COMPILATION OF TURBULENCE DATA FOR A 20^{o} COMPRESSION CORNER AT MACH 2.9

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ABSTRACT

This report presents turbulence measurements for a shock-wave/turbulent boundary layer interaction induced by a 20° compression corner at a Mach number of 2.9. The flow was separated at the corner region. A constant-temperature hot-wire anemometer was used throughout. The data include normal wire and inclined wire measurements.

NOMENCLATURE

$C_{f_{ref}}$	skin friction coefficient = $\tau_w/\frac{1}{2}\,\overline{\rho}_{ref}\,\overline{u}^2_{ref}$
M	Mach number
p	pressure
R	gas constant
Re	Reynolds number
R_{pv}	pressure-velocity correlation coefficient
R_{uv}	velocity correlation coefficient
R_{vT}	velocity-temperature correlation coefficient
$R_{\rho u}$	density-velocity correlation coefficient
T	temperature
u	streamwise velocity
v	velocity normal to the wall
u_τ	friction velocity = $(\tau_w/\rho_w)^{\frac{1}{2}}$
x	coordinate along the test surface
y	distance away from the test surface
α	ramp angle
γ	specific heat ratio
δ	boundary layer thickness, y at $\overline{\rho u}/\overline{(\rho u)}_e = 0.99$
δ_p	boundary layer thickness, y at $(P_o-P)/(P_{oe}-P_e) = 0.99$
δ^*	boundary layer displacement thickness
θ	boundary layer momentum thickness
ξ	inclined wire directional sensitivity
ρ	density
τ	shear stress
ψ	idealized inclined wire angle (i.e. the angle between the freestream mean flow direction and the line normal to the wire.

Subscripts

e	boundary layer edge condition
o	stagnation condition
w	wall condition
ref	reference condition — before the beginning of interaction, at x = -50.8 mm
$\langle\ \rangle$	r.m.s. value of fluctuation

Overbars

$\overline{\ }$	time mean value
$\tilde{\ }$	normalized r.m.s. value of fluctuation (e.g. $\tilde{u} = \langle u \rangle / \overline{u}$)

The program printouts in Tables 5 and 6 use the following variable names:

UT = u_τ

RHOW = ρ_w

TW = T_w

D = δ

Y/D = y/δ

$\frac{\text{(RHO U)'}}{\text{RHO U}} = \frac{\langle \rho u \rangle}{\overline{\rho u}}$

$\frac{\text{(RHO U)'}}{\text{RHOW*UT}} = \frac{\langle \rho u \rangle}{\rho_w u_\tau}$

$\frac{\text{U}}{\text{U}_{\text{ref}}} = \frac{\overline{u}}{\overline{u}_{ref}}$

$\frac{\text{U'}}{\text{UT}} = \frac{\langle u \rangle}{u_\tau}$

$\frac{\text{RHO*U'2}}{\text{RHOW*UT2}} = \frac{\overline{\rho}\ \overline{u'^2}}{\rho_w u_\tau^2}$

$$\frac{\text{RHOU}}{\text{RHOUref}} = \frac{\overline{\rho u}}{(\overline{\rho u})_{ref}}$$

$$\frac{\text{TAU}}{\text{TAUW}} = \frac{\tau}{\tau_w} = \frac{\bar{\rho}\ \overline{u'v'}}{\rho_w\ u_\tau^2}$$

$$\frac{\text{(RHO U)'v'}}{\text{RHOU U}} = \frac{\overline{(\rho u)'v'}}{\bar{\rho}\ \bar{u}^2}$$

1. INTRODUCTION

The interaction between turbulent boundary layers and shock waves has been studied extensively at the Gas Dynamics Laboratory. In particular, compression corners have been used to generate two-dimensional interactions of varying strength. Settles, et al (Refs. 1, 2, 3 & 4) have reported mean flow measurements at Mach 2.9 for corners with turning angles of 8^o, 16^o, 20^o and 24^o (these data were incorporated in the 1981 Stanford Data Catalog as case number 8631).

Under the auspices of NASA,* the Gas Dynamics Laboratory has recently started to gather turbulence data in compressible flows. As part of that program, we intend to supplement the compression-corner mean flow data with a full set of hot-wire measurements.

We have performed hot-wire measurements in the 8^o, 16^o and 20^o corner flow fields using the same models and flow conditions used by Settles (Ref. 1)(Refs. 5, 6, 7, 8, 9 and 10). We hope to eventually cover the 24^o corner flow field as well.

In this report, we present the 20^o corner turbulence data; profiles of rms mass-flow fluctuations, rms velocity fluctuations $\langle u \rangle$ and profiles of $\overline{(\rho u)'v'}$, $\overline{u'v'}$ and $\bar{\rho}\ \overline{u'v'}/\rho_w u_\tau^2$ are tabulated.

This report has been prepared to give other research workers ready access to our data, and for reasons of consistency we follow the general layout and notation used by Fernholz and Finley (Ref. 11).

Before presenting the data, the experimental apparatus and test conditions are described in Sections 2 and 3, and the data analysis is

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discussed in Section 4. In Section 5 the coordinate system is defined, and measurement uncertainties are described in Section 6.

2. APPARATUS

Unless stated otherwise, all experimental conditions were identical to those used in the mean flow study (Refs. 1-4). These conditions are briefly summarized below.

2.1 Wind Tunnel (see Fig. 1)

The measurements were made in the Princeton University 203 mm x 203 mm (8" x 8") supersonic wind tunnel. The tunnel is of the blow-down type, and a typical run time for a single profile was about one minute. During a single run the tunnel stagnation temperature usually fell by 5-8^{o}K. The rms freestream mass-flow fluctuation level, expressed as a fraction of the mean freestream mass-flow rate, was about one percent.

2.2 Test Model (see Fig. 1)

The test model consisted of a flat wall segment mounted flush with the tunnel floor, followed by a 121 mm long compression ramp inclined at an angle of 20^{o} to the floor. The model was installed 1.98 m downstream of the wind tunnel nozzle throat. The model was mounted centrally on the floor, leaving a 25.4 mm gap on either side of the ramp to avoid flow field interference due to the tunnel side-wall boundary layers. Aerodynamic side fences were mounted to further improve the two-dimensionality of the flow.

3. TEST CONDITIONS

The incoming boundary layer was fully turbulent and in equilibrium conditions (Refs. 1-3). The flow was separated at the corner region ($-0.5\delta_o < x < 0.1\delta_o$). The flow parameters for the undisturbed incoming boundary layer taken at x = -50.8 mm are given in Table 1. The conditions at x = -50.8 mm will be designated as reference conditions.

The wall static pressure and skin-friction distributions taken from Ref. 4 are given in Tables 2 and 3. The skin-friction was measured with a Preston tube, using Hopkins and Keener's evaluation scheme (Ref. 12). The local skin-friction coefficients have been defined using the reference conditions to avoid ambiguity within the interaction region. The wall conditions were near-adiabatic.

4. DATA ACQUISITION AND REDUCTION

4.1 Data Acquisition

A DISA 55M10 constant-temperature anemometer was used in the present hot-wire measurements. The hot-wire probes were constructed using 5 μm diameter tungsten wires. These wires were first copper-plated, soft soldered onto the probe prongs, and then etched using diluted sulphuric acid to remove the copper-plating, exposing an active portion of 0.8 ∿ 1.0 mm in length. The wires were slackened slightly to avoid strain-gauging.

Calibrations of the hot-wires were done in a small Mach 3 pilot tunnel. The wires were calibrated for mass-flow sensitivity by changing the stagnation pressure. The inclined wires were additionally calibrated for directional sensitivity by changing the relative flow direction at a constant stagnation pressure (i.e. constant mass flow rate) using a yaw mechanism. The calibration procedures, with correction to temperature drifts, are outlined in Smits et.al. (Ref. 13), and Smits and Muck (Ref. 14). Note that the present calibration only applied where the mass-flow sensitivity was independent of Mach number, that is, where the instantaneous local normal Mach number exceeds 1.2 (see Ref. 15).

The inclined wire measurements were obtained by rotating a single inclined wire as described in Ref. 14.

Under operating conditions, the system frequency response (deduced from a square-wave test) was typically 150 kHz or better. The operating overheat ratio varied between 1.0 and 1.3. Preliminary tests had shown that at these overheat ratios the contribution of the temperature fluctuations to the total signal was small, and it was subsequently neglected.

Digital analysis was used throughout. The mean and fluctuating components of the hot-wire signal were separated by appropriate filtering and digitized directly at sampling rates of 50 kHz and 500 kHz respectively. The raw data was stored on-line in the memory of a Hewlett-Packard HP1000 minicomputer for further processing. At each measurement point, data were taken as an ensemble of 25 records, each of which contained 1024 sampled points. Satisfactory convergence of fluctuation data was achieved with this record length (within 1% at $y/\delta = 0.5$).

4.2 Data Reduction

4.2.1 Normal wire results

The instantaneous values of the anemometer voltage were directly converted to the instantaneous values of mass flow by inverting the calibration curve, thereby avoiding the use of sensitivity coefficients. The instantaneous mass-flow fluctuations were found by subtracting the time-averaged mass flow from the total instantaneous mass flow.

The normal wire data presented in Table 5 are y/δ, $<\rho u>/\overline{\rho u}$, $<\rho u>/\rho_w u_\tau$, $\overline{u}/\overline{u}_{ref}$, M, $<u>/u_\tau$ and $\overline{\rho}\ \overline{u'^2}/\rho_w u_\tau{}^2$. The values of δ, u_τ, ρ_w, $<u>$ and $\overline{\rho}\ \overline{u'^2}/\rho_w u_\tau{}^2$ were found as follows.

(a) Definition of boundary layer thickness: The boundary layer thickness, δ, given for each profile in Table 5 was defined as the distance from the wall to where $\overline{\rho u}/\overline{(\rho u)_e} = 0.99$. Fernholz and Finley (Ref. 18) suggest the boundary layer edge be defined as a point where $(P_o-P)/P_{o_e}-P_e) = 0.99$. For incompressible flows, this corresponds to the $u/u_e = 0.995$ point. Both boundary layer thicknesses, plus some other relevant length scales, are given in Table 4.

(b) In finding $u_\tau = \sqrt{\tau_w/\rho_w}$, τ_w was calculated from $\tau_w = \frac{1}{2}\overline{\rho}_{ref} \cdot \overline{u}_{ref}^2\ Cf_{ref} = \frac{1}{2}\gamma p_{ref}\ M_{ref}^2\ Cf_{ref}$, using Cf_{ref} values from Table 3. The density at the wall, ρ_w, was calculated as follows:

$$\rho_w = \frac{P_w}{R\ T_w} = \left(\frac{P_w}{P_{ref}}\right)\left(\frac{T_o}{T_w}\right)\ \frac{P_{ref}}{T_o}\ \frac{1}{R} \tag{1}$$

where $\frac{P_w}{P_{ref}}$ is given in Table 2,

$$\frac{T_o}{T_w} = \frac{1}{1.04}$$

and $R = 287.227$

Since T_o varied during a run (by about $\pm 2\%$), the average value of the stagnation temperature was used to evaluate ρ_w. Note that the temperatures (T_o and T_w) are measured as mean values, hence no overbars need be shown.

(c) $\frac{\langle u \rangle}{u_\tau}$ was obtained as follows

$$\frac{\langle u \rangle}{u_\tau} = \frac{\langle u \rangle}{\bar{u}} \cdot \frac{\bar{u}}{\bar{u}_{ref}} \cdot \frac{\bar{u}_{ref}}{u_\tau} \tag{2}$$

and
$$\frac{\langle u \rangle}{\bar{u}} = \frac{\langle \rho u \rangle / \overline{\rho u}}{\{1+2\ R_{\rho u}(\gamma-1)\ M^2 + [(\gamma-1)M^2]^2\}^{\frac{1}{2}}} \tag{3}$$

using Morkovin's Strong Reynolds Analogy (Ref. 16).

$R_{\rho u} = 0.8$ was used to evaluate Eqn. 3 throughout the boundary layer (see Ref. 17).

The values of $\bar{u}/\bar{u}_{ref}$ and M are those interpolated from the data given in Ref. 4.

(d) $\frac{\bar{\rho}\ \overline{u'^2}}{\rho_w u_\tau^2}$ is calculated as follows, assuming constant static pressure across the boundary layer. Note that where significant cross-stream pressure gradient occurs (such as in passing a shock wave) no measurements (indicated by NM) are presented.

$$\frac{\bar{\rho}\,\overline{u'^2}}{\rho_w u_\tau^2} = \frac{T_w}{T}\frac{\overline{u'^2}}{u_\tau^2} = \frac{T_w}{T_o}\frac{\overline{u'^2}}{u_\tau^2}\{1 + \frac{(\gamma-1)}{2}M^2\} \qquad (4)$$

Here $T_w/T_o = 1.04$ (from previous mean flow measurements). $\bar{\rho}\,\overline{u'^2}/\rho_w u_\tau^2$ was thus calculated knowing $\langle u\rangle/u_\tau$ and M.

4.2.2 Inclined wire results

The inclined wire data presented in Table 6 are y/δ, M, $\bar{u}/\bar{u}_{ref}$, $\overline{\rho u}/\overline{(\rho u)}_{ref}$, $\bar{\rho}\,\overline{u'v'}/\rho_w u_\tau^2 \equiv \tau/\tau_w$ and $\overline{(\rho u)'v'}/(\overline{\rho u^2})$ respectively. They were evaluated as follows.

(a) Values of δ, M, $\bar{u}/\bar{u}_{ref}$, ρ_w and u_τ were evaluated as described in Section 4.2.1. $\overline{(\rho u)'v'}$ was evaluated from the inclined wire measurements as described in Smits and Muck (Ref. 14). Note that $\overline{(\rho u)'v'}$ in Table 6 is tabulated normalized by the local values of $(\overline{\rho u^2})$.

(b) $\dfrac{\bar{\rho}\,\overline{u'v'}}{\rho_w\, u_\tau^2}$ was evaluated as follows:

For small fluctuations, we can write

$$(\rho u)' = \bar{\rho}\,u' + \rho'\,\bar{u}$$

Multiplying by v' throughout and taking time-mean values, we have

$$\overline{(\rho u)'v'} = \bar{\rho}\,\overline{u'v'}\ \{1 + \frac{\bar{u}}{\bar{\rho}}\frac{\overline{\rho'v'}}{\overline{u'v'}}\} \qquad (5)$$

From equation 5, $\bar{\rho}\,\overline{u'v'}$ can be deduced from the measured $\overline{(\rho u)'v'}$ if $\overline{\rho'v'}$ is known. But $\overline{\rho'v'}$ is not measured and needs to be estimated based on plausible physical assumptions.

Starting from

$$\frac{p'}{\bar{p}} = \frac{T'}{\bar{T}} + \frac{\rho'}{\bar{\rho}}$$

(the overbar for the mean temperature is retained for clarity) we can write

$$\frac{\overline{u}}{\overline{\rho}} \frac{\overline{\rho' v'}}{\overline{u' v'}} = \frac{\overline{p' v'}}{\overline{u' v'}} \frac{\overline{u}}{\overline{p}} - \frac{\overline{v' T'}}{\overline{u' v'}} \frac{\overline{u}}{\overline{T}}$$

Substituting into (5),

$$\overline{(\rho u)' v'} = \overline{\rho}\, \overline{u' v'} \left\{ 1 - \frac{R_{vT}}{R_{uv}} \frac{\tilde{T}}{\tilde{u}} \left(1 - \frac{R_{pv}}{R_{vT}} \frac{\tilde{P}}{\tilde{T}}\right) \right\} \tag{6}$$

If we assume that pressure fluctuations are small with respect to density or temperature fluctuations ("Strong Reynolds Analogy"), R_{pv} can be taken to be negligible. Equation (6) then reduces to

$$\overline{(\rho u)' v'} = \overline{\rho}\, \overline{u' v'} \left\{ 1 - \frac{R_{vT}}{R_{uv}} \frac{\tilde{T}}{\tilde{u}} \right\}$$

or

$$\overline{\rho}\, \overline{u' v'} = \frac{\overline{(\rho u)' v'}}{\left\{ 1 - \frac{R_{vT}}{R_{uv}} \frac{\tilde{T}}{\tilde{u}} \right\}} \tag{7}$$

From the energy equation,

$$C_p T_o' = C_p T' + \overline{u} u'$$

which can be written as

$$T_o' = T' + \frac{u'}{\overline{u}} (\gamma - 1) M^2 \overline{T} \tag{8}$$

and by further assuming that $T_o' = 0$ ("Very Strong Reynolds Analogy"), we have

$$\frac{R_{vT}}{R_{uv}} \frac{\tilde{T}}{\tilde{u}} = \frac{\overline{v' T'}}{\overline{u' v'}} \frac{\overline{u}}{\overline{T}} = - (\gamma - 1) M^2$$

Substituting this into (7) we have

$$\bar{\rho}\ \overline{u'v'} = \frac{\overline{(\rho u)'v'}}{\{1 + (\gamma-1)\ M^2\}} \tag{9}$$

The values of $\bar{\rho}\ \overline{u'v'}$ tabulated in this report is thus calculated from the measured values of M and $\overline{(\rho u)'v'}$ according to equation (9). It is tabulated normalized by $\rho_w u_\tau^2$ (following Fernholz and Finley [18]) according to

$$\frac{\tau}{\tau_w} \equiv \frac{\bar{\rho}\ \overline{u'v'}}{\rho_w u_\tau^2} = \frac{2}{C_{f_{ref}}}\ \frac{\overline{\rho u}}{(\overline{\rho u})_{ref}}\ \frac{\bar{u}}{\bar{u}_{ref}}\ P\ \frac{\overline{(\rho u)'v'}}{(\bar{\rho}\ \bar{u}^2)} \tag{10}$$

where $\quad P = \{1 + (\gamma-1)\ M^2\}^{-1}$

5. COORDINATE DEFINITION AND MEASUREMENT LOCATIONS

The x-coordinate is defined in the streamwise direction along the surface of the wind tunnel wall and the compression ramp. The origin of x is at the compression corner; all locations upstream of the corner have negative x values, while all those on the ramp have positive values. The y-coordinate is measured from the test surface and the y-axis is normal to the test surface as shown below.

x range	y orientation
x = -50.8mm	normal to tunnel wall
$x \geq$ -6.4mm	normal to ramp surface

The x-locations where the normal wire measurements were made are:

x = -50.8, -6.4, 0.0, 4.0, 12.7, 25.4, 41.4, 57.2, 76.2, 95.3 mm

The x-locations where the inclined wire measurements were made are:

x = -50.8, 12.7, 25.4, 41.4, 57.1, 76.2, 95.2, 114.3 mm

6. MEASUREMENT UNCERTAINTIES

6.1 Mean-Flow Measurements

The mean-flow measurement uncertainties were given by Settles et al (Ref. 4). They were:

$P_w = \pm 2\%$	$M = \pm 3\%$
$C_{f_{ref}} = \pm 15\%$	$y = 0.2mm$
$u = \pm 5\%$	$\delta = \pm 5\%$
$p = 4\%$	

6.2 Turbulence Measurements

The turbulence measurements are subject to both random and systematic errors. The random errors are associated with uncertainties in evaluating the sensitivity from the calibration curve and correcting the sensitivity for changes in stagnation temperature, in addition to the possibility of a drift in the hot-wire characteristics. Systematic errors include neglecting temperature fluctuations and mean stagnation temperature changes through the flowfield, as well as the errors due to the limited spatial and temporal resolution of the hot-wire system.

On the following page are some estimates of the errors for the measurements taken in the undisturbed boundary layer upstream of the interaction.

6.2.1 Normal wire measurements

(a) Mass flow fluctuations:

For the normal wire, the specific error bounds on the mass-flow fluctuation measurements are given below.

Random errors:

Source	$\Delta\langle\rho u\rangle$
(i) evaluating the sensitivity from the calibration	$\pm$ 8%
(ii) correcting the sensitivity for variations in freestream stagnation temperature	$\pm$ 1%
(iii) drift in sensitivity during run	$\pm$ 3%
(iv) miscellaneous sources of error (end-conduction effects, filter gain variations, etc.)	$\pm$ 5%
The overall uncertainty in the rms mass-flow fluctuation level due to random errors is therefore	$\pm$10%

Systematic errors:

Source	$\Delta\langle\rho u\rangle$
(i) neglecting mean stagnation temperature variations through the boundary layer (assume 4% increase in T_0 between free-stream and the wall)	
At $y/\delta = 1$	0%
At $y/\delta = 0.05$	-2%
(ii) neglecting the contribution to the hot-wire output due to temperature fluctuations (in central portion of the layer, see Section 6.3 and Ref. 13)	+4%
(iii) limitation on spatial and temporal resolution (assume it is constant throughout the layer)	-2%
Overall systematic error in the rms mass-flow fluctuation level is therefore (maximum level only)	0%

Total error in $\langle\rho u\rangle$ is therefore $\pm$10%

(b) Velocity fluctuation intensity:

In converting the mass-flow fluctuation intensity to a velocity fluctuation intensity, the Strong Reynolds Analogy (equation 3) was assumed. This procedure requires as input the local Mach number, and the density/velocity correlation $R_{\rho u}$. The uncertainty in the Mach number ($\pm 3\%$) leads to an uncertainty in <u> of $\pm 4\%$, and the measurements of $R_{\rho u}$ (Ref. 17) are probably no better than $\pm 10\%$, which gives a corresponding uncertainty in <u> of $\pm 3\%$.

More importantly, the assumption of the Strong Reynolds Analogy is questionable. In fact, if the stagnation temperature fluctuation intensity and the stagnation temperature/mass-flow correlation $R_{\rho u T_o}$ were known, this assumption would not be necessary. For example, Kovasznay (Ref. 15) showed that, for negligible pressure fluctuations, we have exactly

$$\frac{\overline{u'^2}}{\bar{u}^2} = P^2 \frac{\overline{(\rho u)'^2}}{\overline{\rho u}^2} + 2PQ \frac{\overline{(\rho u)'T_o'}}{\overline{\rho u}\ T_o} + Q^2 \frac{\overline{T_o'^2}}{T_o^2} \tag{11}$$

where $$P = (1 + (\gamma-1)\ M^2)^{-1} \tag{12}$$

and $$Q/P = 1 + \left(\frac{\gamma-1}{2}\right) M^2 \tag{13}$$

Comparing equations 3 and 11, we find

$$\left\{ \frac{\langle u\rangle_k}{\langle u\rangle_s} \right\}^2 = \left\{ 1 + 2P(P-1)(1-R_{\rho u}) \right\} \left\{ 1 + 2\ R_{\rho u T_o} \frac{Q}{P} \frac{\langle T_o\rangle}{\langle \rho u\rangle} + \left[\frac{Q}{P} \frac{\langle T_o\rangle}{\langle \rho u\rangle} \right]^2 \right\} \tag{14}$$

where $\langle u\rangle_k$ is the value of <u> found using equation 11, and $\langle u\rangle_s$ is the value found using equation 3. Euqation 14 therefore represents an estimate for the possible error in <u> introduced by the assumption of the Strong

Reynolds Analogy. Clearly, this error varies through the flow field, and to find this error at a given point, we require the Mach number, the ratio $\langle T_o \rangle / \langle \rho u \rangle$, and the correlations $R_{\rho u}$ and $R_{\rho u T_o}$ at that point.

Consider three points in a typical zero pressure gradient boundary layer, such as the one investigated by Kistler (Ref. 19):

$$y/\delta = 0.1 \quad , \quad \langle T_o \rangle / \langle \rho u \rangle \approx 0.4 \quad , \quad R_{\rho u T_o} \approx 0.4$$
$$= 0.4 \qquad \approx 0.35 \qquad \approx 0.1$$
$$= 0.8 \qquad \approx 0.3 \qquad \approx -0.3$$

The quantity which has the greatest uncertainty is the correlation $R_{\rho u T_o}$. Kistler found a significant Mach number dependence, although other data (see Ref. 20) do not. In addition, Kistler found that $R_{\rho u T_o}$ changes sign with increasing y/δ. When this result is compared with other data, some conflict is apparent. Nevertheless, for the purposes of the present analysis, we will assume that the values measured by Kistler are not only correct, but that they are representative of a compressible turbulent boundary layer.

For the undisturbed boundary layer upstream of the 16^o compression corner, we found

$$y/\delta = 0.1 \quad , \quad M \approx 1.65$$
$$= 0.4 \qquad \approx 2.2$$
$$= 0.8 \qquad \approx 2.7$$

Finally, we assume a constant value of 0.8 for the density/velocity correlation $R_{\rho u}$ (see Ref. 17). Hence,

$$y/\delta = 0.1 \quad , \quad \langle u \rangle_k / \langle u \rangle_s = 1.30$$
$$= 0.4 \qquad = 1.21$$
$$= 0.8 \qquad = 1.02$$

Thus, it seems that the use of the Strong Reynolds Analogy underestimates the true value of <u> throughout the layer, although the estimate improves as the distance from the wall increases.

To summarize, the estimate for <u> using the Strong Reynolds Analogy is subject to the following uncertainties:

Source	Δ<u>
(i) Uncertainty in measuring <ρu>	±10%
(ii) Assumption of the Strong Reynolds Analogy	
$y/\delta = 0.1$	-30%
$= 0.4$	-21%
$= 0.8$	- 2%
(iii) Uncertainty in Mach number in Strong Reynolds Analogy	±4%
(iv) Uncertainty in $R_{\rho u}$ in Strong Reynolds Analogy	±3%

(c) Normal Reynolds Stress:

In addition to the errors found in $\langle u\rangle^2$, the normalized normal Reynolds stress, $\bar{\rho}\,\overline{u'^2}/\rho_w u_\tau^2$ have further errors from $\bar{\rho}/\rho_w$ and u_τ^2.

Source	$\bar{\rho}\,\overline{u'^2}/\rho_w u_\tau^2$
(i) Uncertainty in $\bar{\rho}/\rho_w$ of the undisturbed boundary layer	
$y/\delta = 0.1$	±2%
$= 0.4$	±3%
$= 0.8$	±4%
(ii) Uncertainty in evaluating u_τ^2	±16%

(d) Other sources of error:

Note that, for <u> at x = -12.7 and -6.4 mm, the hot-wire probe was traversed normal to the ramp face, whereas the mean flow data was deduced from Pitot profiles measured by traversing normal to the tunnel floor.

6.2.2 Inclined wire measurements

The inclined wire results are subject to random and systematic errors similar to those for the normal wire results. In addition, the inclined wire results are subject to errors arising from uncertainty in the directional sensitivity, and from the rather severe restrictions imposed by the "normal Mach number criterion" mentioned earlier. Further errors arise from the assumptions made during the course of data reduction. Below are some discussions and estimates of these errors.

(a) Restrictions due to the local normal Mach number criterion

One of the major limitations on using inclined hot-wires in low Mach number supersonic flow is the requirement that the instantaneous normal Mach number should be greater than 1.2 (see Smits and Muck[14]). Within the transonic range, the hot wire behavior changes drastically, and the sensitivity is affected such that a sharp fall-off occurs in the inferred turbulence intensity. For this reason, results for which the normal Mach number is below 1.2 are expected to be in error and should be used cautiously.

Below is a sample calculation of the "tolerable" level of rms lateral velocity fluctuation $\langle v \rangle / \overline{u} = r$ for the present undisturbed flat-plate boundary layer, with the various idealized "effective" wire angles.

We assume that v' is normally distributed and we impose the requirement that 98% of the time the normal Mach number must exceed 1.2 (for instance), then the criterion

$$M \cos (\psi - 2r) > 1.2$$

must be satisfied is as follows:

		limit on r%			
y/δ	M	ψ=30°	ψ=40°	ψ=45°	ψ=55°
0.1	1.65	-11.6	-2.9	+1.4*	+10.2*
0.2	1.87	-17.5	-8.8	-4.4	+ 4.3*
0.4	2.18	-23.2	-14.5	-10.1	- 1.4
0.6	2.45	-26.8	-18.0	-13.7	- 5.0
0.8	2.88	-30.9	-22.1	-17.8	- 9.1

We note that downstream of the interaction the overall Mach number is significantly lower than the undisturbed boundary layer, the decrease depends on the strength of the compression. Therefore the normal Mach number criterion is even more restrictive downstream of the interaction.

In the present flow field, r in the undisturbed boundary layer is of the order of 10% in the inner layer. We are therefore compelled to use the $\psi \sim 30^{o}$ (i.e. more normal) wires to reduce errors due to the foregoing restriction. Reducing ψ farther however is expected to reduce accuracy on the directional sensitivity.

For the real wires, the situation is further compounded since the wire is somewhat bowed (to avoid strain-gaging). For $\psi_{average} = 45^{o}$ (say) over the entire length, the local wire angle can vary between 35^{o} to 55^{o}. Therefore it is again necessary to choose a wire with smaller ψ.

(b) Besides the errors described in (a) above, the specific error bounds on the mass weighted Reynolds shear stress measurements are estimated on the following page.

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*For these wire angles, the normal Mach number is less than 1.2 even for r = 0!

Random errors:	Source	$\overline{(\rho u)'v'}$
	(i) evaluating the mass-flow sensitivity k_{mu} from the calibration	±16%
	(ii) evaluating the angle (or directional) sensitivity ξ from the calibration	±10%
	(iii) correcting the mass-flow sensitivity for variations in the freestream stagnation temperature	±2%
	(iv) drifts in the sensitivities during a run	
	in k_{mu}	±6%
	in ξ	±3%
	(v) miscellaneous sources of error (end-conduction effect, filter gain variations, etc.)	±10%

The overall uncertainty in $\overline{(\rho u)'v'}$ due to the above random errors is therefore ±22%

Systematic errors:	Source	$\overline{(\rho u)'v'}$
	(i) neglecting mean stagnation temperature variations through the boundary layer (assume 4% increase in T_0 between free-stream and the wall)	
	At $y/\delta = 1.0$	0%
	At $y/\delta = 0.05$	-4%
	(ii) neglecting the contribution to the hot-wire output due to temperature fluctuations (in central portion of the layer)	+1.6%
	(iii) limitation on spatial and temporal resolution (assume constant through the layer)	- 10%

The overall systematic errors due to the above effects in $\overline{(\rho u)'v'}$ will be underestimated by 10%

(c) In section 4.2.2(b) we have made use of the "Very Strong Reynolds Analogy" assumptions (i.e., $P' = 0$ and $T_o' = 0$) so that the unknown $(R_{vT}/R_{uv})\tilde{T}/\tilde{u}$ is reduced simply to $-(\gamma-1)M^2$. It is informative to assess the errors involved in using these assumptions.

We define a turbulent Prandtl number as

$$\sigma_t = \frac{\overline{u'v'}}{\overline{v'T'}} \frac{\partial T/\partial y}{\partial \bar{u}/\partial y}$$

Thus

$$\frac{R_{vT}}{R_{uv}} \frac{\tilde{T}}{\tilde{u}} = \frac{\overline{v'T'}}{\overline{u'v'}} \frac{\bar{u}}{T} = \frac{1}{\sigma_t} \frac{\frac{1}{T}\, \partial T/\partial y}{\frac{1}{\bar{u}}\, \partial \bar{u}/\partial y} \tag{15}$$

(dropping the overbar for mean T).

Also from the mean energy equation for small fluctuations,

$$C_p\, T_o = C_p\, T + \frac{1}{2} \bar{u}^2$$

we have

$$\frac{\frac{1}{T}\, \partial T/\partial y}{\frac{1}{\bar{u}}\, \partial \bar{u}/\partial y} = \frac{\frac{T_o}{T} \frac{1}{T_o}\, \partial T_o/\partial y}{\frac{1}{\bar{u}}\, \partial \bar{u}/\partial y} - N$$

$[N = (\gamma-1)M^2]$

In order to evaluate $\frac{R_{vT}}{R_{uv}} \frac{\tilde{T}}{\tilde{u}}$ using (15) we make the following assumptions,

$$U/U_e = (y/\delta)^{1/10}$$

$$(T_o - T_w)/T_{o_\infty} = -(y/\delta)^{1/10}$$

$$T_o \simeq 260\text{K}$$

$$T_o - T_w \simeq -12K$$

and $$\sigma_t \simeq \frac{1}{10}\,(9 - y/\delta) \text{ for } y/\delta > 0.05$$

(See Meier and Rotta[21])

y/δ	σ_t	M	A	B	B/A
0.1	0.89	1.65	2.303	2.089	0.907
0.2	0.88	1.87	2.678	2.899	0.896
0.4	0.86	2.18	3.315	2.901	0.875
0.6	0.84	2.45	3.979	3.421	0.855
0.8	0.82	2.88	5.195	4.318	0.831

where $$A = 1 - \frac{R_{vT}}{R_{uv}}\,\frac{\tilde{T}}{\tilde{u}}$$

and $$B = 1 + N$$

Therefore with the above modelling, the values of $\overline{\rho}\;\overline{u'v'}$ evaluated with the "Very Strong Reynolds" (VSR) analogy (i.e. $P'=0$, $T_o'=0$) as given by equation (9) is about 12% higher than that given by equation (7) in the middle of the layer. In other words, the "VSR" analogy tends to overestimate $\overline{\rho}\;\overline{u'v'}$.

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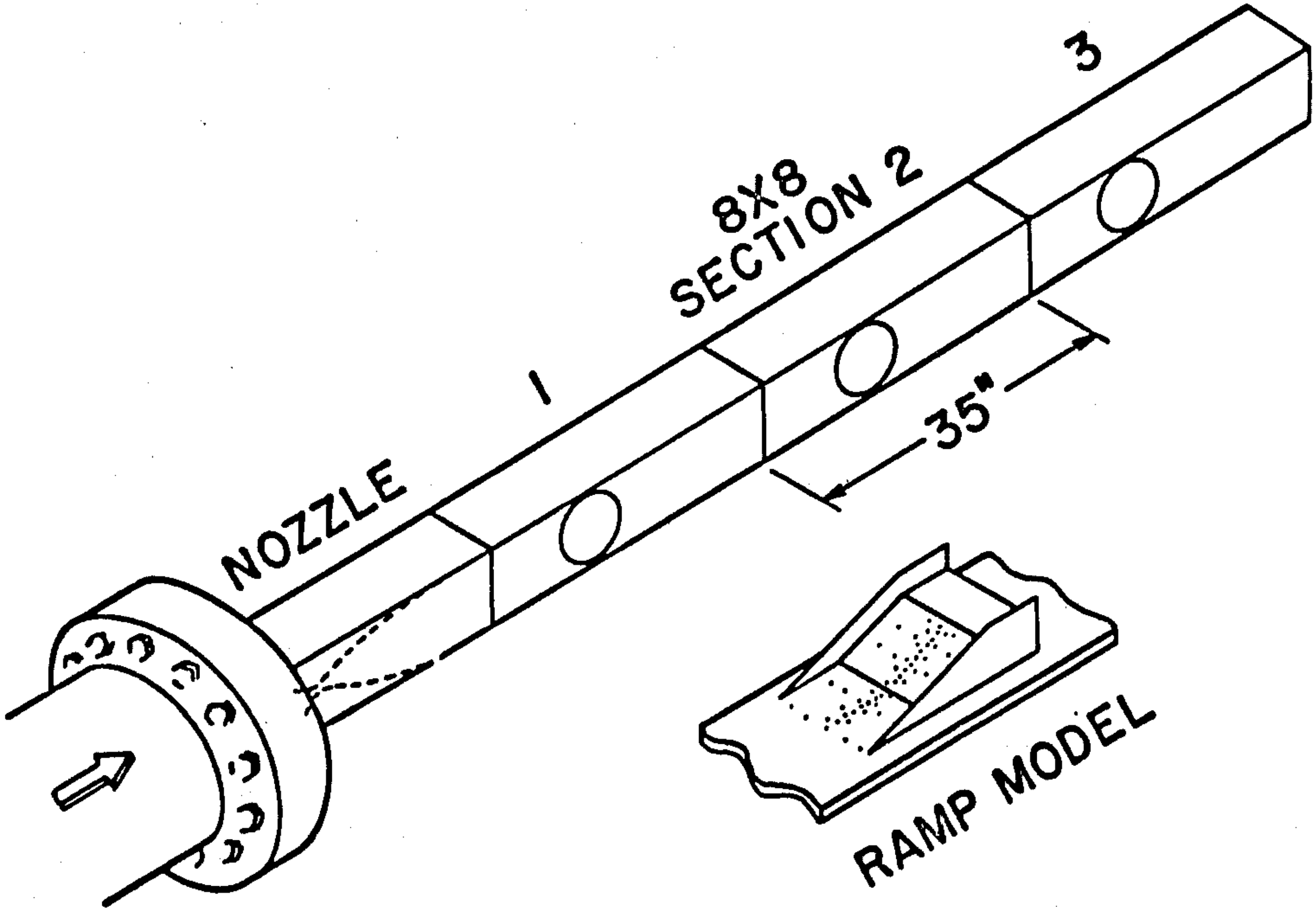

Figure 1. Sketch of the Wind Tunnel and 20° Ramp Model.

α	20^o
Re_{ref}	6.3×10^7/m
M_{ref}	2.79
P_{ref}	2.6×10^4 N/m^2
T_w/T_o	1.04
T_{ref}	103^oK
u_{ref}	562 m/s
δ_{ref}	25.0 mm
δ^*_{ref}	3.5 mm
θ_{ref}	0.5 mm

Table 1. Reference Parameters at x = -50.8 mm .

x, cm	$P_W/P_{W_{ref}}$
-5.08	0.99
-3.81	0.99
-3.81	1.00
-3.81	1.00
-3.81	1.00
-3.81	1.00
-2.70	1.00
-2.38	1.03
-2.22	1.07
-2.06	1.16
-1.91	1.32
-1.75	1.44
-1.59	1.56
-1.43	1.60
-1.27	1.67
-1.11	1.71
-0.95	1.76
-0.79	1.78
-0.64	1.82
-0.64	1.82
-0.56	1.85
-0.56	1.84
-0.48	1.87
-0.40	1.89
-0.32	1.90
-0.24	1.91
-0.16	1.94
-0.08	1.98
-0.08	1.97
0.0	2.00
0.0	2.00
0.08	2.02
0.16	2.06
0.24	2.12
0.48	2.20
0.64	2.30
0.64	2.30
0.95	2.42
1.27	2.53
2.22	2.83
3.81	3.15
3.81	3.13
3.81	3.17
5.72	3.32
7.62	3.43
11.43	3.57
11.43	3.56

Table 2. Wall Static Pressure Distribution.

x, cm	$C_{f_{ref}}$
-3.81	.00100
-3.00	.00100
-2.22	.00089
-1.91	.00057
-1.59	.00032
-1.27	.00015
0.40	.00008
0.64	.00012
0.95	.00027
1.27	.00032
1.59	.00052
1.91	.00057
2.22	.00063
2.54	.00069
2.86	.00083
4.13	.00094
4.45	.00116
5.72	.00126
7.62	.00158
9.53	.00179
11.43	.00192

Table 3. Skin-Friction Distribution.

x mm	δ mm	δ^* mm	θ mm	δ_p mm	$\frac{\nu_w}{u_\tau}$ mm x 10^{-3}
-50.8	25.0	3.5	0.5	28.9	2.55
-6.4	26.3	4.2	0.9	—	—
0.0	26.7	3.9	1.1	—	—
4.0	27.5	3.7	0.8	—	—
12.7	25.8	3.2	1.1	—	—
25.4	16.8	4.0	1.9	16.2	1.72
41.4	18.2	3.8	2.0	18.4	1.44
57.2	19.8	3.8	2.0	18.9	1.24
76.2	20.0	3.2	1.8	17.4	1.09
95.3	21.0	3.1	1.9	18.4	1.02

Table 4. Various Boundary Layer Length Scales.

TABLE 5. Normal Wire Turbulence Data
(All length scales are in meters)

X=-0.00508 UT= 2.0564E+01 RHOW= 3.2832E-01 TW= 2.7295E+02 D= 2.5000E-02

I	Y (M)	Y/D	(RHO U)' / RHO U	(RHO U)' / RHOW*UT	U / Uref	M	U' / UT	RHO*U'2 / RHOW*UT2
1	2.0000E-03	8.0000E-02	1.5320E-01	4.4974E+00	7.5453E-01	1.5873E+00	1.6585E+00	4.2132E+00
2	3.2555E-03	1.3022E-01	1.5040E-01	4.7560E+00	7.9021E-01	1.7098E+00	1.5777E+00	4.0278E+00
3	4.6985E-03	1.8794E-01	1.5220E-01	5.0812E+00	8.2056E-01	1.8189E+00	1.5469E+00	4.0692E+00
4	6.1335E-03	2.4534E-01	1.4930E-01	5.3625E+00	8.4528E-01	1.9198E+00	1.4664E+00	3.8314E+00
5	7.5825E-03	3.0330E-01	1.4770E-01	5.5522E+00	8.6597E-01	2.0070E+00	1.4069E+00	3.6739E+00
6	9.0145E-03	3.6058E-01	1.4290E-01	5.7887E+00	8.8630E-01	2.0977E+00	1.3165E+00	3.3574E+00
7	1.0461E-02	4.1842E-01	1.4540E-01	6.1312E+00	9.0094E-01	2.1678E+00	1.3037E+00	3.4024E+00
8	1.1908E-02	4.7630E-01	1.4060E-01	6.2141E+00	9.1820E-01	2.2541E+00	1.2186E+00	3.0967E+00
9	1.3348E-02	5.3390E-01	1.4050E-01	6.6577E+00	9.3250E-01	2.3282E+00	1.1833E+00	3.0238E+00
10	1.4808E-02	5.9230E-01	1.3400E-01	6.5794E+00	9.4627E-01	2.4047E+00	1.0931E+00	2.6741E+00
11	1.6258E-02	6.5030E-01	1.3150E-01	6.6650E+00	9.5895E-01	2.4787E+00	1.0404E+00	2.5077E+00
12	1.7698E-02	7.0790E-01	1.3150E-01	6.9552E+00	9.6878E-01	2.5391E+00	1.0146E+00	2.4541E+00
13	1.9108E-02	7.6430E-01	1.1330E-01	6.3567E+00	9.8002E-01	2.6115E+00	8.4799E-01	1.7730E+00
14	2.0588E-02	8.2350E-01	1.0620E-01	6.1487E+00	9.8763E-01	2.6657E+00	7.7651E-01	1.5244E+00
15	2.2038E-02	8.8150E-01	8.9470E-02	5.3457E+00	9.9314E-01	2.7147E+00	6.3979E-01	1.0590E+00
16	2.3518E-02	9.4070E-01	7.1770E-02	4.4338E+00	9.9606E-01	2.7456E+00	5.0585E-01	6.7208E-01
17	2.4968E-02	9.9870E-01	6.1220E-02	3.8401E+00	9.9745E-01	2.7625E+00	4.2802E-01	4.8550E-01
18	2.6448E-02	1.0579E+00	4.2980E-02	2.7259E+00	9.9769E-01	2.7710E+00	2.9914E-01	2.3830E-01
19	2.7918E-02	1.1167E+00	3.6300E-02	2.3033E+00	9.9794E-01	2.7790E+00	2.5159E-01	1.6934E-01
20	2.9388E-02	1.1755E+00	2.4520E-02	1.5649E+00	9.9931E-01	2.7918E+00	1.6897E-01	7.6898E-02
21	3.0827E-02	1.2331E+00	1.7400E-02	1.1154E+00	9.9876E-01	2.7895E+00	1.1999E-01	3.8808E-02
22	3.2307E-02	1.2923E+00	1.7560E-02	1.1270E+00	9.9882E-01	2.7936E+00	1.2083E-01	3.9459E-02
23	3.3787E-02	1.3515E+00	1.4960E-02	9.6187E-01	9.9866E-01	2.7950E+00	1.0284E-01	2.8636E-02
24	3.5257E-02	1.4103E+00	1.3550E-02	8.7182E-01	9.9883E-01	2.7950E+00	9.3160E-02	2.3536E-02
25	3.6727E-02	1.4691E+00	1.3690E-02	8.8265E-01	9.9897E-01	2.7950E+00	9.4136E-02	2.4060E-02
26	3.8207E-02	1.5283E+00	1.3390E-02	8.6231E-01	9.9839E-01	2.7906E+00	9.2242E-02	2.3085E-02
27	3.9677E-02	1.5871E+00	1.3220E-02	8.5469E-01	9.9906E-01	2.7955E+00	9.0890E-02	2.2495E-02

X=-0.00063 UT= 1.3044E+19 RHOW= ********** TW= 2.7633E+02 D= 2.6300E-02

I	Y (M)	Y/D	(RHO U)' / RHO U
1	3.0000E-03	1.1407E-01	3.0800E-01
2	4.2790E-03	1.6270E-01	3.3530E-01
3	5.7130E-03	2.1722E-01	3.2080E-01
4	7.1600E-03	2.7224E-01	2.6370E-01
5	8.6010E-03	3.2703E-01	2.1040E-01
6	1.0041E-02	3.8179E-01	1.7150E-01
7	1.1473E-02	4.3624E-01	1.6860E-01
8	1.2940E-02	4.9202E-01	1.4890E-01
9	1.4380E-02	5.4677E-01	1.3400E-01
10	1.5840E-02	6.0228E-01	1.3170E-01
11	1.7280E-02	6.5703E-01	1.2910E-01
12	1.8700E-02	7.1103E-01	1.3070E-01
13	2.0150E-02	7.6616E-01	1.1890E-01
14	2.1620E-02	8.2205E-01	1.0970E-01
15	2.3080E-02	8.7757E-01	1.0010E-01
16	2.4550E-02	9.3346E-01	9.0230E-02
17	2.6010E-02	9.8897E-01	7.4610E-02
18	2.7500E-02	1.0456E+00	5.6810E-02
19	2.8970E-02	1.1015E+00	4.9520E-02
20	3.0410E-02	1.1563E+00	3.6960E-02
21	3.1800E-02	1.2091E+00	3.0020E-02
22	3.3290E-02	1.2658E+00	2.4700E-02
23	3.4760E-02	1.3217E+00	1.9750E-02
24	3.6240E-02	1.3779E+00	1.4720E-02
25	3.7710E-02	1.4338E+00	1.2930E-02

X=0.0 UT= 1.3044E+19 RHOW= ********** TW= 2.7040E+02 D= 2.6700E-02

I	Y (M)	Y/D	(RHO U)' / RHO U
1	3.0000E-03	1.1236E-01	2.4730E-01
2	4.2380E-03	1.5873E-01	2.8590E-01
3	5.6730E-03	2.1247E-01	3.7430E-01
4	7.0960E-03	2.6577E-01	3.4830E-01
5	8.5490E-03	3.2019E-01	3.4800E-01
6	9.9900E-03	3.7416E-01	2.7980E-01
7	1.1429E-02	4.2805E-01	2.2600E-01
8	1.2870E-02	4.8202E-01	1.9240E-01
9	1.4319E-02	5.3629E-01	1.8050E-01
10	1.5779E-02	5.9097E-01	1.7930E-01
11	1.7219E-02	6.4490E-01	1.5110E-01
12	1.8669E-02	6.9921E-01	1.3130E-01
13	2.0079E-02	7.5202E-01	1.2500E-01
14	2.1539E-02	8.0670E-01	1.1640E-01
15	2.2999E-02	8.6138E-01	1.0260E-01
16	2.4469E-02	9.1644E-01	9.6320E-02
17	2.5929E-02	9.7112E-01	8.4410E-02
18	2.7389E-02	1.0258E+00	6.4510E-02
19	2.8889E-02	1.0820E+00	5.4270E-02
20	3.0339E-02	1.1363E+00	3.8580E-02
21	3.1799E-02	1.1910E+00	3.0070E-02
22	3.3259E-02	1.2457E+00	2.6900E-02
23	3.4749E-02	1.3015E+00	1.9980E-02
24	3.6219E-02	1.3565E+00	1.5580E-02
25	3.7699E-02	1.4119E+00	1.5170E-02
26	3.9169E-02	1.4670E+00	1.4150E-02

X=0.000399 UT= 1.3044E+19 RHOW= *********** TW= 2.7139E+02 D= 2.7500E-02

I	Y (M)	Y/D	(RHO U)' / RHO U
1	2.0000E-03	7.2727E-02	2.8100E-01
2	3.2430E-03	1.1793E-01	3.3290E-01
3	4.6700E-03	1.6982E-01	3.5240E-01
4	6.1220E-03	2.2262E-01	3.6610E-01
5	7.5650E-03	2.7509E-01	3.1200E-01
6	9.0040E-03	3.2742E-01	2.7560E-01
7	1.0445E-02	3.7982E-01	2.1610E-01
8	1.1894E-02	4.3251E-01	1.9520E-01
9	1.3354E-02	4.8560E-01	1.7980E-01
10	1.4794E-02	5.3796E-01	1.8890E-01
11	1.6244E-02	5.9069E-01	1.6410E-01
12	1.7654E-02	6.4196E-01	1.2530E-01
13	1.9124E-02	6.9542E-01	1.1480E-01
14	2.0574E-02	7.4815E-01	1.0620E-01
15	2.2044E-02	8.0160E-01	9.5880E-02
16	2.3514E-02	8.5505E-01	8.0310E-02
17	2.4964E-02	9.0778E-01	6.7610E-02
18	2.6454E-02	9.6196E-01	5.0930E-02
19	2.7924E-02	1.0154E+00	4.4560E-02
20	2.9374E-02	1.0681E+00	2.5810E-02
21	3.0844E-02	1.1216E+00	2.3150E-02
22	3.2324E-02	1.1754E+00	2.1750E-02
23	3.3794E-02	1.2289E+00	1.5310E-02
24	3.5274E-02	1.2827E+00	1.4790E-02
25	3.6744E-02	1.3361E+00	1.3550E-02
26	3.8194E-02	1.3889E+00	1.3170E-02

X=0.00127 UT= 1.3044E+19 RHOW= ********** TW= 2.7056E+02 D= 2.5800E-02

I	Y (M)	Y/D	(RHO U)' RHO U
1	2.0000E-03	7.7519E-02	3.3160E-01
2	3.2590E-03	1.2632E-01	3.5000E-01
3	4.6950E-03	1.8198E-01	3.7290E-01
4	6.1360E-03	2.3783E-01	3.8550E-01
5	7.5630E-03	2.9314E-01	3.6390E-01
6	9.0230E-03	3.4973E-01	3.0970E-01
7	1.0483E-02	4.0632E-01	2.4170E-01
8	1.1923E-02	4.6213E-01	2.0150E-01
9	1.3363E-02	5.1795E-01	1.7360E-01
10	1.4783E-02	5.7298E-01	1.6830E-01
11	1.6253E-02	6.2996E-01	1.9170E-01
12	1.7703E-02	6.8616E-01	1.3800E-01
13	1.9173E-02	7.4314E-01	9.7730E-02
14	2.0633E-02	7.9973E-01	8.4130E-02
15	2.2103E-02	8.5671E-01	6.6230E-02
16	2.3593E-02	9.1446E-01	4.6050E-02
17	2.5053E-02	9.7105E-01	3.8930E-02
18	2.6493E-02	1.0269E+00	2.9990E-02
19	2.7973E-02	1.0842E+00	2.3090E-02
20	2.9453E-02	1.1416E+00	1.7710E-02
21	3.0933E-02	1.1990E+00	1.5060E-02
22	3.2403E-02	1.2559E+00	1.3990E-02
23	3.3883E-02	1.3133E+00	1.3660E-02

X=0.00254 UT= 9.9040E+00 RHOW= 9.9657E-01 TW= 2.6796E+02 D= 1.6800E-02

I	Y (M)	Y/D	(RHO U)' RHO U	(RHO U)' RHOW*UT	U Uref	M	U' UT	RHO*U'2 RHOW*UT2
1	2.0000E-03	1.1905E-01	3.1890E-01	7.9386E+00	4.2749E-01	7.6359E-01	6.4745E+00	4.8166E+01
2	3.2420E-03	1.9298E-01	3.2420E-01	8.7997E+00	4.8271E-01	8.7960E-01	7.0404E+00	5.8988E+01
3	4.6920E-03	2.7929E-01	3.6130E-01	9.8506E+00	5.5505E-01	1.0419E+00	8.2921E+00	8.6381E+01
4	6.1520E-03	3.6619E-01	3.7180E-01	1.1847E+01	6.2812E-01	1.2194E+00	8.7277E+00	1.0209E+02
5	7.5920E-03	4.5190E-01	3.5730E-01	1.3257E+01	6.9185E-01	1.3900E+00	8.3327E+00	9.9592E+01
6	9.0220E-03	5.3702E-01	3.3600E-01	1.4301E+01	7.4566E-01	1.5494E+00	7.6448E+00	8.9563E+01
7	1.0452E-02	6.2214E-01	2.9490E-01	1.4126E+01	7.8742E-01	1.6840E+00	6.5063E+00	6.8768E+01
8	1.1932E-02	7.1024E-01	2.3070E-01	1.2645E+01	8.3076E-01	1.8383E+00	4.8684E+00	4.1222E+01
9	1.3382E-02	7.9655E-01	1.9550E-01	1.1831E+01	8.5772E-01	1.9468E+00	3.9772E+00	2.8893E+01
10	1.4862E-02	8.8464E-01	1.5650E-01	1.0202E+01	8.9032E-01	2.0840E+00	3.0325E+00	1.7875E+01
11	1.6312E-02	9.7095E-01	1.3140E-01	8.8013E+00	9.1029E-01	2.1784E+00	2.4555E+00	1.2234E+01
12	1.7792E-02	1.0590E+00	1.9369E-01	1.1898E+01	9.0966E-01	2.1873E+00	3.5956E+00	2.6357E+01
13	1.9242E-02	1.1454E+00	1.7700E-01	8.5935E+00	9.2333E-01	2.2667E+00	3.1786E+00	2.1368E+01
14	2.0722E-02	1.2335E+00	4.9500E-02	2.2167E+00	1.0145E+00	2.8223E+00	7.0692E-01	1.3527E+00
15	2.2182E-02	1.3204E+00	2.9160E-02	1.3038E+00	NM	NM	NM	NM
16	2.3662E-02	1.4085E+00	2.3970E-02	1.0744E+00	NM	NM	NM	NM
17	2.5122E-02	1.4954E+00	1.5790E-02	7.0903E-01	NM	NM	NM	NM
18	2.6612E-02	1.5840E+00	1.6250E-02	7.2870E-01	NM	NM	NM	NM
19	2.8072E-02	1.6710E+00	1.3470E-02	6.0281E-01	NM	NM	NM	NM
20	2.9532E-02	1.7579E+00	1.3540E-02	6.0758E-01	NM	NM	NM	NM
21	3.1022E-02	1.8465E+00	1.4230E-02	6.3912E-01	NM	NM	NM	NM

X=0.00414 UT= 1.1175E+01 RHOW= 1.0665E+00 TW= 2.7076E+02 D= 1.8200E-02

I	Y (M)	Y/D	(RHO U)' RHO U	(RHO U)' RHOW*UT	U Uref	M	U' UT	RHO*U'2 RHOW*UT2
1	2.0000E-03	1.0989E-01	2.6860E-01	6.6286E+00	4.6613E-01	8.4296E-01	5.0814E+00	3.0361E+01
2	3.2900E-03	1.8077E-01	3.0580E-01	8.0214E+00	5.0816E-01	9.3520E-01	6.0258E+00	4.4005E+01
3	4.7000E-03	2.5824E-01	3.2460E-01	8.6888E+00	5.5534E-01	1.0416E+00	6.6074E+00	5.4866E+01
4	6.1800E-03	3.3956E-01	3.6110E-01	1.1035E+01	6.0710E-01	1.1672E+00	7.4862E+00	7.3757E+01
5	7.6400E-03	4.1978E-01	3.3610E-01	1.1360E+01	6.7108E-01	1.3338E+00	6.9751E+00	6.8299E+01
6	9.1000E-03	5.0000E-01	3.4510E-01	1.3477E+01	7.1841E-01	1.4680E+00	7.0565E+00	7.3864E+01
7	1.0560E-02	5.8022E-01	3.1590E-01	1.2915E+01	7.7048E-01	1.6299E+00	6.2552E+00	6.2183E+01
8	1.2040E-02	6.6154E-01	2.6140E-01	1.2378E+01	8.1010E-01	1.7646E+00	4.9961E+00	4.2086E+01
9	1.3510E-02	7.4231E-01	2.0000E-01	1.0912E+01	8.4483E-01	1.8915E+00	3.6780E+00	2.4141E+01
10	1.4970E-02	8.2253E-01	1.5270E-01	9.0526E+00	8.6853E-01	1.9878E+00	2.7169E+00	1.3757E+01
11	1.6430E-02	9.0275E-01	1.0630E-01	6.6274E+00	8.8662E-01	2.0713E+00	1.8325E+00	6.5026E+00
12	1.7900E-02	9.8352E-01	7.1770E-02	4.5143E+00	8.9558E-01	2.1219E+00	1.2110E+00	2.9083E+00
13	1.9380E-02	1.0648E+00	5.6000E-02	3.5055E+00	9.1025E-01	2.1955E+00	9.1780E-01	1.7276E+00
14	2.0860E-02	1.1462E+00	2.1400E-01	1.1419E+01	9.4593E-01	2.3793E+00	3.2603E+00	2.3694E+01
15	2.2320E-02	1.2264E+00	1.7130E-01	6.5546E+00	NM	NM	NM	NM
16	2.3790E-02	1.3071E+00	2.9600E-02	1.0700E+00	NM	NM	NM	NM
17	2.5270E-02	1.3885E+00	1.4440E-02	5.2018E-01	NM	NM	NM	NM
18	2.6760E-02	1.4703E+00	1.3360E-02	4.8049E-01	NM	NM	NM	NM
19	2.8260E-02	1.5527E+00	1.3010E-02	4.6779E-01	NM	NM	NM	NM

X=0.005715 UT= 1.2764E+01 RHOW= 1.0956E+00 TW= 2.7430E+02 D= 1.9800E-02

I	Y (M)	Y/D	(RHO U)' / RHO U	(RHO U)' / RHOW*UT	U / Uref	M	U' / UT	RHO*U'2 / RHOW*UT2
1	2.0000E-03	1.0101E-01	2.3690E-01	5.5122E+00	5.1881E-01	9.5676E-01	4.1263E+00	2.0702E+01
2	3.3040E-03	1.6687E-01	2.7530E-01	6.7227E+00	5.4801E-01	1.0223E+00	4.8922E+00	2.9783E+01
3	4.7560E-03	2.4020E-01	3.0570E-01	7.7842E+00	5.8319E-01	1.1066E+00	5.5179E+00	3.9072E+01
4	6.2060E-03	3.1343E-01	3.2956E-01	8.6591E+00	6.2015E-01	1.1998E+00	5.9942E+00	4.7772E+01
5	7.6560E-03	3.8667E-01	3.4010E-01	1.0175E+01	6.6649E-01	1.3231E+00	6.1769E+00	5.3259E+01
6	9.0960E-03	4.5939E-01	3.2940E-01	1.1172E+01	7.1053E-01	1.4474E+00	5.9075E+00	5.1258E+01
7	1.0526E-02	5.3162E-01	3.1780E-01	1.1799E+01	7.6567E-01	1.6144E+00	5.5288E+00	4.8189E+01
8	1.1966E-02	6.0434E-01	2.6730E-01	1.1191E+01	8.0152E-01	1.7326E+00	4.5160E+00	3.3874E+01
9	1.3446E-02	6.7909E-01	2.0070E-01	9.5121E+00	8.2755E-01	1.8277E+00	3.2958E+00	1.8826E+01
10	1.4906E-02	7.5283E-01	1.8190E-01	8.9631E+00	8.5951E-01	1.9500E+00	2.8714E+00	1.5099E+01
11	1.6366E-02	8.2657E-01	1.2190E-01	6.4398E+00	8.8169E-01	2.0458E+00	1.8588E+00	6.6101E+00
12	1.7816E-02	8.9980E-01	6.8500E-02	3.7427E+00	8.8839E-01	2.0856E+00	1.0266E+00	2.0549E+00
13	1.9306E-02	9.7505E-01	4.5200E-02	2.4793E+00	8.9248E-01	2.1103E+00	6.6999E-01	8.8603E-01
14	2.0776E-02	1.0493E+00	2.9740E-02	1.6217E+00	8.9233E-01	2.1150E+00	4.3961E-01	3.8247E-01
15	2.2226E-02	1.1225E+00	2.4720E-02	1.3335E+00	8.9358E-01	2.1230E+00	3.6411E-01	2.6362E-01
16	2.3696E-02	1.1968E+00	3.4420E-02	1.8405E+00	8.9809E-01	2.1448E+00	5.0270E-01	5.0800E-01
17	2.5166E-02	1.2710E+00	2.4910E-01	1.0643E+01	9.3382E-01	2.3196E+00	3.3997E+00	2.5150E+01
18	2.6646E-02	1.3458E+00	8.6210E-02	2.6791E+00	9.5835E-01	2.4512E+00	1.1162E+00	2.8783E+00
19	2.8106E-02	1.4195E+00	1.3590E-02	4.1728E-01	NM	NM	NM	NM
20	2.9596E-02	1.4947E+00	1.3300E-02	4.0847E-01	NM	NM	NM	NM
21	3.1046E-02	1.5680E+00	1.2490E-02	3.8475E-01	NM	NM	NM	NM

X=0.00762 UT= 1.4050E+01 RHOW= 1.1339E+00 TW= 2.7383E+02 D= 2.0000E-02

I	Y (M)	Y/D	(RHO U)' / RHO U	(RHO U)' / RHOW*UT	U / Uref	M	U' / UT	RHO*U'2 / RHOW*UT2
1	2.0000E-03	1.0000E-01	2.3320E-01	5.2419E+00	5.5696E-01	1.0433E+00	3.7828E+00	1.7904E+01
2	3.3600E-03	1.6800E-01	2.5700E-01	5.8672E+00	5.8369E-01	1.1068E+00	4.2174E+00	2.2787E+01
3	4.7900E-03	2.3950E-01	2.9490E-01	7.3081E+00	6.0925E-01	1.1713E+00	4.8681E+00	3.1126E+01
4	6.2700E-03	3.1350E-01	3.0040E-01	7.7555E+00	6.3910E-01	1.2492E+00	4.9689E+00	3.3438E+01
5	7.7100E-03	3.8550E-01	3.2040E-01	8.7002E+00	6.7756E-01	1.3536E+00	5.2751E+00	3.9291E+01
6	9.2000E-03	4.6000E-01	3.2070E-01	9.4653E+00	7.1505E-01	1.4605E+00	5.2155E+00	4.0144E+01
7	1.0650E-02	5.3250E-01	3.2390E-01	1.0377E+01	7.5593E-01	1.5864E+00	5.1445E+00	4.1221E+01
8	1.2130E-02	6.0650E-01	2.9760E-01	1.0737E+01	7.8864E-01	1.6928E+00	4.6094E+00	3.4668E+01
9	1.3600E-02	6.8000E-01	2.6020E-01	1.0136E+01	8.2433E-01	1.8181E+00	3.8902E+00	2.6104E+01
10	1.5060E-02	7.5300E-01	2.0900E-01	9.1662E+00	8.5682E-01	1.9418E+00	3.0033E+00	1.6448E+01
11	1.6520E-02	8.2600E-01	1.4580E-01	6.7129E+00	8.7186E-01	2.0062E+00	2.0473E+00	7.8741E+00
12	1.8000E-02	9.0000E-01	1.0420E-01	4.9558E+00	8.8016E-01	2.0499E+00	1.4382E+00	3.9647E+00
13	1.9460E-02	9.7300E-01	7.5230E-02	3.6366E+00	8.8240E-01	2.0660E+00	1.0299E+00	2.0503E+00
14	2.0940E-02	1.0470E+00	3.9180E-02	1.9099E+00	8.8146E-01	2.0660E+00	5.3581E-01	5.5556E-01
15	2.2410E-02	1.1205E+00	2.7570E-02	1.3400E+00	8.7982E-01	2.0604E+00	3.7766E-01	2.7563E-01
16	2.3880E-02	1.1940E+00	2.1400E-02	1.0363E+00	8.7876E-01	2.0590E+00	2.9322E-01	1.6617E-01
17	2.5350E-02	1.2675E+00	2.0570E-02	9.9305E-01	8.7746E-01	2.0507E+00	2.8271E-01	1.5409E-01
18	2.6850E-02	1.3425E+00	2.0450E-02	9.8071E-01	8.7661E-01	2.0440E+00	2.8197E-01	1.5306E-01
19	2.8350E-02	1.4175E+00	2.0490E-02	9.7954E-01	8.7676E-01	2.0440E+00	2.8257E-01	1.5383E-01
20	2.9810E-02	1.4905E+00	6.4110E-02	3.0008E+00	8.6527E-01	2.0867E+00	8.6926E-01	1.4854E+00
21	3.1320E-02	1.5660E+00	1.9670E-01	5.7380E+00	9.1218E-01	2.2109E+00	2.5451E+00	1.3476E+01
22	3.2810E-02	1.6405E+00	1.4230E-02	3.8596E-01	9.7269E-01	2.5744E+00	1.5806E-01	6.1165E-02

X=0.009525 UT= 1.4836E+01 RHOW= 1.1522E+00 TW= 2.7498E+02 D= 2.1000E-02

I	Y (M)	Y/D	(RHO U)' / RHO U	(RHO U)' / RHOW*UT	U / Uref	M	U' / UT	RHO*U'2 / RHOW*UT2
1	2.0000E-03	9.5238E-02	2.3780E-01	5.2712E+00	5.7206E-01	1.0839E+00	3.6692E+00	1.7046E+01
2	3.4100E-03	1.6238E-01	2.6290E-01	6.1336E+00	6.0268E-01	1.1571E+00	4.0996E+00	2.1878E+01
3	4.8800E-03	2.3238E-01	2.7110E-01	6.4566E+00	6.2518E-01	1.2159E+00	4.2372E+00	2.3922E+01
4	6.3600E-03	3.0286E-01	2.7770E-01	6.7324E+00	6.5305E-01	1.2993E+00	4.3371E+00	2.5813E+01
5	7.8300E-03	3.7286E-01	3.0080E-01	7.8925E+00	6.7932E-01	1.3617E+00	4.6790E+00	3.0944E+01
6	9.2800E-03	4.4190E-01	3.1130E-01	8.8345E+00	7.1362E-01	1.4606E+00	4.7848E+00	3.3713E+01
7	1.0750E-02	5.1190E-01	3.0230E-01	9.3520E+00	7.4751E-01	1.5652E+00	4.5574E+00	3.1978E+01
8	1.2220E-02	5.8190E-01	3.0320E-01	1.0056E+01	7.8066E-01	1.6719E+00	4.4613E+00	3.2102E+01
9	1.3700E-02	6.5238E-01	2.4780E-01	9.1867E+00	8.1224E-01	1.7789E+00	3.5443E+00	2.1245E+01
10	1.5170E-02	7.2238E-01	2.2990E-01	9.0651E+00	8.3682E-01	1.8682E+00	3.2012E+00	1.8043E+01
11	1.6650E-02	7.9286E-01	1.7540E-01	7.3871E+00	8.5540E-01	1.9444E+00	2.3795E+00	1.0321E+01
12	1.8110E-02	8.6238E-01	1.2510E-01	5.4063E+00	8.6706E-01	1.9979E+00	1.6631E+00	5.1693E+00
13	1.9610E-02	9.3381E-01	9.9300E-02	4.3994E+00	8.6975E-01	2.0129E+00	1.3118E+00	3.2414E+00
14	2.1110E-02	1.0052E+00	5.7200E-02	2.5720E+00	8.6880E-01	2.0100E+00	7.5628E-01	1.0767E+00
15	2.2570E-02	1.0748E+00	3.7520E-02	1.6921E+00	8.6741E-01	2.0090E+00	4.9555E-01	4.6261E-01
16	2.4080E-02	1.1467E+00	2.4980E-02	1.1297E+00	8.6542E-01	2.0069E+00	3.2960E-01	2.0469E-01
17	2.5570E-02	1.2176E+00	1.8140E-02	8.1895E-01	8.6353E-01	2.0020E+00	2.3957E-01	1.0802E-01
18	2.7050E-02	1.2881E+00	1.9560E-02	8.8123E-01	8.6398E-01	2.0020E+00	2.5845E-01	1.2587E-01
19	2.8560E-02	1.3600E+00	1.8140E-02	8.1375E-01	8.6410E-01	2.0020E+00	2.3972E-01	1.0841E-01
20	3.0060E-02	1.4314E+00	1.8650E-02	8.3248E-01	8.6276E-01	1.9965E+00	2.4693E-01	1.1488E-01
21	3.1550E-02	1.5024E+00	1.8980E-02	8.4433E-01	8.6515E-01	2.0066E+00	2.5040E-01	1.1875E-01
22	3.3080E-02	1.5752E+00	1.8700E-02	8.3198E-01	8.6835E-01	2.0214E+00	2.4534E-01	1.1489E-01
23	3.4590E-02	1.6471E+00	1.8050E-02	7.9958E-01	8.6995E-01	2.0293E+00	2.3608E-01	1.0687E-01
24	3.6100E-02	1.7190E+00	7.4940E-02	3.2640E+00	9.9091E-01	2.1180E+00	9.4884E-01	1.7981E+00
25	3.7620E-02	1.7914E+00	1.4210E-01	3.6794E+00	9.2556E-01	2.2882E+00	1.6855E+00	6.1298E+00
26	3.9150E-02	1.8643E+00	1.4590E-02	3.6643E-01	1.0505E+00	3.1598E+00	1.2018E-01	4.5672E-02

TABLE 6. Inclined Wire Turbulence Data
(All length scales are in meters)

X= -.0508 UT= 2.0887E+01 RHOW= 3.2474E-01 TW= 2.7596E+02 D= 2.8000E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	7.1429E-02	1.5873E+00	7.5453E-01	4.0574E-01	8.9735E-01	-2.9426E-03
2	3.2164E-03	1.1487E-01	1.7060E+00	7.8910E-01	4.3335E-01	8.4055E-01	-2.6598E-03
3	4.6574E-03	1.6634E-01	1.8158E+00	8.1970E-01	4.7323E-01	9.2744E-01	-2.7721E-03
4	6.1034E-03	2.1798E-01	1.9177E+00	8.4476E-01	5.0825E-01	9.8661E-01	-2.8391E-03
5	7.5274E-03	2.6884E-01	2.0037E+00	8.6518E-01	5.4531E-01	9.7825E-01	-2.7016E-03
6	8.9414E-03	3.1934E-01	2.0931E+00	8.8534E-01	5.8851E-01	9.6903E-01	-2.5595E-03
7	1.0368E-02	3.7030E-01	2.1633E+00	9.0001E-01	6.2400E-01	8.5895E-01	-2.1963E-03
8	1.1829E-02	4.2248E-01	2.2494E+00	9.1726E-01	6.6688E-01	7.3218E-01	-1.8098E-03
9	1.3290E-02	4.7466E-01	2.3252E+00	9.3193E-01	7.0189E-01	6.4622E-01	-1.5623E-03
10	1.4750E-02	5.2680E-01	2.4017E+00	9.4573E-01	7.3779E-01	6.6390E-01	-1.5734E-03
11	1.6190E-02	5.7823E-01	2.4753E+00	9.5836E-01	7.7483E-01	4.9294E-01	-1.1453E-03
12	1.7680E-02	6.3144E-01	2.5384E+00	9.6666E-01	8.1185E-01	4.0544E-01	-9.2215E-04
13	1.9130E-02	6.8323E-01	2.6123E+00	9.8014E-01	8.5004E-01	3.2053E-01	-7.1744E-04
14	2.0580E-02	7.3501E-01	2.6654E+00	9.8759E-01	8.8250E-01	2.2532E-01	-4.9656E-04
15	2.2040E-02	7.8716E-01	2.7148E+00	9.9314E-01	9.0793E-01	2.2460E-01	-4.9169E-04
16	2.3500E-02	8.3930E-01	2.7452E+00	9.9603E-01	9.3793E-01	1.3035E-01	-2.8007E-04
17	2.4960E-02	8.9144E-01	2.7624E+00	9.9744E-01	9.6003E-01	7.2605E-02	-1.5363E-04
18	2.6430E-02	9.4394E-01	2.7709E+00	9.9769E-01	9.7081E-01	-2.7360E-02	5.7502E-05
19	2.7900E-02	9.9644E-01	2.7789E+00	9.9794E-01	9.7827E-01	-2.0035E-02	4.1956E-05
20	2.9350E-02	1.0482E+00	2.7915E+00	9.9927E-01	9.8264E-01	-7.5159E-04	1.5756E-06
21	3.0830E-02	1.1011E+00	2.7895E+00	9.9876E-01	9.8570E-01	4.8741E-03	-1.0181E-05
22	3.2330E-02	1.1547E+00	2.7936E+00	9.9882E-01	9.8742E-01	-2.3352E-03	4.8795E-06
23	3.3790E-02	1.2068E+00	2.7950E+00	9.9866E-01	9.9077E-01	-2.1552E-04	4.4923E-07
24	3.5270E-02	1.2597E+00	2.7950E+00	9.9883E-01	9.9188E-01	8.8606E-04	-1.8445E-06
25	3.6760E-02	1.3129E+00	2.7949E+00	9.9896E-01	9.9210E-01	7.1121E-04	-1.4800E-06
26	3.8240E-02	1.3657E+00	2.7907E+00	9.9840E-01	9.9242E-01	2.3144E-03	-4.8063E-06
27	3.9740E-02	1.4193E+00	2.7955E+00	9.9906E-01	9.9694E-01	-1.6483E-03	3.4141E-06

X= .0127 UT= 7.2832E+00 RHOW= 8.5464E-01 TW= 2.6797E+02 D= 2.5800E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	7.7519E-02	***********	***********	5.0985E-01	***********	-7.4598E-03
2	3.3800E-03	1.3101E-01	***********	***********	5.4103E-01	***********	-1.0193E-02
3	4.8120E-03	1.8651E-01	***********	***********	6.0424E-01	***********	-1.4380E-02
4	6.2523E-03	2.4234E-01	***********	***********	6.7303E-01	***********	-1.3787E-02
5	7.6850E-03	2.9787E-01	***********	***********	7.6099E-01	***********	-1.1825E-02
6	9.1310E-03	3.5391E-01	***********	***********	8.5026E-01	***********	-1.2438E-02
7	1.0581E-02	4.1012E-01	***********	***********	9.4316E-01	***********	-1.0874E-02
8	1.2007E-02	4.6539E-01	***********	***********	1.0386E+00	***********	-8.2707E-03
9	1.3435E-02	5.2074E-01	***********	***********	1.1281E+00	***********	-6.6326E-03
10	1.4853E-02	5.7570E-01	***********	***********	1.1628E+00	***********	-2.0318E-03
11	1.6319E-02	6.3252E-01	***********	***********	1.0644E+00	***********	6.2285E-03
12	1.7771E-02	6.8880E-01	***********	***********	8.9618E-01	***********	6.7703E-04
13	1.9231E-02	7.4539E-01	***********	***********	8.6762E-01	***********	-1.2251E-03
14	2.0671E-02	8.0120E-01	***********	***********	8.8384E-01	***********	-7.2524E-04
15	2.2161E-02	8.5895E-01	***********	***********	8.9811E-01	***********	-5.4293E-04
16	2.3611E-02	9.1516E-01	***********	***********	9.0917E-01	***********	-1.7249E-04
17	2.5061E-02	9.7136E-01	***********	***********	9.1793E-01	***********	-1.6980E-04
18	2.6511E-02	1.0276E+00	***********	***********	9.2214E-01	***********	-1.0151E-04
19	2.7981E-02	1.0845E+00	***********	***********	9.2424E-01	***********	-3.6079E-05
20	2.9441E-02	1.1411E+00	***********	***********	9.2663E-01	***********	-1.6228E-05
21	3.0911E-02	1.1981E+00	***********	***********	9.2797E-01	***********	-5.4022E-06
22	3.2381E-02	1.2551E+00	***********	***********	9.2837E-01	***********	5.1394E-06
23	3.3831E-02	1.3113E+00	***********	***********	9.2964E-01	***********	5.9088E-06
24	3.5321E-02	1.3690E+00	***********	***********	9.2996E-01	***********	-3.4792E-06

X= .0254 UT= 9.9851E+00 RHOW= 9.8044E-01 TW= 2.7236E+02 D= 1.6800E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	1.1905E-01	7.6359E-01	4.2749E-01	5.9145E-01	5.7260E+00	-9.6354E-03
2	3.4397E-03	2.0474E-01	9.0173E-01	4.9257E-01	5.9824E-01	8.5130E+00	-1.3209E-02
3	4.8907E-03	2.9111E-01	1.0661E+00	5.6499E-01	6.5867E-01	1.0180E+01	-1.3728E-02
4	6.3317E-03	3.7689E-01	1.2407E+00	6.3607E-01	7.1537E-01	9.6557E+00	-1.1829E-02
5	7.7597E-03	4.6189E-01	1.4087E+00	6.9816E-01	8.0504E-01	1.5440E+01	-1.7001E-02
6	9.1727E-03	5.4599E-01	1.5636E+00	7.5006E-01	9.2809E-01	1.2716E+01	-1.2454E-02
7	1.0614E-02	6.3177E-01	1.7009E+00	7.9216E-01	1.0770E+00	1.1153E+01	-9.7295E-03
8	1.2079E-02	7.1897E-01	1.8493E+00	8.3349E-01	1.2191E+00	1.0925E+01	-8.7832E-03
9	1.3539E-02	8.0588E-01	1.9613E+00	8.6117E-01	1.3498E+00	9.3446E+00	-7.0410E-03
10	1.4979E-02	8.9159E-01	2.0916E+00	8.9193E-01	1.4382E+00	5.2634E+00	-3.8929E-03
11	1.6439E-02	9.7849E-01	2.1792E+00	9.1024E-01	1.4732E+00	-2.6447E+00	1.9729E-03
12	1.7919E-02	1.0666E+00	2.1942E+00	9.1085E-01	1.2637E+00	-1.8059E+01	1.5837E-02
13	1.9369E-02	1.1529E+00	2.3143E+00	9.3113E-01	9.7570E-01	-5.3959E+00	6.4388E-03
14	2.0789E-02	1.2374E+00	2.6934E+00	9.6816E-01	9.0664E-01	-4.3754E-01	6.7099E-04
15	2.2259E-02	1.3249E+00	**********	**********	9.0072E-01	**********	-9.9790E-05
16	2.3729E-02	1.4124E+00	**********	**********	9.0069E-01	**********	-1.8152E-05
17	2.5199E-02	1.4999E+00	**********	**********	9.0213E-01	**********	-9.2807E-06
18	2.6669E-02	1.5874E+00	**********	**********	9.0328E-01	**********	-4.9639E-06
19	2.8139E-02	1.6749E+00	**********	**********	9.0505E-01	**********	-1.8212E-06
20	2.9589E-02	1.7612E+00	**********	**********	9.0812E-01	**********	1.6975E-06
21	3.1079E-02	1.8499E+00	**********	**********	9.1215E-01	**********	3.7784E-06

X= .0414 UT= 1.1240E+01 RHOW= 1.0540E+00 TW= 2.7396E+02 D= 1.8200E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U Uref	RHOU RHOUref	TAU TAUW	(RHO U)'V' RHOU U
1	2.0000E-03	1.0989E-01	8.4296E-01	4.6613E-01	7.4210E-01	4.7967E+00	-8.3699E-03
2	3.4123E-03	1.8749E-01	9.4443E-01	5.1225E-01	7.6200E-01	5.8540E+00	-9.5636E-03
3	4.8441E-03	2.6616E-01	1.0538E+00	5.6038E-01	8.0385E-01	7.8767E+00	-1.1869E-02
4	6.2771E-03	3.4490E-01	1.1783E+00	6.1136E-01	8.3753E-01	1.0014E+01	-1.4296E-02
5	7.7321E-03	4.2484E-01	1.3423E+00	6.7407E-01	9.3411E-01	1.0872E+01	-1.3964E-02
6	9.1571E-03	5.0314E-01	1.4743E+00	7.2045E-01	1.0434E+00	9.7551E+00	-1.1402E-02
7	1.0600E-02	5.8242E-01	1.6335E+00	7.7155E-01	1.1865E+00	9.9207E+00	-1.0530E-02
8	1.2032E-02	6.6110E-01	1.7639E+00	8.0989E-01	1.3275E+00	9.1954E+00	-9.0229E-03
9	1.3485E-02	7.4094E-01	1.8894E+00	8.4424E-01	1.4833E+00	7.4937E+00	-6.8285E-03
10	1.4945E-02	8.2116E-01	1.9862E+00	8.6813E-01	1.5985E+00	5.4537E+00	-4.7618E-03
11	1.6385E-02	9.0028E-01	2.0687E+00	8.8606E-01	1.6914E+00	2.0016E+00	-1.7023E-03
12	1.7815E-02	9.7885E-01	2.1190E+00	8.9506E-01	1.7320E+00	3.3761E-01	-2.0618E-04
13	1.9225E-02	1.0563E+00	2.1878E+00	9.0871E-01	1.6776E+00	-3.5141E+00	3.1577E-03
14	2.0695E-02	1.1371E+00	2.3588E+00	9.4195E-01	1.2266E+00	-2.0306E+01	2.6645E-02
15	2.2155E-02	1.2173E+00	2.6873E-01	1.0684E-01	9.2284E-01	-7.9331E-01	3.8909E-03
16	2.3615E-02	1.2975E+00	***********	***********	8.7519E-01	***********	1.3858E-04
17	2.5065E-02	1.3772E+00	***********	***********	8.7473E-01	***********	-3.1165E-06
18	2.6545E-02	1.4585E+00	***********	***********	8.7499E-01	***********	5.0684E-07

X= .0571 UT= 1.2768E+01 RHOW= 1.0950E+00 TW= 2.7445E+02 D= 1.9800E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	1.0101E-01	9.5676E-01	5.1881E-01	8.0909E-01	3.7468E+00	-7.6823E-03
2	3.4270E-03	1.7308E-01	1.0294E+00	5.5099E-01	8.3613E-01	4.0193E+00	-7.8262E-03
3	4.8680E-03	2.4586E-01	1.1138E+00	5.8604E-01	8.6442E-01	5.0377E+00	-9.3737E-03
4	6.3030E-03	3.1833E-01	1.2080E+00	6.2325E-01	9.2151E-01	6.7751E+00	-1.1770E-02
5	7.7510E-03	3.9146E-01	1.3313E+00	6.6940E-01	9.7127E-01	8.0863E+00	-1.3390E-02
6	9.2110E-03	4.6520E-01	1.4608E+00	7.1496E-01	1.0632E+00	8.9146E+00	-1.3695E-02
7	1.0641E-02	5.3742E-01	1.6238E+00	7.6853E-01	1.2174E+00	8.3194E+00	-1.1511E-02
8	1.2081E-02	6.1015E-01	1.7400E+00	8.0354E-01	1.3630E+00	5.8333E+00	-7.4190E-03
9	1.3491E-02	6.8136E-01	1.8315E+00	8.2854E-01	1.5175E+00	6.0847E+00	-7.1395E-03
10	1.4971E-02	7.5611E-01	1.9543E+00	8.6050E-01	1.6114E+00	3.8965E+00	-4.4749E-03
11	1.6421E-02	8.2934E-01	2.0473E+00	8.8194E-01	1.7234E+00	2.7585E+00	-3.0604E-03
12	1.7891E-02	9.0359E-01	2.0869E+00	8.8860E-01	1.7719E+00	9.8070E-01	-1.0760E-03
13	1.9341E-02	9.7682E-01	2.1109E+00	8.9248E-01	1.7809E+00	1.7474E-01	-1.9271E-04
14	2.0821E-02	1.0516E+00	2.1152E+00	8.9237E-01	1.7601E+00	-4.5774E-02	5.0989E-05
15	2.2291E-02	1.1258E+00	2.1240E+00	8.9378E-01	1.7544E+00	-1.0557E-01	1.1895E-04
16	2.3741E-02	1.1990E+00	2.1502E+00	8.9918E-01	1.7189E+00	-1.6965E+00	1.9703E-03
17	2.5201E-02	1.2728E+00	2.3227E+00	9.3440E-01	1.1513E+00	-1.2884E+01	2.3828E-02
18	2.6661E-02	1.3465E+00	2.4260E+00	9.4850E-01	8.9275E-01	-1.9564E-01	4.8823E-04
19	2.8141E-02	1.4213E+00	**********	**********	8.6957E-01	**********	-5.7250E-06

X= .0762 UT= 1.4090E+01 RHOW= 1.1275E+00 TW= 2.7539E+02 D= 2.0000E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	1.0000E-01	1.0433E+00	5.5696E-01	8.8604E-01	2.2188E+00	-5.0985E-03
2	3.4400E-03	1.7200E-01	1.1104E+00	5.8512E-01	8.9484E-01	2.7790E+00	-6.2611E-03
3	4.8700E-03	2.4350E-01	1.1755E+00	6.1086E-01	9.2231E-01	3.4165E+00	-7.4384E-03
4	6.2900E-03	3.1450E-01	1.2506E+00	6.3963E-01	9.7312E-01	4.8564E+00	-1.0020E-02
5	7.7500E-03	3.8750E-01	1.3565E+00	6.7857E-01	1.0232E+00	5.5449E+00	-1.0953E-02
6	9.2000E-03	4.6000E-01	1.4605E+00	7.1505E-01	1.0965E+00	5.8946E+00	-1.1007E-02
7	1.0680E-02	5.3400E-01	1.5886E+00	7.5659E-01	1.1884E+00	6.7183E+00	-1.1861E-02
8	1.2130E-02	6.0650E-01	1.6928E+00	7.8864E-01	1.3065E+00	6.4460E+00	-1.0608E-02
9	1.3590E-02	6.7950E-01	1.8172E+00	8.2409E-01	1.4452E+00	4.1860E+00	-6.4444E-03
10	1.5060E-02	7.5300E-01	1.9418E+00	8.5682E-01	1.6048E+00	4.0834E+00	-5.8844E-03
11	1.6530E-02	8.2650E-01	2.0065E+00	8.7192E-01	1.7195E+00	3.3324E+00	-4.5837E-03
12	1.7970E-02	8.9850E-01	2.0480E+00	8.7999E-01	1.7891E+00	1.8283E+00	-2.4567E-03
13	1.9450E-02	9.7250E-01	2.0659E+00	8.8238E-01	1.8039E+00	6.1775E-01	-8.2769E-04
14	2.0920E-02	1.0460E+00	2.0660E+00	8.8147E-01	1.8147E+00	2.1138E-01	-2.8262E-04
15	2.2390E-02	1.1195E+00	2.0605E+00	8.7984E-01	1.8131E+00	7.1905E-03	-9.6080E-06
16	2.3850E-02	1.1925E+00	2.0580E+00	8.7878E-01	1.8074E+00	-1.6580E-02	2.2218E-05
17	2.5340E-02	1.2670E+00	2.0507E+00	8.7747E-01	1.8027E+00	-4.3317E-02	5.8025E-05
18	2.6790E-02	1.3395E+00	2.0443E+00	8.7664E-01	1.7925E+00	-5.4377E-02	7.3037E-05
19	2.8290E-02	1.4145E+00	2.0440E+00	8.7675E-01	1.7844E+00	-8.8137E-02	1.1889E-04
20	2.9790E-02	1.4895E+00	2.0861E+00	8.8515E-01	1.7509E+00	-1.4191E+00	1.9826E-03
21	3.1250E-02	1.5625E+00	2.2051E+00	9.1093E-01	1.0472E+00	-4.5829E+00	1.1177E-02
22	3.2740E-02	1.6370E+00	2.5573E+00	9.6985E-01	8.9638E-01	7.0292E-02	-2.3097E-04

X= .0952 UT= 1.4889E+01 RHOW= 1.1440E+00 TW= 2.7694E+02 D= 2.1000E-02 RHOUREF= 4.8300E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	9.5238E-02	1.0839E+00	5.7200E-01	1.0107E+00	6.8717E-01	-1.5636E-03
2	3.4430E-03	1.6395E-01	1.1584E+00	6.0319E-01	1.0405E+00	1.3519E+00	-2.9628E-03
3	4.8240E-03	2.2971E-01	1.2137E+00	6.2432E-01	1.0548E+00	1.6956E+00	-3.6621E-03
4	6.2040E-03	2.9543E-01	1.2825E+00	6.5011E-01	1.0767E+00	2.9213E+00	-6.1928E-03
5	7.6640E-03	3.6495E-01	1.3536E+00	6.7635E-01	1.1271E+00	4.4260E+00	-9.0052E-03
6	9.1240E-03	4.3448E-01	1.4500E+00	7.0993E-01	1.1716E+00	5.1729E+00	-1.0247E-02
7	1.0574E-02	5.0352E-01	1.5527E+00	7.4345E-01	1.2423E+00	5.9336E+00	-1.1295E-02
8	1.2014E-02	5.7210E-01	1.6569E+00	7.7601E-01	1.3327E+00	6.7008E+00	-1.2167E-02
9	1.3444E-02	6.4019E-01	1.7604E+00	8.0678E-01	1.4192E+00	7.1238E+00	-1.2471E-02
10	1.4924E-02	7.1067E-01	1.8533E+00	8.3271E-01	1.5274E+00	5.2553E+00	-8.7787E-03
11	1.6394E-02	7.8067E-01	1.9312E+00	8.5225E-01	1.6486E+00	5.0976E+00	-8.0913E-03
12	1.7864E-02	8.5067E-01	1.9889E+00	8.6511E-01	1.7216E+00	4.4925E+00	-6.9736E-03
13	1.9324E-02	9.2019E-01	2.0100E+00	8.6924E-01	1.7802E+00	2.5346E+00	-3.8350E-03
14	2.0814E-02	9.9114E-01	2.0106E+00	8.6905E-01	1.8024E+00	1.4009E+00	-2.0948E-03
15	2.2294E-02	1.0616E+00	2.0092E+00	8.6769E-01	1.8068E+00	6.0199E-01	-8.9862E-04
16	2.3764E-02	1.1316E+00	2.0073E+00	8.6584E-01	1.8078E+00	1.4871E-01	-2.2207E-04
17	2.5234E-02	1.2016E+00	2.0031E+00	8.6396E-01	1.8045E+00	3.0448E-02	-4.5535E-05
18	2.6704E-02	1.2716E+00	2.0020E+00	8.6387E-01	1.7986E+00	-4.6371E-02	6.9531E-05
19	2.8174E-02	1.3416E+00	2.0020E+00	8.6407E-01	1.7926E+00	-6.0824E-02	9.1492E-05
20	2.9664E-02	1.4126E+00	1.9980E+00	8.6311E-01	1.7859E+00	-7.6941E-02	1.1601E-04
21	3.1134E-02	1.4826E+00	2.0038E+00	8.6448E-01	1.7769E+00	-8.9607E-02	1.3606E-04
22	3.2614E-02	1.5530E+00	2.0169E+00	8.6738E-01	1.7693E+00	-9.1652E-02	1.4042E-04
23	3.4104E-02	1.6240E+00	2.0268E+00	8.6944E-01	1.7667E+00	-1.0765E-01	1.6579E-04

X= .1143 UT= 1.5108E+01 RHOW= 1.1917E+00 TW= 2.7042E+02 D= 2.2000E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	9.0909E-02	1.1857E+00	6.2717E-01	9.6970E-01	1.0174E+00	-2.5092E-03
2	3.4498E-03	1.5681E-01	1.2555E+00	6.5428E-01	9.7288E-01	1.4332E+00	-3.5244E-03
3	4.9028E-03	2.2285E-01	1.3138E+00	6.7553E-01	1.0011E+00	2.1775E+00	-5.2249E-03
4	6.3208E-03	2.8731E-01	1.3693E+00	6.9568E-01	1.0331E+00	3.3194E+00	-7.7596E-03
5	7.7528E-03	3.5240E-01	1.4370E+00	7.1903E-01	1.0762E+00	3.9958E+00	-9.0516E-03
6	9.1778E-03	4.1717E-01	1.5414E+00	7.5242E-01	1.1363E+00	4.9570E+00	-1.0856E-02
7	1.0638E-02	4.8354E-01	1.6037E+00	7.7302E-01	1.2256E+00	4.8944E+00	-1.0061E-02
8	1.2084E-02	5.4926E-01	1.7276E+00	8.1109E-01	1.3544E+00	5.1902E+00	-9.9505E-03
9	1.3544E-02	6.1563E-01	1.7991E+00	8.3071E-01	1.4049E+00	5.3167E+00	-1.0036E-02
10	1.4984E-02	6.8108E-01	1.8622E+00	8.4765E-01	1.5247E+00	4.3193E+00	-7.6586E-03
11	1.6464E-02	7.4835E-01	1.9355E+00	8.6640E-01	1.6589E+00	3.3901E+00	-5.6574E-03
12	1.7924E-02	8.1472E-01	1.9827E+00	8.7869E-01	1.7193E+00	2.3040E+00	-3.8972E-03
13	1.9374E-02	8.8063E-01	1.9951E+00	8.8092E-01	1.7661E+00	1.4022E+00	-2.2428E-03
14	2.0834E-02	9.4699E-01	1.9993E+00	8.8188E-01	1.8149E+00	4.6769E-01	-7.2942E-04
15	2.2304E-02	1.0138E+00	2.0020E+00	8.8136E-01	1.8419E+00	4.8524E-01	-7.4699E-04
16	2.3764E-02	1.0802E+00	1.9940E+00	8.7878E-01	1.8504E+00	3.8909E-01	-5.9504E-04
17	2.5214E-02	1.1461E+00	1.9833E+00	8.7653E-01	1.8580E+00	1.6320E-01	-2.4757E-04
18	2.6694E-02	1.2134E+00	1.9810E+00	8.7452E-01	1.8574E+00	5.2459E-02	-7.9670E-05
19	2.8144E-02	1.2793E+00	1.9810E+00	8.7396E-01	1.8555E+00	1.6182E-02	-2.4607E-05
20	2.9624E-02	1.3465E+00	1.9810E+00	8.7413E-01	1.8575E+00	6.1191E-03	-9.2972E-06
21	3.1104E-02	1.4138E+00	1.9869E+00	8.7672E-01	1.8556E+00	-1.0064E-03	1.5309E-06
22	3.2594E-02	1.4815E+00	1.9938E+00	0.7762E-01	1.8516E+00	-6.9169E-03	1.0584E-05

X= -.0508 UT= 2.0669E+01 RHOW= 3.3162E-01 TW= 2.7023E+02 D= 2.8000E-02 RHOUREF= 4.6200E+02

I	Y (M)	Y/D	M	U / Uref	RHOU / RHOUref	TAU / TAUW	(RHO U)'V' / RHOU U
1	2.0000E-03	7.1429E-02	1.5873E+00	7.5453E-01	4.3041E-01	9.2404E-01	-2.8564E-03
2	3.3752E-03	1.2054E-01	1.7189E+00	7.9273E-01	4.6856E-01	9.3553E-01	-2.7476E-03
3	4.8092E-03	1.7176E-01	1.8267E+00	8.2247E-01	5.0806E-01	9.9128E-01	-2.7693E-03
4	6.2482E-03	2.2315E-01	1.9267E+00	8.4692E-01	5.4957E-01	8.4855E-01	-2.2651E-03
5	7.6892E-03	2.7461E-01	2.0138E+00	8.6749E-01	5.8890E-01	7.4651E-01	-1.9158E-03
6	9.1252E-03	3.2590E-01	2.1031E+00	8.8749E-01	6.2759E-01	9.1921E-01	-2.2850E-03
7	1.0576E-02	3.7772E-01	2.1747E+00	9.0231E-01	6.7311E-01	7.7292E-01	-1.8400E-03
8	1.2016E-02	4.2915E-01	2.2597E+00	9.1927E-01	7.0070E-01	8.5755E-01	-2.0252E-03
9	1.3466E-02	4.8094E-01	2.3344E+00	9.3361E-01	7.5105E-01	8.2389E-01	-1.8601E-03
10	1.4916E-02	5.3272E-01	2.4102E+00	9.4722E-01	7.8853E-01	7.7682E-01	-1.7284E-03
11	1.6356E-02	5.8415E-01	2.4828E+00	9.5962E-01	8.4381E-01	6.3404E-01	-1.3569E-03
12	1.7776E-02	6.3486E-01	2.5431E+00	9.6940E-01	8.8130E-01	2.8853E-01	-6.0570E-04
13	1.9216E-02	6.8629E-01	2.6155E+00	9.8058E-01	9.0576E-01	4.0391E-01	-8.4957E-04
14	2.0686E-02	7.3879E-01	2.6690E+00	9.8800E-01	9.4974E-01	2.0737E-01	-4.2537E-04
15	2.2146E-02	7.9094E-01	2.7170E+00	9.9335E-01	9.8281E-01	2.9572E-01	-5.9865E-04
16	2.3606E-02	8.4308E-01	2.7466E+00	9.9614E-01	1.0046E+00	3.4603E-02	-6.9459E-05
17	2.5066E-02	8.9522E-01	2.7631E+00	9.9747E-01	1.0239E+00	8.8849E-02	-1.7632E-04
18	2.6546E-02	9.4808E-01	2.7715E+00	9.9771E-01	1.0334E+00	4.4572E-02	-8.8029E-05
19	2.8016E-02	1.0006E+00	2.7799E+00	9.9803E-01	1.0391E+00	1.7877E-02	-3.5259E-05
20	2.9446E-02	1.0517E+00	2.7917E+00	9.9929E-01	1.0401E+00	1.5483E-02	-3.0668E-05
21	3.0926E-02	1.1045E+00	2.7898E+00	9.9876E-01	1.0424E+00	2.2123E-03	-4.3701E-06
22	3.2406E-02	1.1574E+00	2.7937E+00	9.9881E-01	1.0445E+00	-2.2673E-03	4.4790E-06
23	3.3866E-02	1.2095E+00	2.7950E+00	9.9867E-01	1.0468E+00	-3.1993E-04	6.3120E-07