/// - 2

NASA Contractor Report 4571

209758
23 P

The Measurement of Disturbance Levels in the Langley Research Center 20-Inch Mach 6 Tunnel

P. C. Stainback and L. R. Kubendran

(NASA-CR-4571) THE MEASUREMENT OF DISTURBANCE LEVELS IN THE LANGLEY RESEARCH CENTER 20-INCH MACH 6 TUNNEL Final Report (Analytical Services and Materials) 23 p

N94-26548

Unclas

H1/02 0209758

Contract NAS1-19320
Prepared for Langley Research Center

March 1994

NASA Contractor Report 4571

The Measurement of Disturbance Levels in the Langley Research Center 20-Inch Mach 6 Tunnel

P. C. Stainback and L. R. Kubendran
Analytical Services & Materials, Inc. • Hampton, Virginia

National Aeronautics and Space Administration
Langley Research Center • Hampton, Virginia 23681-0001

Prepared for Langley Research Center
under Contract NAS1-19320

March 1994

ABSTRACT

Constant-temperature anemometry was used to measure the disturbance levels in the Langley Research Center 20-Inch Mach 6 Tunnel over a limited range of total pressures. The measurements were made using a dual wire probe where each wire was operated at a high but different overheat. The fluctuating voltages were digitized and a system of two equations was solved to obtain the instantaneous mass flow and total temperature fluctuations as a function of time. Statistical techniques were used to obtain statistical quantities of interest. The mass flow and total temperature fluctuations varied between 2 to 3 percent and 1 to 1.5 percent respectively over the limited Reynolds numbers of the test. The total temperature fluctuations were larger than can be expected assuming only sound in the test section, suggesting the existence of entropy fluctuations in the flow. The total pressure fluctuation obtained from the mass flow and total temperature fluctuations were comparable with those measured using a pitot probe.

SYMBOLS

A,B	functions of τ in equation (9)
C,D,E	functions of m in equation (11)
c_p	specific heat at constant pressure
c_v	specific heat at constant volume
d	diameter of wire
E	mean voltage across wire or bridge of anemometer
e	fluctuating voltage across wire or bridge
M	Mach number
m	mean mass flow
n_t	$\frac{\partial \log \mu_t}{\partial \log T_o}$
n_x	$\frac{1}{\left(\frac{u_s}{u}-1\right)M}$
p	static pressure
p_t	total pressure

Re_t $\frac{\rho u d}{\mu_t}$

R_w resistance of wire

R_{ref} reference resistance for wire

S_m mass flow sensitivity

S_{To} total temperature sensitivity

T_{adw} recovery temperature of wire

T_o total temperature

T_w wire temperature

T_{ref} reference temperature for wire

u velocity

u_s sound source velocity

γ $\frac{c_p}{c_v}$

ρ density

η $\frac{T_{adw}}{T_o}$

τ_w $\frac{(T_w - T_{adw})}{T_o}$

μ_t coefficient of viscosity evaluated at T_o

Θ T_w/T_o

$\varnothing$ angle between plane wave and axis of probe

α linear coefficient for resistance-temperature equation for wire

β second degree coefficient for resistance-temperature equation for wire

INTRODUCTION

In the past, most measurements of disturbances in the test section of supersonic wind tunnels were made using a single wire probe with a constant current anemometer. The fluctuation diagram technique developed by Kovasznay [1] was generally used to obtain the mass flow and total temperature fluctuations and their correlation. Fluctuation diagrams were generated by operating the wire at several overheats and fitting a curve to the resulting data. The fluctuation diagram is, in general, a hyperbola; where it intercepts on the y-axis gives the total temperature fluctuations and its asymptote gives the mass flow fluctuations.

The constant temperature anemometer cannot be used to generate fluctuation diagrams since the frequency response of the anemometer approaches the frequency response of the wire at low overheats [2]. The frequency response of the wire alone is too low to furnish useful data at supersonic speeds. Because of this, a two-wire probe technique was developed for use with constant temperature anemometers [3,4]. Using this technique, the fluctuating voltages from the anemometer were digitized and two equations solved for the mean flow and total temperature fluctuations.

The present investigation, using a constant-temperature anemometer, was conducted to measure the disturbance levels in the Langley Research Center 20-Inch Mach 6 Tunnel.

FACILITY

The Langley 20-Inch Mach 6 Tunnel is a blowdown type hypersonic facility [5]. With a system of three vacuum spheres having diameters of 40, 60, and 100 feet, this facility can run in excess of 20 minutes. The total temperature of the facility is usually established at a level just high enough to prevent liquefaction of air in the test section. For the present tests, which were conducted over a range of total pressures from 30 to 200 psia, the total temperature was held constant at a value of 410°F. Measurements were made on the centerline of the test section at an axial position which coincided with the center of the schlieren windows.

INSTRUMENTATION

Each hot-wire probe had two wires installed and each wire was powered by a constant-temperature anemometer. The DC output from the anemometers was recorded using a scanning voltmeter which was controlled by a computer. The AC component of the signal was amplified and band-pass filtered from 1 Hz to 400 KHz using a signal conditioner. The AC signal was amplified sufficiently to produce a signal which was adequate for recording on an analog tape recorder. The tape recorder was of the wide band II type and was operated at 120 inch/sec. After the test, the tape was played back at a lower speed of 30 inch/sec, and the data were digitized with a sampling period of 5 μs and cut-off filter at 50 KHz. With this procedure, it was possible to examine frequencies up to (120/30*50 =) 200 KHz in the signal.

Because of wire breakage, which was due to particles in the flow and several erroneous emergency tunnel shut-downs, two probes were used during the tests. The severity of the particles in the flow is illustrated in figure 1. The figure presents two photographs of the blunt end of a teflon cylinder which was impacted by particles in the flow.

The first probe was operated from 30 to 125 psia before failure of a wire. The wires in the second probe survived from 30 through part of a 200 psia run. After this latter wire failure, the tests were terminated due to lack of tunnel availability.

THEORETICAL CONSIDERATIONS

The voltage across the wire was assumed to be given by the following relationship:

$$E = f\,(m, \tau_w) \tag{1}$$

Using this equation, the change in voltage across the wire is given by:

$$d \log E = \frac{\partial \log E}{\partial \log m}\, d \log m + \frac{\partial \log E}{\partial \log \tau_w}\, d \log \tau_w \tag{2}$$

Equation (2) can be transformed into the following equation:

$$d \log E = S_m\, d \log m + S_{To}\, d \log T_o \tag{3}$$

where

$$S_m = \left\{\frac{\partial \log E}{\partial \log m} - \frac{\eta}{\tau_w}\, \frac{\partial \log E}{\partial \log \tau_w}\, \frac{\partial \log \eta}{\partial \log Re_t}\right\} \tag{4}$$

$$S_{To} = \left\{\frac{1}{\tau_w}\, \frac{\partial \log E}{\partial \log \tau_w}\left[n_t \eta\, \frac{\partial \log \eta}{\partial \log Re_t} - \theta\right]\right\} \tag{5}$$

Equation (3) is a single equation with two unknowns. By using a probe with two wires, equation (3) can be written for each of the wires as:

$$\left(\frac{e'}{E}\right)_1 = S_{m,1}\frac{m'}{m} + S_{To,1}\frac{T_o'}{T_o} \tag{6}$$

$$\left(\frac{e'}{E}\right)_2 = S_{m,2}\frac{m'}{m} + S_{To,2}\frac{T_o'}{T_o} \tag{7}$$

Using equations (6) and (7), the mean flow calibration for the wires, the digitized fluctuating voltages, and the mean voltages, the fluctuations of m and T_o can be obtained as a function of time. Statistical techniques can then be used to obtain any statistical quantity of interest.

CALIBRATION OF PROBES

The tunnel was operated over a range of total pressures to obtain the variation of E with m. The wire resistance was varied at each total pressure to obtain the variation of E with τ_w. In order to obtain this latter variation, a calibration of the wire resistance as a function of wire temperature was required. This was done in an "oven" where the temperature could be accurately controlled. A typical calibration curve is presented in Figure 2. The temperature limitations of the oven did not permit the evaluation of the coefficient of the $(\Delta T)^2$ term in the following equation:

$$\frac{R_w}{R_{ref}} = 1 + \alpha(T_w - T_{ref}) + \beta(T_w - T_{ref})^2 \tag{8}$$

The variation of the wire voltage with mass flow was found to fit the following equations:

$$E^2 = A + Bm^{1/2} \tag{9}$$

The partial derivative of E with respect to m required in equation (4) is given by

$$\frac{\partial \log E}{\partial \log m} = \frac{1}{4}\,\frac{Bm^{1/2}}{E^2} \tag{10}$$

The variation of E with τ_w was obtained using a polynomial curve fit to the data. The equation which gave the best fit to the data was

$$E = C(m) + D(m)\tau + E(m)\tau^2 \tag{11}$$

where C(m), D(m), and E(m) were functions of mass flow. The partial derivatives were obtained from:

$$\frac{\partial \log E}{\partial \log \tau} = \frac{D(m)\tau + 2E(m)\tau^2}{C(m) + D(m)\tau + E(m)\tau^2} \tag{12}$$

The recovery temperature was obtained from a separate probe which was operated as a four-wire resistance thermometer.

Because of the low wire Reynolds numbers of the present tests, the values of the recovery temperature ratio, η, exceeded 1 and its values varied with Reynolds number. The values of η and its derivatives were obtained from a curve fit of η versus Reynolds number.

RESULTS AND DISCUSSION

The mass flow and total temperature sensitivities were obtained as functions of mass flow and overheat parameter τ_w. The overheat parameters of τ=0.80 and τ=0.60 were chosen for wires 1 and 2, respectively. Examples of the mass flow and total temperature sensitivities as a function of p_o are presented in figure 3. The mass flow sensitivities did not vary significantly with the chosen values of τ_w. There was a significant variation of the total temperature sensitivities with τ_w. Neither of the two sensitivities were strong functions of mass flow.

Figure 4 gives the autospectra plots of mass flow and total temperature fluctuations at various tunnel total pressures. The spikes in these spectra are presumed to be due to environmental noise such as radio frequency emission from the tunnel heaters; the broad peak observed in some cases at about 50 KHz has been reported in Reference 6, and its origin is unknown.

The mass flow and total temperature fluctuations obtained using the first probe are presented in Figure 5. The mass flow fluctuations ranged from 2 to 3 percent but showed no significant variation with total pressure. The total temperature fluctuation ranged from about 1 to 1.5 percent. This level of temperature fluctuation is high based on the usual assumption that the predominant fluctuation in supersonic wind tunnels is sound. At a Mach number of 6 and the assumption that all the fluctuations are sound would require the total temperature fluctuations to be about 3 to 4 percent of the mass flow fluctuation. Figure 5 shows that the total temperature fluctuations were about 50 percent of the mass flow fluctuation. Therefore, the results indicate that either there is an error in the total temperature fluctuation or there is an additional fluctuation present in the facility.

The heating of the flow required at Mach 6 and the fact that there are no temperature equalizing treatment in the tunnel suggest that some of the fluctuations are due to entropy fluctuations. Similar relatively high total temperature fluctuations were observed in hypersonic tunnels and reported in reference 7.

All of the data taken with the second probe resulted in excessive total temperature fluctuation. However, the mass flow fluctuation tended to agree with those obtained with the first probe. Because of the uncertainty of the results obtained with the second probe the data will not be presented.

Fluctuating total pressure measurements made in the 20 inch Mach 6 Tunnel were reported in reference 8. The present results were compared with these data by converting the mass flow fluctuations to pressure fluctuations using the following equation [9]:

$$\frac{\tilde{p}}{p} = \frac{\gamma M}{|\cos\theta + M|}\frac{\tilde{m}}{m} \tag{13}$$

Thus the total pressure fluctuation can be computed using [9]:

$$\frac{\overline{p'^{2}_{t2}}}{p_{t2}^{2}} = \frac{\overline{p'^{2}}}{(\gamma p)^{2}}\left[1 - \frac{4n_x}{M_\infty} + 4\left(\frac{n_x}{M_\infty}\right)^{2}\right] \tag{14}$$

where

$$n_x = \frac{1}{\left(\frac{u_s}{u_\infty} - 1\right)M} \tag{15}$$

The source velocity required in the above equation was estimated using the results reported in reference 10.

The comparison between the present data and those of reference 8 is presented in Figure 6. There was a reasonable agreement between the present data obtained with hot wire anemometers and the results from reference 8 obtained with a pitot probe.

RECOMMENDATION

Because of the particles in the flow of the 20-inch Mach 6 Tunnel and because of the expense of calibration probes in large wind tunnels, it is recommended that several probes be calibrated in the nozzle test chamber for use in the 20-inch Mach 6 Tunnel. In this way if a wire on a probe breaks while making measurements in the 20-inch Mach 6 Tunnel at a given pressure the calibration of the probes need not be restarted. Using pre-calibrated probes, tests can be started at the pressure at which a wire broke and continued until the test is completed or wire breakage occurs again.

Instead of assuming that the voltage across the wire is given by

$$E = f(m, \tau_w) \tag{16}$$

consider instead the following equation

$$E = f(m, a_w') \tag{17}$$

where

$$a_w' = \frac{R_w - R_{adw}}{R_{adw}} \tag{18}$$

In this manner the wire resistance need not be calibrated with temperature and a more accurate calibration can be obtained since a'_w is obtained from the anemometer with good accuracy.

CONCLUSIONS

From the test conducted using a two-wire hot-wire anemometer system to measure the disturbance levels in the Langley Research Center 20-Inch Mach 6 Tunnel the following conclusions can be made:

1. Particles in the flow resulted in the breakage of several wires and limited the pressure range of the test.
2. It appears that a two wire probe can be used with a constant temperature anemometer to obtain mass flow and total temperature fluctuations in supersonic flow up to a Mach number of 6.
3. The mass flow and total temperature fluctuations varied between 2 to 3 percent and 1 to 1.5 percent respectively over the limited Reynolds numbers of the test.
4. The total temperature fluctuations were larger than can be expected assuming only sound in the test section. This suggests the existence of entropy fluctuations in the flow.
5. The total pressure fluctuation obtained from the mass flow and total temperature fluctuations were comparable with those measured using a pitot probe.

REFERENCES

1. Kovasznay, L.S.G., "Turbulence in Supersonic Flow," Journal of the Aeronautical Sciences, Vol. 20, No. 10, 1953, pp. 657-674.
2. Hinze, J.O., "Turbulence," McGraw-Hall Book Co., New York, 1975.

3. Walker, D.A., Ng, W.F. and Walker, M.D., "Experimental Comparison of Two Hot-Wire Techniques in Supersonic Flow," AIAA Journal, Vol. 27, No. 8, pp. 1074-1080, 1989.

4. Smith, D.R. and Smits A. J., "The Simultaneous Measurement of Velocity and Temperature Fluctuations in the Boundary Layer of a Supersonic Flow," Experimental Thermal and Fluid Science, Vol. 6, 1993.

5. Miller, C. G., III, "Hypersonic Aerodynamic/ Aerothermo-dynamic Testing Capabilities at the Langley Research Center," AIAA Paper 92-3937, AIAA 17th Aerospace Ground Testing Conference, Nashville, TN, July, 1992.

6. Mangalam, S.M., Sarma, G.R., Kuppa, S. and Kubendran, L.R., "A New Approach to High-Speed Flow Measurements Using Constant Voltage Anemometry," AIAA No. 92-3957, AIAA 17th Aerospace Ground Testing Conference, Nashville, TN, July 1992.

7. Stainback, P.C., Wagner, R.D., Owens, F.K. and Horstman, C.C., "Experimental Studies of Hypersonic Boundary Layer Transition and Effects of Wind-Tunnel Disturbances," NASA TN D-7453, March 1974.

8. Harvey, W.D., Stainback, P.C. and Srokawski, A.J., "Effect of Slot Width on Transition and Noise Attenuation of a Sound Shield Panel for Supersonic Wind Tunnels," AIAA 9th Aerodynamic Testing Conference Proceedings, pp.198-222, Arlington, Texas, June 7-9, 1976.

9. Stainback, P.C. and Wagner, R.D., "A comparison of Disturbance Levels Measured in Hypersonic Tunnel Using a Hot-Wire Anemometer and a Pitot Pressure Probe," AIAA 7th Aerodynamic Testing Conference, Palo Alto, California, Sept. 13-15, 1972.

10. Laufer, J., "Aerodynamic Noise in Supersonic Wind Tunnels," Journal of the Aerodynamic Sciences, Vol. 28, No. 9, pp. 685-692, 1961.

Table 1
Measured mass flow & total temperature fluctuations and calculated static pressure and total pressure fluctuations

Po (psia)	Re/ft	m'/m	To'/To	p'/p	p't2/pt2
30	5.60E+05	0.025	0.012	0.035	0.029
75	1.40E+06	0.028	0.017	0.039	0.032
100	1.87E+06	0.020	0.011	0.028	0.023
125	2.33E+06	0.024	0.014	0.034	0.028

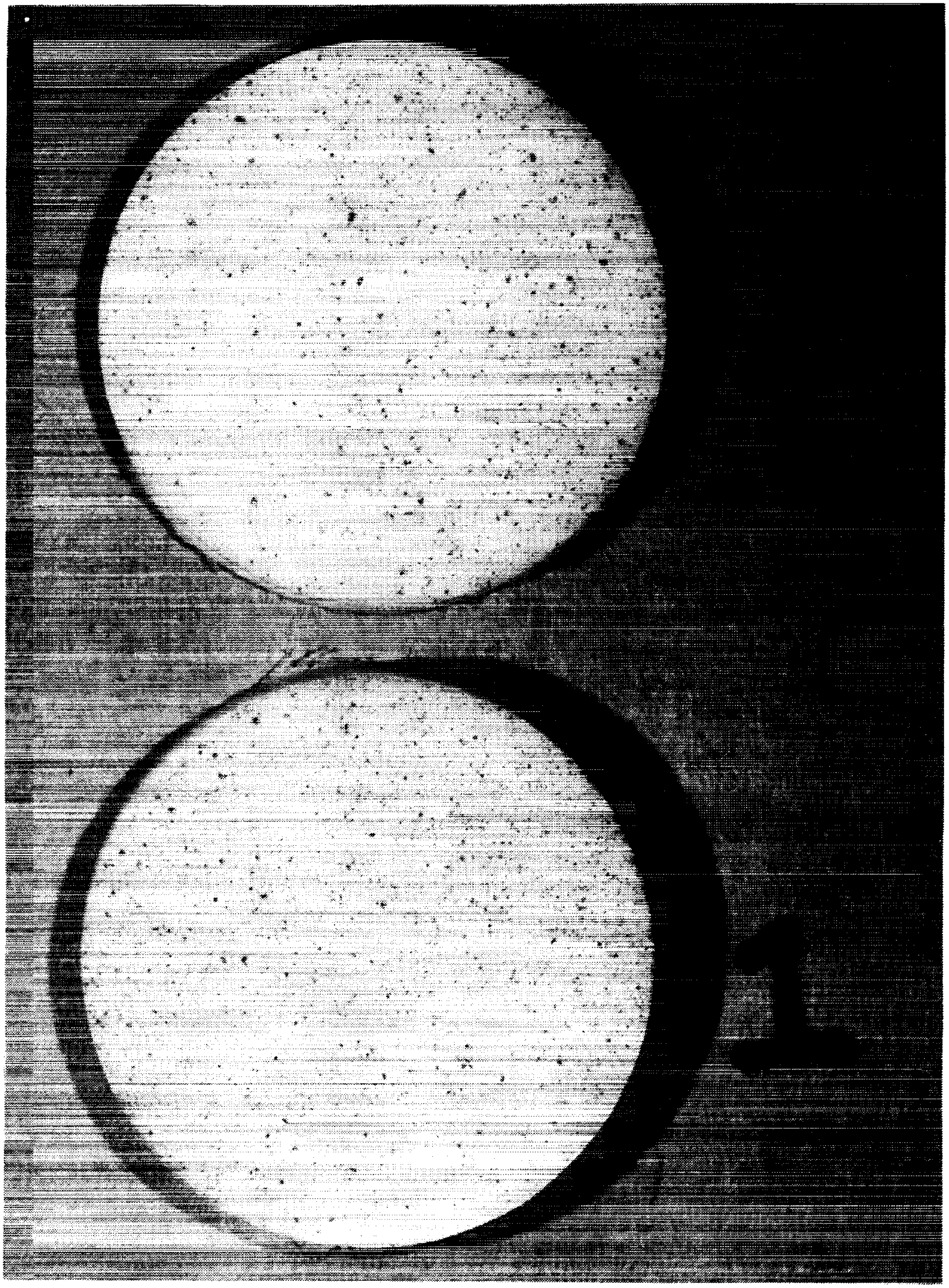


Figure 1. - Particle impact on the face of a blunt teflon cylinder facing the flow.

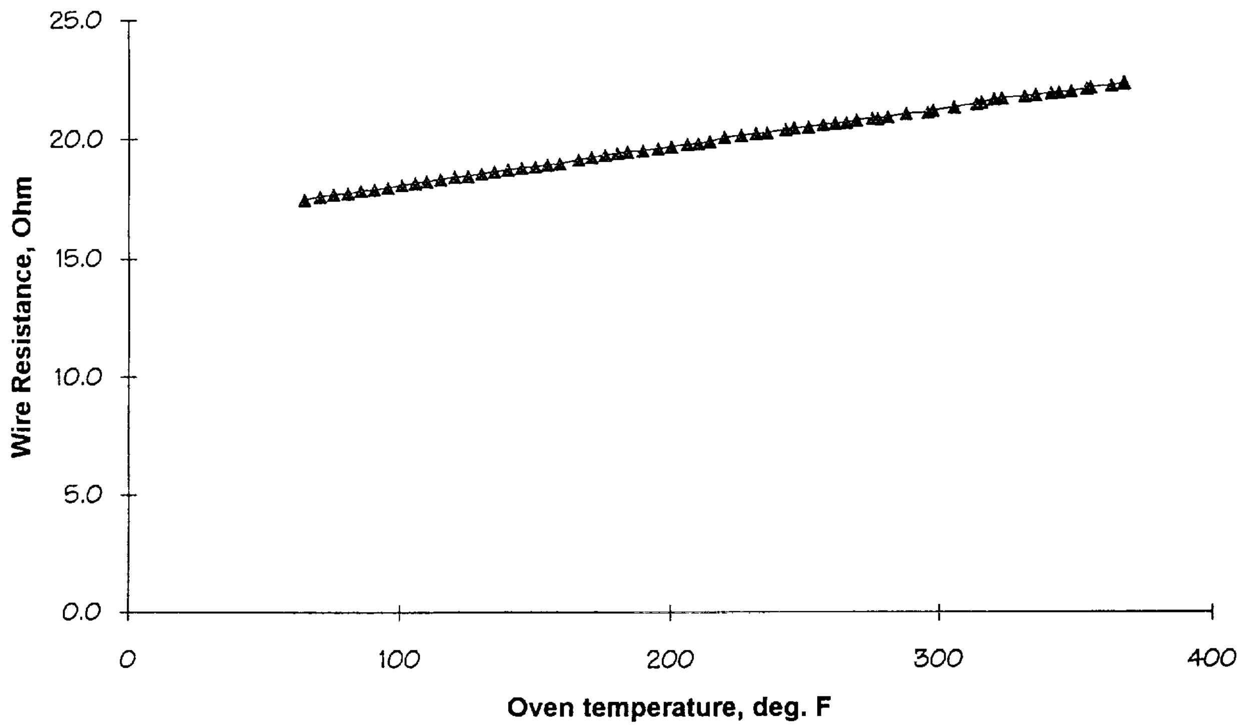
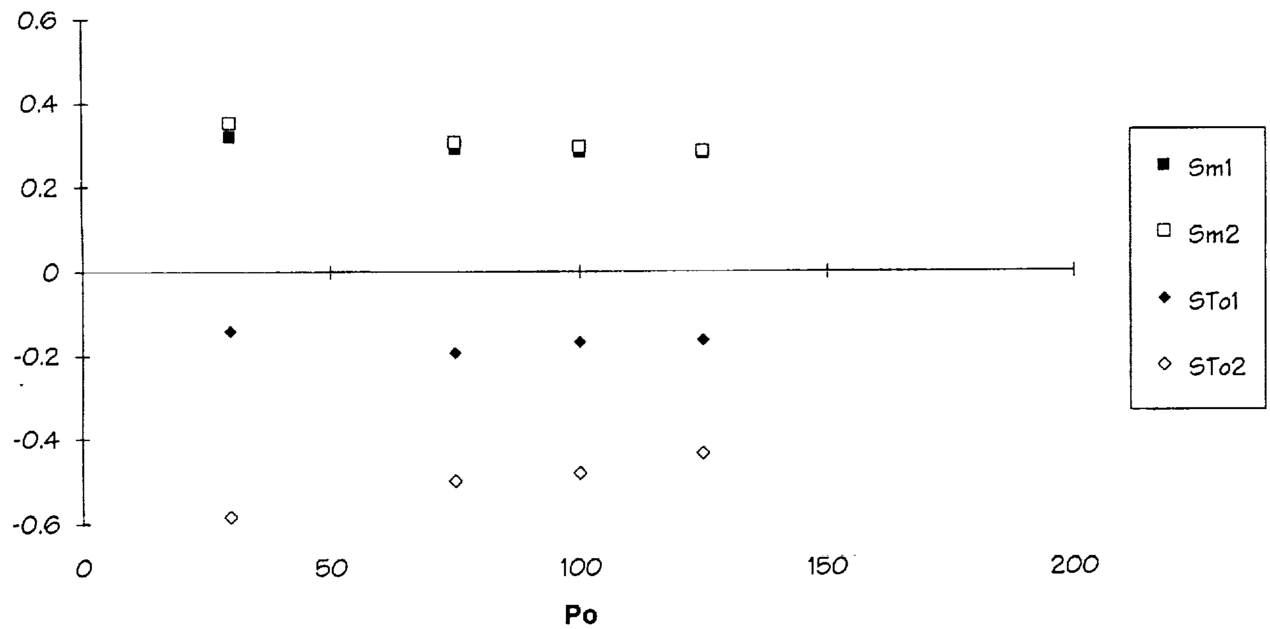
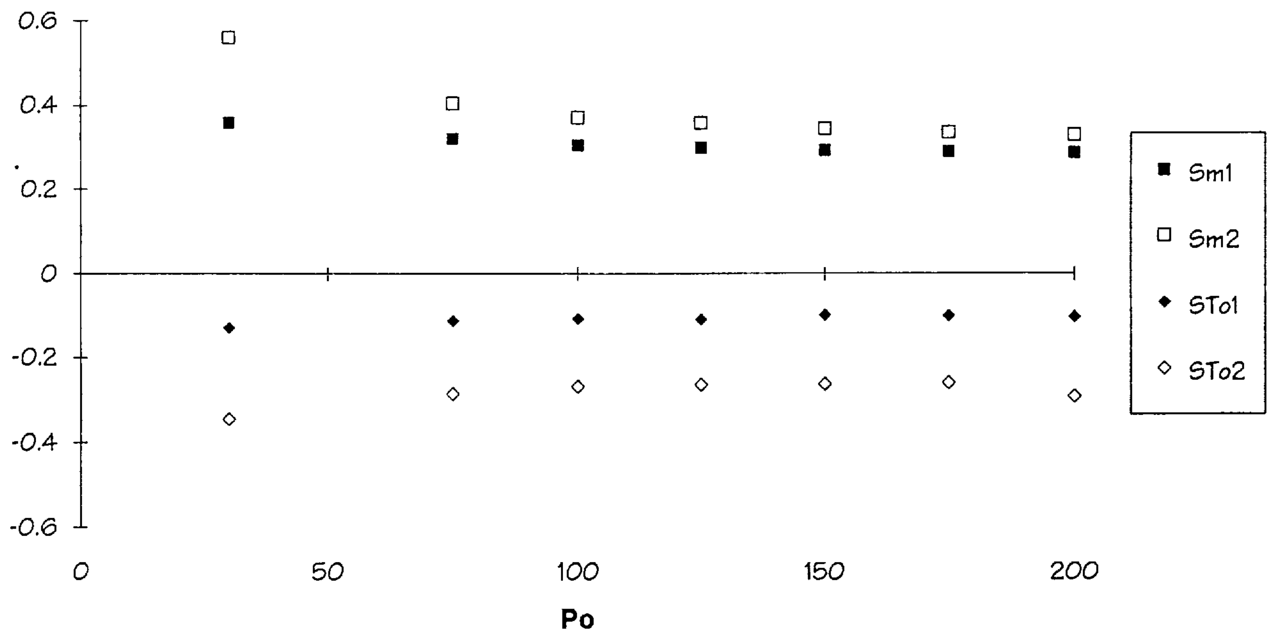


Figure 2. - Calibration of wire resistance as a function of wire temperature.



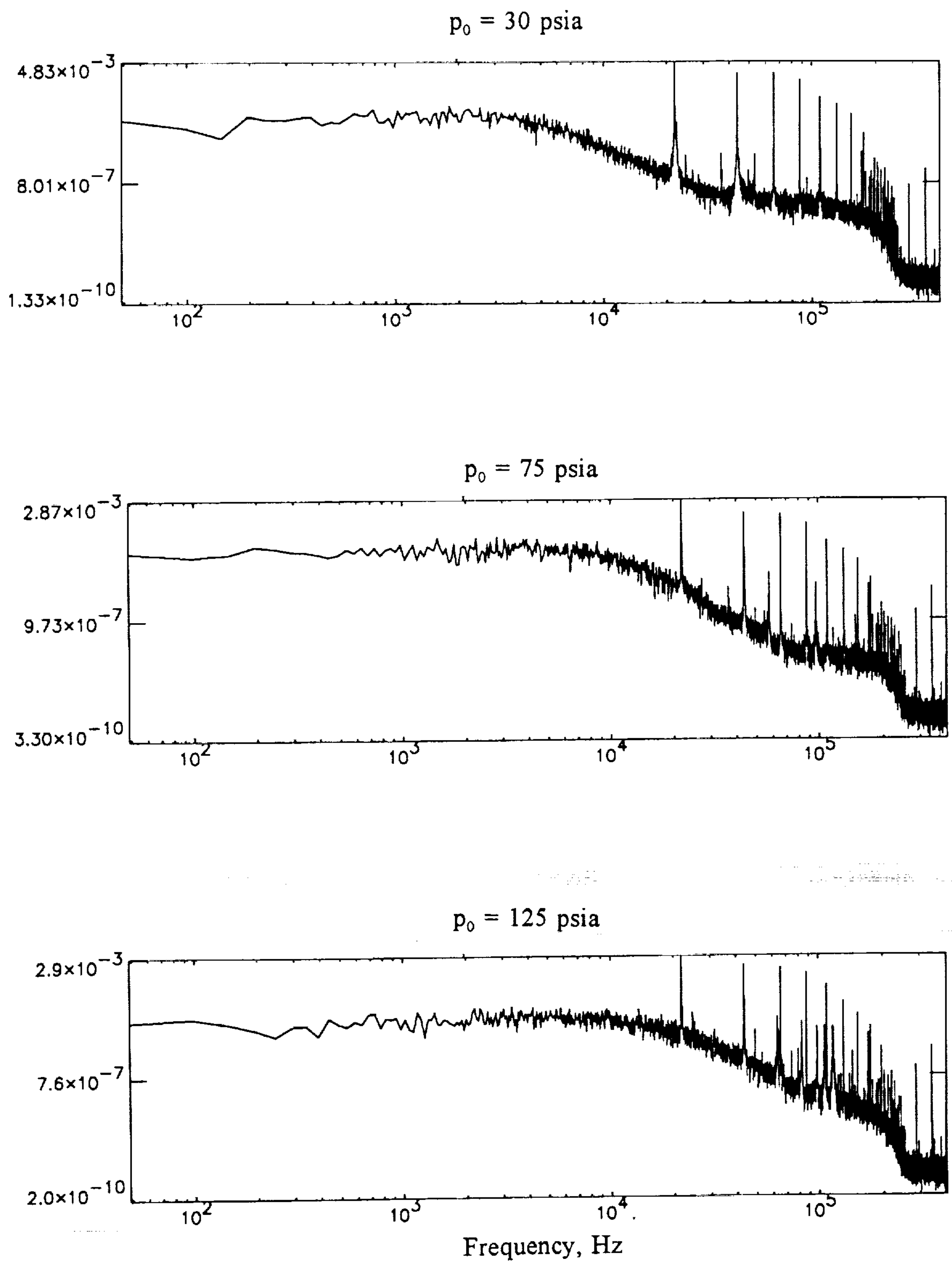
(a) Probe 1

Figure 3. - Mass flow and total temperature sensitivities as a function of p_0.



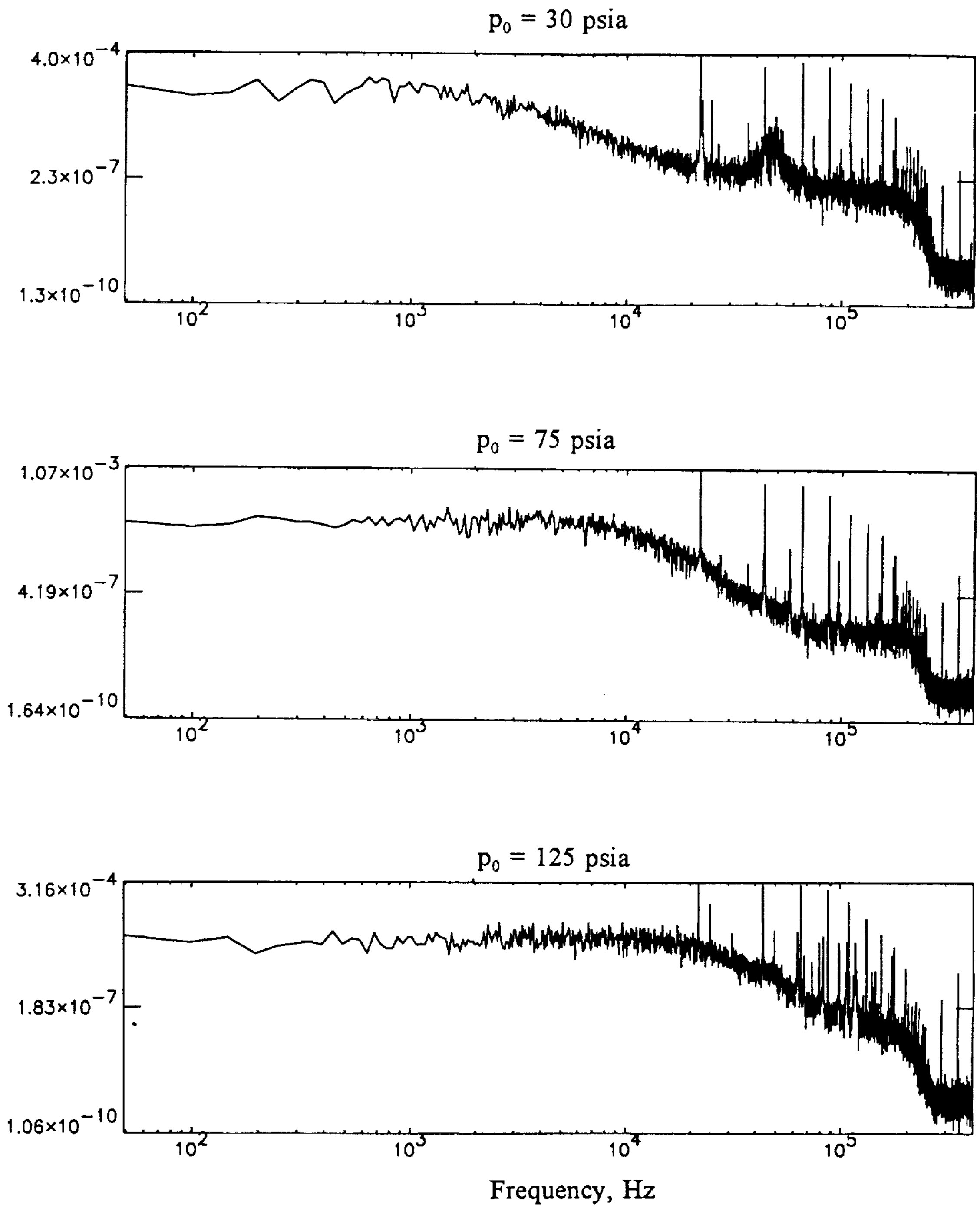
(b) Probe 2

Figure 3. - Concluded.



(a) Mass flow fluctuations

Figure 4. - Autospectra of fluctuations at various p_0
(y scale arbitrary)



(b) Total temperature fluctuations

Figure 4. - Concluded.

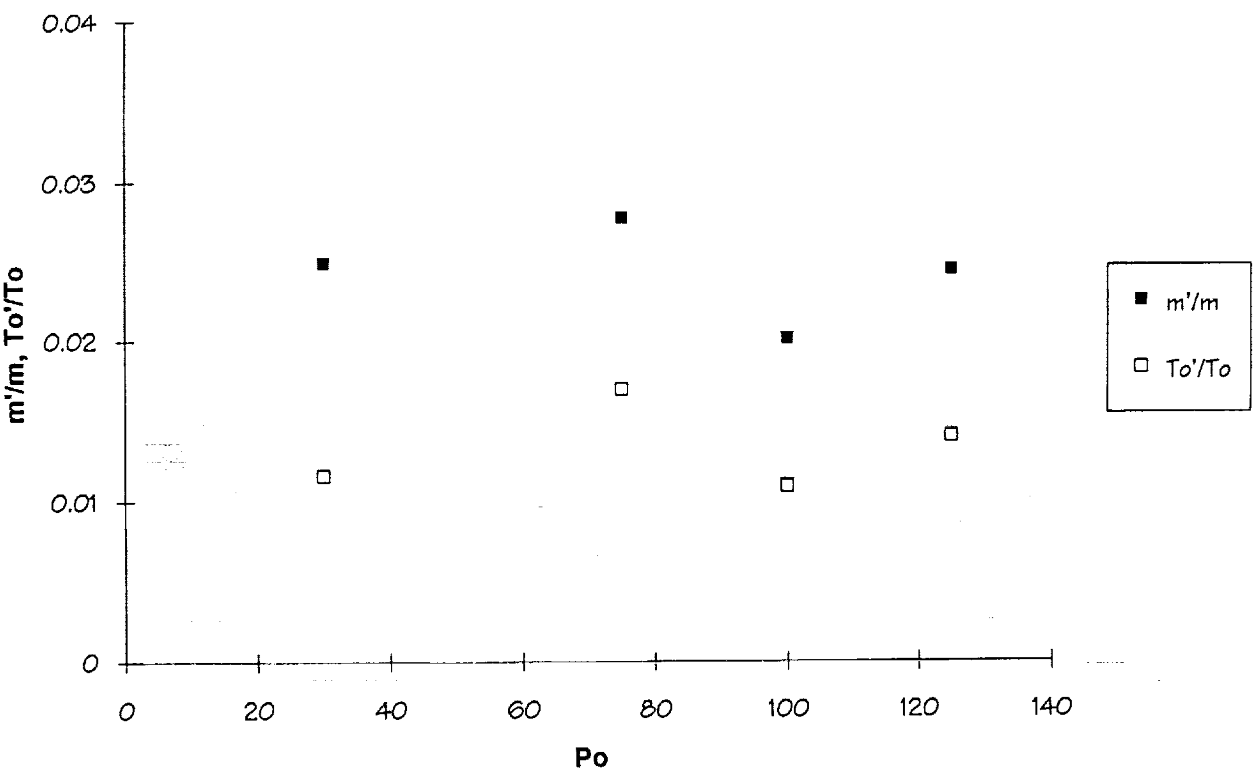


Figure 5. - Mass flow and total temperature fluctuations as a function of p_0.

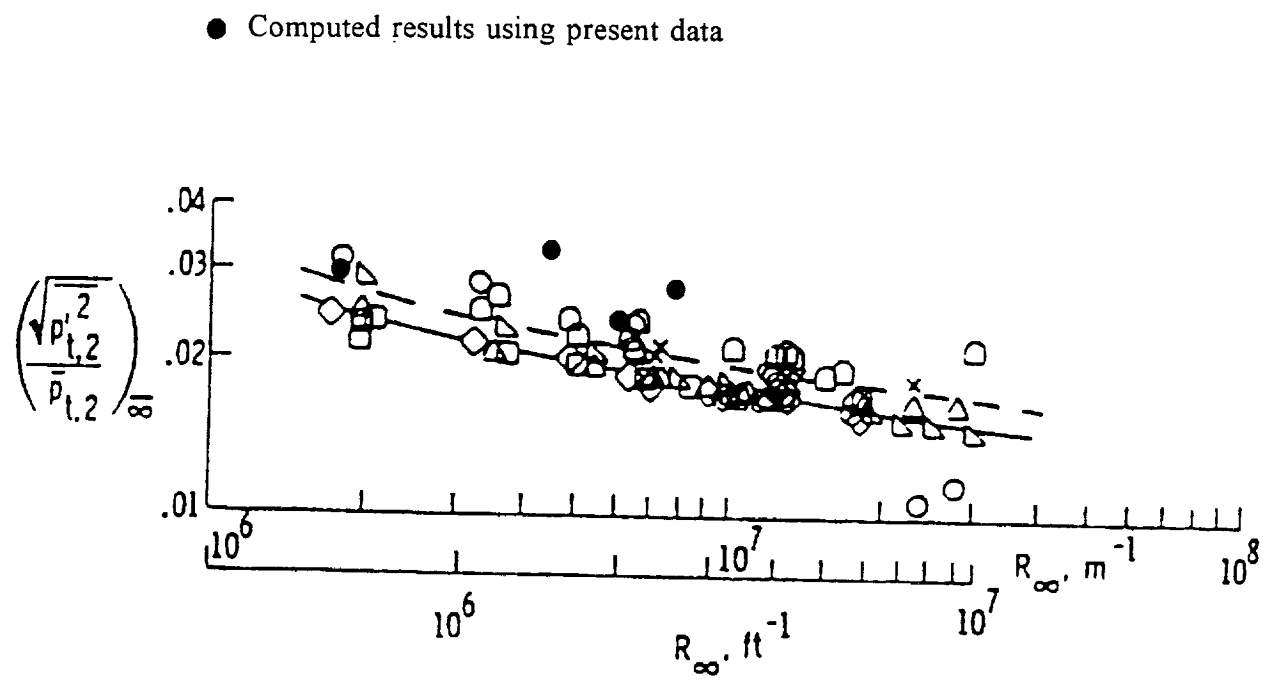


Figure 6. - Comparison of total pressure fluctuations computed using present data with results from Reference 8.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1994	Contractor Report

4. TITLE AND SUBTITLE
The Measurement of Disturbance Levels in the Langley Research Center 20-Inch Mach 6 Tunnel

5. FUNDING NUMBERS
WU 505-70-59-03
C NAS1-19320

6. AUTHOR(S)
P. C. Stainback and L. R. Kubendran

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Analytical Services and Materials, Inc.
17 Research Drive
Hampton, VA 23666-1398

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA CR-4571

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: James L. Dillon
Final Report

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified---Unlimited

Subject Category 02

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Constant-temperature anemometry was used to measure the disturbance levels in the Langley Research Center 20-Inch Mach 6 Tunnel over a limited range of total pressures. The measurements were made using a dual wire probe where each wire was operated at a high but different overheat. The fluctuating voltages were digitized and a system of two equations was solved to obtain the instantaneous mass flow and total temperature fluctuations as a function of time. Statistical techniques were used to obtain statistical quantities of interest.

14. SUBJECT TERMS
Hypersonic Flow
Fluctuating Measurements
Flow Quality
Wind Tunnel Freestream
Disturbance levels

15. NUMBER OF PAGES
24

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102