.00092941	.00364314	.010479[illegible]
4.5	−.51557867	−.00061900	.00254495	−.00756805
4.6	−.51562920	−.00040332	.00174937	−.00534733
4.7	−.51566165	−.00025643	.00117511	−.00369017
4.8	−.51568210	−.00015855	.00077120	−.00248157
4.9	−.51569447	− 00009485	.00049309	−.00162095
5.0	−.51570182	−.00005449	.00030596	−.00102372
5.1	−.51570590	−.00002969	.00018310	−.00062014
5.2	−.51570807	−.00001502	.00010465	−.00035567
5.3	−.51570911	−.00000679	.00005618	−.00018852
5.4	−.51570958	−.00000246	.00002733	−.00008745
5.5	−.51570972	−.00000041	.00001100	−.00002956
5.6	−.51570964	.00000035	.00000236	−.00000099
5.7	−.51570967	.00000046	.00000173	−.00001498
5.8	− 51570965	.00000027	.00000321	−.00001935
5.9	−.51570961	.00000000	.00000288	−.00001606

TABLE 4

$\bar{\eta}$	F_{11}	F'_{11}	F''_{11}	F'''_{11}
0	0	0	.01827934	−.08121781
.1	.00007816	.00143387	.01051845	−.07400224
.2	.00026211	.00212782	.00348284	−.06666854
.3	.00048151	.00215537	−.00280393	−.05899391
.4	.00067053	.00159338	−.00829987	−.05083212
.5	.00078326	−.00052351	−.01295250	−.04211854
.6	.00076420	−.00096716	−.01670714	−.03287309
.7	.00057887	−.00278632	−.01951553	−.02320157
.8	.00019920	−.00483751	−.02134424	−.01329158
.9	−.00039307	−.00702199	−.02218243	−.00340246
1.0	−.00120635	−.00924135	−.02204819	.00615133
1.1	−.00223933	−.01140061	−.02099293	.01502343
1.2	−.00348152	−.01341168	−.01910313	.02286465
1.3	−.00491412	−.01519685	−.01649902	.02935359
1.4	−.00651121	−.01669193	−.01333014	.03422848
1.5	−.00824122	−.01784887	−.00976793	.03731340
1.6	−.01006869	−.01863745	−.00599599	.03853822
1.7	−.01195603	−.01904597	−.00219894	.03794764
1.8	−.01385541	−.01908077	.00144910	.03569316
1.9	−.01576048	−.01876462	.00479510	.03204423
2.0	−.01760786	−.01813420	.00771567	.02731338
2.1	−.01937843	−.01723677	.01082296	.02187621
2.2	−.02104814	−.01612650	.01196710	.01611235
2.3	−.02259856	−.01486068	.01323543	.01037962
2.4	−.02401700	−.01349611	.01394885	.00498691
2.5	−.02529629	−.01208612	.01415574	.00017619
2.6	−.02643431	−.01067807	.01392470	−.00388680
2.7	−.02743332	−.00931181	.01333661	−.00711376
2.8	−.02829914	−.00801879	.01247717	−.00948692
2.9	−.02904030	−.00682190	.01143038	−.01104675

TABLE 4—(*contd*)

$\bar{\eta}$	F_{11}	F'_{11}	F''_{11}	F'''_{11}
3.0	−.02966723	−.00573595	.01027344	−.01187735
3.1	−.03019145	−.00476851	.00907324	−.01209046
3.2	−.03062494	−.00392105	.00788438	−.01181090
3.3	−.03097955	−.00319022	.00674862	−.01116429
3.4	−.03126664	−.00256911	.00569541	−.01026769
3.5	−.03149672	−.00204846	.00471310	−.00922357
3.6	−.03167932	−.00161762	.00390077	−.00811634
3.7	−.03182286	−.00126543	.00317010	−.00701167
3.8	−.03193465	−.00098086	.00254730	−.00595716
3.9	−.03202093	−.00075347	.00202482	.00498454
4.0	−.03208692	−.00057369	.00159287	−.00411219
4.1	−.03213696	−.00043298	.00124056	−.00334804
4.2	−.03217457	−.00032395	.00095682	.00269212
4.3	−.03220260	−.00024027	.00073100	−.00213925
4.4	−.03222328	−.00017665	.00055328	−.00168065
4.5	−.03223844	−.00012873	.00051494	−.00130595
4.6	−.03224943	−.00009295	.00030805	−.00100397
4.7	−.03225733	−.00006649	.00022706	−.00076372
4.8	−.03226297	−.00004710	.00016567	−.00057494
4.9	−.03226692	−.00003301	.00011977	−.00042836
5.0	−.03226969	−.00002288	.00008579	−.00031589
5.1	−.03227160	−.00001565	.00006087	−.00023053
5.2	−.03227289	−.00001055	.00004278	−.00016650
5.3	−.03227376	−.00000698	.00002978	−.00011899
5.4	−.03227433	−.00000451	.00002052	−.00008415
5.5	−.03227469	−.00000281	.00001400	−.00005888
5.6	−.03227491	−.00000166	.00000946	−.00004075
5.7	−.00227504	−.00000089	.00000632	−.00002790
5.8	−.03227510	−.00000037	.00000422	−.00001906
5.9	−.03227511	−.00000000	.00000331	−.00001533

TABLE 5

$\bar{\eta}$	θ_{10}	θ'_{10}	θ''_{10}
0	0	.74610695	−.00000000
.1	.06974531	.65011353	−.92114643
.2	.13027321	.56163953	−.84943845
.3	.18230158	.48002027	−.78390017
.4	.22648653	.40468238	−.72367747
.5	.26343091	.33513301	−.66801035
.6	.29369197	.27095133	−.61621533
.7	.31778817	.21178171	−.56767060
.8	.33620543	.15732784	−.52181021
.9	.34940278	.10734741	−.47812071
1.0	.35781751	.06164673	−.43614366
1.1	.36186974	.02007494	−.39548248
1.2	.36190623	−.01748262	−.35581066
1.3	.35850409	−.05111182	−.31588091
1.4	.35187264	−.08087819	−.27853551
1.5	.34245541	−.10683624	−.24071245
1.6	.33063052	−.12903925	−.20344886
1.7	.31677062	−.14754907	−.16687816
1.8	.30124121	−.16244536	−.13122188
1.9	.28439851	−.17383326	−.09677493
2.0	.25658677	−.18185225	−.06388498
2.1	.24813463	−.18667520	−.03292790
2.2	.22935124	−.18851488	−.00428089
2.3	.21052282	−.18762016	.02170455
2.4	.19190900	−.18427274	.04472836
2.5	.17373975	−.17878088	.06456190
2.6	.15621343	−.17147148	.08106330
2.7	.13949486	−.16268090	.09418587
2.8	.12371539	−.15274533	.10397893
2.9	.10897300	−.14199844	.11058294

TABLE 5 —(*contd*)

$\bar{\eta}$	θ_{10}	θ'_{10}	θ''_{10}
3.0	.09533403	−.13072770	.11421865
3.1	.08283500	−.11923713	.11517209
3.2	.07148575	−.10777157	.11377709
3.3	.06127261	−.09654786	.11039746
3.4	.05216210	−.08574572	.10540855
3.5	.04410470	−.07550744	09918147
3.6	.03703831	−.06593896	[illegible]
3.7	.03089213	−.05711233	.08439592
3.8	.02558973	−.04906895	.07644914
3.9	.02105180	−.04182349	06847503
3.0	.01719874	−.03533681	[illegible]
4.1	.01395272	−.02967706	.05321409
4.2	.01123921	−.02471029	[illegible]
4.3	.00898825	−.02041795	.03973633
4.4	.00713508	−.01674360	.03385260
4.5	.00562099	−.01362729	[illegible]
4.6	.00439308	−.01100813	[illegible]
4.7	.00340483	−.00882627	.01982636
4.8	.00261524	−.00702448	[illegible]
4 9	.00198905	−.00554930	.01328679
5.0	.00149614	−.00435170	.01073987
5.1	.00111102	−.00338756	.00810920
5.2	.00081222	−.00261776	.00684462
5.3	.00058211	−.00200815	.00539748
5,4	.00040624	−.00152929	.00422201
5.5	.00027278	−.00115616	.00327611
5 6	.00017220	−.00086774	.00252194
5.7	.00009696	−.00064655	.00192606
5.8	.00004114	−.00047826	.00145942
5.9	.00000000	−.00035122	.00109720

TABLE 6

$\bar{\eta}$	θ_{01}	θ'_{01}	θ''_{01}
0	0	.01200758	.23029542
.1	.00227609	.03277859	.18615828
.2	.00641839	.04942431	.14756998
.3	.01204000	.06243692	.11330775
.4	.01879745	.07219588	.08234110
.5	.02638037	.07898733	.05383429
.6	.03450316	.08302387	.02715449
.7	.04289868	.08446545	.00188386
.8	.05131307	.08344142	−.02217198
.9	.05950879	.08007278	−.04498515
1.0	.06725491	.07449399	−.06631913
1.1	.07433943	.06687230	−.08576121
1.2	.08056836	.05742303	−.10277232
1.3	.08577212	.04641907	−.11675232
1.4	.08981137	.03419321	−.12711719
1.5	.09258287	.02113251	−.13337825
1.6	.09402427	.00766504	−.13521529
1.7	.09411728	−.00575994	−.13253291
1.8	.09288859	−.01869636	−.12549215
1.9	.09040825	−.03072729	−.11451370
2.0	.08678549	−.04148978	−.10024944
2.1	.08216228	−.05069553	−.08352916
2.2	.07670504	−.05814518	−.06528830
2.3	.07059536	−.06373479	−.04648764
2.4	.06406824	−.06651986	−.02884108
2.5	.05712294	−.07201627	−.00828072
2.6	.05032030	−.06117589	.16457600
2.7	.04498794	−.04650836	.10307320
2.8	.04060564	−.04279565	.00292632
2.9	.03635810	−.04199054	.01278524
3.0	.03223652	−.04031495	.02035345

TABLE 6 —(*contd*)

$\bar{\eta}$	θ_{10}	θ'_{10}	θ''_{10}
3.1	.02831669	−.03799102	.02578547
3.2	.02465314	−.03522130	.02931281
3.3	.02128136	−.03218271	.03121082
3.4	.01822058	−.02902370	.03177002
3.5	.01547662	−.02586380	.03127466
3.6	.01304475	−.02279513	.02998721
3.7	.01091230	−.01988500	.02813969
3.8	.00906093	−.01717927	.02592919
3.9	.00746870	−.01470586	.02351748
4.0	.00611157	−.01247821	.02103289
4.1	.00496480	−.01049846	.01857356
4.2	.00400084	−.00876029	.01621144
4.3	.00320512	−.00725130	.01399647
4.4	.00254651	−.00595507	.01196047
4.5	.00200766	−.00485270	.01012084
4.6	.00157019	−.00392419	.00848368
4.7	.00121772	−.00314934	.00704659
4.8	.00093587	−.00250854	.00580100
4.9	.00071218	−.00198323	.00473413
5.0	.00053596	−.00155631	.00383052
5.1	.00039817	−.00121228	.00307336
5.2	.00029121	−.00093737	.00244543
5.3	.00020880	−.00071948	.00192984
5.4	.00014577	−.00054821	.00151060
5.5	.00009791	−.00041467	.00117293
5.6	.00006184	−.00031138	.00090347
5.7	.00003484	−.00023212	.00069039
5.8	.00001479	−.00017178	.00052341
5.9	.00000000	−.00012620	.00039371

TABLE 7

$\bar{\eta}$	θ_{11}	θ'_{10}	θ''_{10}
0	0	.00108388	−.01201757
.1	.00005675	.00013163	−.00719227
.2	.00004083	=.00038484	−.00327469
.3	−.00000849	−.00054904	−.00012926
.4	−.00005966	−.00043359	+.00232833
.5	−.00008809	−.00010474	+.00414370
.6	−.00007560	.00037446	.00533685
.7	−.00001025	.00094223	.00591581
.8	.00011376	.00153757	.00589055
.9	.00029620	.00210112	.00528570
1.0	.00053106	.00257715	.00415113
1.1	.00080706	.00291650	.00256848
1.2	.00110847	.00307983	.00065256
1.3	.00141626	.00304077	−.00145286
1,4	.00170950	.00278842	−.00358503
1.5	.00196700	.00232849	−.00557651
1.6	.00216899	.00168301	−.00727163
1 7	.00229861	.00088829	−.00854278
1.8	.00234323	−.00000855	−.00930353
1.9	.00229527	−.00095419	−.00951662
2,0	.00215259	−.00189411	−.00919549
2.1	.00191834	−.00277750	−.00839929
2.2	.00160042	−.00356134	−.00722262
2.3	.00121049	−.00421327	−.00578186
2.4	.00077657	−.00444453	−.00443203
2.5	.00026067	−.00582305	−.00188273
2.6	−.00020677	−.00273123	.04614743
2.7	−.00026415	.00123829	.02563733
2.8	−.00008926	.00173071	−.00628651
2.9	.00005474	.00117205	−.00491885
3.0	.00014938	.00074088	−.00374802

TABLE 7—(*contd*)

$\bar{\eta}$	θ_{12}	θ'_{12}	F''_{12}
3.1	.00020638	.00041588	−.00277425
3.2	.00023549	.00017936	−.00198581
3.3	.00024459	.00001319	−.00136349
3.4	.00023995	−.00009811	−.00088442
3.5	.00022636	−.00016767	−.00052494
3.6	.00020744	−.00020632	−.00026253
3.7	.00018583	−.00022273	−.00007700
3.8	.00016341	−.00022370	.00004903
3.9	.00014143	−.00021443	.00013000
4.0	.00012073	−.00019881	.00017757
4.1	.00010178	−.00017971	.00020102
4.2	.00008483	−.00015917	.00020752
4.3	.00006995	−.00013859	.00020255
4.4	.00005709	−.00011890	.00019024
4.5	.00004612	−.00010068	.00017362
4.6	.00003689	−.00008425	.00015490
4.7	.00002921	−.00006972	.00013561
4.8	.00002288	−.00005711	.00011682
4.9	.00001773	−.00004632	.00009919
5.0	.00001356	−.00003722	.00008314
5.1	.00001023	−.00002964	.00006885
5.2	.00000759	−.00002339	.00005638
5.3	.00000551	−.00001830	.00004568
5.4	.00000390	−.00001420	.00003663
5.5	.00000265	−.00001093	.00002909
5.6	.00000169	−.00000834	.00002288
5.7	.00000096	−.00000631	.00001783
5.8	.00000041	−.00000474	.00001377
5.9	.00000000	−.00000353	.00001054

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