

HEAT TRANSFER FROM IN-LINE AND PERPENDICULAR ARRANGEMENTS OF CYLINDERS
IN STEADY AND PULSATING CROSSFLOW

by

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(ABSTRACT)

An investigation was conducted to determine the effect of organized flow pulsations on mean heat transfer from a single cylinder, in-line arrangements and perpendicular arrangements of cylinders. Pulsation frequencies of up to twice the natural vortex shedding frequency and zero to peak amplitudes as high as 36 percent were used. Pulsations were sinusoidal with at least 93 percent of the power at the fundamental frequency. Turbulence levels ($Tu=0.5$ percent) were not altered by the addition of unsteady flow. Reynolds number ranged from $23,000 < Re < 49,000$. Results for heat transfer on the front and back of the cylinder are given for a constant wall temperature boundary condition. Heat transfer measurements were made by applying a heat balance to a thick walled copper tube divided into four individually heated segments with guard heaters located at each end.

Mean heat transfer was found to increase for all three arrangements when organized flow pulsations were applied. For a single cylinder and for perpendicular arrangements, heat transfer increases were found primarily on the back of the cylinder. For in-line arrangements, increases occurred mostly on the front of the cylinder. for the range of pitch

ratio most useful to heat exchanger design, in-line arrangements were found to have a higher Nusselt number than perpendicular arrangements.

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NOMENCLATURE

Symbol	Meaning
A_i	- surface area of segment i
Bi	- local Biot number, hd/k or hw/k (Appendix A)
CWT	- constant wall temperature boundary condition
CHF	- constant heat flux boundary condition
d	- depth of insulation strip (Appendix A)
D	- cylinder Diameter, cm
f_d	- pulsation or driving frequency, Hz
f_s	- natural vortex shedding frequency for steady crossflow, Hz
F_d	- dimensionless pulsation frequency ($f_d D/U_\infty$)
F_s	- dimensionless natural vortex shedding frequency ($f_s D/U_\infty$)
h_i	- heat transfer coefficient, $W/m^2\text{ }^\circ C$
h_ϕ	- local heat transfer coefficient at ϕ degrees from stagnation point, $W/m^2\text{ }^\circ C$
k	- thermal conductivity, $W/m\text{ }^\circ C$
l	- length of cylinder segment
L	- distance between cylinders in the direction of
L_t	- distance between cylinders in the direction of flow, cm
L_s	- distance between cylinders measured perpendicular to the flow, cm

L/D	- pitch ratio
L_s/D	- spanwise pitch ratio
Nu	- Nusselt number, hD/k
Q_e	- experimental power measurement for a cylinder segment, w
Q_{L1}	- convection heat transfer on the top surface of insulation strips, w
Q_{L2}	- conduction heat transfer accross an insulation strip, w
q_{L1}	- dimentionless form of Q_{L1}
q_{L2}	- dimentionless form of Q_{L2}
R_i	- heater resistance for segment i , Ohms
R	- resistance to heat transfer (Appendix D)
Re	- Reynolds number based on cylinder diameter
T, T_i	- mean temperature on segment i
$T_{i,j}$	- temperature at location j of cylinder segment i , $^{\circ}C$
T_{∞}	- temperature of the freestream, $^{\circ}C$
T_a	- ambient temperature, $^{\circ}C$
Tu	- turbulence intensity
U_{∞}	- freestream velocity, m/s
v_i	- heater voltage for segment i , volts AC
w	- width of insulation strip, cm

Greek Symbols

- ϵ - correction to experimental power measurement for insulation heat loss, percent
- ϵ - emissivity of cylinder wall
- θ - x/w , dimensionless form of X (appendix A)
- μ - kinematic viscosity, $\text{Kg/m}^2\text{-s}$
- ν - y/d , dimensionless form of Y (appendix A)
- ρ_a - density of air, Kg/m^3
- ρ_w - density of water, Kg/m^3
- σ - Stefan-Boltzman constant, $5.67 \times 10^{-8} \text{ W/m}^2\text{K}$
- σ_v - standard deviation of controller voltage measurement, volts.
- τ - pulsation amplitude, percent
- ϕ - angular position from the stagnation point, degrees
- ω - uncertainty

1.0 INTRODUCTION

This thesis reports on an experimental investigation to determine the effects of one-dimensional organized sinusoidal freestream pulsations on the heat transfer from a single cylinder and from in-line and perpendicular arrangements of cylinders in a crossflow of air. The results can be applied to heat transfer problems on the leading edge of turbine blades, and to heat exchangers.

This research is part of a larger project funded by the Department of Energy. Previous work includes 1) localized heat transfer and pressure measurements for a single cylinder in steady and pulsating crossflow, both with and without free stream turbulence, 2) numerical calculations for the heat transfer and flow around a single cylinder and banks of cylinders in steady and unsteady crossflow, and 3) the development of a rapid response heat flux gage.

Many studies have considered the problem of the heat transfer from a single cylinder in crossflow, and of increases in heat transfer resulting from freestream turbulence. More recently, some investigators have reported increases in heat transfer in the wake region when pulsations are added to the freestream. Studies for pulsating flow have not been extended to banks of cylinders, although this information would be more applicable for heat exchangers.

Heat transfer for downstream cylinders of in-line banks of cylinders is higher than for a single cylinder in crossflow. The higher heat transfer occurs because turbulence is generated by upstream cylinders.

The turbulence consists of both random three dimensional turbulence and large scale vortices shed from upstream cylinders. Perpendicular arrangements alter both the flow and the manner which turbulence impinges on downstream cylinders. This could have the effect of further increasing heat transfer.

Several aspects of this research are unique to the problem under consideration. This study first re-examines the case of a single cylinder in pulsating crossflow, and also extends results to in-line arrangements of cylinders in pulsating crossflow. Perpendicular arrangements of cylinders, for which no other experimental data is currently available, were also investigated and compared with similar in-line arrangements at the same spacing. Pulsation driving frequencies were considered up to twice the natural shedding frequency for a single cylinder, which is higher than any found in current literature for this type of pulsation. Pulsations were nearly sinusoidal, with at least 93 percent of the waveform's energy at the fundamental driving frequency.

Emphasis was given to measuring time-and space-averaged heat transfer on the front and back of the cylinder, rather than to conducting more time consuming localized measurements. This allowed the effects of Reynolds number, pitch ratio, pulsation frequency, and amplitude to be considered. Parameters of interest for future localized measurements and for unsteady heat transfer measurements were identified.

2.0 LITERATURE REVIEW

Previous studies which apply to this research are divided into three categories. The first considers aspects of the flow and heat transfer around a single cylinder. More recent studies focusing on the effect of free stream turbulence and flow pulsations are treated separately as a second category. Finally, previous work for banks of cylinders is reviewed with emphasis given to single in-line arrangements of cylinders. No previous work on perpendicular arrangements was found.

Heat transfer and flow around a single cylinder in steady crossflow has been the subject of numerous investigations in the last half century [1,2]. Three flow regimes exist. Subcritical flow ($1000 < Re < 2.0 \times 10^5$) is characterized by a laminar boundary layer which develops on the front of the cylinder and separates around eighty-five degrees from the foreward stagnation point. The free shear layer rolls up and Von Karman vortices are shed alternately on the top and bottom of the cylinder. The frequency of vortex shedding in dimensionless form is known as the Strouhal number ($St = f_d D / U_\infty$). For the subcritical flow regime, the Strouhal number is nearly constant ($St = 0.2$). Above the critical Reynolds number ($Re > 2.0 \times 10^5$), the boundary layer becomes turbulent and separates on the back of the cylinder ($\phi \approx 140$ degrees). For $Re > 2 \times 10^6$, the supercritical flow regime is established, with final boundary layer separation occurring near $\phi = 115$ degrees. The remainder of this review considers only the subcritical flow regime ($Re < 1000 < 2 \times 10^5$).

The separated flow region has received special attention in recent years [3,4,5]. Three different flow regions have been identified in the wake (figure 1). Lebouche and Martin [5] used an electrochemical reduction technique to measure velocity gradients and flow direction on the surface of a cylinder in crossflow. Their conclusions are summarized in Table 1. A separation bubble and secondary vortex region exists for $85 < \phi < 110$ degrees. The secondary vortex causes reverse flow on the wall of the cylinder. A second region is characterized by reattachment of the free shear layer ($\phi \approx 110$ degrees) and final separation ($\phi = 120$ to 150 degrees) of the free shear layer [3,5]. For $Re > 30,000$, Kraabel [3] states that the free shear layer will become turbulent before reattachment, resulting in an increase in heat transfer on the back of the cylinder. In the third region ($145 < \phi < 180$), the back of the cylinder is alternately swept by the two primary vortices, and flow direction can be either positive or negative.

Spalding and Punn [6] reviewed numerical calculations for the heat transfer on the front of the cylinder. Theoretical predictions for the heat transfer in the laminar boundary layer on the front of the cylinder indicate that $Nu \propto Re^{\frac{1}{2}}$. Frossling's exact solution, while slightly lower, was found to be in good agreement with early experimental results presented by Schmidt and Wenner [7]. More recently, measurements were made by Kraabel [3], Kestin [14], Achenbach [8], and Andraka and Diller [9]. An example of local heat transfer measurements by various authors is given in Figure 2.

Heat transfer in the wake of a single cylinder has a higher Reynolds-number dependence than for the front of the cylinder. Zukauskas

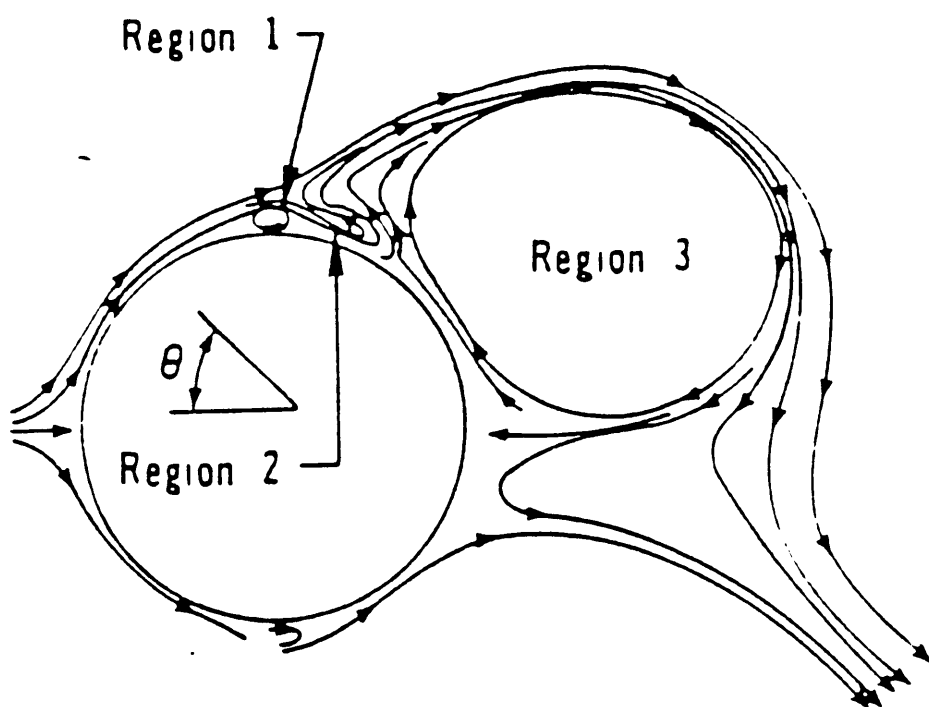


Figure 1. Flow around a single cylinder from ref. [5]

Table 1. Summary of flow around a single cylinder, from ref. [5]

POSITION θ°	0°	84°	85°	86°	105° 110°	110° 115°	125°	155° 160°	180°
MEAN FLOW DIRECTION		+			-		+		- (WEAK)
DIRECTION FOR 1 CYCLE	+	+	-		-	+	+		+
REGION	UPSTREAM FACE	SEPARATION			REGION 2				REGION 3

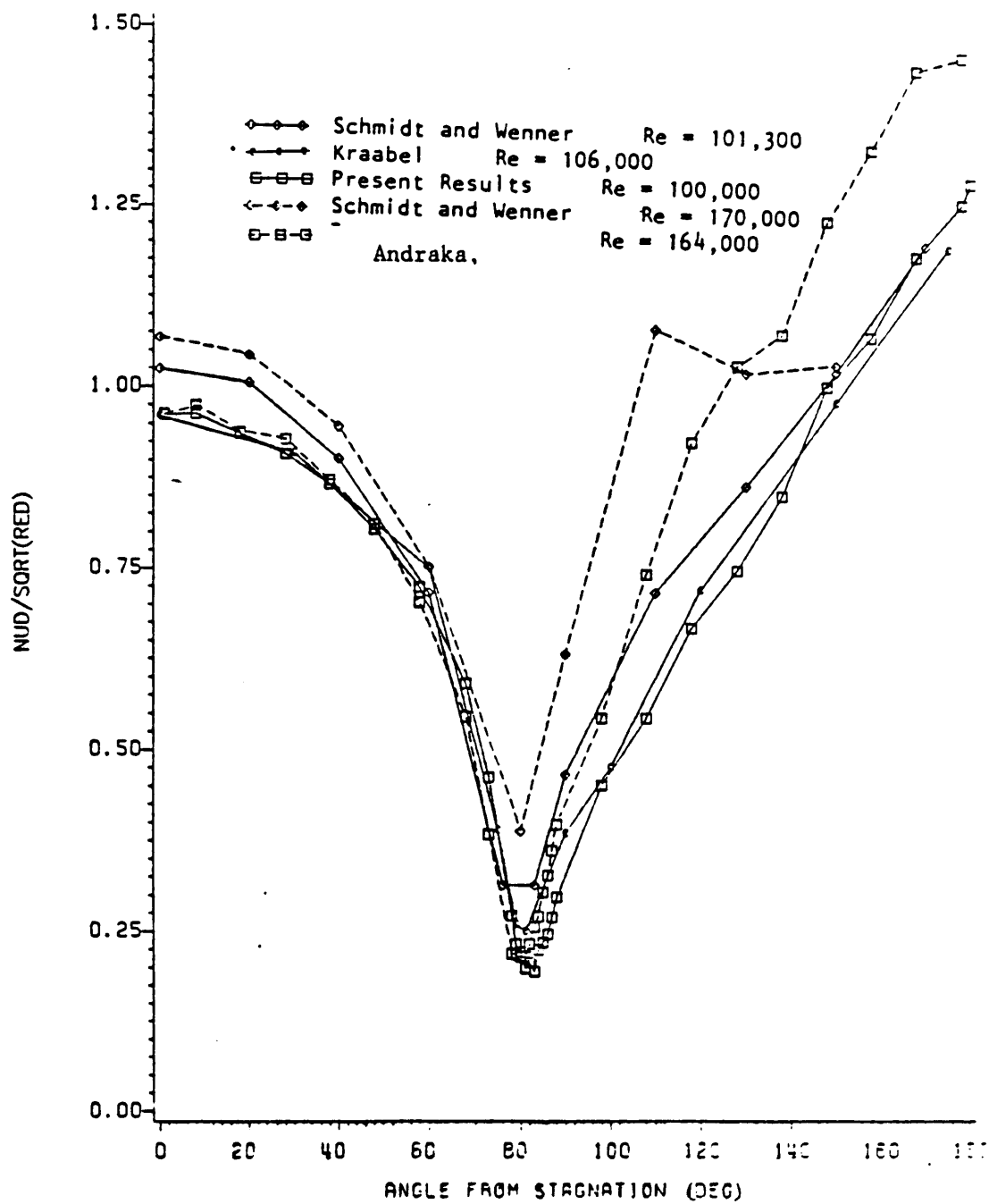


Figure 2. Local heat transfer measurements by different authors from ref [34]

[1] suggests a power law dependence of $Nu_b \propto Re^{0.73}$, where Reynolds number is based on velocity at the minimum free cross section. Igarashi [10] investigated heat transfer and fluid flow in the wake region and suggested $Nu_b \propto \Delta P_s^{0.31}$, where ΔP_s is the root mean square fluctuating pressure.

Morgan [2] and Zukauskas [1] have each reviewed a number of investigations for a single cylinder in crossflow. Both suggest a power law correlation of the form $Nu = C \times Re^n$. Constants C and n are given in Table 2. It should be noted that both correlations underpredict experimental results from Ref. 9 and Ref. 31 by about 10 percent in the range of $10^4 < Re < 10^5$.

Morgan suggests the following correlations for tunnel blockage:

$$U_{\infty} = U_t \left[1 - 0.411 \left(\frac{D}{L} \right)^2 \right] \quad (1)$$

$$\frac{\delta Nu}{Nu} = \left[1 - 0.411 \left(\frac{D}{L} \right)^2 \right]^{n-1} \quad (2)$$

Where n is given in Table 2. For turbulence, Morgan suggests:

$$\frac{\delta Nu}{Nu} = \begin{array}{ll} 1.29 Tu^{1/2} & 0.01 < Tu < 0.03 \\ 2.54 Tu^{2/3} & 0.03 \leq Tu < 0.05 \end{array} \quad (3)$$

The combined effect of these corrections for tunnel blockage and free stream turbulence is shown in Figure 3.

Table 2. Coefficients for correlations given ref. [1,2]

from Re=	MORGAN [2] to Re=	constant C	exponent n
10^{-4}	4×10^{-3}	0.437	0.0895
4×10^{-3}	9×10^{-2}	0.565	0.136
9×10^{-2}	1.0	0.800	0.280
1.0	35	0.795	0.384
35	5×10^3	0.583	0.471
5×10^3	5×10^4	0.148	0.633
5×10^4	2×10^5	0.0208	0.814

from Re=	ZUKAUSKAS [1] to Re=	constant C	exponent n
1	40	0.75	0.4
40	1×10^3	0.51	0.5
1×10^3	2×10^5	0.26	0.6
2×10^5	1×10^6	0.076	0.7

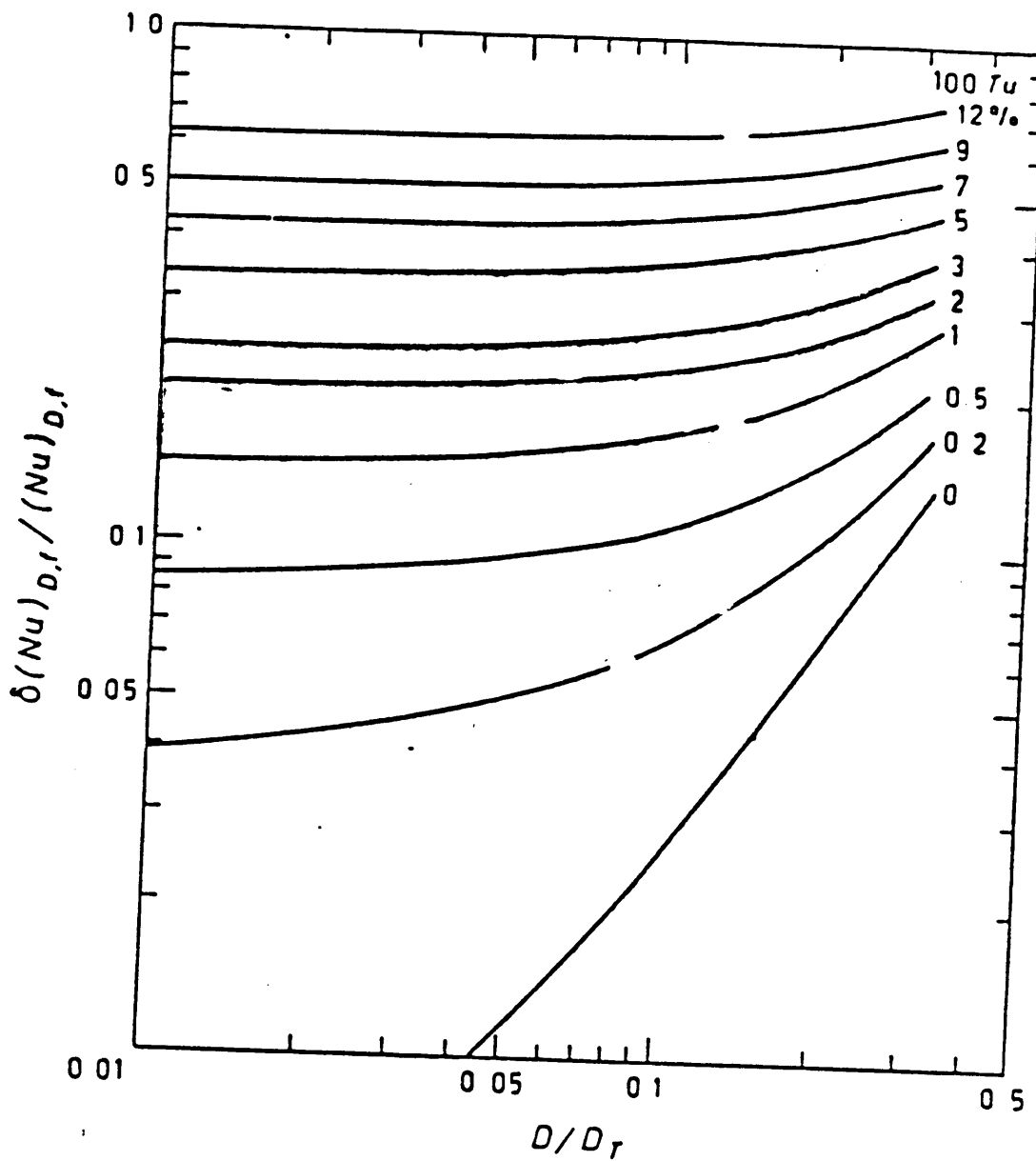


Figure 3. Combined effect of blockage and freestream turbulence from ref[1]

Zukauskas [1], Boulos and Pei [4] and Papell [11] have suggested that a constant heat flux boundary condition (CHF) results in a Nusselt number which is higher (about 20 percent) on the back of the cylinder than the Nusselt number for a constant wall temperature (CWT) boundary condition. Papell reported little difference between CHF and CWT boundary conditions on the front of the cylinder.

Sparrow et al. [12] considered the effect of the cylinder root vortex on mass transfer, finding a negligible effect on local mass transfer one diameter from the tunnel wall. This result was useful in the design of the test cylinder.

Increases in heat transfer resulting from high levels of free stream turbulence have been the subject of numerous investigations in the past; a few examples are cited here [4,13-16]. The increase is generally more pronounced on the front of the cylinder. One mechanism commonly used to explain the increase is that high turbulence levels in the freestream reduce the critical Reynolds number. The laminar boundary becomes turbulent even at subcritical Reynolds numbers, changing the separation point and increasing heat transfer on both the front and back of the cylinder. Lowery and Vachon [15] measured increases of up to 66 percent for Reynolds numbers in the range of $109,000 < Re < 302,000$ and turbulence levels up to 20 percent. Boulos and Pei [4] reported increases in heat transfer on the front and in the secondary vortex region, and a decrease in the primary vortex region.

Several investigations have considered the case of a single cylinder moving in a freestream. Sreenivasan and Richardson [17] moved a cylinder perpendicular to the flow at $Re=2500$ to $15,000$ and frequencies up to 47

Hz. They noticed no increase in overall heat transfer. Saxena [18], reported no increase in heat transfer on the front of a cylinder oscillating in crossflow, however increases of up to 60 percent were reported on the back. Marziale and Mayle [19] oscillated a cylinder rotationally about its axis. Increases in mass transfer were observed at turbulence levels up to 4.9 percent, however no increase occurred once the freestream turbulence level was reduced.

Previous investigations considering a single cylinder in a pulsating freestream [5,9,16,20-23] are of particular interest because a similar method of pulsation is used for this investigation. Most of these papers lack some important turbulence level and pulsation waveform data. Free stream turbulence level in strady flow is not difficult to measure, and the value is usually included with experimental results. Unsteady turbulence level, or turbulence added by the device used to produce the freestream pulsation, is more difficult to measure, and is only given in ref. [9,16,23]. Because even low freestream turbulence levels ($Tu=1$ percent) have been shown to cause an increase in heat transfer, unreported turbulence levels that may exist with the pulsation make it difficult to distinguish between an increase in heat transfer resulting from free stream pulsations and any increase resulting from increased random three-dimensional turbulence.

Moreover, for most unsteady flow studies, pulsation waveforms are not included with the data. Because the effect of non-dimensional frequency on cylinder heat transfer is being investigated, it is useful to determine the percentage of the total pulsation energy which is present at each frequency in the waveform.

Base, Patel and Valaitis [19] investigated the heat transfer from a cylinder in low frequency ($f_d D/U_\infty < 0.04$) square wave pulsating crossflow for $1220 < Re < 4890$. Decreases in heat transfer of up to 12 percent were reported for very low pulsation frequencies ($f_d D/V < 0.01$). At higher frequencies, no increase or decrease was observed. Very high turbulence levels ($Tu \approx 20$ percent) were present in the steady freestream, and the authors suggested that results may be different at lower turbulence levels. Simoneau et al. [21] measured the heat transfer from a cylinder in the wake of a rotor. The rotor produced both three dimensional turbulence and one dimensional flow oscillations. They noted increases in heat transfer of up to 45 percent for overall turbulence levels (oscillation plus turbulence) of 6 to 10 percent. For higher turbulence levels ($Tu \approx 20$ percent), increases in heat transfer of up to 20 percent were noted.

Lebouche and Martin [5] measured local heat and mass transfer for pulsating flow in the range $15,000 < Re < 50,000$. Pulsation frequencies of up to 86 percent of the natural vortex shedding frequency for heat transfer measurements, and up to 125 percent of the natural shedding frequency for mass transfer, were used with amplitudes of up to 32 percent. For steady flow at $Re = 27,000$, heat transfer on the front of the cylinder was higher than on the back. At $f_d/f_s = 0.43$ and an amplitude of 36 percent, they reported no increase in heat transfer on the front, and a 31 percent increase on the back of the cylinder. Lower amplitudes had almost no effect on the heat transfer for $f_d/f_s < 0.5$. A local increase in heat transfer was found at the steady flow point of separation, followed by a decrease just after separation. The authors explain this ef-

fect by suggesting that the separation point shifts slightly downstream for pulsating flow.

At frequencies closer to the natural shedding frequency, smaller amplitudes had a more pronounced effect on the heat transfer than higher amplitudes at lower frequencies. The highest increases in mass transfer were reported at $f_d/f_s=1.25$. For frequencies above the natural shedding frequency, the authors suggest that the pulsations cause a transition to critical flow. For all frequencies, the authors conclude that increases in heat and mass transfer occur largely because the pulsations either disorganize or entirely eliminate the principal shedding vortex. conclusions made from the present results were different.

Borell et al. [21] used a Gardon heat flux gage in a CWT cylinder to investigate pulsating flow local heat transfer for $33,000 < Re < 66,000$. Well-organized sinusoidal pulsations were used both below and slightly above the natural shedding frequency. They reported increases in local heat transfer near the separation point, which were largest near $f_d/f_s=1$. No increase outside of experimental error was observed for the overall heat transfer.

Kim et al. [22] showed numerically the unsteady boundary layer equations on the front of the cylinder. For a 10 percent oscillation in velocity at the edge of the boundary layer, they reported a small increase in heat transfer at the front stagnation point, and a small decrease upstream of the separation point.

Andraka and Diller [9] extended Borrell's investigation, producing more accurate results at $Re=50,000$ with a larger cylinder ($D=8.89$ cm) and lower tunnel blockage. Oscillations consisted of a well-organized iso-

lated sinusoidal pulsation with 95 percent or more of the energy in the waveform at the fundamental frequency. Pulsations were reported to have no effect on turbulence level. Reduced driving frequencies ranged from 0.006 to 0.24 with zero to peak amplitudes ranging from 25 percent to 6 percent, respectively. Andraka reported an increase in local heat transfer of up to 30 percent at the separation point for $f_d/f_s=1$. Overall, no increase in heat transfer, outside of experimental error, was observed on the front or back of the cylinder. Present results do not show good agreement with Andraka's measurements.

Gundappa and Diller [16] used Andraka's test cylinder at the same flow conditions ($Re=50,000$) to differentiate between the increase in local heat transfer resulting from three-dimensional freestream turbulence, and from one dimensional organized flow pulsations. Turbulence levels of up to 7.5 percent were generated by placing coarse screens upstream of the test cylinder. The authors observed increases in heat transfer which agreed with previous investigations. When a sinusoidal pulsation was added to the turbulence, no additional increase in heat transfer was observed. Their results indicate that the nature of the unsteadiness present in the flow is important for predicting heat transfer augmentation.

Heat transfer from banks of cylinders is useful because results can be applied directly to the design of heat exchangers. Zukauskas presents a summary of the problem for subcritical flow [1,23] and for critical flow [24]. Savkar [25] considers the effect of transverse pitch ratio on flow measurements for bundles of cylinders.

Several recent investigations have focused on the more fundamental problem of a cylinder in a single in-line row in an effort to gain more understanding about the mechanism of heat transfer involved. Kostic and Oka [26] investigated CHF heat transfer and fluid flow around a tandem arrangement of two cylinders at subcritical Reynolds numbers. They suggest three flow regimes based on pitch ratio (figure 4). For $L/D > 3.8$, the heat transfer and pressure distribution on the first cylinder are essentially the same as for a single cylinder in a freestream. The second cylinder behaves like a single cylinder in critical flow. Turbulence in the wake of the first cylinder causes transition to a turbulent boundary layer on the front of the second cylinder, resulting in an overall increase in heat transfer of about 20 percent. Flow unsteadiness between the cylinders is both small-scale random turbulence and macroscale organized turbulence. The second flow regime exists for $2.3 < L/D < 3.8$. A closed quasi-steady cavity or vortex forms between the cylinders. Reattachment of the free shear layer to the second cylinder results in laminar boundary layer growth which may become turbulent before final separation. Local heat transfer is at a maximum at the point of reattachment. A third flow regime was suggested for $L/D < 2.3$. The second cylinder enters into the vortex formation region of the first cylinder. Kostic and Oka reported irregularities for both local and overall heat transfer in this region.

Hiwada et al. [27] measured mass transfer and fluid flow around a tandem arrangement of two cylinders, and commented on the heat transfer based on a mass transfer analogy. The local mass transfer distributions were similar to those presented by Kostic and Oka for heat transfer. It

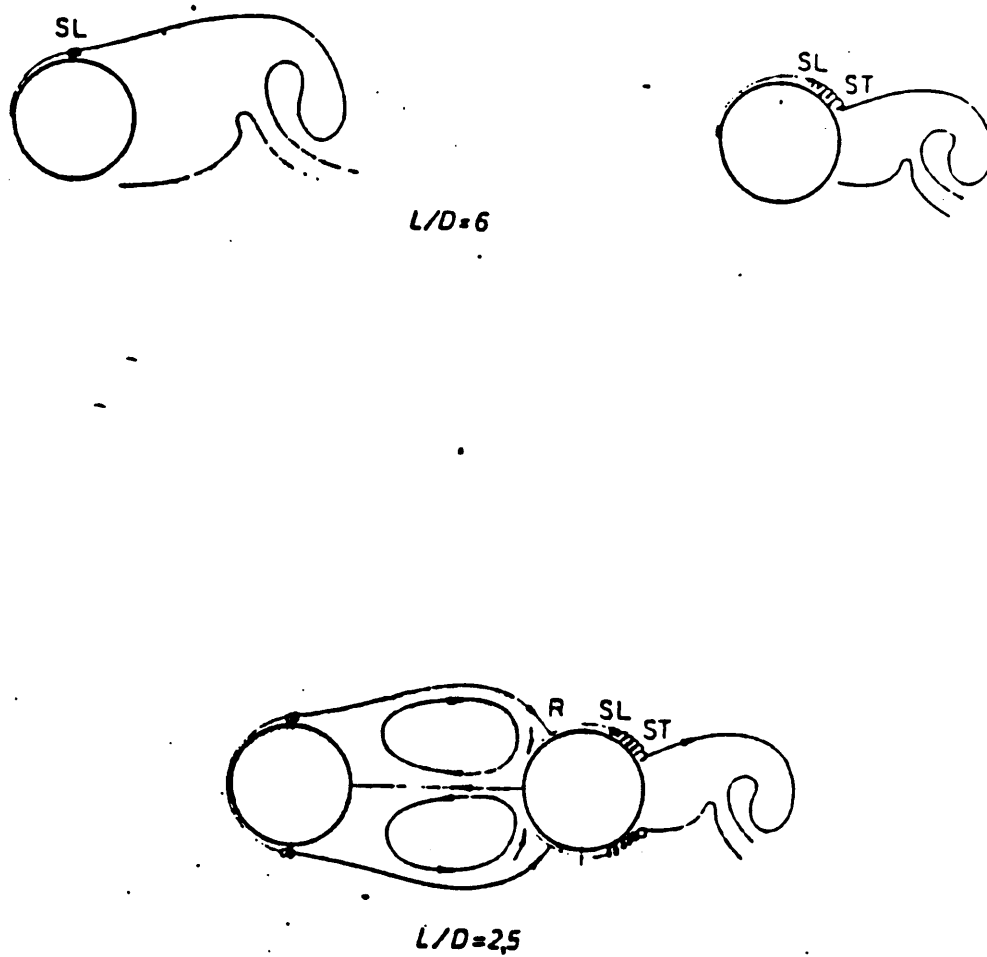


Figure 4. Flow around two in-line cylinders from ref. [26]

should be noted, however, that local heat transfer and local mass transfer can show qualitatively different profiles. An example of this can be found in the single cylinder data presented by Lebouche and Martin [5] for a single cylinder.

Hiwada et al. disagree with Kostic's interpretation of flow around the cylinders, suggesting a more complicated flow pattern. They also reported on a discontinuity in Strouhal number, hereafter referred to as a jump phenomenon, at the beginning of the closed vortex formation region ($L/D=3.8$). The authors suggest a power law ($Nu \propto Re^{2/3}$) for the second cylinder with $L/D \leq 2.3$, which is in agreement with Kostic and Oka.

Zdravkovich [28] reviewed studies of flow interference between two circular cylinders. Citing the work of Ishigai, and of Kostic, he suggested that no vortex shedding exists behind the first cylinder at spacings below $L/D=3.8$, where the jump phenomenon occurs. At $L/D=3.8$, two values of Strouhal number exist intermittantly.

More recently, a second discontinuity has been observed both in heat transfer and Strouhal number measurements for spacings smaller than $L/D=3.8$. This second jump phenomenon is dependent on both Reynolds number and L/D . Aiba et al. [29-32] investigated the flow and heat transfer around an in-line arrangement of four cylinders [29,30] and three cylinders [31,32]. They reported on the jump phenomenon only in references 29 and 30. Aiba et al. suggest the following correlation for four cylinders:

$$Re_c = 1.14 \times 10^5 (L/D)^{-5.84}$$

Recent investigations by Igarashi [33,34] suggest a different correlation for three cylinders:

$$Re_c = 5.2 \times 10^4 (L/D)^{-3.8}$$

The correlations of Aiba et al. and Igarashi are plotted in Figure 5.

Igarashi characterized the flow around three cylinders based on instantaneous and time-averaged flow visualizations along with pressure, velocity, drag and shedding frequency measurements. His results are summarized in Table 3.

Igarashi suggests that five different flow regimes exist for three cylinder arrangements. For pattern A ($Re < Re_c$), vortex shedding occurs only behind the third cylinder. Free shear layers separated from the first cylinder do not reattach to either the second or third cylinders. For pattern B' ($Re = Re_c$) the flow is bistable. Intermittent patterns exist where the free shear layers either remain separated, or alternately reattach to the second and third cylinder. Two shedding frequencies are observed ($St=0.23$ and $St=0.09$). At slightly higher Reynolds numbers, shear layers reattach alternately to the downstream cylinders, and velocity fluctuations exist between the second and third cylinders. For pattern C ($Re > Re_c$, $2.21 < L/D < 3.25$), one shear layer reattaches to the second cylinder while the other rolls up and forms a separated vortex between the second and third cylinders. This contrasts previous investigations [25-27] which state that vortex shedding only occurs between cylinders for $L/D \geq 3.8$. Pattern D exists after the Strouhal number discontinuity at $L/D=3.24$. Kostic and Oka [26], Aiba [30] and Savkar [25] report the

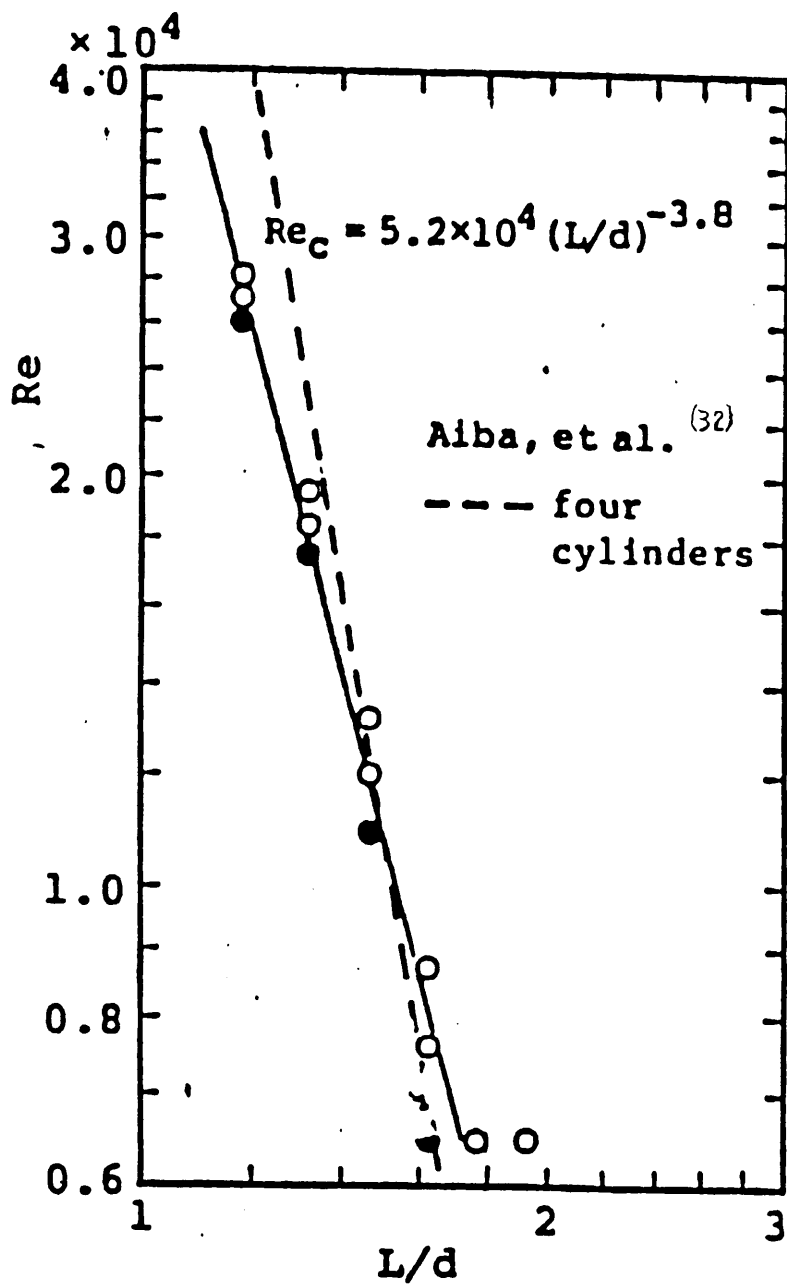


Figure 5. Correlations for predicting jump phenomenon from ref. [32]

discontinuity at $L/d=3.8$. For pattern D, the Strouhal number increases to $St=0.16$ and vortices are shed from all three cylinders. A fifth pattern (pattern E) is a bistable condition at $L/D=3.24$ where the free shear layer either reattaches to the second cylinder, or rolls up forming a separated vortex between the second and third cylinders. Two Strouhal numbers exist ($St=0.13$ and $St=0.19$). Igarashi also notes that bistable regions for three cylinders exist in a much smaller range of Reynolds number and spacings than for arrangements of two cylinders in tandem.

No CWT heat transfer data was found for in-line arrangements of three cylinders. Aiba et al. [29-32] reported on the second cylinder in three and four cylinder arrangements for a CHF boundary condition. Local heat transfer on the second cylinder is shown in Figure 6. Overall heat transfer for $L/d=1.8$ is shown in Figure 7.

The current investigation considered the effects of organized flow pulsations on heat transfer from a single cylinder and from the second cylinder of in-line arrangements of cylinders. Measurements were also conducted for perpendicular arrangements, for which no previous data was available.

Table 3. Summary of flow around three cylinders from ref. [33]

Flow Pattern	Shear Layer	Range	S	CD2	$\overline{C_D}$
A	(W,W)	Re < Rec	0.23 ~ 0.24	-0.6	0.16
B'	(W,W) & (W,R)	Re = Rec, L/d = 1.32	bistable, hysteresis		
B	(R,R)	Re ≥ Rec, L/d < 2.21	0.09 ~ 0.13	-0.4 ~ -0.3	0.3 ~ 0.4
C	(R,J)	2.21 ≤ L/d < 3.24	0.13	-0.3 ~ -0.1	0.4 ~ 0.5
E	(R,J) & (J,J)	L/d = 3.24	bistable: Jump C → D and D → C		
D	(J,J)	L/d > 3.24	0.16 ~ 0.18	0.35 ~ 0.42	0.6 ~ 0.7

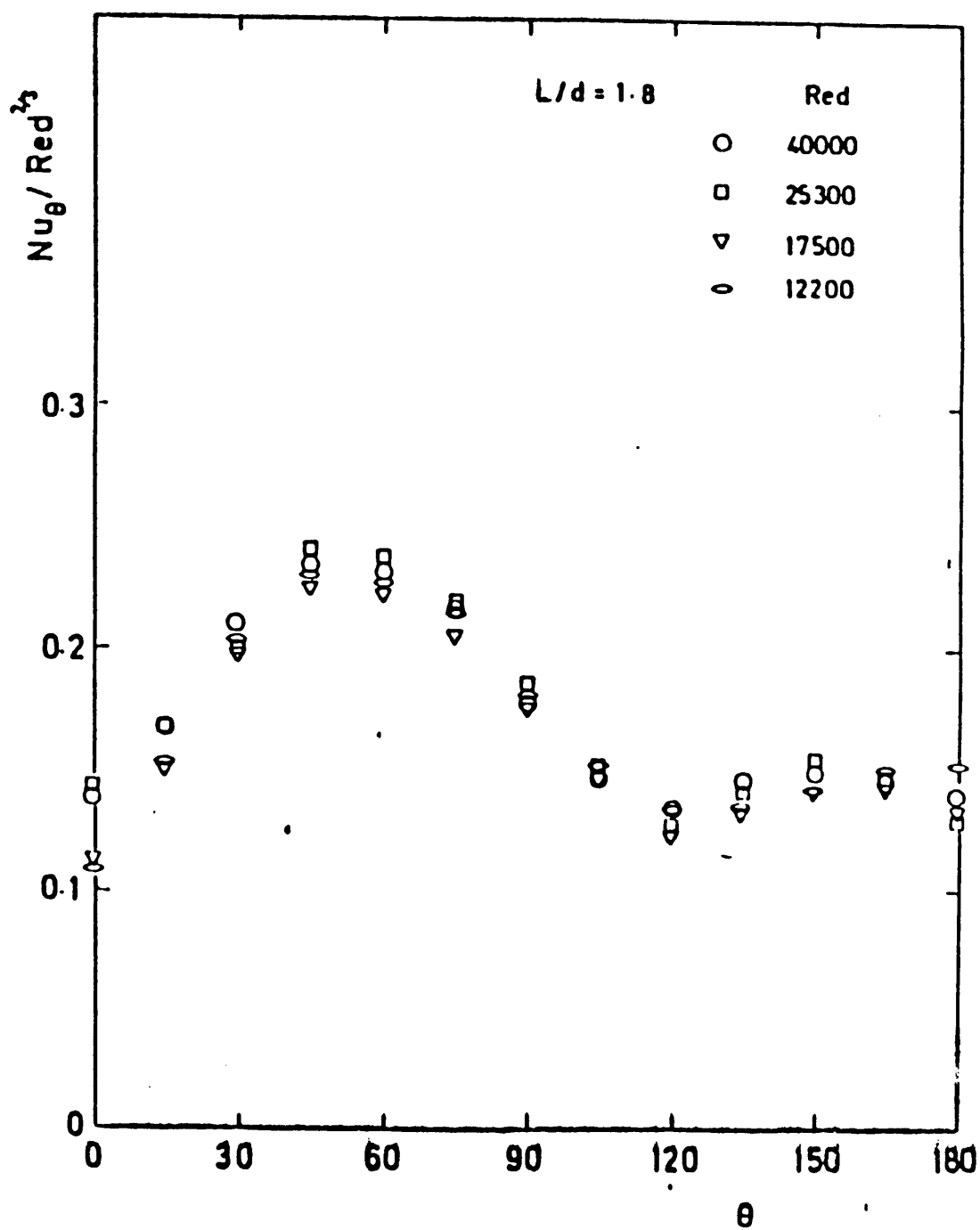


Figure 6. Local heat transfer for three cylinders from ref. [2]

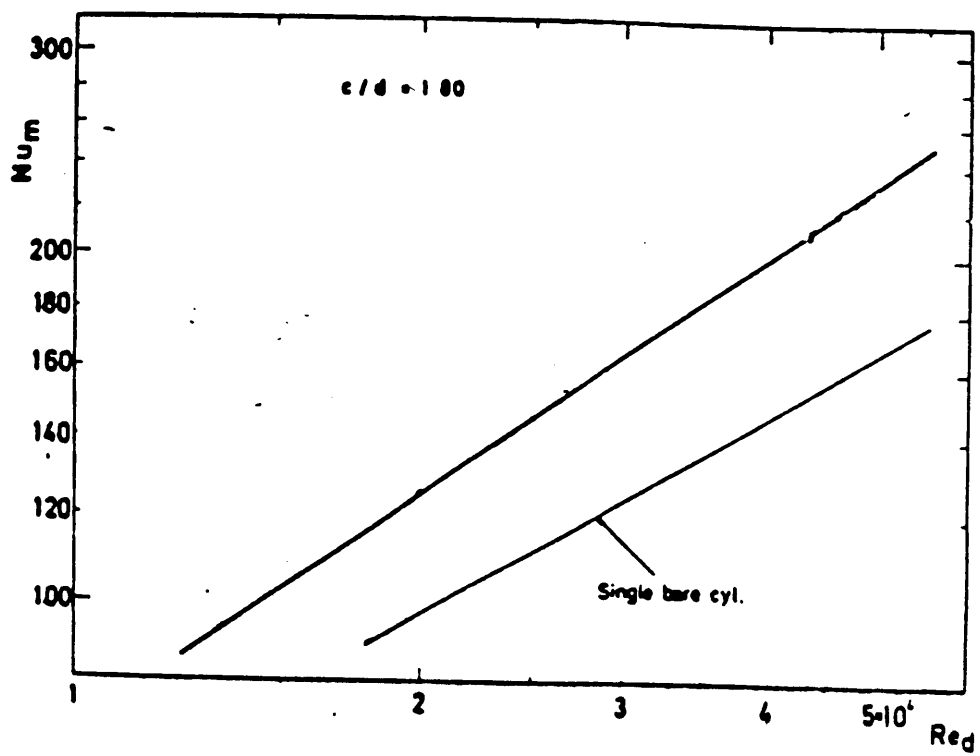


Figure 7. overall heat transfer for in-line arrangements from ref. [31]

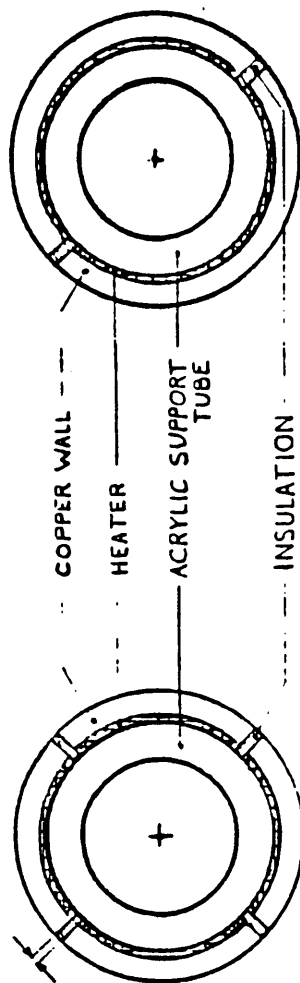
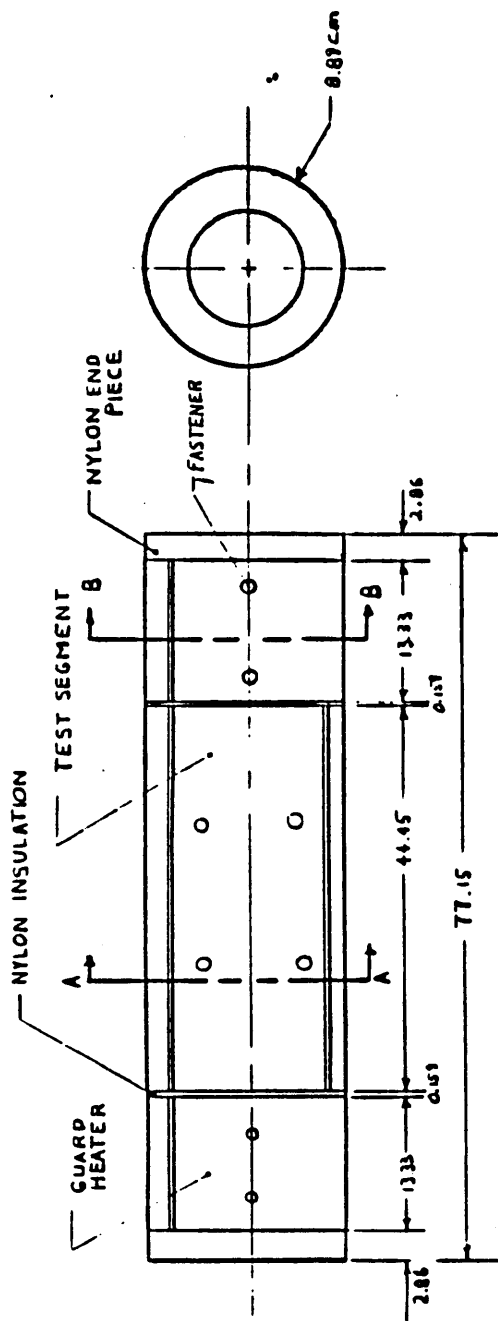
3.0 EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental investigation was conducted using a heated test cylinder and various arrangements of tube banks in a low speed pulsating flow wind tunnel. This section gives details on the test cylinder, accompanying instrumentation, and the wind tunnel used for this study. The experimental procedure is given next, followed by a description of equations used to reduce the experimental data.

3.1 TEST CYLINDER

The test cylinder (Figure 8) was designed and constructed to measure time-averaged heat transfer on each of four 44.5 cm $\times$ 90 $^\circ$ cylinder segments. The heat transfer for each segment was determined by measuring the voltage drop across a heater located below each cylinder segment. Two 14.0 cm $\times$ 180 $^\circ$ guard heater segments were placed at each end of the test cylinder to reduce end losses.

An isothermal wall boundary condition (CWT) was insured by constructing the outer wall of the cylinder using 8.89 cm OD, 0.77 cm thick copper pipe (Revere 102) containing less than 0.05 percent impurities. The high thermal conductivity of pure copper ($k=390 \text{ W/m}^2\text{ }^\circ\text{C}$) and the thick wall of each cylinder segment allowed heat to diffuse easily within the cylinder wall. The temperature was therefore nearly uniform on each segment, regardless of local variations in convection heat transfer.



SECTION B-B

SECTION A-A

Figure 8. The cylinder model used for this investigation

Each cylinder section or guard heater was independently heated by a Watlow silicone-rubber wire resistance heater. The heaters were rated at 0.78 W/m^2 at 120 volts. Heaters had a nominal resistance of 87Ω for cylinder segment heaters and 134Ω for guard heaters. The resistance of this type of heater was virtually independent of temperature for the operating range used in this investigation. The change in resistance was measured to be $\Delta R/R\Delta T = 1.4 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$ at $23 \text{ } ^\circ\text{C}$. Because the resistance can be considered to be constant over the 10 degree range of the test cylinder temperature, the power delivered to each heater could therefore be determined by measuring the voltage drop across each heater.

The copper wall of the test cylinder (segments plus guard heaters) was supported by 6.06 cm OD, 5.40 cm ID acrylic tube. The heaters were 1.5 mm thick and fit between the acrylic tube and the copper cylinder wall. Each cylinder segment or guard heater was fastened to the acrylic tube using four 3/16 inch (.476 cm) brass counter sink screws. The screws did not extend beyond the acrylic tube. Each brass fastener was filed so that when tightened, the screw head was below the surface of the cylinder. A solder plug was then added over the fastener, filed and sanded to provide a smooth cylinder surface (Figure 9).

A nylon ring (0.16 cm thick) was used as insulation between the cylinder segments and guard heaters. Insulation separating cylinder segments (Figure 10) consisted of a top layer of auto body filler ($k=0.25 \text{ W/m}^2\text{ } ^\circ\text{C}$) and a lower layer of balsa wood ($k=0.055 \text{ W/m}^2$). The thermal conductivity of insulation materials used for the cylinder was also measured. The measurement technique is described in Appendix E.

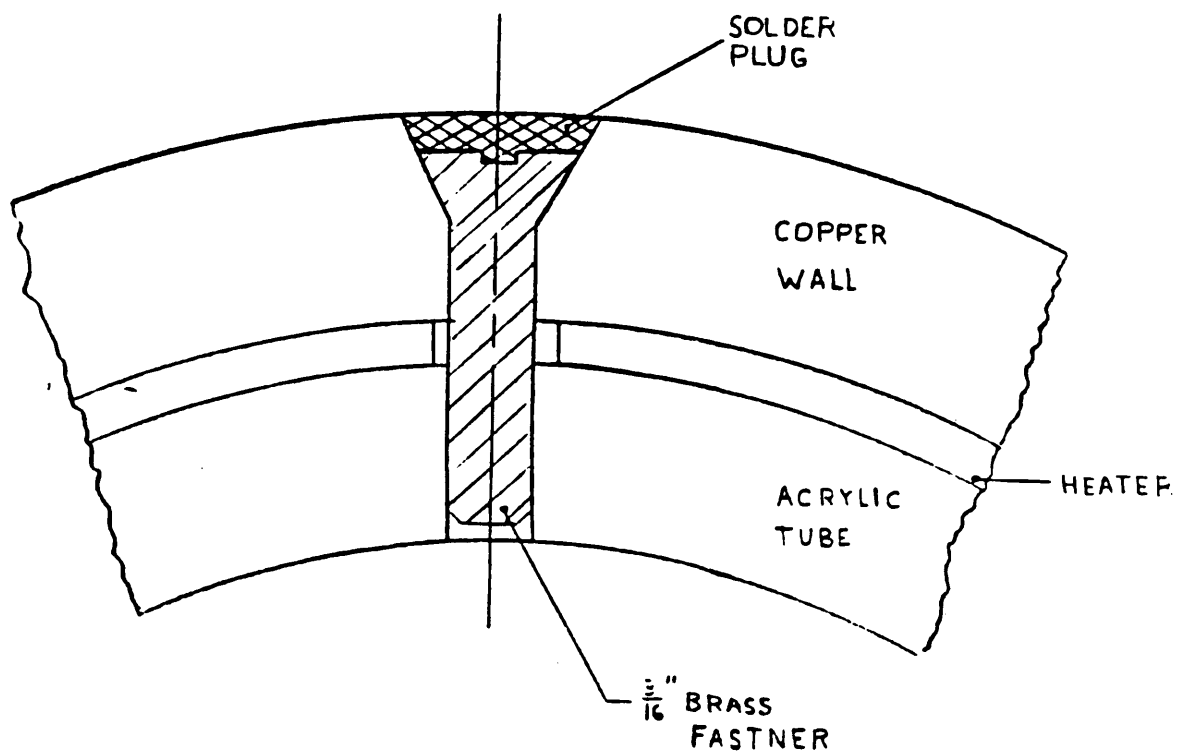


Figure 9. Method for fastening copper segments to support tube

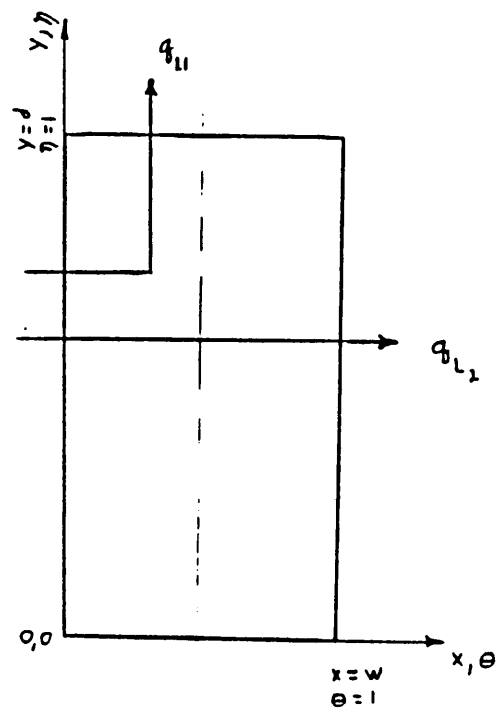
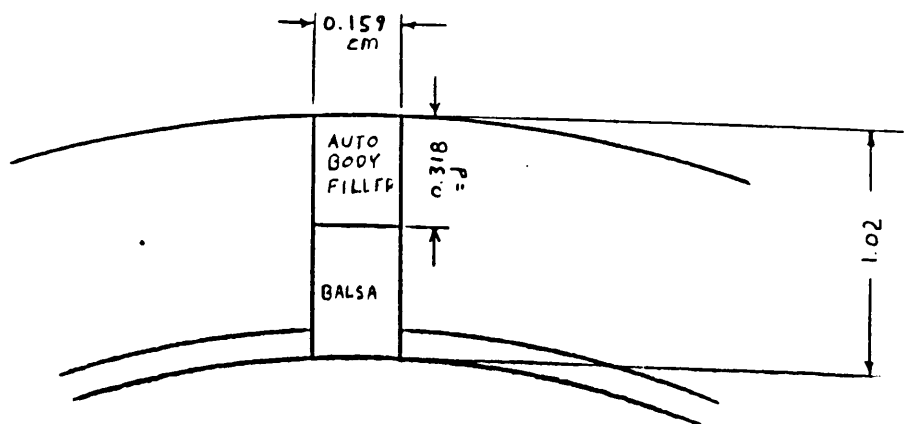


Figure 10. Insulation strips separating cylinder segments

A two-dimensional heat conduction analysis was performed on the insulation strips to determine the effect of heat losses, and to minimize these losses by choosing appropriate insulation dimensions and materials. Two types of losses were considered: 1) heat conducted through the insulation and lost by convection to the free stream (q_{L1}) and heat conducted through the insulation to another section (q_{L2}). These losses are shown schematically in Figure 10.

Convection heat transfer through the insulation to the air was smaller than heat losses that would occur if no insulation were present. Convection heat transfer (q_{L1}) is smaller because the temperature on the surface of the insulation is lower than the temperature of the surrounding wall. A correction was made to the experimental power measurement to account for the reduced convection heat transfer with insulation. The correction was always less than 0.4 percent of the total power for each segment.

The two-dimensional analysis for conduction losses (q_{L2}) showed that very little error results if conduction losses across the insulation are assumed to be one dimensional. Conduction losses between cylinder segments are proportional to the difference in edge temperatures. The difference in edge temperatures was generally controlled to within the uncertainty of temperature measurement, therefore Q_{L2} was nominally zero. The effect of Q_{L2} was considered only in the uncertainty analysis. Insulation strips between cylinder segments were designed to minimize the combined effect of correction to experimental power measurement for q_{L1} and uncertainty resulting primarily from q_{L2} .

Several additional comments should be made regarding the analysis of insulation losses. First, the losses were small enough that a correction was not really necessary. This is partly because the surface of each cylinder segment is large compared to the surface area of the insulation surrounding it, and partly because the insulation strips were designed to minimize the correction. Second, while the analytical technique used may not perfectly model the losses, the analysis was still useful for determining the approximate size of the losses relative to the total power of each cylinder segment. Finally, the analysis in Appendix C could be applied to active heat flux gages, where the ratio of insulation surface area to gage area is much larger, and modeling of thermal losses from the gage is more important. Examples of active gages where the analysis in Appendix C could apply are given in References [3,4,5,8,15].

The test cylinder contained a total of 49 type T thermocouples (Figure 11). Six were located in the wall of each segment. Segment A contained four additional thermocouples which surround Thermocouple A1. Of the six thermocouples on each segment, four were located 0.64 cm from each corner. A double thermocouple in the center of each segment was used for temperature measurement (Thermocouples A1, B1, etc.) and for control (Thermocouples CA, CB, etc.).

Guard heaters contained five thermocouples located 0.64 cm from the edge closest to the cylinder segments. A double thermocouple near the center of each guard heater was used for temperature measurement and control. Guard heater thermocouples were located directly across the nylon insulation ring from a corner thermocouple on a cylinder segment.

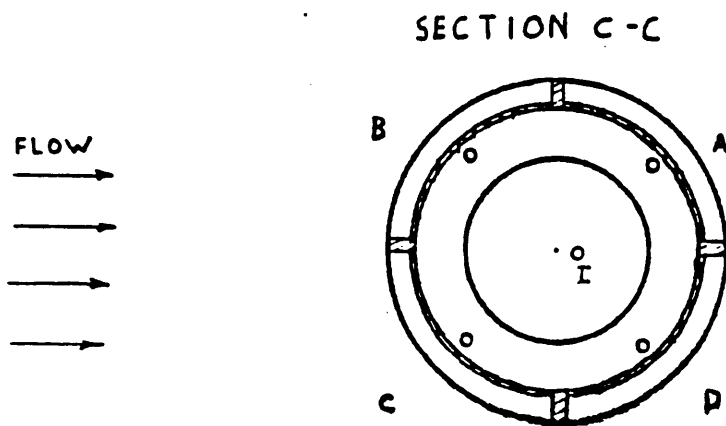
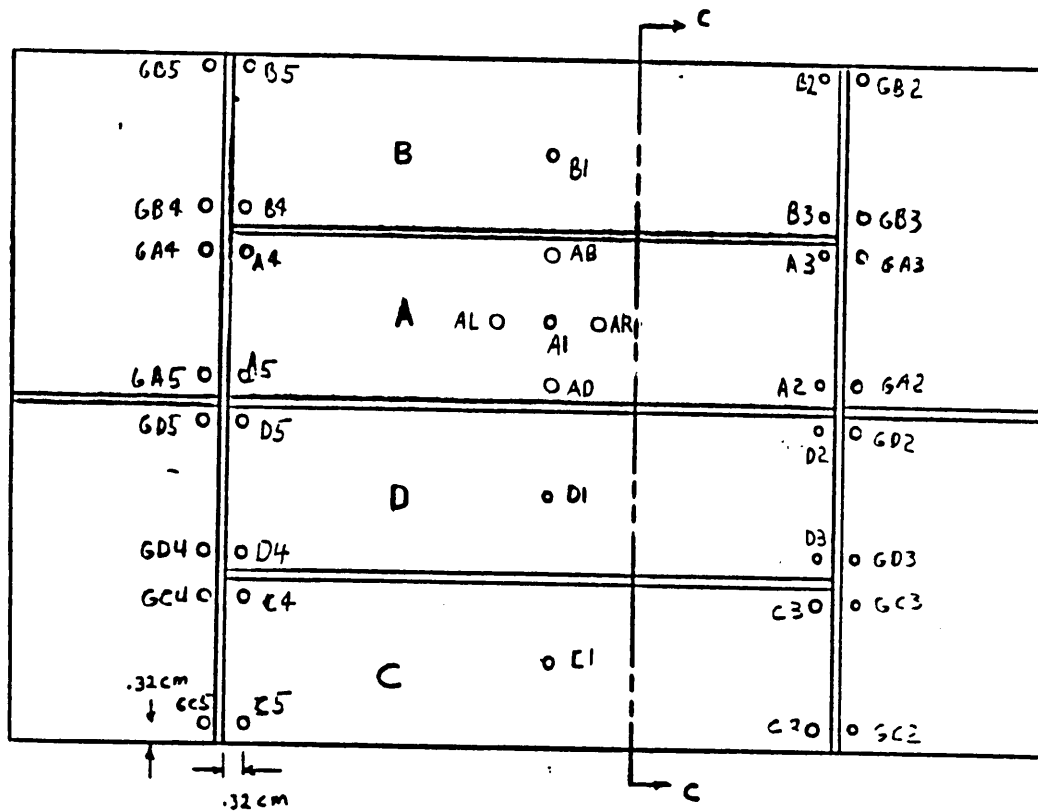


Figure 11. Thermocouple locations on the cylinder model

One thermocouple was also glued into the acrylic support tube wall 0.16 cm below each heater, and 5 cm from the center thermocouple along the axis of the cylinder. One additional thermocouple was also placed inside the acrylic tube to record the centerline temperature of the cylinder.

Figure 12 gives a typical temperature distribution around the cylinder. The circumferential temperature differences were generally maintained to within ± 0.1 °C on each section. The temperature difference between the center and the ends could be as large as 0.8 °C. For this reason, the five thermocouples on each segment were averaged when experimental data was reduced.

The four temperatures in the wall of the acrylic tube were always higher than the surface temperatures, and could differ by several degrees. An attempt was made to calibrate losses in the acrylic wall and to the center of the cylinder. The results of the calibration were questionable, and no correction was made. More detail on these losses is given in the data reduction section and in Appendix E.

The procedure for constructing thermocouples (Figure 13) is similar to that given in Ref. [35]. An arc welder was first used to form a junction with omega 24-guage-S copper- constantan thermocouple wire. A plug was formed by soldering the bead into 0.32 cm brass tubes. The thermocouple was then press fit into the copper cylinder wall.

Five Eurotherm temperature controllers were used to maintain the cylinder at constant temperature. Each unit consisted of a model 810 three-term (proportional, integral, derivative) controller and model 831 SCR. The input for each controller was one of the double thermocouples

36.4	36.3	B	36.9	36.5	36.4
36.5	36.5			36.7	36.7
36.6	36.6	A	37.0	36.6	36.8
36.6	36.5		36.9 36.5	36.4	36.6
36.5	36.6	D	37.1	36.5	36.7
36.6	36.7			36.6	36.8
36.7	36.7	C	37.0	36.4	36.9
36.5	36.6			36.2	36.6

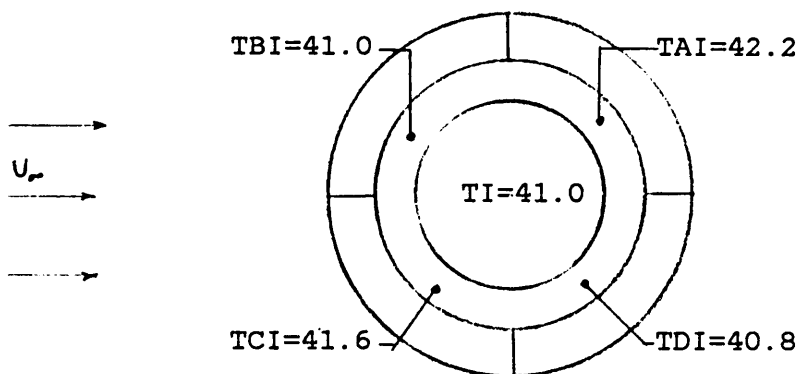


Figure 12. A typical temperature distribution on the cylinder for $Re=49000$

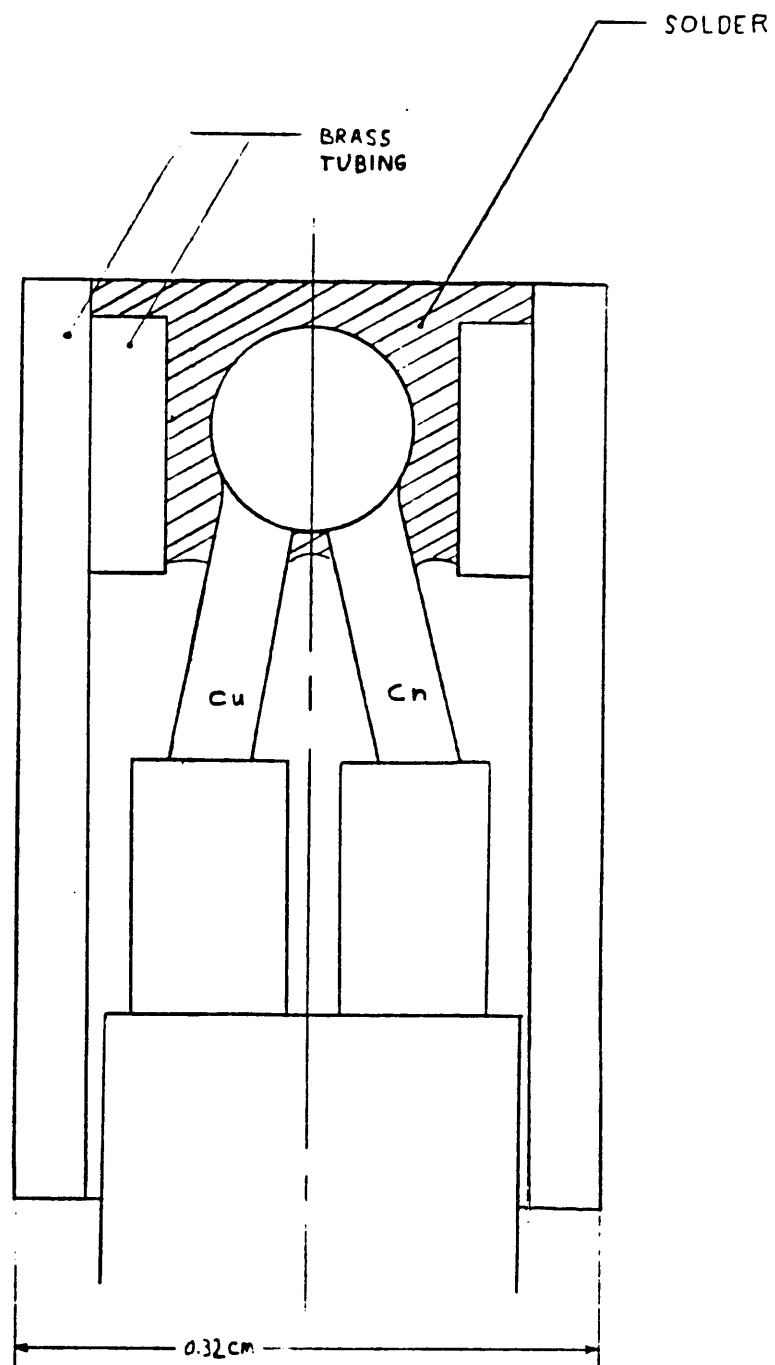


Figure 13. Construction of thermocouple plugs.

located at the center of each segment. SCR output was a 0-120 volt RMS signal proportional to an input received from the 810 controller. The SCR output was connected to a cylinder segment heater or guard heater. One controller was used for each cylinder segment. The fifth controller was used for the guard heaters, with the four heaters connected in parallel to the SCR. A more detailed description of the use of the controllers is given in Appendix B.

3.2 WIND TUNNEL

The experimental investigation was conducted in the same low speed pulsating flow wind tunnel (Figure 14) that was used by Andraka [35]. The blower type tunnel had a contraction ratio of 6:1. The test section was 248 cm long and had a cross section of 74.1×52.9 cm. The settling chamber contained an aluminum honeycomb flow straightener and six screens. The tunnel could provide up to 33 m/s of steady flow, which was uniform across the test section to within 1.2 percent, excluding tunnel wall boundary layers.

Six rotating vanes mounted on parallel shafts immediately upstream from the settling chamber were used to pulse the flow at frequencies up to 23 Hz. The pulsations were of the form:

$$U = U_{\infty} [1 + \tau \sin(2\pi f_d t)]$$

The vanes alternately directed part of the flow either into the settling chamber or out of the tunnel through two openings located above and below

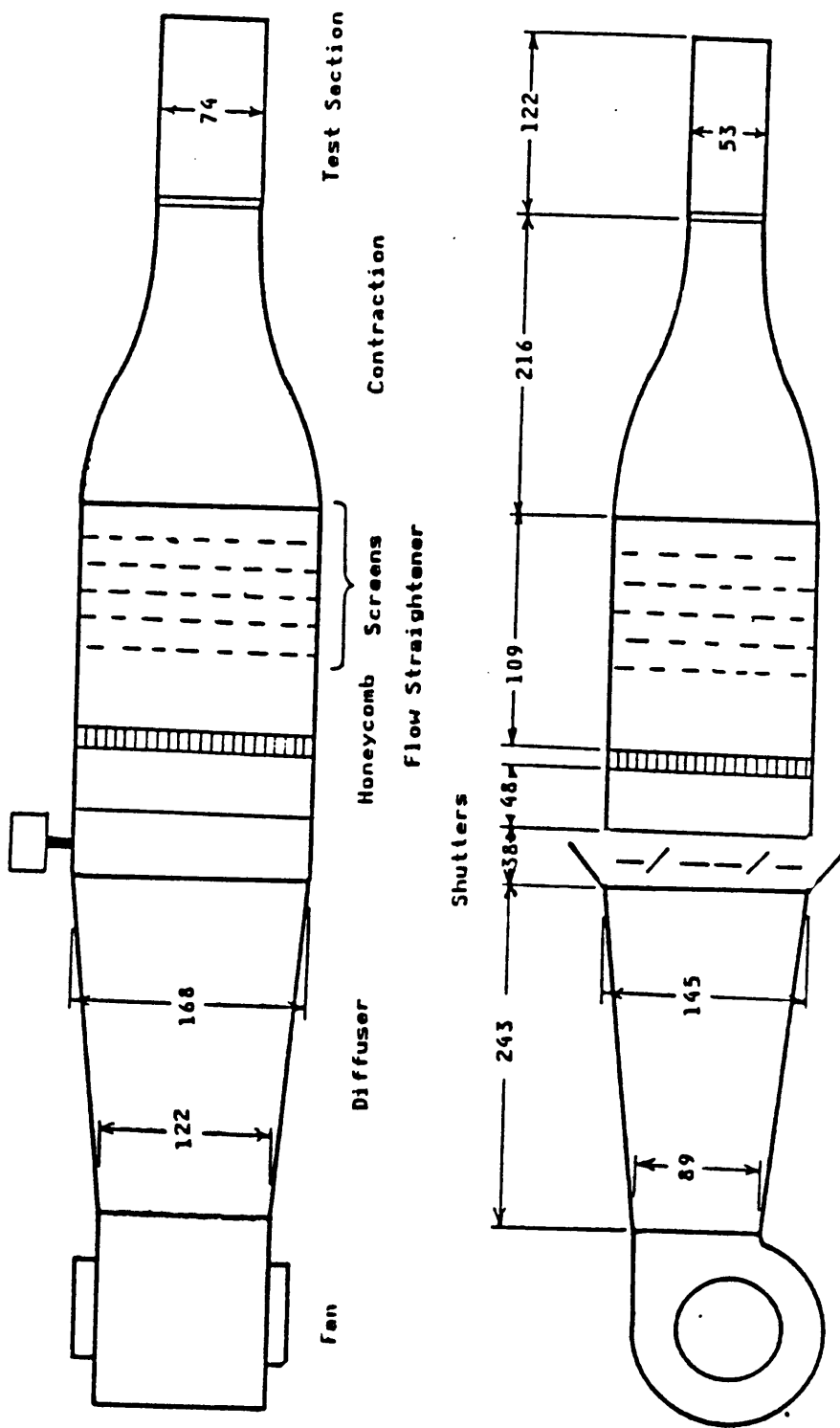


Figure 14. The pulsating flow wind tunnel used for this investigation from ref. [35]

the vanes. The pulsation waveform could be controlled by adjusting the relative position of the vanes. Vane positions used to produce the sinusoidal waveforms for this investigation are shown in Figure 15.

A typical waveform for this investigation is given in Figure 16. The pulsation waveforms were nearly sinusoidal, with at least 93 percent of the pulsation energy at the fundamental frequency. Other waveforms at different frequencies are given in Appendix F. This percentage is slightly less than what Andraka reported using the same wind tunnel. The difference in waveforms is attributed to modifications made to the tunnel after Andraka completed his study.

The first modification consisted of mounting angle-iron frames on the outside of the tunnel in an effort to reduce vibration and noise. Though noise was considerably reduced, pulsation amplitudes decreased by a factor of two. Additional modifications were made to regain the lost pulsation amplitude (Figure 17). The first involved reducing the size of the opening above and below the vanes so that less air escaped when the vanes were closed. The second consisted of creating a large flow resistance between the vanes and the honeycomb flow straighteners. The flow resistance increases the pressure immediately downstream from the vanes by about 0.5 inches H_2O (124 Pa). Because the pressure is higher, more flow escapes through the flaps when the vanes are open.

The flow resistance was created by stretching a sheet of an open weave fabric across the cross section of the settling chamber. The cloth was supported by a screen of hardware netting. Larger amplitudes could also be obtained using a cloth with a higher pressure drop. Small modifica-

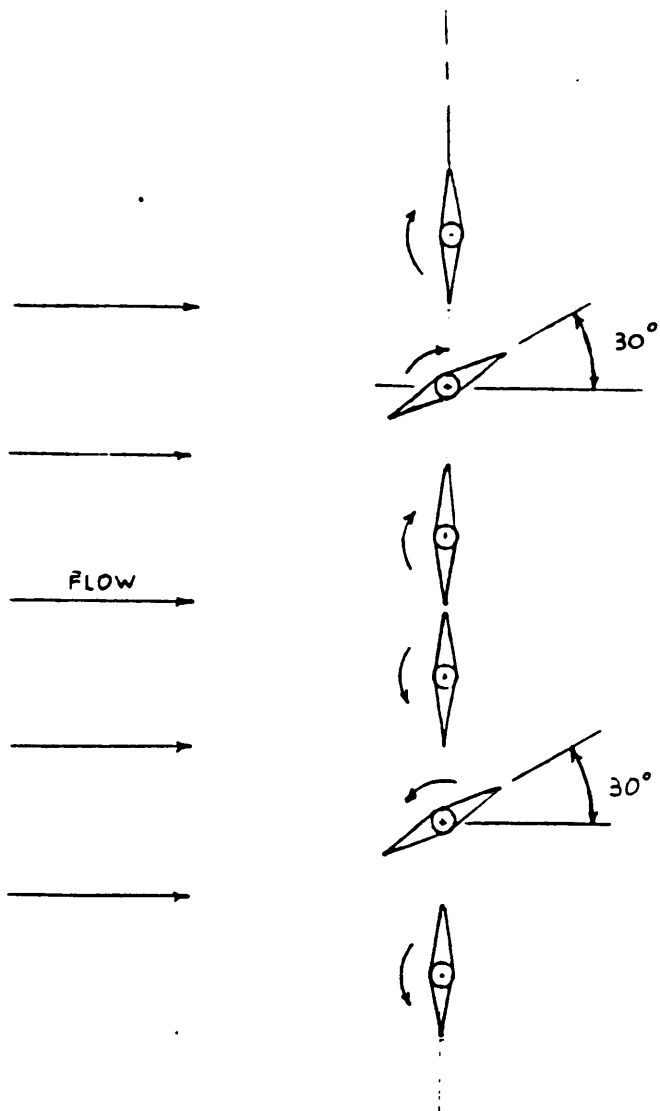


Figure 15. Position of rotating vanes for sinusoidal waveforms

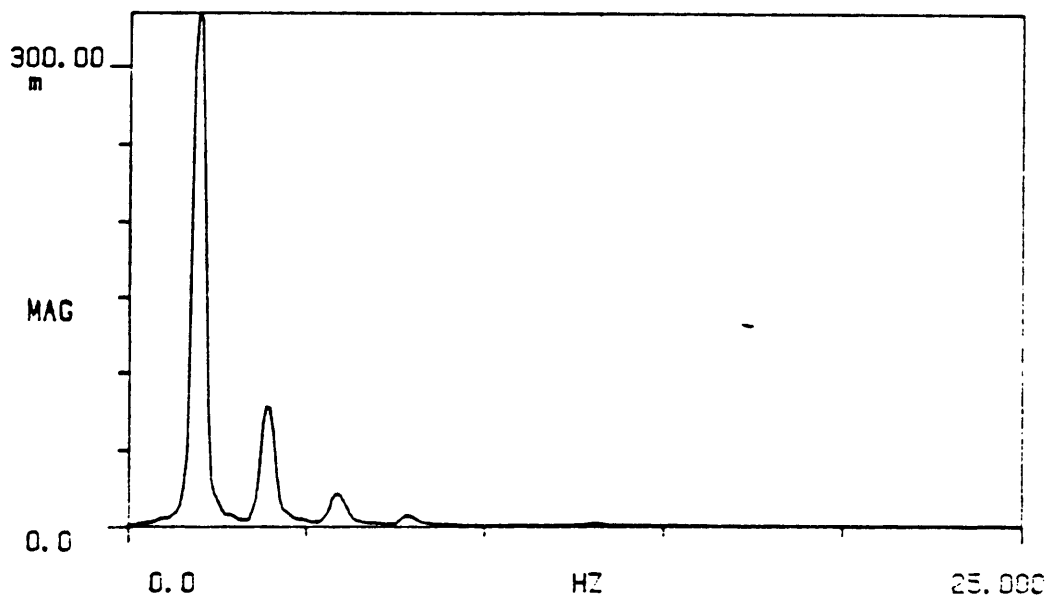
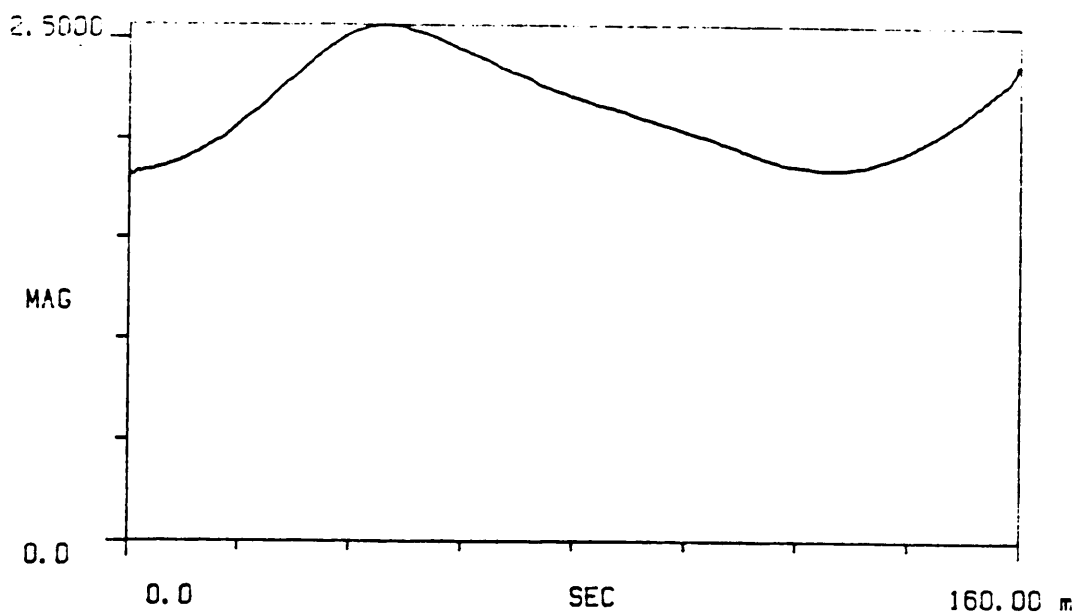


Figure 16 Waveform and frequency content at $f_0=1.96$ Hz. $Re=23000$

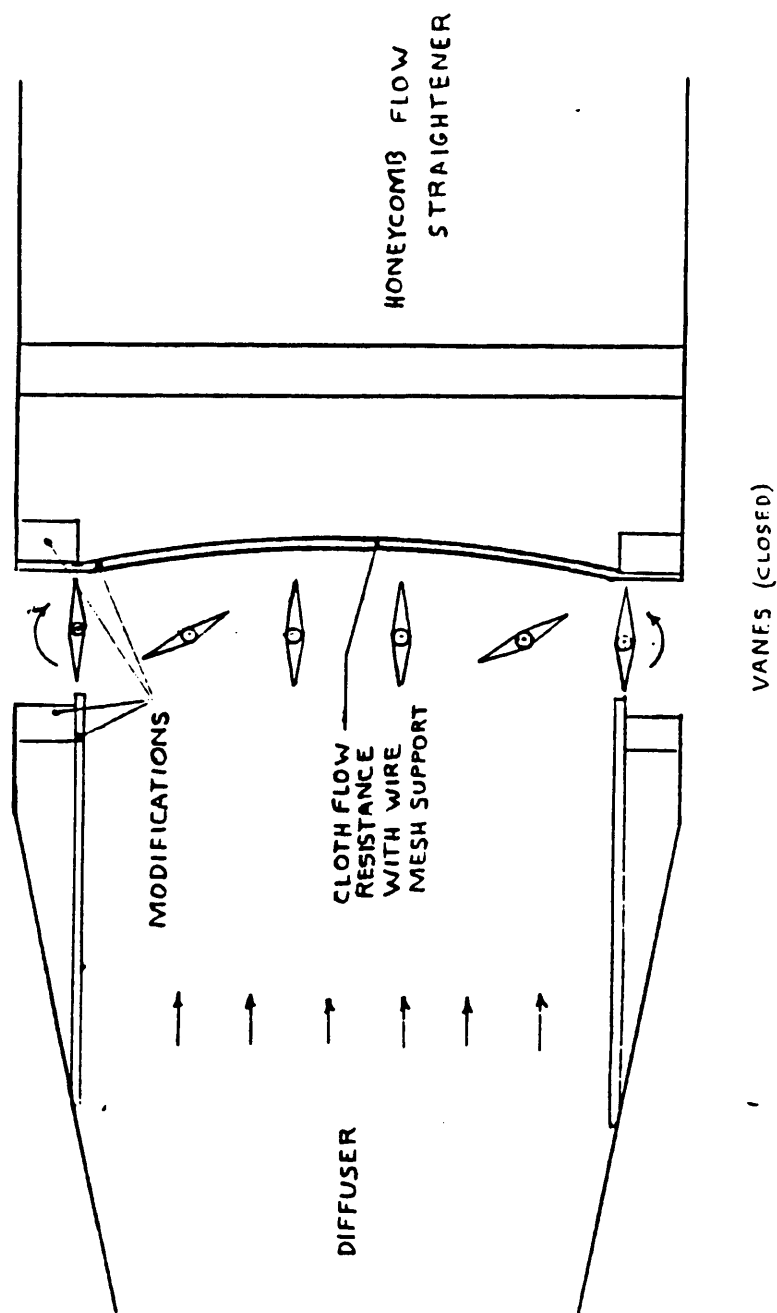


Figure 17. Modifications to the wind tunnel to increase pulsation amplitude.

tions in amplitude could also be made by opening or closing flaps above and below the vanes.

Turbulence intensity, measured after the modifications were made, was 0.68 percent at $Re=47,000$ and 1 percent at $Re=22,000$. For most tests, minimum amplitude varied from 28 percent at 2 Hz to 6 percent at 23 Hz. Amplitudes up to 50 percent could be obtained.

Random turbulence above the pulsation was measured at several frequencies for $Re=50,000$. Results indicated that the pulsations added no additional turbulence to the free stream, which is consistent with Andraka's data. Additionally, the signal from a hot wire placed in the freestream was checked before each data point was taken to insure that no significant amount of turbulence was not present with pulsations. Some random turbulence was found below 10 Hz for high amplitude pulsations. For this reason, the high amplitude test was conducted at $f_d=10$ Hz. Unsteady flow turbulence data is included in Appendix F.

3.3 ARRANGEMENT OF CYLINDERS

The test cylinder was mounted horizontally in 8.9 cm holes on either side of the test section. The holes were located 61 cm from the front of the test section. Cylinder segments A and D were generally on the downstream side of the cylinder. The location of segment A is given with a brief description of the test at the beginning of each data file in Appendix H.

Acrylic cylinders were used to create in-line and perpendicular arrangements of cylinders. Cylinder arrangements are referred to using the

pitch ratio L/D (Figure 18). The cylinders were constructed using 8.9 cm acrylic tubes. A 3/8 inch (0.952 cm) carriage head bolt with the head removed, was fastened to each end of the cylinder. For in-line arrangements, a slot was created on either side of the tunnel using 0.64 cm thick acrylic sheet (Figure 19) which were attached to the tunnel wall using 3/8 inch (0.952 cm) carriage head bolts. The end bolt on the cylinder made a friction fit with the slot at the side of the tunnel. The cylinders could be moved forward or backward in the tunnel to vary the pitch ratio in the range $1.1 < L/D < 4.75$. A scale attached to the side of the tunnel was used to measure L to ± 0.25 cm (0.1 inch). Cylinders were aligned with the test cylinder and test section using a level.

The method for creating the perpendicular arrangements of cylinders was similar to that used for in-line arrangements (Figure 20). Both spanwise (L_s/D) and transverse pitch ratio (L/D) could be adjusted. For all tests with perpendicular arrangements, the three front cylinders were evenly spaced across the test section: $L_s = L_t/3$. Transverse pitch ratio could be varied in the range of $1.0 < L/D < 5$.

3.4 EXPERIMENTAL PROCEDURE

Each experimental data point consisted in part of 32 thermocouple readings (thirty on the cylinder, T_∞ , and T_a) and time-averaged RMS voltage readings for each cylinder segment heater. Freestream velocity, pitch ratio, pulsation frequency and zero-to-peak amplitude were also recorded. For each test, one of the last four parameters was varied, usually frequency.

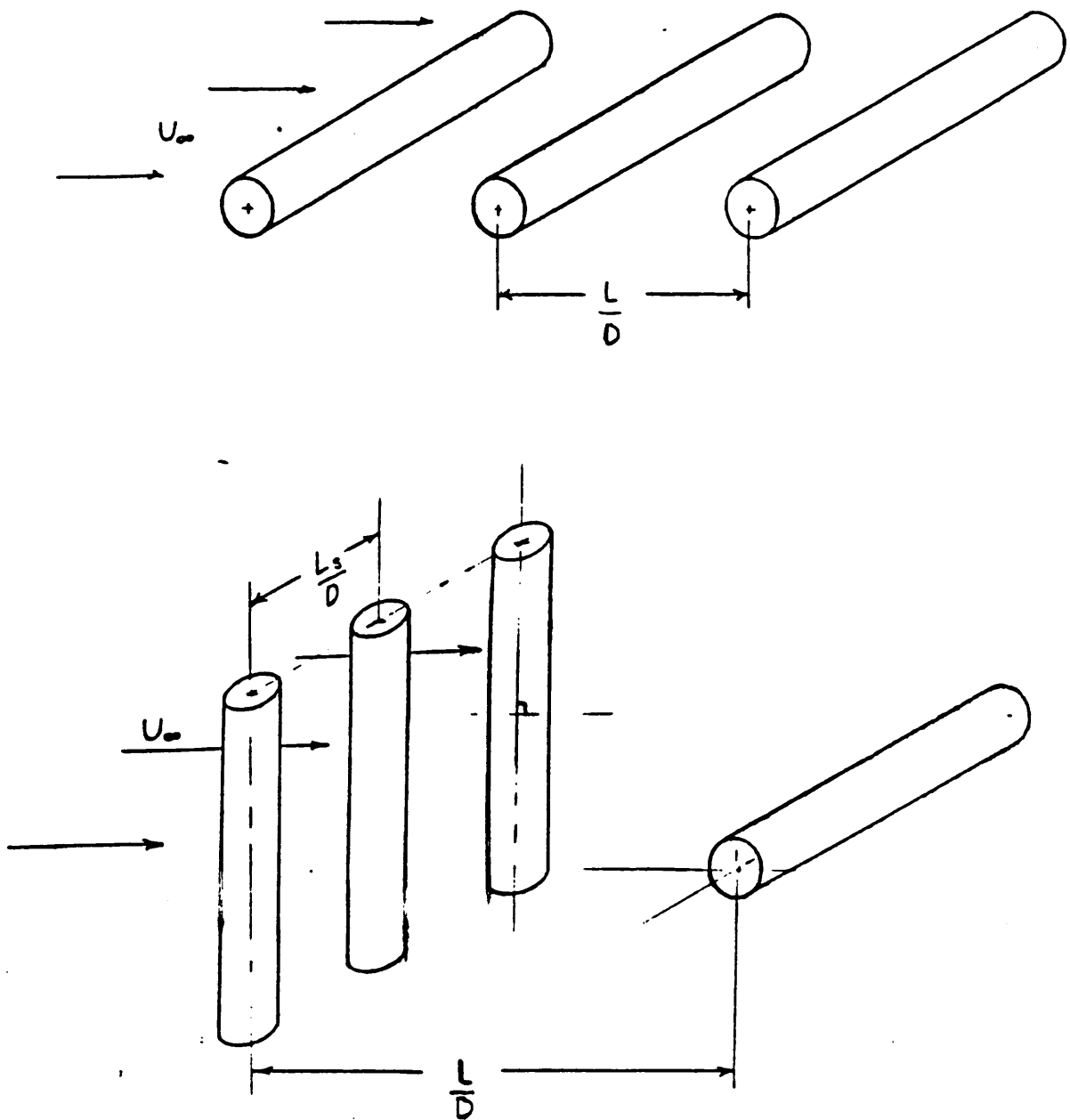


Figure 18. Definition of pitch ratio for in-line arrangements and perpendicular arrangements of cylinders.

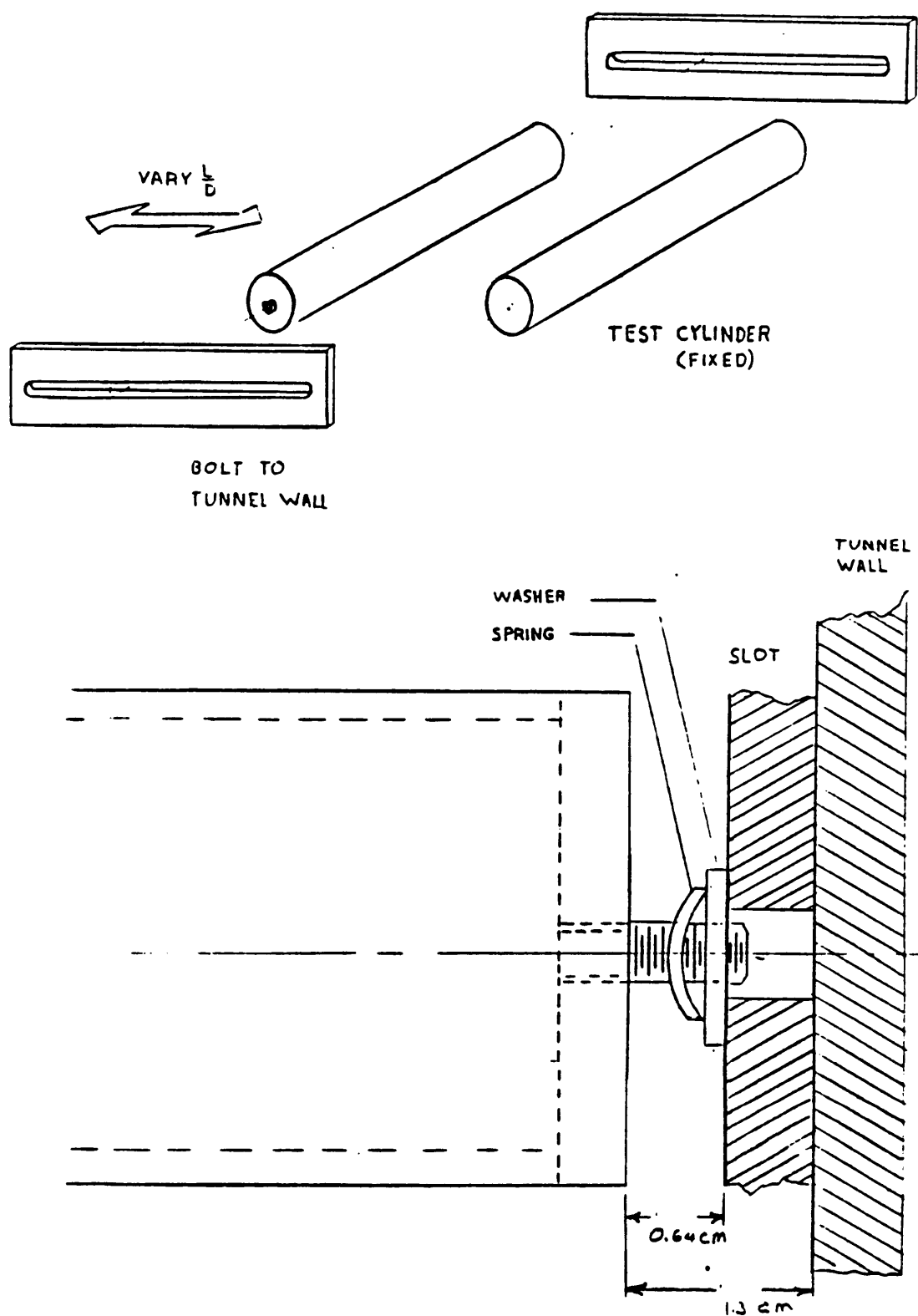


Figure 19. Mounting acrylic cylinders in the test section for in-line arrangements

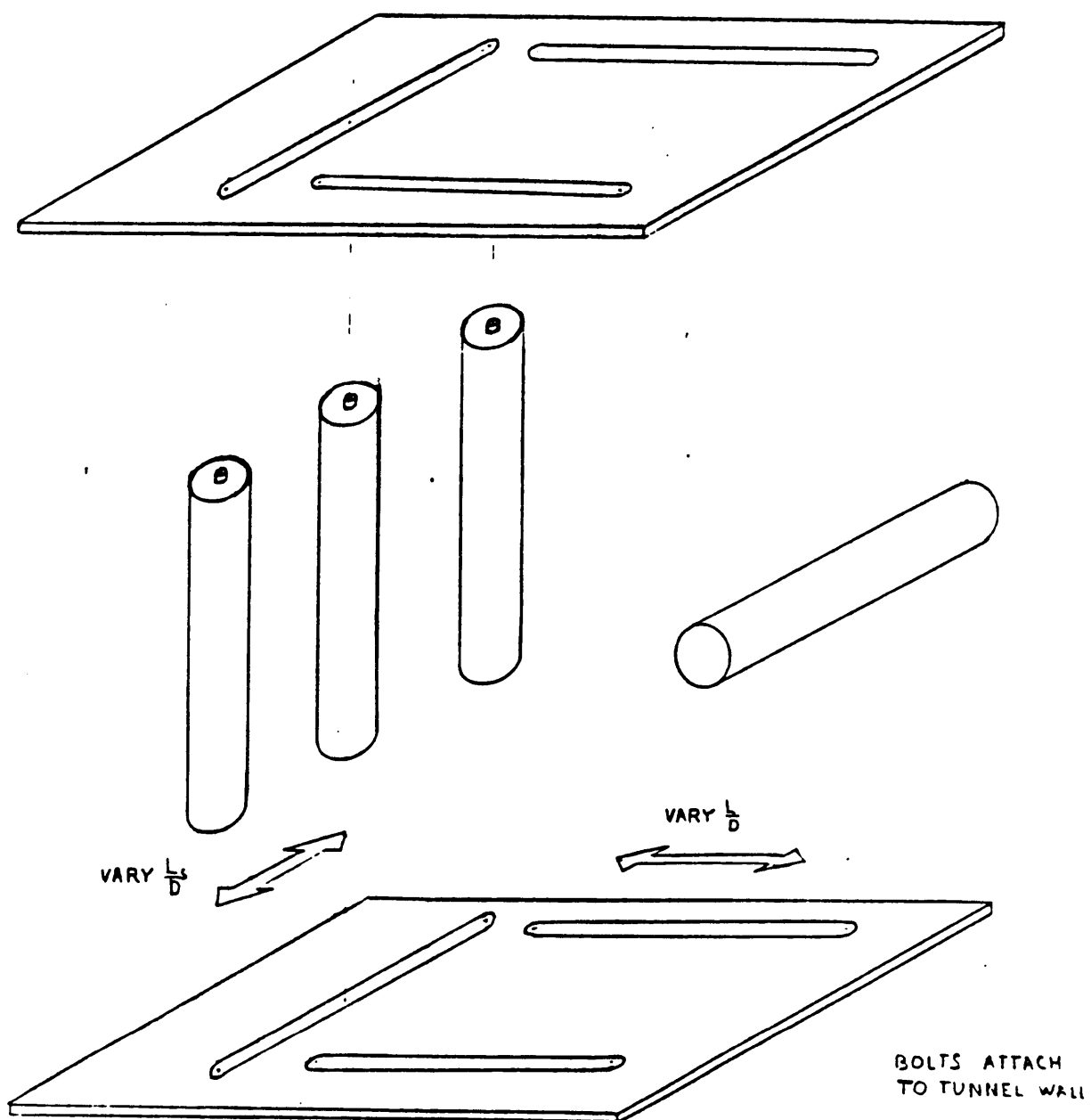


Figure 20. Perpendicular arrangements of cylinders

A schematic of the experimental system is given in Figure 21. A TRS-80 based data acquisition system developed by Andraka was modified for use in this investigation. The system was used for temperature measurement, to control a multiplexer which switched channels for SCR output voltage measurement, and to store data on a diskette. Individual heater voltage readings were made using a HP-3468A digital multimeter (DMM), and averaged using a HP-41CV calculator connected to the multiplexer through an HP-IL interface. A listing of Andraka's modified data acquisition program is given in Appendix G. The original program, machine language subroutines, and a description of the system are given in Appendix A of reference [35].

3.4.1 TEMPERATURE MEASUREMENT

A Doric #410A thermocouple readout calibrated to $\pm 0.1^{\circ}\text{C}$ was used to read 30 thermocouples on the cylinder, the freestream and ambient temperatures. The Doric was connected to the TRS-80 through a D-80 interface box. Channel selection was controlled by the TRS-80 through a junction box containing 32 reed relays. Five thermocouples were generally read on each segment (TC no. A1-A5, B1-B5, etc.) and one thermocouple was read on each heater (TC no. GA3,GA4,GC3,GC4). The temperature below each heater and the centerline temperature were also recorded.

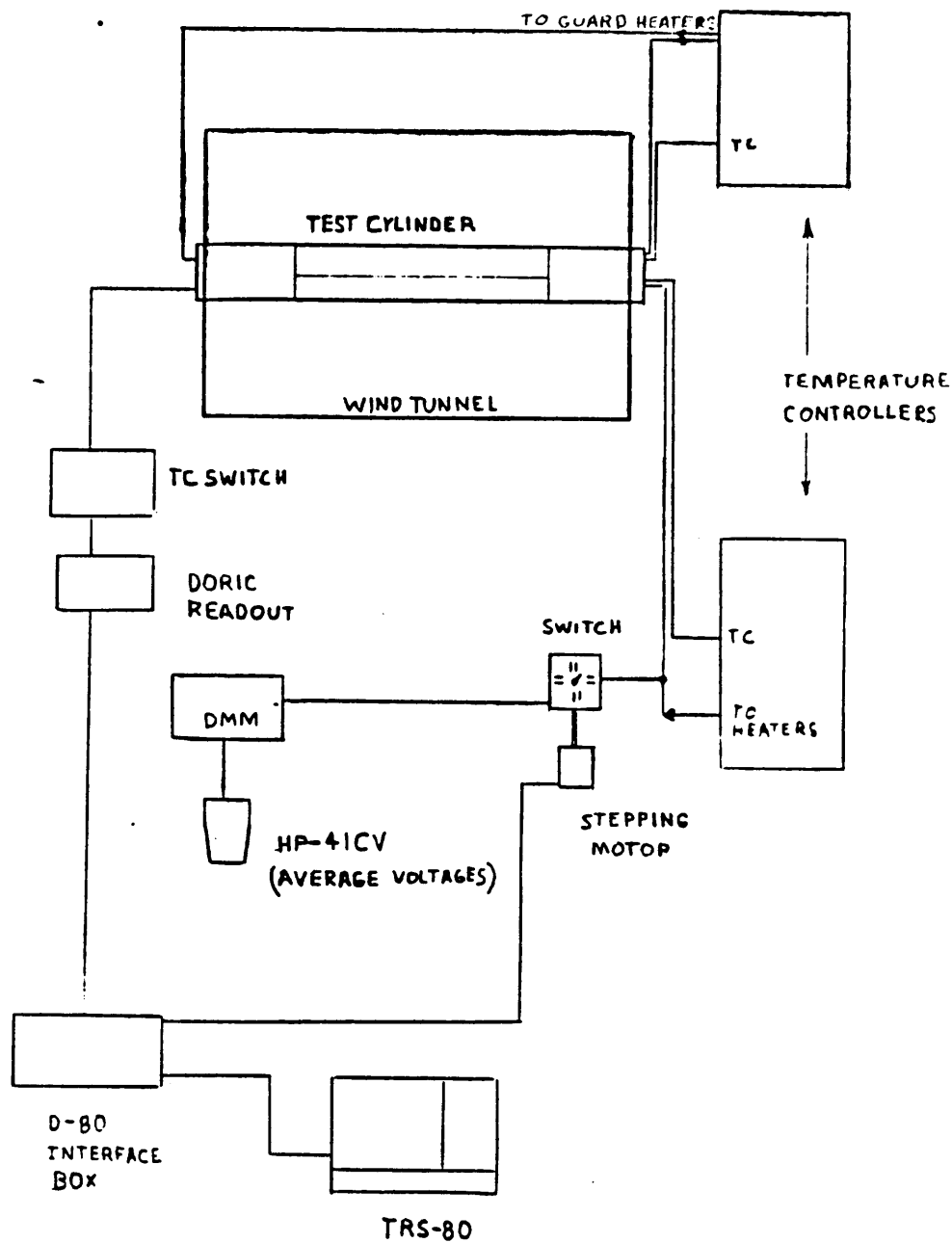


Figure 21. Schematic of experimental system

3.4.2 VOLTAGE MEASUREMENT

While the Eurotherm controllers maintain the temperature of each segment to $\pm 0.1^{\circ}\text{C}$, the voltage output by an SCR to a heater was found to vary with time. The standard deviation of individual voltage readings made with the multimeter was between $0.42 < \sigma_v < 1.8$ volts, depending on controller settings. This large standard deviation would have introduced an unacceptable uncertainty into the results. Time averaging of individual voltage readings was used to reduce the uncertainty of voltage measurement.

It was also necessary to determine whether or not a heater voltage from a given SCR was in equilibrium before recording a data point. This was accomplished by continuously reading the average voltage on each channel and comparing successive voltage readings until the average voltage changed by less than ± 0.3 volts. An HP-41CV calculator and HP-IL interface were used as a data logger for the HP-3468 multimeter. The data acquisition program is listed in Appendix B. A multiplexer controlled by the TRS-80 allowed voltages to be read on four channels corresponding to heaters for segments A to D. The multiplexer consisted of a TRS-80 controlled stepping motor and eight magnetic reed switches. When the stepping motor moved a magnet into the proximity of a pair of reed switches, the leads of the DMM were connected across the heater.

The multiplexer contained four closed switch and four open switch positions. When a switch is closed, the HP-DMM-41CV recorded true AC RMS voltage continuously until successive readings differed by five or more volts. This voltage drop occurred when the multiplexer began a channel

switch by moving to a neutral position. The HP-41CV removed the two most recent voltages from memory before averaging the voltage readings. The average was stored in memory and the HP-DMM-41CV began recording voltages on the next channel. At this point, the multiplexer had already moved to the next closed switch position.

The number of individual voltage readings taken for each average voltage could be adjusted by modifying the timing loop for the stepping motor in the TRS-80 data acquisition program. The timing loop was adjusted so that voltages for each channel were read over a period of 2 1/2 minutes, which corresponds to approximately 150 voltage readings per average. The HP-41CV program ran continuously until two successive averages on each of the four channels differed by less than ± 0.3 volts. The standard deviation of voltage averages was found to be $\sigma_v = 0.19$ volts (Appendix B) for the controller settings used in this investigation.

3.4.3 VELOCITY MEASUREMENT

Freestream velocity was measured using a Pitot tube placed 31 cm in front and 21 cm above the centerline of the test cylinder. For the perpendicular arrangement, the Pitot tube was moved to the front of the test section. Velocity was adjusted with the front cylinder moved back to $L/D=1.1$. At this position, it was found that the the front cylinder did not appear to affect the flow at the Pitot tube. The front cylinder was then moved forward to the pitch ratio used for the test. A test with a second Pitot tube placed at the front of the test section indicated that

the freestream velocity does not change when the first cylinder is moved forward.

The difference between static and dynamic pressure from the Pitot tube was measured using a manometer accurate to ± 0.7 PA (± 0.003 inches H_2O) for steady flow and at pulsation frequencies above 5 Hz. For low frequency, the manometer could be read to ± 0.01 inches H_2O (2.4 Pa).

Unsteady velocity was measured using a TSI IFA-100 constant-temperature anemometer, a model 1073 output linearizer, and a model 1210 hot film probe. The anemometer was used to determine steady flow turbulence level, pulsation frequency and amplitude, cylinder vortex shedding frequency, and to verify mean velocity measurements made with the Pitot tube.

3.4.4 MEASUREMENT OF TURBULENCE LEVEL, PULSATION FREQUENCY AND AMPLITUDE

To measure the freestream turbulence level, the hot film probe was positioned at the front of the test section. True RMS AC and DC linearized output voltages from the IFA-100 were averaged 20 times using the HP-DMM-41CV. The turbulence level for steady flow was determined by dividing AC RMS voltage by the DC voltage. The program listing for the HP-41CV is given in Appendix B.

The procedure for measuring pulsation amplitude was similar to the procedure for measuring steady flow and unsteady flow turbulence level. Because the pulsations were very nearly sinusoidal, the zero-to-peak amplitude was determined by applying a correction to the AC RMS voltage:

$$\tau = \sqrt{2} \frac{V_{AC}}{V_{DC}} \quad (4)$$

Pulsation frequency and vortex shedding frequency were determined from the hot film signal using a Spectral Dynamics SD330a real time analyzer. Pulsation frequency was adjusted and amplitude was measured before each data point was taken with the probe at the front of the test section. For shedding frequency measurements, the probe was positioned near the back of the tunnel and in the wake of the test cylinder. Auto spectra for the wake were recorded using an HP-5420A signal analyzer.

3.5 DATA REDUCTION

Raw data stored on a TRS-80 diskette was passed to an IBM 3081 mainframe for data reduction. Each data point consisted of 32 thermocouple readings ($^{\circ}\text{C}$), heater voltage for each cylinder segment (true AC RMS), Pitot tube reading (in. H_2O), pulsation frequency (Hz) and amplitude (percent zero-to-peak).

The temperature for each segment was evaluated by averaging the center and corner temperatures. For section i :

$$T_i = \frac{T_{i1}}{2} + \frac{1}{8} (T_{i2} + T_{i3} + T_{i4} + T_{i5}) \quad (5)$$

The temperature of the cylinder, which was used to determine film temperature, was taken as the average of the temperatures of the four cylinder segments.

The electrical power for each heater was evaluated using:

$$P = \frac{V_i^2}{R_i} \quad (6)$$

the resistance of the 15 cm heater leads was negligible compared to the resistance of the heaters, therefore no correction was necessary.

The heat transfer coefficient for each segment was calculated using:

$$h_i = \frac{P_i - \sum_i Q_{Li}}{A_i (T_i - T_\infty)} \quad (7)$$

where Q_{Li} represents a correction to the experimental power measurement for heat transferred from section i other than by convection. The overall heat transfer coefficient for the cylinder was evaluated by averaging the heat transfer coefficient for each section.

Three cylinder power corrections were considered:

$$Q = Q_{Ri} + \Delta Q_{Li} + Q_{Ci} \quad (8)$$

The first term, Q_{Ri} , was the radiation heat transfer for segment i . A second correction, ΔQ_{Li} , was calculated to compensate for a decrease in heat transfer caused by a temperature drop on the surface of the insulation strips separating cylinder segments. A third correction, Q_{Ci} , would have compensated for conduction losses between cylinder segments through the acrylic support tube. As previously stated, the correction was investigated, but not implemented.

The radiation correction assumes a diffuse gray cylinder surface and blackbody surroundings:

$$Q_{Ri} = A_i \sigma \epsilon (T_i^4 - T_\infty^4) \quad (9)$$

with $\epsilon=0.15$ for slightly polished copper [42]. This correction is generally on the order of 2 percent of the total power for each segment.

The correction for the effect of insulation strips is given in Appendix C. The temperature on the top face of the insulation drops by about 10 to 15 percent of $T_i - T_\infty$, slightly reducing heat transfer from each section. The correction was the difference between heat transferred with the insulation and heat transferred if no insulation were present (isothermal surface at T_i):

$$\Delta Q = \left[h \frac{w}{2} - q_{L1}(Bi, w/d) k \right] L_c (T_i - T_\infty) \quad (10)$$

where h is the local heat transfer coefficient and q_{L1} is the convective heat loss from an insulation strip in dimensionless form. Losses on each insulation strip surrounding a section were considered separately. The local heat transfer coefficient was approximated using the experimental power measurement for a segment and the local heat transfer distribution around a single cylinder. The correction was generally between 0.1 and 0.3 percent of the experimental power, and was always negative, increasing h_i .

A third correction was considered to compensate for internal heat transfer between segments through the acrylic support tube. An attempt

was made to calibrate the cylinder to determine the resistance to heat transfer between each segment and the surrounding segments or guard heaters. The resulting correction was up to 15 percent of the experimental power measurement for a segment. It was not considered correct because the calculated resistances to heat transfer were too small. For example, once the correction was applied, the power on the top and bottom of the cylinder was no longer symmetric. Although the correction was not made, the method of calibration and the effect of the correction are given in Appendix D.

Nusselt number based on cylinder diameter was calculated from the heat transfer coefficient using:

$$Nu_i = \frac{h_i D}{k} \quad (11)$$

Thermal conductivity was evaluated at the film temperature:

$$T_f = \frac{1}{2} (T_i + T_\infty) \quad (12)$$

Velocity was calculated from the Pitot tube reading using:

$$U_\infty = \frac{2\Delta P}{\sqrt{\rho_a}} \quad (13)$$

with air density evaluated at the free stream temperature and local atmospheric pressure using the ideal gas law. Reynolds number was calculated using:

$$Re = \frac{\rho_a U_\infty D}{\mu} \quad (14)$$

with density evaluated using the ideal gas law (at the average film temperature for the four segments) and dynamic viscosity, which has very little pressure dependence, evaluated at the film temperature. Frossling number was calculated using:

$$Fr_i = Nu_i Re_i^{-1/2} \quad (15)$$

Driving and shedding frequencies were put in dimensionless form:

$$F_d = \frac{f_d D}{U_\infty} \quad (16)$$

$$F_s = \frac{f_s D}{U_\infty} \quad (17)$$

Reduced data for each test follow the data file in Appendix H.

4.0 RESULTS

Time averaged heat transfer on the front and back of a test cylinder was measured for a single cylinder in a free stream, for the second cylinder in tandem arrangements, and for a cylinder in the wake of three perpendicular cylinders. Results are presented for both steady and pulsating crossflow. For pulsating flow, driving frequencies ranged from 2 Hz. to 23 Hz. Pitch ratio for arrangements of multiple cylinders was varied in the range of $1.1 < L/D < 5$. Reynolds number ranged from 23,000 to 49,000.

The results are discussed in different sections for the cases of a single cylinder, in-line arrangements and perpendicular arrangements of cylinders. Flow conditions for each test are given in tabular form at the beginning of each section. Whenever possible, a comparison is made with similar data from references. Nusselt number for steady flow is given first, followed by relative Nusselt number (Nu_f/Nu_s) for pulsating flow. Separate Figures are given for front and back, and overall heat transfer. In addition, unsteady flow data obtained with a hot-film placed in the wake of the test cylinder is given at the end of each section.

Overall experimental uncertainty (Appendix A) was estimated to be 2.4 percent at $Re=49,000$ and 2.9 percent at $Re=23,000$. A steady flow test was conducted for each arrangement of cylinders. The steady flow data was also repeated at the beginning of each unsteady flow test by including a data point at $f_d=0$ Hz. Comparison of steady flow results taken with the same flow conditions (Table 4) indicates that results are

repeatable to within the levels of experimental uncertainty. The 95 percent confidence interval for heat transfer measurements was found to be 2.9 percent for a half section of the cylinder, and 1.5 percent overall.

4.1 SINGLE CYLINDER

Flow conditions for tests with a single cylinder are given in Table 5. Reduced data is given in Appendix H. Figures 22 and 23 show the Nusselt number dependence on Reynolds number for steady flow. Results are compared to Andraka and Diller's data (Ref. 9) and to a correlation given by Zuskaukas [1] in Table 6. Nusselt numbers in Table 6 were not adjusted for blockage. Overall Nusselt number measured for this investigation at $Re=49,000$ shows good agreement with Andraka's data. Both current results and results from Andraka are about 15 percent higher than the Nusselt number predicted by Zukauskas' correlation for all Reynolds numbers tested. The Nusselt number measured on the front of the cylinder is 11 percent higher than Andraka's data, and 7 percent lower on the back.

The ratio of Nusselt number for pulsating flow to Nusselt number for steady flow (Nu_f/Nu_s) is shown in Figures 24 and 25 for four Reynolds numbers between $Re=23,000$ and $Re=49,000$. Increases of up to 36 percent were observed on the back of the cylinder. No increase outside of experimental error was seen on the front of the cylinder. For the test at $Re=49,000$, the amplitude was adjusted to match Andraka's conditions. Pulsating flow data is compared to Andraka's results in Table 7. Increases of up to 7 percent were observed on the back of the cylinder.

Table 4. Repeatability for a single cylinder for $Re=49000$

Page (Appendix H)	Nu_{front}	Nu_{back}	$Nu_{overall}$
	177.13	159.23	168.18
	179.50	162.13	170.81
	174.45	150.83	162.64
	181.05	154.13	167.59
	177.96	157.70	167.83
	174.93	150.23	166.20
average	177.49	155.70	167.22
standard deviation	± 2.78	± 4.78	± 2.69
standard deviation (percent)	± 1.4	± 3.1	± 1.6
95 % confidence limit (percent)	± 1.3	± 2.9	± 1.5

Table 5. Test conditions for a single cylinder

Reynolds number	f_d Hz	Page (Appendix H)
23000-106000	0	204
23000	0-23	206
32000	0-23	210
42000	0-23	212
49000	0-23	214
49000	10 (vary amp 0-34%)	216

AMPLITUDES:

	Re=23000	Re=32000	Re=40000	Re=49000*
f_d Hz	amplitude	amplitude	amplitude	amplitude
2.0	23.3	28.0	29.5	9.8
5.0	17.5	-	-	-
7.0	15.7	14.7	17.4	4.1
11.0	12.3	-	-	-
13.0	11.1	13.6	14.5	-
18.0	7.0	13.8	18.5	-
18.5	-	-	-	8.9
20.0	9.0	-	-	-
23.0	6.7	8.0	8.6	8.9
26.0	-	7.0	-	-

* amplitudes adjusted to match Andraka's values (ref. 40)

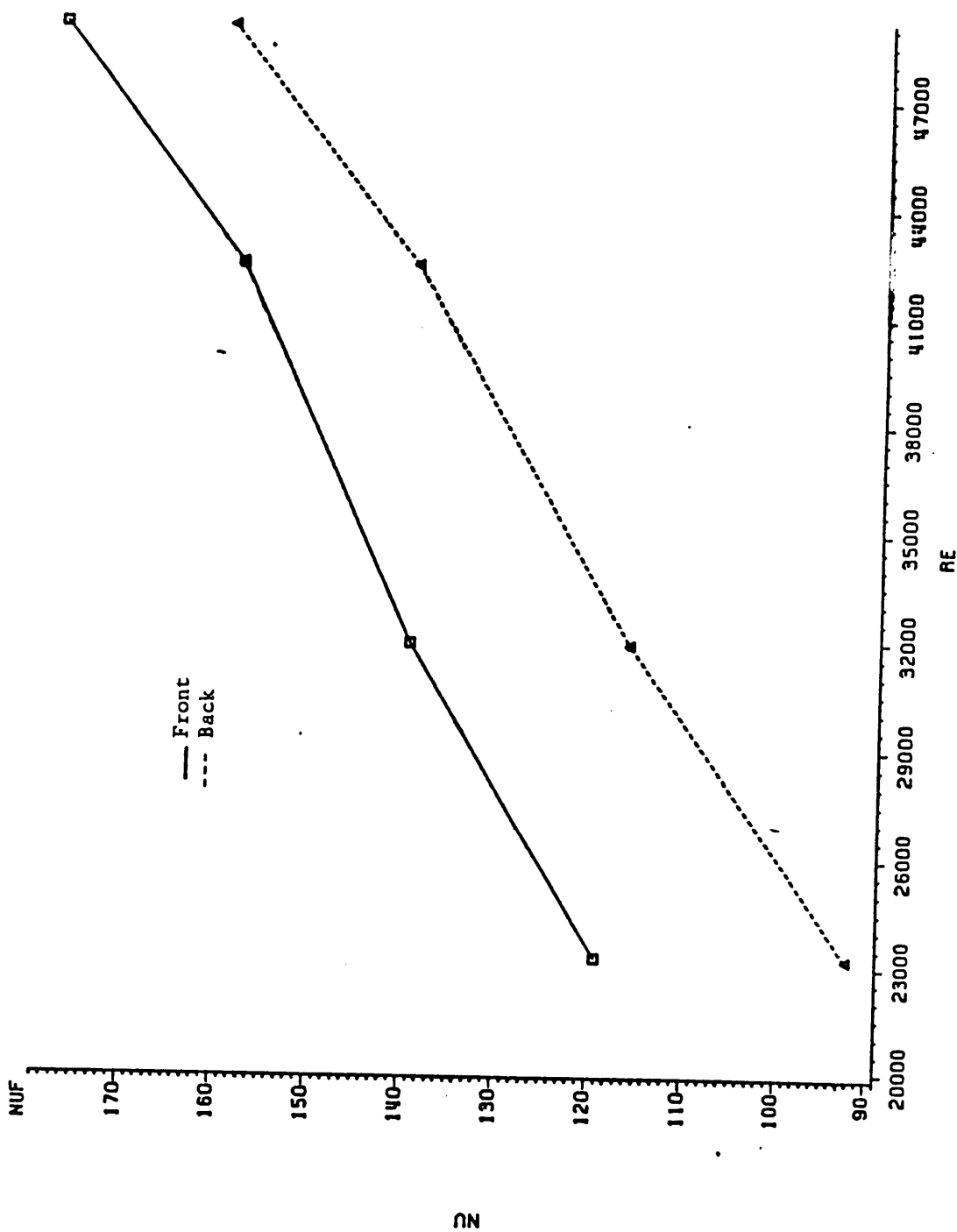


Figure 22. Nusselt number variation with Reynolds number for the front and back

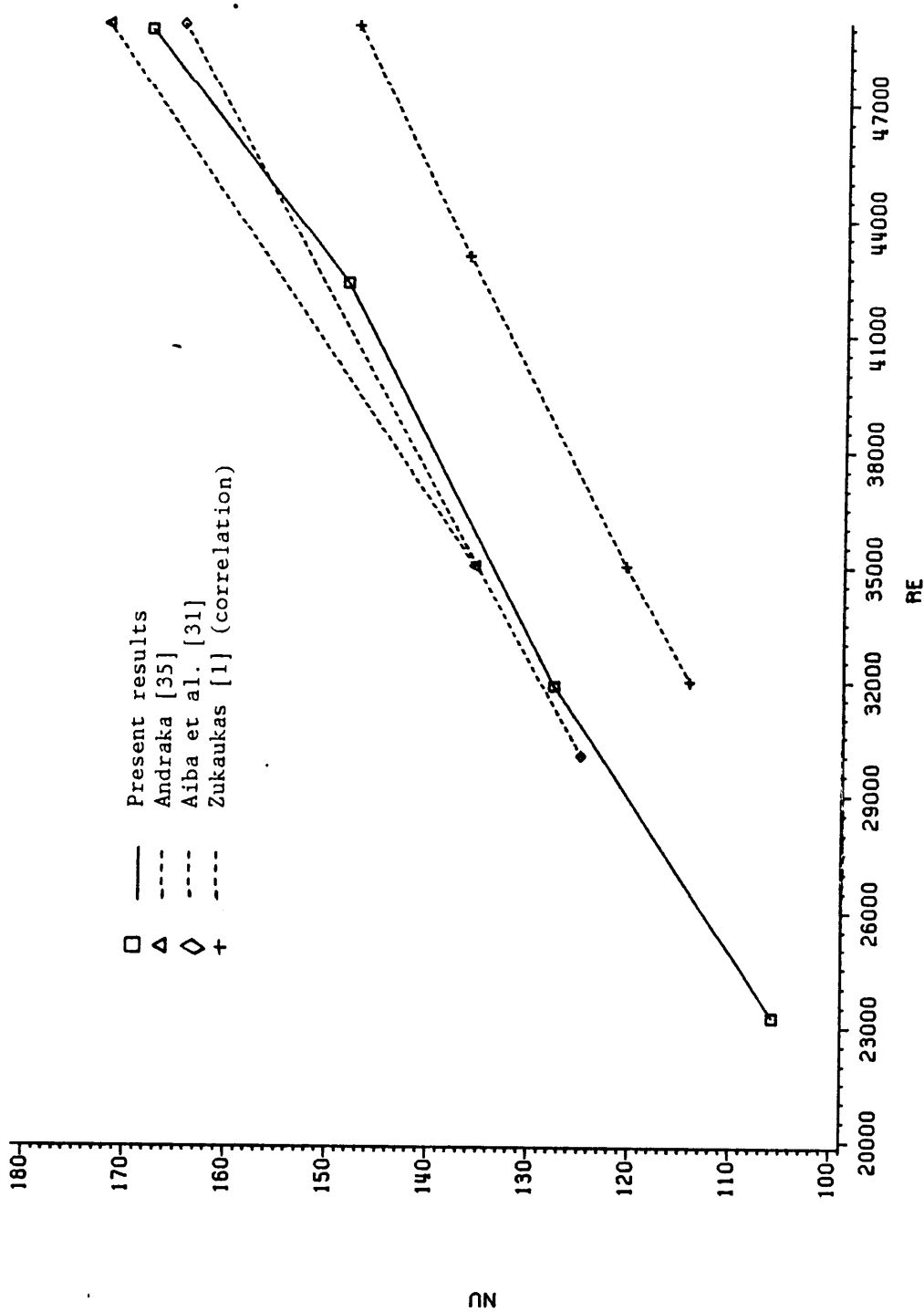


Figure 23. Overall Nusselt number variation with Reynolds number

Table 6. Comparisson of current results with references

Reynolds Number	Nu _{overall}		
	Present Results	Andraka [33]	Zukauskas [1]
32000	127.7	-	114.3
35000	-	135.7	120.7
43000	148.5	-	136.5
49000	168.1	172.5	147.7
99600	-	244.4	225.9

Reynolds Number	Nu _{back}		
	Present Results	Andraka [33]	Zukauskas [1]
32000	116.0	-	140.6
35000	-	131.1	150.1
43000	139.2	-	174.4
49000	159.2	178.0	181.7
99600	-	255.5	322.0

Reynolds Number	Nu _{front}		
	Present Results	Andraka [33]	Zukauskas [1]
32000	139.4	-	-
35000	-	140.3	-
43000	157.8	-	-
49000	177.1	166.9	-
99600	-	233.3	-

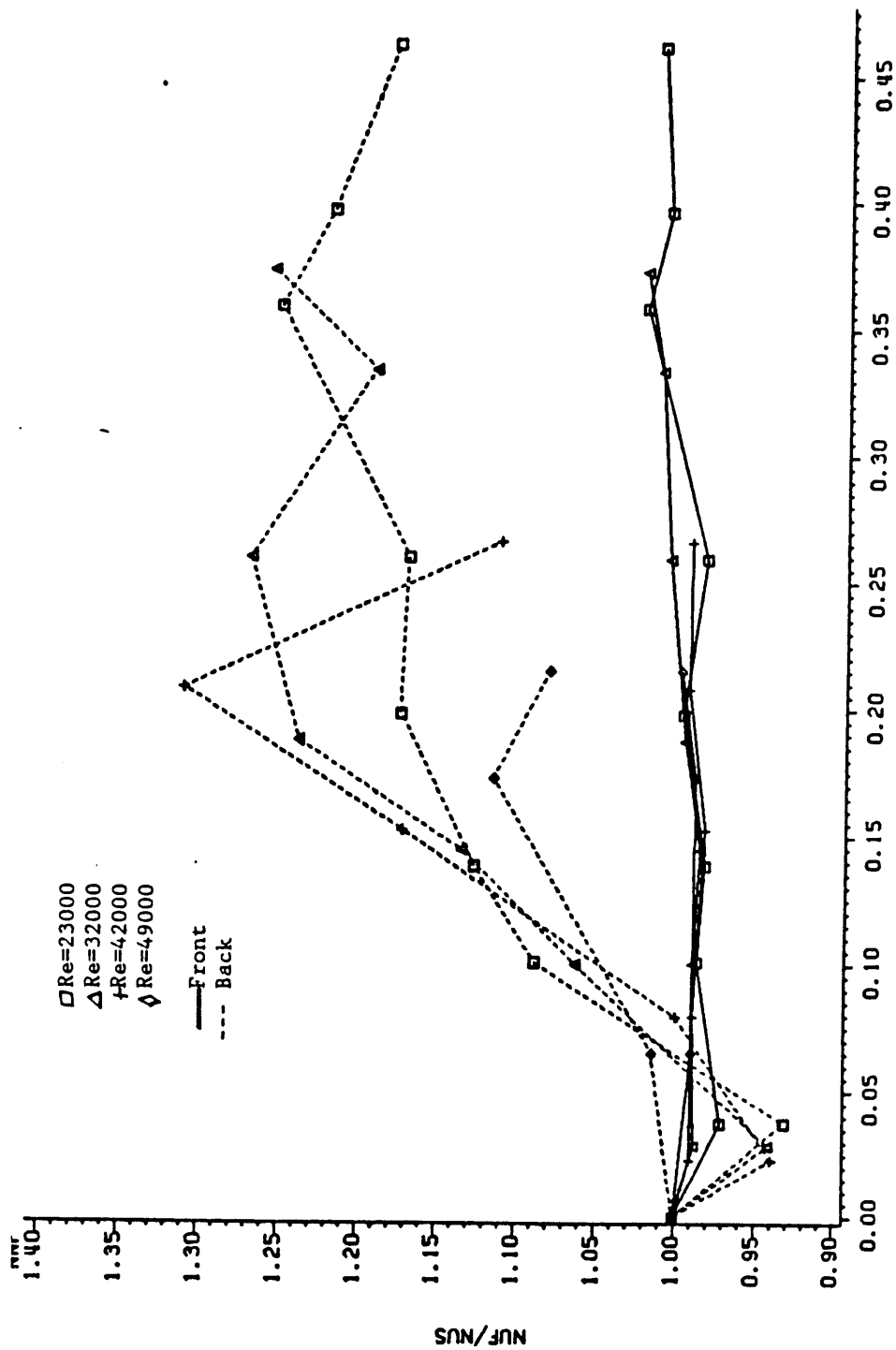


Figure 24. Relative Nusselt number dependence on pulsation frequency, front and back

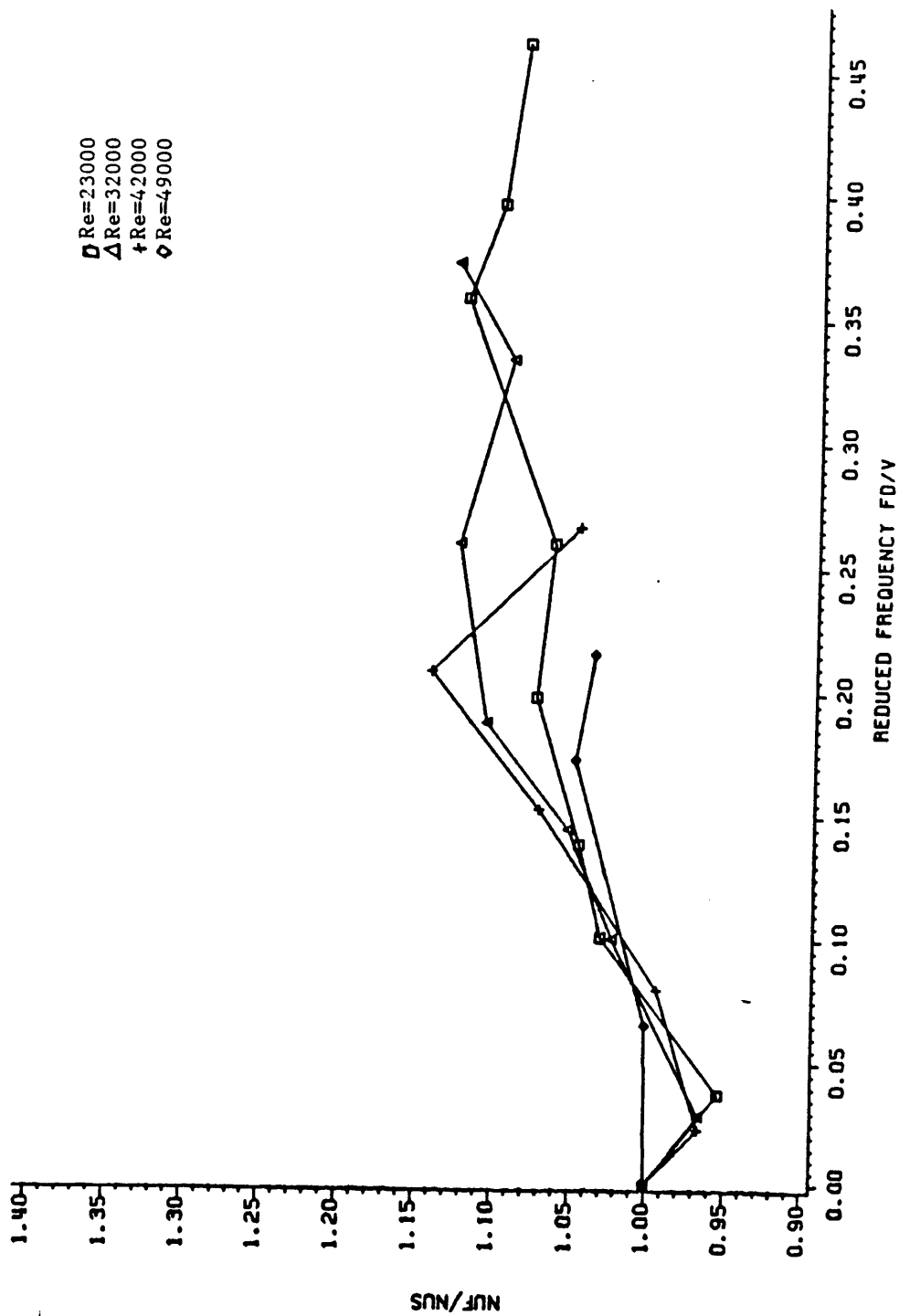


Figure 25. Relative Nusselt number dependence on pulsation frequency, overall

Table 7 Comparisson of current unsteady flow results with Andraka [35] at $Re=49000$

Overall					
f_d Hz	amp	Present Results	Nu_f/Nu_s	Andraka [33]	Nu_f/Nu_s
		Nu		Nu	
0	0	168.2	-	172.4	-
7	4.1%	168.4	1.001	173.1	1.004
18.5	8.9%	176.2	1.048	170.9	0.991
23.0	8.9%	174.3	1.037	170.6	0.990

Front					
f_d Hz	amp	Present Results	Nu_f/Nu_s	Andraka [33]	Nu_f/Nu_s
		Nu		Nu	
0	0	177.1	-	166.9	-
7	4.1%	175.3	0.990	164.9	0.988
18.5	8.9%	175.1	0.989	162.2	0.972
23.0	8.9%	176.7	0.998	161.3	0.967

Back					
f_d Hz	amp	Present Results	Nu_f/Nu_s	Andraka [33]	Nu_f/Nu_s
		Nu		Nu	
0	0	159.2	-	178.0	-
7	4.1%	161.5	1.014	181.2	1.017
18.5	8.9%	177.4	1.115	178.0	1.000
23.0	8.9%	172.0	1.080	179.8	1.010

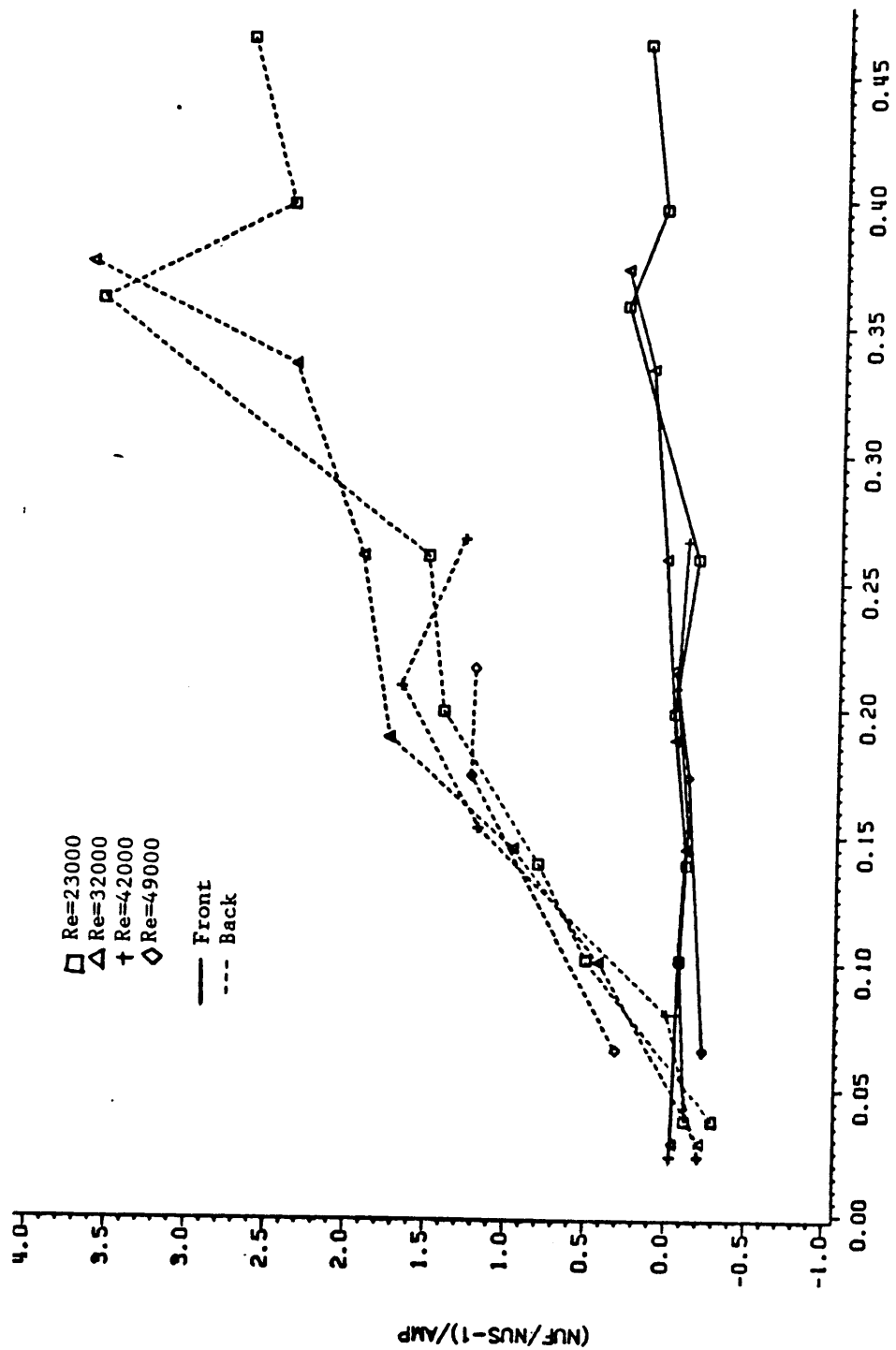
This is in contrast to Andraka's results, which suggest no increase in heat transfer outside of experimental uncertainty both overall and on the front or back of the cylinder.

The relative increase in Nusselt number per unit amplitude ($[\text{Nu}_f/\text{Nu}_s - 1]/\tau$) is shown in Figures 26 and 27. Once the effect of pulsation amplitude is accounted for, the increase in Nusselt number for $f_d/f_s < 1$ appears to be independent of Reynolds number for $23,000 < \text{Re} < 49,000$. Figures 28 and 29 show the results of a test where pulsation amplitude was varied.

Figure 30 shows Autospectra of the linearized signal from a hot wire placed in the wake of the cylinder at $\text{Re}=32,000$. The shedding frequency is slightly lower than the steady flow value at low driving frequencies. As driving frequency increases beyond the natural shedding frequency for steady flow, vortex shedding locks on at half the driving frequency.

4.2 IN-LINE ARRANGEMENTS OF CYLINDERS.

Flow conditions for tests with a single in-line row of cylinders are given in Table 8. Figures 31 and 32 show Nusselt number variation on the second cylinder at various spacings for $\text{Re}=23,000$ and $\text{Re}=49,000$. Data from Aiba et al. [31] for similar flow conditions but with a CHF boundary condition is included with overall data in Figure 32. Results at $L/D=1.8$ show good agreement with Aiba.



LEGEND: CASE

Figure 26. Nusselt number increase per unit amplitude, front and back

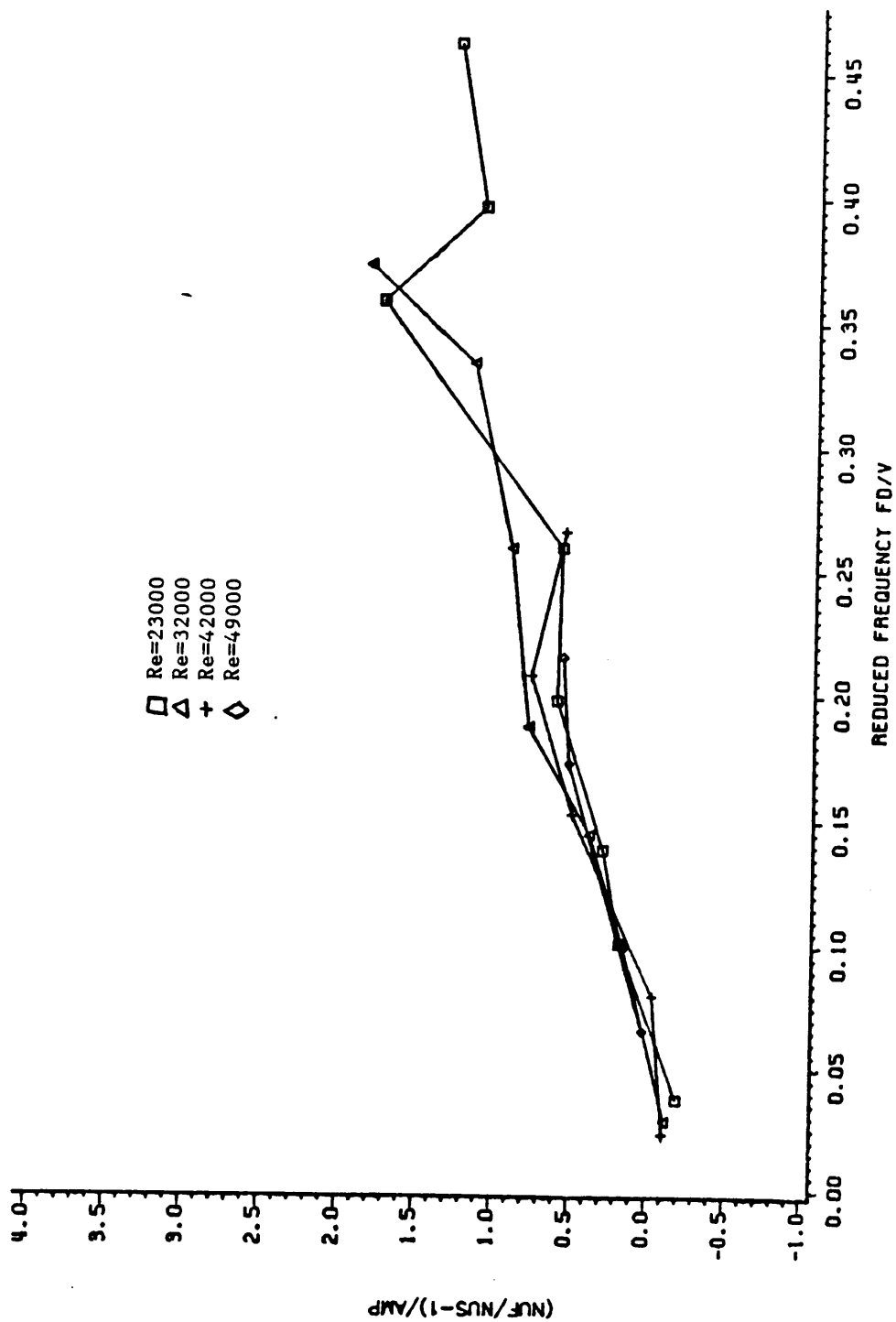


Figure 27. Nusselt number increase per unit amplitude, overall

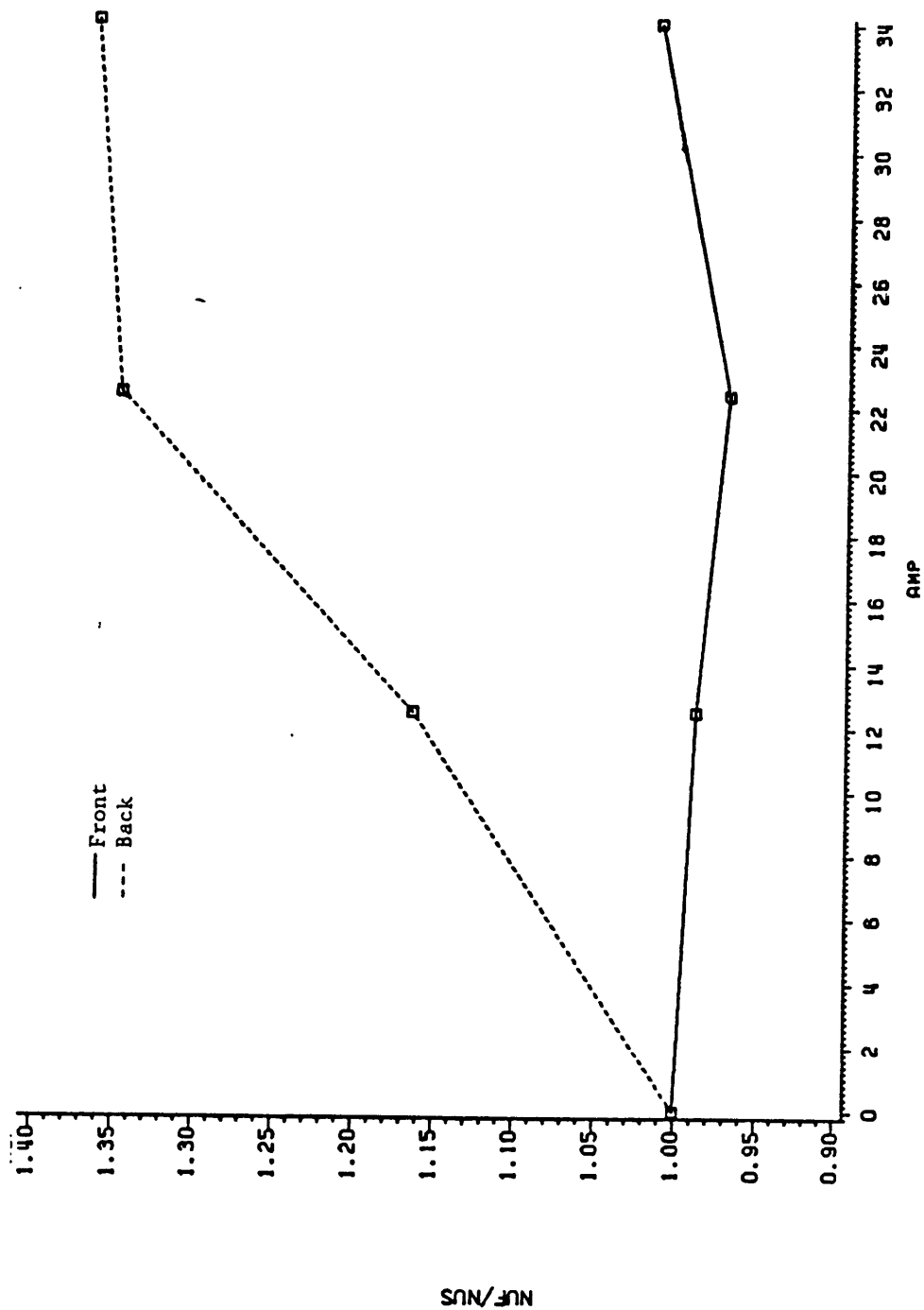


Figure 28. Effect of pulsation amplitude on relative Nusselt Number, front and back

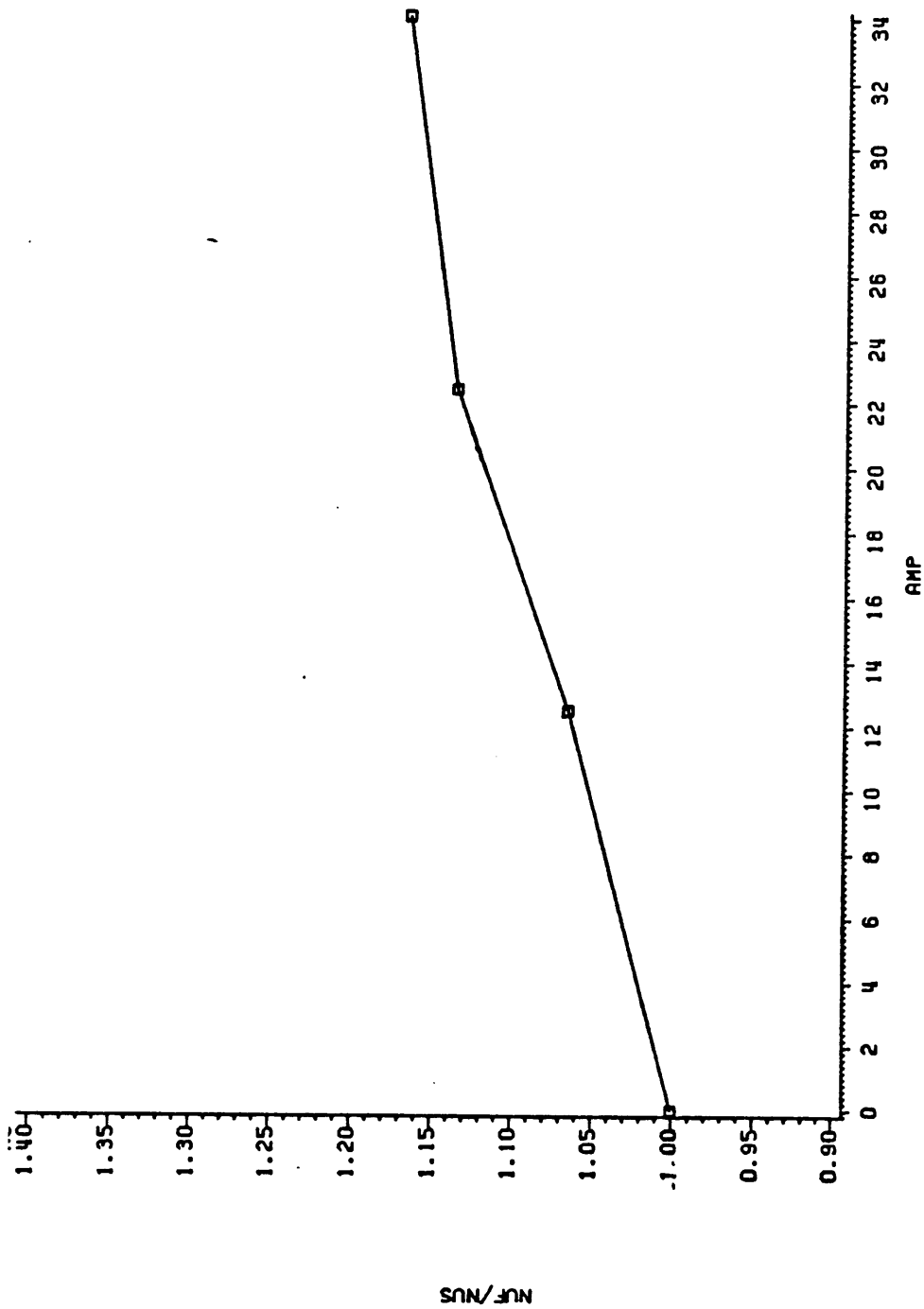


Figure 29. Effect of pulsation amplitude on relative Nusselt Number, overall

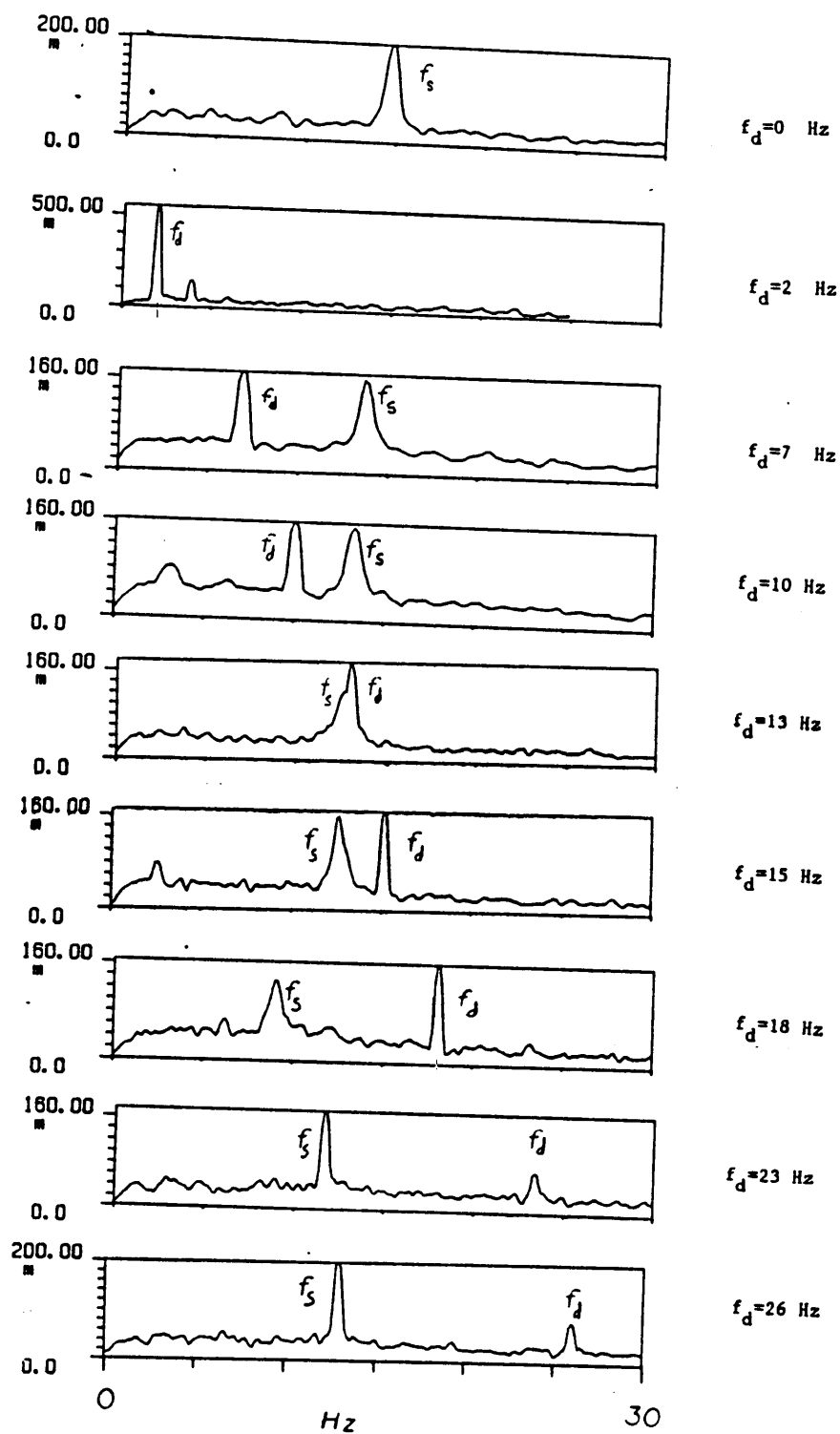


Figure 30. Driving and Shedding frequencies in the wake of a single cylinder at $Re=32000$.

Table 8. Test conditions for a in-line arrangements

Reynolds number	L/D	f_d Hz	Page (Appendix H)
10000-460000	1.2-4.75	0	237
23000	1.1	0	239
23000	1.1	0-23	223
49000	1.1	0-23	225
23000	1.25	0-23	227
49000	1.25	0-23	229
23000	1.8	0-23	231
49000	1.8	0-23	233
49000	4.75.1	0-23	235

AMPLITUDES:

	Re=23000	Re=49000
f_d Hz	amplitude	amplitude
2.0	27.4	28.6
5.0	18.6	21.7
7.0	16.6	19.2
10.0	12.1	13.5
13.0	10.3	15.0
17.0	6.0	18.6
23.0	3.9	6.8

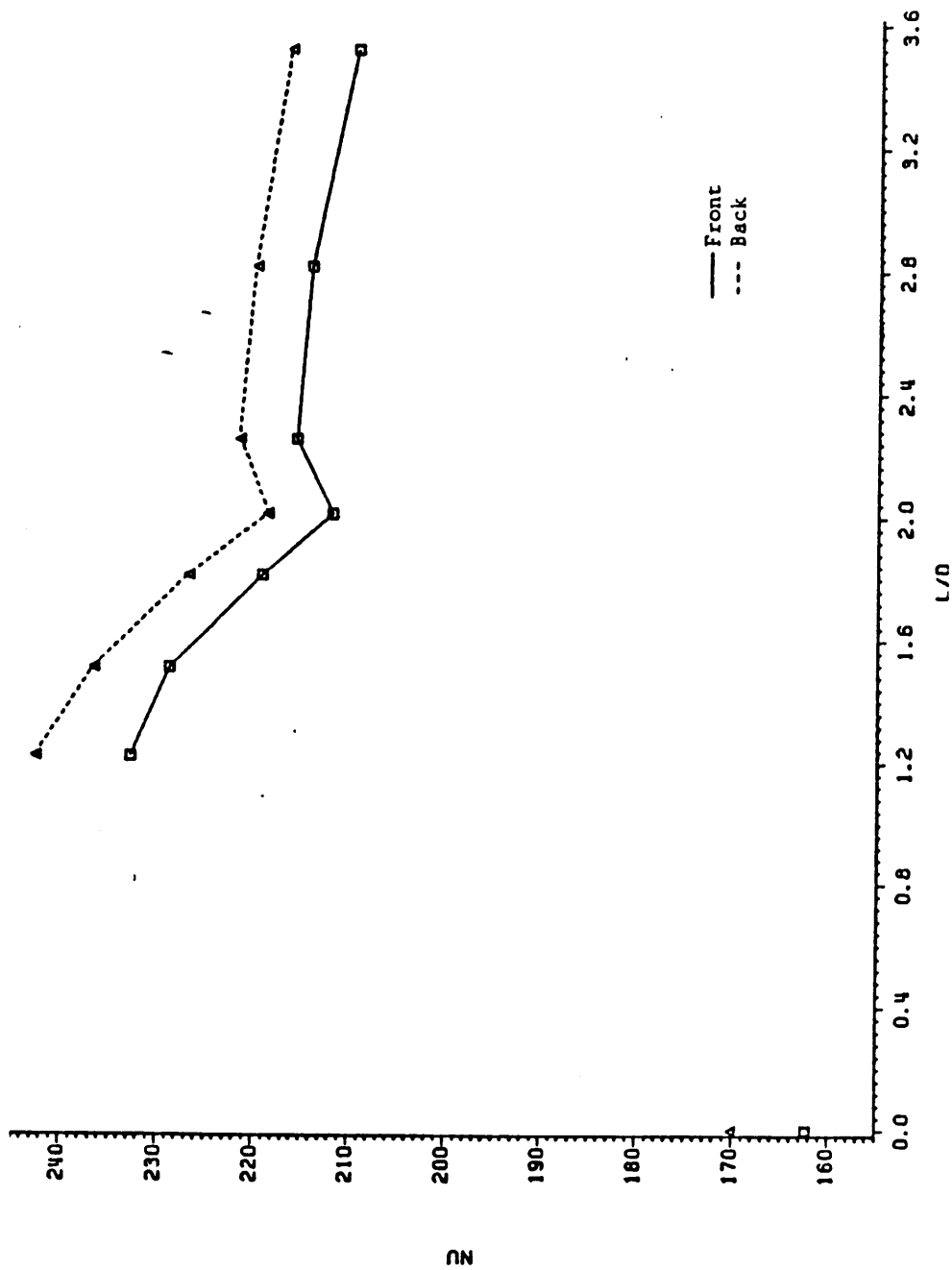


Figure 31. Nusselt number at various spacings for $Re=49000$, front and back.

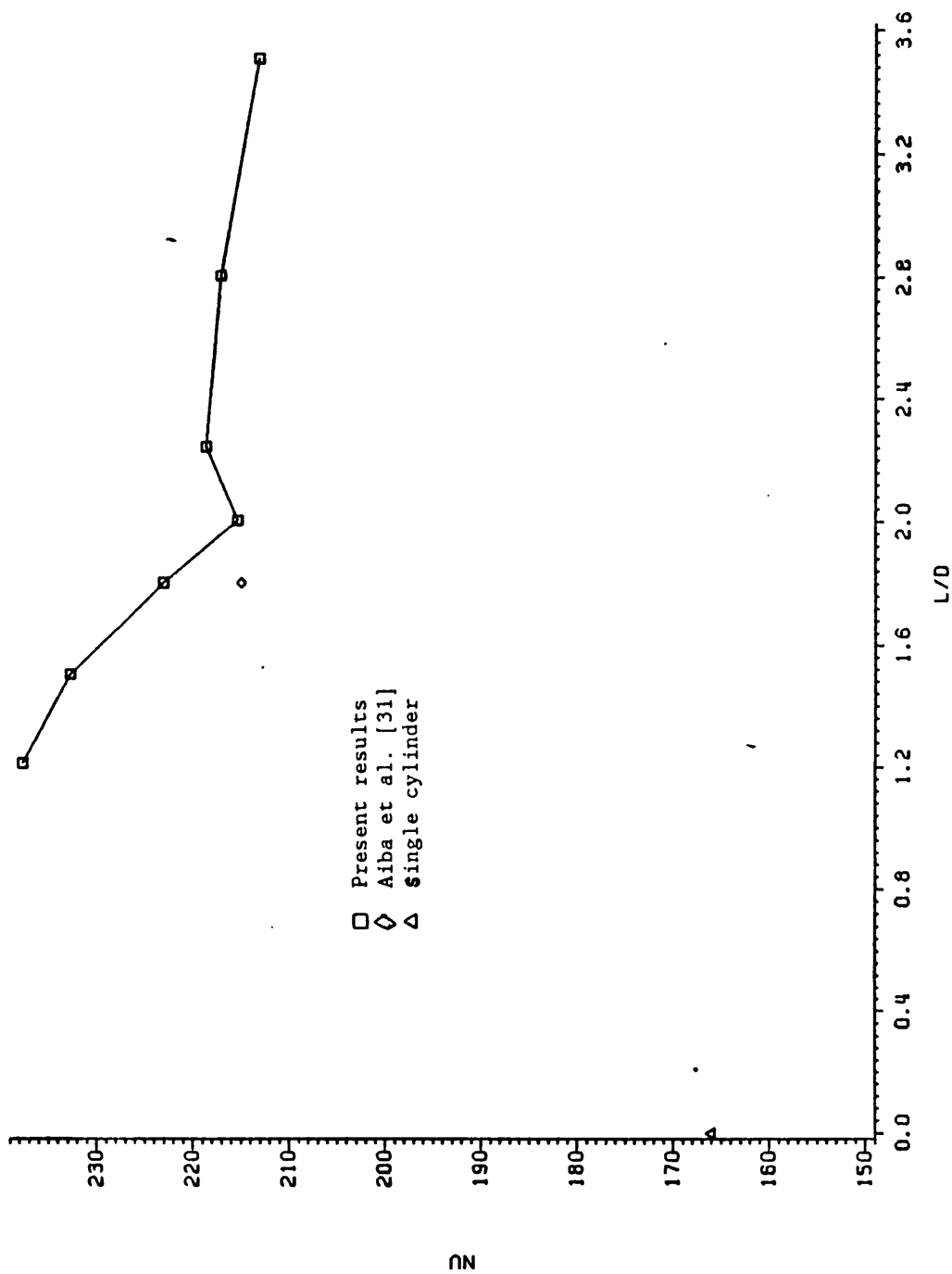


Figure 32. Nusselt number at various spacings for $Re=49,000$, overall

Figures 33 and 34 show Nusselt number dependence on Reynolds number for $L/D=1.1$. For four cylinders in an in-line arrangement, Aiba et al. [29] report a discontinuous increase of 10 to 35 percent in Nusselt number as the Reynolds number increases past the critical Reynolds number corresponding to the jump phenomenon. For three cylinders, the correlation presented by Igarashi [33] predicts the critical Reynolds number to be $Re_c=36,000$ for $L/D=1.1$. The present results show no sudden increase in Nusselt number between $Re=10,000$ and $Re=47,000$.

Figures 35 to 42 show the dependence of Nu_f/Nu_s on reduced frequency for pitch ratios of $L/D=1.1, 1.25, 1.8, 4.75$. Results are given for $Re=23,000$ and $49,000$. Increases in Nusselt number are smaller than for a single cylinder at the same flow and pulsation conditions. Unlike the results for a single cylinder, however, the largest increases in Nusselt number occur on the front of the cylinder. Nusselt number on the front of the cylinder was generally about 5 percent higher for pulsation frequencies above the natural vortex shedding frequency for steady flow. Increases of up to 11 percent were observed on the front for $L/D=1.1$. The flow pulsations also appear to have a greater effect on heat transfer at $Re=23,000$. As for a single cylinder, a decrease in heat transfer of up to 8 percent was observed at low driving frequencies ($f_d/f_s < 0.05$).

Unsteady velocity data was taken both in the wake of the three cylinders and between the first and second cylinders. Figure 43 shows autospectra of a hot film signal in the wake for $L/D=1.1$. As Reynolds number increases, two intermittent shedding frequencies exist. Igarashi [33] noticed a similar phenomenon which he attributed to the critical Reynolds number where the jump phenomenon occurs. The Strouhal numbers

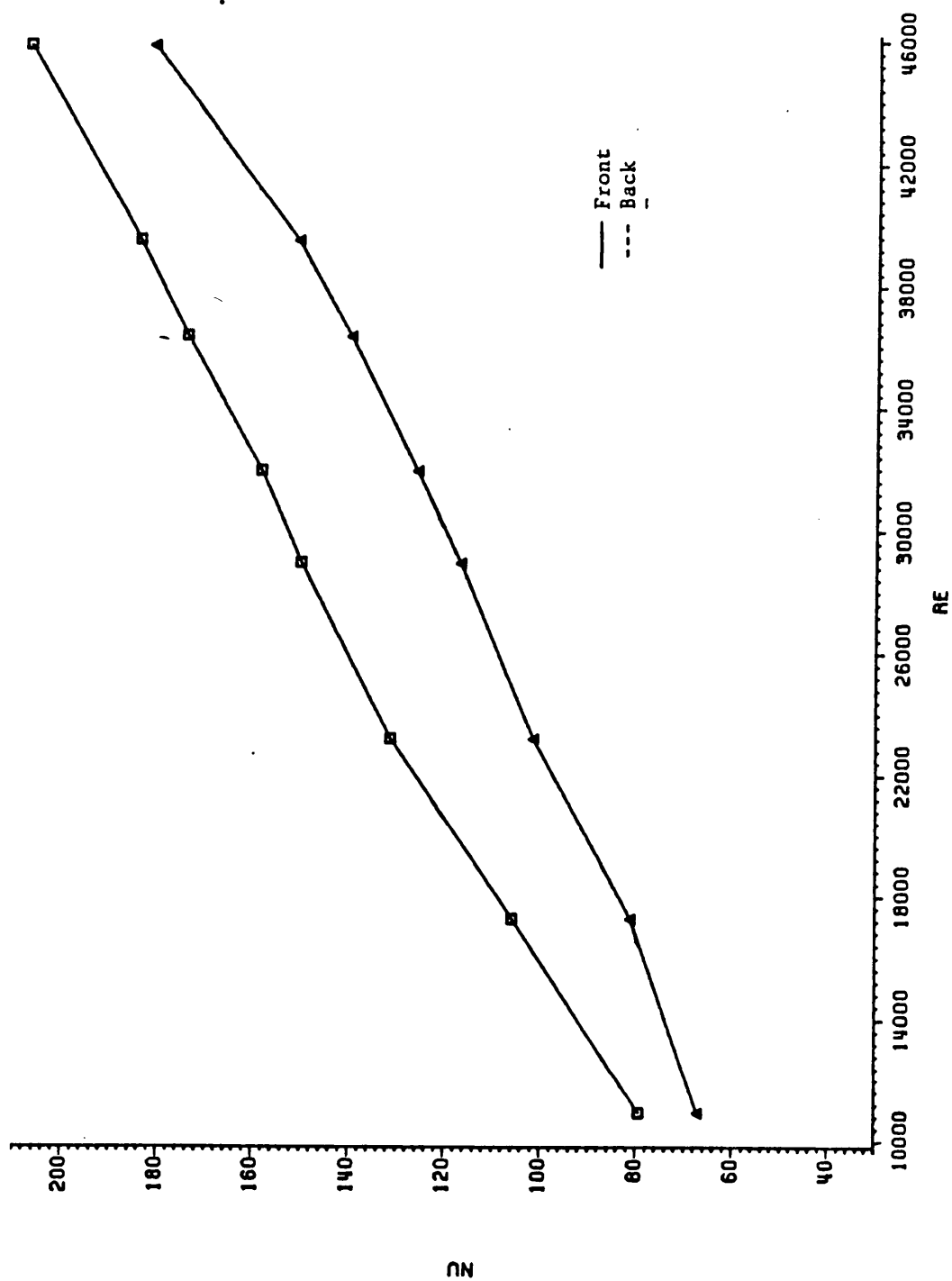


Figure 33. Nusselt number dependence on Reynolds number for $L/D=1.1$, front and back.

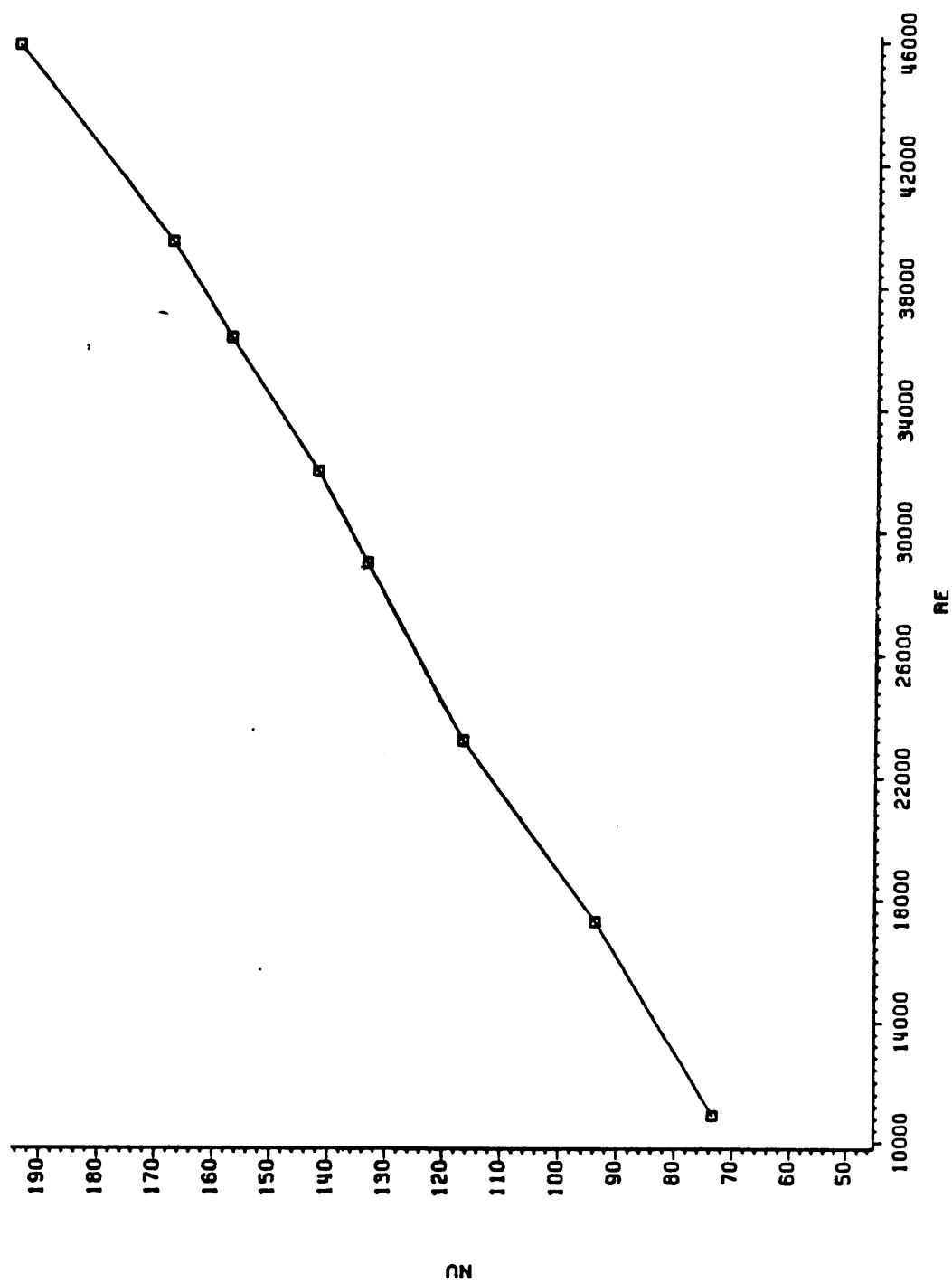


Figure 34. Nusselt number dependence on Reynolds number for $L/D=1.1$, overall.

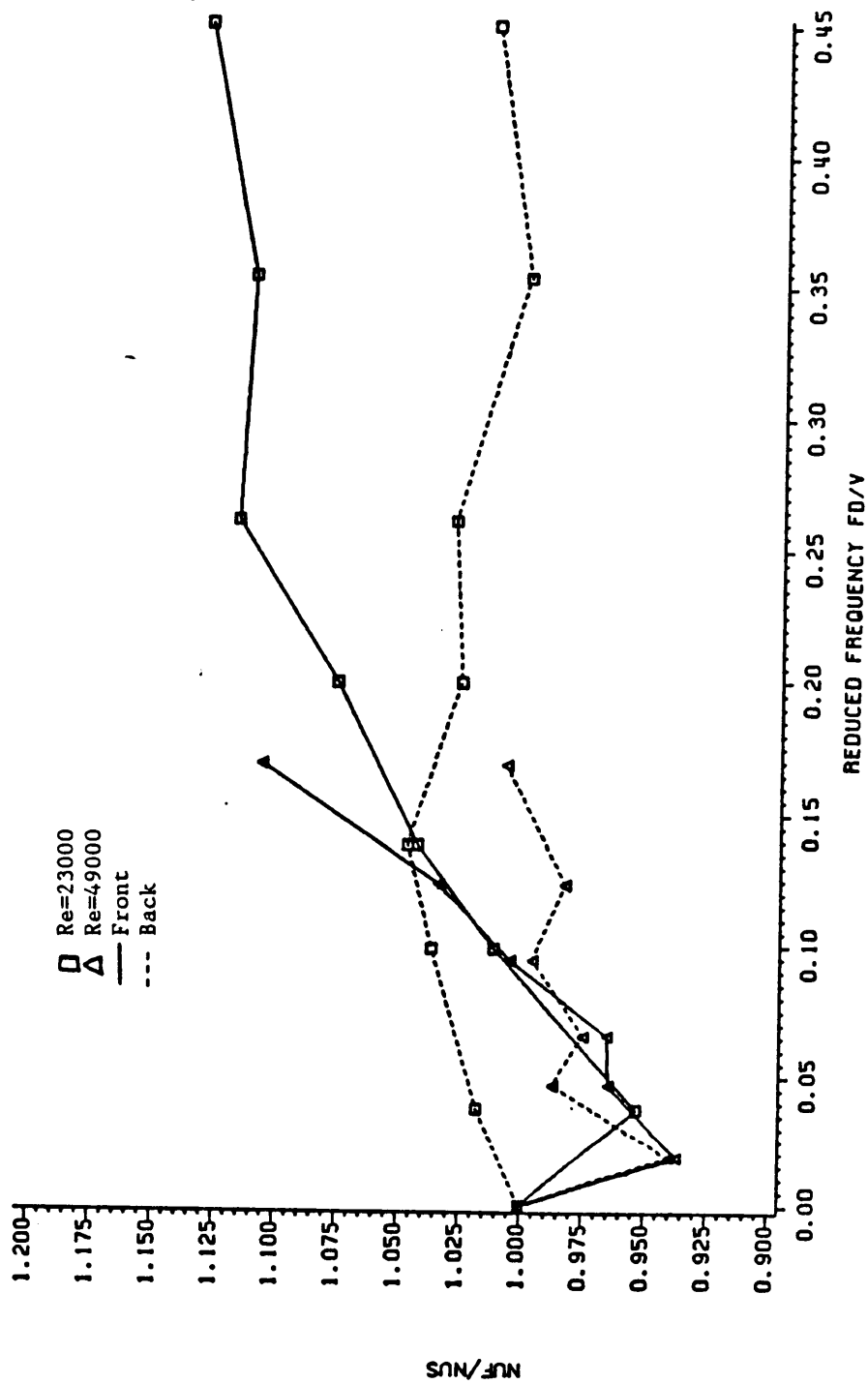


Figure 35. Relative Nusselt number dependence on driving frequency for $L/D=1.1$, front and back.

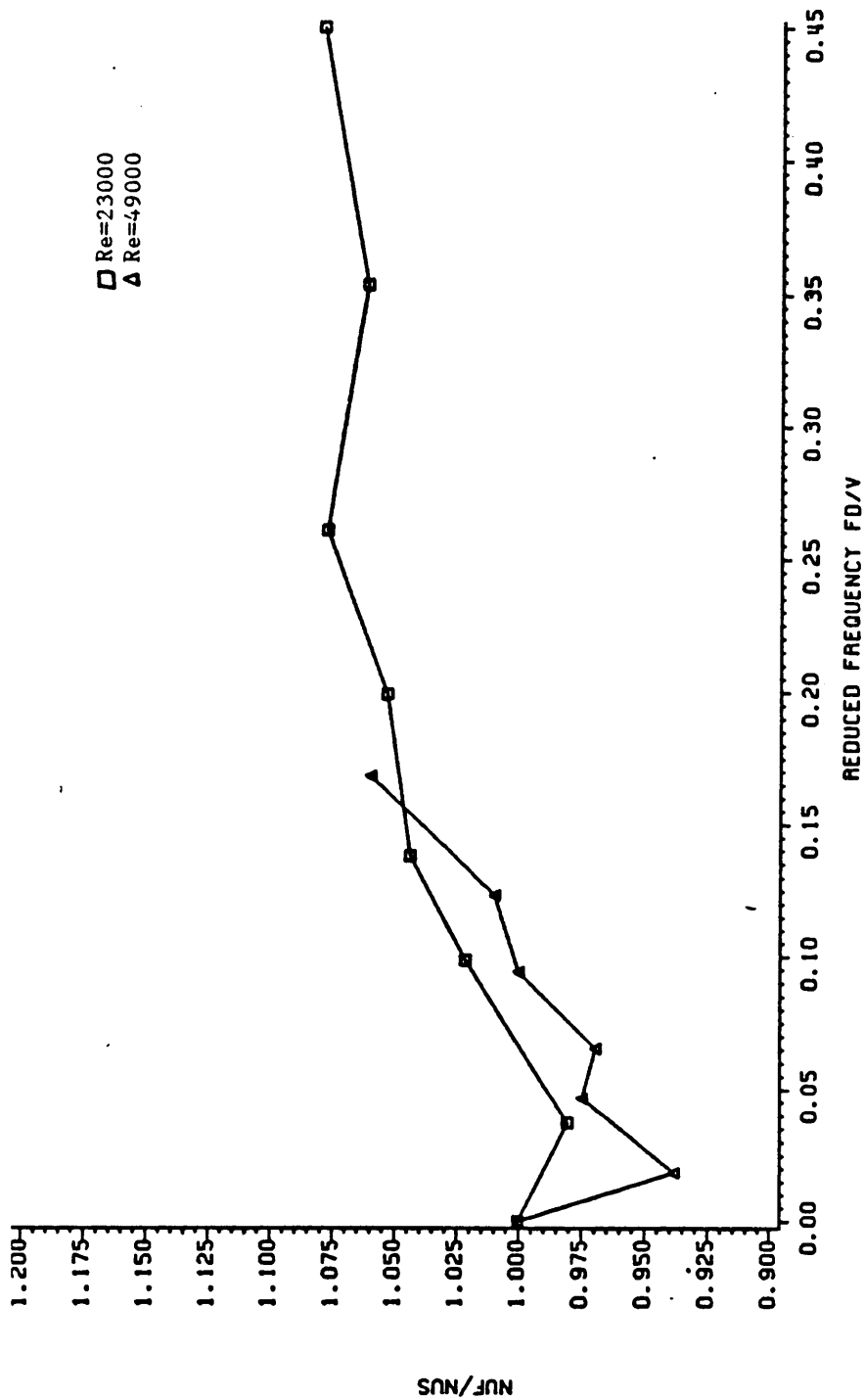


Figure 36. Relative Nusselt number dependence on driving frequency for $L/D=1.1$, overall.

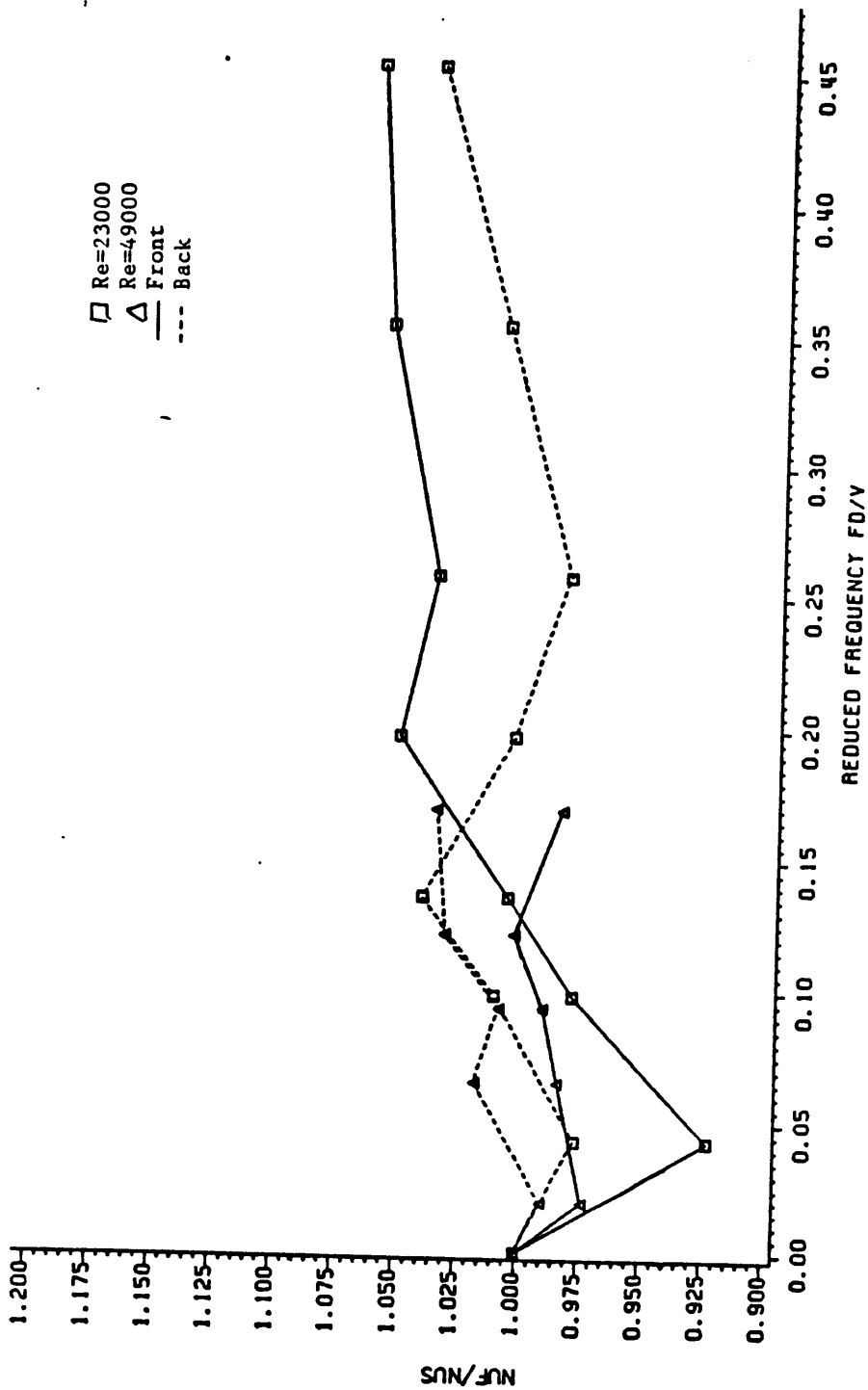


Figure 37. Relative Nusselt number dependence on driving frequency for $L/D=1.25$, front and back.

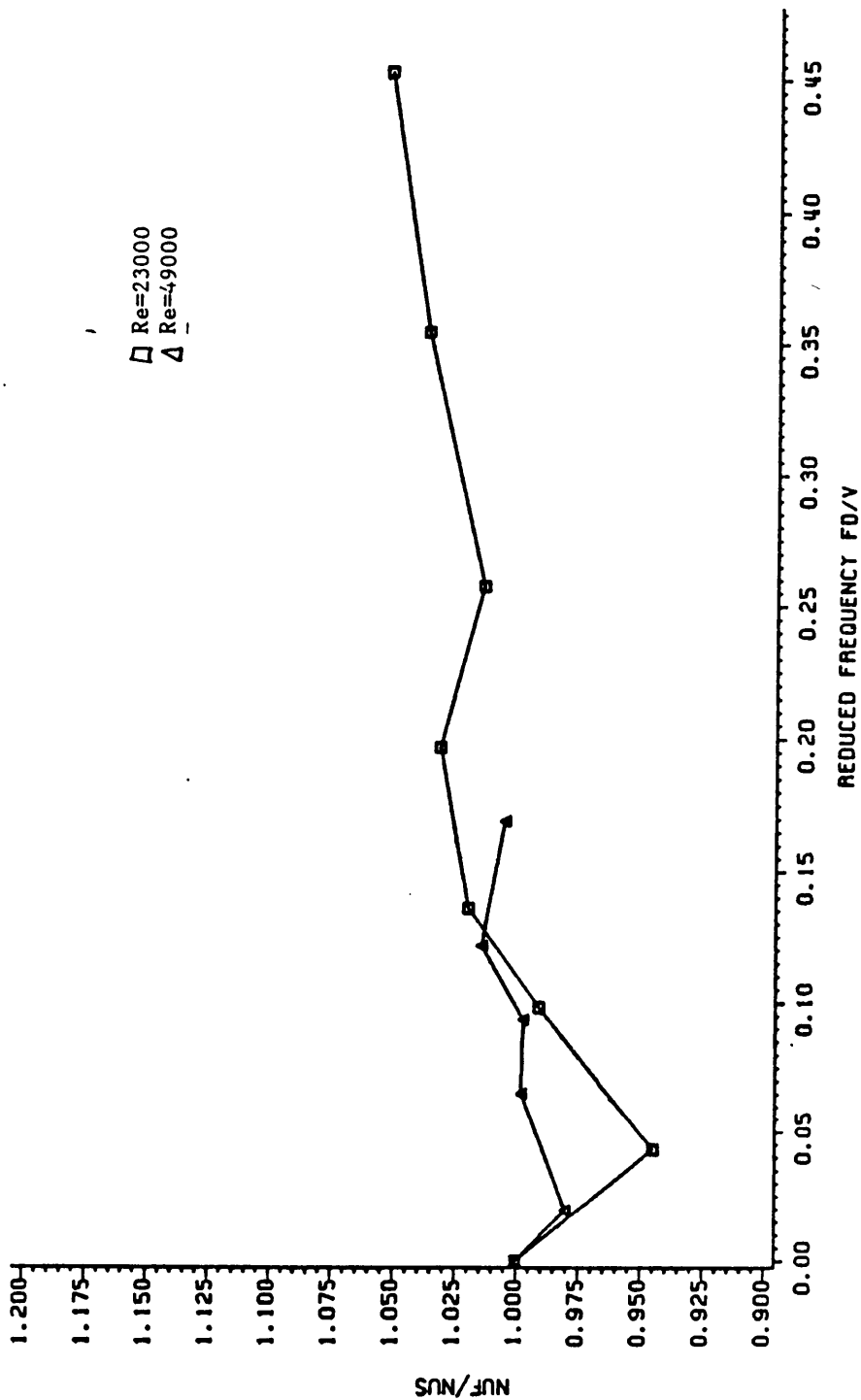


Figure 38. Relative Nusselt number dependence on driving frequency for $L/D=1.25$, overall.

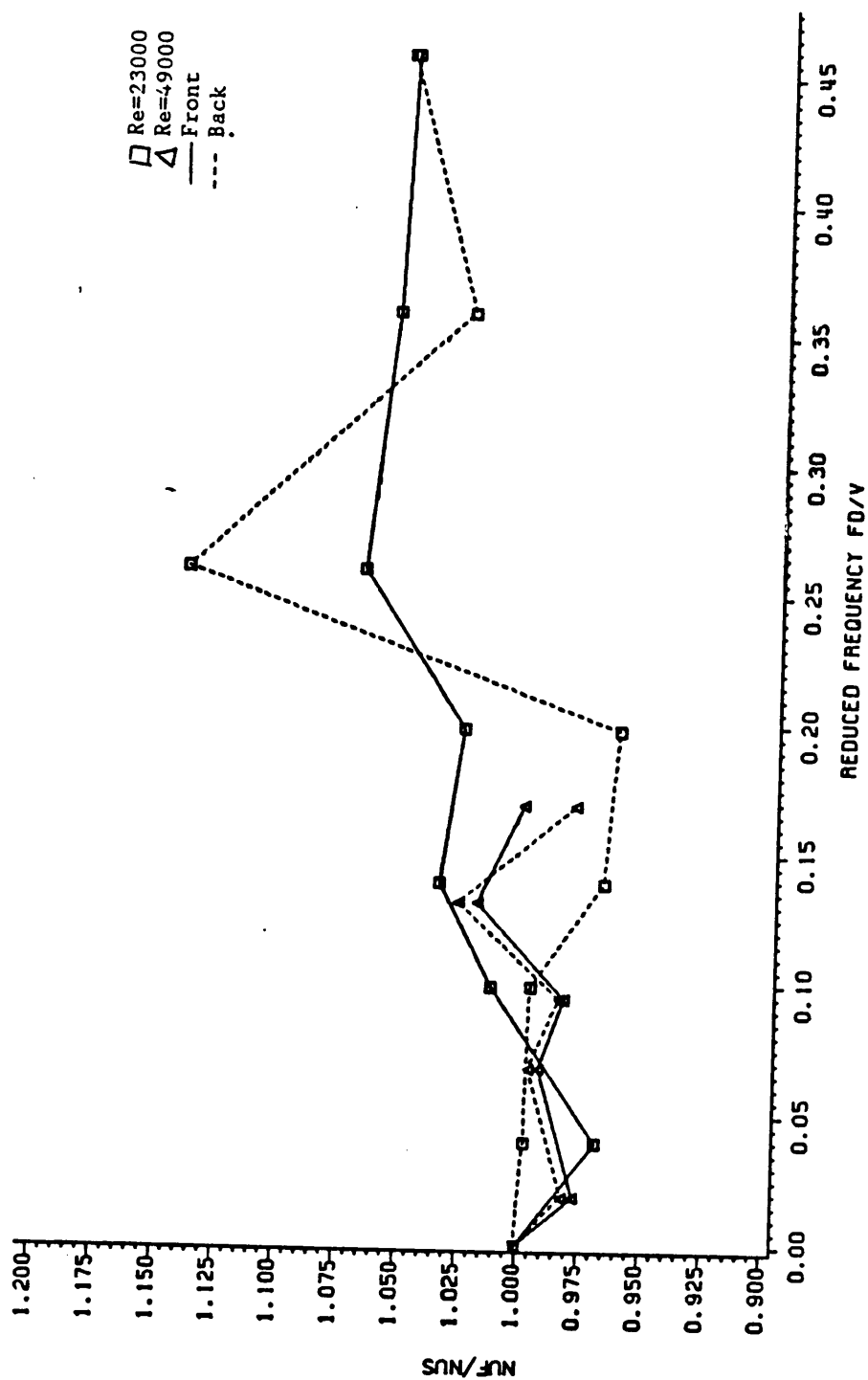


Figure 39. Relative Nusselt number dependence on driving frequency for $L/D=1.8$, front and back.

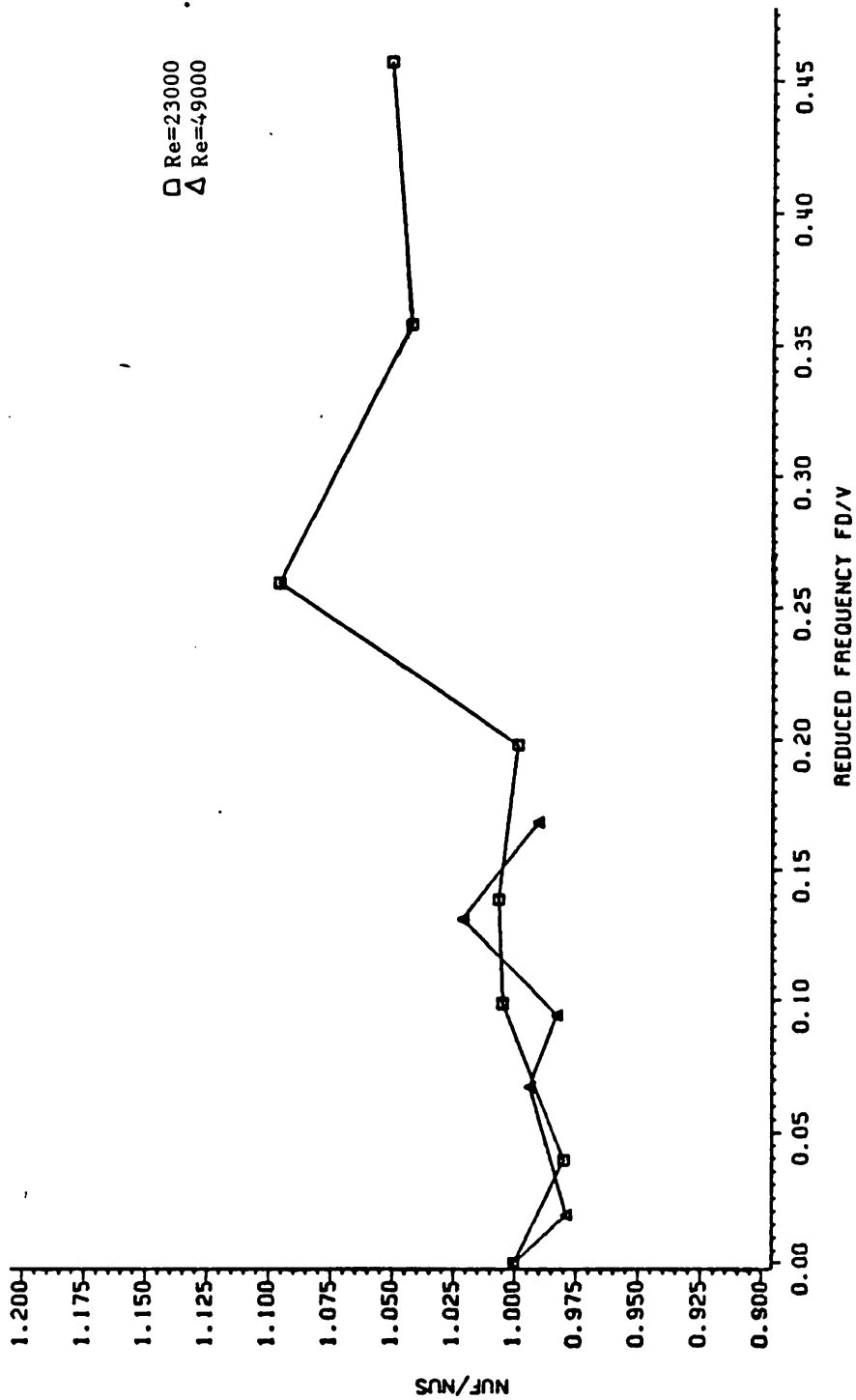


Figure 40. Relative Nusselt number dependence on driving frequency for $L/D=1.8$, overall.

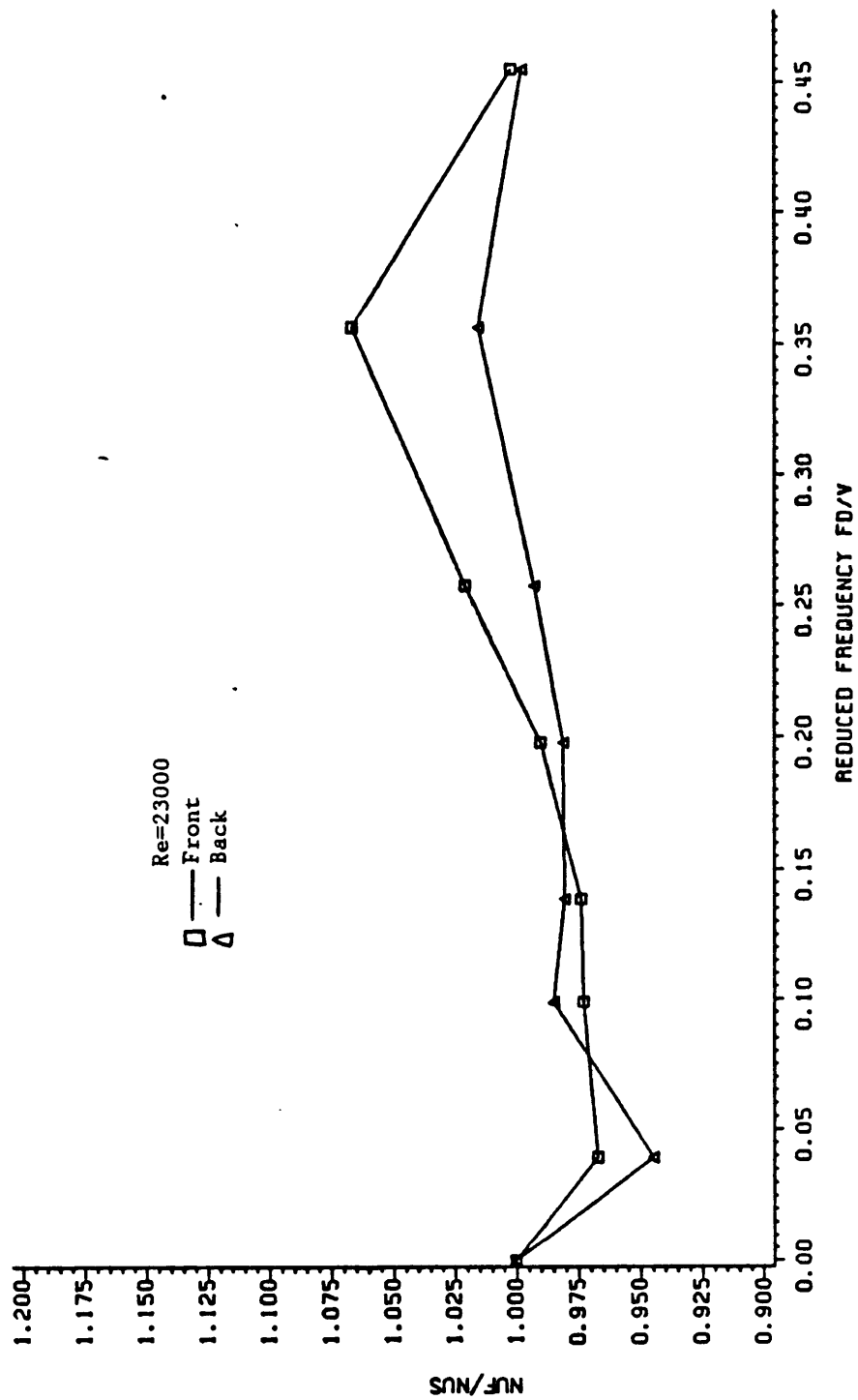


Figure 41. Relative Nusselt number dependence on driving frequency for $L/D=4.75$, front and back.

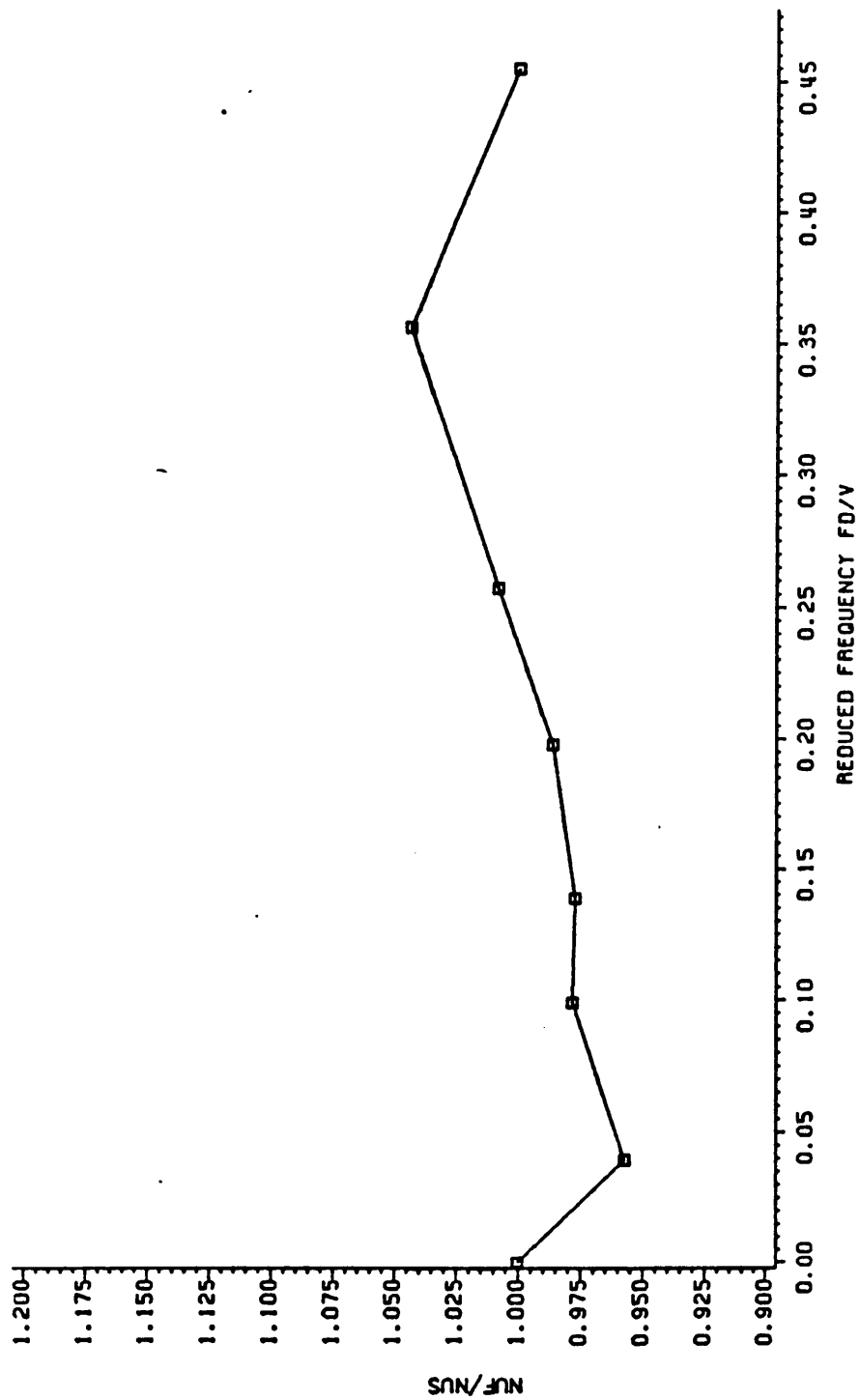


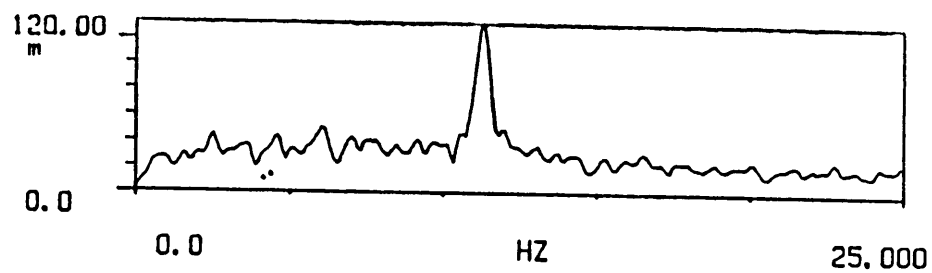
Figure 42. Relative Nusselt number dependence on driving frequency for $L/D=4.75$, overall.

corresponding to the two jump frequencies are $St=0.23$ and 0.10 , which shows good agreement with Igarashi's results (Table 3). Current results do not show good agreement with the correlation given by Igarashi to predict the critical Reynolds number where the jump occurs. For $L/D=1.1$, the correlation gives $Re_c=36,000$, whereas current results indicate the jump occurred at $Re=30,000$.

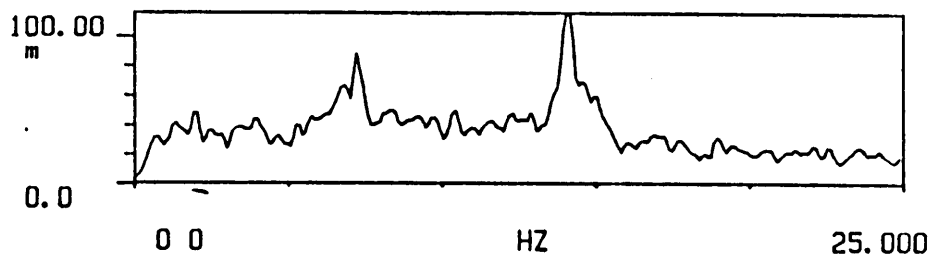
Figure 44 shows organization present in the flow between the two cylinders as the Reynolds number decreases from $Re=46,000$. The hot wire was placed half way between the cylinders and half a cylinder diameter under the test section center-line. Below the jump phenomenon ($Re=23,000$), very little flow organization can be seen. For higher Reynolds numbers, organization at the vortex shedding frequency was observed in the cavity. When a 5 Hz pulsation was applied (figure 44) at $Re=23,000$, unsteadiness at the driving frequency appeared between the cylinders.

Figure 45 shows driving and shedding frequencies behind the three cylinders for $L/D=1.1$ and $Re=23,000$. As for a single cylinder, the vortex shedding frequency locks on at half the driving frequency for $f_d/f_s > 1$. For all driving frequencies, the amplitude of velocity in the separated vortex increases.

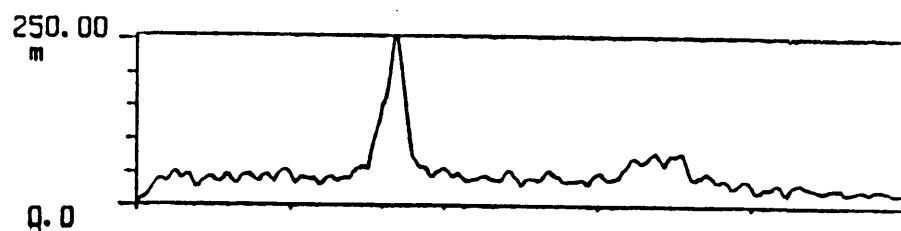
Figure 46 shows the autospectrum for a hot film in the wake of the cylinders at $Re=48,000$, $L/D=1.25$ and $f_d/f_s=0.2$. Several frequencies can be seen apart from the driving frequency. A similar phenomenon was observed for a single cylinder near $f_d/f_s=0.2$.



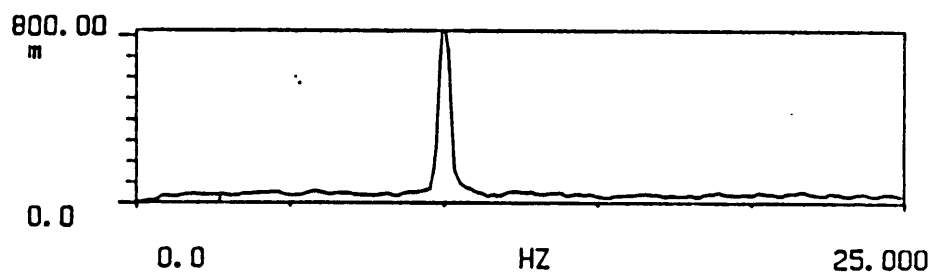
$Re=23000$



$Re=30000$



$Re=35600$



$Re=45000$

Figure 43. Shedding frequencies in the wake near the jump phenomenon for $L/d = 1.1$.

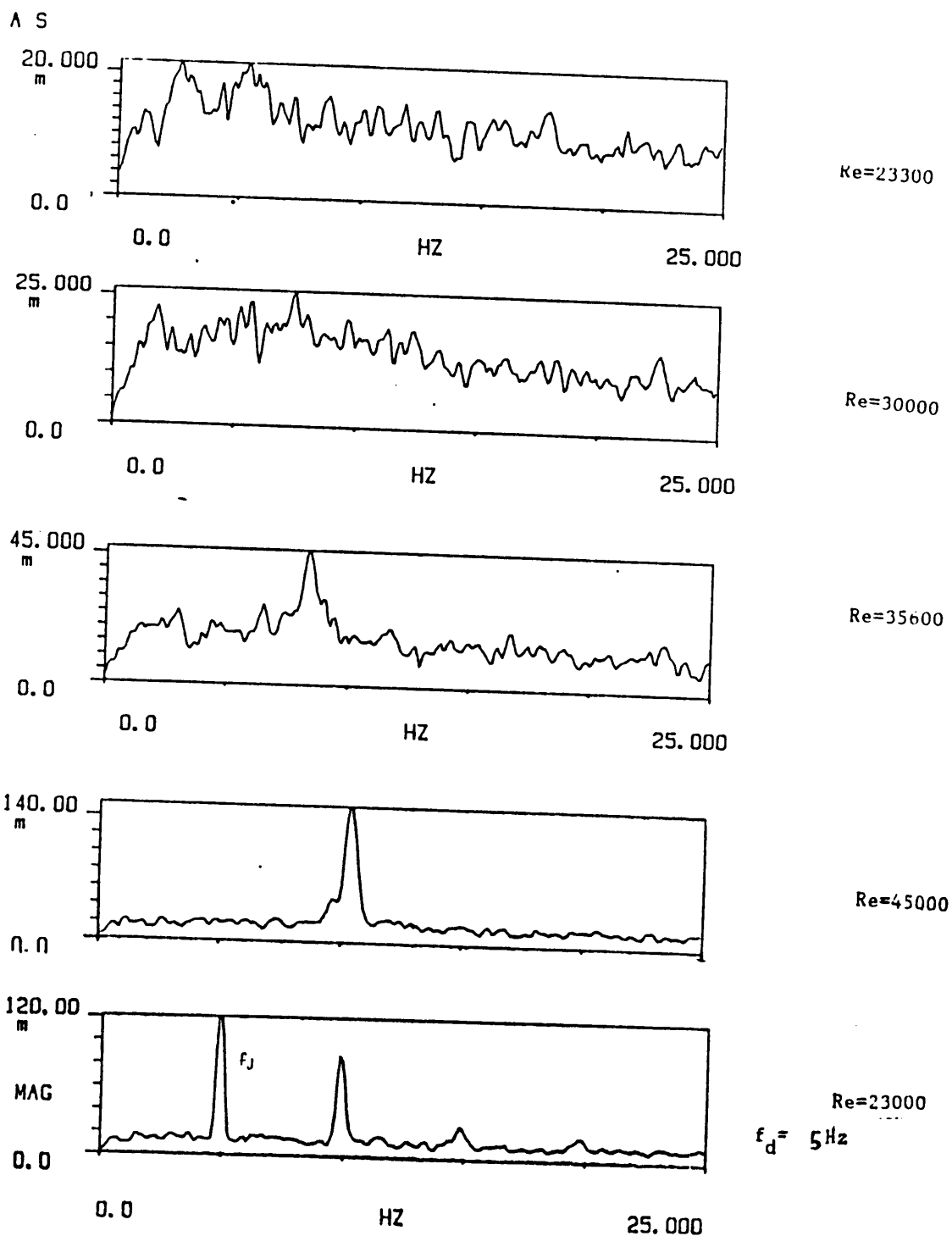


Figure 44. Shedding frequencies between the first and second cylinders near the jump phenomenon for $L/d = 1.1$.

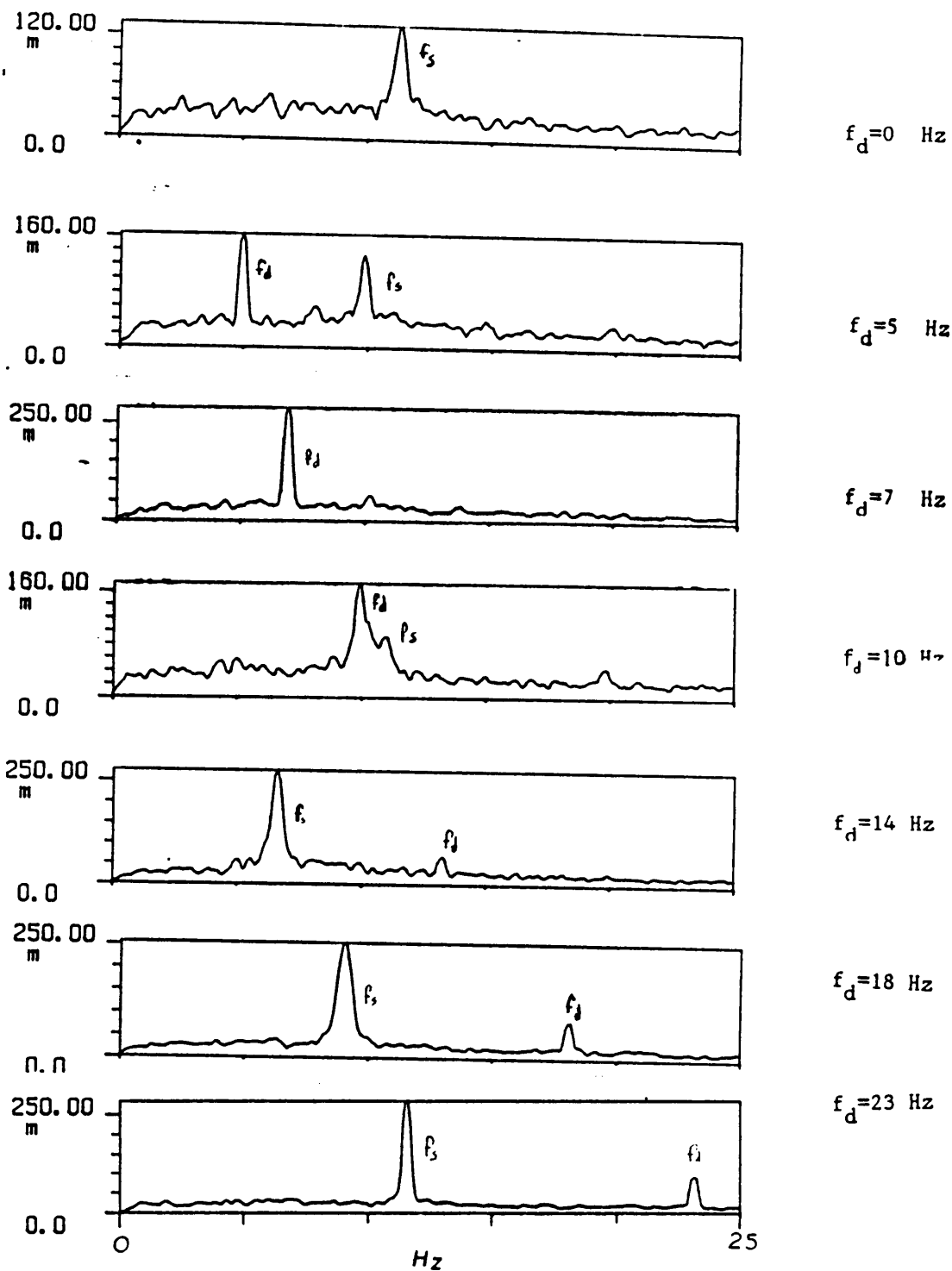


Figure 45. Shedding frequencies in the wake at different driving frequencies for $Re=48000$, $L/D=1.1$.

X: 2.1491
A SPEC 1

Y: 714.97 m

#A: 10

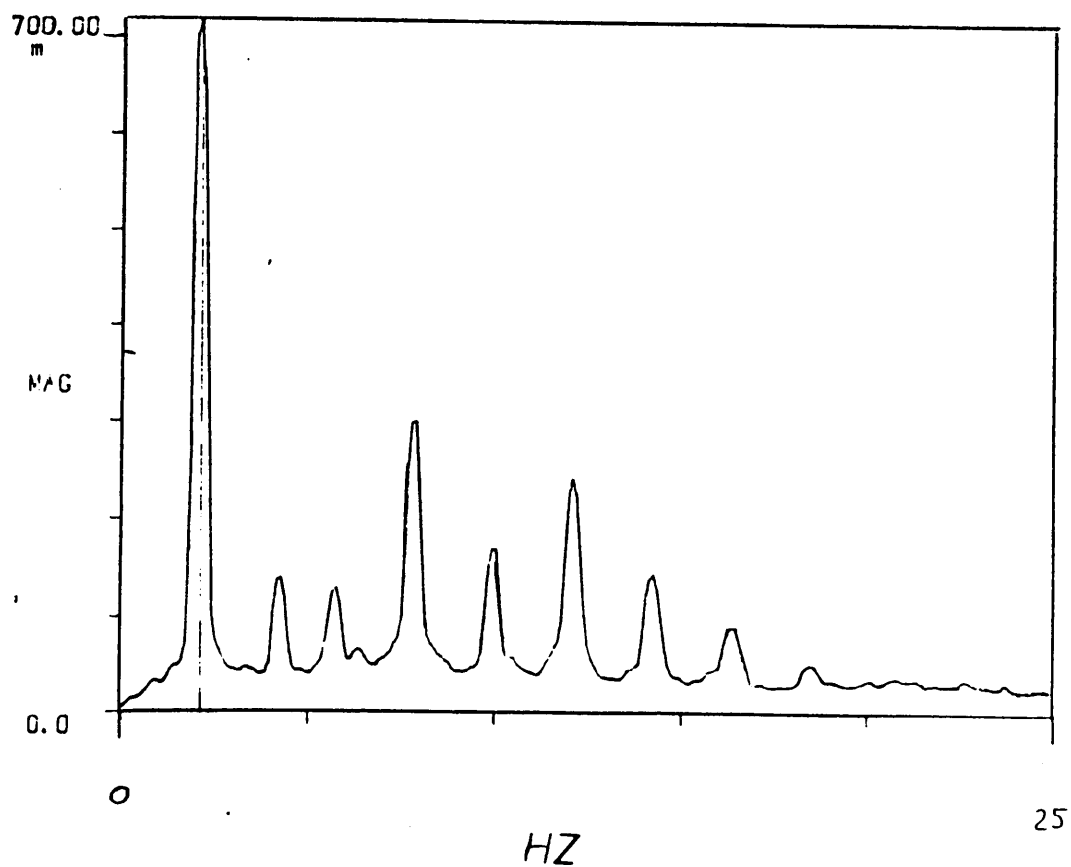


Figure 46. Shedding frequencies observed for $f_d/f_s = .2$, $L/D = 1.25$.

4.3 PERPENDICULAR ARRANGEMENTS

Flow conditions for tests with perpendicular arrangements are given in Table 9. No heat transfer or flow data was found to compare with in the literature. Steady flow Nusselt numbers for the perpendicular arrangement and for the second cylinder in a tandem arrangement of two cylinders is given in figures 47 and 48. The overall Nusselt number for the perpendicular arrangement is about 18 percent higher than for the in-line arrangement at large spacings ($L/D > 3$). Below $L/D=3$, Nusselt number for the in-line arrangement is about 10 percent higher. For the in-line arrangement, Nusselt number was lower on the back of the test cylinder for all spacings.

Relative Nusselt number (Nu_f/Nu_s) dependence on reduced pulsation frequency is given in Figures 49 to 58. Results are presented separately for $L/D=1.5, 2, 2.5, 3$ and 5 . The Nusselt number decreased by 2 to 5 percent for low frequency pulsations ($f_d < 5$ Hz). At higher driving frequencies, increases on the order of the experimental uncertainty were observed on the front of the test cylinder. The Nusselt number increased by as much as 17 percent on the back of the cylinder at higher driving frequencies ($f_d=.16$ to $.21$). Figure 59 shows the relative Nusselt number dependence on pitch ratio for the back of the cylinder. Increases in heat transfer were largest for $L/D=2$ and $L/D=2.5$. For higher values of L/D , the increase was smaller.

Unsteady flow data taken in the wake of the perpendicular arrangement shows higher levels of free stream turbulence than were present for in-

Table 9. Test conditions for perpendicular arrangements

Reynolds number	L/D	L_s/D	f_d Hz	Page (Appendix H)
49000	1.2-5.0	0*	0	255
49000	1.2-5.0	2.8	0	241
49000	1.5	2.8	0-23	243
49000	2.0	2.8	0-23	245
49000	2.5	2.8	0-23	247
49000	3.0	2.8	0-23	249
49000	3.5	2.8	0-23	251

AMPLITUDES:

f_d Hz	amplitude
2.0	23.6
5.0	16.8
7.0	13.5
13.0	10.4
18.0	9.3
23.0	7.6
26.0	6.3

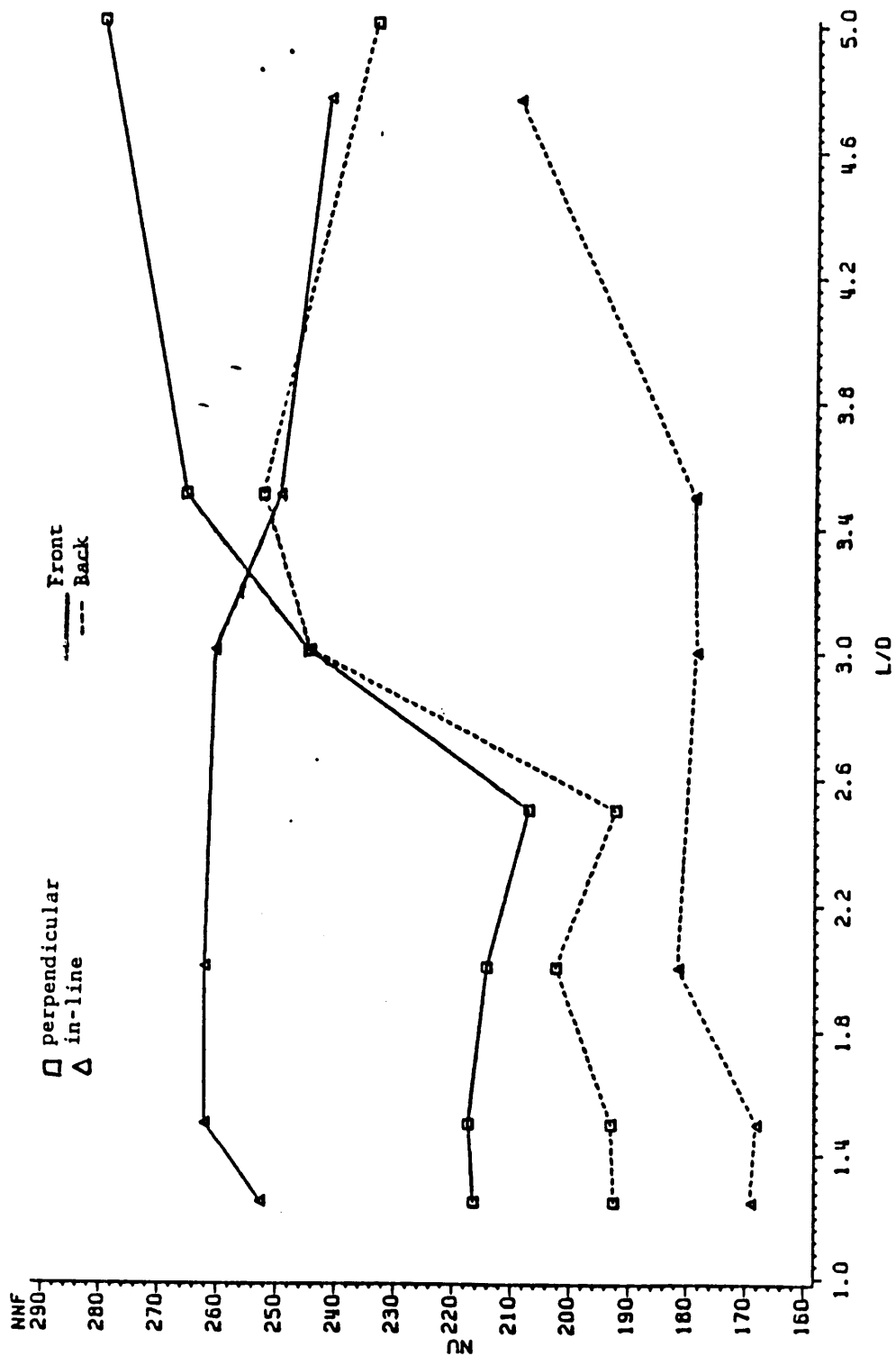


Figure 47. Steady flow Nusselt number for in-line and perpendicular arrangements at $Re=49000$, front and back.

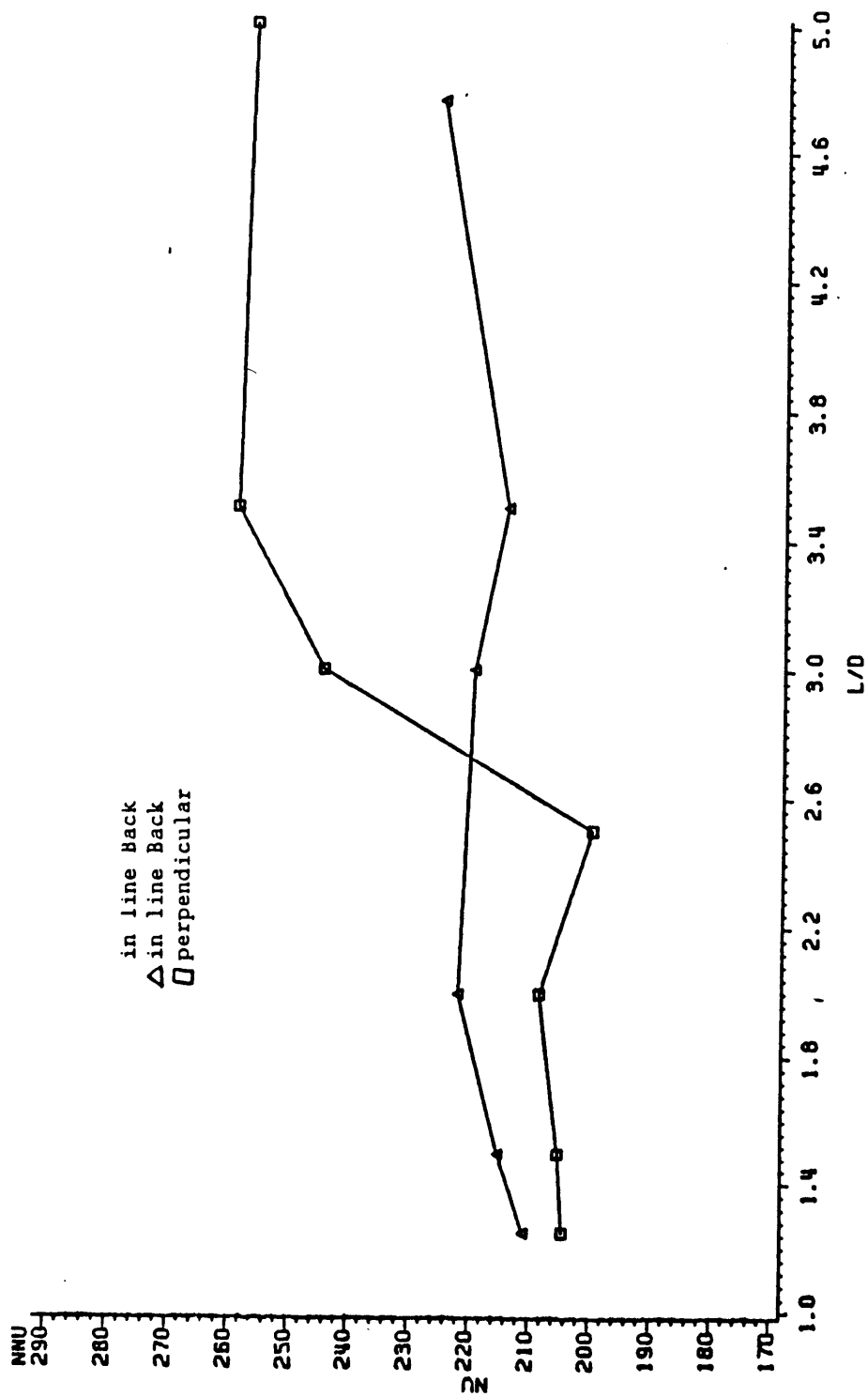


Figure 48. Steady flow Nusselt number for in-line and perpendicular arrangements at $Re=49000$, overall.

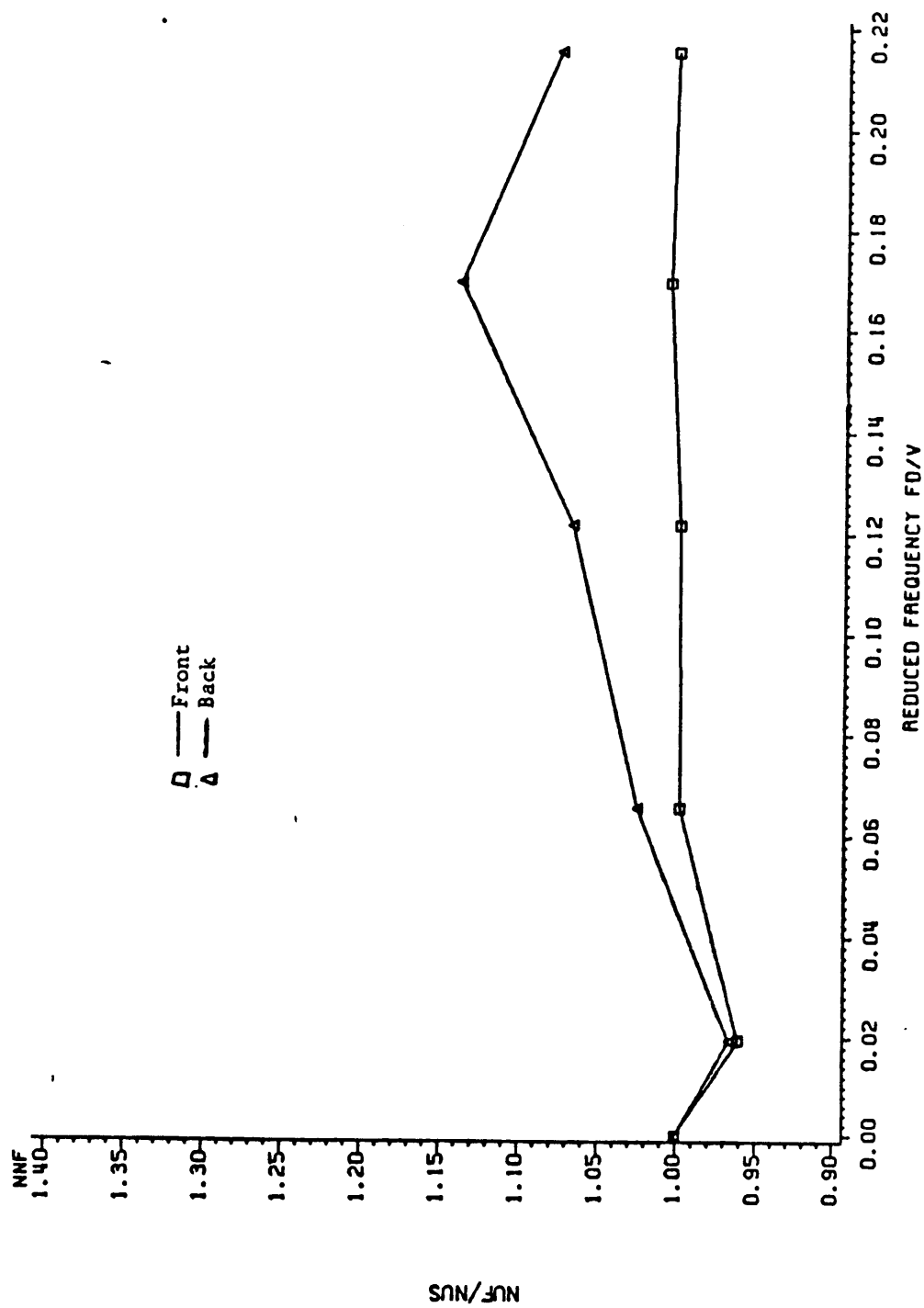


Figure 49. Relative Nusselt number dependence on driving frequency for $L/D=1.5$, front and back.

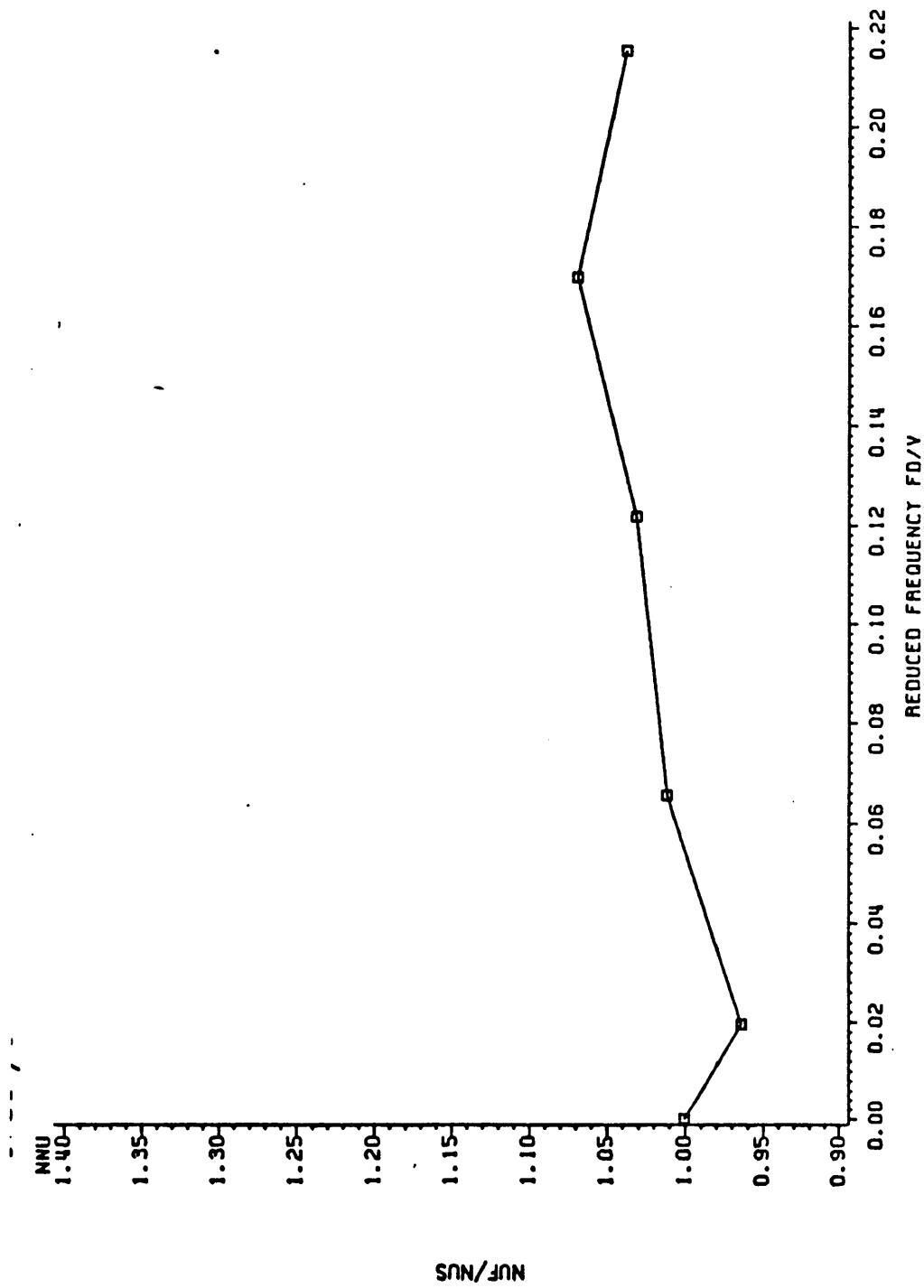


Figure 50. Relative Nusselt number dependence on driving frequency for $L/D=1.5$, overall.

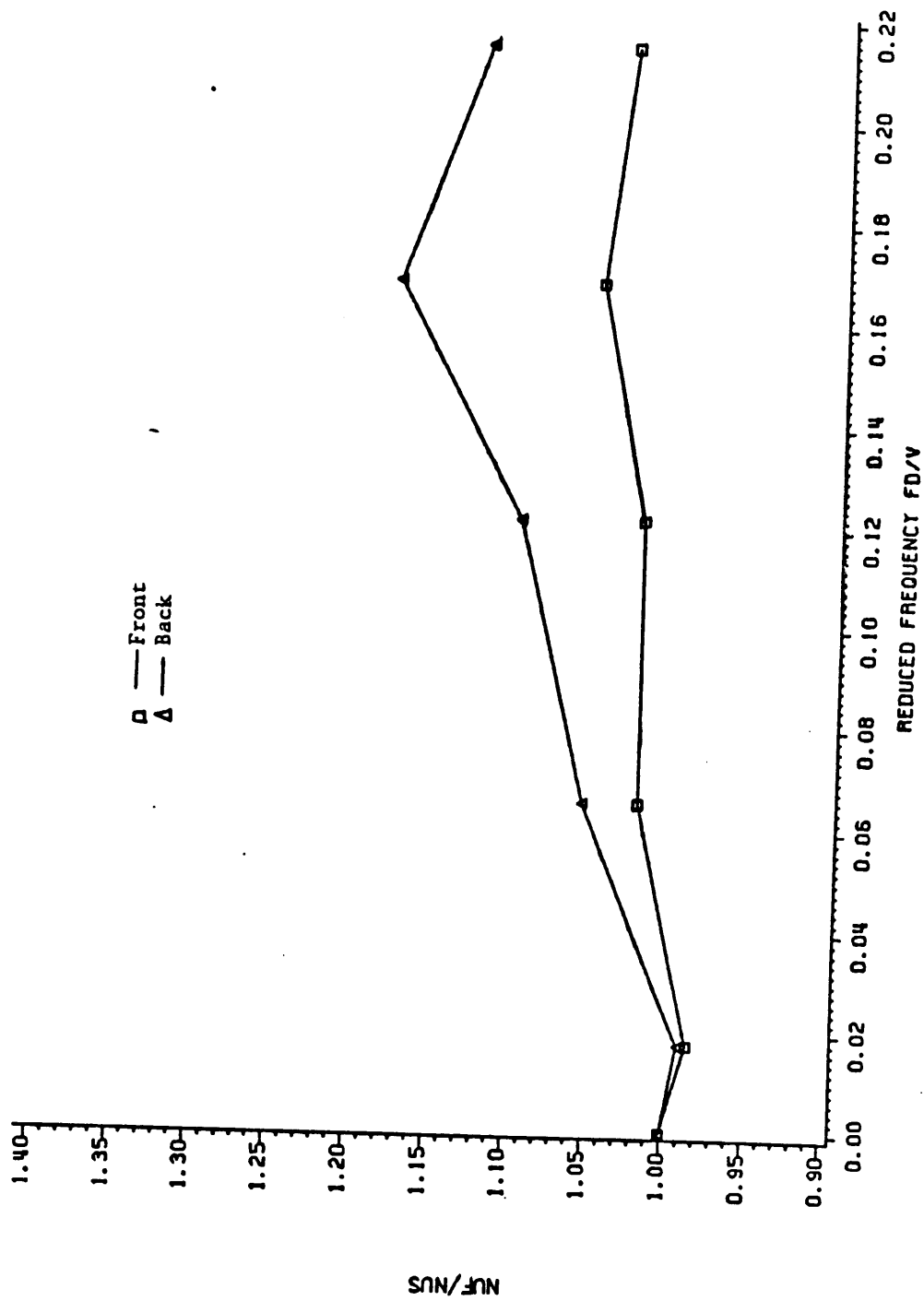


Figure 51. Relative Nusselt number dependence on driving frequency for $L/D=2.0$, front and back.

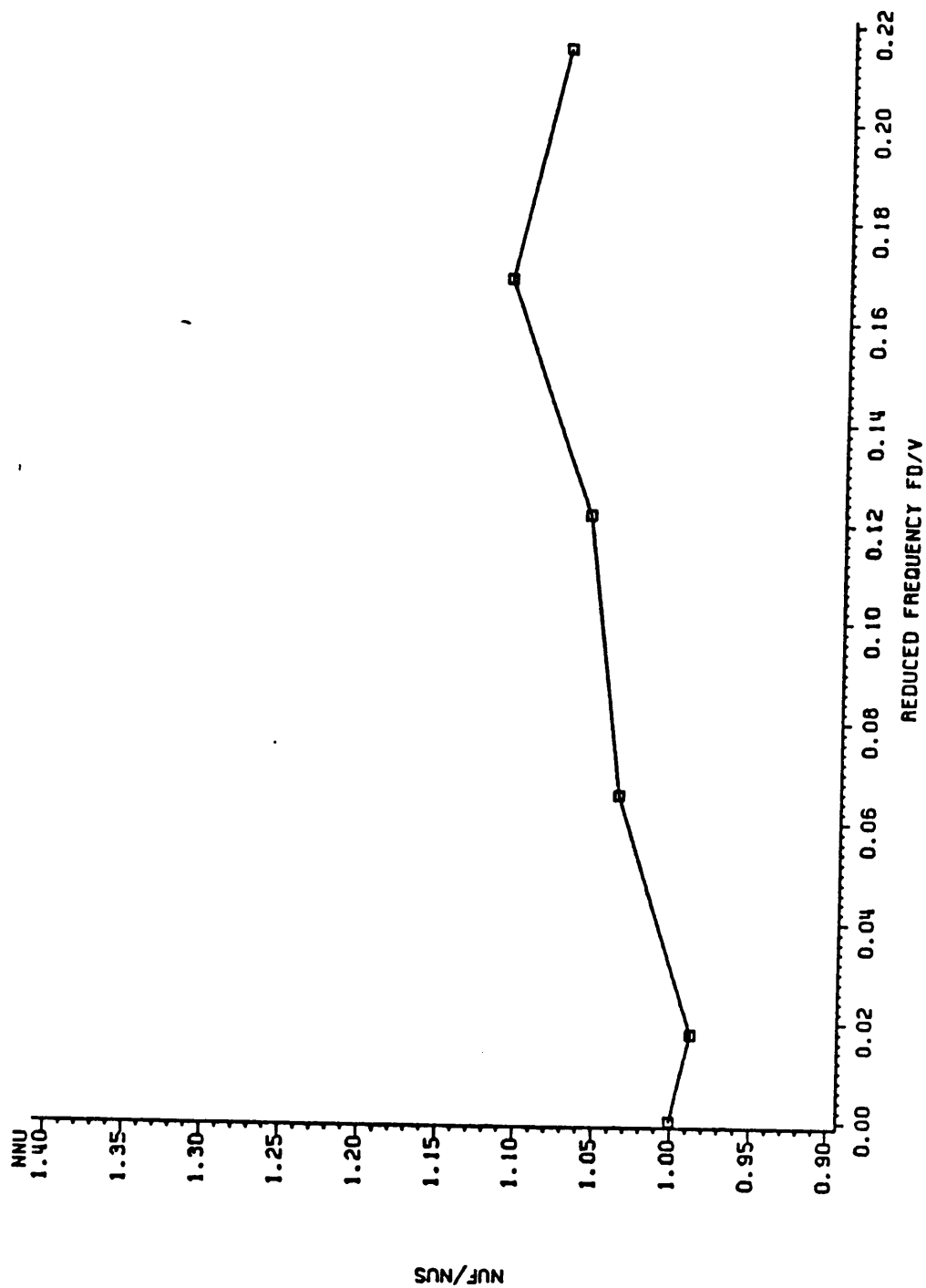


Figure 52. Relative Nusselt number dependence on driving frequency for $L/D=2.0$, overall.

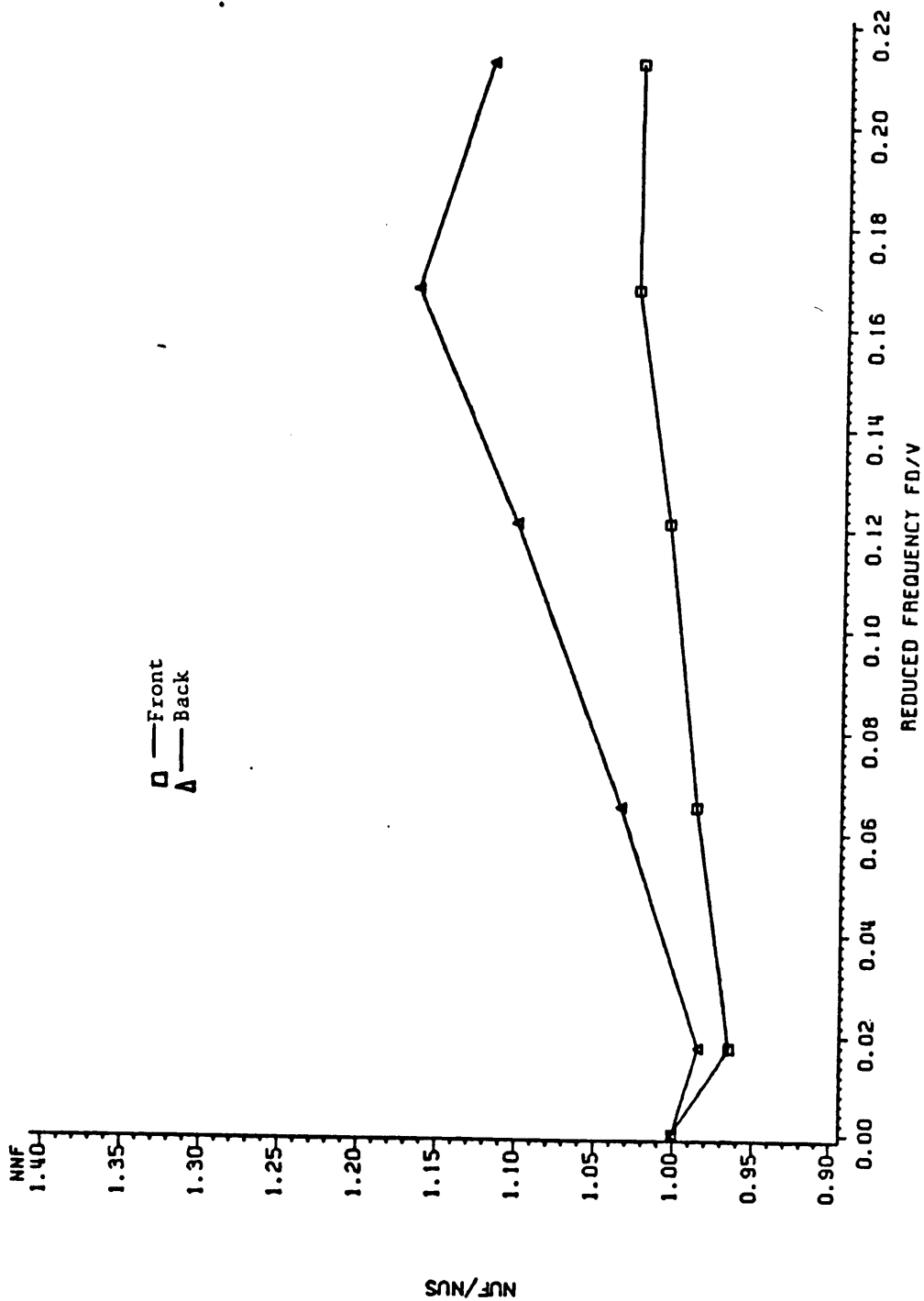


Figure 53. Relative Nusselt number dependence on driving frequency for $L/D=2.5$, front and back.

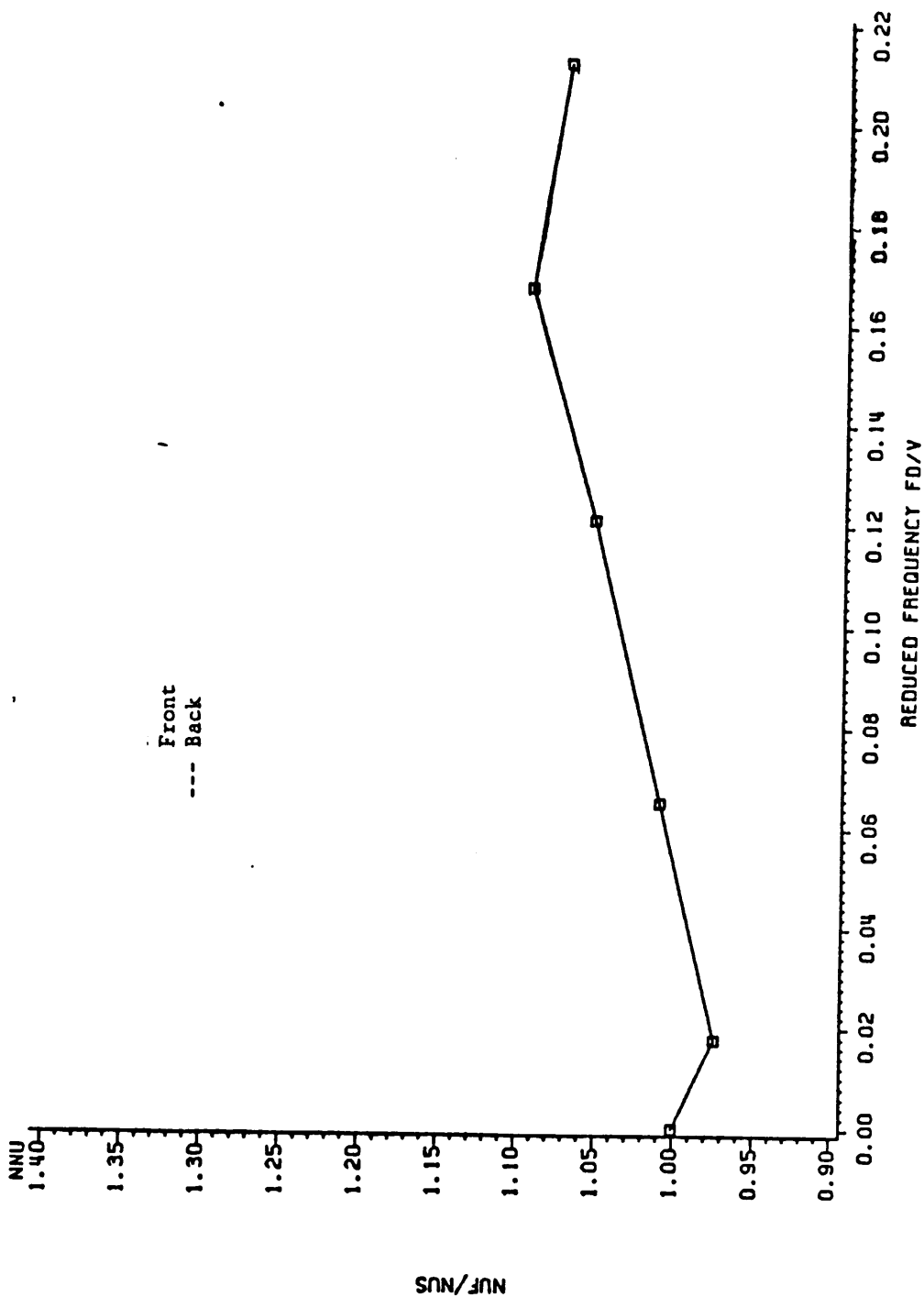


Figure 54. Relative Nusselt number dependence on driving frequency for $L/D=2.5$, overall.

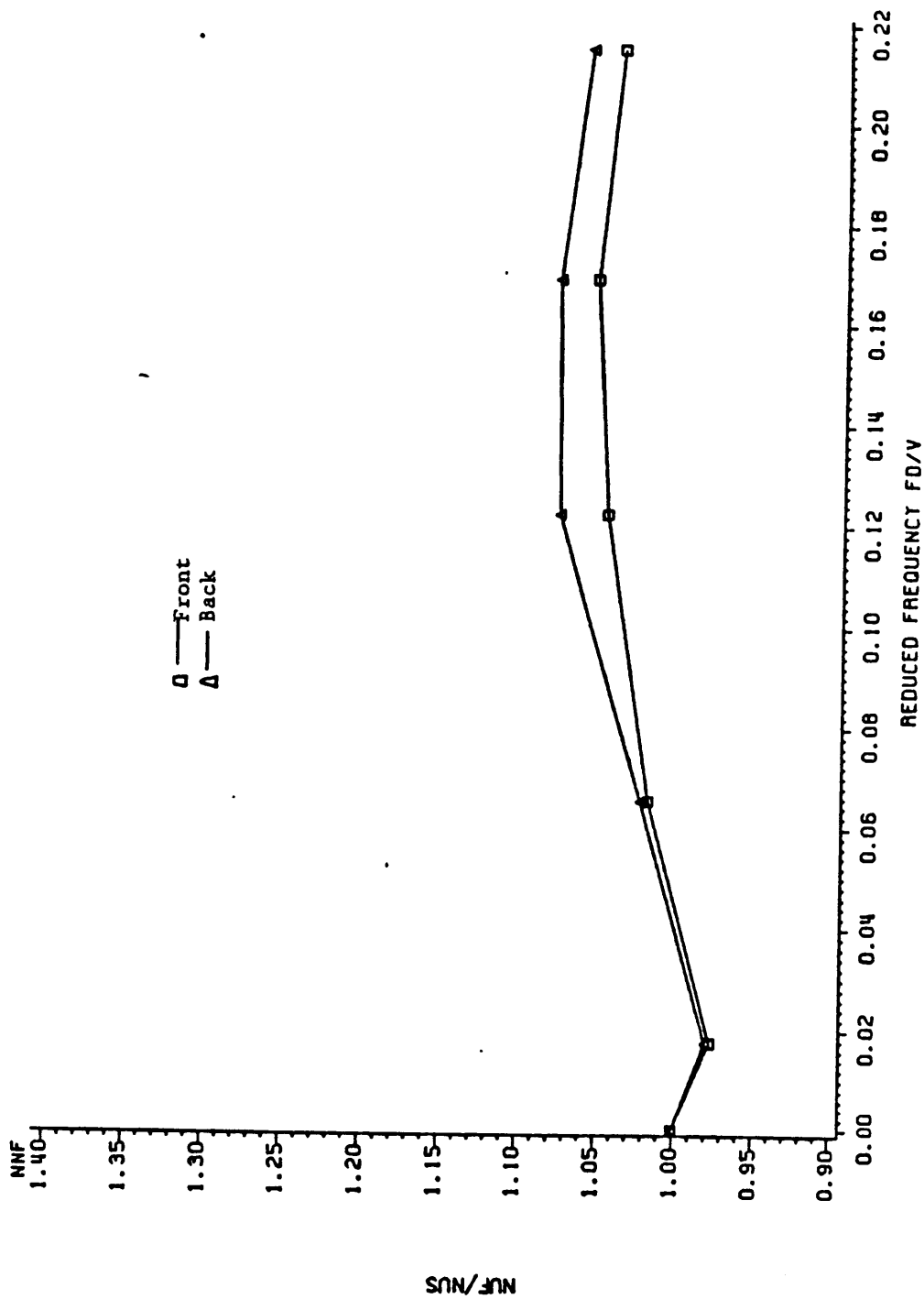


Figure 55. Relative Nusselt number dependence on driving frequency for $L/D=3.0$, front and back.

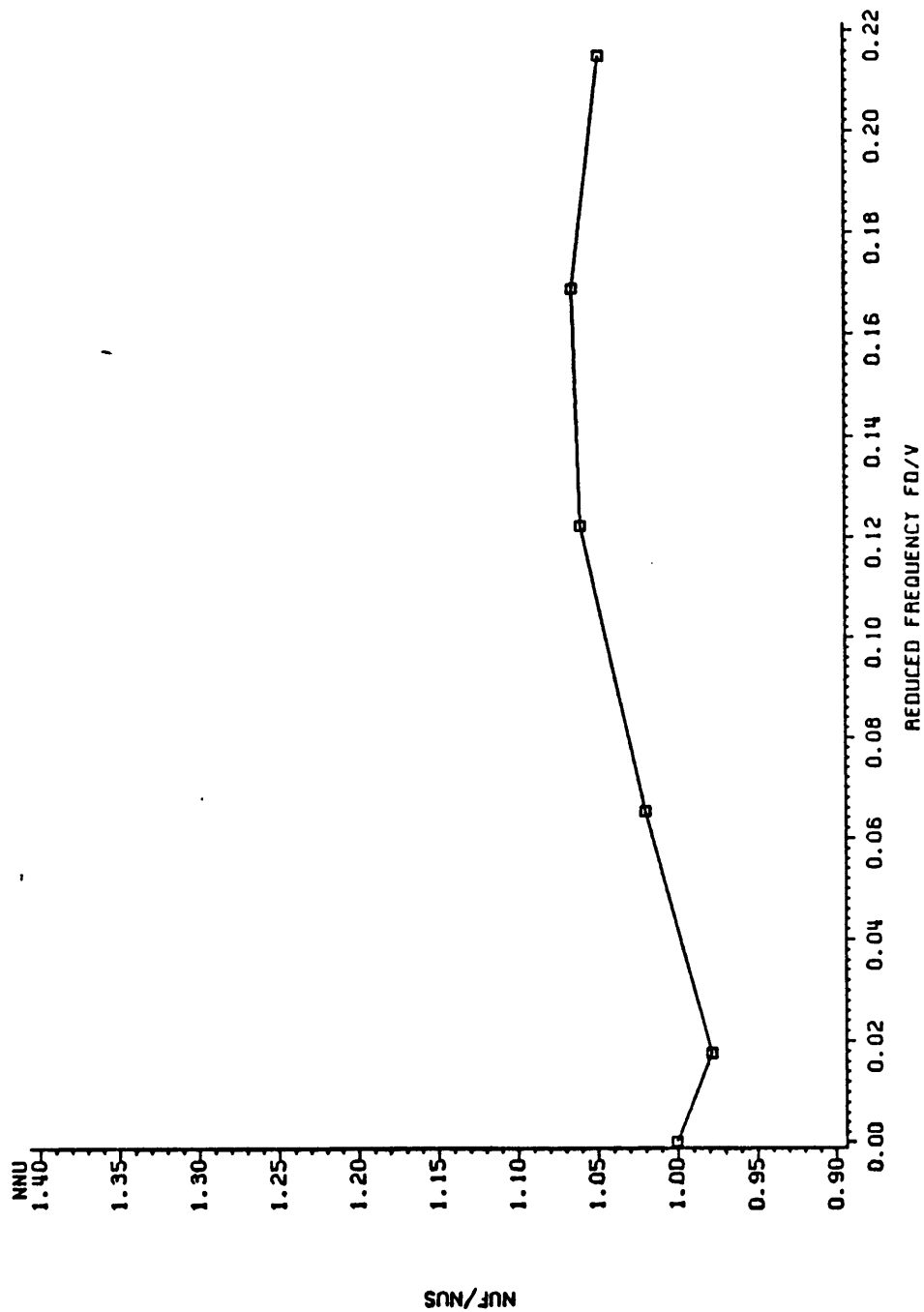


Figure 56. Relative Nusselt number dependence on driving frequency for $L/D=3.0$, overall.

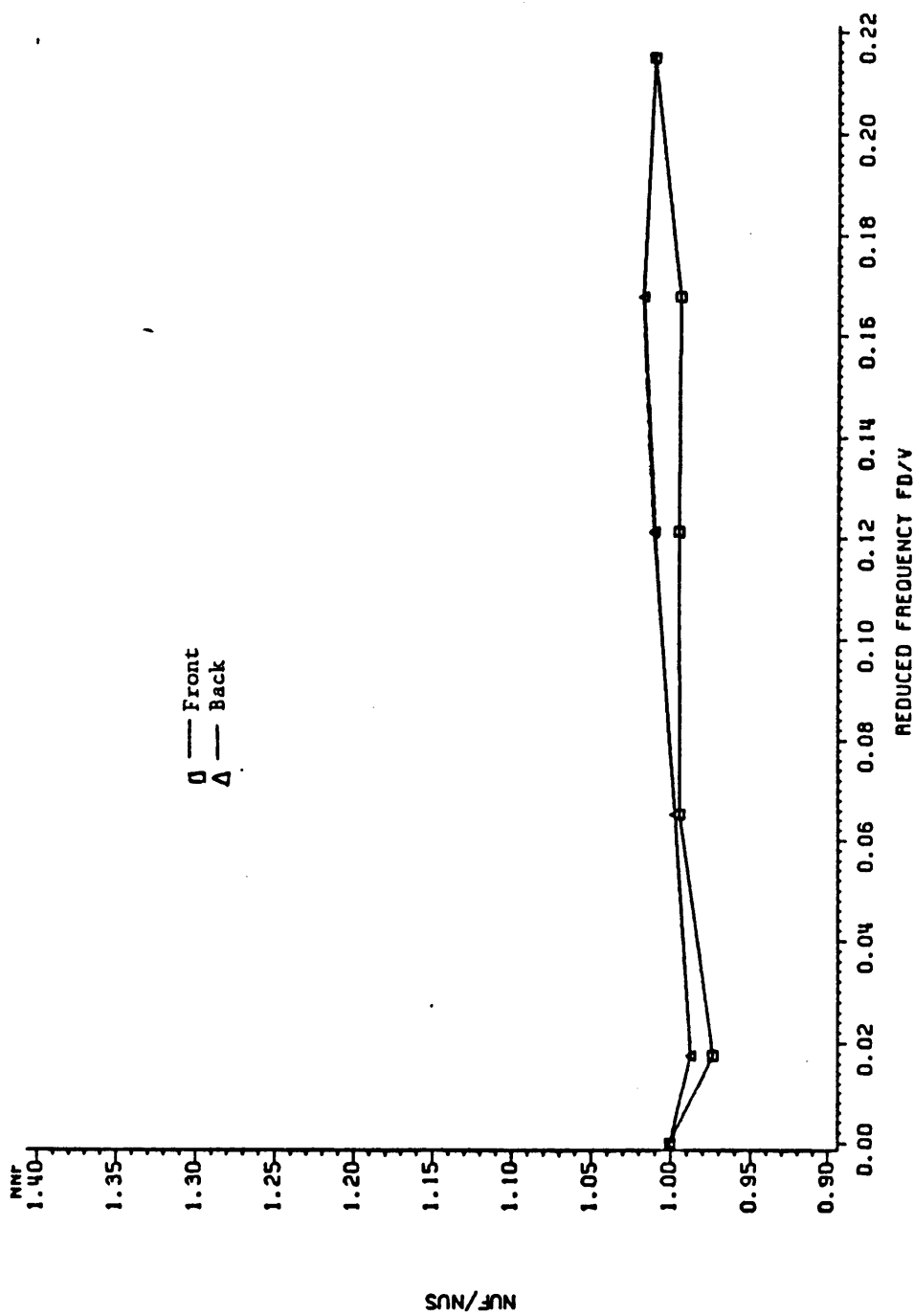


Figure 57. Relative Nusselt number dependence on driving frequency for $L/D=5.0$, front and back.

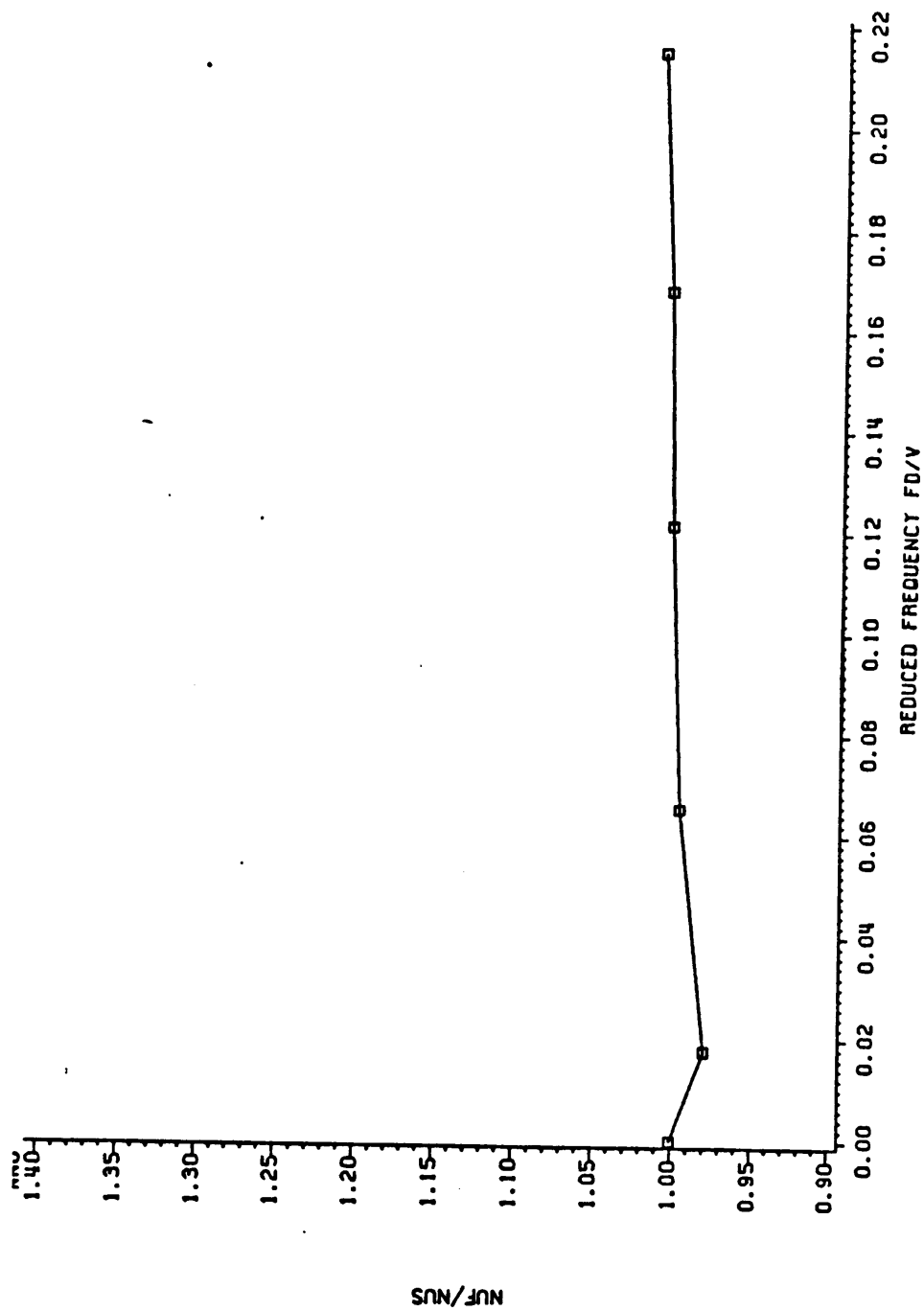


Figure 58. Relative Nusselt number dependence on driving frequency for $L/D=5.0$, overall.

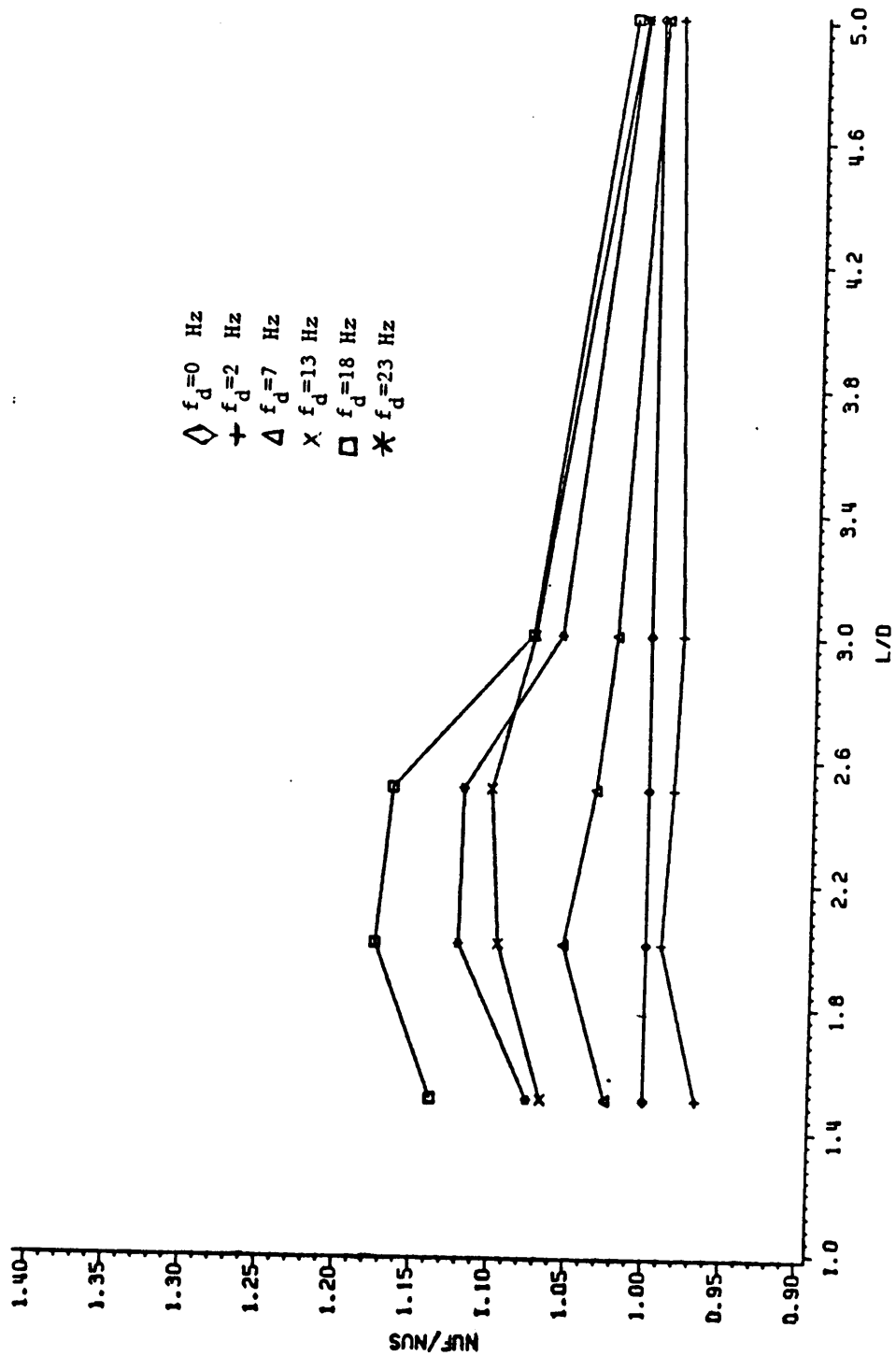


Figure 59. Relative Nusselt number dependence on pitch ratio for several driving frequencies, back only.

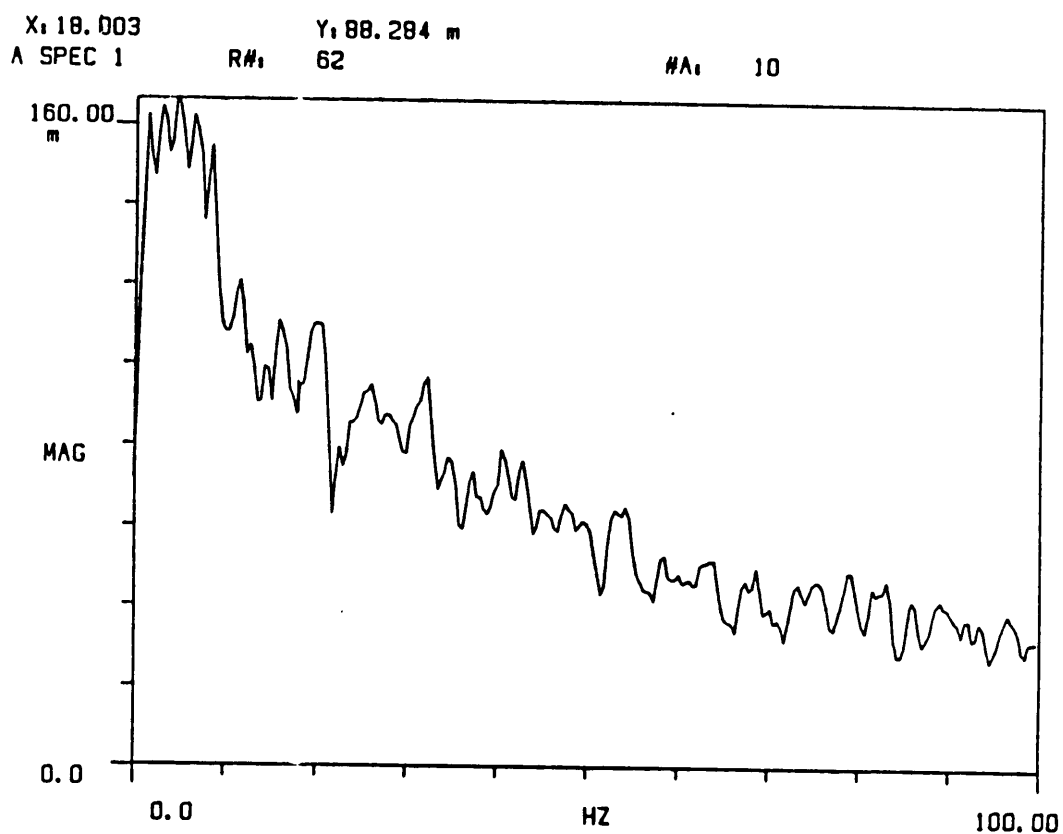


Figure 60. Autospectrum showing low frequency turbulence on the wake of the perpendicular arrangement.

line arrangements (figure 60). No organization of the wake (shedding frequency) was observed.

5.0 DISCUSSION OF RESULTS

5.1 SINGLE CYLINDER

Overall heat transfer measured for a single cylinder is about 15 percent higher than values predicted by Zukauskas' empirical correlation (Table 7). Experimental data from Ref. [31] indicates that the correlation underpredicts Nusselt number for the range of Reynolds numbers considered here. A correlation presented by Zukauskas for the back of the cylinder results in a Nusselt number which is higher than current results and results presented by Andraka.

Andraka's local heat transfer data was integrated over the front and back of the cylinder for comparison with current results. The integration was performed using the original data which were stored digitally on tape. Overall Nusselt number measured for this investigation agrees with data given by Andraka to within 3 percent; however, differences were observed for the heat transfer on the front and back of the cylinder. Current results are higher than Andraka's results by about 7 percent on the front of the cylinder, and are about 10 percent lower on the back.

Nusselt number results for pulsating flow also show some disagreement with Andraka's results. Andraka reported no increase in heat transfer outside of experimental uncertainty for a single cylinder in pulsating crossflow. Results presented for this investigation, where flow conditions (Re, F_d, τ) matched those used by Andraka, show an increase in heat

transfer of up to 11 percent over the steady flow value on the back of the cylinder.

One possible explanation for the difference in both steady and unsteady flow heat transfer is that internal losses occurred between the front and back of the test cylinder used for this investigation. An attempt was made to solve for these losses (Appendix D). The method used was found to over-predict heat losses, therefore no correction was made to experimental data. It is unlikely, however, that internal heat losses had much effect on the measurement of heat transfer on the front and back of the cylinder. Results presented to determine repeatability (Table 4) were obtained with the cylinder at different positions (eg. segments A and D on the front for one test, and on the back for another). Even if relatively large losses existed between the front and back of the cylinder, the losses would change only as a result of cylinder temperature distributions. The losses would therefore be the same for steady and pulsating flow, and relative Nusselt number (Nu_f/Nu_s) would not be affected.

No reason was found which would account for differences between current heat transfer measurements and those obtained by Andraka. It should be noted that the measurement technique was different for the two studies. Andraka used a Gardon heat flux gage (differential thermocouple) placed in a heated cylinder split into two halves. For the present investigation, an active technique was used which involved measuring the electric power input to a heated cylinder split into quarter sections. The insulation strips separating cylinder segments were placed at 0, 90 and 180 degrees (measured from stagnation) so that the insulation strips

would not effect the point of separation ($\phi=85$ degrees). It is unlikely that the insulation at $\phi=90$ degrees changed the flow in the wake region, which would also effect heat transfer.

Current results show good qualitative and quantative agreement with Lebouche and Martin [5]. For the high amplitude test with $f_d/f_s=0.44$, $\tau=34$ percent, $Re=23300$, an increase in Nusselt number of 36 percent was observed on the back of the test cylinder. Lebouche and Martin presented data for $f_d/f_s=0.43$, $\tau=36$ percent, $Re=27,000$ which shows a 31 percent increase on the back of the cylinder. No increase was seen on the front of the cylinder in either case. Unfortunately only one data point matched flow conditions well enough for a direct comparison.

Unsteady flow results (Figure 30) show that at driving frequencies above the natural shedding frequency for steady flow, the vortex shedding locks-on at half the driving frequency. Because vortices are alternately shed from the top and bottom of the cylinder, two vortices are actually shed during one cycle. At $f_d/f_s=1$, pulsations could result alternately in constructive interference and destructive interference with the vortices forming on the back of the cylinder. For $f_d/f_s>1$ with vortex shedding locked-on at half the driving frequency, constructive interference would be more likely to occur. Unsteady flow results for a single cylinder (figure 30) do not conclusively show any increase in vortex strength when shedding is locked on at half the driving frequency. Still, it is interesting to note that the largest increases in heat transfer generally occur at $f_d/f_s>1$. Some vortex amplification appears to occur for the in-line arrangement of cylinders at $f_d/f_s>1$ (figure 45).

In Figure 30 at $f_d=2$ Hz, no vortex shedding was observed. A 2 Hz driving frequency also corresponded to a 2 to 5 percent decrease in heat transfer. The decrease for low frequency pulsations was also reported by Base et al. [19]. This suggests that when vortex shedding is suppressed and the wake is disorganized, heat transfer decreases. Again, results are not conclusive, however they appear to contradict conclusions made by Lebouche and Martin, who attributed their increases in heat transfer partly to the effect of pulsations disorganizing flow in the wake region.

5.2 IN-LINE ARRANGEMENTS.

For single rows of three in-line cylinders, no CWT heat transfer data was found for comparison. Current steady flow results show good agreement with CHF data from Aiba et al. [31] for $Re=23,000$ and $Re=49,000$ with $L/d=1.8$. No unsteady data was available for comparison.

For pulsed flow, increases in heat transfer were smaller than for a single cylinder. Increases in Nusselt number were generally only seen above the natural vortex shedding frequency for steady flow. The increase was observed primarily on the front of the cylinder. The relative Nusselt number for pulsed flow (Nu_f/Nu_s) also appears to have some Reynolds number dependence. At $Re=49,000$, increases in heat transfer were lower than at $Re=23,000$, even though pulsation amplitudes were somewhat higher. Unsteady flow data (figure 45) indicates that very little unsteadiness existed between the cylinders before the jump phenomenon. When a freestream pulsation at 5 Hz. was applied (figure 45), flow organization between the first and second cylinders and heat transfer on the front of the test

cylinder increased. No increase was observed at this frequency at $Re=49,000$, where unsteadiness was already present between the cylinders for steady flow (figure 45d).

5.3 PERPENDICULAR ARRANGEMENTS

Heat transfer and flow around perpendicular arrangements of cylinders is a complex three-dimensional problem which was not considered in detail for this investigation. Mean heat transfer on a test cylinder in the wake of three perpendicular cylinders was measured to determine whether or not flow unsteadiness created by the leading cylinders had a greater effect on heat transfer than flow unsteadiness created by parallel in-line cylinders. No previous studies of this kind were found in the literature.

Results showed that the overall heat transfer for the perpendicular arrangement was greater than overall heat transfer for an in-line arrangement for $L/D > 3$. Below $L/D = 3$, overall heat transfer was less for the perpendicular arrangement. For heat exchanger designs, pitch ratio is generally less than $L/D = 3$, and the perpendicular arrangement is therefore less favorable than an in-line arrangement.

It should be noted that the test cylinder was located behind a row of three perpendicular cylinders, with no cylinders placed downstream of the test cylinder. It is therefore unclear whether an analogy can be made between heat transfer from the test cylinder and heat transfer from the second cylinder in a large bank of tubes. Additionally, present results apply only to the second cylinder. Unsteady flow data taken behind the test cylinder shows high levels of turbulence and little or no flow or-

ganization. Gundappa and Diller [16] suggested that small length scale turbulence has a greater effect on heat transfer than large length scale unsteadiness. This turbulence may further increase heat transfer on downstream cylinders. Overall, heat transfer for a perpendicular bank could be higher than for an in-line bank once downstream cylinders are taken into account. No data for banks of perpendicular cylinders currently exists and more data is needed.

Pulsed flow results for the perpendicular arrangement show that heat transfer increases with pulsation frequency. Nusselt numbers were up to 17 percent higher on the back of the cylinder for pulsed flow. No increase was observed on the front of the cylinder. It is unclear whether the increase on the back of the cylinder would occur for a tube bundle.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The present investigation provides results which can be used in an effort to better understand the mechanisms of heat transfer for a single cylinder in steady and unsteady crossflow, and for in-line rows of cylinders in steady crossflow. Additionally, this investigation provides data for the first time on the case of in line rows of cylinders in pulsating crossflow. Heat transfer from perpendicular arrangements of cylinders was also investigated and results were compared to data for similar in-line rows of cylinders.

The following conclusions can be made based on results from this investigation:

6.1 SINGLE CYLINDER

- 1) When one dimensional organized flow pulsations are added to the free stream with $f_d/f_s > 0.25$, heat transfer increases on the back of the cylinder. No increase or decrease occurs on the front of the cylinder.
- 2) As driving frequency increases past the natural vortex shedding frequency for steady flow, shedding frequency locks-on to half the driving frequency. The largest increases in heat transfer, which were about 20 to 25 percent, were observed for $f_d/f_s > 1$.
- 3) For $f_d/f_s < 1$, the increase in Nusselt number per unit amplitude showed almost no Reynolds number dependence in the range

23,000 < Re < 49,000. Very little data were taken at higher Reynolds numbers for $f_d/f_s > 1$, though the increase appears to be larger at Re=23,000.

4) At low pulsation frequencies ($f_d/f_s < 0.25$), a slight decrease in heat transfer was observed and vortex shedding appeared to be suppressed.

5) While results are not conclusive, experimental data suggest that when pulsations have the effect of organizing the wake (increasing shedding vortex strength), heat transfer in the wake region increases. When organization in the wake is decreased (weakening or suppressing vortex shedding), heat transfer is decreased.

6.2 IN-LINE ARRANGEMENTS:

1) For pulsed flow, heat transfer increases primarily on the front side of the cylinder. The increase on the front was generally about 5 percent. The largest increase was 11 percent at frequencies above the natural shedding frequency for steady flow, and at L/D=1.1.

2) As for a single cylinder, Nusselt number increased the most at frequencies where vortex shedding was locked on at half the driving frequency. Larger increases were observed at Re=23,000 than at Re=49,000.

6.3 PERPENDICULAR ARRANGEMENTS

- 1) Heat transfer from perpendicular arrangements in steady crossflow was found to be lower than for a similar in-line arrangement for $L/D < 3$, and higher for $L/D > 3$.
- 2) For pulsed flow, increases in heat transfer of up to 17 percent were observed on the back of the cylinder. Increases of between 2 and 5 percent were seen on the front. The increase was largest near $f_d/f_s = 1$ and at $L/D = 2$ and 2.5 .
- 3) The perpendicular arrangement may be less suitable for heat exchanger design because overall heat transfer is lower than for in-line arrangements. Vortex shedding appears to be suppressed behind the test cylinder. Current results however, are not sufficient to predict heat transfer in a bundle of tubes and more data is needed.

6.4 RECOMMENDATIONS

The following recommendations are made for future investigations:

- 1) More flow data is needed for in line and perpendicular arrangements. Local pressure distribution and shear stress, both mean and RMS values, would be useful. Also of interest would be the velocity distribution and turbulence levels in the wake of the

cylinder(s). An understanding of the flow around the cylinders could lead to a correlation to predict heat transfer.

2) Mean and fluctuating lift and drag measurements are needed to determine whether increases in heat transfer for unsteady cross-flow would also result in a higher pressure drop in banks of tubes.

3) The heat transfer problems considered in this investigation are inherently unsteady. Instantaneous heat transfer data taken with a rapid response heat flux gage would be of great interest for interpreting both results from this investigation and those from previous studies.

4) No previous data was found to compare with current results for the perpendicular arrangement, and more data is needed. High levels of low frequency turbulence were observed in the wake of the perpendicular arrangement, which could have the effect of increasing heat transfer on the front of downstream cylinders. Current results could therefore be extended to perpendicular bundles of tubes.

LIST OF REFERENCES

1. Zukauskas, A., "Heat Transfer from Tubes in Crossflow," Advances in Heat Transfer, Vol. 8, 1972, pp. 96-160.
2. Morgan, V. T., "The overall convective Heat Transfer from Tubes in Crossflow," Advances in Heat Transfer, Vol. 11, Academic Press 1975, pp. 196-264
3. Kraabel, J. S., McKillop, A. A. and Baughn, J. W. "Heat Transfer to Air from a Yawed Cylinder," International Journal of Heat and Mass Transfer, Vol. 25, No. 3, 1982, pp. 409-418.
4. Boulos, M. I. and Pei, D. C. T., "Dynamics of Heat Transfer from Cylinders in a Turbulent Air Stream," International Journal of Heat and Mass Transfer, Vol. 17, 1974, pp. 767-782.
5. Lebouche, M. and Martin, M., "Convection Forcee Autour du Cylindre; Sensibilite aux Pulsations de L'Ecoulement Externe," International Journal of Heat and Mass Transfer, Vol. 18, 1975, pp. 1161-1175.
6. Spalding, D. B. and Pun, W.M., "A Review of Methods for Predicting Heat Transfer Coefficients for Laminar Uniform Property Boundary Layer Flows," International Journal of Heat and Mass Transfer, Vol. 5, 1962, pp. 239-249.
7. Schmidt, E. and Wenner, K., "Heat Transfer over the Circumference of a Heated Cylinder in Transverse Flow," NACA TM 1050, 1943.
8. Achenbach, E., "Total and Local Heat Transfer from a Smooth Circular Cylinder in Crossflow at High Reynolds Number," International Journal of Heat and Mass Transfer, Vol. 18, 1975, pp. 1387-1396.
9. Andraka, C. E. and Diller, T. E., "Heat Transfer Distribution around a Circular Cylinder in Pulsating crossflow," ASME Paper No. 85-GT-67, 1985, to be published in ASME Journal of Engineering for Gas Turbines and Power.
10. Igarashi, T., "Correlation Between Heat Transfer and Fluctuating Pressure in the Separated Region of a Circular Cylinder," International Journal of Heat and Mass Transfer, Vol. 27, No. 6, 1984, pp. 927-937.
11. Papell, S. S., "Influence of Thermal Boundary Conditions on Heat Transfer From a Cylinder in Crossflow," NASA Technical Paper No. 1894, 1981.

12. Sparrow, E.M., Stahl, T.J. and Traub, P., "Heat Transfer Adjacent to the Attached End of a Cylinder in Crossflow," International Journal of Heat and Mass Transfer, Vol. 27, No. 2, 1984, pp. 233-242.
13. Boulos, M. I. and Pei, D.C.T., "Heat and Mass Transfer from Cylinders to a Turbulent Fluid Stream; A Critical Review," The Canadian Journal of Chemical Engineering, Vol. 51, Dec., 1983.
14. Kestin, J., Meader, P. F., and Sogin, H. H., "The Influence of Turbulence on the Transfer of Heat to Cylinders Near the Stagnation Point," Z. Agneu. Math. Phys., Vol. 12, 1969, pp. 115-132.
15. Lowery, G. W. and Vachon, R. I., "The Effect of Turbulence on Heat Transfer from Heated Cylinders," International Journal of Heat and Mass Transfer, Vol. 18, 1975, pp. 1229-1242.
16. Gundappa, M. and Diller, T. E., "The Effects of Freestream Turbulence and Flow Pulsation on Heat Transfer from a Cylinder in Crossflow," Accepted for ASME WAM, Miami, Nov., 1985.
17. Sreenivasan, K. and Ramachandran, A., "Effects of Vibration on Heat Transfer from a Horizontal Cylinder to a Normal Air stream," International Journal of Heat and Mass Transfer, Vol. 3, No. 3, 1961, pp. 60-67.
18. Saxena, V. C. and Liard, A. D. K., "Heat Transfer from a Cylinder Oscillating in a Crossflow," Journal of Heat Transfer, Trans. ASME, Vol. 100, 1978, pp. 684-689.
19. Base, T. E., Patel, J. M. and Valaitis, G. C., "Heat Transfer from Cylinders in Unsteady Flow," Canadian Journal of Chemical Engineering, Vol. 59, 1981, pp. 247-250.
20. Simoneau, R. J., Morehouse, K. A., Van Fossen, G. J. and Behning, F., "Effect of a Rotor Wake on Heat Transfer from a Circular Cylinder," ASME Paper No. 84-ht-25, 1984.
21. Kim, B. K., Borell, G. J., Diller, T. E., Cramer, M. S., and Telionis, D. P., "Pulsating Flow and Heat Transfer Over a Circular Cylinder," in Proceedings of the Symposium on Nonlinear Problems in Energy, DOE CONF-830413, 1983, pp. 96-101.
22. Kim, B. K., VandenBrink, D. J., Cramer, M. S., and Telionis, D. P., "Unsteady Heat Convection Over Circular Cylinders," ASME Paper No. 84-HT-100, 1984.
23. Zukauskas, A. A., "Air Cooled Heat Exchangers," in Heat Exchangers: Design and Theory Sourcebook, eds. N. Afgan and E. V. Schlunder, Scripta Book Co., Washington DC, 1974.

24. Zukauskas, A. A., "Heat Transfer of Banks of Tubes in Crossflow at High Reynolds Numbers," in Heat Exchangers: Design and Theory Sourcebook, eds. N. Afgan and E. V. Schlunder, Scripta Book Co., Washington DC, 1974, pp. 75-100.
25. Savkar, S. D., "A Survey of Flow induced Vibrations of Cylindrical Arrays in Crossflow," ASME Paper, presented at winter annual meeting, New York, Dec. 5, 1976.
26. Kostic, Z., Oka, S., "Fluid Flow and Heat Transfer with Two Cylinders in Crossflow," International Journal of Heat and Mass Transfer, Vol. 15, 1972, pp. 279-299.
27. Hiwada, M., Mabuchi, I. and Yanagihara, H., "Fluid Flow and Heat Transfer around Two Circular Cylinders," Bulletin of the JSME, Vol. 25, No. 209, Non., 1982.
28. Zdravkovich, M. M., "Review of Flow Interference Between Two Circular Cylinders in Various Arrangements," Transactions of the ASME, Dec. 1977, pp. 618-633.
29. Aiba, S., Ota, T. and Tsuchida, H., "Heat Transfer of Tubes Closely Spaced in a Bank," International Journal of Heat and Mass Transfer, Vol. 23, 1980, pp. 311-319.
30. Aiba, S., Ota, T. and Tsuchida, H., "Heat Transfer around a Tube in a Bank," Bulletin of the JSME, Vol. 24, No. 188, Feb. 1981.
31. Aiba, S., Ota, T. and Tsuchida, H., "Heat Transfer around a Tube in a Bank," Bulletin of the JSME, Vol. 23, No. 181, July, 1980.
32. Aiba, S. and Yamazaki, Y., "Investigation of Heat Transfer Around a Tube in a Bank," Trans. ASME, Journal of Heat Transfer, Ser. C, 98-3, 1978, pp503-508.
33. Igarashi, T., and Suzuki, K., "Characteristics of Flow around Three Circular Cylinders Arranged In Line," Bulletin JSME, Vol. 27, No. 233, Nov., 1984, pp. 2397-2404.
34. Igarashi, T., and Suzuki, K., "Characteristics of the Flow around two e Circular Cylinders Arranged In Tandem," Bulletin JSME, Vol. 27, No. 233, Nov., 1984, pp. 2380-2387.
35. Andraka C. E., "Heat Transfer From a Circular Cylinder in a Pulsating Crossflow," M.S. Thesis, VPI&SU, 1984.
36. Kostic, Z., Oka, S. and Sikmanovic, S., "Investigation of the Heat Transfer Processes in Tube Banks in Crossflow," in Heat Exchangers: Design and Theory Sourcebook, eds. N. Afgan and E. V. Schlunder, Scripta Book Co., Washington DC, 1974, pp. 617-636.

37. Achenbach, E., "Total and Local Heat Transfer and Pressure Drop of Staggered and In-Line Tube Bundles," in Heat Exchangers, Thermal-Hydraulic Fundamentals and Design, eds. S. Kakac, A. E. Bergles, and F. Mayinger, Hemisphere Publishing Co., Washington DC, 1981.
38. Holman, J. P., Experimental Methods for Engineers, McGraw-Hill, New York, 1978.
39. Holman, J. P., Heat Transfer, ed. 5, McGraw-Hill, New York, 1976.
40. Blevens, Robert D., Applied Fluid Dynamics Handbook, Van Nostrand Reinhold Co. Inc., 1984.
41. Vargaftik, N. B., Tables of Thermophysical properties of liquids and Gasses, ed. 2, Hemisphere Publishing Company, 1983.
42. Siegel, Robert and Howell, John, Thermal Radiation Heat Transfer, ed. 2, Hemisphere Publishing Company, 1981.
43. "Three Term Control System Applied To Temperature", Eurotherm Corporation Technical Note, No. TN100.
44. Sweat, V. E. and Haugh, C. G., "A Thermal Conductivity Probe For Small Food Samples," Trans. ASAE, Vol. 17, no. 1, 1974.

APPENDIX A. EXTERNAL ERROR ANALYSIS

This appendix gives the results of the external error analysis for heat transfer measurements. The external error was calculated using a Kline and McClintock uncertainty analysis [38]. It should be noted that this is only an estimate, because the calculated value for experimental error is based on individual uncertainties which themselves are based on experience, judgment or are calculated. Additionally, many sources of small experimental error exist which cannot all be taken into account.

For a function $G(a,b,c,d)$, the uncertainty of G , in units of G , is given by:

$$\omega_G^2 = \left(\frac{\partial G}{\partial a} \omega_a\right)^2 + \left(\frac{\partial G}{\partial b} \omega_b\right)^2 + \left(\frac{\partial G}{\partial c} \omega_c\right)^2 + \left(\frac{\partial G}{\partial d} \omega_d\right)^2 \quad (18)$$

From chapter 3, the heat transfer coefficient is given by:

$$h = \frac{\frac{V^2}{R} - \frac{\Sigma Q}{L}}{A (T - T_{\infty})} \quad (19)$$

For terms such as heater resistance R_i , which was accurately measured, the uncertainty was negligible. For other terms such as thermal radiation heat loss, Q_{Ri} , the uncertainty could be neglected because the correction itself was only a small percentage of the total experimental power measurement. Uncertainty associated with convection losses on the top face

of the insulation strips, Q_{L1} , was included in the uncertainty of power measurement. Therefore, only conduction losses in the insulation need be considered in the uncertainty analysis: $\omega_{Q_{Li}} = \omega_{Q_{Ri}}$. Substituting equation 19 into 18, the uncertainty for h is given by:

$$\omega_h^2 = \left(\frac{\partial h}{\partial V} \omega_V \right)^2 + \left(\frac{\partial h}{\partial Q} \omega_Q \right)^2 + \left(\frac{\partial h}{\partial A} \omega_A \right)^2 + \left(\frac{\partial h}{\partial \Delta T} \omega_{\Delta T} \right)^2 \quad (20)$$

$L2$

Where $\Delta T = T - T_\infty$. The partial derivatives are as follows:

$$\frac{\partial h}{\partial V} = \frac{\frac{2V}{R}}{A (T - T_\infty)} \quad (21)$$

$$\frac{\partial h}{\partial Q} = \frac{-1}{A (T - T_\infty)} \quad (22)$$

$$\frac{\partial h}{\partial A} = \frac{\frac{Q}{L2} - \frac{V^2}{R}}{2 A (T - T_\infty)} \quad (23)$$

$$\frac{\partial h}{\partial \Delta T} = \frac{\frac{Q}{L^2} - \frac{V^2}{R}}{A (T - T_{\infty})^2} \quad (24)$$

Dividing ω_h by h , the uncertainty in dimensionless form (eg. $e_h = \omega_h/h$) is given by:

$$e_h^2 = (2e_v)^2 + e_{Q_{L2}}^2 + e_a^2 + e_{\Delta T}^2 \quad (25)$$

The uncertainties are as follows. For voltage:

$$e_v = \frac{\pm 1.96 \sigma_v}{V}$$

where the numerator represents the 95 percent confidence limit obtained from Appendix B. For the controller settings used $\sigma_v = \pm 0.19$. The voltage was generally between 30 and 40 volts. Voltage was assumed to be 30 volts at $Re=23,000$ and 40 volts at $Re=49,000$. For conduction losses in the insulation:

$$e_{Q_{L2}} = \pm 0.01$$

which was obtained from Appendix C. The highest value of $e_{Q_{L2}}$ calculated in appendix C was assumed. The uncertainty from conduction losses is halved for a half cylinder, and assumed to be zero for the cylinder overall. For temperature, the uncertainty assumes a ten degree overheat with T and T_{∞} measured to $\omega_T = \omega_{T_{\infty}} = \pm 0.1^\circ C$.

$$e_{\Delta T} = \pm 0.014$$

Uncertainty of the cylinder surface area ($A = 1.24 \times 10^{-1} \text{ m}^2$) assumed cylinder diameter measured to $\pm 0.05 \text{ cm}$ ($e_D = 5.6 \times 10^{-3}$) and length measured to $w_L = \pm 0.05 \text{ cm}$ ($e_L = 1.1 \times 10^{-3}$).

$$e_A = \pm n \times 0.0057$$

For the entire cylinder, $n=1$. For a half segment of the cylinder, the uncertainty of area is double, because length and diameter are the same, while area is halved ($n=2$). For a single cylinder segment, the error would be quadrupled ($n=4$).

When equation 24 is evaluated, the uncertainty for measurement of heat transfer coefficient is dependent on voltage measured, which depends on Reynolds Number. The overall external error was calculated to be:

$$e_h = \pm 2.4 \text{ percent at } Re = 49,000$$

$$e_h = \pm 2.9 \text{ percent at } Re = 23,000$$

For a half cylinder section:

$$e_h = \pm 2.6 \text{ percent at } Re = 49,000$$

$$e_h = \pm 3.1 \text{ percent at } Re = 23,000$$

For a quarter cylinder section:

$$e_h = \pm 3.4 \text{ percent at } Re = 49,000$$

$$e_h = \pm 3.8 \text{ percent at } Re = 23,000$$

The largest contributions to overall error were the result of voltage uncertainty. Uncertainty for temperature and for conduction losses could have been neglected without significantly changing the calculated external error for h . For a half cylinder and quarter cylinder, the uncertainty associated with surface area measurement had a larger effect on overall uncertainty.

APPENDIX B. TEMPERATURE CONTROL AND HEATER VOLTAGE MEASUREMENT USING EUROTHERM CONTROLLERS

This appendix provides information on the use of Eurotherm three term temperature controllers for cylinder temperature control. The principal of operation of the controllers is given first. The method used for determining time averaged controller output voltage is given next. A description of controller settings used and their effect on uncertainty of power measurement is also included.

B.1 PRINCIPAL OF OPERATION OF PID TEMPERATURE CONTROLLERS

As described in chapter 3, Eurotherm PID (proportional, integral, derivative) temperature controllers [43] were used to maintain each cylinder segment at constant temperature. Each unit consisted of a model 831 controller and model 810 PAP (phase-angle fired) SCR. The input to the controller was a T-type thermocouple located in the wall of a cylinder segment. The output of the controller unit was a 0-5 volt PAP signal to the SCR. The SCR unit output was 0-120 volts RMS, proportional to the input signal.

The controllers hold the cylinder at constant temperature by switching power to a heater on and off. Two types of switching exist; phase-angle firing and zero-crossover firing. Phase-angle fired controllers vary the RMS output voltage by switching power on at some point (phase angle) during each half cycle of the 60 Hz line voltage supplied

to the SCR. The phase angle of each half cycle where switching occurs determines the RMS output voltage, and for a resistive load, the power supplied. For zero-crossover firing, power is switched on at the beginning of a line voltage cycle, and stays on for several cycles. Time averaged output power depends on the percentage of time that power is switched on.

Phase-angle-fired controllers were used for this investigation because the output voltage switches on and off during each half cycle of the line voltage, which allowed the output voltage to be read using a conventional true RMS voltmeter.

Three term controllers use proportional, integral and derivative action to vary the output voltage. The principal of operation is given in the following paragraphs.

When proportional control is used, the power output of the controller is proportional to the difference between the actual temperature and the setpoint. At the setpoint, the controller outputs 50 percent of maximum power. The proportional band is the region where proportional control occurs. At the upper limit of the proportional band, the power output is zero, and at the lower limit, the power output is 100 percent of maximum power. For the Eurotherm controllers used for this investigation, the proportional band could be varried between 0.5 percent and 100 percent of full scale, which corresponds to 200 °C.

Proportional control provides an advantage over on-off control as long as the temperature remains within the proportional band. For on-off control, temperature must change (move across the setpoint) for switching

to occur. Proportional control can result in less oscillation because power is provided continuously.

One problem introduced by proportional control is "droop". When only proportional control is used, power at the setpoint is always 50 percent of maximum power. If the power required to maintain the load at the setpoint is not 50 percent, the temperature of the load will come to equilibrium at some point away from the setpoint. The temperature difference between the actual temperature and the setpoint is known as droop. One method of reducing droop involves reducing the size of the proportional band, however, this may increase temperature oscillation. Integral and derivative action can also be used to reduce droop.

Integral control shifts the proportional band until the power output at the setpoint corresponds to load power. The integral action must take place slowly, otherwise a change in load power conditions may cause an effective narrowing of the proportional band and temperature oscillation. Integral action could be adjusted on the Eurotherm controllers by varying the integral time (t_I), which is the time required to shift the proportional band to halve or double the power in order to respond to droop. The range of t_I was from 5 to 1800 seconds, and integral action could also be turned off. Because integral action takes place over a period of time, the response to changes in power conditions is slower than if only proportional control is used.

Derivative control can be used indirectly to reduce droop, by reducing the size of the proportional band. Derivative control, characterized by the derivative time (t_D), shifts the proportional band according to how fast the temperature is changing. For a temperature changing at $1/t_D$ de-

degrees per second, the controller will shift the proportional band to half the power for temperature increasing above the setpoint, or to double the power for temperature decreasing below the setpoint. Because derivative control adjusts output power to respond to changes in temperature, the size of the proportional band can be reduced. However when the derivative time is set too large and integral action is used, control can be unstable, driving the temperature to the limits of the proportional band where the system reverts to on-off control.

B.2 CONTROLLER OUTPUT POWER MEASUREMENT

The temperature controllers easily maintained the temperature of the cylinder segments to within $\pm 0.1^{\circ}\text{C}$ for most controller settings. If only temperature control were required, on-off controllers would have been sufficient. It was also necessary, however, to maintain the output power constant so that voltage readings could be made with a voltmeter. The thermal mass of the cylinder was large and an on-off controller would shift on and off only a few times per minute, making average readings with a voltmeter difficult. Even when the controllers were used, voltage readings made with the DMM varied by 0.4 to 1.8 volts at equilibrium, depending on controller settings. Individual voltage readings could vary by several volts in response to even a small perturbation. For this reason, it was necessary to take a large number of voltage readings for the purpose of both obtaining a time averaged voltage, and to determine whether or not the output power was in equilibrium.

As described in chapter 3, an HP-41CV calculator was interfaced to the multimeter. A program written for the HP-41CV allowed time averaged voltage to be read on all four channels. Time-averaged voltage was recorded on each channel and saved in memory. By comparing successive averages, or for a large number of averages, computing the standard deviation, voltage readings could be stopped when all four channels were in equilibrium. A flowchart for the HP-41CV program is given in Figure 61, and a listing is included at the end of this appendix.

The programme worked as follows: After initialization, a subroutine triggered the DMM and read the voltage continuously until a change in successive voltage readings of at least -5 volts occurred. The change in voltage took place when the multiplexer, controlled by the TRS-80, switched to a neutral position where the voltage was nominally zero. While voltages were being read, the values were stored in the statistical registers. When a channel change of the multiplexer was detected (nominal zero voltage), the calculator ignored the current voltage reading, removed the previous reading from the statistical registers, averaged the values in the statistical registers and stored the average in memory. Voltage averages were stored in registers 41-50, starting with register 41, for channel A, 51-60 for channel B, etc. After 10 voltage averages were taken, the memory counters were reset to the original values (41 for channel A, 51 for B, etc.), and data acquisition continued. The standard deviation of voltage averages in the storage registers was also computed. When large numbers of averages were taken, the standard deviation could be used to determine whether or not the cylinder was in equilibrium. This method was used while data for perpendicular arrangements was taken where

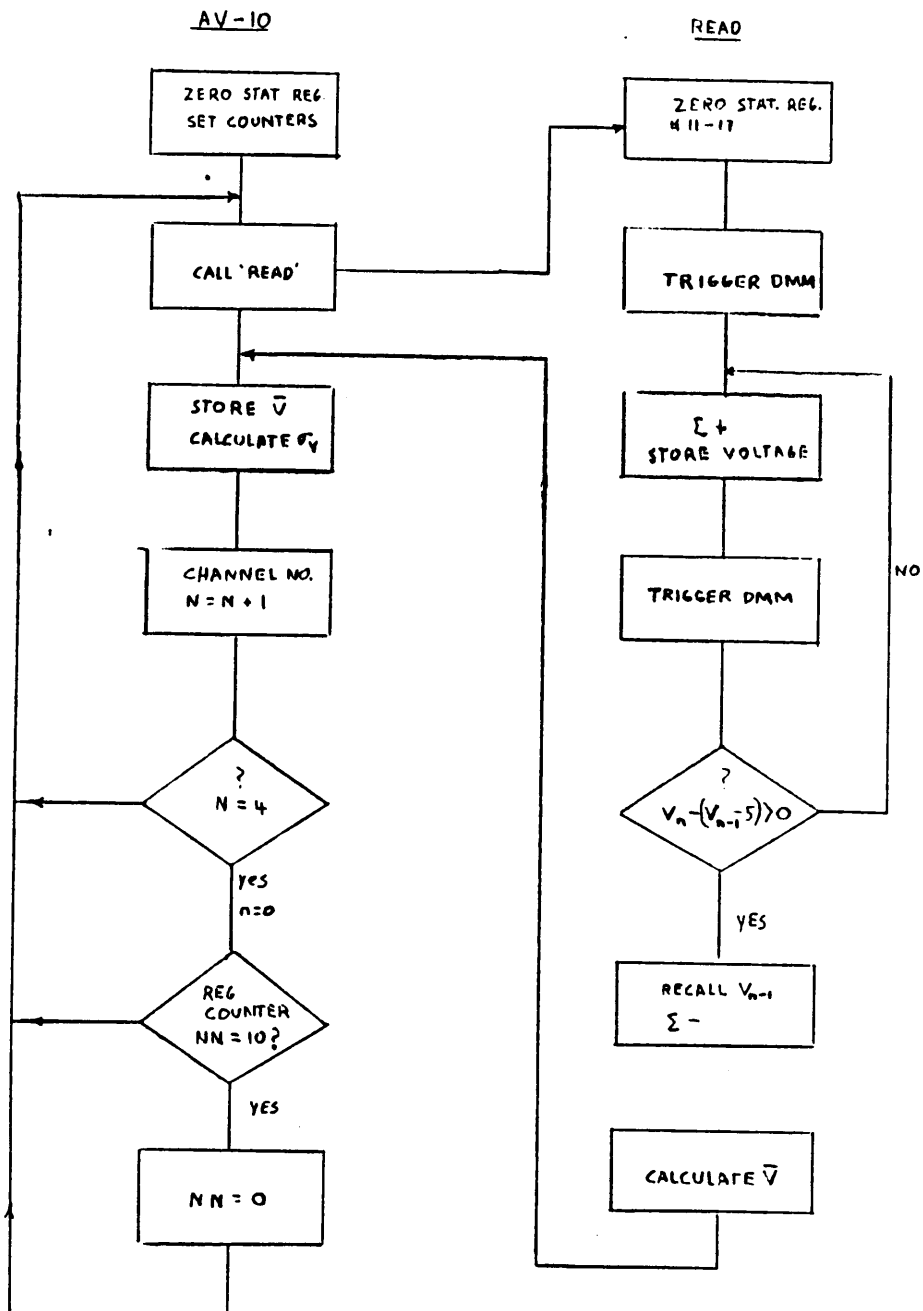


Figure 61. Flowchart for HP-41CV data acquisition program

averages of ten readings were used. Later, the method of obtaining data was changed and averages of 150 individual readings were used. The number of averages taken was adjusted by varying the timing loop on the TRS-80 which controlled the multiplexer. Averages of 150 readings required approximately two minutes for each channel. Equilibrium could therefore be determined by comparing successive readings on each channel, which were separated by a period of 8 minutes.

When all four channels were in equilibrium, four averages of 150 readings were manually entered into the TRS-80, flow conditions were reset, and the HP-41CV program began averaging for the next data point.

B.3 CONTROLLER SETTINGS

Even though the mean of 150 voltage readings was taken, it was still necessary to optimize controller settings. A modified version of the HP-41CV program was used to record up to 80 voltage averages. The standard deviation of the averages was computed and used to obtain the 95 percent confidence limit. The 95 percent confidence limit was taken as the uncertainty of voltage measurement, and for a large number of voltage readings, $w_{95\%} = 1.96 \sigma_V$. The standard deviation of averaged voltage readings for different controller settings is given in Table 10. Based on these results controller settings were as follows:

Proportional band = 6% (p6)

Integral time = 90 sec (I90)

Derivative time off (D off)

The uncertainty of voltage measurement used for the uncertainty analysis in Appendix A is given by:

$$\omega_V = \pm 1.96\sigma_V = \pm 0.35 \text{ volts}$$

It may have been possible to further reduce voltage measurement uncertainty by reading more averages or further optimizing controller settings. The former would have reduced the amount of data that could be taken because data acquisition would have been more time consuming. There is also a lower limit on the uncertainty of voltage measurement imposed by the performance of the controllers. For example, assuming the Frossling number is constant for a segment on the front of the cylinder and neglecting heat losses:

$$Fr = Nu Re^{-1/2} = \frac{4P}{\pi DL_c (T - T_\infty)} \frac{k_a}{D} Re^{-1/2}$$

where $P = V^2/R$. Solving for voltage:

$$V = \left[\frac{1}{4} Fr Re^{1/2} \pi k_a L_c R (T - T_\infty) \right]^{1/2}$$

The derivative is the sensitivity of voltage measurement:

$$\frac{dV}{dT} = \left(\frac{1}{16} Fr Re^{1/2} \pi k_a L_c R \right)^{1/2} (T - T_\infty)^{-1/2} \quad (26)$$

Evaluating the previous expression, and approximating dT by ΔT :

$$\frac{\Delta V}{\Delta T} = 0.379 R^{1/4} (T - T_\infty)^{-1/2} \quad (27)$$

Assuming the temperature of the cylinder is controlled to $\Delta T = \pm 0.1^\circ C$:

$$\Delta V = \pm 3.79 Re^{1/4} (T - T_\infty)^{-1/2} \quad (28)$$

For $T - T_{inf.} = 10^\circ C$, the minimum error for voltage At $Re=50,000$, ΔV is ± 0.17 Volts, which is close to the value of $\sigma_V = 0.19$ volts obtained by averaging 100 individual voltage readings. This indicates that controller settings have been nearly optimized.

Table 10. Standard deviation of voltage readings for different controller settings

controller settings	individual readings (200)	averages.of 10 readings (20)	averages.of 140 readings (15)
	volts	volts	volts
P12 tI90 tDoff	0.43	0.30	0.190
P4 tI30 tD10	1.78	0.84	0.41
P6 tI30 tDoff	0.86	0.79	0.38

HP-41CV DATA ACQUISITION PROGRAM 'AV10'

AVERAGED VOLTAGES; CHANNEL A-D IN REGISTERS 41-50, 51-60, 61-70, 71-80
REGISTERS 11-16, 17-22, 23-28, 29-34 (STAT REGISTERS FOR CH A-D) USED TO
TAKE MEAN AND STANDARD DEVIATION OF LAST 10 AVERAGE VOLTAGES
REGISTER 99 MAX NUMBER OF AVERAGES BEFORE PROGRAM STOPS. COUNTER IN REG
00 IS DOWN-LOADED FROM REG 99 AT BEGINNING OF PROGRAMME FORMAT IS
XXXX.YYYZZ XXXX=CURRENT NO. YYY=MAX NO. ZZ=INCREMENT
REGISTER 98 CHANNEL COUNTER DOWNLOADED TO REG 01 AT BEG OF PROG
REGISTER 97 COUNTER POSITION OF CURRENT AVERAGE FORM FIRST REG POS DOWN-
LOADED TO REG 04 AT BEGINNING OF PROGRAM
REGISTERS NORMALLY SET FOR: REG99=1.24001 REG98=0.00401 REG97=1.01001
OTHER COUNTERS:

REG 02 COUNTER FOR BEGINNING OF CURRENT STATISTICAL REGISTERS
REG 05 COUNTER FOR STORAGE REGISTER OF NEXT STANDARD
DEVIATION
REG 03 COUNTER FOR STORAGE REGISTER OF NEXT VOLTAGE AVERAGE
REG 07 COUNTER FOR STORAGE REGISTER OF MEAN VOLTAGE
(NOT CURR USED)
'AV10' CURRENTLY SET ON USER KEY: SQUARE ROOT

LINE #	PROGRAMME LINE
01	LBL ALPHA AV10 ALPHA
02	40
03	STO 07
04	LBL 15
05	RCL 99
06	STO 00
07	RCL 98
08	STO 01
09	RCL 97
10	STO 04
11	10
12	Σ REG 11
13	STO 16
14	Σ REG 17
15	STO 22
16	Σ REG 23
17	STO 28
18	Σ REG 29
19	STO 34
20	CF 01
21	CF 02
22	CF 03
23	CF 04
24	LBL 05
25	RCL 98
26	1
27	+
28	ISG 01
29	GTO 06
30	STO 01

31	RCL 97
32	ISG 04
33	GTO 06
34	STO 04
35	LBL 06
36	LBL 07.
37	SF IND 01
38	RCL 01
39	INT
40	ENTER
41	6
42	*
43	5
44	+
45	STO 02
46	RCL 01
47	5
48	+
49	STO 05
50	RCL 01
51	INT
52	ENTER
53	10
54	*
55	30
56	+
57	RCL 04
58	INT
59	+
60	STO 03
61	0
62	ENTER
63	XEQ ALPHA READ ALPHA
64	X<> IND 03
65	Σ REG IND 02
66	Σ -
67	RCL IND 03
68	Σ +
69	CF IND 01
70	SDEV
71	STO IND 05
72	VIEW IND 05
73	ISG 00
74	GTO 05
75	STOP
76	XEQ APLHA PSE APLHA
77	Σ REG 11
78	1
79	STO+ 07
80	XEQ ALPHA MEAN ALPHA
81	STO IND 07
82	1
83	STO+ 07
84	Σ REG 17

85 XEQ ALPHA MEAN ALPHA
86 STO IND 07
87 1
88 ST+ 07
89 Σ REG 23
90 XEQ ALPHA MEAN ALPHA
91 ST IND 07
92 1
93 ST+ 07
94 Σ REG 29
95 XEQ ALPHA MEAN ALPHA
96 ST IND 07
97 GTO 15
98 STOP

SUBPROGRAM READ

PROGRAM READS VOLTAGES AND ADDS VALUES TO STATISTICAL REGISTERS UNTIL TWO SUCCESSIVE VOLTAGES DIFFER BY 5 OR MORE VOLTS (DETECTION OF A MULTIPLEXER CHANNEL SWITCH). THE LAST TWO VOLTAGES (LOWER VOLTAGE AND VALUE PRECEEDING IT) ARE REMOVED FORM STATISTICAL REGISTERS BEFORE AVERAGE AND STANDARD DEVIATION ARE CALCULATED. 'READ' THEN RETURNS TO MAIN PROGRAM (AV10 OR CH1) THAT CALLED IT WITH AVERAGE IN X REGISTER AND NUMBER OF INDIVIDUAL READINGS FOR THE AVERAGE IN REGISTER 40.

STATISTICAL REGISTERS 35-40

'READ' CURRENTLY SET ON USER KEY: LOG

LINE # PROGRAM LINE

```
01 LBL ALPHA READ ALPHA
02 Σ REG 35
03 CLΣ
04 -5
05 XEQ ALPHA IND ALPHA HP-IL COMMAND, READS ONE VOLTAGE
06 +
07 LAST X
08 ENTER
09 LBL 00
10 Σ+
11 RDN
12 X<>Y
13 XEQ APLHA IND APLHA
14 X<=Y?
15 GTO 01
16 -5
17 X<>Y
18 +
19 LAST X
20 ENTER
21 GTO 00
22 LBL 01
23 RDN
24 RDN
25 GTO 03
26 STO 94
27 XEQ APLHA MEAN APLHA
28 STO 93
29 RCL 35
30 STO 92
31 RCL 94
32 LBL 03
33 Σ-
34 0
35 STO 37
```

35 STO 38
36 RCL 40
37 VIEW X
38 ENTER
39 XEQ APLHA XEQ APLHA PSE APLHAAPLHA
40 ENTER .
41 X<>Y
42 ENTER
43 XEQ APLHA MEAN APLHA
44 VIEW X
45 X<>Y
46 RDN
47 XEQ APLHA CLD APLHA
48 RTN
49 END

Appendix C: Insulation Losses and Uncertainties

This Appendix investigates the heat losses in the insulation strips between cylinder sections, and the effect of these losses on mean Nusselt number uncertainty. An overview of the heat transfer problem to be solved is given first. A 2-dimensional heat conduction model was used. A generalized analytical solution was obtained for the temperature distribution and heat flux in the form of an infinite series. The numerical values for heat loss and temperature distribution in the insulation strip were then determined by evaluating the infinite series using a digital computer. This solution was used first to optimize the insulation strip design, and later to make a correction for losses and to estimate the uncertainty once insulation strip thickness and material were chosen.

Description of Insulation Losses

Each thin insulation strip considered here separated either two larger heated sections of the copper cylinder, or a copper cylinder section and a guard heater. The insulation strip was rectangular in cross section (Fig. 62). The top face was exposed to convection. The two side faces each make contact with either a copper cylinder section or a guard heater. The bottom face was glued to the acrylic support cylinder. Losses from a cylinder section which occur through the insulation strip were as follows: 1) lost by convection through the top face, Q_{L_1} or 2) conduction through the insulation strip to another cylinder section or guard heater, Q_{L_2} . The heat loss between two independently heated copper sections Q_{L_2} , existed because the temperature of each cylinder section could not be maintained exactly at the setpoint of

the temperature controller. If each cylinder section is maintained at $T_w \pm 0.1^\circ\text{C}$, (the accuracy of the type T thermocouple used as inputs to the temperature controllers), then the temperature difference between two adjacent section is known only as an uncertainty: $\omega_{T_w} = \pm 0.14^\circ\text{C}$. The nominal value of ΔT_w is zero. For this reason Q_{L2} is considered only in the uncertainty analysis of losses in the insulation strip. For the uncertainty analysis it is still necessary to determine the effect of insulation material, dimensions, and temperature on Q_{L2} . To make a correction for losses, it was assumed that $Q_L = Q_{L1}$.

Analytical Solution for Losses:

In order to solve for losses, the insulation strip was modeled as a 2-dimensional conduction heat transfer problem, given schematically in Fig. 63. The governing differential equation is

$$\nabla^2 T = 0 \quad T = T(x,y)$$

with boundary conditions

$$\begin{array}{ll} (1) \quad T(0,y) = T_w & (2) \quad T(w,y) = T_w + \Delta T_w \\ (3) \quad \left. \frac{dT}{dy} \right|_{y=0} = 0 & (4) \quad K \frac{dT}{dy} + h(T - T_\infty) = 0 \end{array}$$

This problem was then put in dimensionless form, and separated into two simpler problems by superposition, each having only one nonhomogeneous boundary condition.

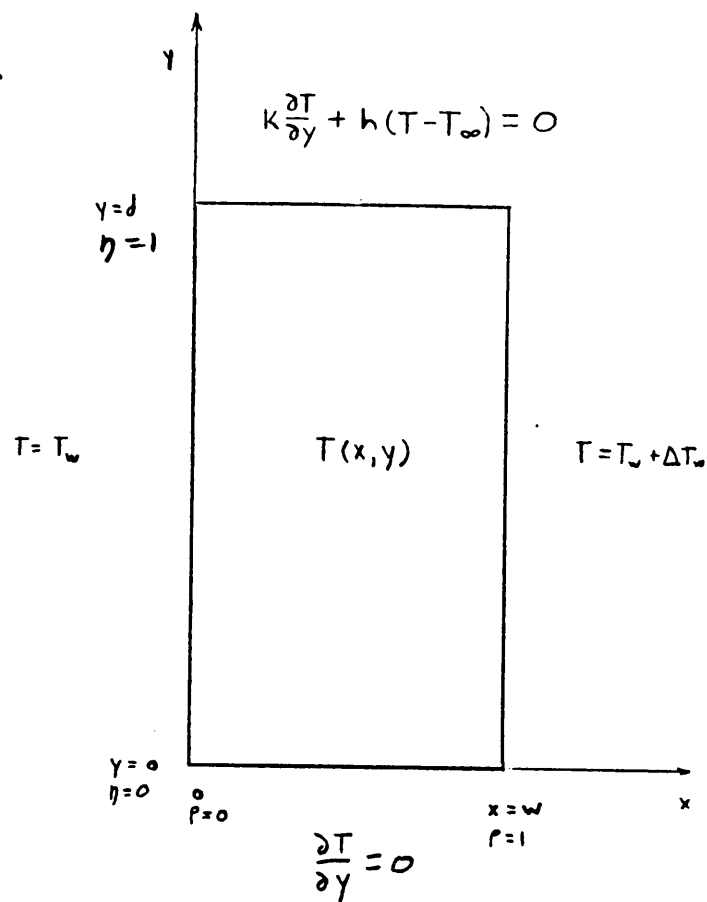


Figure 62. Two dimensional heat transfer problem for insulation strips

$$\theta = \frac{T - T_{\infty}}{T_w - T_{\infty}} = \theta_1(x, y) + \theta_2(x, y) \quad (29)$$

$$\frac{1}{w^2} \frac{\partial^2 \theta_1}{\partial \rho^2} + \frac{1}{d^2} \frac{\partial^2 \theta_1}{\partial \eta^2} = 0 \quad \frac{1}{w^2} \frac{\partial^2 \theta_2}{\partial \rho^2} + \frac{1}{d^2} \frac{\partial^2 \theta_2}{\partial \eta^2} = 0 \quad (30)$$

where $x = w\rho$, $y = \eta d$

The boundary conditions were

$$(1) \quad \theta_1 = 0 \quad , \quad \rho = 0 \quad \theta_2 = 0 \quad , \quad \rho = 0$$

$$(2) \quad \theta_2 = 0 \quad , \quad \rho = 1 \quad \theta_2 = \Delta T_w \quad , \quad \rho = 1$$

$$(3) \quad \frac{\partial \theta_1}{\partial \eta} = 0 \quad , \quad \eta = 0 \quad \frac{\partial \theta_2}{\partial \eta} = 0 \quad , \quad \eta = 0$$

$$(4) \quad \frac{\partial \theta_1}{\partial \eta} + Bi_d \theta_1 = -Bi_d \quad , \quad \eta = 1 \quad \frac{\partial \theta_2}{\partial \eta} + Bi_d \theta_2 = 0 \quad , \quad \eta = 1$$

$$\text{where } Bi_d = \frac{hd}{k} \quad , \quad Bi_w = \frac{hw}{k}$$

Each subproblem was solved using separation of variables. The resulting infinite series for the dimensionless temperature distribution in the strip is:

$$\theta(\rho, \eta) = \theta_1(\rho, \eta) + \theta_2(\rho, \eta)$$

$$\theta_1(\rho, \eta) = \frac{2Bi_w}{\pi} \sum_{n=1}^{\infty} \frac{(1 - \cos(n\pi\rho))}{n} \frac{\sin(n\pi\rho) \cosh(\frac{d}{w} n\pi\eta)}{[Bi_w \cosh(\frac{d}{w} n\pi) + n\pi \sinh(\frac{d}{w} n\pi)]} \quad (31)$$

$$\theta_2(\rho, \eta) =$$

$$\frac{\Delta T_w}{T_w - T_\infty} \sum_{n=1}^{\infty} \frac{\lambda_n^2 + Bi_d^2}{[\lambda_n^2 + Bi_d^2 + Bi_d]} \cdot \frac{1}{\lambda_n} \sin(\lambda_n) \cdot \frac{1}{\sinh(\lambda_n \frac{w}{d})} \cdot \cos(\lambda_n \eta) \sinh(\lambda_n \frac{w}{d} \rho) \quad (32)$$

$$\text{where } \lambda_n \tan(\lambda_n) = Bi_d$$

Heat losses per unit length through the insulation strip for a copper section were evaluated using

$$Q_L = -k L_2 \int_0^d \frac{dT}{dx} \Big|_{x=0} dy \quad (33)$$

where Q_L is the total loss per unit length of insulation strip. In dimensionless form:

$$q_{L1} = \frac{Q_{L1}}{L_2 k (T_w - T_\infty)} = \frac{2Bi_w}{\pi} \sum_{n=1}^{\infty} \frac{(1 - \cos(n\pi))}{[Bi_w \cosh(\frac{d}{w} n\pi) + n\pi \sinh(\frac{d}{w} n\pi)]} \sinh(\frac{d}{w} n\pi) \quad (34)$$

$$q_{L2} = \frac{Q_{L2}}{L_2 k \Delta T} = \sum_{n=1}^{\infty} \frac{\lambda_n^2 + Bi_d^2}{[\lambda_n^2 + Bi_d^2 + Bi_d]} \frac{1}{\sinh(\lambda_n \frac{w}{d})^2} \cdot \frac{\sin^2(\lambda_n)}{\lambda_n^2} \quad (35)$$

A digital computer was used to numerically evaluate the series in Eqs. 31-35. A program listing is in Appendix G.

Figure 63 gives the dependence of q_{L1} , (dimensionless form), on parameters Bi_w and $\frac{w}{D}$. For small values of w/d ($w/d < 0.5$), the convective losses depend only on Bi_w . For constant Bi_w , losses decrease as the aspect ratio (w/d) increases past $w/d = 1.0$. For small values of Bi_w , losses approach the constant surface temperature solution $q_{L1} = \frac{Bi_w}{2}$. As Bi_w is increased, losses increase, but are always less than the constant surface temperature case.

Unlike convective losses, dimensionless conduction losses generally show little dependence on Biot Number (Fig. 64). For low values of aspect ratio ($w/D < 0.5$), Biot number dependence can be neglected, and $q_{L2} \approx (w/D)^{-1}$, which represents one dimensional steady state conduction.

Correction to Cylinder Power Measurement:

The convective heat loss, Q_{L1} , is used to make a correction for losses on each cylinder section. The experimental power measurement for each cylinder section heater, (P), which represents the heat transfer for one quarter of the cylinder (88° copper section + 2° insulation), must be corrected because the surface of the insulation strip is not isothermal.

$$\frac{P_c}{P} = 1 + \epsilon_t \quad (36)$$

$$\text{where } \epsilon_t = \frac{q_2(\phi) - Q_{L1}(\phi) + q_2(\phi + 90^\circ) - Q_{L1}(\phi + 90^\circ)}{P} \quad (37)$$

and q_t is the predicted isothermal loss per unit length based on steady flow data for h :

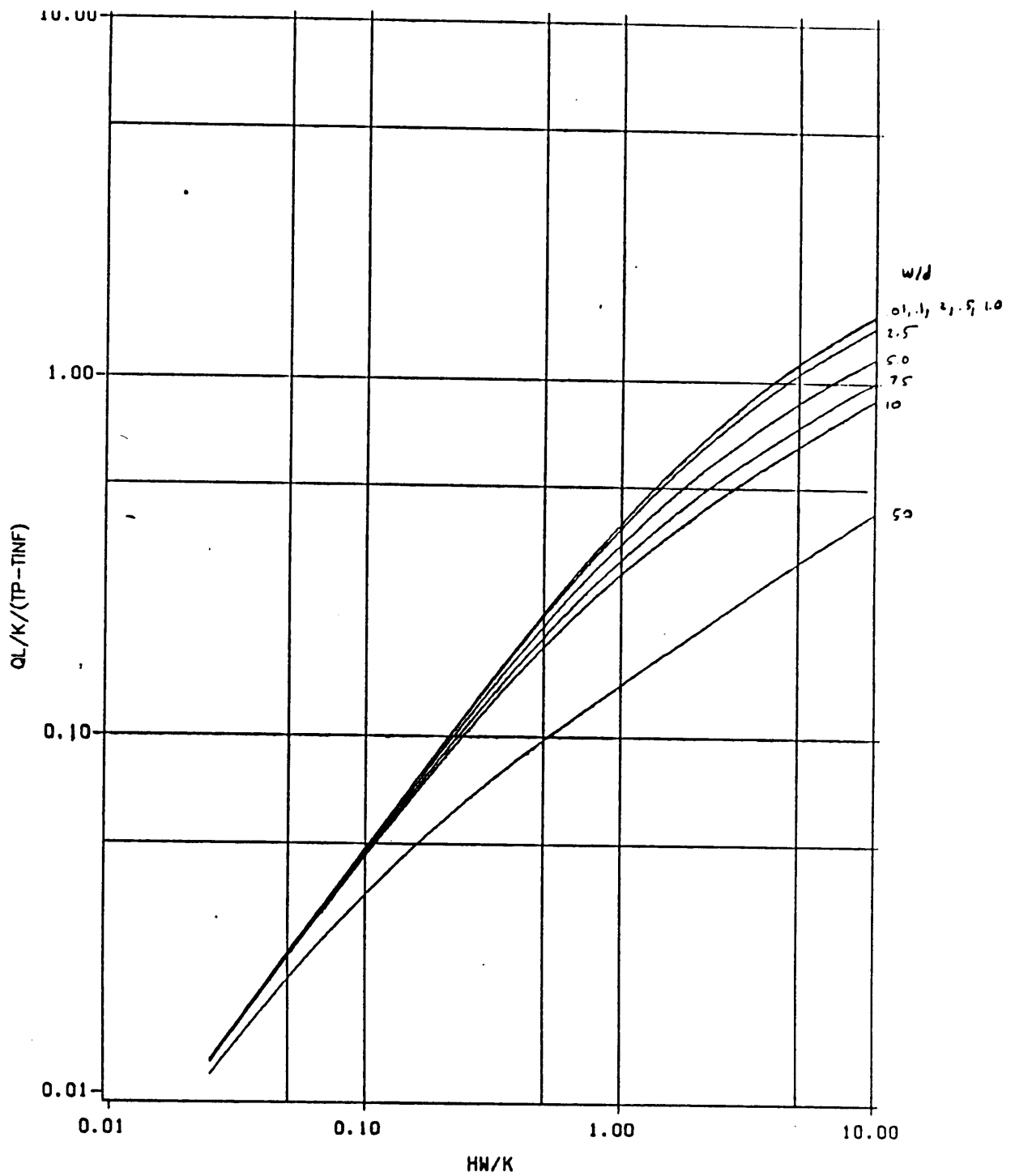


Figure 63. Dependence of dimensionless convection losses on Biot number and w/d

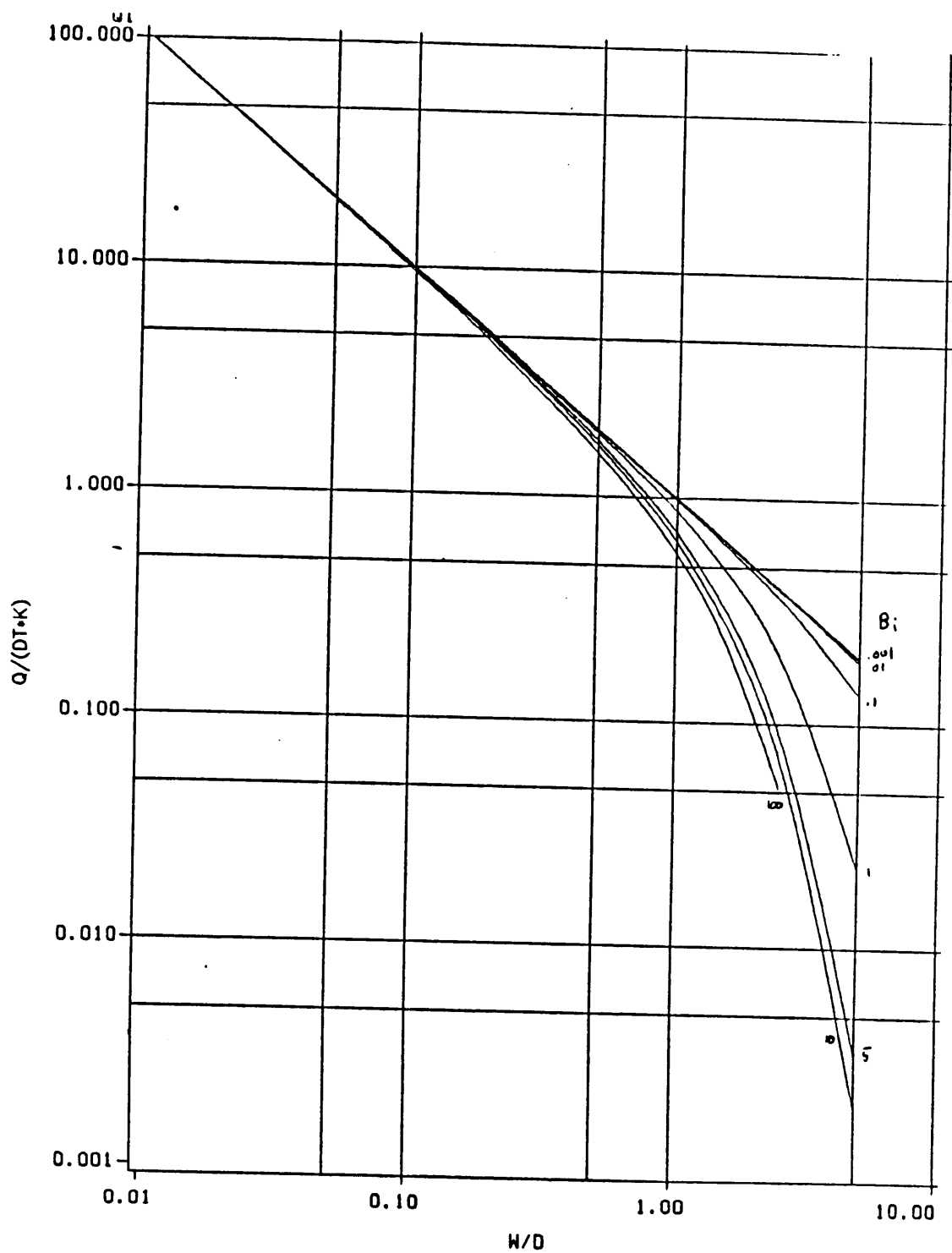


Figure 64. Dependence of dimensionless conduction losses on Biot number and w/d

$$q_T = hL_c \frac{w}{2} (T - T_\infty) \quad (38)$$

Convective losses were assumed to take place at locations ϕ and $\phi + 90^\circ$ on the cylinder segment.

Uncertainty

A Kline-McClintock uncertainty analysis is used to approximate the effect of losses on the uncertainty of measurement of Q_T .

The uncertainty for Q_T is given by

$$\omega_q = \left[\sum_i \left[\left(\frac{\partial Q_T}{\partial x_i} \omega_{xi} \right)^2 \right] \right]^{1/2}$$

Only the uncertainties related to insulation strip losses are considered here. This uncertainty will be used for the external error analysis in Appendix A.

$$\frac{\omega_{qL}}{P_c} = \frac{[\sum \omega_{qL1}^2 + \sum \omega_{qL2}^2]^{1/2}}{P_c} \quad (39)$$

$$q_{L1} = q_{L1}(Bi, T - T_\infty, d) \quad q_{L2} = q_{L2}(w, k, \Delta T_w, d)$$

$$\omega_{q_{L1}} = \left[\left(\frac{\omega_{Bi}}{Bi} \right)^2 + \left(\frac{\omega_{(T - T_\infty)}}{T - T_\infty} \right)^2 + \left(\frac{\omega_d}{d} \right)^2 \right]^{1/2} \cdot q_{L1}(\text{approximate}) \quad (40)$$

$$\text{where } \omega_{Bi_w} = \left[\left(\frac{\omega_h}{h} \right)^2 + \left(\frac{\omega_w}{w} \right)^2 + \left(\frac{\omega_k}{k} \right)^2 \right]^{1/2} \cdot Bi_w \quad (41)$$

$$\omega_{q_{L2}} = \left[\left(\frac{\omega_w}{w} \right)^2 + \left(\frac{\omega_k}{k} \right)^2 + \left(\frac{\omega_{\Delta T_w}}{\Delta T_w} \right)^2 + \left(\frac{\omega_d}{d} \right)^2 \right]^{1/2} \cdot q_{L2} \quad (42)$$

Values for individual uncertainties can often only be approximated. These uncertainties are as follows

$$e_d = \omega_d/d = 0$$

$$e_{T_p - T_\infty} = \frac{\omega_{T_w - T_\infty}}{T_w - T_\infty} = \frac{\pm 0.2}{20} = 0.014$$

$$e_k = \frac{\omega_k}{k} = 0.05 \text{ for } QL_1 \quad \frac{\omega_k}{k} = 0 \text{ for } qL_2$$

$$e_h = \frac{\omega_h}{h} = 0.05 \quad \frac{\omega_h}{h} = 0 \text{ for } qL_2$$

$$e_w = \frac{\omega_w}{w} = \begin{cases} \frac{\pm \frac{1}{64}}{w} & \text{for } w > \frac{1}{32} \\ \pm 0.5 & \text{for } w < \frac{1}{32} \end{cases}$$

$$e_{\Delta T_w} = \frac{\omega_{\Delta T}}{\Delta T} = 1.0$$

Uncertainties for K and h were neglected in calculating e_{qL_2} because other uncertainties (e_w and $e_{\Delta T}$) are much larger.

The correction for insulation heat loss and the effect of the correction on uncertainty of Q_T were used to design the insulation strips. Equation (36) and (37) is used to calculate ϵ_T , using

$$P_c = \frac{K_{air}}{D} \frac{D}{2} \frac{\pi}{180} (T - T_\infty) \int_{\phi_1}^{\phi_1 + 90^\circ} Nu(\phi) d\phi \quad (43)$$

For the purpose of designing the cylinder, $Nu(\phi)$ is approximated using

local Nusselt number data for a cylinder in steady crossflow.

Figure 65 gives the insulation thickness dependence of the correction to power and the resulting uncertainty for P_c . Figure 66 gives the centerline temperature $\theta'(\rho = \frac{1}{2}, \eta = 1)$ dependence on w . Both figures 65 and 66 are for insulation at $\phi = -45^\circ$ and $\phi = 45^\circ$ for a single cylinder in crossflow.

For low values of w , the correction to power was small. This is because the temperature on the convective surface of the insulation stayed close to the temperature of the surrounding wall. Thus, the convective losses on the top face differ only slightly from the convective losses for an isothermal top face at T . The uncertainty, however, increases rapidly for $w < 0.03$ " (0.76 cm). This can be explained by noting that the conduction losses q_{L2} are inversely proportional to the thickness w .

For larger values of w ($w > 0.5$) the effect of q_{L2} on uncertainty is negligible and the uncertainty is approximately constant at $e_{qL} = 0.6\%$. Both the correction factor ϵ_T and centerline temperature difference θ increase as w increases.

The design of the insulation thickness involved a compromise between a large correction factor for large w and a large uncertainty for small values of w . An additional criterion was that θ_{CL} remain small (small w). A large drop in insulation strip temperature may have an effect on the developing thermal boundary layer, further increasing ϵ_T and possibly having an effect on the downstream measurement of power on a cylinder section. The effect of insulation surface temperature distribution on the developing boundary layer is beyond the

scope of this investigation. This effect was minimized by choosing insulation material and thickness to reduce Q_{CL} .

The design point was chosen to be $w = \frac{1}{16}$ " (.0625) with $\frac{w}{d} = 0.5$. Autobody filler was used as the material for the top face of the insulation. The thermal conductivity was measured (Appendix E) to be $k = 0.25 \frac{W}{m^2 \cdot ^\circ C}$ at $T = 30^\circ C$.

The dependence of ϵ_T , and e_{qL} on insulation strip position is given in figure 68. For a single cylinder in crossflow at $Re = 49000$:

$$\epsilon_T = 0.23 - 0.46\%$$

$$e_p = \pm 0.53 \pm 1.0\%$$

$$\Theta_{CL} = .04 - .19$$

Equations used for calculating the correction to experimental power measurement are given in section 3.4.4. A local value of h was calculated from the experimental power measurement and an assumed distribution of heat transfer coefficient $(\frac{h(\phi)}{\bar{h}})$. The dimensionless convection loss was then determined by interpolation using digitized data that is shown in figure 63. Equations (37) and (38) were then used to compute the correction. A subroutine to correct experimental power measurements was included in the data reduction program (Appendix G).

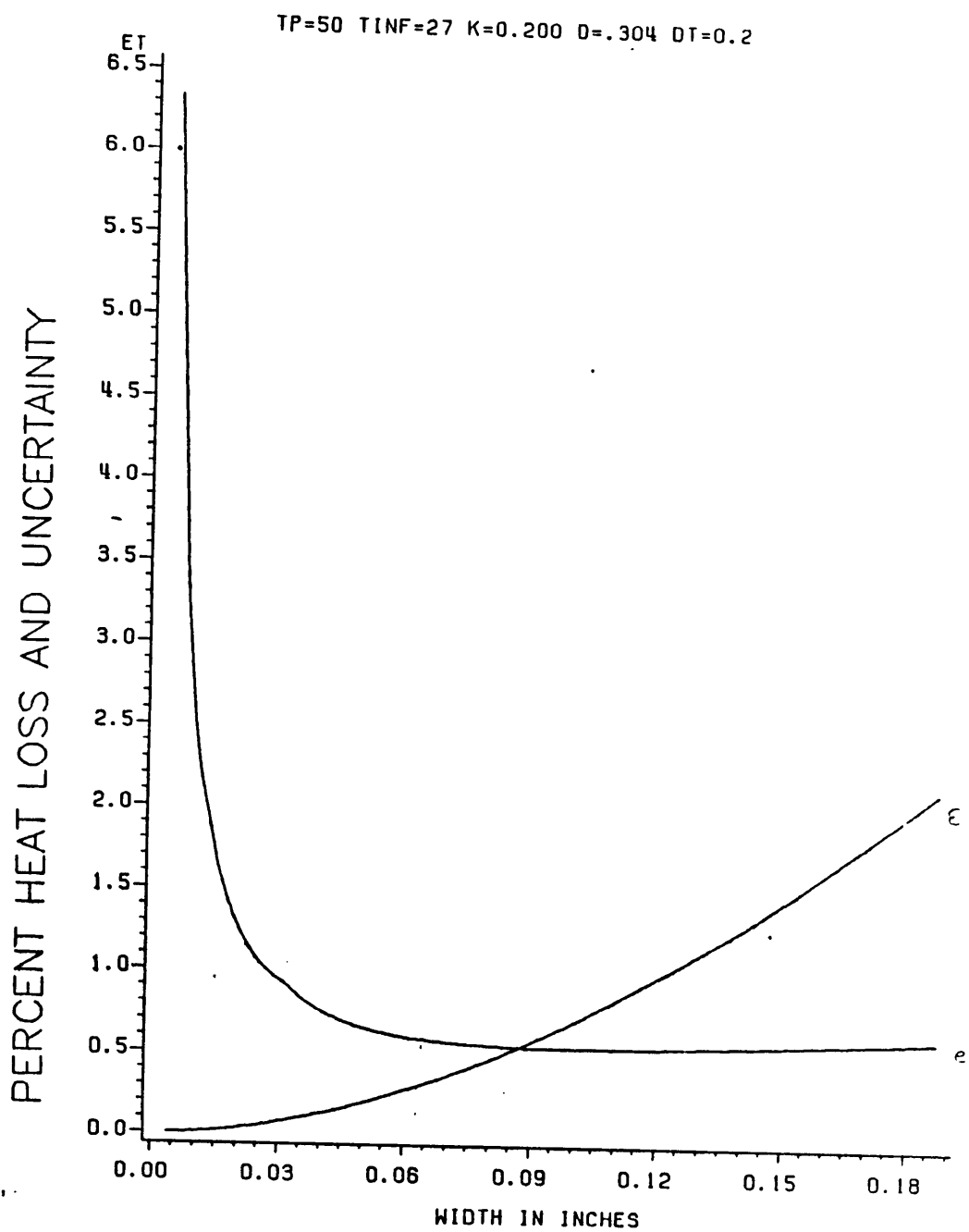


Figure 65. Percent correction to experimental power and uncertainty for a single cylinder

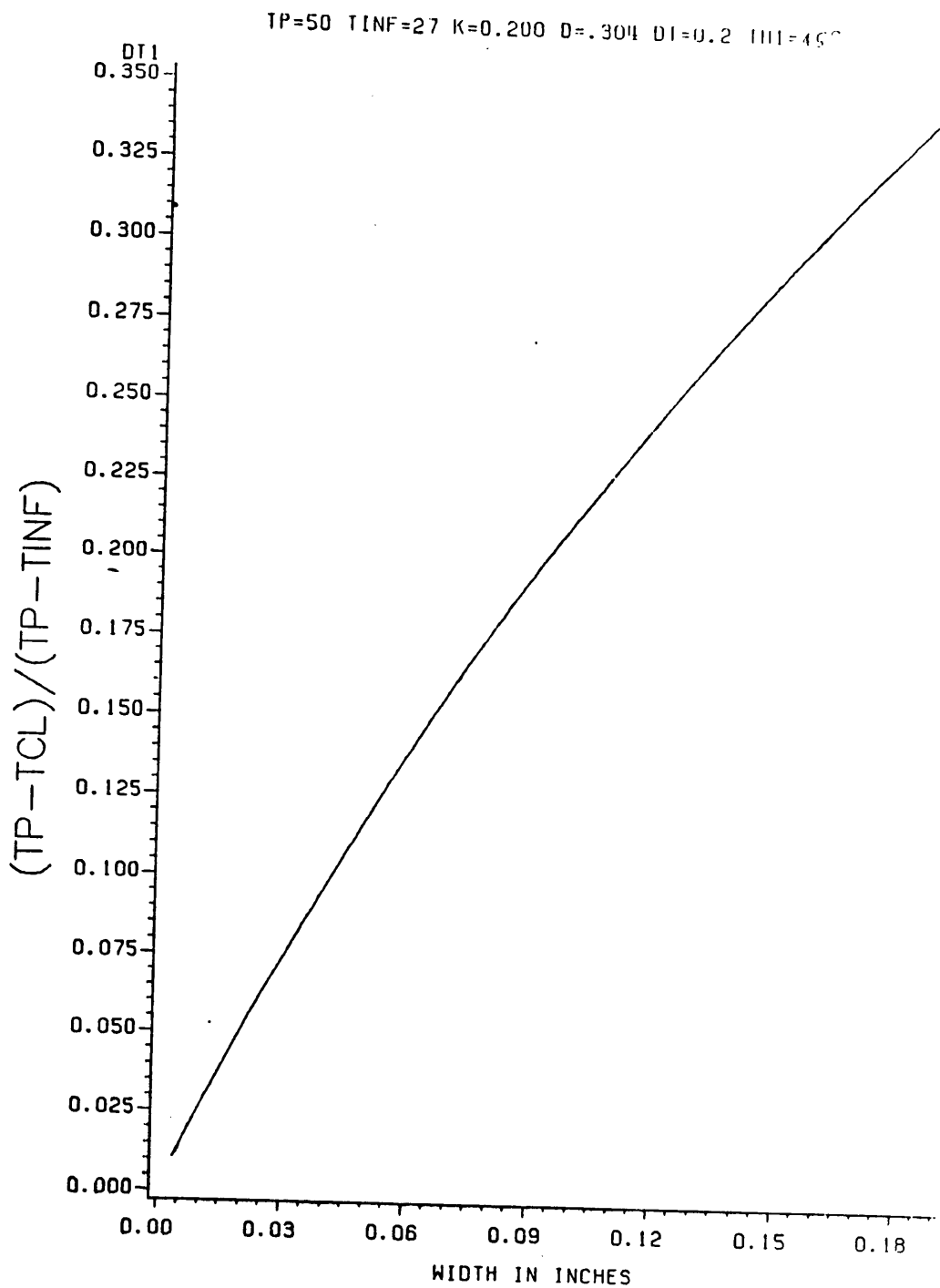


Figure 66. Centerline temperature drop for different cylinder widths.

APPENDIX D. ANALYSIS OF CONDUCTION LOSSES BETWEEN SEGMENTS

This appendix gives the results of an analysis to determine internal conduction losses between cylinder segments. An attempt was made to solve for the resistance to heat transfer between a cylinder segment and surrounding cylinder segments and guard heaters. The resistances were to be used to make a correction the experimental power measurement on each cylinder segment. When the correction was calculated and applied to the experimental power measurement, heat transfer was no longer the same for segments A and D on the front nor for segments B and C on the back. For this reason, it was assumed that the calculated resistances were too small, and no correction for internal conduction losses was made to the experimental data.

Resistances to heat transfer for segment A are shown in Figure 67. Five unknown resistances were considered. For segment A, heat could be lost through the acrylic support tube to segment B (R_{AB}), to segment C (R_{AC}), to segment D (R_{AD}), to the guard heaters (R_{AE}), and to the freestream. Heat losses by conduction in the insulation strips, and to the center of the cylinder were assumed to be known.

Using the nomenclature presented in Figure 67, the following equation can be written for losses from segment A:

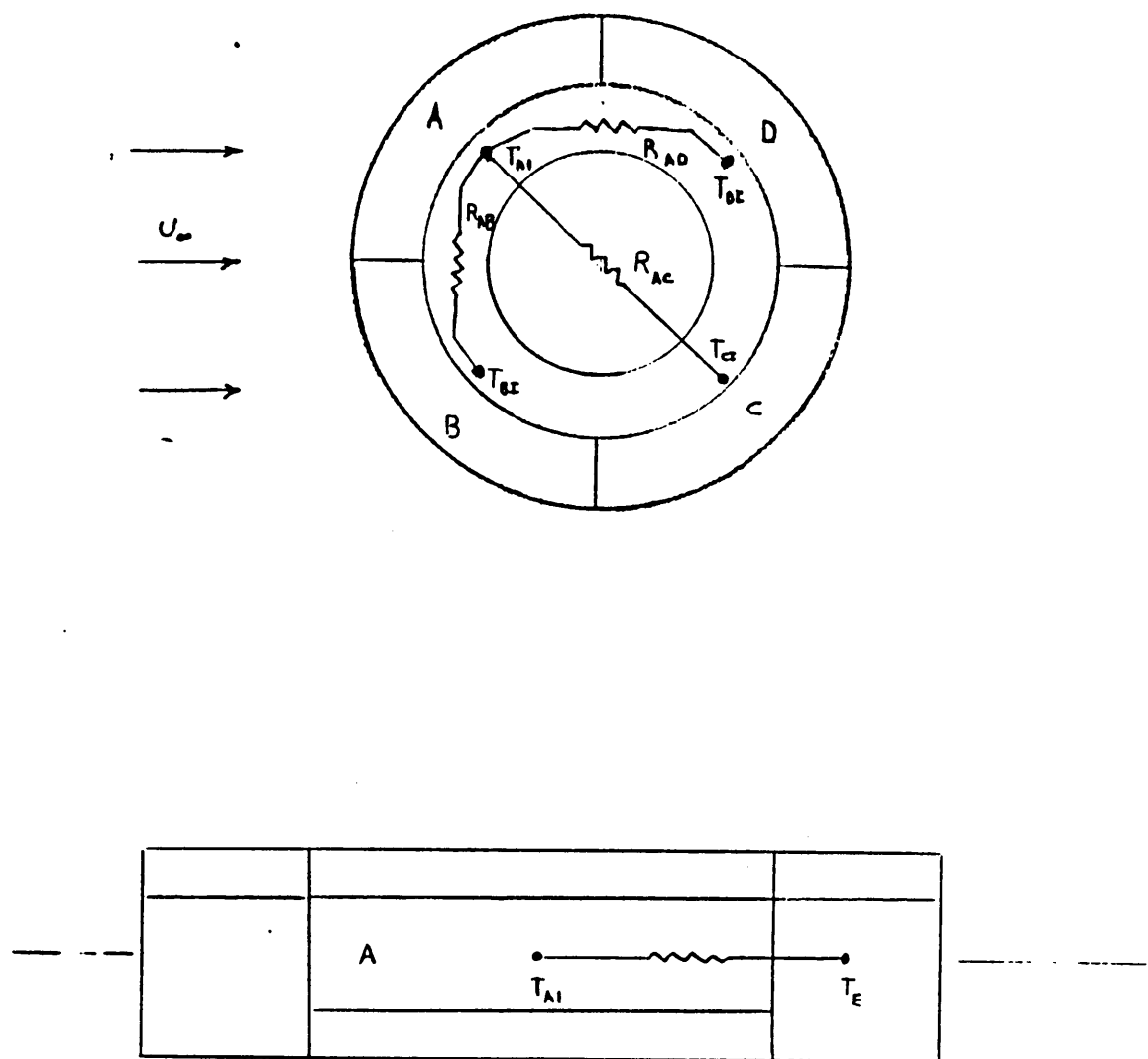


Figure 67. Internal heat transfer resistances for segment A.

Experimental = Known heat + Unknown heat
power measurement losses losses

$$\frac{V_A^2}{R} = Q_{AI} + Q_{L2} + Q_{L2} + c_h(T_{ai} - T_\infty) + C_{AB}(T_{Ai} - T_{Bi}) \quad (44)$$

$$+ C_{AC}(T_{Ai} - T_{Ci}) + C_{AD}(T_{Ai} - T_{Di}) + C_{AE}(T_{Ai} - T_E)$$

Where $C_{AB} = 1/R_{AB}$ and T_E is the temperature of the guard heaters. The temperature of the wall of the guard heaters was used because no internal thermocouples were located below the heaters on the guard heaters. From Appendix C, losses Q_{L2} can be approximated using a one-dimensional conduction analysis. One-dimensional conduction also applies to Q_{AI} . If the temperatures and experimental power measurement are known, there are five unknowns for segment A: $C_h, C_{AB} - C_{AE}$.

A test was conducted to provide data for determining the unknown resistances. The cylinder was rotated so that segment A was on the front of the cylinder. Five data points were obtained by varying the surface temperature of the of different segments on cylinder. Equation D-1 was then solved as five equations and five unknowns.

Tests were also conducted for segments B and D. A reciprocal relationship exists between resistances on different segments. For example, $R_{BA} = R_{AB}$. The three tests were therefore sufficient to determine the resistances to heat transfer on all four segments.

The best results were obtained when Q_{L2} and Q_{AI} were removed from equation D-1. The resistances are given in Table 10.

The correction to experimental power measurement for segment A is:

Table 11. Calculated internal heat transfer resistances ($^{\circ}\text{C}/\text{watt}$)

$R_{aa} = --.$	$R_{ba} = 0.331$	$R_{ca} = 0.133$	$R_{da} = 0.368$
$R_{ab} = 0.331$	$R_{bb} = --$	$R_{cb} = 0.258$	$R_{db} = 0.125$
$R_{ac} = 0.133$	$R_{bc} = 0.258$	$R_{cc} = --$	$R_{dc} = 0.503$
$R_{ad} = 0.368$	$R_{bd} = 0.125$	$R_{cd} = 0.503$	$R_{dd} = --$
$R_{ae} = 0.081$	$R_{be} = 0.017$	$R_{ce} = --$	$R_{de} = 0.021$

$$\begin{aligned}
 P_A = \frac{V_A^2}{R} & - C_{AB}(T_{Ai} - T_{Bi}) - C_{AC}(T_{Ai} - T_{Ci}) \\
 & - C_{AD}(T_{Ai} - T_{Di}) - C_{AE}(T_{Ai} - T_E)
 \end{aligned}
 \tag{45}$$

The effect of the correction is given in Table 11. Because the correction was too large, no correction was actually made.

Table 12. Effect of internal loss correction

SINGLE Cylinder $Re=49000$

	A	B	C	D
$f_d=0$ Hz:				
power (watts)	15.82	16.97	17.99	15.40
corrected power	14.16	17.24	17.10	16.44
% correction	-10.44	1.58	-4.98	6.76
$f_d=18.5$ Hz:				
power (watts)	17.75	17.35	17.80	18.09
corrected power	15.90	17.77	17.29	18.71
% correction	-10.40	2.46	-2.89	3.42
$f_d=23$ Hz:				
power (watts)	17.88	17.78	18.55	17.19
corrected power	15.92	18.08	17.86	18.23
% correction	-10.95	1.71	-3.73	6.06

APPENDIX E. THERMAL CONDUCTIVITY OF INSULATING MATERIALS

This appendix reports on the measurement of thermal conductivity of three materials considered for the insulation between cylinder segments. It was necessary to know the conductivity in order to correct for heat losses in the insulation and to determine the effect of the losses on the uncertainty of power measurement on a cylinder segment.

Thermal conductivity was measured using a line heat source technique (Sweat Reference 44). The procedure is as follows: A small heater is placed in a sample and used to simulate a line source. When constant power is provided to the heater, the temperature increases linearly with the logarithm of time. The slope of the temperature-time curve can be used to calculate the thermal conductivity. Sweat gives the following equation:

$$k = \frac{P \ln[(t_2 - t_0)/(t_1 - t_0)]}{4\pi (T_2 - T_1)} \quad (46)$$

where

k = thermal conductivity (watts/m-°C)

P = power per unit length of the heater (watts/m)

T_1 = Temperature at time t_1 (°C)

T_2 = Temperature at time t_2 ($^{\circ}\text{C}$)

t_1 = time since heater was turned on (seconds)

t_2 = time since heater was turned on (seconds)

t_0 = time correction factor to account for non-linear

region shortly after time is turned on. (seconds)

The probe which was used for this study was developed by Sweat. A sketch of the probe and a typical temperature vs. time response are given in Figure 68. The probe consisted of a heater made from constantan wire, and a chromel-constantan thermocouple, both placed inside a 21 gage (0.08 cm) stainless steel tube which was 3.81 cm long. The resistance of the heater was measured to be 15.33Ω . The manufacturer recommends that the electric power to the probe never exceed 5 watts/foot (.16 watts/cm). This results in a maximum voltage of 3.0 volts which can be connected across the heater leads.

When the probe is first turned on, the temperature is not always linear with the logarithm of time (region I in Fig. 68). A time correction factor (t_0) is used to correct for this effect, which is caused by finite probe size and probe properties which differ from the surrounding material (sample).

The thermal conductivity can be measured over the linear portion of the curve (region II). Equation (46) assumes an infinite medium. When the boundary condition changes at the outer edge of the sample, the curve in Figure 69 is no longer linear (region III). The time required for the temperature wave to propagate through the sample can be calculated using the expression $0.06 = 4\alpha t_m / d^2$, where α is the thermal diffusivity and d is

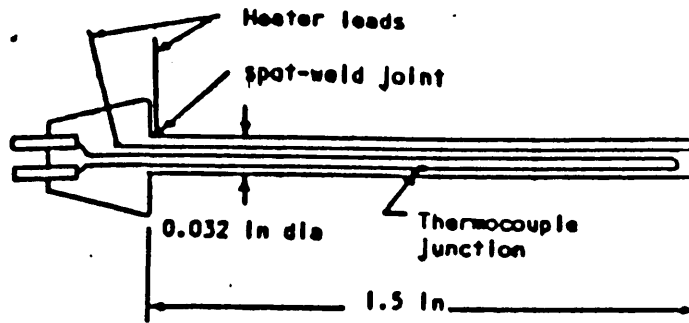
the minimum diameter of the sample. The expression is useful for determining the size of the sample which is necessary, assuming a suitable approximation for thermal diffusivity exists.

A sketch of the experimental system is given in Figure 69. The leads of the heater were connected to a HP 6200B power supply. The voltage across the heater leads was measured using a HP 3468A digital multimeter. The leads of the thermocouple (Omega subminiature plug) were connected to an Omega OMNI11 amplifier. Amplifier output was fed into a X-Y recorder.

The probe was calibrated before each test by adjusting the gain and zero on the X-Y recorder. Full scale (Y) corresponded to 15°C . The reference points for the calibration were two water baths at 22°C and 33°C . The temperature of the baths was determined using a Doric 410A Thermocouple readout and a copper- constantan thermocouple calibrated to $\pm 0.1^{\circ}\text{C}$.

At the beginning of each test, the trace on the X-Y recorder was started, then the power supply was turned on. Sweep times ranged from 5 seconds to 30 seconds, with probe temperature typically varying 3 to 4 degrees.

The materials tested were an auto body filler, a spot putty and a balsa wood control sample. Each sample was approximately 1.5 cm in diameter. A test was also conducted for each sample to determine an approximate value of t_m . The test consisted of immersing the sample in the 33°C water bath and measuring the time elapsed when the temperature indicated on the X-Y recorder started to rise.



Heater wire is 0.003 in dia constantan coated with 0.003 in thickness of Teflon
 Thermocouple wires are 0.003 in dia chromel and constantan wires insulated with plastic tubing
 Outer tubing is 21 gage hypodermic tubing
 Probe handle is an Omega miniature thermocouple connector

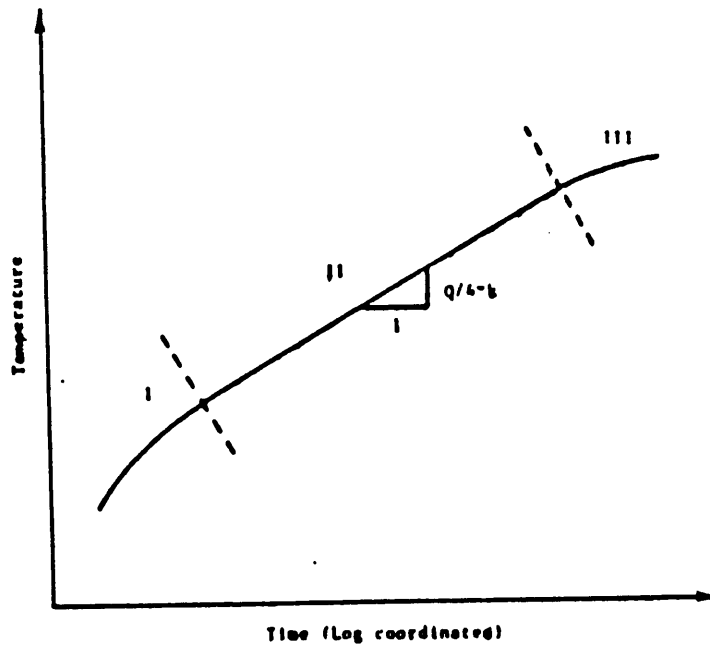


Figure 68. Thermal conductivity probe and typical temperature vs. timeresponse from ref. 44

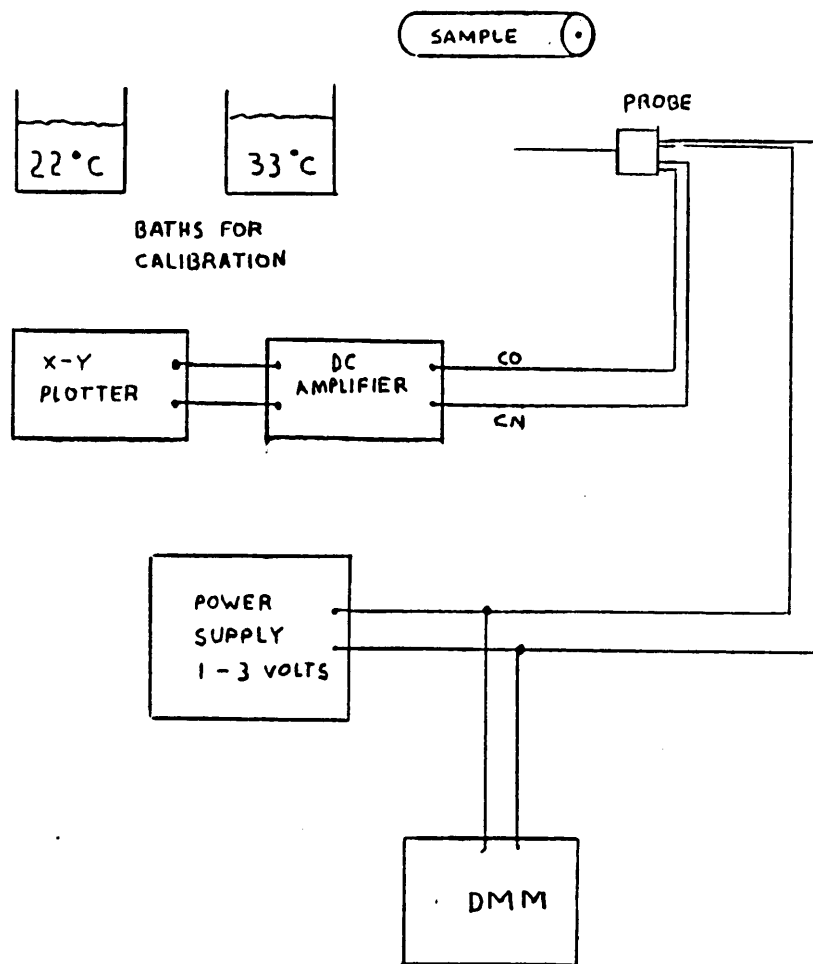


Figure 69. Experimental system for thermal conductivity measurement

Figure 70 shows a temperature vs. time plot for the spot putty. For all tests, the nonlinear region when power is first switched on cannot be seen. This indicates that t_0 is very small and can be neglected for the samples considered in this investigation.

Calculated results for thermal conductivity are as follows:

auto body filler: $k = 0.778 \text{ watts/m-}^\circ\text{C}$

spot putty: $k = 0.247 \text{ watts/m-}^\circ\text{C}$

balsa wood: $k = 0.062 \text{ watts/m-}^\circ\text{C}$

For balsa wood, Holman [39] gives: $k = 0.055 \text{ watts/m-}^\circ\text{C}$. The difference between Holman's value and current experimental results is 13 percent. One possible reason for the difference is that the moisture content of the wood was not controlled for this investigation. It is more likely, however, that any error resulted from evaluating the slope of the curve for balsa. Unlike the other two samples, linearity was poor for the tests with balsa.

Using the technique described here, the measurement of thermal conductivity could be performed much more efficiently using a micro-computer-based data acquisition system. The experimental procedure used here is very time consuming. Data was first plotted on the X-Y recorder, then temperature and time were read manually from the output. The data was reduced and plotted again in semi-log coordinates. Finally, the

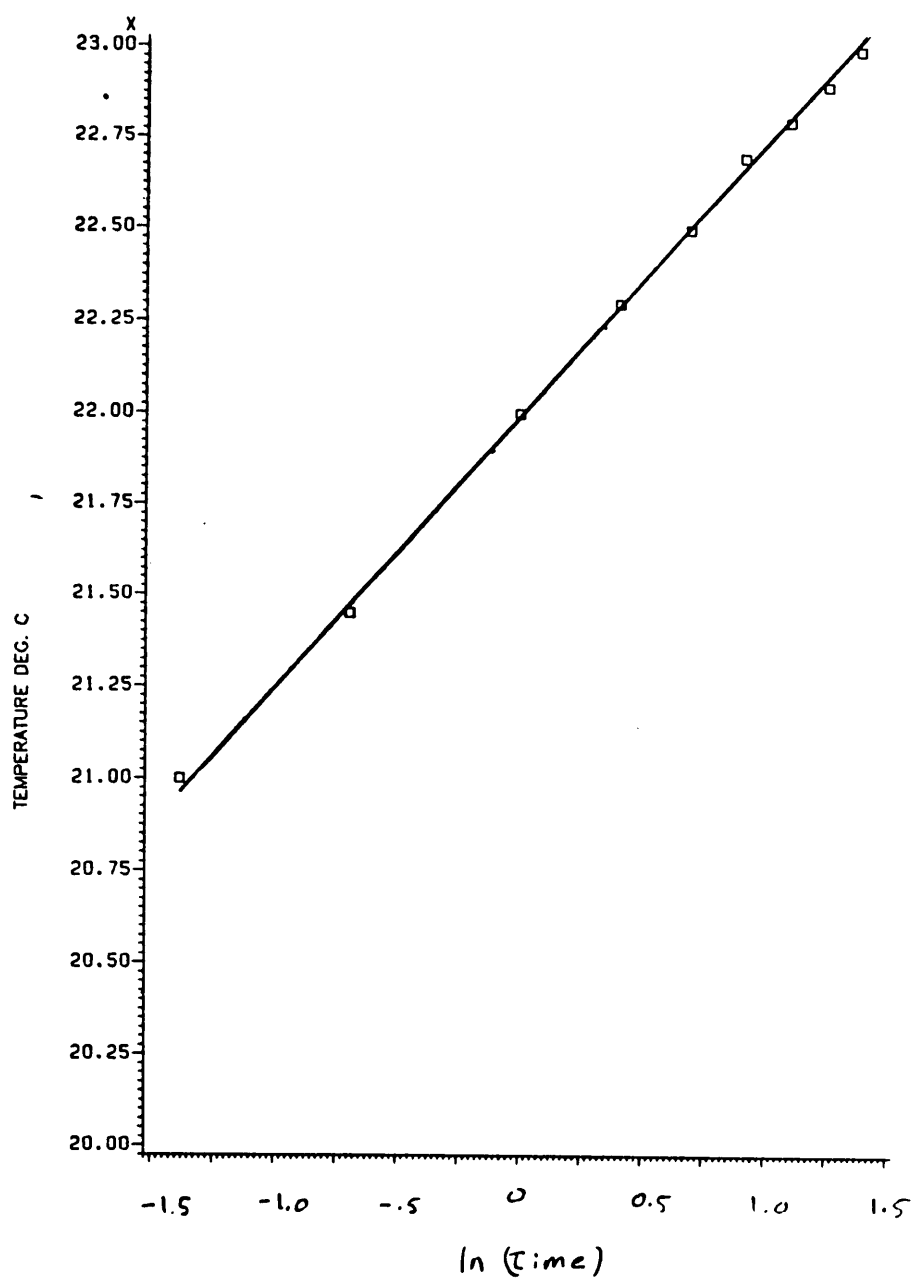


Figure 70. Probe response for spot putty

thermal conductivity was calculated using points in the linear region. It was also impossible to determine whether output from the X-Y recorder was acceptable data until the data had already been reduced. A micro-computer based data acquisition system would allow for data to be reduced immediately. For the balsa sample, this may have resulted in a more linear curve and a thermal conductivity closer to the known value.

APPENDIX F. PULSATION WAVEFORMS

This appendix gives waveforms and autospectra for pulsations ranging in frequency from 0 to 23 Hz. Waveforms were averaged 20 times and autospectra were averaged 10 times. No significant differences in waveforms were observed at higher Reynolds numbers. Small amounts of turbulence were observed in the pulsation for high amplitude tests with $f_d < 7$ Hz (not shown). Table 12 lists the percentage of pulsation energy at the fundamental frequency corresponding to Figures 70-78. Unsteady turbulence levels were measured for $Re=49,000$. The results are given in table 12.

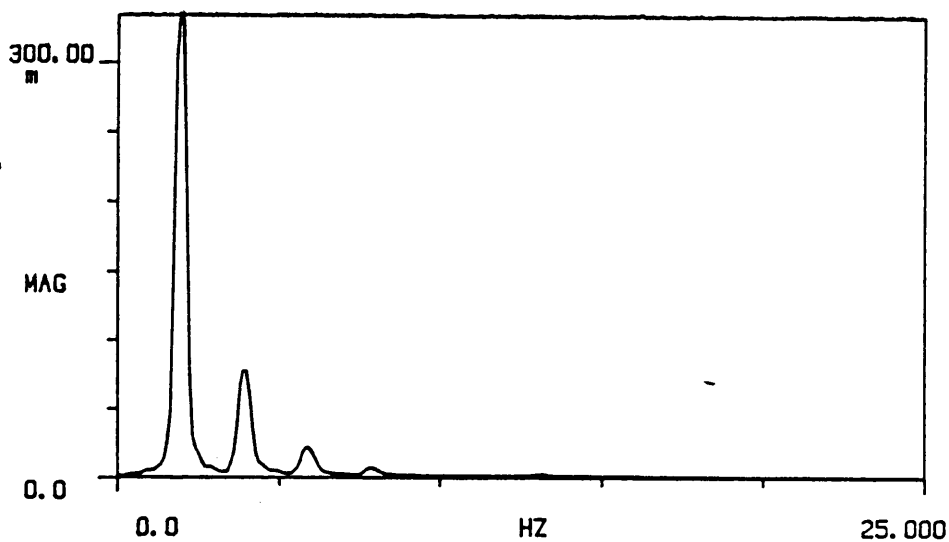
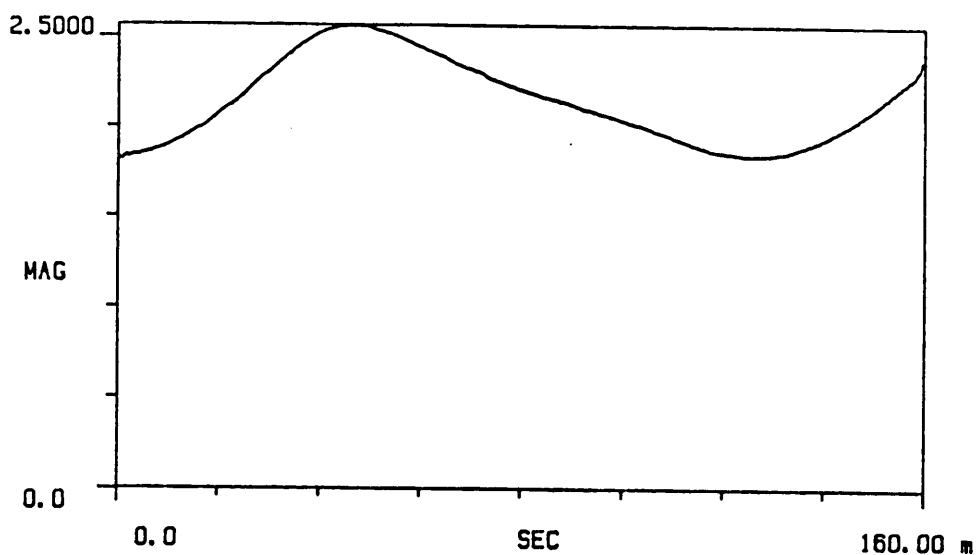


Figure 71. Waveform and frequency content at $f_d = 1.96$ Hz, $Re = 23000$

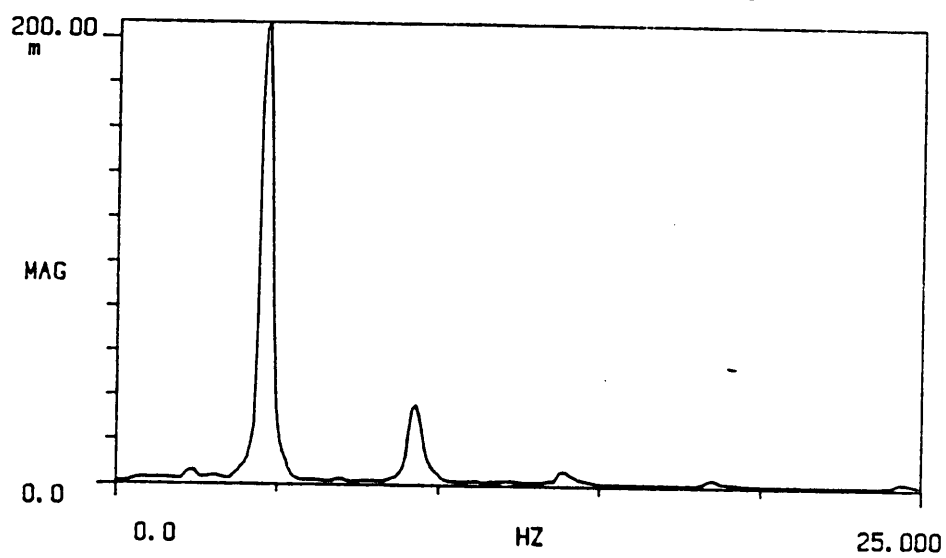
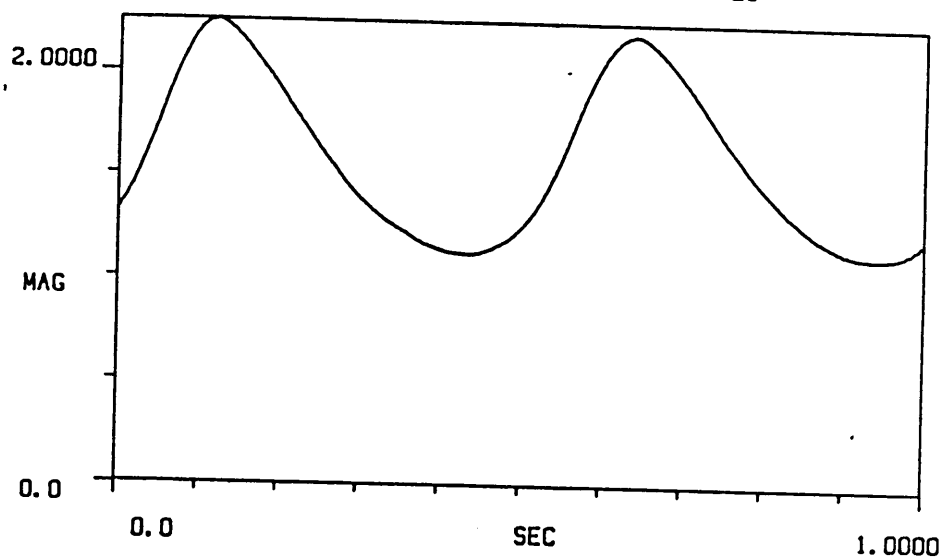


Figure 72. Waveform and frequency content at $f_d=5.08$ Hz, $Re=23000$

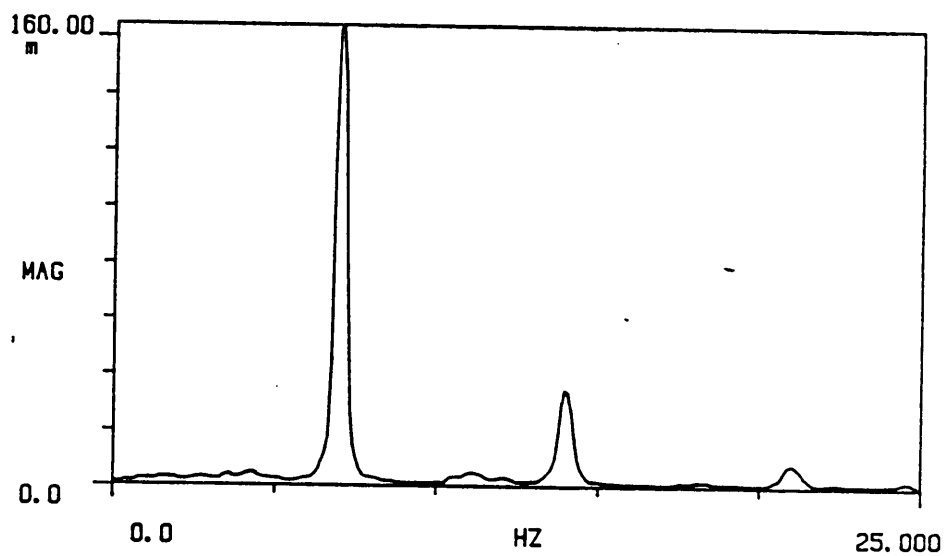
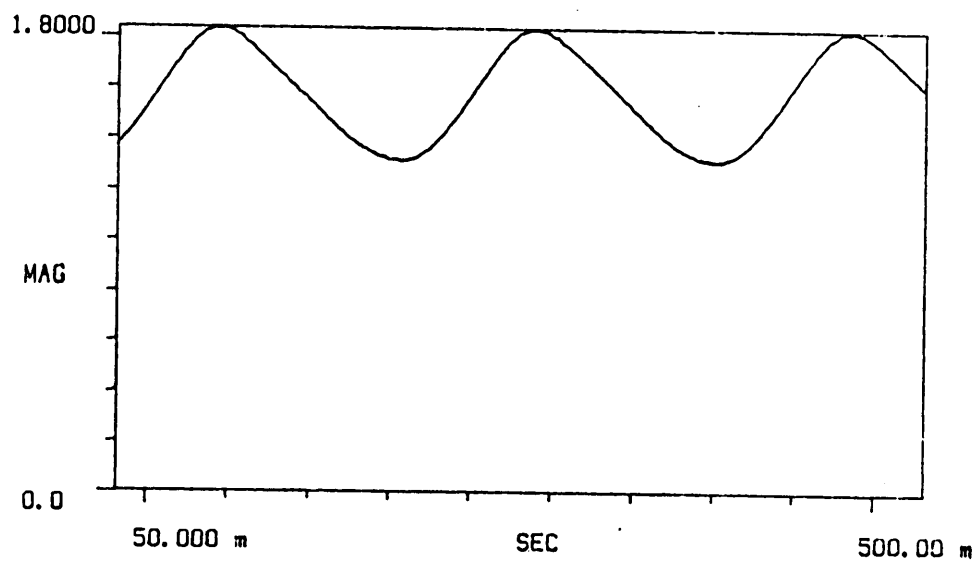


Figure 73. Waveform and frequency content at $f_d=7.02$ Hz, $Re=23000$

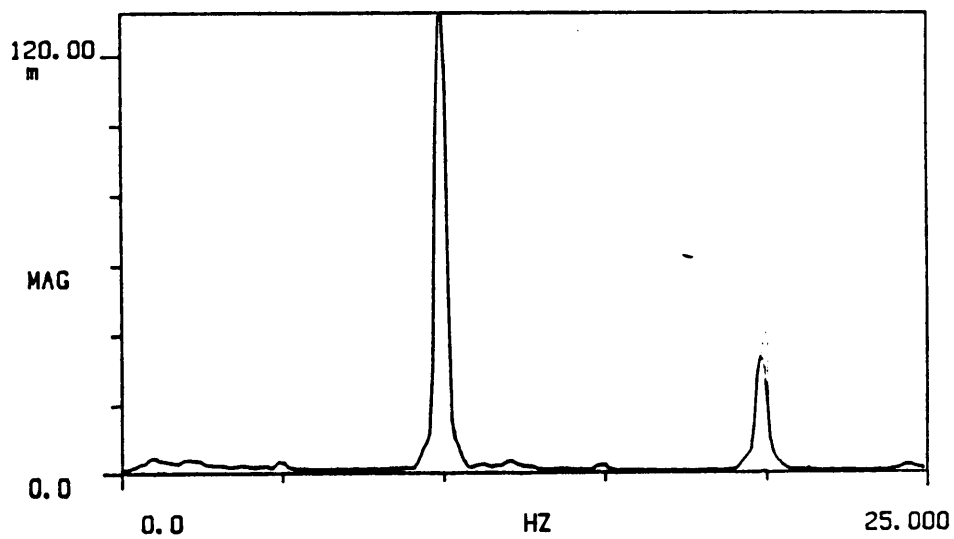
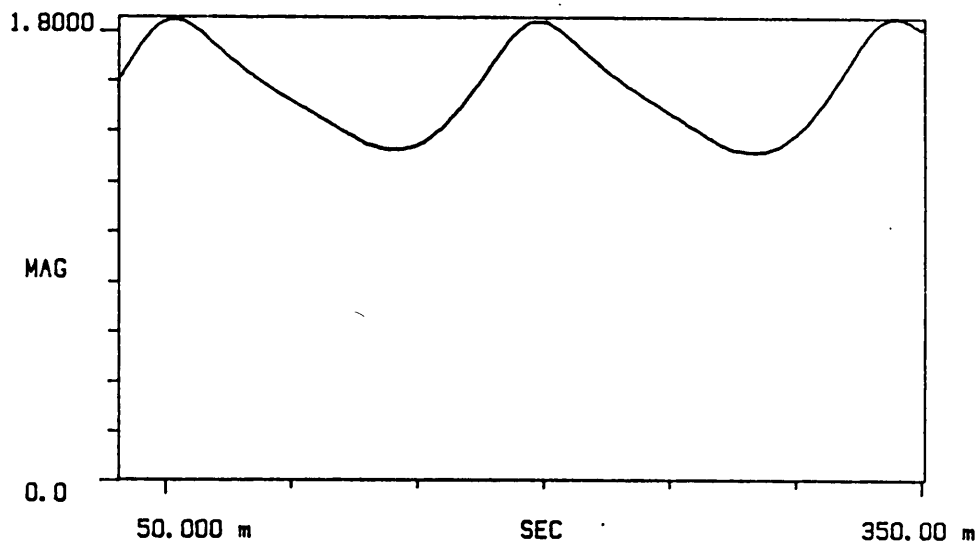


Figure 74. Waveform and frequency content at $f_d=9.96$ Hz, $Re=23000$

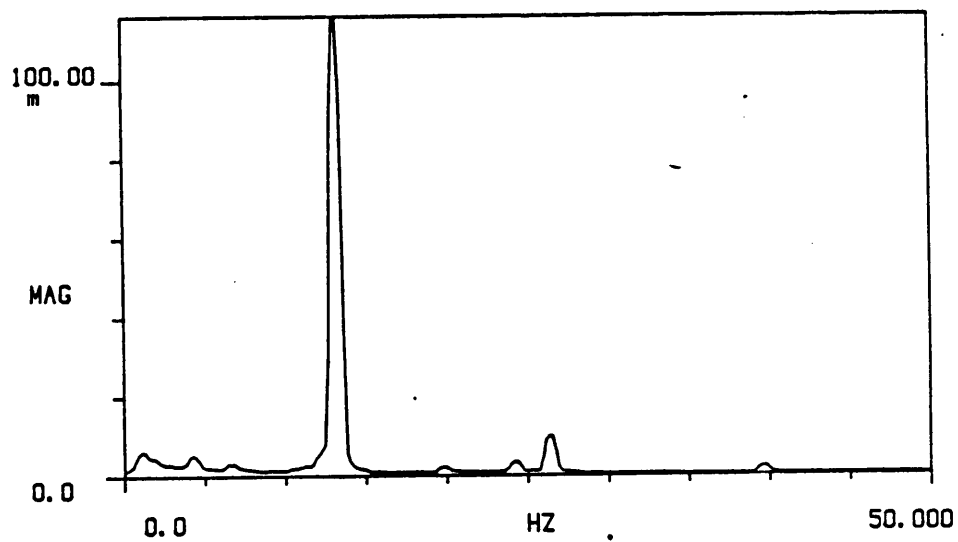
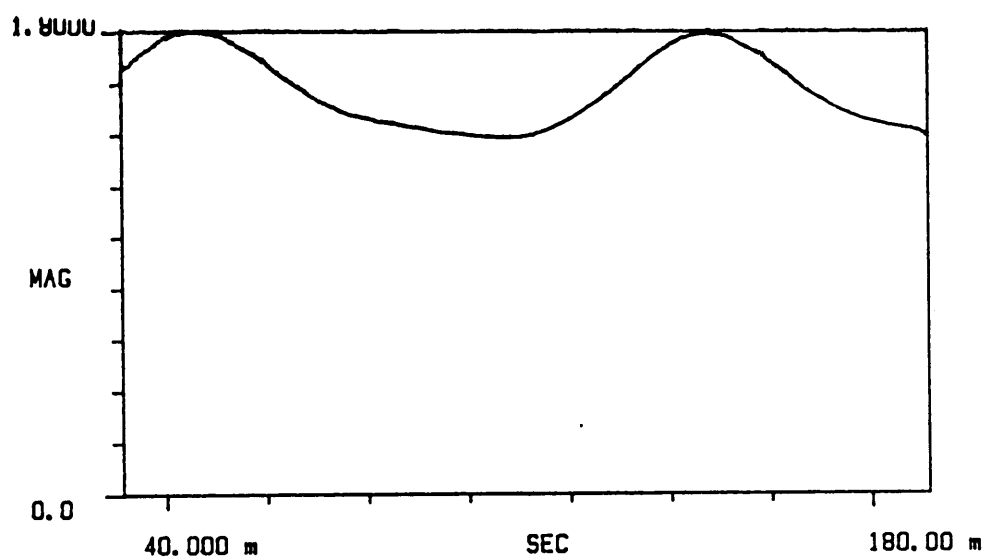


Figure 75. Waveform and frequency content at $f_d=13.07$ Hz, $Re=23000$

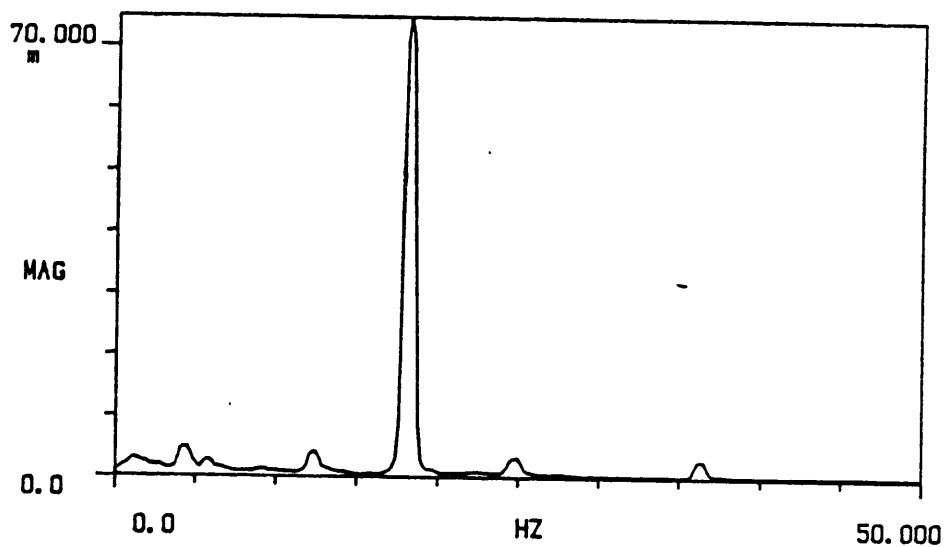
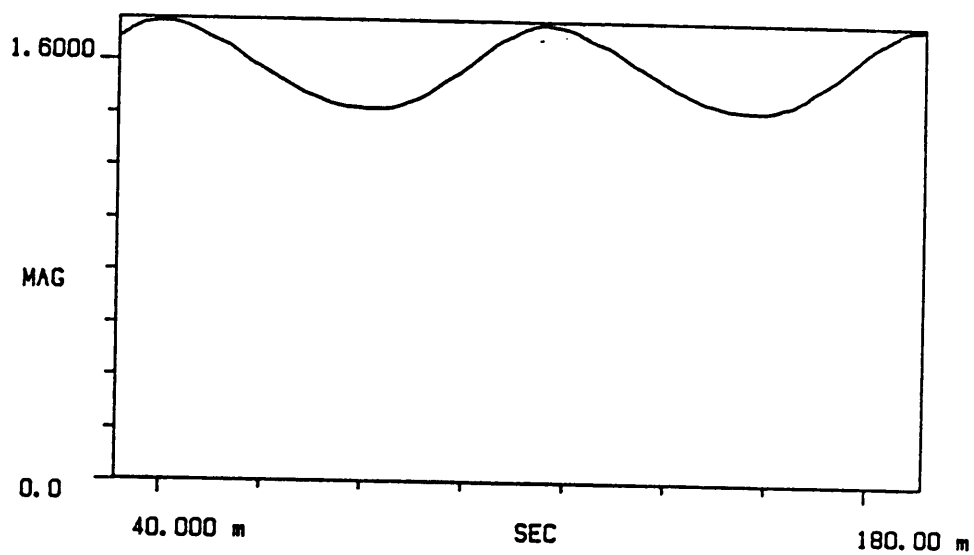


Figure 76. Waveform and frequency content at $f_d=18.15$ Hz, $Re=23000$

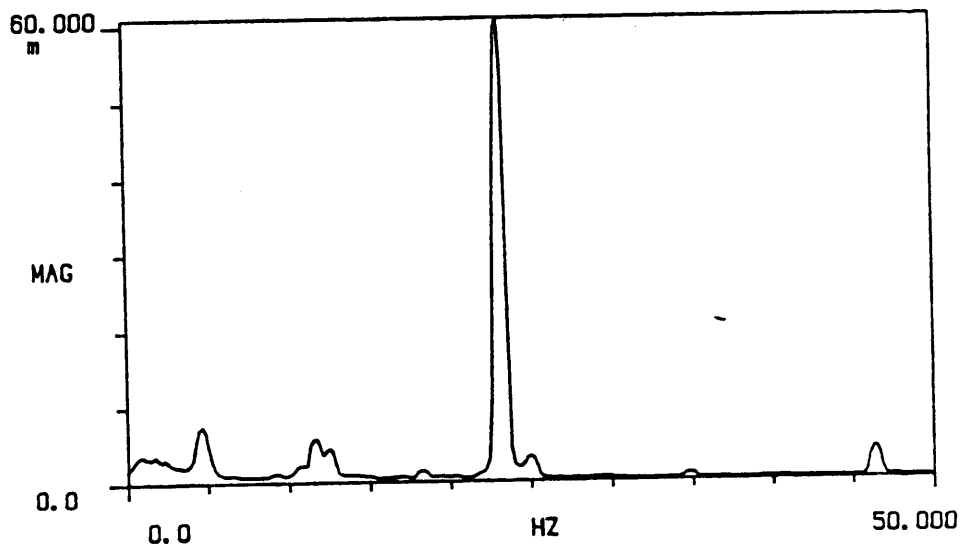
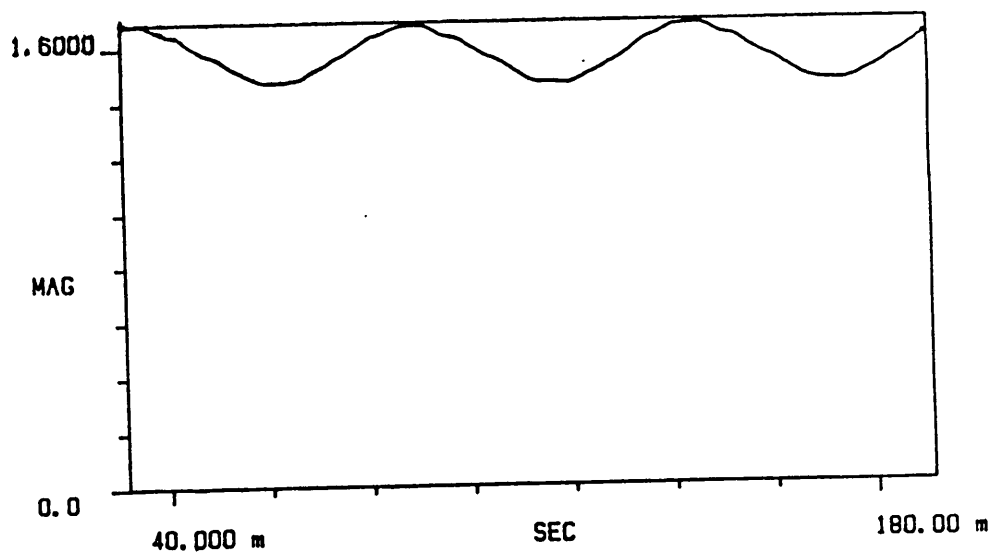


Figure 77. Waveform and frequency content at $f_d=23.2$ Hz, $Re=23000$

Table 13. Percent power at the fundamental frequency and unsteady flow turbulence level

f Hz	percent power
------	---------------

1.96	93.6%
------	-------

5.00	96.0%
------	-------

7.02	93.9%
------	-------

9.96	93.0%
------	-------

13.07	95.5%
-------	-------

18.15	97.6%
-------	-------

23.20	94.6%
-------	-------

f Hz	Tu (percent)
------	--------------

0.	0.34 %
----	--------

13.	0.31 %
-----	--------

18.	0.46 %
-----	--------

APPENDIX G. PROGRAM LISTINGS

```

C *****
C DATA REDUCTION PROGRAM FOR OUTPUT FROM TRS-80 PROGRAM 'T/BAS'
C EXEC FILE 'CRED' <FN> <DATA> WILL RUN AFTER COMPILATION
C OTHER INPUT IS QQIN DATA FOR INSULATION LOSSES
C (FROM LOSSC AND ERC)
C OUTPUT IS: 1) FN OUT....ORIGINAL DATA WITH REDUCED DATA FOR POWE
C AND VELOCITY. TEMPERATURE PROFILES .
C 2) FN ROUT...REDUCED DATA FOR NUSSELT NUMBER AND
C FROSSLING NUMBER
C 2) FN COROUT...RESULT OF CORRECTIONS FOR RADIATION
C AND INSULATION SURFACE TEMPERATURE
C
C *'CRED1 FORTRAN' CALCULATES CORRECTION FOR INTERNAL LOSSES
C
C TERRY VANDENBERGHE 1985
C *****
C DIMENSION NUA(50),NUB(50),NUC(50),NUD(50),NU(50),RE(50),AR(50)
C DIMENSION NUFR(50),NUBK(50),FRFR(50),FRBK(50)
C DIMENSION FF(50),AMP(50),FRA(50),FRB(50),FRC(50),FRD(50),FR(50)
C DIMENSION FND(50),RFRA(50),RFRB(50),RFRC(50),RFRD(50),RFR(50)
C DIMENSION RNU(50),RNA(50),RNUB(50),RNUC(50),RNUD(50),AMPFND(50)
C DIMENSION RNUFR(50),RNUBK(50),ARNUFR(50),ARNUBK(50)
C DIMENSION ARNUA(50),ARNUB(50),ARNUC(50),ARNUD(50),ARNU(50)
C DIMENSION HH(4)
C REAL KAIR,LEN,NUA,NUB,NUC,NUD,NU,MU,NUFR,NUBK
C REAL*8 FN
C SUMAMP=0
C IPG=0
C ICLOSS=0
C KAIR=.026
C DENW=996.5
C D=3.5*2.54/100.
C LEN=17.5*2.54/100.
C **HEATER RESISTANCES
C RA=86.61
C RB=87.05
C RC=86.934
C RD=87.208
C S=3.14*D*LEN*.250
C ** READ DATA FILE
C READ (5,*)N
C READ (5,90)FN
C WRITE(9,9)FN
C 9 FORMAT(1X,'CORRECTIONS FOR ',A8)
C 90 FORMAT(9X,A8)
C READ (5,95)PH
C 95 FORMAT(21X,G4.1)
C WRITE(6,*)PH
C DO 100 I=1,2
C READ (5,*)DN
C PH=180
C 100 CONTINUE
C READ (5,105)DN,PATM
C 105 FORMAT(1X,F4.0,26X,G10.5)
C DO 120 I=1,6
C READ (5,*)DN
C 120 CONTINUE

```

Appendix G: Program Listings

```

DO 500 I=1,N
READ(5,*)DN,TBM,TINF,TAMB,TA1
READ(5,*)DN,TB1,TC1,TD1,TGA3
READ(5,*)DN,TGA4,TGC3,TGC4,TI
READ(5,*)DN,TAM,TDM,TA2,TA3
READ(5,*)DN,TA4,TA5,TAD,TD2
READ(5,*)DN,TD3,TD4,TD5,TC2
READ(5,*)DN,TC3,TC4,TC5,TB2
READ(5,*)DN,TB3,TB4,TB5,TCM
READ(5,*)DN,VA,VB,VC,VD
READ(5,*)DN,FF(I),AR(I),AMP(I),DPT
SUMAMP=SUMAMP+AMP(I)
**CALCULATE SURFACE TEMPERATURES
TA=.50*(TA1+(TA2+TA3+TA4+TA5)/4.)
TB=.50*(TB1+(TB2+TB3+TB4+TB5)/4.)
TC=.50*(TC1+(TC2+TC3+TC4+TC5)/4.)
TD=.50*(TD1+(TD2+TD3+TD4+TD5)/4.)
T=.25*(TA+TB+TC+TD)
C**CALCULATE INTERNAL TEMPERATURE DIFFERENCES TO SOLVE FOR INTERNAL
C RESISTANCES
TTAD=.5*(TA2+TA5-TD5-TD2)
TTDA=-TTAD
TTAB=.5*(TA3+TA4-TB3-TB4)
TTBA=-TTAB
TTDC=.5*(TD3+TD4-TC3-TC4)
TTCD=-TTDC
TTCB=.5*(TC5+TC2-TB5-TB2)
TTBC=-TTCB
TTDI=TDM-TI
TTBI=TBM-TI
TTCI=TCM-TI
TTAI=TAM-TI
TIDA=TDM-TAM
TIAD=-TIDA
TIDC=TDM-TCM
TICD=-TIDC
TIDB=TDM-TBM
TIBD=-TIDB
TIAB=TAM-TBM
TIBA=-TIAB
TIBC=TBM-TCM
TICB=-TIBC
TIAC=TAM-TCM
TICA=-TIAC
TGAB=TGA3/2+TGA4/2
TGCD=TGC3/2+TGC4/2
TTDG=.25*(TD2+TD3+TD4+TD5)-TGCD
TTCG=.25*(TC2+TC3+TC4+TC5)-TGCD
TTBG=.25*(TB2+TB3+TB4+TB5)-TGAB
TTAG=.25*(TA2+TA3+TA4+TA5)-TGAB
DTINA=TA-TINF
DTINB=TB-TINF
DTINC=TC-TINF
DTIND=TD-TINF
C**CALCULATE POWER
PA=VA**2/RA
PB=VB**2/RB
PC=VC**2/RC
PD=VD**2/RD
P=PA+PB+PC+PD
C PCA=PA
C PCB=PB
C PCC=PC
C PCD=PD

```

Appendix G: Program Listings

```

C      PCOR=P
C      WRITE(9,220)PD,DTIND,TTDA,TTDC,TTDI,TIDA,TIDC,TIDB,TTDG
C      WRITE(9,220)PA,DTINA,TTAB,TTAD,TTAI,TIAB,TIAD,TIAC,TTAG
C      WRITE(9,220)PB,DTINB,TTBA,TTBC,TTBI,TIBA,TIBC,TIBD,TTBG
C      WRITE(9,220)PC,DTIND,TTCB,TTCD,TTCI,TICB,TICD,TICA,TTCG
      220 FORMAT(1X,9(F5.2,2X))
C**CALL SUBROUTINE FOR RADIATION CORRECTION
      CALL RADCOR(TA,TB,TC,TD,T,TAMB,QRA,QRB,QRC,QRD,QR,S)
C**CORRECT FOR RADIATION
      PCA=PA-QRA
      PCB=PB-QRB
      PCC=PC-QRC
      PCD=PD-QRD
      PCOR=P-QRA-QRB-QRC-QRD
      DTA=TA-TINF
      DTB=TB-TINF
      DTC=TC-TINF
      DTD=TD-TINF
      DT=T-TINF
C**CALCULATE H WITHOUT INSULATION LOSS CORRECTION
      HH(1)=PCA/S/DTA
      HH(2)=PCB/S/DTB
      HH(3)=PCC/S/DTC
      HH(4)=PCD/S/DTD
C**INSULATION LOSS CORRECTION SUBROUTINE
      CALL CLOSS(ICLOSS,PH,HH,QCLA,QCLB,QCLC,QCLD,DTA,DTB,DTC,DTD)
      PCA=PCA+QCLA
      PCB=PCB+QCLB
      PCC=PCC+QCLC
      PCD=PCD+QCLD
      PCOR=PCOR+QRA+QRB+QRC+QRD
C**OUTPUT TO FN COROUT
      WRITE(9,225)I,PA,PB,PC,PD,QRA,QRB,QRC,QRD,QCLA,QCLB,QCLC,QCLD,
      +PCA,PCB,PCC,PCD
      225 FORMAT(1X,'POINT # ',I2,'/',1X,'POWER ',4(F10.3,3X),
      +/,1X,'RADIATION ',3X,4(F10.4,3X),/,
      +1X,'INSULATION ',3X,4(F10.4,3X),/,1X,'CORRECTED POWER',1X,
      +4(F10.3,3X),//)
C**CALCULATE FINAL HEAT TRANSFER COEFFICIENT
      HA=PCA/S/DTA
      HB=PCB/S/DTB
      HC=PCC/S/DTC
      HD=PCD/S/DTD
      H=(HA+HB+HC+HD)/4.
C*****VELOCITY *****
C RAIR=.287 MKS 6.894757 KPA/PSI 2.036 IN HG/PSI
      TINFK=TINF+273.15
      TK=T+273.15
      TFILMK=(TK+TINFK)/2.
      DENAIR=PATM/TINFK/2.036*6.894757/.287
      DENAF =PATM/TFILMK/2.036*6.894757/.287
C      MU=1.431E-5+1.84E-8*TINFK ***** BAD DATA POINT FROM HOLMAN!
      MU=(1.8462+(TFILMK-300.)/50.)*(2.075-1.8462))*1E-5
      KAIR=.02624+(TFILMK-300.)/50.*(.03003-.02624)
      VEL=(2.*DENW*9.81*DPT*2.54/100/DENAIR)**.5
      RE(I)=D*VEL*DENAF/MU
C
C*****NOTE RE CALCULATED USING MU WHICH IS NOT PRESSURE DEPENDENT
C      NU IS BOTH PRESSURE AND TEMPERATURE DEPENDENT
C
C      WRITE(6,*)RE,VEL,PA,PCA,DTA,TA,S,VA
C*****
C**NUSSELT NUMBER
      NUA(I)=HA*D/KAIR

```

Appendix G: Program Listings

```

      NUB(I)=HB*D/KAIR
      NUC(I)=HC*D/KAIR
      NUD(I)=HD*D/KAIR
      NU(I)=H*D/KAIR
C**DIMENSIONLESS FREQUENCY
      FND(I)=FF(I)*D/VEL
      AMPFND(I)=FF(I)*D/VEL*AMP(I)
C**FROSSLING NUMBER
      FRA(I)=NUA(I)/RE(I)**.5
      FRB(I)=NUB(I)/RE(I)**.5
      FRC(I)=NUC(I)/RE(I)**.5
      FRD(I)=NUD(I)/RE(I)**.5
      FR(I)=NU(I)/RE(I)**.5
C**FRD/FRS
      RFR(I)=FR(I)/FR(1)
      RFRA(I)=FRA(I)/FRA(1)
      RFRB(I)=FRB(I)/FRB(1)
      RFRC(I)=FRC(I)/FRC(1)
      RFRD(I)=FRD(I)/FRD(1)
C**NUD/NUS
      RNU(I)=NU(I)/NU(1)
      RNUA(I)=NUA(I)/NUA(1)
      RNUB(I)=NUB(I)/NUB(1)
      RNUC(I)=NUC(I)/NUC(1)
      RNUD(I)=NUD(I)/NUD(1)
C**FRONT AND BACK NUSSELT NUMBER AND FROSSLING NUMBER
C*****FOLLOWING LINES VALID ONLY FOR A AND D ON BACK OF CYLINDER!!!!*****
      NUBK(I)=(NUA(I)+NUD(I))/2.
      NUFR(I)=(NUC(I)+NUB(I))/2.
      FRFR(I)=NUFR(I)/(RE(I)**.5)
      FRBK(I)=NUBK(I)/(RE(I)**.5)
      RNUFR(I)=RNUB(I)/2+RNUC(I)/2
      RNUBK(I)=RNUA(I)/2+RNUD(I)/2
C*****FOLLOWING LINES FOR NONZERO AMPLITUDES ONLY
C**NUSSELT NUMBER INCREASE PER UNIT AMPLITUDE
      IF(AMP(I).LT.0.001)GOTO299
      ARNUA(I)=(RNUA(I)-1)/AMP(I)*100.
      ARNUB(I)=(RNUB(I)-1)/AMP(I)*100.
      ARNUC(I)=(RNUC(I)-1)/AMP(I)*100.
      ARNUD(I)=(RNUD(I)-1)/AMP(I)*100.
      ARNUFR(I)=(RNUFR(I)-1)/AMP(I)*100.
      ARNUBK(I)=(RNUBK(I)-1)/AMP(I)*100.
      ARNU(I)=(RNU(I)-1)/AMP(I)*100.

C
C
C
C**OUTPUT TO FN OUT
C
299 WRITE(6,305)I
300 FORMAT(1X,8(F6.3,1X))
305 FORMAT(1X,'DATA POINT #',I2)
C 320 FORMAT(1X,5(F8.4,1X))
      WRITE(6,380)
      WRITE(6,350)TB5,TB2
      WRITE(6,360)TB1,TBM
      WRITE(6,350)TB4,TB3
      WRITE(6,382)
      WRITE(6,370)TGA4,TA4,TA3,TGA3
      WRITE(6,362)TA1,TAM
      WRITE(6,350)TA5,TA2
      WRITE(6,380)
      WRITE(6,350)TD5,TD2
      WRITE(6,364)TD1,TDM
      WRITE(6,350)TD4,TD3

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Appendix G: Program Listings

```

WRITE(6,382)
WRITE(6,370)TGC4,TC4,TC3,TGC3
WRITE(6,366)TC1,TCM
WRITE(6,350)TC5,TC2
WRITE(6,380)
350 FORMAT(1X,'|',7X,'|',F4.1,16X,F4.1,'|',7X,'|')
360 FORMAT(1X,'|',7X,'|',5X,'B',4X,F4.1,10X,'|',7X,'|',8X,'TBI=',
+ F4.1)
362 FORMAT(1X,'|',3X,'GA4',1X,'|',5X,'A',4X,F4.1,10X,'|',
+ 1X,'GA3',3X,'|',8X,'TAI=',F4.1)
364 FORMAT(1X,'|',7X,'|',5X,'D',4X,F4.1,10X,'|',7X,'|',8X,'TDI=',
+ F4.1)
366 FORMAT(1X,'|',3X,'GC4',1X,'|',5X,'C',4X,F4.1,10X,'|',
+ 1X,'GC3',3X,'|',8X,'TCI=',F4.1)
370 FORMAT(1X,'|',2X,F4.1,'|',F4.1,16X,F4.1,'|',2X,F4.1,'|')
380 FORMAT(1X,46(' '))
382 FORMAT(1X,'|',8X,28(' '),8X,'|')
WRITE(6,390)TA,TB,TC,TD,T,TINF,TAMB,TI
WRITE(6,400)VA,VB,VC,VD
WRITE(6,405)PCA,PCB,PCC,PCD,PCOR
WRITE(6,410)DPT,AR(I),FF(I),AMP(I),VEL
390 FORMAT(/,1X,'TA=',F5.2,' TB=',F5.2,' TC=',F5.2,' TD=',F5.2,
+/, 'TAV=',F5.2,' T FREE STREAM=',F5.2,' T AMBIENT=',F5.2,
+ 'TI=',F5.2)
400 FORMAT(1X,'VOLTAGES: VA=',F5.2,' VB=',F5.2,' VC=',F5.2,
+ 'VD=',F5.2)
405 FORMAT(1X,'CORR. POWER: PA=',F5.2,' PB=',F5.2,' PC=',F5.2,
+ 'PD=',F5.2,' P=',F6.2)
410 FORMAT(1X,'PILOT=',F5.3,' IN. L/D=',F4.2,' FREQ=',F5.1,' HZ',
+ '0-P AMPLITUDE=',F5.1,'%',' VEL=',F5.2,' M/S',////)
IPG=IPG+1
IF(IPG.LT.3)GOTO500
IPG=0
WRITE(6,499)
499 FORMAT(1X,////////)
500 CONTINUE
C
C
C
C**OUTPUT TO FN ROUT
C
WRITE(7,550)FN
550 FORMAT(////,1X,'REDUCED DATA FOR: ',A8,
+/,1X,' # NUA NUB NUC ',
+ NUD NU RE L/D FREQ. AMP')
DO 600 I=1,N
C WRITE(7,300)TA,TB,TC,TD,T,TINF,TAMB,TI
WRITE(7,310)I,NUA(I),NUB(I),NUC(I),NUD(I),NU(I),RE(I),AR(I),FF(I),
+ AMP(I)
310 FORMAT(1X,I2,2X,5(F5.1,2X),F8.0,2X,3(F5.2,2X))
C WRITE(6,320)FRA(I),FRB(I),FRC(I),FRD(I),FR(I)
600 CONTINUE
IF(INT(PH).EQ.180)GOTO900
WRITE(7,650)
650 FORMAT(////,1X,'FROSSLING NO.: ',/1X,' # FRA FRB FRC ',
+ FRD FR RE L/D FREQ. AMP')
DO 700 I=1,N
C WRITE(7,300)TA,TB,TC,TD,T,TINF,TAMB,TI
WRITE(7,320)I,FRA(I),FRB(I),FRC(I),FRD(I),FR(I),RE(I),AR(I),FF(I),
+ AMP(I)
320 FORMAT(1X,I2,2X,5(F5.3,2X),F8.0,2X,3(F5.2,2X))
700 CONTINUE
C
C

```

Appendix G: Program Listings

```

      IF(SUMAMP.LT.1)GOTO1100
      WRITE(7,750)
750  FORMAT(////, 'NUF/NUS
+    C      D      AVERAGE      RE      L/D      RED FREQ      AMP') B      ',
      DO 800 I=1,N
      WRITE(7,330)I,RNUA(I),RNUB(I),RNUC(I),RNUD(I),
+RNU(I),RE(I),AR(I),FND(I),AMPFND(I)
330  FORMAT(1X,I2,2X,5(F5.3,2X),F8.0,2X,F5.2,2X,F5.4,2X,F5.2)
800  CONTINUE
      WRITE(7,810)
810  FORMAT(////, '(NUF/NUS-1)/AMP
+    C      D      AVERAGE      RE      L/D      RED FREQ      AMP') B      ',
      DO 830 I=1,N
      IF(AMP(I).LT.0.001)GOTO830
      WRITE(7,820)I,ARNUA(I),ARNUB(I),ARNUC(I),ARNUD(I),
+ARNU(I),RE(I),AR(I),FND(I),AMP(I)
820  FORMAT(1X,I2,2X,5(F5.3,2X),F8.0,2X,F5.2,2X,F5.4,2X,F5.2)
830  CONTINUE
      GOTO1100
900  WRITE(7,910)
910  FORMAT(////, 'NUSSELT NUMBER FOR FRONT AND BACK',/,2X, ' # ' , AMP')
+    NU FRONT      NU BACK      NU      RE      L/D      RED FREQ.      AMP')
      DO 920 I=1,N
      WRITE(7,930)I,NUFR(I),NUBK(I),NU(I),RE(I),AR(I),FND(I),AMP(I)
930  FORMAT(1X,I2,2X,F7.3,5X,2(F7.3,3X),F8.0,2X,F5.2,3X,F5.4,4X,F5.2)
920  CONTINUE
940  WRITE(7,950)
950  FORMAT(////, 'FROSSLING NUMBER FOR FRONT AND BACK',/,2X, ' # ' , AMP')
+    FR FRONT      FR BACK      FR      RE      L/D      RED FREQ.      AMP')
      DO 970 I=1,N
      WRITE(7,960)I,FRFR(I),FRBK(I),FR(I),RE(I),AR(I),FND(I),AMP(I)
960  FORMAT(1X,I2,2X,F6.4,5X,2(F6.4,3X),F8.0,2X,F5.2,3X,F5.4,4X,F5.2)
970  CONTINUE
980  WRITE(7,990)
990  FORMAT(////, 'NUF/NUS FOR FRONT AND BACK
+    FRONT      BACK      TOTAL      RE      L/D      RED FREQ.      AMP')
      IF(SUMAMP.LT.1)GOTO1100
      DO 1000 I=1,N
      WRITE(7,995)I,RNUFR(I),RNUBK(I),RNU(I),RE(I),AR(I),FND(I),AMP(I)
995  FORMAT(1X,I2,2X,F6.4,5X,2(F6.4,3X),F8.0,2X,F5.2,3X,F5.4,4X,F5.2)
1000 CONTINUE
1010 WRITE(7,1020)
1020 FORMAT(////, '(NUF/NUS-1)/AMP FOR FRONT AND BACK',/,2X, ' # ' ,
+    FRONT      BACK      TOTAL      RE      L/D      RED FREQ.      AMP')
      DO 1040 I=1,N
      IF(AMP(I).EQ.0)GOTO1040
      WRITE(7,1030)I,ARNUFR(I),ARNUBK(I),ARNU(I),
+RE(I),AR(I),FND(I)
1030 FORMAT(1X,I2,2X,F6.4,5X,2(F6.4,3X),F8.0,2X,F5.2,3X,F5.4)
1040 CONTINUE
      STOP
1100 END
C
C
C*****
C*****
C
C
C***RADIATION CORRECTION SUBROUTINE
C
      SUBROUTINE RADCOR(TA,TB,TC,TD,T,TAMB,QRA,QRB,QRC,QRD,QR,S)
      SIGMA=5.729E-8
      EPSLON=.15
      TAK=TA+273.15

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Appendix G: Program Listings

```

      TBK=TB+273.15
      TCK=TC+273.15
      TDK=TD+273.15
      TK=T+273.15
      TAMBK=TAMB+273.15
      QRA=SIGMA*EPSILON*S*(TAK**4-TAMBK**4)
      QRB=SIGMA*EPSILON*S*(TBK**4-TAMBK**4)
      QRC=SIGMA*EPSILON*S*(TCK**4-TAMBK**4)
      QRD=SIGMA*EPSILON*S*(TDK**4-TAMBK**4)
      QR=SIGMA*EPSILON*S*(TK**4-TAMBK**4)*4
C     WRITE(9,*)PAC,PBC,PCC,PDC,PCOR
      RETURN
      END

C
C
C
C
C*****
C*****
C
C
C***INSULATION LOSS CORRECTION
C
      SUBROUTINE CLOSS(ICLOSS,PH,HH,QCLA,QCLB,QCLC,QCLD,DTA,DTB,DTC,DTD)
      DIMENSION PHI(4,2),HR(4,2),BI(4,2),HH(4),BIR(16),QQ(16),QCL(4,2)
      IF(ICLOSS.GT.0)GOTO5
C     READ QL1 AND BI FROM FILE
      READ(4,*)NN
      READ(4,*)
      READ(4,*)
      DO 3 I=1,NN
      READ(4,*)QQ(I),C1,C2,BIR(I)
3     CONTINUE
5     ICLOSS=ICLOSS+1
C     WRITE(6,*)PH
C     HLOCAL/HAV FOR A QUARTER SECTION MOVING AROUND CYL AT 45 DEGREE
      INCREMENT
      QR1=1.312
      QR2=.3802
      QR3=.3565
      QR4=1.627
      QR5=0.9016
      QR6=1.477
      QR7=1.435
      QR8=0.8536
      RK=.25
      WW=1./16.*2.54/100.
      RL=(17.5+3.5/4*3.14)*2.54/100
      PH1=PH
      DPH=-90.
      IF(PH.LT.0)DPH=-DPH
C     WRITE(6,*)PH1,PH,WW,RL
CDETERMINE POSITION OF INSULATION STRIPS BASED ON INPUT FROM FN DATA
      DO 10 I=1,4
      PHI(I,1)=PH1
      IF(DPH.LT.0)PHI(I,2)=PHI(I,1)-90.
      IF(DPH.GT.0)PHI(I,2)=PHI(I,1)+90.
      PH1=PH1-90.
      IF(PH1.LT.-180)PH1=PH1+360.
10    CONTINUE
      DO 25 I=1,4
      DO 20 J=1,2
      PHI(I,J)=ABS(PHI(I,J))
      PHI(I,J)=INT(PHI(I,J))

```

Appendix G: Program Listings

```

      IF(PHI(I,J).EQ.0)HR(I,J)=QR1
      IF(PHI(I,J).EQ.45.AND.PHI(I,2).EQ.PHI(I,1))HR(I,J)=QR5
      IF(PHI(I,J).EQ.45.AND.(PHI(I,2).GT.PHI(I,J).OR.PHI(I,1).GT.PHI(I,J
+)))HR(I,J)=QR6
      IF(PHI(I,J).EQ.90.AND.(PHI(I,2).LT.PHI(I,J).OR.PHI(I,1).LT.PHI(I,J
+)))HR(I,J)=QR2
      IF(PHI(I,J).EQ.90.AND.(PHI(I,2).GT.PHI(I,J).OR.PHI(I,1).GT.PHI(I,J
+)))HR(I,J)=QR3
      IF(PHI(I,J).EQ.135.AND.(PHI(I,2).LT.PHI(I,J).OR.PHI(I,1).LT.PHI(I,
+J)))HR(I,J)=QR7
      IF(PHI(I,J).EQ.135.AND.(PHI(I,2).EQ.PHI(I,1)))HR(I,J)=QR8
      IF(PHI(I,J).EQ.180)HR(I,J)=QR4
      BI(I,J)=HR(I,J)*HH(I)*WW/RK
C      WRITE(6,*)BI(I,J),HR(I,J),I,J,WW,RK,RL
      20 CONTINUE
C      WRITE(9,*)PHI(I,1),PHI(I,2)
      25 CONTINUE
C
C BASED ON APPROX H, FIND BI LIMITA AND INTERPOLATE FOR QL
      DO 100 I=1,4
      DO 90 J=1,2
      DO 80 K=1,16
C      BIREF2=BIR(K)
      IF(K.EQ.1)GOTO80
      IF(BI(I,J).LT.BIR(K-1).OR.BI(I,J).GE.BIR(K))GOTO80
      QCL(I,J)=(QQ(K)-QQ(K-1))*(BI(I,J)-BIR(K-1))/(BIR(K)-BIR(K-1))
      QCL(I,J)=QCL(I,J)+QQ(K-1)
C      WRITE(6,*)I,J,K,BIR(K),BIR(K-1),QQ(K),QQ(K-1),QCL(I,J),BI(I,J)
      80 CONTINUE
      90 CONTINUE
      100 CONTINUE
C      WRITE(6,*)HH(1),QCL(1,1),QCL(1,2),RK,WW,RL,DTA
C CORRECTION BASED ON LOCAL H AND DIMENTIONLESS QL1
      QCLA=(HH(1)*WW/2*(HR(1,1)+HR(1,2))-(QCL(1,1)+QCL(1,2))*RK)*RL*DTA
      QCLB=(HH(2)*WW/2*(HR(2,1)+HR(2,2))-(QCL(2,1)+QCL(2,2))*RK)*RL*DTB
      QCLC=(HH(3)*WW/2*(HR(3,1)+HR(3,2))-(QCL(3,1)+QCL(3,2))*RK)*RL*DTC
      QCLD=(HH(4)*WW/2*(HR(4,1)+HR(4,2))-(QCL(4,1)+QCL(4,2))*RK)*RL*DTD
C      WRITE(6,*)HH(1),HR(1,1),HR(1,2),BI(1,1),BI(1,2),QCL(1,1),QCL(1,2)
C      WRITE(6,*)PH,QCLA,QCLB,QCLC,QCLD
      RETURN
      END

```



```

      CALL QCYL(RE,RK,RMAX,TP,TINF,PI,QCL,MCN,H1,H2,TH1,TH2)
      H=H1
      HH=H/RK
C*****INITIALIZE VALUES FOR ROOT SEARCH
      F=.5-1.E-6
      DF=0.05
      N=1
      M=1
C
C
C*****ROOT SEARCH TO FIND NN EIGENVALUES
      9 M=0
      DF=DF/10.
      10 M=M+1
      F=F-DF
      IF(F)11,12,12
      11 F=F+DF
      GO TO 9
      12 RN=N-1
      IF(H) 14,13,14
      13 RN=N
      14 RNU(N)=RN*PI+F*PI
      17 RES1=DTAN(RNU(N))
      RES2=-H*D/(RK*RNU(N))
      RES=RES1+RES2
C      WRITE(6,50)RES,RNU(N),M
C 50 FORMAT(1X,2(G12.5,2X),I5)
      IF(RES)20,20,10
      20 ARES=ABS(RES)
C      IF(ARES.LT.1.E-6)GO TO 25
      IF(DF.LT.1.E-12)GO TO 25
      F=F+DF
      GO TO 9
      25 RLAMDA(N)=RNU(N)/D
      RLF(N)=RNU(N)/PI
      F=F+DF
      DF=0.05
      N=N+1
      IF(NN-N)30,9,9
C 30 WRITE(6,100)(RLAMDA(I),RLF(I),I,I=1,NN)
C 100 FORMAT(1X,2(G12.5,2X),I5)
      30 JJ=1
C
C
C
C
C      INCREMENT W
      DW=WM/48.DO
      31 W=0.0DO
      HH=H/RK
      32 W=W+DW
      WW=W/2.54DO*100.DO
      MCI=MCI+1
      IF(W.GT.WM)GO TO 520
C*****LOOPS TO INITIALIZE TEMPERATURE ARRAYS
      DO 66 M=1,50
      DO 65 MM=1,50
      TN(MM,M)=0.
      TM(MM,M)=0.
      TT(MM,M)=TP
      65 CONTINUE
      66 CONTINUE
C
C

```

Appendix G: Program Listings

```

C   DIVIDE STRIP INTO RML+1 NODES IN X AND RMLY+1 NODES IN Y
C   TERMS OF SERIES ARE CALCULATED FIRST IN X(STARTING ACCROSS TOP FACE
C   AND THEN IN Y(J) UP TO NN TERMS FOR EACH NODE
C
      DX=W/RML
      DY=D/RMLY
      Q1=0.0
      Q2=0.0
C
      DO 205 L=1,NN
      Y=D+DY
C
      DO 203 J=1,1
      X=-DX
      Y=Y-DY
      DO 200 I=1,ML
      X=X+DX
      K=2*L-1
C
      RL=RLAMDA(L)
      AR1=RL*W
      AR2=RL*X
      C1=RL**2+HH**2
      C2=2.*C1/(RL*(D*C1+HH))
      CQ11=DT*C2*(SIN(RL*D))**2
      C2=DT*C2*SIN(RL*D)*COS(RL*Y)
C
C   CALL SUBROUTINE TO EVALUATE HYPERBOLIC SIN OF AR1 AND AR2
      CALL SHOSH(AR1,AR2,CC1,C1Q1)
      TN(I,J)=C2*CC1
      Q11=C1Q1*CQ11
      SK=K
C
      C3=4.*HH*(TINF-TP)/(SK*PI)*SIN(SK*PI*X/W)
      CQ12=4.*HH*(TINF-TP)/(SK*PI)
      AR4=SK*PI*D/W
      AR5=SK*PI*Y/W
C
C   CALL SUBROUTINE TO EVALUATE HYPERBOLIC COSINE OF AR3 AND AR4
      CALL CHOCS(AR4,AR5,CC2,D,HH,C2Q1)
      Q12=CQ12*C2Q1
      TM(I,J)=CC2*C3
C
      TT(I,J)=TN(I,J)+TM(I,J)+TT(I,J)
C DT SOL NOT CONSIDERED IN T PROFILE
      TT(I,J)=TM(I,J)+TT(I,J)
      IF(I.GT.1.OR.J.GT.1)GO TO 200
      Q1 =Q1-RK*(Q11)
      Q2 =Q2-RK*(Q12)
C
      QQ =Q1+Q2
      QQ =Q2
      Q1CON=Q1
C
      200 CONTINUE
      203 CONTINUE
      205 CONTINUE
C
      DO 505 LL=1,ML
      I=ML+1-LL
      WRITE(6,500)(TT(I,J),J=1,6),I,J
      IF(MCI.GT.1)GO TO 505
C 500 FORMAT(1X,6(F9.4,2X),2I5)
C

```

Appendix G: Program Listings


```

C
C
SUBROUTINE CHOCS(AR4,AR5,CC2,D,HH,C2Q1)
IF(AR4.LE.150.)GO TO 20
AR6=AR5-AR4
IF(AR6.GE.-130.)GO TO 15
MMO=0
CC2=0.
C2Q1=1/(HH+AR4/D)
GO TO 30
15 CC2=EXP(AR6)/(HH+AR4/D)
C2Q1=1/(HH+AR4/D)
MMO=1
GO TO 30
20 CC2=COSH(AR5)/((HH*COSH(AR4)+(AR4/D)*SINH(AR4))
C2Q1=SINH(AR4)/(HH*COSH(AR4)+(AR4/D)*SINH(AR4))
C C2Q1=(CC2/COSH(AR5))*SINH(AR4)
MMO=2
C 30 WRITE(6,*)MMO,AR4,AR5,AR6
C RETURN
C 30 RETURN
END

C
C
C
C
C*****
C
C SUBROUTINE TO CALCULATE THE CONVECTIVE HEAT TRANSFER BETWEEN ANGLE
C TH1 AND TH2 ON A CYLINDER IN STEADY CROSS FLOW. TRAPAZOIDAL
C INTEGRATION IS USED TO INTEGRATE NUSSELT NUMBER PROFILE (IN THETA)
C FROM FILE 'CSTDY DATA'
C SUBROUTINE QCYL(RE,RK,RMAX,TP,TINF,PI,QCL,MCN,H1,H2,TH1,TH2)
C DIMENSION THREF(100),DTH(100),TH(100)
C REAL NU(100),NUM(100)
C MCN=MCN+1
C RE=50320.
C SRE=RE**0.500000
C RMAX=3.5*2.54/(100.*2)
C RKAIR=0.0270
C PI=3.1415
C IF(MCN.GT.1)GO TO 9
C READ(5,4)
C 4 FORMAT(1X,///)
C
C *****LOOP TO READ NUSSELT NUMBER AND THETA BETWEEN ZERO AND 180 DEGREES
C USES SYMETRY TO FOR NU BETWEEN -180 TO 360 DEGREES
C
C DO 5 II=1,29
C IJ=30-II
C IJJ=29+II
C IJJJ=88-II
C READ(5,6)THREF(IJ),NU(IJ)
C 6 FORMAT(5X,F6.1,4X,F5.3)
C THREF(IJ)=THREF(IJ)+2.
C -2 DEGREE CORRECTION FOR STEP MOTOR POSITION
C THREF(IJJ)=-THREF(IJ)
C NU(IJJ)=NU(IJ)
C THREF(IJJJ)=THREF(IJ)+360
C NU(IJJJ)=NU(IJ)
C 5 CONTINUE

```

```

      DO 7 II=1,90
C      WRITE(6,11)II,THREF(II),NU(II)
C 11  FORMAT(2X,2(I5,2(F12.5,2X)))
      7 CONTINUE
C
C****LOCATE LOWER LIMIT OF THETA IN DATA SET AND INTERPOLATE FOR NU
C
      9 DO 10 I=1,100
      IF(TH1.GE.THREF(I).AND.TH1.LT.THREF(I+1))GO TO 20
C      WRITE(6,15)I,THREF(I)
      10 CONTINUE
      15 FORMAT(2X,I5,F12.5)
      20 NUM(I)=(NU(I+1)-NU(I))*(TH1-THREF(I))/(THREF(I+1)-THREF(I))+NU(I)
      DTH(I)=THREF(I+1)-TH1
      TH(I)=TH1
C
C****LOCATE UPPER LIMIT OF THETA IN DATA SET AND INTERPOLATE FOR NU
C
      DO 30 J=1,100
      JJ=J-1
      IF(TH2.GT.THREF(J).AND.TH2.LE.THREF(J+1))GO TO 40
      30 CONTINUE
      40 NUM(J+1)=(NU(J+1)-NU(J))*(TH2-THREF(J))/(THREF(J+1)-THREF(J))
      ++NU(J)
      TH(J+1)=TH2
C      WRITE(6,51)I,J+1,NUM(I),THREF(I),NU(J+1),THREF(J+1)
      51 FORMAT(2X,2I5,4(F12.5,2X))
      DO 50 L=I+1,J
      DTH(L)=THREF(L+1)-THREF(L)
      TH(L)=THREF(L)
      50 NUM(L)=NU(L)
      DTH(J)=TH2-THREF(J)
      QCL=0.
      QQCL=0.
      RII=0.
      MM=0
C
C
C****INTEGRATE NUSSELT NUMBER USING TRAPAZOIDAL RULE
C
      DO 60 K=I,J
      MM=MM+1
      RI=(NUM(K)+(NUM(K+1)-NUM(K))/2.)*DTH(K)
      RII=RII+RI
      HC=SRE*RKAIR/(2.*RMAX)*NUM(K)
C      H AT THETA NOT USED FOR INTEGRATION
      QCL=QCL+RI*SRE*RKAIR*(TP-TINF)*RMAX*PI/(180.*2.*RMAX)
C QCL IN WATT/M
C      WRITE(6,59)MM,K,HC,TH(K),DTH(K),RI,RII
      59 FORMAT(2X,2I5,5(F12.5,2X))
      60 CONTINUE
      HAVG=RII*SRE*RKAIR/(2.*RMAX*(TH2-TH1))
C      WRITE(6,61)MM,K,NUM(K),TH(K),DTH(K),RI,RII
      61 FORMAT(2X,2I5,5(F12.5,2X))
C      WRITE(6,62)QCL,PI,SRE,RKAIR,TP,TINF,RMAX
      62 FORMAT(2X,7(F12.5,2X))
C
C****CALCULATE H1 AND HY2 FROM NU AT TH1 AND TH2 FOR USE IN MAIN PROGRAM
      H1=NUM(I)*SRE*RKAIR/(2.*RMAX)
      H2=NUM(J+1)*SRE*RKAIR/(2.*RMAX)
C      WRITE(6,100)RII,QCL,H1,H2,HAVG
      100 FORMAT(1X,5(F10.5,2X))

```

Appendix G: Program Listings

RETURN
END

Appendix G: Program Listings

```

C*****
C
C*****PROGRAM TO CALCULATE PERCENT LOSSES AND UNCERTAINTY USING OUTPUT
C      FROM LOSSC FORTRAN.  LOSSES AT TH1 AND TH2 ARE INCLUDED.  END
C      LOSSES ARE NEGLECTED.
C
C
C
C
C
C
C
C
C
C
C*****TERRY VANDENBERGHE 1984
C*****
C      DIMENSION QQ(100,2),Q1(100,2),WW(100,2),BI(100,2),H(100)
C      DIMENSION DTRED(100,2)
C      DIMENSION PERQ1(100),PERQ2(100),ERR1(100),ERR2(100),ERR(100)
C      DIMENSION PERQ(100),PQMX(100,2)
C      J=0
C  VERIFY TP AND TINF IN PROGRAM LOSSC
C      TP=50
C      TINF=27
C
C
C
C*****LOOP TO READ OUTPUT FILE FROM LOSSC.  MCII=1 FOR THETA1 AND MCII=2
C      FOR THETA2
C      II=NO. OF DATA POINTS FOR EACH MCII
C      II=48
C
C      20 DO 40 I=1,II
C          M=MCII
C          RI=I
C          READ(5,518)QCL,A2,A3,A4,A5,A6,A7,MCII
C          QQ(I,MCII)=A2
C          Q1(I,MCII)=A3
C          H(MCII)=A4
C          DTRED(I,MCII)=A5
C          WW(I,MCII)=A6
C          BI(I,MCII)=A7
C      518 WRITE(6,518)QCL,QQ(I,M),Q1(I,M),H(MCII),RI,WW(I,M),BI(I,M),MCII
C      518 FORMAT(1X,3(F10.5,1X),4(F9.4,1X),13)
C      40 CONTINUE
C
C
C      QQ(II+1,MCII)=(QQ(II,MCII)-QQ(II-1,MCII))/(WW(II,MCII)-
C      +WW(II-1,MCII))+QQ(II,MCII)
C      BI(II+1,MCII)=(BI(II,MCII)-BI(II-1,MCII))/(WW(II,MCII)-
C      +WW(II-1,MCII))+BI(II,MCII)
C      J=J+1
C*****RETURN TO READ LOOP FOR MCII=2
C      IF(J.LT.2)GO TO 20
C      QQ(0,MCII)=0.
C      BI(0,MCII)=0.
C
C
C*****LOOP TO CALCULATE PERCENT LOSS AND UNCERTAINTY
C
C
C      DO 70 I=1,II
C
C
C*****PERCENT OF ISOTHERMAL TOP FACE HEAT CONVECTED
C      PQMX(I,1)=100.*QQ(I,1)/(H(1)*WW(I,1)*(2.54/100.))*{TP-TINF}}
C      PQMX(I,2)=100.*QQ(I,2)/(H(2)*WW(I,2)*(2.54/100.))*{TP-TINF}}
C      PQM=100*(QQ(I,1)+QQ(I,2))/((H(1)+H(2))*WW(I,1)*2.54/(100.*2.))
C      PQM=PQM/(TP-TINF)
C

```

Appendix G: Program Listings

```

C
C*****PERCENT LOSS OF TOTAL POWER FOR A CYLINDER SECTION
C   PERQ1(I)=QQ(I,1)/(QCL+QQ(I,1))*100.
C   PERQ2(I)=QQ(I,2)/(QCL+QQ(I,2))*100.
C   PERQ(I)=(QQ(I,1)+QQ(I,2))/(QCL+QQ(I,1)+QQ(I,2))*100.
C
C
C
C
C*****DIMENSIONLESS UNCERTAINTY
C   EH=.05
C   EK=.05
C   EDT=1.
C   EDLT=0.2/23.
C   TP-TINF=23
C
C   UNCERTAINTY FOR W IS 1/64 INCH FOR W GREATER EQUAL 1/32 OTHERWISE
C   UNCERTAINTY IS 50% OF WW
C   WREF=1/32.
C   IF(WW(I,1)-WREF)47,48,48
C   47 EW=.5
C   GO TO 49
C   48 EW=WREF/(2.*WW(I,1))
C
C
C*****DERIVATIVE OF QQ W.R.T. BIOT NUMBER
C   49 DELBI1=(QQ(I+1,1)-QQ(I-1,1))/(BI(I+1,1)-BI(I-1,1))
C   DELBI2=(QQ(I+1,2)-QQ(I-1,2))/(BI(I+1,2)-BI(I-1,2))
C
C
C*****UNCERTAINTY FOR BI
C   ERBI1=((EH**2+EK**2+EW**2)**.5000)*BI(I,1)
C   ERBI2=((EH**2+EK**2+EW**2)**.5000)*BI(I,2)
C
C
C*****UNCERTAINTY FOR Q1 AND QQ
C   ERQ11=((EDT**2+EK**2+EW**2)**.5000)*Q1(I,1)
C   ERQ12=((EDT**2+EK**2+EW**2)**.5000)*Q1(I,2)
C   ERQQ1=((DELBI1*ERBI1/QQ(I,1))**2+EDLT**2)**.500)*QQ(I,1)
C   ERQQ2=((DELBI2*ERBI2/QQ(I,2))**2+EDLT**2)**.500)*QQ(I,2)
C
C
C*****PERCENT UNCERTAINTY OF TOTAL POWER FOR CYLINDER SECTION
C   E1=((ERQ1**2+ERQ11**2)**.5)/(QQ(I,1))*100.
C   E2=((ERQ2**2+ERQ12**2)**.5)/(QQ(I,2))*100.
C   ET1=((ERQQ1**2+ERQ11**2)**.5)/(QCL+QQ(I,1)+QQ(I,2))*100.
C   ET2=((ERQQ2**2+ERQ12**2)**.5)/(QCL+QQ(I,1)+QQ(I,2))*100.
C   ET=(ET1**2+ET2**2)**.5
C
C
C*****PERCENT UNCERTAINTY FROM DT ONLY
C   ERRT1=EDT*Q1(I,1)/(QCL+QQ(I,1))*100.
C   ERRT2=EDT*Q1(I,2)/(QCL+QQ(I,2))*100.
C   ERRT=((ERRT1**2+ERRT2**2)**.5)
C   WRITE(6,69)ET,ERRT,PERQ(I),DTRED(I,1),DTRED(I,2),PQMX(I,1),
C   +PQMX(I,2),WW(I,1),I
C   69 FORMAT(1X,2(F7.4,1X),F8.4,1X,5(F7.4,1X),I3)
C   71 FORMAT(1X,3(E12.5,1X),I4)
C   70 CONTINUE
C   600 END

```

TRS-80 Data Acquisition Program

Appendix G: Program Listings

```

5 ON ERR GOTO 7500
10 CLS: CLEAR 250: PRINT@192, "DATA AQUISITION FOR COPPER CYLINDER"
12 DIM T2(100)
30 POKE 16419, 196
40 PRINT@320, "DEVELOPED BY TERRY VANDENBERGHE 1985 ": PRINT@440, "MACHINE LANGUAGE
  SUBROUTINES FROM PROGRAM 'A19' BY CHUCK ANDRAKA"
45 FOR I=1 TO 500:NEXT I:CLS
60 GOSUB 1000 'GOTO SETUP ROUTINE
70 REM
90 GOTO 150
150 GOSUB 3000 : '      RUN SETUP
155 NY=1:NZ=1: INPUT "MULTIPLEXER?": G$=IF G$="Y" GOSUB 6000
156 IF G$="E": GOTO 7500
157 IF G$="T": GOSUB 5160
158 IF G$="S": GOSUB 7000: GOTO 155
159 IF G$="M": X=USR1(25): GOTO 155
160 IF RS=1 GOTO 70
161 IF G$="YY": INPUT "INPUT YN": YN
170 REM
180 GOTO 155
230 RE=INP(252) OR 16: OUT 236, RE
240 OUT 18, 0
250 INPUT "RUN AGAIN?": G$: IF G$="Y" GOTO 70
260 POKE 16916, 0
270 END
1000 REM *****: SETUP ROUTINE
1010 DIM JX(5000), T1%(64), N1(4), N(4), T(4), TM(35)
1015 DIM TA(10), TB(6), TC(6), TD(6), GA(51), GB(5), GC(5), GD(5)
1020 DIM NM$(4), GL(4), GD$(4), DS(12,4)
1030 DIM AVG(4), SD(4), TC$(35)
1040 CMD "L", "DMACH2/CMD"
1050 DEFUSR1=&HFE00
1060 DEFUSR3=&HFF00: REM      TEMPERATURE ROUTINE
1090 DEFUSR5=&HFD00: REM      DIRECTORY CHECK ROUTINE
1100 POKE &HFFFF, &HCC
1120 RE=INP(252): RE=RE OR 16: OUT(236), RE
1130 OUT(17), 0
1140 OUT(18), 0
1180 P0=P0*20
1184 PRINT " "
1185 INPUT "SET MULTIPLEXER POSITION TO CHANNEL1 AND INPUT TWAIT, TMUX": AA, AB
1186 N1=370*AA: N2=370*AB
1188 INPUT "HOW MANY THERMOCOUPLES?": NC
1190 OUT(17), &HCC
1200 CMD "R" 'TURN ON CLOCK
1210 CLS: PRINT@384, "RESET CLOCK (Y/N)":
1220 G$=INKEY$: IF G$="" GOTO 1220
1230 IF G$ <> "Y" GOTO 1280
1240 PRINT @384, "INPUT HOUR, MIN, SEC: ": INPUT T(1), T(2), T(3)
1250 FOR I=1 TO 3
1260 POKE 16922-I, T(I)
1270 NEXT I
1280 RETURN
3000 '*****
3010 'RUN SETUP ROUTINE
3020 '  -INPUTS SPECIFICATIONS FOR THIS RUN
3030 '*****
3040 CLS
3050 H%=100
3060 I%=100
3070 X=100
3080 SD=0
3090 AVG=0
3100 WT=5
3110 RS=0

```

```

3200 CLS:POKE 16916,2
3300 CLS
3400 POKE 16916,2
3470 NTC=3
3500 GOTO 3620
3620 CLS
4160 CLS:PRINT"THERMOCOUPLE ASSIGNMENTS:"
4170 FOR I=1 TO NTC STEP 3
4180 PRINT USING "% % IS IN ## : % % IS IN ## : % % IS IN ##":TC$(I),I,TC
$(I+1),I+1,TC$(I+2),I+2
4190 'PRINT TC$(I):" IS IN ":I:"      " :TC$(I+1):" IS IN ":I+1
4200 NEXT I
4240 CLOSE#1
4250 CLS
4260 RE=INP(252) OR 16:OUT 236,RE
4270 OUT 18,&H80 'HOLD SET ON TC AMPL.
4275 INPUT"INPUT FILE NAME":F$
4276 FF$=F$+"/DAT:1"
4280 INPUT"CREATE DATA FILE?":G$
4285 IF G$="N":GOTO 4340
4296 PRINT FF$
4298 I%=VARPTR(FF$):I%=PEEK(I%+1)+256*PEEK(I%+2)-65536
4299 X=USR5(I%):IFX=2:PRINT"TEST":FF$:"EXISTS":GOTO4275
4310 INPUT"POSITION(A ANG1)":AN$
4320 INPUT"TEMPERATURE CONFIGURATION?":C1$
4330 INPUT"ATMOSPHERIC PRESSURE?":PA
4336 INPUT"COMMENTS?":CM$
4340 INPUT "DEFAULT FREQUENCY? CONSTANT?":FF,F1$
4345 INPUT "DEFAULT ASPECT RATIO, COND TANT?":AR,AR$
4347 INPUT"DEFAULT AMPLITUDE, CONSTANT?":AP,AP$
4350 INPUT"DEFAULT PITOT TUBE READING? CONSTANT?":PT,PT$
4351 INPUT"INPUT STARTING DATA VALUE":DS
4355 PRINT FF$
4356 IF G$="N":GOTO4440
4360 OPEN"O",1,FF$
4370 DD=DS-15:PRINT#1,001
4375 PRINT#1,DD:" DATA ":F$
4380 DD=DD+1:PRINT#1,DD:" DATA ":"A POSITION=":AN$
4385 DD=DD+1:PRINT#1,DD:" DATA ":"TEMP CONFIG.":C1$
4390 DD=DD+1:PRINT#1,DD:" DATA COMMENTS ":CM$
4400 DD=DD+1:PRINT#1,DD:" DATA ATMOSPHERIC PRESSURE=":PA
4410 DD=DD+1:PRINT#1,DD:" DATA TEMPERATURES ARE:"
4415 DD=DD+1:PRINT#1,DD:" DATA NUL TINF TO TA1 TB1 TC1 TD1 TGA3"
4420 DD=DD+1:PRINT#1,DD:" DATA TGA4 TGC3 TGC4 TI TAM TDM TA2 TA3"
4425 DD=DD+1:PRINT#1,DD:" DATA TA4 TA5 TAD TD2 TD3 TD4 TD5 TC2"
4430 DD=DD+1:PRINT#1,DD:" DATA TC3 TC4 TC5 TB2 TB3 TB4 TB5 NUL"
4435 PRINT#1,DD:" DATA V1,V2,V3,V4,FREQUENCY,ASPECT RATIO,AMPLITUDE,PITOT TUBE,S
TD, DEV. CH.1-4"
4440 CLOSE 1
4480 CLS:RETURN
5160 PRINT"READING ":NTC:" THERMOCOUPLES":
5165 NTC=NC
5170 POLD=P0
5180 T1%(0)=NTC
5190 H%=VARPTR(T1%(0))
5200 X=USR3(H%) 'GET THERMOCOUPLE READINGS
5210 FOR IT=1 TO T1%(0)
5220 TM(IT)=(T1%(2*IT-1)+100*T1%(2*IT))/10
5230 NEXT IT
5239 FOR I=1 TONTC:PRINT TM(I):NEXT I
5245 TA(1)=TM(4)
5250 TA(2)=TM(15)
5252 TA(3)=TM(16)
5254 TA(4)=TM(17)
5256 TA(5)=TM(18)
5258 TA(6)=TM(13)

```

```

5260 TA(7)=TM(19)
5262 TB(1)=TM(5)
5264 TB(2)=TM(28)
5266 TB(3)=TM(29)
5268 TB(4)=TM(30)
5270 TB(5)=TM(31)
5271 TB(6)=TM(1)
5272 TC(1)=TM(6)
5274 TC(2)=TM(24)
5276 TC(3)=TM(25)
5278 TC(4)=TM(26)
5280 TC(5)=TM(27)
5281 TC(6)=TM(32)
5282 TD(1)=TM(7)
5284 TD(2)=TM(20)
5286 TD(3)=TM(21)
5288 TD(4)=TM(22)
5290 TD(5)=TM(23)
5292 TD(6)=TM(14)
5294 T0=TM(2):REM TINF
5296 TI=TM(12):REM CENTERLINE TEMP
5298 TE=TM(1):REM T AMBIENT
5300 GA(3)=TM(8)
5302 GA(4)=TM(9)
5304 GC(3)=TM(10)
5306 GC(4)=TM(11)
5307 CLS
5308 PRINT064,"GP5=":GB(5)
5310 PRINT076,"TP5=":TB(5)
5312 PRINT0100,"TB2=":TB(2)
5314 PRINT0112,"GB2=":GB(2)
5316 PRINT0152,"TB1=":TB(1)
5318 PRINT0192,"GB4=":GB(4)
5320 PRINT0204,"TB4=":TB(4)
5322 PRINT0220,"TB3=":TB(3)
5324 PRINT0240,"GB3=":GB(3)
5326 PRINT0256,"GA4=":GA(4):PRINT0263,"TA4=":TA(4):PRINT0292,"TA3=":TA(3):PRINT0
304,"GA3=":GA(3)
5328 PRINT0344,"TA1=":TA(1)
5330 PRINT0384,"GA5=":GA(5):PRINT0396,"TA5=":TA(5):PRINT0420,"TA2=":TA(2):PRINT0
432,"GA2=":GA(2)
5332 PRINT0448,"GD5=":GD(5):PRINT0460,"TD5=":TD(5):PRINT0484,"TD2=":TD(2):PRINT0
496,"GD2=":GD(2)
5334 PRINT0536,"TD1=":TD(1)
5336 PRINT0576,"GD4=":GD(4):PRINT0588,"TD4=":TD(4):PRINT0612,"TD3=":TD(3):PRINT0
624,"GD3=":GD(3)
5338 PRINT0640,"GC4=":GC(4):PRINT0652,"TC4=":TC(4):PRINT0676,"TC3=":TC(3):PRINT0
688,"GC3=":GC(3)
5340 PRINT0728,"TC1=":TC(1)
5342 PRINT0768,"GC5=":GC(5):PRINT0780,"TC5=":TC(5):PRINT0804,"TC2=":TC(2):PRINT0
816,"GC2=":GC(2)
5344 PRINT0832,"TA1=":TA(6):" TB1=":TB(6):" TC1=":TC(6):" TD(1)=":TD(6):" TI
NF=":T0
5346 NZ=NZ+1:TZ(NZ)=T0:PRINT0920,"POINT NUMBER=":NZ:" TI=":TH(12):
5350 RETURN
5400 END
6000 REM *****MULTIPLEXING ROUTINE
6001 FOR II=1TO700:NEXTII
6005 IK=1
6010 PC%=25
6015 REMN1=2200:N2=4500
6018 REM*****APPROX 370.37 ITERATIONS/SEC*****
6020 X=USR1(PC%)
6022 AG$=INKEY$:IF AG$="":GOTO 6025
6023 AA$=AG$
6024 PRINT0896,AA$

```

```

6025 FOR I=1TON1:NEXT I
6027 IF NY>YN:X=USR1(PC%):N6=4*N2:GOSUB 5160:FOR I=1TON6:NEXT I:GOTO 6033
6030 X=USR1(PC%)
6032 IF AA$="C":GOSUB 5160:IK=IK-1:GOTO 6036
6033 IF AA$="R":GOTO 6036
6035 FOR I=1TON2:NEXT I
6036 IK=IK+1
6037 IF IK=5:IK=1
6038 IF AA$="R":PP%=50*(5-IK):AA$="":X=USR1(PP%):RETURN
6040 NY=NY+1:PRINT@896,"POINT #":NY;" CH#":IK
6050 GOTO 6020
6060 END
7000 REM*****SAVE ROUTINE
7010 PRINT@892,"INPUT 4 VOLTAGES":INPUT V1,V2,V3,V4
7020 IF F1$="Y":GOTO 7030
7025 INPUT"INPUT FREQUENCY":FF
7030 IF AR$="Y":GOTO 7040
7035 INPUT"INPUT ASPECT RATIO":AR
7040 IF PT$="Y":GOTO 7045
7045 INPUT"INPUT PITOT TUBE PRESSURE":PT
7046 IF AP$="Y":GOTO 7050
7047 INPUT"INPUT AMPLITUDE 0-PEAK":AP
7050 INPUT "INPUT 4 STANDARD DEVIATIONS":S1,S2,S3,S4
7060 OPEN"E",1,FF$
7075 DS=DS+1
7080 FOR IJ=1TO8
7084 DS=DS+1
7085 PRINT#1,DS;" DATA ":
7087 FOR IL=1TO4
7088 IM=(IJ-1)*4+IL:PRINT#1,TM(IM);
7089 IF IL<4:PRINT#1," ";
7092 NEXT IL
7094 PRINT#1,""
7095 NEXT IJ
7098 DS=DS+1
7100 PRINT#1,DS;" DATA ":V1;" ";V2;" ";V3;" ";V4
7104 DS=DS+1
7105 PRINT#1,DS;" DATA ":FF;" ";AR;" ";AP;" ";PT
7110 DS=DS+1
7200 CLOSE 1
7220 RETURN
7500 CLOSE
7510 END

```

APPENDIX H. EXPERIMENTAL DATA

SINGLE CYLINDER

REDUCED DATA FOR: CS003

#	NJA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	91.4	111.5	119.1	94.5	104.1	22615.	0.00	0.00	0.00
2	133.3	127.0	148.8	157.5	141.6	36154.	0.00	0.00	0.00
3	164.6	160.0	169.8	183.6	169.5	48728.	0.00	0.00	0.00
4	216.3	205.5	209.9	222.7	213.6	70611.	0.00	0.00	0.00
5	265.1	246.2	263.8	276.1	262.8	110275.	0.00	0.00	0.00

MUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	115.256	92.944	104.100	22615.	0.00	.0000	0.00
2	137.897	145.395	141.646	36154.	0.00	.0000	0.00
3	164.884	174.089	169.487	48728.	0.00	.0000	0.00
4	207.697	219.505	213.601	70611.	0.00	.0000	0.00
5	255.015	270.593	262.804	110275.	0.00	.0000	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7664	0.6181	0.6922	22615.	0.00	.0000	0.00
2	0.7252	0.7647	0.7449	36154.	0.00	.0000	0.00
3	0.7469	0.7886	0.7678	48728.	0.00	.0000	0.00
4	0.7816	0.8261	0.8038	70611.	0.00	.0000	0.00
5	0.7679	0.8149	0.7914	110275.	0.00	.0000	0.00

9485 CS003
9486 A POSITION=,180
9487 TEMP CONFIG,1
9488 COMMENTS STEADY FIVE CONTROLLERS
9489 ATMOSPHERIC PRESSURE=, 27.82
POINT # 1
TA=37.61 TB=37.72 TC=37.67 TD=37.45
TAV=37.62 T FREE STREAM =25.00 T AMBIENT =24.00 TI=41.50
VOLTAGES: VA=30.98 VB=34.34 VC=35.36 VD=31.38
CORR. POWER: PA=10.69 PB=13.15 PC=13.99 PD=10.91 P= 50.30
PITOT=0.043IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 4.40M/S

POINT # 2
TA=37.76 TB=37.67 TC=37.89 TD=37.76
TAV=37.77 T FREE STREAM =25.00 T AMBIENT =24.00 TI=42.80
VOLTAGES: VA=37.41 VB=36.51 VC=39.75 VD=40.71
CORR. POWER: PA=15.78 PB=14.93 PC=17.79 PD=18.64 P= 68.65
PITOT=0.110IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 7.04M/S

POINT # 3
TA=37.77 TB=37.75 TC=37.74 TD=37.77
TAV=37.76 T FREE STREAM =25.40 T AMBIENT =24.90 TI=43.40
VOLTAGES: VA=40.82 VB=40.33 VC=41.48 VD=43.21
CORR. POWER: PA=18.90 PB=18.33 PC=19.45 PD=21.09 P= 79.13
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 4
TA=37.68 TB=37.70 TC=37.64 TD=37.75
TAV=37.69 T FREE STREAM =25.60 T AMBIENT =25.00 TI=44.10
VOLTAGES: VA=46.10 VB=45.14 VC=45.47 VD=47.08
CORR. POWER: PA=24.24 PB=23.08 PC=23.46 PD=25.12 P= 97.14
PITOT=0.420IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL=13.78M/S

POINT # 5
TA=37.42 TB=37.51 TC=37.26 TD=37.25
TAV=37.36 T FREE STREAM =24.60 T AMBIENT =24.50 TI=43.20
VOLTAGES: VA=52.45 VB=50.90 VC=52.12 VD=53.32
CORR. POWER: PA=31.50 PB=29.45 PC=30.95 PD=32.36 P=125.37
PITOT=1.020IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL=21.43M/S

REDUCED DATA FOR: CFOA9 R

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	92.2	116.1	122.4	92.4	105.8	23240.	0.00	0.00	0.00
2	87.2	113.3	118.3	84.7	100.9	23228.	0.00	1.90	23.30
3	102.0	115.5	119.8	98.9	109.0	23234.	0.00	5.10	17.50
4	105.5	113.5	120.8	102.5	110.6	23233.	0.00	7.00	15.70
5	110.0	115.6	122.0	106.6	113.6	23234.	0.00	10.00	12.30
6	110.1	113.7	120.6	105.7	112.5	23227.	0.00	13.10	11.10
7	117.0	118.8	124.8	114.0	118.6	23227.	0.00	18.10	7.00
8	114.1	116.1	124.0	110.9	116.3	23228.	0.00	20.00	9.10
9	108.7	118.0	123.4	108.9	114.8	23231.	0.00	23.30	6.70

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	119.250	92.297	105.773	23240.	0.00	.0000	0.00
2	115.832	85.960	100.896	23228.	0.00	.0376	23.30
3	117.622	100.440	109.031	23234.	0.00	.1009	17.50
4	117.147	103.998	110.573	23233.	0.00	.1384	15.70
5	118.832	108.311	113.571	23234.	0.00	.1978	12.30
6	117.130	107.907	112.518	23227.	0.00	.2590	11.10
7	121.779	115.491	118.635	23227.	0.00	.3579	7.00
8	120.082	112.478	116.280	23228.	0.00	.3955	9.10
9	120.722	108.819	114.771	23231.	0.00	.4608	6.70

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7822	0.6054	0.6938	23240.	0.00	.0000	0.00
2	0.7600	0.5640	0.6620	23228.	0.00	.0376	23.30
3	0.7717	0.6589	0.7153	23234.	0.00	.1009	17.50
4	0.7686	0.6823	0.7254	23233.	0.00	.1384	15.70
5	0.7796	0.7106	0.7451	23234.	0.00	.1978	12.30
6	0.7685	0.7080	0.7383	23227.	0.00	.2590	11.10
7	0.7990	0.7578	0.7784	23227.	0.00	.3579	7.00
8	0.7879	0.7380	0.7630	23228.	0.00	.3955	9.10
9	0.7920	0.7140	0.7530	23231.	0.00	.4608	6.70

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	23240.	0.00	.0000	0.00
2	0.9715	0.9314	0.9539	23228.	0.00	.0376	23.30
3	0.9866	1.0882	1.0308	23234.	0.00	.1009	17.50
4	0.9822	1.1268	1.0454	23233.	0.00	.1384	15.70
5	0.9965	1.1735	1.0737	23234.	0.00	.1978	12.30
6	0.9821	1.1692	1.0638	23227.	0.00	.2590	11.10
7	1.0212	1.2513	1.1216	23227.	0.00	.3579	7.00
8	1.0068	1.2187	1.0993	23228.	0.00	.3955	9.10
9	1.0124	1.1790	1.0851	23231.	0.00	.4608	6.70

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.1225	-.2946	-.1979	23228.	0.00	.0376
3	-.0769	0.5043	0.1760	23234.	0.00	.1009
4	-.1132	0.8077	0.2890	23233.	0.00	.1384
5	-.0287	1.4108	0.5993	23234.	0.00	.1978
6	-.1609	1.5239	0.5745	23227.	0.00	.2590
7	0.3034	3.5903	1.7370	23227.	0.00	.3579
8	0.0747	2.4031	1.0915	23228.	0.00	.3955
9	0.1857	2.6719	1.2696	23231.	0.00	.4608

9485 CF0A9 RENAMED FROM CS005
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS RE=22K 1 CYL NAT F=10.9 PITOT BACK UNCOR VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.96
 POINT # 1
 TA=36.85 TB=36.77 TC=36.82 TD=36.84
 TAV=36.82 T FREE STREAM =25.20 T AMBIENT =24.10 TI=40.60
 VOLTAGES: VA=29.89 VB=33.40 VC=34.31 VD=30.01
 CORR. POWER: PA= 9.95 PB=12.46 PC=13.18 PD= 9.96 P= 47.00
 PITOT=0.045IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 4.50M/S

POINT # 2
 TA=36.93 TB=37.04 TC=37.09 TD=36.94
 TAV=37.00 T FREE STREAM =25.20 T AMBIENT =24.00 TI=40.60
 VOLTAGES: VA=29.21 VB=33.39 VC=34.14 VD=28.91
 CORR. POWER: PA= 9.48 PB=12.55 PC=13.04 PD= 9.21 P= 45.65
 PITOT=0.045IN. L/D=0.00 FREQ= 1.9HZ 0-P AMPLITUDE= 23.3% VEL= 4.50M/S

POINT # 3
 TA=36.84 TB=36.93 TC=37.01 TD=36.86
 TAV=36.91 T FREE STREAM =25.20 T AMBIENT =24.30 TI=40.80
 VOLTAGES: VA=31.36 VB=33.52 VC=34.22 VD=31.03
 CORR. POWER: PA=11.00 PB=12.55 PC=13.11 PD=10.69 P= 48.77
 PITOT=0.045IN. L/D=0.00 FREQ= 5.1HZ 0-P AMPLITUDE= 17.5% VEL= 4.50M/S

POINT # 4
 TA=36.85 TB=36.97 TC=37.02 TD=36.88
 TAV=36.93 T FREE STREAM =25.20 T AMBIENT =24.20 TI=40.90
 VOLTAGES: VA=31.90 VB=33.31 VC=34.39 VD=31.59
 CORR. POWER: PA=11.39 PB=12.38 PC=13.24 PD=11.09 P= 49.54
 PITOT=0.045IN. L/D=0.00 FREQ= 7.0HZ 0-P AMPLITUDE= 15.7% VEL= 4.50M/S

POINT # 5
 TA=36.77 TB=36.97 TC=37.01 TD=36.88
 TAV=36.91 T FREE STREAM =25.20 T AMBIENT =24.10 TI=41.00
 VOLTAGES: VA=32.44 VB=33.62 VC=34.54 VD=32.21
 CORR. POWER: PA=11.80 PB=12.62 PC=13.36 PD=11.54 P= 50.75
 PITOT=0.045IN. L/D=0.00 FREQ= 10.0HZ 0-P AMPLITUDE= 12.3% VEL= 4.50M/S

POINT # 6
 TA=37.06 TB=36.88 TC=37.01 TD=36.93
 TAV=36.97 T FREE STREAM =25.30 T AMBIENT =24.10 TI=40.90
 VOLTAGES: VA=32.73 VB=33.07 VC=34.20 VD=32.01
 CORR. POWER: PA=12.01 PB=12.20 PC=13.09 PD=11.39 P= 50.14
 PITOT=0.045IN. L/D=0.00 FREQ= 13.1HZ 0-P AMPLITUDE= 11.1% VEL= 4.50M/S

POINT # 7
 TA=37.07 TB=36.88 TC=36.97 TD=36.95
 TAV=36.97 T FREE STREAM =25.30 T AMBIENT =24.20 TI=41.20
 VOLTAGES: VA=33.72 VB=33.77 VC=34.72 VD=33.23
 CORR. POWER: PA=12.77 PB=12.74 PC=13.51 PD=12.31 P= 52.76
 PITOT=0.045IN. L/D=0.00 FREQ= 18.1HZ 0-P AMPLITUDE= 7.0% VEL= 4.50M/S

POINT # 8
 TA=37.02 TB=36.93 TC=36.99 TD=37.07
 TAV=37.00 T FREE STREAM =25.20 T AMBIENT =24.10 TI=41.20
 VOLTAGES: VA=33.38 VB=33.62 VC=34.78 VD=33.10
 CORR. POWER: PA=12.51 PB=12.62 PC=13.55 PD=12.20 P= 52.33
 PITOT=0.045IN. L/D=0.00 FREQ= 20.0HZ 0-P AMPLITUDE= 9.1% VEL= 4.50M/S

POINT # 9
 TA=37.01 TB=36.88 TC=36.92 TD=37.00
 TAV=36.95 T FREE STREAM =25.20 T AMBIENT =24.30 TI=41.10
 VOLTAGES: VA=32.58 VB=33.80 VC=34.60 VD=32.71
 CORR. POWER: PA=11.90 PB=12.77 PC=13.41 PD=11.91 P= 51.42
 PITOT=0.045IN. L/D=0.00 FREQ= 23.3HZ 0-P AMPLITUDE= 6.7% VEL= 4.50M/S

REDUCED DATA FOR: CF009

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	116.7	135.0	140.5	115.5	126.9	31924.	0.00	0.00	0.00
2	107.9	133.1	136.4	109.1	121.6	31907.	0.00	2.00	28.00
3	126.6	130.9	139.4	122.4	129.8	31897.	0.00	6.90	14.71

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	137.757	116.089	126.923	31924.	0.00	.0000	0.00
2	134.764	108.505	121.635	31907.	0.00	.0287	28.00
3	135.125	124.548	129.837	31897.	0.00	.0990	14.71

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7710	0.6497	0.7104	31924.	0.00	.0000	0.00
2	0.7545	0.6074	0.6809	31907.	0.00	.0287	28.00
3	0.7566	0.6974	0.7270	31897.	0.00	.0990	14.71

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	31924.	0.00	.0000	0.00
2	0.9784	0.9347	0.9583	31907.	0.00	.0287	28.00
3	0.9807	1.0728	1.0230	31897.	0.00	.0990	14.71

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0771	-.2331	-.1488	31907.	0.00	.0287
3	-.1314	0.4949	0.1560	31897.	0.00	.0990

8985 CF009
 8986 A POSITION=,180
 8987 TEMP CONFIG,1
 8988 COMMENTS SINGLE CYL RE=30K PITOT BACK UNCOR VARY F
 8989 ATMOSPHERIC PRESSURE=, 28.04
 POINT # 1
 TA=36.66 TB=36.65 TC=36.63 TD=36.70
 TAV=36.66 T FREE STREAM =27.20 T AMBIENT =26.70 TI=40.40
 VOLTAGES: VA=30.21 VB=32.50 VC=33.07 VD=30.22
 CORR. POWER: PA=10.26 PB=11.85 PC=12.30 PD=10.19 P= 45.72
 PITOT=0.085IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 6.19M/S

POINT # 2
 TA=36.68 TB=36.84 TC=36.74 TD=36.81
 TAV=36.77 T FREE STREAM =27.40 T AMBIENT =26.60 TI=40.30
 VOLTAGES: VA=28.82 VB=32.27 VC=32.47 VD=29.28
 CORR. POWER: PA= 9.30 PB=11.67 PC=11.84 PD= 9.54 P= 43.51
 PITOT=0.085IN. L/D=0.00 FREQ= 2.0HZ O-P AMPLITUDE= 28.0% VEL= 6.19M/S

POINT # 3
 TA=36.93 TB=36.74 TC=36.72 TD=36.77
 TAV=36.79 T FREE STREAM =27.60 T AMBIENT =26.80 TI=40.50
 VOLTAGES: VA=31.23 VB=31.50 VC=32.44 VD=30.58
 CORR. POWER: PA=10.98 PB=11.12 PC=11.83 PD=10.45 P= 45.49
 PITOT=0.085IN. L/D=0.00 FREQ= 6.9HZ O-P AMPLITUDE= 14.7% VEL= 6.19M/S

REDUCED DATA FOR: CF010

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	118.0	134.4	144.4	114.1	127.7	31849.	0.00	0.00	0.00
2	110.7	135.2	140.1	107.7	123.4	31827.	0.00	2.00	28.00
3	124.6	133.6	142.5	122.0	130.7	31824.	0.00	7.00	14.70
4	133.2	133.0	141.6	130.2	134.5	31823.	0.00	10.10	13.90
5	147.2	134.3	143.2	140.2	141.2	31822.	0.00	13.10	13.60
6	148.2	136.7	143.5	146.2	143.6	31819.	0.00	18.10	13.90
7	139.6	137.7	144.1	136.8	139.5	31822.	0.00	23.30	8.03
8	147.4	138.4	146.4	144.2	144.1	31828.	0.00	26.00	7.00
9	112.3	129.5	139.8	111.3	123.2	29914.	0.00	0.00	0.00

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	139.413	116.060	127.736	31849.	0.00	.0000	0.00
2	137.652	109.215	123.434	31827.	0.00	.0286	28.00
3	138.005	123.338	130.671	31824.	0.00	.1002	14.70
4	137.300	131.662	134.481	31823.	0.00	.1446	13.90
5	138.742	143.710	141.226	31822.	0.00	.1875	13.60
6	140.064	147.226	143.645	31819.	0.00	.2590	13.90
7	140.876	138.213	139.545	31822.	0.00	.3334	8.03
8	142.365	145.793	144.079	31828.	0.00	.3721	7.00
9	134.680	111.809	123.244	29914.	0.00	.0000	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7812	0.6503	0.7158	31849.	0.00	.0000	0.00
2	0.7716	0.6122	0.6919	31827.	0.00	.0286	28.00
3	0.7736	0.6914	0.7325	31824.	0.00	.1002	14.70
4	0.7697	0.7381	0.7539	31823.	0.00	.1446	13.90
5	0.7778	0.8056	0.7917	31822.	0.00	.1875	13.60
6	0.7852	0.8254	0.8053	31819.	0.00	.2590	13.90
7	0.7897	0.7748	0.7823	31822.	0.00	.3334	8.03
8	0.7980	0.8172	0.8076	31828.	0.00	.3721	7.00
9	0.7787	0.6465	0.7126	29914.	0.00	.0000	0.00

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	31849.	0.00	.0000	0.00
2	0.9880	0.9411	0.9663	31827.	0.00	.0286	28.00
3	0.9900	1.0628	1.0230	31824.	0.00	.1002	14.70
4	0.9850	1.1345	1.0528	31823.	0.00	.1446	13.90
5	0.9953	1.2381	1.1056	31822.	0.00	.1875	13.60
6	1.0051	1.2688	1.1245	31819.	0.00	.2590	13.90
7	1.0110	1.1910	1.0924	31822.	0.00	.3334	8.03
8	1.0215	1.2563	1.1279	31828.	0.00	.3721	7.00
9	0.9660	0.9636	0.9648	29914.	0.00	.0000	0.00

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0428	-.2104	-.1203	31827.	0.00	.0286
3	-.0678	0.4273	0.1563	31824.	0.00	.1002
4	-.1079	0.9679	0.3799	31823.	0.00	.1446
5	-.0345	1.7506	0.7765	31822.	0.00	.1875
6	0.0366	1.9335	0.8960	31819.	0.00	.2590
7	0.1366	2.3788	1.1512	31822.	0.00	.3334
8	0.3066	3.6617	1.8277	31828.	0.00	.3721

9485 CF010
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS SINGLE CYL RE=30K PITOT BACK UNCOR VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.94
 POINT # 1
 TA=36.84 TB=36.75 TC=36.82 TD=36.71
 TAV=36.78 T FREE STREAM =27.40 T AMBIENT =26.50 TI=40.50
 VOLTAGES: VA=30.36 VB=32.28 VC=33.54 VD=29.77
 CORR. POWER: PA=10.35 PB=11.68 PC=12.65 PD= 9.88 P= 45.71
 PITOT=0.085IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 6.20M/S

POINT # 2
 TA=36.84 TB=36.85 TC=36.92 TD=36.80
 TAV=36.85 T FREE STREAM =27.80 T AMBIENT =26.80 TI=40.30
 VOLTAGES: VA=28.82 VB=31.87 VC=32.53 VD=28.48
 CORR. POWER: PA= 9.31 PB=11.38 PC=11.89 PD= 9.02 P= 42.73
 PITOT=0.085IN. L/D=0.00 FREQ= 2.0HZ O-P AMPLITUDE= 28.0% VEL= 6.21M/S

POINT # 3
 TA=36.76 TB=36.80 TC=36.91 TD=36.72
 TAV=36.80 T FREE STREAM =28.00 T AMBIENT =27.00 TI=40.30
 VOLTAGES: VA=30.06 VB=31.24 VC=32.42 VD=29.79
 CORR. POWER: PA=10.16 PB=10.93 PC=11.81 PD= 9.90 P= 43.91
 PITOT=0.085IN. L/D=0.00 FREQ= 7.0HZ O-P AMPLITUDE= 14.7% VEL= 6.21M/S

POINT # 4
 TA=36.70 TB=36.77 TC=36.85 TD=36.74
 TAV=36.77 T FREE STREAM =28.10 T AMBIENT =27.20 TI=40.40
 VOLTAGES: VA=30.75 VB=30.95 VC=32.03 VD=30.58
 CORR. POWER: PA=10.66 PB=10.73 PC=11.53 PD=10.46 P= 44.45
 PITOT=0.085IN. L/D=0.00 FREQ= 10.1HZ O-P AMPLITUDE= 13.9% VEL= 6.21M/S

POINT # 5
 TA=36.67 TB=36.74 TC=36.84 TD=36.70
 TAV=36.74 T FREE STREAM =28.20 T AMBIENT =27.30 TI=40.50
 VOLTAGES: VA=32.05 VB=30.85 VC=32.00 VD=31.46
 CORR. POWER: PA=11.61 PB=10.67 PC=11.51 PD=11.09 P= 45.92
 PITOT=0.085IN. L/D=0.00 FREQ= 13.1HZ O-P AMPLITUDE= 13.6% VEL= 6.21M/S

POINT # 6
 TA=36.70 TB=36.75 TC=36.82 TD=36.66
 TAV=36.73 T FREE STREAM =28.30 T AMBIENT =27.40 TI=40.60
 VOLTAGES: VA=32.02 VB=30.96 VC=31.82 VD=31.85
 CORR. POWER: PA=11.59 PB=10.75 PC=11.38 PD=11.38 P= 46.13
 PITOT=0.085IN. L/D=0.00 FREQ= 18.1HZ O-P AMPLITUDE= 13.9% VEL= 6.21M/S

POINT # 7
 TA=36.67 TB=36.68 TC=36.77 TD=36.65
 TAV=36.69 T FREE STREAM =28.30 T AMBIENT =27.20 TI=40.40
 VOLTAGES: VA=31.06 VB=30.94 VC=31.80 VD=30.82
 CORR. POWER: PA=10.88 PB=10.73 PC=11.36 PD=10.63 P= 44.66
 PITOT=0.085IN. L/D=0.00 FREQ= 23.3HZ O-P AMPLITUDE= 8.0% VEL= 6.21M/S

POINT # 8
 TA=36.69 TB=36.65 TC=36.75 TD=36.61
 TAV=36.67 T FREE STREAM =28.20 T AMBIENT =27.40 TI=40.50
 VOLTAGES: VA=32.09 VB=31.14 VC=32.17 VD=31.72
 CORR. POWER: PA=11.64 PB=10.88 PC=11.64 PD=11.29 P= 46.47
 PITOT=0.085IN. L/D=0.00 FREQ= 26.0HZ O-P AMPLITUDE= 7.0% VEL= 6.21M/S

POINT # 9
 TA=36.75 TB=36.72 TC=36.75 TD=36.71
 TAV=36.73 T FREE STREAM =27.60 T AMBIENT =26.60 TI=40.20
 VOLTAGES: VA=29.19 VB=31.33 VC=32.54 VD=29.11
 CORR. POWER: PA= 9.55 PB=10.99 PC=11.89 PD= 9.43 P= 43.01
 PITOT=0.075IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 5.83M/S

REDUCED DATA FOR: CF011

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	140.0	151.9	163.7	138.4	148.5	42295.	0.00	0.00	0.00
2	132.7	152.0	160.4	128.8	143.5	42288.	0.00	2.00	29.50
3	141.4	153.1	158.9	136.9	147.6	42298.	0.00	6.90	17.40
4	165.1	149.6	160.4	161.2	159.1	42302.	0.00	13.20	14.50
5	183.9	150.6	162.7	180.8	169.5	42305.	0.00	18.00	18.50
6	157.0	152.3	160.6	152.4	155.6	42290.	0.00	23.00	8.60

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	157.809	139.211	148.510	42295.	0.00	.0000	0.00
2	156.225	130.736	143.481	42288.	0.00	.0231	29.50
3	156.009	139.192	147.601	42298.	0.00	.0797	17.40
4	154.976	163.180	159.078	42302.	0.00	.1525	14.50
5	156.641	182.383	169.512	42305.	0.00	.2079	18.50
6	156.433	154.685	155.559	42290.	0.00	.2656	8.60

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7673	0.6769	0.7221	42295.	0.00	.0000	0.00
2	0.7597	0.6357	0.6977	42288.	0.00	.0231	29.50
3	0.7586	0.6768	0.7177	42298.	0.00	.0797	17.40
4	0.7535	0.7934	0.7734	42302.	0.00	.1525	14.50
5	0.7616	0.8867	0.8241	42305.	0.00	.2079	18.50
6	0.7607	0.7522	0.7564	42290.	0.00	.2656	8.60

NUF/NUS FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	42295.	0.00	.0000	0.00
2	0.9904	0.9391	0.9661	42288.	0.00	.0231	29.50
3	0.9893	0.9998	0.9939	42298.	0.00	.0797	17.40
4	0.9822	1.1721	1.0712	42302.	0.00	.1525	14.50
5	0.9926	1.3101	1.1414	42305.	0.00	.2079	18.50
6	0.9917	1.1111	1.0475	42290.	0.00	.2656	8.60

(NUF/NUS-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0327	-.2065	-.1148	42288.	0.00	.0231
3	-.0615	-.0011	-.0352	42298.	0.00	.0797
4	-.1230	1.1871	0.4908	42302.	0.00	.1525
5	-.0402	1.6762	0.7644	42305.	0.00	.2079
6	-.0966	1.2918	0.5519	42290.	0.00	.2656

9485 CF011
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 1 CYL RE=40K PITOT BACK UNCOR VARY F
 9489 ATMOSPHERIC PRESSURE=, 29.96
 POINT # 1
 TA=36.64 TB=36.71 TC=36.79 TD=36.66
 TAV=36.70 T FREE STREAM =28.20 T AMBIENT =27.30 TI=40.50
 VOLTAGES: VA=31.21 VB=32.71 VC=34.06 VD=31.19
 CORR. POWER: PA=10.99 PB=12.03 PC=13.08 PD=10.90 P= 48.04
 PITOT=0.140IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 7.70M/S

POINT # 2
 TA=36.82 TB=36.85 TC=36.89 TD=36.79
 TAV=36.84 T FREE STREAM =28.00 T AMBIENT =27.20 TI=40.70
 VOLTAGES: VA=31.09 VB=33.36 VC=34.30 VD=30.68
 CORR. POWER: PA=10.89 PB=12.52 PC=13.27 PD=10.53 P= 48.27
 PITOT=0.140IN. L/D=0.00 FREQ= 2.0HZ 0-P AMPLITUDE= 29.5% VEL= 7.70M/S

POINT # 3
 TA=36.79 TB=36.74 TC=36.82 TD=36.69
 TAV=36.76 T FREE STREAM =28.00 T AMBIENT =27.20 TI=40.70
 VOLTAGES: VA=32.00 VB=33.26 VC=34.02 VD=31.43
 CORR. POWER: PA=11.56 PB=12.44 PC=13.05 PD=11.07 P= 49.17
 PITOT=0.140IN. L/D=0.00 FREQ= 6.9HZ 0-P AMPLITUDE= 17.4% VEL= 7.70M/S

POINT # 4
 TA=36.74 TB=36.72 TC=36.81 TD=36.64
 TAV=36.73 T FREE STREAM =28.00 T AMBIENT =27.30 TI=41.00
 VOLTAGES: VA=34.41 VB=32.86 VC=34.14 VD=33.93
 CORR. POWER: PA=13.42 PB=12.14 PC=13.14 PD=12.95 P= 52.68
 PITOT=0.140IN. L/D=0.00 FREQ= 13.2HZ 0-P AMPLITUDE= 14.5% VEL= 7.70M/S

POINT # 5
 TA=36.67 TB=36.71 TC=36.77 TD=36.63
 TAV=36.70 T FREE STREAM =28.00 T AMBIENT =27.30 TI=41.30
 VOLTAGES: VA=36.14 VB=32.94 VC=34.31 VD=35.86
 CORR. POWER: PA=14.84 PB=12.20 PC=13.28 PD=14.51 P= 55.83
 PITOT=0.140IN. L/D=0.00 FREQ= 18.0HZ 0-P AMPLITUDE= 18.5% VEL= 7.70M/S

POINT # 6
 TA=36.74 TB=36.72 TC=36.81 TD=36.70
 TAV=36.74 T FREE STREAM =28.20 T AMBIENT =27.50 TI=40.80
 VOLTAGES: VA=33.19 VB=32.77 VC=33.78 VD=32.75
 CORR. POWER: PA=12.47 PB=12.08 PC=12.87 PD=12.05 P= 50.48
 PITOT=0.140IN. L/D=0.00 FREQ= 23.0HZ 0-P AMPLITUDE= 8.6% VEL= 7.70M/S

REDUCED DATA FOR: CF015

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	161.1	172.4	181.9	157.4	168.2	48847.	0.00	0.00	0.00
2	174.0	173.1	180.4	170.0	174.4	48884.	0.00	23.00	6.60
3	177.1	172.9	177.3	177.8	176.3	48831.	0.00	18.50	9.30
4	162.2	172.2	178.3	160.8	168.4	48846.	0.00	7.00	4.50
5	153.1	167.4	173.8	152.0	161.6	48929.	0.00	1.70	9.60
6	153.7	170.3	174.6	156.8	163.9	48913.	0.00	7.00	4.50
7	166.3	164.0	171.5	164.8	166.6	48912.	0.00	18.50	8.80

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	177.133	159.235	168.184	48847.	0.00	.0000	0.00
2	176.727	172.005	174.366	48884.	0.00	.2151	6.60
3	175.086	177.481	176.283	48831.	0.00	.1729	9.30
4	175.281	161.465	168.373	48846.	0.00	.0654	4.50
5	170.610	152.587	161.599	48929.	0.00	.0159	9.60
6	172.450	155.252	163.851	48913.	0.00	.0656	4.50
7	167.726	165.517	166.622	48912.	0.00	.1732	8.80

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.8015	0.7205	0.7610	48847.	0.00	.0000	0.00
2	0.7993	0.7780	0.7886	48884.	0.00	.2151	6.60
3	0.7923	0.8032	0.7977	48831.	0.00	.1729	9.30
4	0.7931	0.7306	0.7618	48846.	0.00	.0654	4.50
5	0.7713	0.6898	0.7306	48929.	0.00	.0159	9.60
6	0.7797	0.7020	0.7409	48913.	0.00	.0656	4.50
7	0.7584	0.7484	0.7534	48912.	0.00	.1732	8.80

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48847.	0.00	.0000	0.00
2	0.9979	1.0802	1.0368	48884.	0.00	.2151	6.60
3	0.9888	1.1148	1.0482	48831.	0.00	.1729	9.30
4	0.9898	1.0141	1.0011	48846.	0.00	.0654	4.50
5	0.9634	0.9583	0.9608	48929.	0.00	.0159	9.60
6	0.9739	0.9752	0.9742	48913.	0.00	.0656	4.50
7	0.9470	1.0395	0.9907	48912.	0.00	.1732	8.80

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0322	1.2151	0.5569	48884.	0.00	.2151
3	-.1203	1.2340	0.5178	48831.	0.00	.1729
4	-.2269	0.3131	0.0250	48846.	0.00	.0654
5	-.3815	-.4339	-.4079	48929.	0.00	.0159
6	-.5793	-.5503	-.5725	48913.	0.00	.0656
7	-.6022	0.4493	-.1055	48912.	0.00	.1732

9485 CF015
 9486 A POSITION=,180
 9487 TEMP CONFIG,2
 9488 COMMENTS 1 CYL PITOT BACK UNCOR CA'S AMPS RE=47K VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.87
 POINT # 1
 TA=36.79 TB=36.82 TC=36.89 TD=36.75
 TAV=36.81 T FREE STREAM =26.40 T AMBIENT =26.00 TI=41.70
 VOLTAGES: VA=37.01 VB=38.44 VC=39.55 VD=36.65
 CORR. POWER: PA=15.53 PB=16.68 PC=17.70 PD=15.12 P= 66.18
 PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.51M/S

POINT # 2
 TA=36.80 TB=36.79 TC=36.81 TD=36.62
 TAV=36.76 T FREE STREAM =25.90 T AMBIENT =25.60 TI=42.10
 VOLTAGES: VA=39.35 VB=39.34 VC=40.16 VD=38.72
 CORR. POWER: PA=17.59 PB=17.48 PC=18.25 PD=16.91 P= 71.40
 PITOT=0.200IN. L/D=0.00 FREQ= 23.0HZ O-P AMPLITUDE= 6.6% VEL= 9.50M/S

POINT # 3
 TA=36.93 TB=36.92 TC=36.94 TD=37.09
 TAV=36.97 T FREE STREAM =26.30 T AMBIENT =25.90 TI=42.40
 VOLTAGES: VA=39.21 VB=38.86 VC=39.34 VD=39.72
 CORR. POWER: PA=17.47 PB=17.05 PC=17.51 PD=17.81 P= 70.99
 PITOT=0.200IN. L/D=0.00 FREQ= 18.5HZ O-P AMPLITUDE= 9.3% VEL= 9.51M/S

POINT # 4
 TA=36.80 TB=36.81 TC=36.82 TD=36.99
 TAV=36.86 T FREE STREAM =26.30 T AMBIENT =25.90 TI=42.00
 VOLTAGES: VA=37.33 VB=38.58 VC=39.24 VD=37.63
 CORR. POWER: PA=15.80 PB=16.80 PC=17.42 PD=15.95 P= 67.14
 PITOT=0.200IN. L/D=0.00 FREQ= 7.0HZ O-P AMPLITUDE= 4.5% VEL= 9.51M/S

POINT # 5
 TA=36.88 TB=36.86 TC=36.84 TD=36.97
 TAV=36.89 T FREE STREAM =24.80 T AMBIENT =26.60 TI=42.50
 VOLTAGES: VA=38.81 VB=40.64 VC=41.33 VD=38.97
 CORR. POWER: PA=17.12 PB=18.70 PC=19.38 PD=17.15 P= 73.43
 PITOT=0.200IN. L/D=0.00 FREQ= 1.7HZ O-P AMPLITUDE= 9.6% VEL= 9.49M/S

POINT # 6
 TA=36.84 TB=36.76 TC=36.80 TD=36.96
 TAV=36.84 T FREE STREAM =25.20 T AMBIENT =26.90 TI=42.30
 VOLTAGES: VA=38.18 VB=40.14 VC=40.67 VD=38.90
 CORR. POWER: PA=16.57 PB=18.25 PC=18.77 PD=17.09 P= 71.72
 PITOT=0.200IN. L/D=0.00 FREQ= 7.0HZ O-P AMPLITUDE= 4.5% VEL= 9.49M/S

POINT # 7
 TA=36.77 TB=36.77 TC=36.80 TD=36.69
 TAV=36.76 T FREE STREAM =25.40 T AMBIENT =26.90 TI=42.20
 VOLTAGES: VA=39.24 VB=39.09 VC=39.97 VD=39.05
 CORR. POWER: PA=17.53 PB=17.29 PC=18.11 PD=17.24 P= 71.19
 PITOT=0.200IN. L/D=0.00 FREQ= 18.5HZ O-P AMPLITUDE= 8.8% VEL= 9.50M/S

REDUCED DATA FOR: CF016

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	93.0	116.0	120.3	92.8	105.5	23208.	0.00	0.00	0.00
2	127.1	118.9	120.4	126.1	123.1	23206.	0.00	10.00	34.00
3	125.1	112.3	116.6	125.1	119.8	23203.	0.00	10.00	22.40
4	108.0	113.6	119.9	108.2	112.4	23198.	0.00	10.00	12.50

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	118.151	92.905	105.528	23208.	0.00	.0000	0.00
2	119.657	126.600	123.128	23206.	0.00	.1975	34.00
3	114.446	125.096	119.771	23203.	0.00	.1974	22.40
4	116.726	108.079	112.402	23198.	0.00	.1973	12.50

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7756	0.6098	0.6927	23208.	0.00	.0000	0.00
2	0.7855	0.8311	0.8083	23206.	0.00	.1975	34.00
3	0.7513	0.8212	0.7863	23203.	0.00	.1974	22.40
4	0.7664	0.7096	0.7380	23198.	0.00	.1973	12.50

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	23208.	0.00	.0000	0.00
2	1.0130	1.3627	1.1668	23206.	0.00	.1975	34.00
3	0.9686	1.3465	1.1350	23203.	0.00	.1974	22.40
4	0.9878	1.1633	1.0651	23198.	0.00	.1973	12.50

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	0.0381	1.0667	0.4905	23206.	0.00	.1975
3	-.1400	1.5469	0.6025	23203.	0.00	.1974
4	-.0978	1.3066	0.5211	23198.	0.00	.1973

9485 CF016
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 1 CYL RE=22K VARY AMP PITOT BACK UNCOR
 9489 ATMOSPHERIC PRESSURE=, 27.98
 POINT # 1
 TA=37.07 TB=37.15 TC=37.11 TD=37.01
 TAV=37.09 T FREE STREAM =26.00 T AMBIENT =25.30 TI=40.60
 VOLTAGES: VA=29.28 VB=32.78 VC=33.28 VD=29.26
 CORR. POWER: PA= 9.56 PB=12.01 PC=12.40 PD= 9.48 P= 44.80
 PITOT=0.045IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 4.50M/S

POINT # 2
 TA=37.07 TB=37.07 TC=37.04 TD=37.00
 TAV=37.05 T FREE STREAM =26.20 T AMBIENT =25.80 TI=41.10
 VOLTAGES: VA=33.74 VB=32.75 VC=32.88 VD=33.60
 CORR. POWER: PA=12.83 PB=12.00 PC=12.12 PD=12.64 P= 50.85
 PITOT=0.045IN. L/D=0.00 FREQ= 10.0HZ O-P AMPLITUDE= 34.0% VEL= 4.50M/S

POINT # 3
 TA=36.96 TB=36.97 TC=37.01 TD=36.88
 TAV=36.96 T FREE STREAM =26.50 T AMBIENT =26.30 TI=40.80
 VOLTAGES: VA=32.83 VB=31.27 VC=31.87 VD=32.81
 CORR. POWER: PA=12.15 PB=10.93 PC=11.38 PD=12.05 P= 47.70
 PITOT=0.045IN. L/D=0.00 FREQ= 10.0HZ O-P AMPLITUDE= 22.4% VEL= 4.50M/S

POINT # 4
 TA=36.97 TB=36.97 TC=37.01 TD=36.85
 TAV=36.95 T FREE STREAM =26.70 T AMBIENT =26.80 TI=40.50
 VOLTAGES: VA=30.29 VB=31.13 VC=31.99 VD=30.23
 CORR. POWER: PA=10.31 PB=10.84 PC=11.48 PD=10.20 P= 43.98
 PITOT=0.045IN. L/D=0.00 FREQ= 10.0HZ O-P AMPLITUDE= 12.5% VEL= 4.51M/S

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	161.5	143.8	115.4	218.0	159.7	49291.	0.00	0.00	0.00
2	139.8	191.8	84.0	214.8	157.6	49117.	0.00	0.00	0.00
3	141.4	171.1	164.1	189.1	166.4	48954.	0.00	0.00	0.00
4	190.3	177.5	77.9	203.7	162.4	48942.	0.00	0.00	0.00
5	188.3	154.1	161.4	178.1	170.5	48793.	0.00	0.00	0.00
6	186.2	151.9	156.4	175.9	167.6	48793.	0.00	0.00	0.00

FROSSLING NO.:

#	FRA	FRB	FRC	FRD	FR	RE	L/D	FREQ.	AMP
1	0.727	0.648	0.520	0.982	0.719	49291.	0.00	0.00	0.00
2	0.631	0.866	0.379	0.969	0.711	49117.	0.00	0.00	0.00
3	0.639	0.773	0.742	0.855	0.752	48954.	0.00	0.00	0.00
4	0.860	0.802	0.352	0.921	0.734	48942.	0.00	0.00	0.00
5	0.852	0.698	0.731	0.806	0.772	48793.	0.00	0.00	0.00
6	0.843	0.688	0.708	0.796	0.759	48793.	0.00	0.00	0.00

9485 CHKL4
 9486 A POSITION=,-135
 9487 TEMP CONFIG,1
 9488 COMMENTS CHECK LOSSES RE=50K
 9489 ATMOSPHERIC PRESSURE=, 27.5
 POINT # 1
 TA=34.93 TB=34.84 TC=34.81 TD=39.61
 TAV=36.05 T FREE STREAM =25.40 T AMBIENT =25.10 TI=43.10
 VOLTAGES: VA=35.43 VB=33.42 VC=29.97 VD=50.31
 CORR. POWER: PA=14.24 PB=12.56 PC=10.06 PD=28.68 P= 66.68
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.68M/S

POINT # 2
 TA=34.94 TB=39.69 TC=34.85 TD=39.63
 TAV=37.27 T FREE STREAM =25.40 T AMBIENT =25.00 TI=43.70
 VOLTAGES: VA=33.08 VB=47.40 VC=25.79 VD=50.02
 CORR. POWER: PA=12.37 PB=25.42 PC= 7.37 PD=28.34 P= 74.79
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.68M/S

POINT # 3
 TA=35.01 TB=39.70 TC=39.60 TD=39.45
 TAV=38.44 T FREE STREAM =25.40 T AMBIENT =25.00 TI=44.60
 VOLTAGES: VA=33.42 VB=44.87 VC=43.78 VD=46.73
 CORR. POWER: PA=12.63 PB=22.73 PC=21.65 PD=24.68 P= 83.11
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.68M/S

POINT # 4
 TA=39.57 TB=39.63 TC=34.77 TD=39.64
 TAV=38.40 T FREE STREAM =25.70 T AMBIENT =25.20 TI=45.30
 VOLTAGES: VA=46.44 VB=45.10 VC=24.40 VD=48.29
 CORR. POWER: PA=24.54 PB=22.98 PC= 6.57 PD=26.39 P= 81.86
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.68M/S

POINT # 5
 TA=39.61 TB=39.65 TC=39.62 TD=39.65
 TAV=39.63 T FREE STREAM =25.30 T AMBIENT =25.00 TI=46.00
 VOLTAGES: VA=46.94 VB=42.74 VC=43.65 VD=45.90
 CORR. POWER: PA=25.07 PB=20.58 PC=21.51 PD=23.78 P= 92.50
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.68M/S

POINT # 6
 TA=39.64 TB=39.70 TC=39.65 TD=39.70
 TAV=39.67 T FREE STREAM =25.20 T AMBIENT =24.90 TI=46.20
 VOLTAGES: VA=46.89 VB=42.66 VC=43.16 VD=45.85
 CORR. POWER: PA=25.02 PB=20.49 PC=21.02 PD=23.73 P= 91.83
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.67M/S

REDUCED DATA FOR: CHKL5

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	209.3	127.2	146.8	144.1	156.8	48997.	0.00	0.00	0.00
2	207.9	99.5	205.5	112.9	156.4	48813.	0.00	0.00	0.00
3	196.8	94.8	177.1	181.9	162.6	48636.	0.00	0.00	0.00
4	191.4	156.6	180.7	113.3	160.5	48633.	0.00	0.00	0.00
5	180.4	155.2	154.7	175.1	166.3	48476.	0.00	0.00	0.00
6	177.4	149.2	152.4	171.5	162.6	48461.	0.00	0.00	0.00

FROSSLING NO.:

#	FRA	FRB	FRC	FRD	FR	RE	L/D	FREQ.	AMP
1	0.946	0.574	0.663	0.651	0.709	48997.	0.00	0.00	0.00
2	0.941	0.450	0.930	0.511	0.708	48813.	0.00	0.00	0.00
3	0.893	0.430	0.803	0.825	0.737	48636.	0.00	0.00	0.00
4	0.868	0.710	0.819	0.514	0.728	48633.	0.00	0.00	0.00
5	0.819	0.705	0.702	0.795	0.756	48476.	0.00	0.00	0.00
6	0.806	0.678	0.692	0.779	0.739	48461.	0.00	0.00	0.00

9485 CHKL5

9486 A POSITION=-, -135

9487 TEMP CONFIG,1

9488 COMMENTS CHECK LOSSES SECTION A RE=50000

9489 ATMOSPHERIC PRESSURE=, 27.8

POINT # 1

TA=39.40 TB=34.93 TC=34.81 TD=34.75
TAV=35.97 T FREE STREAM =24.80 T AMBIENT =24.40 TI=41.00
VOLTAGES: VA=49.79 VB=32.59 VC=34.73 VD=34.36
CORR. POWER: PA=28.26 PB=11.91 PC=13.59 PD=13.27 P= 68.24
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 2

TA=39.44 TB=34.96 TC=39.46 TD=34.75
TAV=37.15 T FREE STREAM =25.10 T AMBIENT =24.60 TI=41.20
VOLTAGES: VA=49.23 VB=28.59 VC=49.11 VD=30.08
CORR. POWER: PA=27.63 PB= 9.09 PC=27.36 PD=10.10 P= 75.49
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 3

TA=39.61 TB=34.91 TC=39.49 TD=39.50
TAV=38.38 T FREE STREAM =25.20 T AMBIENT =24.70 TI=45.50
VOLTAGES: VA=48.10 VB=27.74 VC=45.58 VD=46.25
CORR. POWER: PA=26.35 PB= 8.55 PC=23.50 PD=24.15 P= 83.98
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 4

TA=39.60 TB=39.65 TC=39.59 TD=34.93
TAV=38.44 T FREE STREAM =25.10 T AMBIENT =24.60 TI=41.70
VOLTAGES: VA=47.59 VB=43.33 VC=46.35 VD=30.44
CORR. POWER: PA=25.78 PB=21.15 PC=24.31 PD=10.34 P= 83.05
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 5

TA=39.61 TB=39.65 TC=39.61 TD=39.42
TAV=39.57 T FREE STREAM =25.10 T AMBIENT =24.70 TI=45.80
VOLTAGES: VA=46.28 VB=43.18 VC=43.02 VD=45.47
CORR. POWER: PA=24.35 PB=21.01 PC=20.88 PD=23.33 P= 91.15
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 6

TA=39.69 TB=39.75 TC=39.71 TD=39.57
TAV=39.68 T FREE STREAM =25.10 T AMBIENT =24.60 TI=46.00
VOLTAGES: VA=46.03 VB=42.51 VC=42.87 VD=45.25
CORR. POWER: PA=24.08 PB=20.34 PC=20.72 PD=23.09 P= 89.84
PITOT=0.200IN. L/D=0.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

REDUCED DATA FOR: CHKL6

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	129.9	210.9	158.0	150.1	162.2	49627.	0.00	0.00	0.00
2	119.5	206.4	118.0	206.1	162.5	49460.	0.00	0.00	0.00
3	115.4	195.3	184.1	180.9	168.9	49314.	0.00	0.00	0.00
4	170.6	193.5	114.1	191.6	167.4	49293.	0.00	0.00	0.00
5	166.6	180.0	179.7	162.4	172.2	49118.	0.00	0.00	0.00
6	164.7	178.9	180.1	159.6	170.8	49102.	0.00	0.00	0.00

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	184.438	139.990	162.214	49627.	0.00	.0000	0.00
2	162.176	162.781	162.478	49460.	0.00	.0000	0.00
3	189.687	148.151	168.919	49314.	0.00	.0000	0.00
4	153.791	181.088	167.439	49293.	0.00	.0000	0.00
5	179.849	164.509	172.179	49118.	0.00	.0000	0.00
6	179.501	162.128	170.815	49102.	0.00	.0000	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.8279	0.6284	0.7282	49627.	0.00	.0000	0.00
2	0.7292	0.7319	0.7306	49460.	0.00	.0000	0.00
3	0.8542	0.6671	0.7607	49314.	0.00	.0000	0.00
4	0.6927	0.8156	0.7542	49293.	0.00	.0000	0.00
5	0.8115	0.7423	0.7769	49118.	0.00	.0000	0.00
6	0.8101	0.7317	0.7709	49102.	0.00	.0000	0.00

9485 CHKL6
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS CHECK LOSSES SECTION B RE=50K
 9489 ATMOSPHERIC PRESSURE=, 27.83
 POINT # 1
 TA=34.86 TB=39.32 TC=34.75 TD=34.76
 TAV=35.92 T FREE STREAM =25.00 T AMBIENT =24.30 TI=39.60
 VOLTAGES: VA=32.42 VB=49.67 VC=35.54 VD=34.73
 CORR. POWER: PA=11.85 PB=27.95 PC=14.25 PD=13.56 P= 68.84
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.61M/S

POINT # 2
 TA=34.86 TB=39.34 TC=34.65 TD=39.22
 TAV=37.02 T FREE STREAM =25.20 T AMBIENT =24.60 TI=43.10
 VOLTAGES: VA=30.84 VB=48.86 VC=30.38 VD=48.65
 CORR. POWER: PA=10.70 PB=27.04 PC=10.33 PD=26.79 P= 76.16
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.62M/S

POINT # 3
 TA=34.85 TB=39.32 TC=38.79 TD=39.21
 TAV=38.04 T FREE STREAM =25.20 T AMBIENT =24.60 TI=44.00
 VOLTAGES: VA=30.33 VB=47.57 VC=45.29 VD=45.65
 CORR. POWER: PA=10.34 PB=25.61 PC=23.22 PD=23.52 P= 84.11
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.62M/S

POINT # 4
 TA=39.35 TB=39.32 TC=34.77 TD=39.15
 TAV=38.15 T FREE STREAM =25.30 T AMBIENT =24.80 TI=43.80
 VOLTAGES: VA=44.27 VB=47.19 VC=29.95 VD=46.69
 CORR. POWER: PA=22.25 PB=25.20 PC=10.04 PD=24.64 P= 83.53
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.62M/S

POINT # 5
 TA=39.61 TB=39.30 TC=39.11 TD=39.39
 TAV=39.35 T FREE STREAM =25.40 T AMBIENT =24.80 TI=45.30
 VOLTAGES: VA=44.06 VB=45.39 VC=45.01 VD=43.32
 CORR. POWER: PA=22.03 PB=23.28 PC=22.92 PD=21.13 P= 90.90
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.62M/S

POINT # 6
 TA=39.66 TB=39.32 TC=39.27 TD=39.45
 TAV=39.43 T FREE STREAM =25.50 T AMBIENT =25.00 TI=45.40
 VOLTAGES: VA=43.74 VB=45.13 VC=45.17 VD=42.89
 CORR. POWER: PA=21.70 PB=23.01 PC=23.09 PD=20.71 P= 90.05
 PITOT=0.205IN. L/D=0.00 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.62M/S

IN-LINE ARRANGEMENTS OF CYLINDERS

REDUCED DATA FOR: CF005

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	95.4	125.0	133.7	103.2	114.3	23185.	1.10	0.00	0.00
2	102.6	117.0	129.7	99.1	112.1	23167.	1.10	1.90	27.40
3	102.6	126.5	135.1	102.9	116.8	23163.	1.10	5.00	18.60
4	102.3	131.3	138.4	105.4	119.3	23172.	1.10	7.00	16.61
5	101.3	134.8	143.4	102.0	120.4	23169.	1.10	10.10	12.10
6	100.5	140.0	148.7	103.5	123.2	23167.	1.10	13.20	10.30
7	98.9	139.0	148.3	99.2	121.3	23167.	1.10	17.90	6.04
8	98.8	139.6	152.9	102.4	123.4	23167.	1.10	22.80	3.90

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	129.334	99.312	114.323	23185.	1.10	.0000	0.00
2	123.358	100.846	112.102	23167.	1.10	.0375	27.40
3	130.798	102.775	116.786	23163.	1.10	.0986	18.60
4	134.819	103.832	119.326	23172.	1.10	.1380	16.61
5	139.104	101.665	120.385	23169.	1.10	.1992	12.10
6	144.357	102.013	123.185	23167.	1.10	.2602	10.30
7	143.614	99.084	121.349	23167.	1.10	.3530	6.04
8	146.216	100.576	123.396	23167.	1.10	.4495	3.90

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.8494	0.6522	0.7508	23185.	1.10	.0000	0.00
2	0.8105	0.6626	0.7365	23167.	1.10	.0375	27.40
3	0.8594	0.6753	0.7674	23163.	1.10	.0986	18.60
4	0.8857	0.6821	0.7839	23172.	1.10	.1380	16.61
5	0.9139	0.6679	0.7909	23169.	1.10	.1992	12.10
6	0.9484	0.6702	0.8093	23167.	1.10	.2602	10.30
7	0.9435	0.6510	0.7973	23167.	1.10	.3530	6.04
8	0.9606	0.6608	0.8107	23167.	1.10	.4495	3.90

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	23185.	1.10	.0000	0.00
2	0.9532	1.0177	0.9806	23167.	1.10	.0375	27.40
3	1.0113	1.0364	1.0215	23163.	1.10	.0986	18.60
4	1.0426	1.0465	1.0438	23172.	1.10	.1380	16.61
5	1.0756	1.0251	1.0530	23169.	1.10	.1992	12.10
6	1.1163	1.0282	1.0775	23167.	1.10	.2602	10.30
7	1.1104	0.9992	1.0615	23167.	1.10	.3530	6.04
8	1.1301	1.0136	1.0794	23167.	1.10	.4495	3.90

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.1707	0.0646	-.0709	23167.	1.10	.0375
3	0.0609	0.1958	0.1159	23163.	1.10	.0986
4	0.2568	0.2801	0.2634	23172.	1.10	.1380
5	0.6249	0.2077	0.4382	23169.	1.10	.1992
6	1.1289	0.2738	0.7526	23167.	1.10	.2602
7	1.8286	-.0135	1.0175	23167.	1.10	.3530
8	3.3351	0.3484	2.0349	23167.	1.10	.4495

9485 CF005
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS RE=22K 3CYL TAND. VARY FREQ
 9489 ATMOSPHERIC PRESSURE=, 27.77
 POINT # 1
 TA=36.85 TB=36.77 TC=36.84 TD=36.72
 TAV=36.80 T FREE STREAM =24.40 T AMBIENT =24.10 TI=41.10
 VOLTAGES: VA=31.36 VB=35.74 VC=36.99 VD=32.52
 CORR. POWER: PA=10.99 PB=14.32 PC=15.38 PD=11.77 P= 53.89
 PITOT=0.045IN. L/D=1.10 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 4.50M/S

POINT # 2
 TA=36.93 TB=36.84 TC=36.91 TD=36.75
 TAV=36.86 T FREE STREAM =24.90 T AMBIENT =24.00 TI=40.80
 VOLTAGES: VA=31.96 VB=34.03 VC=35.86 VD=31.30
 CORR. POWER: PA=11.43 PB=12.94 PC=14.43 PD=10.87 P= 51.12
 PITOT=0.045IN. L/D=1.10 FREQ= 1.9HZ O-P AMPLITUDE= 27.4% VEL= 4.51M/S

POINT # 3
 TA=36.91 TB=36.95 TC=36.85 TD=36.77
 TAV=36.87 T FREE STREAM =25.00 T AMBIENT =24.20 TI=41.00
 VOLTAGES: VA=31.81 VB=35.36 VC=36.33 VD=31.78
 CORR. POWER: PA=11.33 PB=14.00 PC=14.83 PD=11.23 P= 52.81

POINT # 4
 TA=36.84 TB=36.88 TC=36.85 TD=36.72
 TAV=36.82 T FREE STREAM =24.80 T AMBIENT =24.00 TI=41.00
 VOLTAGES: VA=31.92 VB=36.18 VC=37.06 VD=32.34
 CORR. POWER: PA=11.40 PB=14.68 PC=15.44 PD=11.64 P= 54.59
 PITOT=0.045IN. L/D=1.10 FREQ= 7.0HZ O-P AMPLITUDE= 16.6% VEL= 4.51M/S

POINT # 5
 TA=36.84 TB=36.86 TC=36.85 TD=36.72
 TAV=36.82 T FREE STREAM =24.90 T AMBIENT =24.10 TI=41.00
 VOLTAGES: VA=31.64 VB=36.48 VC=37.56 VD=31.71
 CORR. POWER: PA=11.20 PB=14.93 PC=15.88 PD=11.18 P= 54.60
 PITOT=0.045IN. L/D=1.10 FREQ= 10.1HZ O-P AMPLITUDE= 12.1% VEL= 4.51M/S

POINT # 6
 TA=36.82 TB=36.88 TC=36.86 TD=36.70
 TAV=36.82 T FREE STREAM =25.00 T AMBIENT =24.20 TI=41.00
 VOLTAGES: VA=31.38 VB=37.03 VC=38.09 VD=31.76
 CORR. POWER: PA=11.01 PB=15.40 PC=16.34 PD=11.22 P= 55.38
 PITOT=0.045IN. L/D=1.10 FREQ= 13.2HZ O-P AMPLITUDE= 10.3% VEL= 4.51M/S

POINT # 7
 TA=36.85 TB=36.88 TC=36.96 TD=36.71
 TAV=36.85 T FREE STREAM =24.90 T AMBIENT =24.10 TI=41.00
 VOLTAGES: VA=31.30 VB=37.05 VC=38.35 VD=31.27
 CORR. POWER: PA=10.95 PB=15.41 PC=16.56 PD=10.86 P= 55.21
 PITOT=0.045IN. L/D=1.10 FREQ= 17.9HZ O-P AMPLITUDE= 6.0% VEL= 4.51M/S

POINT # 8
 TA=36.85 TB=36.79 TC=36.86 TD=36.76
 TAV=36.82 T FREE STREAM =25.00 T AMBIENT =24.40 TI=41.10
 VOLTAGES: VA=31.14 VB=36.83 VC=38.60 VD=31.67
 CORR. POWER: PA=10.84 PB=15.24 PC=16.80 PD=11.15 P= 55.42
 Pitot=0.045IN. L/D=1.10 FREQ= 22.8HZ O-P AMPLITUDE= 3.9% VEL= 4.51M/S

REDUCED DATA FOR: CF006

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	185.7	207.0	218.9	183.2	198.7	48896.	1.10	0.00	0.00
2	175.7	195.6	203.3	171.1	186.4	48865.	1.10	2.00	28.60
3	184.4	201.4	209.2	179.7	193.7	48849.	1.10	5.00	21.70
4	180.4	203.3	207.6	179.3	192.6	48856.	1.10	7.00	19.20
5	187.0	209.8	218.0	180.3	198.8	48868.	1.10	10.10	13.50
6	180.6	215.9	224.5	181.8	200.7	48866.	1.10	13.20	15.06
7	183.7	223.6	247.6	187.5	210.6	48857.	1.10	18.00	18.60

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	212.967	184.447	198.707	48896.	1.10	.0000	0.00
2	199.450	173.358	186.404	48865.	1.10	.0187	28.60
3	205.324	182.020	193.672	48849.	1.10	.0468	21.70
4	205.454	179.822	192.638	48856.	1.10	.0655	19.20
5	213.869	183.653	198.761	48868.	1.10	.0945	13.50
6	220.154	181.185	200.670	48866.	1.10	.1235	15.06
7	235.599	185.600	210.600	48857.	1.10	.1683	18.60

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.9631	0.8341	0.8986	48896.	1.10	.0000	0.00
2	0.9023	0.7842	0.8433	48865.	1.10	.0187	28.60
3	0.9290	0.8236	0.8763	48849.	1.10	.0468	21.70
4	0.9295	0.8135	0.8715	48856.	1.10	.0655	19.20
5	0.9675	0.8308	0.8991	48868.	1.10	.0945	13.50
6	0.9959	0.8196	0.9078	48866.	1.10	.1235	15.06
7	1.0659	0.8397	0.9528	48857.	1.10	.1683	18.60

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48896.	1.10	.0000	0.00
2	0.9368	0.9398	0.9381	48865.	1.10	.0187	28.60
3	0.9644	0.9868	0.9747	48849.	1.10	.0468	21.70
4	0.9652	0.9749	0.9695	48856.	1.10	.0655	19.20
5	1.0045	0.9956	1.0003	48868.	1.10	.0945	13.50
6	1.0340	0.9824	1.0099	48866.	1.10	.1235	15.06
7	1.1056	1.0064	1.0598	48857.	1.10	.1683	18.60

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.2211	-.2104	-.2165	48865.	1.10	.0187
3	-.1643	-.0608	-.1168	48849.	1.10	.0468
4	-.1812	-.1305	-.1591	48856.	1.10	.0655
5	0.0332	-.0325	0.0020	48868.	1.10	.0945
6	0.2257	-.1170	0.0656	48866.	1.10	.1235
7	0.5675	0.0342	0.3218	48857.	1.10	.1683

9485 CF006
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS RE=50K 3CYL PITOT FRONT UNCOR AR=1.1 VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.8
 POINT # 1
 TA=36.77 TB=36.75 TC=36.67 TD=36.54
 TAV=36.68 T FREE STREAM =24.80 T AMBIENT =24.30 TI=42.80
 VOLTAGES: VA=42.54 VB=44.96 VC=46.04 VD=41.99
 CORR. POWER: PA=20.58 PB=22.90 PC=24.07 PD=19.91 P= 88.72
 PITOT=0.200IN. L/D=1.10 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 2
 TA=36.82 TB=36.95 TC=36.85 TD=36.69
 TAV=36.83 T FREE STREAM =25.00 T AMBIENT =24.30 TI=42.30
 VOLTAGES: VA=41.16 VB=43.75 VC=44.36 VD=40.53
 CORR. POWER: PA=19.24 PB=21.66 PC=22.31 PD=18.52 P= 83.02
 PITOT=0.200IN. L/D=1.10 FREQ= 2.0HZ O-P AMPLITUDE= 28.6% VEL= 9.50M/S

POINT # 3
 TA=36.91 TB=36.95 TC=36.85 TD=36.72
 TAV=36.86 T FREE STREAM =25.20 T AMBIENT =24.60 TI=42.90
 VOLTAGES: VA=41.95 VB=44.01 VC=44.62 VD=41.23
 CORR. POWER: PA=20.01 PB=21.93 PC=22.59 PD=19.19 P= 84.96
 PITOT=0.200IN. L/D=1.10 FREQ= 5.0HZ O-P AMPLITUDE= 21.7% VEL= 9.50M/S

POINT # 4
 TA=36.89 TB=36.91 TC=36.81 TD=36.77
 TAV=36.85 T FREE STREAM =25.10 T AMBIENT =24.50 TI=43.20
 VOLTAGES: VA=41.63 VB=44.33 VC=44.56 VD=41.45
 CORR. POWER: PA=19.70 PB=22.25 PC=22.52 PD=19.39 P= 85.13
 PITOT=0.200IN. L/D=1.10 FREQ= 7.0HZ O-P AMPLITUDE= 19.2% VEL= 9.50M/S

POINT # 5
 TA=36.80 TB=36.85 TC=36.70 TD=36.69
 TAV=36.76 T FREE STREAM =25.10 T AMBIENT =24.50 TI=43.20
 VOLTAGES: VA=42.21 VB=44.89 VC=45.42 VD=41.41
 CORR. POWER: PA=20.27 PB=22.83 PC=23.42 PD=19.36 P= 87.11
 PITOT=0.200IN. L/D=1.10 FREQ= 10.1HZ O-P AMPLITUDE= 13.5% VEL= 9.50M/S

POINT # 6
 TA=36.76 TB=36.77 TC=36.71 TD=36.70
 TAV=36.74 T FREE STREAM =25.20 T AMBIENT =24.50 TI=43.30
 VOLTAGES: VA=41.26 VB=45.19 VC=45.91 VD=41.42
 CORR. POWER: PA=19.35 PB=23.15 PC=23.94 PD=19.37 P= 87.03
 PITOT=0.200IN. L/D=1.10 FREQ= 13.2HZ O-P AMPLITUDE= 15.1% VEL= 9.50M/S

POINT # 7
 TA=36.76 TB=36.77 TC=36.69 TD=36.65
 TAV=36.72 T FREE STREAM =25.40 T AMBIENT =24.70 TI=43.60
 VOLTAGES: VA=41.25 VB=45.59 VC=47.71 VD=41.60
 CORR. POWER: PA=19.34 PB=23.57 PC=25.90 PD=19.55 P= 89.55
 Pitot=0.200IN. L/D=1.10 FREQ= 18.0HZ O-P AMPLITUDE= 18.6% VEL= 9.51M/S

REDUCED DATA FOR: CF012

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	111.5	155.3	161.4	107.6	134.0	23132.	1.25	0.00	0.00
2	109.2	142.5	149.8	104.8	126.6	23119.	1.25	2.20	27.40
3	109.8	149.6	160.3	111.4	132.8	23119.	1.25	5.00	18.60
4	116.7	152.2	166.3	111.2	136.6	23117.	1.25	6.90	16.60
5	112.2	159.0	173.8	107.7	138.2	23123.	1.25	10.00	12.10
6	110.1	157.4	170.8	105.1	135.8	23121.	1.25	13.10	10.30
7	110.9	161.5	173.2	110.2	138.9	23118.	1.25	18.00	6.00
8	114.1	163.6	173.1	113.3	141.0	23124.	1.25	23.00	3.90

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	158.367	109.551	133.959	23132.	1.25	.0000	0.00
2	146.140	106.987	126.564	23119.	1.25	.0432	27.40
3	154.962	110.610	132.786	23119.	1.25	.0982	18.60
4	159.238	113.949	136.594	23117.	1.25	.1355	16.60
5	166.397	109.933	138.165	23123.	1.25	.1965	12.10
6	164.100	107.582	135.841	23121.	1.25	.2573	10.30
7	167.360	110.522	138.941	23118.	1.25	.3536	6.00
8	168.357	113.699	141.028	23124.	1.25	.4519	3.90

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.0413	0.7203	0.8808	23132.	1.25	.0000	0.00
2	0.9611	0.7036	0.8324	23119.	1.25	.0432	27.40
3	1.0192	0.7275	0.8733	23119.	1.25	.0982	18.60
4	1.0473	0.7494	0.8984	23117.	1.25	.1355	16.60
5	1.0943	0.7229	0.9086	23123.	1.25	.1965	12.10
6	1.0792	0.7075	0.8934	23121.	1.25	.2573	10.30
7	1.1007	0.7269	0.9138	23118.	1.25	.3536	6.00
8	1.1071	0.7477	0.9274	23124.	1.25	.4519	3.90

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	23132.	1.25	.0000	0.00
2	0.9227	0.9765	0.9448	23119.	1.25	.0432	27.40
3	0.9782	1.0101	0.9912	23119.	1.25	.0982	18.60
4	1.0050	1.0400	1.0197	23117.	1.25	.1355	16.60
5	1.0502	1.0034	1.0314	23123.	1.25	.1965	12.10
6	1.0358	0.9819	1.0140	23121.	1.25	.2573	10.30
7	1.0565	1.0091	1.0372	23118.	1.25	.3536	6.00
8	1.0629	1.0381	1.0528	23124.	1.25	.4519	3.90

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.2821	-.0856	-.2015	23119.	1.25	.0432
3	-.1171	0.0545	-.0471	23119.	1.25	.0982
4	0.0302	0.2412	0.1185	23117.	1.25	.1355
5	0.4148	0.0285	0.2595	23123.	1.25	.1965
6	0.3472	-.1753	0.1364	23121.	1.25	.2573
7	0.9411	0.1523	0.6198	23118.	1.25	.3536
8	1.6128	0.9780	1.3531	23124.	1.25	.4519

9485 CF012
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 3 CYL AR=1.25 RE=22K PITOT BACK UNCOR VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.87
 POINT # 1
 TA=36.81 TB=36.79 TC=36.84 TD=36.77
 TAV=36.80 T FREE STREAM =27.80 T AMBIENT =26.60 TI=40.40
 VOLTAGES: VA=28.89 VB=33.98 VC=34.70 VD=28.43
 CORR. POWER: PA= 9.35 PB=12.98 PC=13.57 PD= 8.98 P= 46.02
 PITOT=0.045IN. L/D=1.25 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 4.52M/S

POINT # 2
 TA=36.81 TB=36.80 TC=36.93 TD=36.96
 TAV=36.87 T FREE STREAM =28.10 T AMBIENT =26.90 TI=40.30
 VOLTAGES: VA=28.13 VB=32.07 VC=33.07 VD=27.90
 CORR. POWER: PA= 8.85 PB=11.54 PC=12.30 PD= 8.64 P= 42.46
 PITOT=0.045IN. L/D=1.25 FREQ= 2.2HZ O-P AMPLITUDE= 27.4% VEL= 4.52M/S

POINT # 3
 TA=36.77 TB=36.82 TC=36.86 TD=36.86
 TAV=36.83 T FREE STREAM =28.20 T AMBIENT =27.00 TI=40.30
 VOLTAGES: VA=27.98 VB=32.70 VC=33.87 VD=28.42
 CORR. POWER: PA= 8.76 PB=12.01 PC=12.92 PD= 8.98 P= 43.78
 PITOT=0.045IN. L/D=1.25 FREQ= 5.0HZ O-P AMPLITUDE= 18.6% VEL= 4.53M/S

POINT # 4
 TA=36.80 TB=36.76 TC=36.85 TD=36.82
 TAV=36.81 T FREE STREAM =28.30 T AMBIENT =27.00 TI=40.30
 VOLTAGES: VA=28.70 VB=32.67 VC=34.26 VD=28.17
 CORR. POWER: PA= 9.23 PB=11.99 PC=13.23 PD= 8.82 P= 44.37
 PITOT=0.045IN. L/D=1.25 FREQ= 6.9HZ O-P AMPLITUDE= 16.6% VEL= 4.53M/S

POINT # 5
 TA=36.72 TB=36.75 TC=36.85 TD=36.75
 TAV=36.77 T FREE STREAM =28.20 T AMBIENT =26.90 TI=40.30
 VOLTAGES: VA=28.19 VB=33.54 VC=35.21 VD=27.78
 CORR. POWER: PA= 8.90 PB=12.65 PC=13.99 PD= 8.57 P= 45.21
 PITOT=0.045IN. L/D=1.25 FREQ= 10.0HZ O-P AMPLITUDE= 12.1% VEL= 4.53M/S

POINT # 6
 TA=36.77 TB=36.76 TC=36.85 TD=36.80
 TAV=36.80 T FREE STREAM =28.20 T AMBIENT =26.80 TI=40.20
 VOLTAGES: VA=28.02 VB=33.40 VC=34.92 VD=27.54
 CORR. POWER: PA= 8.78 PB=12.54 PC=13.75 PD= 8.41 P= 44.60
 PITOT=0.045IN. L/D=1.25 FREQ= 13.1HZ O-P AMPLITUDE= 10.3% VEL= 4.53M/S

POINT # 7
 TA=36.79 TB=36.76 TC=36.85 TD=36.95
 TAV=36.84 T FREE STREAM =28.20 T AMBIENT =27.00 TI=40.50
 VOLTAGES: VA=28.13 VB=33.82 VC=35.15 VD=28.41
 CORR. POWER: PA= 8.86 PB=12.87 PC=13.94 PD= 8.97 P= 45.74
 PITOT=0.045IN. L/D=1.25 FREQ= 18.0HZ O-P AMPLITUDE= 6.0% VEL= 4.53M/S

POINT # 8
 TA=36.80 TB=36.70 TC=36.84 TD=36.85
 TAV=36.80 T FREE STREAM =28.10 T AMBIENT =27.00 TI=40.50
 VOLTAGES: VA=28.70 VB=34.10 VC=35.31 VD=28.79
 CORR. POWER: PA= 9.23 PB=13.09 PC=14.07 PD= 9.23 P= 46.71
 Pitot=0.045IN. L/D=1.25 FREQ= 23.0HZ O-P AMPLITUDE= 3.9% VEL= 4.52M/S

REDUCED DATA FOR: CF013

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	193.0	255.6	266.0	189.3	226.0	48851.	1.25	0.00	0.00
2	193.8	248.6	259.2	184.6	221.5	48849.	1.25	2.10	28.60
3	196.5	249.1	264.2	192.5	225.6	48845.	1.25	7.00	19.20
4	192.5	259.6	256.7	192.9	225.4	48857.	1.25	10.00	13.50
5	200.1	257.0	266.0	193.9	229.3	48850.	1.25	13.00	15.00
6	200.1	257.0	266.0	193.9	229.3	48850.	1.25	13.00	15.00
7	200.8	248.3	264.8	194.8	227.2	48851.	1.25	18.10	18.60
8	198.2	260.5	275.0	194.2	232.0	48843.	1.25	23.00	0.00

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	260.830	191.158	225.994	48851.	1.25	.0000	0.00
2	253.856	189.242	221.549	48849.	1.25	.0196	28.60
3	256.654	194.522	225.588	48845.	1.25	.0654	19.20
4	258.138	192.706	225.422	48857.	1.25	.0934	13.50
5	261.503	197.014	229.259	48850.	1.25	.1215	15.00
6	261.503	197.014	229.259	48850.	1.25	.1215	15.00
7	256.557	197.793	227.175	48851.	1.25	.1691	18.60
8	267.743	196.193	231.968	48843.	1.25	.2148	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.1801	0.8649	1.0225	48851.	1.25	.0000	0.00
2	1.1486	0.8562	1.0024	48849.	1.25	.0196	28.60
3	1.1613	0.8802	1.0207	48845.	1.25	.0654	19.20
4	1.1678	0.8718	1.0198	48857.	1.25	.0934	13.50
5	1.1832	0.8914	1.0373	48850.	1.25	.1215	15.00
6	1.1832	0.8914	1.0373	48850.	1.25	.1215	15.00
7	1.1608	0.8949	1.0278	48851.	1.25	.1691	18.60
8	1.2115	0.8877	1.0496	48843.	1.25	.2148	0.00

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48851.	1.25	.0000	0.00
2	0.9732	0.9898	0.9803	48849.	1.25	.0196	28.60
3	0.9838	1.0176	0.9982	48845.	1.25	.0654	19.20
4	0.9902	1.0082	0.9975	48857.	1.25	.0934	13.50
5	1.0026	1.0306	1.0144	48850.	1.25	.1215	15.00
6	1.0026	1.0306	1.0144	48850.	1.25	.1215	15.00
7	0.9834	1.0347	1.0052	48851.	1.25	.1691	18.60
8	1.0264	1.0263	1.0264	48843.	1.25	.2148	0.00

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0936	-.0355	-.0688	48849.	1.25	.0196
3	-.0844	0.0916	-.0094	48845.	1.25	.0654
4	-.0727	0.0607	-.0188	48857.	1.25	.0934
5	0.0175	0.2038	0.0963	48850.	1.25	.1215
6	0.0175	0.2038	0.0963	48850.	1.25	.1215
7	-.0894	0.1863	0.0281	48851.	1.25	.1691

9485 CF013
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS AR=1.25 RE=50K PT BACK UNCOR VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.96
 POINT # 1
 TA=36.77 TB=36.82 TC=36.74 TD=36.86
 TAV=36.80 T FREE STREAM =27.70 T AMBIENT =27.00 TI=42.30
 VOLTAGES: VA=37.84 VB=43.69 VC=44.31 VD=37.79
 CORR. POWER: PA=16.29 PB=21.69 PC=22.36 PD=16.13 P= 77.42
 PITOT=0.200IN. L/D=1.25 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 2
 TA=36.95 TB=36.90 TC=36.84 TD=36.90
 TAV=36.90 T FREE STREAM =27.50 T AMBIENT =26.80 TI=42.70
 VOLTAGES: VA=38.69 VB=43.73 VC=44.46 VD=37.81
 CORR. POWER: PA=17.03 PB=21.72 PC=22.50 PD=16.14 P= 78.38
 PITOT=0.200IN. L/D=1.25 FREQ= 2.1HZ O-P AMPLITUDE= 28.6% VEL= 9.51M/S

POINT # 3
 TA=36.93 TB=36.88 TC=36.82 TD=36.90
 TAV=36.88 T FREE STREAM =27.60 T AMBIENT =26.80 TI=42.80
 VOLTAGES: VA=38.70 VB=43.49 VC=44.62 VD=38.39
 CORR. POWER: PA=17.04 PB=21.48 PC=22.66 PD=16.65 P= 78.82
 PITOT=0.200IN. L/D=1.25 FREQ= 7.0HZ O-P AMPLITUDE= 19.2% VEL= 9.52M/S

POINT # 4
 TA=36.85 TB=36.84 TC=36.80 TD=36.86
 TAV=36.84 T FREE STREAM =27.50 T AMBIENT =26.70 TI=42.90
 VOLTAGES: VA=38.36 VB=44.53 VC=44.16 VD=38.55
 CORR. POWER: PA=16.74 PB=22.54 PC=22.19 PD=16.79 P= 79.24
 PITOT=0.200IN. L/D=1.25 FREQ= 10.0HZ O-P AMPLITUDE= 13.5% VEL= 9.51M/S

POINT # 5
 TA=36.86 TB=36.86 TC=36.80 TD=36.86
 TAV=36.85 T FREE STREAM =27.60 T AMBIENT =26.80 TI=42.90
 VOLTAGES: VA=38.91 VB=44.13 VC=44.71 VD=38.45
 CORR. POWER: PA=17.23 PB=22.13 PC=22.76 PD=16.70 P= 79.80
 PITOT=0.200IN. L/D=1.25 FREQ= 13.0HZ O-P AMPLITUDE= 15.0% VEL= 9.52M/S

POINT # 6
 TA=36.86 TB=36.86 TC=36.80 TD=36.86
 TAV=36.85 T FREE STREAM =27.60 T AMBIENT =26.80 TI=42.90
 VOLTAGES: VA=38.91 VB=44.13 VC=44.71 VD=38.45
 CORR. POWER: PA=17.23 PB=22.13 PC=22.76 PD=16.70 P= 79.80
 PITOT=0.200IN. L/D=1.25 FREQ= 13.0HZ O-P AMPLITUDE= 15.0% VEL= 9.52M/S

POINT # 7
 TA=36.84 TB=36.80 TC=36.74 TD=36.81
 TAV=36.80 T FREE STREAM =27.70 T AMBIENT =27.00 TI=42.90
 VOLTAGES: VA=38.71 VB=43.01 VC=44.21 VD=38.22
 CORR. POWER: PA=17.06 PB=21.01 PC=22.25 PD=16.51 P= 77.78
 PITOT=0.200IN. L/D=1.25 FREQ= 18.1HZ O-P AMPLITUDE= 18.6% VEL= 9.52M/S

POINT # 8
 TA=36.85 TB=36.77 TC=36.77 TD=36.86
 TAV=36.82 T FREE STREAM =27.80 T AMBIENT =27.00 TI=42.90
 VOLTAGES: VA=38.29 VB=43.74 VC=44.89 VD=38.06
 CORR. POWER: PA=16.68 PB=21.74 PC=22.95 PD=16.36 P= 78.70
 Pitot=0.200IN. L/D=1.25 FREQ= 23.0HZ O-P AMPLITUDE= 0.0% VEL= 9.52M/S

REDUCED DATA FOR: CF007

#	NJA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	107.6	157.2	153.8	104.7	130.8	23241.	1.80	0.00	0.00
2	107.0	153.1	148.0	104.6	128.2	23228.	1.80	2.00	27.40
3	99.7	159.9	154.8	111.4	131.5	23234.	1.80	5.00	18.60
4	105.5	159.5	161.9	99.6	131.6	23233.	1.80	7.00	16.60
5	103.7	159.3	159.3	100.3	130.7	23231.	1.80	10.00	12.10
6	122.1	161.7	169.9	119.6	143.3	23224.	1.80	13.10	10.30
7	109.6	162.6	165.4	107.8	136.4	23225.	1.80	18.10	6.00
8	113.5	161.2	165.2	109.8	137.4	23227.	1.80	23.10	3.90

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	155.495	106.119	130.807	23241.	1.80	.0000	0.00
2	150.554	105.807	128.181	23228.	1.80	.0395	27.40
3	157.363	105.538	131.450	23234.	1.80	.0988	18.60
4	160.732	102.565	131.648	23233.	1.80	.1384	16.60
5	159.347	101.976	130.661	23231.	1.80	.1977	12.10
6	165.812	120.878	143.345	23224.	1.80	.2588	10.30
7	164.010	108.717	136.364	23225.	1.80	.3576	6.00
8	163.225	111.641	137.433	23227.	1.80	.4564	3.90

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.0200	0.6961	0.8580	23241.	1.80	.0000	0.00
2	0.9878	0.6942	0.8410	23228.	1.80	.0395	27.40
3	1.0324	0.6924	0.8624	23234.	1.80	.0988	18.60
4	1.0545	0.6729	0.8637	23233.	1.80	.1384	16.60
5	1.0455	0.6691	0.8573	23231.	1.80	.1977	12.10
6	1.0881	0.7932	0.9406	23224.	1.80	.2588	10.30
7	1.0762	0.7134	0.8948	23225.	1.80	.3576	6.00
8	1.0710	0.7325	0.9018	23227.	1.80	.4564	3.90

NUF/NUS FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	23241.	1.80	.0000	0.00
2	0.9682	0.9971	0.9799	23228.	1.80	.0395	27.40
3	1.0119	0.9955	1.0049	23234.	1.80	.0988	18.60
4	1.0339	0.9663	1.0064	23233.	1.80	.1384	16.60
5	1.0249	0.9609	0.9989	23231.	1.80	.1977	12.10
6	1.0668	1.1391	1.0958	23224.	1.80	.2588	10.30
7	1.0550	1.0246	1.0425	23225.	1.80	.3576	6.00
8	1.0500	1.0520	1.0507	23227.	1.80	.4564	3.90

(NUF/NUS-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.1162	-.0106	-.0733	23228.	1.80	.0395
3	0.0642	-.0244	0.0264	23234.	1.80	.0988
4	0.2041	-.2030	0.0387	23233.	1.80	.1384
5	0.2057	-.3230	-.0092	23231.	1.80	.1977
6	0.6482	1.3508	0.9306	23224.	1.80	.2588
7	0.9164	0.4093	0.7079	23225.	1.80	.3576
8	1.2815	1.3331	1.2988	23227.	1.80	.4564

9485 CF007
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 3 CYL AR=1.8 RE=22K PITOT BACK UNCOR VARY RE
 9489 ATMOSPHERIC PRESSURE=,28.00
 POINT # 1
 TA=37.18 TB=36.93 TC=36.90 TD=37.06
 TAV=37.02 T FREE STREAM =25.30 T AMBIENT =24.30 TI=41.60
 VOLTAGES: VA=32.51 VB=38.79 VC=38.31 VD=32.04
 CORR. POWER: PA=11.84 PB=16.94 PC=16.54 PD=11.41 P= 58.14
 PITOT=0.045IN. L/D=1.80 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 4.49M/S

POINT # 2
 TA=37.18 TB=37.00 TC=36.93 TD=37.05
 TAV=37.04 T FREE STREAM =25.70 T AMBIENT =24.50 TI=41.30
 VOLTAGES: VA=31.89 VB=37.77 VC=37.01 VD=31.49
 CORR. POWER: PA=11.39 PB=16.04 PC=15.41 PD=11.02 P= 55.26
 PITOT=0.045IN. L/D=1.80 FREQ= 2.0HZ O-P AMPLITUDE= 27.4% VEL= 4.50M/S

POINT # 3
 TA=36.88 TB=36.97 TC=36.90 TD=36.90
 TAV=36.91 T FREE STREAM =25.80 T AMBIENT =24.70 TI=41.20
 VOLTAGES: VA=30.28 VB=38.37 VC=37.61 VD=30.29
 CORR. POWER: PA=10.24 PB=16.58 PC=15.94 PD=11.47 P= 55.58
 PITOT=0.045IN. L/D=1.80 FREQ= 5.0HZ O-P AMPLITUDE= 18.6% VEL= 4.50M/S

POINT # 4
 TA=36.85 TB=36.94 TC=36.86 TD=36.89
 TAV=36.88 T FREE STREAM =25.90 T AMBIENT =24.80 TI=41.00
 VOLTAGES: VA=30.95 VB=38.09 VC=38.21 VD=30.25
 CORR. POWER: PA=10.72 PB=16.33 PC=16.47 PD=10.15 P= 55.01
 PITOT=0.045IN. L/D=1.80 FREQ= 7.0HZ O-P AMPLITUDE= 16.6% VEL= 4.50M/S

POINT # 5
 TA=37.07 TB=36.88 TC=36.84 TD=36.89
 TAV=36.92 T FREE STREAM =25.90 T AMBIENT =24.80 TI=41.10
 VOLTAGES: VA=31.00 VB=37.96 VC=37.87 VD=30.35
 CORR. POWER: PA=10.75 PB=16.22 PC=16.17 PD=10.22 P= 54.71
 PITOT=0.045IN. L/D=1.80 FREQ= 10.0HZ O-P AMPLITUDE= 12.1% VEL= 4.50M/S

POINT # 6
 TA=36.90 TB=36.91 TC=36.89 TD=36.89
 TAV=36.90 T FREE STREAM =26.20 T AMBIENT =25.10 TI=41.40
 VOLTAGES: VA=32.84 VB=37.78 VC=38.64 VD=32.61
 CORR. POWER: PA=12.13 PB=16.07 PC=16.86 PD=11.87 P= 58.22
 PITOT=0.045IN. L/D=1.80 FREQ= 13.1HZ O-P AMPLITUDE= 10.3% VEL= 4.50M/S

POINT # 7
 TA=36.94 TB=36.86 TC=36.84 TD=36.89
 TAV=36.88 T FREE STREAM =26.20 T AMBIENT =25.10 TI=41.20
 VOLTAGES: VA=31.22 VB=37.80 VC=38.04 VD=31.01
 CORR. POWER: PA=10.92 PB=16.09 PC=16.33 PD=10.69 P= 55.34
 PITOT=0.045IN. L/D=1.80 FREQ= 18.1HZ O-P AMPLITUDE= 6.0% VEL= 4.50M/S

POINT # 8
 TA=37.00 TB=36.84 TC=36.84 TD=36.75
 TAV=36.86 T FREE STREAM =26.20 T AMBIENT =25.50 TI=41.10
 VOLTAGES: VA=31.83 VB=37.58 VC=38.01 VD=31.06
 CORR. POWER: PA=11.38 PB=15.91 PC=16.31 PD=10.75 P= 55.60
 Pitot=0.045IN. L/D=1.80 FREQ= 23.1HZ O-P AMPLITUDE= 3.9% VEL= 4.50M/S

REDUCED DATA FOR: CF004

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	188.7	252.7	267.3	186.9	223.9	48976.	1.80	0.00	0.00
2	187.1	248.6	259.3	181.6	219.2	48962.	1.80	2.00	24.40
3	191.0	249.5	266.4	183.2	222.5	48951.	1.80	7.20	12.10
4	183.9	245.2	265.4	185.7	220.0	48948.	1.80	10.10	10.30
5	185.7	259.2	270.2	199.6	228.7	48937.	1.80	14.00	10.20
6	186.1	253.7	266.0	181.4	221.8	48958.	1.80	18.00	12.60

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	259.994	187.817	223.906	48976.	1.80	.0000	0.00
2	253.961	184.362	219.161	48962.	1.80	.0187	24.40
3	257.950	187.083	222.517	48951.	1.80	.0674	12.10
4	255.315	184.766	220.040	48948.	1.80	.0945	10.30
5	264.703	192.640	228.672	48937.	1.80	.1310	10.20
6	259.869	183.742	221.806	48958.	1.80	.1685	12.60

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.1748	0.8487	1.0117	48976.	1.80	.0000	0.00
2	1.1477	0.8332	0.9905	48962.	1.80	.0187	24.40
3	1.1659	0.8456	1.0057	48951.	1.80	.0674	12.10
4	1.1540	0.8351	0.9946	48948.	1.80	.0945	10.30
5	1.1966	0.8708	1.0337	48937.	1.80	.1310	10.20
6	1.1745	0.8304	1.0024	48958.	1.80	.1685	12.60

NUF/NUS FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48976.	1.80	.0000	0.00
2	0.9770	0.9816	0.9788	48962.	1.80	.0187	24.40
3	0.9920	0.9960	0.9938	48951.	1.80	.0674	12.10
4	0.9817	0.9838	0.9827	48948.	1.80	.0945	10.30
5	1.0183	1.0259	1.0213	48937.	1.80	.1310	10.20
6	0.9996	0.9783	0.9906	48958.	1.80	.1685	12.60

(NUF/NUS-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0943	-.0756	-.0868	48962.	1.80	.0187
3	-.0660	-.0329	-.0513	48951.	1.80	.0674
4	-.1778	-.1573	-.1676	48948.	1.80	.0945
5	0.1796	0.2538	0.2087	48937.	1.80	.1310
6	-.0028	-.1725	-.0744	48958.	1.80	.1685

9485 CF004
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS VARY FREQ FOR PITCH=1.8 RE=50K
 9489 ATMOSPHERIC PRESSURE=, 28.00
 POINT # 1
 TA=36.69 TB=36.80 TC=36.61 TD=36.70
 TAV=36.70 T FREE STREAM =26.40 T AMBIENT =25.50 TI=42.80
 VOLTAGES: VA=39.81 VB=46.33 VC=47.17 VD=39.78
 CORR. POWER: PA=18.02 PB=24.39 PC=25.33 PD=17.87 P= 86.70
 PITOT=0.200IN. L/D=1.80 FREQ= 0.0HZ O-P AMPLITUDE= 0.0% VEL= 9.49M/S

POINT # 2
 TA=36.76 TB=36.79 TC=36.69 TD=36.80
 TAV=36.76 T FREE STREAM =26.50 T AMBIENT =25.90 TI=42.80
 VOLTAGES: VA=39.59 VB=45.71 VC=46.41 VD=39.22
 CORR. POWER: PA=17.83 PB=23.74 PC=24.52 PD=17.36 P= 84.51
 PITOT=0.200IN. L/D=1.80 FREQ= 2.0HZ O-P AMPLITUDE= 24.4% VEL= 9.49M/S

POINT # 3
 TA=36.60 TB=36.72 TC=36.70 TD=36.65
 TAV=36.67 T FREE STREAM =26.90 T AMBIENT =26.10 TI=42.60
 VOLTAGES: VA=38.89 VB=44.77 VC=46.14 VD=38.34
 CORR. POWER: PA=17.20 PB=22.77 PC=24.24 PD=16.59 P= 81.83
 PITOT=0.200IN. L/D=1.80 FREQ= 7.2HZ O-P AMPLITUDE= 12.1% VEL= 9.50M/S

POINT # 4
 TA=36.55 TB=36.64 TC=36.62 TD=36.62
 TAV=36.61 T FREE STREAM =27.10 T AMBIENT =26.50 TI=42.40
 VOLTAGES: VA=37.68 VB=43.73 VC=45.41 VD=38.14
 CORR. POWER: PA=16.14 PB=21.72 PC=23.48 PD=16.43 P= 78.76
 PITOT=0.200IN. L/D=1.80 FREQ= 10.1HZ O-P AMPLITUDE= 10.3% VEL= 9.50M/S

POINT # 5
 TA=36.60 TB=36.65 TC=36.64 TD=36.54
 TAV=36.61 T FREE STREAM =27.30 T AMBIENT =26.50 TI=42.50
 VOLTAGES: VA=37.57 VB=44.51 VC=45.37 VD=38.93
 CORR. POWER: PA=16.04 PB=22.52 PC=23.44 PD=17.13 P= 80.11
 PITOT=0.200IN. L/D=1.80 FREQ= 14.0HZ O-P AMPLITUDE= 10.2% VEL= 9.50M/S

POINT # 6
 TA=36.59 TB=36.62 TC=36.52 TD=36.57
 TAV=36.58 T FREE STREAM =27.00 T AMBIENT =26.50 TI=42.30
 VOLTAGES: VA=38.17 VB=44.67 VC=45.45 VD=37.80
 CORR. POWER: PA=16.57 PB=22.68 PC=23.53 PD=16.13 P= 79.89
 PITOT=0.200IN. L/D=1.80 FREQ= 18.0HZ O-P AMPLITUDE= 12.6% VEL= 9.50M/S

REDUCED DATA FOR: CF008

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	117.7	142.0	147.6	118.3	131.4	23250.	5.00	0.00	0.00
2	113.1	135.8	144.5	109.9	125.8	23233.	5.00	2.00	27.40
3	116.6	137.1	144.8	115.8	128.6	23235.	5.00	5.00	18.60
4	116.8	136.7	145.5	114.6	128.4	23237.	5.00	7.00	16.60
5	115.7	140.1	146.8	115.9	129.6	23237.	5.00	10.00	12.10
6	119.2	143.5	152.2	115.1	132.5	23234.	5.00	13.00	10.30
7	120.0	149.6	159.4	119.7	137.2	23232.	5.00	18.00	6.00
8	118.6	142.5	147.7	116.9	131.4	23240.	5.00	23.00	3.90

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	144.828	118.012	131.420	23250.	5.00	.0000	0.00
2	140.110	111.496	125.803	23233.	5.00	.0395	27.40
3	140.923	116.203	128.563	23235.	5.00	.0988	18.60
4	141.092	115.717	128.405	23237.	5.00	.1383	16.60
5	143.433	115.805	129.619	23237.	5.00	.1976	12.10
6	147.872	117.159	132.516	23234.	5.00	.2569	10.30
7	154.526	119.831	137.178	23232.	5.00	.3556	6.00
8	145.122	117.752	131.437	23240.	5.00	.4545	3.90

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.9498	0.7740	0.8619	23250.	5.00	.0000	0.00
2	0.9192	0.7315	0.8253	23233.	5.00	.0395	27.40
3	0.9245	0.7623	0.8434	23235.	5.00	.0988	18.60
4	0.9256	0.7591	0.8423	23237.	5.00	.1383	16.60
5	0.9409	0.7597	0.8503	23237.	5.00	.1976	12.10
6	0.9701	0.7686	0.8694	23234.	5.00	.2569	10.30
7	1.0138	0.7862	0.9000	23232.	5.00	.3556	6.00
8	0.9520	0.7724	0.8622	23240.	5.00	.4545	3.90

NUF/NUS FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	23250.	5.00	.0000	0.00
2	0.9672	0.9448	0.9573	23233.	5.00	.0395	27.40
3	0.9729	0.9847	0.9783	23235.	5.00	.0988	18.60
4	0.9740	0.9806	0.9771	23237.	5.00	.1383	16.60
5	0.9903	0.9813	0.9863	23237.	5.00	.1976	12.10
6	1.0208	0.9928	1.0083	23234.	5.00	.2569	10.30
7	1.0667	1.0154	1.0438	23232.	5.00	.3556	6.00
8	1.0021	0.9978	1.0001	23240.	5.00	.4545	3.90

(NUF/NUS-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	
2	-.1197	-.2014	-.1560	23233.	5.00	.0395	
3	-.1458	-.0824	-.1169	23235.	5.00	.0988	
4	-.1567	-.1170	-.1382	23237.	5.00	.1383	
5	-.0803	-.1546	-.1133	23237.	5.00	.1976	
6	0.2021	-.0698	0.0809	23234.	5.00	.2569	
7	1.1117	0.2570	0.7302	23232.	5.00	.3556	
8	0.0527	-.0560	0.0033	23240.	5.00	.4545	

9485 CF008
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS AR=5 3 CYL RE=22K PITOT BACK CORR(.007) VARY F
 9489 ATMOSPHERIC PRESSURE=, 28.04
 POINT # 1
 TA=36.69 TB=36.74 TC=36.77 TD=36.81
 TAV=36.75 T FREE STREAM =26.20 T AMBIENT =25.40 TI=41.00
 VOLTAGES: VA=31.93 VB=35.16 VC=35.87 VD=32.30
 CORR. POWER: PA=11.46 PB=13.89 PC=14.49 PD=11.65 P= 52.74
 PITOT=0.045IN. L/D=5.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 4.50M/S

POINT # 2
 TA=36.99 TB=36.91 TC=36.91 TD=36.86
 TAV=36.92 T FREE STREAM =26.40 T AMBIENT =25.20 TI=40.90
 VOLTAGES: VA=31.49 VB=34.38 VC=35.41 VD=30.97
 CORR. POWER: PA=11.12 PB=13.25 PC=14.10 PD=10.67 P= 50.45
 PITOT=0.045IN. L/D=5.00 FREQ= 2.0HZ 0-P AMPLITUDE= 27.4% VEL= 4.50M/S

POINT # 3
 TA=36.80 TB=36.82 TC=36.95 TD=36.86
 TAV=36.86 T FREE STREAM =26.50 T AMBIENT =25.40 TI=40.90
 VOLTAGES: VA=31.51 VB=34.23 VC=35.34 VD=31.62
 CORR. POWER: PA=11.15 PB=13.14 PC=14.04 PD=11.14 P= 50.75
 PITOT=0.045IN. L/D=5.00 FREQ= 5.0HZ 0-P AMPLITUDE= 18.6% VEL= 4.50M/S

POINT # 4
 TA=36.86 TB=36.82 TC=36.91 TD=36.85
 TAV=36.86 T FREE STREAM =26.40 T AMBIENT =25.50 TI=40.90
 VOLTAGES: VA=31.78 VB=34.34 VC=35.52 VD=31.58
 CORR. POWER: PA=11.34 PB=13.23 PC=14.20 PD=11.12 P= 51.16
 PITOT=0.045IN. L/D=5.00 FREQ= 7.0HZ 0-P AMPLITUDE= 16.6% VEL= 4.50M/S

POINT # 5
 TA=36.89 TB=36.82 TC=36.89 TD=36.85
 TAV=36.86 T FREE STREAM =26.40 T AMBIENT =25.40 TI=41.00
 VOLTAGES: VA=31.67 VB=34.75 VC=35.64 VD=31.76
 CORR. POWER: PA=11.26 PB=13.55 PC=14.29 PD=11.25 P= 51.63
 PITOT=0.045IN. L/D=5.00 FREQ= 10.0HZ 0-P AMPLITUDE= 12.1% VEL= 4.50M/S

POINT # 6
 TA=36.94 TB=36.82 TC=36.85 TD=36.89
 TAV=36.87 T FREE STREAM =26.50 T AMBIENT =25.50 TI=41.00
 VOLTAGES: VA=32.06 VB=35.00 VC=36.04 VD=31.56
 CORR. POWER: PA=11.55 PB=13.76 PC=14.63 PD=11.10 P= 52.30
 PITOT=0.045IN. L/D=5.00 FREQ= 13.0HZ 0-P AMPLITUDE= 10.3% VEL= 4.50M/S

POINT # 7
 TA=36.89 TB=36.88 TC=36.86 TD=36.82
 TAV=36.86 T FREE STREAM =26.60 T AMBIENT =25.50 TI=41.10
 VOLTAGES: VA=31.94 VB=35.64 VC=36.71 VD=31.91
 CORR. POWER: PA=11.46 PB=14.28 PC=15.19 PD=11.36 P= 53.55
 PITOT=0.045IN. L/D=5.00 FREQ= 18.0HZ 0-P AMPLITUDE= 6.0% VEL= 4.50M/S

POINT # 8
 TA=36.80 TB=36.76 TC=36.76 TD=36.81
 TAV=36.78 T FREE STREAM =26.50 T AMBIENT =25.60 TI=40.90
 VOLTAGES: VA=31.77 VB=34.77 VC=35.36 VD=31.67
 CORR. POWER: PA=11.34 PB=13.58 PC=14.07 PD=11.19 P= 51.43
 Pitot=0.045IN. L/D=5.00 FREQ= 23.0HZ 0-P AMPLITUDE= 3.9% VEL= 4.50M/S

REDUCED DATA FOR: CF005

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	63.5	74.8	84.2	71.1	73.4	10928.	1.10	0.00	0.00
2	79.2	101.5	110.4	83.6	93.7	17285.	1.10	0.00	0.00
3	98.9	128.0	134.9	104.6	116.6	23194.	1.10	0.00	0.00
4	114.4	145.4	155.0	119.3	133.5	28927.	1.10	0.00	0.00
5	124.7	154.4	162.5	127.2	142.2	31874.	1.10	0.00	0.00
6	139.1	169.5	179.2	141.1	157.2	36260.	1.10	0.00	0.00
7	149.3	179.6	188.9	153.0	167.7	39408.	1.10	0.00	0.00
8	181.4	202.9	211.5	181.6	194.4	45724.	1.10	0.00	0.00

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	79.511	67.261	73.386	10928.	1.10	.0000	0.00
2	105.962	81.363	93.663	17285.	1.10	.0000	0.00
3	131.453	101.746	116.599	23194.	1.10	.0000	0.00
4	150.211	116.822	133.516	28927.	1.10	.0000	0.00
5	158.435	125.950	142.192	31874.	1.10	.0000	0.00
6	174.370	140.091	157.230	36260.	1.10	.0000	0.00
7	184.252	151.182	167.717	39408.	1.10	.0000	0.00
8	207.205	181.512	194.358	45724.	1.10	.0000	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.7606	0.6434	0.7020	10928.	1.10	.0000	0.00
2	0.8060	0.6189	0.7124	17285.	1.10	.0000	0.00
3	0.8631	0.6681	0.7656	23194.	1.10	.0000	0.00
4	0.8832	0.6869	0.7850	28927.	1.10	.0000	0.00
5	0.8874	0.7055	0.7965	31874.	1.10	.0000	0.00
6	0.9157	0.7357	0.8257	36260.	1.10	.0000	0.00
7	0.9282	0.7616	0.8449	39408.	1.10	.0000	0.00
8	0.9690	0.8489	0.9089	45724.	1.10	.0000	0.00

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
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9485 CF005
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS VARY RE AR=1.1 LOOK FOR JUMP PH. PITOT BACK UNCOR
 9489 ATMOSPHERIC PRESSURE=, 27.94
 POINT # 1
 TA=36.82 TB=36.86 TC=36.88 TD=37.10
 TAV=36.92 T FREE STREAM =26.80 T AMBIENT =26.30 TI=39.40
 VOLTAGES: VA=23.21 VB=25.21 VC=26.69 VD=24.91
 CORR. POWER: PA= 5.91 PB= 6.99 PC= 7.88 PD= 6.80 P= 28.83
 PITOT=0.010IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 2.13M/S

POINT # 2
 TA=36.63 TB=36.72 TC=36.72 TD=36.71
 TAV=36.70 T FREE STREAM =27.00 T AMBIENT =26.90 TI=39.50
 VOLTAGES: VA=25.25 VB=28.69 VC=29.86 VD=26.12
 CORR. POWER: PA= 7.08 PB= 9.17 PC= 9.97 PD= 7.54 P= 34.90
 PITOT=0.025IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 3.36M/S

POINT # 3
 TA=36.59 TB=36.65 TC=36.64 TD=36.65
 TAV=36.63 T FREE STREAM =27.00 T AMBIENT =27.20 TI=40.00
 VOLTAGES: VA=28.03 VB=31.97 VC=32.75 VD=29.00
 CORR. POWER: PA= 8.80 PB=11.47 PC=12.07 PD= 9.38 P= 42.79
 PITOT=0.045IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 4.51M/S

POINT # 4
 TA=36.55 TB=36.52 TC=36.59 TD=36.61
 TAV=36.57 T FREE STREAM =27.20 T AMBIENT =27.30 TI=40.30
 VOLTAGES: VA=29.71 VB=33.45 VC=34.60 VD=30.53
 CORR. POWER: PA= 9.93 PB=12.60 PC=13.52 PD=10.43 P= 47.50
 PITOT=0.070IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 5.63M/S

POINT # 5
 TA=36.49 TB=36.52 TC=36.59 TD=36.60
 TAV=36.55 T FREE STREAM =27.30 T AMBIENT =27.40 TI=40.50
 VOLTAGES: VA=30.72 VB=34.26 VC=35.22 VD=31.31
 CORR. POWER: PA=10.65 PB=13.23 PC=14.02 PD=10.99 P= 49.89
 PITOT=0.085IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 6.20M/S

POINT # 6
 TA=36.54 TB=36.51 TC=36.56 TD=36.57
 TAV=36.55 T FREE STREAM =27.30 T AMBIENT =27.60 TI=40.80
 VOLTAGES: VA=32.48 VB=35.83 VC=36.90 VD=32.88
 CORR. POWER: PA=11.94 PB=14.51 PC=15.42 PD=12.15 P= 54.99
 PITOT=0.110IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 7.06M/S

POINT # 7
 TA=36.55 TB=36.54 TC=36.56 TD=36.57
 TAV=36.56 T FREE STREAM =27.50 T AMBIENT =28.00 TI=40.90
 VOLTAGES: VA=33.28 VB=36.51 VC=37.45 VD=33.84
 CORR. POWER: PA=12.56 PB=15.09 PC=15.91 PD=12.90 P= 57.36
 PITOT=0.130IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 7.67M/S

POINT # 8
 TA=36.47 TB=36.65 TC=36.55 TD=36.51
 TAV=36.55 T FREE STREAM =27.50 T AMBIENT =27.80 TI=41.40
 VOLTAGES: VA=36.46 VB=39.01 VC=39.57 VD=36.68
 CORR. POWER: PA=15.13 PB=17.25 PC=17.79 PD=15.21 P= 66.27
 Pitot=0.175IN. L/D=1.10 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 8.90M/S

REDUCED DATA FOR: CP001

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	164.3	150.8	173.9	175.9	166.2	49530.	0.00	22.80	0.00
2	215.5	195.5	270.2	269.7	237.7	49511.	1.21	10.60	0.00
3	202.8	185.0	272.7	270.6	232.8	49496.	1.50	13.00	0.00
4	191.0	176.3	262.4	262.9	223.1	49490.	1.80	14.50	0.00
5	186.0	169.3	254.6	251.6	215.4	49493.	2.00	15.20	0.00
6	187.1	175.4	256.1	256.3	218.7	49489.	2.24	15.80	0.00
7	183.3	170.2	258.3	257.0	217.2	49486.	2.80	16.20	0.00
8	185.2	170.0	249.5	248.2	213.2	49470.	3.50	16.40	0.00

FROSSLING NO.:

#	FRA	FRB	FRC	FRD	FR	RE	L/D	FREQ.	AMP
1	0.738	0.678	0.781	0.790	0.747	49530.	0.00	22.80	0.00
2	0.968	0.879	1.214	1.212	1.068	49511.	1.21	10.60	0.00
3	0.911	0.832	1.226	1.216	1.046	49496.	1.50	13.00	0.00
4	0.859	0.792	1.179	1.182	1.003	49490.	1.80	14.50	0.00
5	0.836	0.761	1.145	1.131	0.968	49493.	2.00	15.20	0.00
6	0.841	0.789	1.151	1.152	0.983	49489.	2.24	15.80	0.00
7	0.824	0.765	1.161	1.155	0.976	49486.	2.80	16.20	0.00
8	0.833	0.764	1.122	1.116	0.959	49470.	3.50	16.40	0.00

9485 CP001
 9486 A POSITION=-, -180
 9487 TEMP CONFIG, 1
 9488 COMMENTS STEADY 3CYL VARY PITCH RE=50K FREQ IS SHEDDING
 9489 ATMOSPHERIC PRESSURE=, 27.5
 POINT # 1
 TA=37.64 TB=37.61 TC=37.67 TD=37.66
 TAV=37.65 T FREE STREAM =27.60 T AMBIENT =26.30 TI=42.20
 VOLTAGES: VA=36.82 VB=35.37 VC=38.01 VD=38.24
 CORR. POWER: PA=15.35 PB=14.06 PC=16.31 PD=16.47 P= 63.41
 PITOT=0.210IN. L/D=0.00 FREQ= 22.8HZ O-P AMPLITUDE= 0.0% VEL= 9.83M/S

POINT # 2
 TA=37.59 TB=37.55 TC=37.56 TD=37.42
 TAV=37.53 T FREE STREAM =28.20 T AMBIENT =27.00 TI=43.90
 VOLTAGES: VA=40.67 VB=38.82 VC=45.50 VD=45.17
 CORR. POWER: PA=18.84 PB=17.03 PC=23.56 PD=23.18 P= 83.62
 PITOT=0.210IN. L/D=1.21 FREQ= 10.6HZ O-P AMPLITUDE= 0.0% VEL= 9.84M/S

POINT # 3
 TA=37.40 TB=37.44 TC=37.52 TD=37.35
 TAV=37.43 T FREE STREAM =28.70 T AMBIENT =27.70 TI=43.40
 VOLTAGES: VA=38.01 VB=36.53 VC=44.39 VD=43.82
 CORR. POWER: PA=16.44 PB=15.07 PC=22.43 PD=21.82 P= 76.70
 PITOT=0.210IN. L/D=1.50 FREQ= 13.0HZ O-P AMPLITUDE= 0.0% VEL= 9.85M/S

POINT # 4
 TA=37.43 TB=37.45 TC=37.30 TD=37.35
 TAV=37.38 T FREE STREAM =28.90 T AMBIENT =27.80 TI=43.00
 VOLTAGES: VA=36.55 VB=35.30 VC=42.50 VD=42.71
 CORR. POWER: PA=15.18 PB=14.05 PC=20.55 PD=20.71 P= 71.43
 PITOT=0.210IN. L/D=1.80 FREQ= 14.5HZ O-P AMPLITUDE= 0.0% VEL= 9.85M/S

POINT # 5
 TA=37.35 TB=37.44 TC=37.30 TD=37.35
 TAV=37.36 T FREE STREAM =28.90 T AMBIENT =28.00 TI=42.80
 VOLTAGES: VA=35.91 VB=34.58 VC=41.87 VD=41.79
 CORR. POWER: PA=14.65 PB=13.48 PC=19.94 PD=19.82 P= 68.82
 PITOT=0.210IN. L/D=2.00 FREQ= 15.2HZ O-P AMPLITUDE= 0.0% VEL= 9.85M/S

POINT # 6
 TA=37.36 TB=37.40 TC=37.29 TD=37.35
 TAV=37.35 T FREE STREAM =29.00 T AMBIENT =28.20 TI=42.80
 VOLTAGES: VA=35.83 VB=34.90 VC=41.71 VD=41.92
 CORR. POWER: PA=14.59 PB=13.74 PC=19.79 PD=19.95 P= 68.98
 PITOT=0.210IN. L/D=2.24 FREQ= 15.8HZ O-P AMPLITUDE= 0.0% VEL= 9.85M/S

POINT # 7
 TA=37.41 TB=37.39 TC=37.26 TD=37.25
 TAV=37.33 T FREE STREAM =29.10 T AMBIENT =28.20 TI=42.70
 VOLTAGES: VA=35.37 VB=34.16 VC=41.57 VD=41.48
 CORR. POWER: PA=14.21 PB=13.15 PC=19.66 PD=19.53 P= 67.46
 PITOT=0.210IN. L/D=2.80 FREQ= 16.2HZ O-P AMPLITUDE= 0.0% VEL= 9.86M/S

POINT # 8
 TA=37.44 TB=37.45 TC=37.24 TD=37.31
 TAV=37.36 T FREE STREAM =29.30 T AMBIENT =28.40 TI=42.40
 VOLTAGES: VA=35.18 VB=33.86 VC=40.31 VD=40.44
 CORR. POWER: PA=14.06 PB=12.92 PC=18.47 PD=18.55 P= 64.90
 PITOT=0.210IN. L/D=3.50 FREQ= 16.4HZ O-P AMPLITUDE= 0.0% VEL= 9.86M/S

PERPENDICULAR ARRANGEMENTS OF CYLINDERS

REDUCED DATA FOR: CX002

#	NUA	NUB	NUC	MUD	NU	RE	L/D	FREQ.	AMP
1	196.8	211.9	220.6	188.1	204.4	48785.	1.25	0.00	0.00
2	196.5	211.8	222.9	189.6	205.2	48798.	1.50	0.00	0.00
3	205.5	209.9	218.6	199.2	208.3	48833.	2.00	0.00	0.00
4	195.1	202.8	211.6	189.5	199.7	48822.	2.50	0.00	0.00
5	247.3	240.8	248.6	241.3	244.5	48828.	3.00	0.00	0.00
6	257.4	259.4	271.4	247.1	258.8	48829.	3.50	0.00	0.00
7	237.7	273.4	285.5	229.0	256.4	48820.	5.00	0.00	0.00

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	216.270	192.439	204.354	48785.	1.25	.0000	0.00
2	217.332	193.059	205.196	48798.	1.50	.0000	0.00
3	214.249	202.389	208.319	48833.	2.00	.0000	0.00
4	207.187	192.282	199.735	48822.	2.50	.0000	0.00
5	244.666	244.294	244.480	48828.	3.00	.0000	0.00
6	265.391	252.269	258.830	48829.	3.50	.0000	0.00
7	279.475	233.353	256.414	48820.	5.00	.0000	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.9792	0.8713	0.9252	48785.	1.25	.0000	0.00
2	0.9838	0.8740	0.9289	48798.	1.50	.0000	0.00
3	0.9695	0.9159	0.9427	48833.	2.00	.0000	0.00
4	0.9377	0.8702	0.9040	48822.	2.50	.0000	0.00
5	1.1072	1.1055	1.1064	48828.	3.00	.0000	0.00
6	1.2010	1.1416	1.1713	48829.	3.50	.0000	0.00
7	1.2649	1.0561	1.1605	48820.	5.00	.0000	0.00

9485 CX002
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS THREE CYL IN FRONT PERPINDICULAR RE=50K AR2=2.76
 9489 ATMOSPHERIC PRESSURE=, 27.82
 POINT # 1
 TA=37.05 TB=37.07 TC=37.04 TD=36.91
 TAV=37.02 T FREE STREAM =26.20 T AMBIENT =26.60 TI=42.10
 VOLTAGES: VA=41.69 VB=43.42 VC=44.18 VD=40.66
 CORR. POWER: PA=19.82 PB=21.39 PC=22.19 PD=18.70 P= 83.13
 PITOT=0.200IN. L/D=1.25 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 2
 TA=36.99 TB=37.01 TC=36.99 TD=36.90
 TAV=36.97 T FREE STREAM =26.10 T AMBIENT =28.00 TI=42.10
 VOLTAGES: VA=42.99 VB=43.45 VC=44.46 VD=40.93
 CORR. POWER: PA=19.86 PB=21.44 PC=22.52 PD=19.00 P= 83.68
 PITOT=0.200IN. L/D=1.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 3
 TA=36.91 TB=36.85 TC=36.84 TD=36.79
 TAV=36.85 T FREE STREAM =25.80 T AMBIENT =29.50 TI=43.00
 VOLTAGES: VA=42.99 VB=43.45 VC=44.27 VD=42.24
 CORR. POWER: PA=21.18 PB=21.51 PC=22.37 PD=20.30 P= 86.03
 PITOT=0.200IN. L/D=2.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.51M/S

POINT # 4
 TA=36.91 TB=36.81 TC=36.84 TD=36.80
 TAV=36.84 T FREE STREAM =26.00 T AMBIENT =29.70 TI=42.80
 VOLTAGES: VA=41.52 VB=42.26 VC=43.17 VD=40.86
 CORR. POWER: PA=19.75 PB=20.34 PC=21.27 PD=18.99 P= 81.00
 PITOT=0.200IN. L/D=2.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.51M/S

POINT # 5
 TA=36.88 TB=36.74 TC=36.75 TD=36.65
 TAV=36.75 T FREE STREAM =26.10 T AMBIENT =30.20 TI=43.80
 VOLTAGES: VA=46.37 VB=45.61 VC=46.33 VD=45.49
 CORR. POWER: PA=24.72 PB=23.76 PC=24.56 PD=23.62 P= 97.14
 PITOT=0.200IN. L/D=3.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 6
 TA=36.81 TB=36.55 TC=36.67 TD=36.64
 TAV=36.67 T FREE STREAM =26.30 T AMBIENT =31.20 TI=44.00
 VOLTAGES: VA=46.70 VB=46.43 VC=47.74 VD=45.54
 CORR. POWER: PA=25.11 PB=24.67 PC=26.12 PD=23.70 P= 99.94
 PITOT=0.200IN. L/D=3.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 7
 TA=36.80 TB=36.52 TC=36.63 TD=36.65
 TAV=36.65 T FREE STREAM =26.50 T AMBIENT =30.90 TI=43.70
 VOLTAGES: VA=44.46 VB=47.15 VC=48.38 VD=43.47
 CORR. POWER: PA=22.73 PB=25.44 PC=26.83 PD=21.57 P= 96.95
 PITOT=0.200IN. L/D=5.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

REDUCED DATA FOR: CX007

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	198.4	213.3	224.3	193.7	207.4	48880.	1.50	0.00	0.00
2	192.4	203.3	217.3	186.8	199.9	48878.	1.50	2.10	26.20
3	204.3	211.9	225.0	197.8	209.7	48885.	1.50	7.00	16.80
4	211.5	211.3	225.9	206.7	213.8	48889.	1.50	13.00	13.80
5	226.3	214.3	225.8	220.0	221.6	48900.	1.50	18.10	12.40
6	213.0	211.4	227.2	208.8	215.1	48888.	1.50	23.00	6.70

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	218.815	196.060	207.438	48880.	1.50	.0000	0.00
2	210.284	189.577	199.931	48878.	1.50	.0196	26.20
3	218.422	201.050	209.736	48885.	1.50	.0655	16.80
4	218.560	209.089	213.825	48889.	1.50	.1216	13.80
5	220.064	223.158	221.611	48900.	1.50	.1693	12.40
6	219.286	210.876	215.081	48888.	1.50	.2151	6.70

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.9897	0.8868	0.9383	48880.	1.50	.0000	0.00
2	0.9512	0.8575	0.9043	48878.	1.50	.0196	26.20
3	0.9879	0.9093	0.9486	48885.	1.50	.0655	16.80
4	0.9885	0.9456	0.9671	48889.	1.50	.1216	13.80
5	0.9952	1.0092	1.0022	48900.	1.50	.1693	12.40
6	0.9918	0.9537	0.9727	48888.	1.50	.2151	6.70

NUF/NUS FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48880.	1.50	.0000	0.00
2	0.9608	0.9669	0.9638	48878.	1.50	.0196	26.20
3	0.9981	1.0254	1.0111	48885.	1.50	.0655	16.80
4	0.9986	1.0665	1.0308	48889.	1.50	.1216	13.80
5	1.0057	1.1382	1.0683	48900.	1.50	.1693	12.40
6	1.0019	1.0756	1.0368	48888.	1.50	.2151	6.70

(NUF/NUS-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.1496	-.1263	-.1381	48878.	1.50	.0196
3	-.0114	0.1512	0.0660	48885.	1.50	.0655
4	-.0100	0.4816	0.2231	48889.	1.50	.1216
5	0.0458	1.1144	0.5510	48900.	1.50	.1693
6	0.0281	1.1283	0.5500	48888.	1.50	.2151

9485 CX007
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 3 CYL AR2=2.78 AR1=1.5 RE=50K PITOT FRONT CORR
 9489 ATMOSPHERIC PRESSURE=, 27.95
 POINT # 1
 TA=36.86 TB=36.92 TC=36.88 TD=36.80
 TAV=36.87 T FREE STREAM =26.90 T AMBIENT =26.60 TI=42.00
 VOLTAGES: VA=40.15 VB=41.86 VC=42.77 VD=39.69
 CORR. POWER: PA=18.36 PB=19.87 PC=20.78 PD=17.81 P= 77.85
 PITOT=0.200IN. L/D=1.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.51M/S

POINT # 2
 TA=37.01 TB=37.02 TC=37.01 TD=36.96
 TAV=37.00 T FREE STREAM =26.60 T AMBIENT =26.10 TI=42.20
 VOLTAGES: VA=40.43 VB=41.69 VC=43.02 VD=39.89
 CORR. POWER: PA=18.60 PB=19.68 PC=21.01 PD=17.97 P= 78.37
 PITOT=0.200IN. L/D=1.50 FREQ= 2.1HZ 0-P AMPLITUDE= 26.2% VEL= 9.50M/S

POINT # 3
 TA=36.90 TB=36.95 TC=37.00 TD=36.81
 TAV=36.92 T FREE STREAM =26.70 T AMBIENT =26.40 TI=42.60
 VOLTAGES: VA=41.21 VB=42.18 VC=43.52 VD=40.52
 CORR. POWER: PA=19.36 PB=20.17 PC=21.52 PD=18.57 P= 80.66
 PITOT=0.200IN. L/D=1.50 FREQ= 7.0HZ 0-P AMPLITUDE= 16.8% VEL= 9.50M/S

POINT # 4
 TA=36.77 TB=36.91 TC=36.97 TD=36.70
 TAV=36.84 T FREE STREAM =26.80 T AMBIENT =26.80 TI=42.50
 VOLTAGES: VA=41.44 VB=41.83 VC=43.33 VD=40.96
 CORR. POWER: PA=19.59 PB=19.84 PC=21.34 PD=19.00 P= 80.76
 PITOT=0.200IN. L/D=1.50 FREQ= 13.0HZ 0-P AMPLITUDE= 13.8% VEL= 9.50M/S

POINT # 5
 TA=36.67 TB=36.90 TC=36.89 TD=36.60
 TAV=36.77 T FREE STREAM =26.80 T AMBIENT =26.70 TI=42.80
 VOLTAGES: VA=42.63 VB=42.10 VC=43.14 VD=42.02
 CORR. POWER: PA=20.76 PB=20.10 PC=21.15 PD=20.02 P= 83.00
 PITOT=0.200IN. L/D=1.50 FREQ= 18.1HZ 0-P AMPLITUDE= 12.4% VEL= 9.50M/S

POINT # 6
 TA=36.70 TB=36.85 TC=36.89 TD=36.63
 TAV=36.77 T FREE STREAM =27.00 T AMBIENT =27.00 TI=41.80
 VOLTAGES: VA=41.01 VB=41.30 VC=42.84 VD=40.59
 CORR. POWER: PA=19.19 PB=19.34 PC=20.87 PD=18.67 P= 79.02
 PITOT=0.200IN. L/D=1.50 FREQ= 23.0HZ 0-P AMPLITUDE= 6.7% VEL= 9.51M/S

REDUCED DATA FOR: CX003

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	195.4	205.6	213.0	191.1	201.3	48829.	2.00	0.00	0.00
2	194.3	201.0	211.2	188.5	198.8	48798.	2.00	1.90	26.20
3	207.3	208.4	218.1	199.9	208.4	48811.	2.00	7.00	16.80
4	216.2	207.7	218.8	207.5	212.5	48822.	2.00	13.00	13.80
5	232.0	214.1	224.4	222.4	223.2	48812.	2.00	18.00	12.40
6	194.7	205.2	211.9	192.0	201.0	48791.	2.00	0.00	0.00
7	220.4	210.7	220.4	213.2	216.2	48789.	2.00	23.00	6.70

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	209.296	193.225	201.261	48829.	2.00	.0000	0.00
2	206.108	191.396	198.752	48798.	2.00	.0177	26.20
3	213.272	203.619	208.445	48811.	2.00	.0653	16.80
4	213.261	211.817	212.539	48822.	2.00	.1214	13.80
5	219.292	227.177	223.234	48812.	2.00	.1680	12.40
6	208.578	193.350	200.964	48791.	2.00	.0000	0.00
7	215.551	216.768	216.159	48789.	2.00	.2146	6.70

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.9472	0.8744	0.9108	48829.	2.00	.0000	0.00
2	0.9330	0.8664	0.8997	48798.	2.00	.0177	26.20
3	0.9653	0.9216	0.9435	48811.	2.00	.0653	16.80
4	0.9652	0.9586	0.9619	48822.	2.00	.1214	13.80
5	0.9926	1.0283	1.0104	48812.	2.00	.1680	12.40
6	0.9443	0.8753	0.9098	48791.	2.00	.0000	0.00
7	0.9759	0.9814	0.9786	48789.	2.00	.2146	6.70

NUF/NUSE FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48829.	2.00	.0000	0.00
2	0.9846	0.9905	0.9875	48798.	2.00	.0177	26.20
3	1.0189	1.0537	1.0357	48811.	2.00	.0653	16.80
4	1.0188	1.0961	1.0560	48822.	2.00	.1214	13.80
5	1.0477	1.1756	1.1092	48812.	2.00	.1680	12.40
6	0.9966	1.0007	0.9985	48791.	2.00	.0000	0.00
7	1.0298	1.1218	1.0740	48789.	2.00	.2146	6.70

(NUF/NUSE-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0586	-.0363	-.0476	48798.	2.00	.0177
3	0.1125	0.3197	0.2125	48811.	2.00	.0653
4	0.1362	0.6964	0.4061	48822.	2.00	.1214
5	0.3843	1.4160	0.8805	48812.	2.00	.1680
7	0.4447	1.8175	1.1048	48789.	2.00	.2146

9485 CX003
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 3 CYL AR2=2.78 RE=50K PT FRONT CORREECTED
 9489 ATMOSPHERIC PRESSURE=, 27.85
 POINT # 1
 TA=36.64 TB=36.71 TC=36.61 TD=36.63
 TAV=36.65 T FREE STREAM =26.80 T AMBIENT =26.40 TI=42.00
 VOLTAGES: VA=39.59 VB=40.87 VC=41.35 VD=39.27
 CORR. POWER: PA=17.85 PB=18.92 PC=19.41 PD=17.43 P= 74.64
 PITOT=0.200IN. L/D=2.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 2
 TA=36.69 TB=36.89 TC=36.77 TD=36.77
 TAV=36.78 T FREE STREAM =27.00 T AMBIENT =26.60 TI=41.90
 VOLTAGES: VA=40.64 VB=41.05 VC=41.11 VD=38.92
 CORR. POWER: PA=17.48 PB=18.46 PC=19.18 PD=17.12 P= 73.27
 PITOT=0.200IN. L/D=2.00 FREQ= 1.9HZ 0-P AMPLITUDE= 26.2% VEL= 9.52M/S

POINT # 3
 TA=36.67 TB=36.76 TC=36.80 TD=36.69
 TAV=36.73 T FREE STREAM =26.90 T AMBIENT =26.40 TI=42.40
 VOLTAGES: VA=40.64 VB=41.05 VC=42.03 VD=40.08
 CORR. POWER: PA=18.82 PB=19.09 PC=20.06 PD=18.17 P= 77.17
 PITOT=0.200IN. L/D=2.00 FREQ= 7.0HZ 0-P AMPLITUDE= 16.8% VEL= 9.52M/S

POINT # 4
 TA=36.65 TB=36.70 TC=36.72 TD=36.55
 TAV=36.66 T FREE STREAM =26.90 T AMBIENT =26.60 TI=42.30
 VOLTAGES: VA=41.42 VB=40.84 VC=41.93 VD=40.52
 CORR. POWER: PA=19.57 PB=18.90 PC=19.97 PD=18.59 P= 78.02
 PITOT=0.200IN. L/D=2.00 FREQ= 13.0HZ 0-P AMPLITUDE= 13.8% VEL= 9.52M/S

POINT # 5
 TA=36.63 TB=36.67 TC=36.71 TD=36.55
 TAV=36.64 T FREE STREAM =27.10 T AMBIENT =26.70 TI=42.60
 VOLTAGES: VA=42.39 VB=40.99 VC=42.00 VD=41.50
 CORR. POWER: PA=20.52 PB=19.05 PC=20.04 PD=19.52 P= 80.09
 PITOT=0.200IN. L/D=2.00 FREQ= 18.0HZ 0-P AMPLITUDE= 12.4% VEL= 9.53M/S

POINT # 6
 TA=36.88 TB=36.80 TC=36.70 TD=36.79
 TAV=36.79 T FREE STREAM =27.10 T AMBIENT =26.70 TI=42.00
 VOLTAGES: VA=39.41 VB=40.41 VC=40.81 VD=39.10
 CORR. POWER: PA=17.68 PB=18.50 PC=18.90 PD=17.28 P= 73.38
 PITOT=0.200IN. L/D=2.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.53M/S

POINT # 7
 TA=36.76 TB=36.77 TC=36.70 TD=36.66
 TAV=36.72 T FREE STREAM =27.30 T AMBIENT =26.80 TI=42.00
 VOLTAGES: VA=41.21 VB=40.46 VC=41.18 VD=40.47
 CORR. POWER: PA=19.38 PB=18.55 PC=19.26 PD=18.55 P= 76.70
 PITOT=0.200IN. L/D=2.00 FREQ= 23.0HZ 0-P AMPLITUDE= 6.7% VEL= 9.53M/S

REDUCED DATA FOR: CX005

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	196.8	204.8	212.5	192.9	201.8	48663.	2.50	0.00	0.00
2	196.1	197.0	205.6	187.6	196.6	48673.	2.50	1.90	26.20
3	205.4	201.4	210.3	197.7	203.7	48668.	2.50	7.00	16.80
4	217.6	206.6	213.0	211.9	212.2	48658.	2.50	13.00	13.80
5	232.2	210.6	217.6	222.2	220.7	48654.	2.50	18.00	12.40
6	222.4	211.0	216.9	213.9	216.0	48644.	2.50	22.80	6.70

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	208.644	194.868	201.756	48663.	2.50	.0000	0.00
2	201.283	191.847	196.565	48673.	2.50	.0177	26.20
3	205.847	201.519	203.683	48668.	2.50	.0651	16.80
4	209.776	214.722	212.249	48658.	2.50	.1209	13.80
5	214.142	227.191	220.666	48654.	2.50	.1674	12.40
6	213.929	218.167	216.048	48644.	2.50	.2120	6.70

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	0.9458	0.8834	0.9146	48663.	2.50	.0000	0.00
2	0.9124	0.8696	0.8910	48673.	2.50	.0177	26.20
3	0.9331	0.9135	0.9233	48668.	2.50	.0651	16.80
4	0.9510	0.9734	0.9622	48658.	2.50	.1209	13.80
5	0.9708	1.0300	1.0004	48654.	2.50	.1674	12.40
6	0.9700	0.9892	0.9796	48644.	2.50	.2120	6.70

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48663.	2.50	.0000	0.00
2	0.9647	0.9844	0.9743	48673.	2.50	.0177	26.20
3	0.9865	1.0340	1.0096	48668.	2.50	.0651	16.80
4	1.0055	1.1019	1.0520	48658.	2.50	.1209	13.80
5	1.0264	1.1657	1.0937	48654.	2.50	.1674	12.40
6	1.0254	1.1195	1.0708	48644.	2.50	.2120	6.70

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.1349	-.0596	-.0982	48673.	2.50	.0177
3	-.0801	0.2026	0.0569	48668.	2.50	.0651
4	0.0398	0.7381	0.3769	48658.	2.50	.1209
5	0.2128	1.3366	0.7559	48654.	2.50	.1674
6	0.3794	1.7829	1.0573	48644.	2.50	.2120

9485 CX005
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS RE=50K AR2=2.78 3CYL AR1=2.5
 9489 ATMOSPHERIC PRESSURE=, 27.72
 POINT # 1
 TA=36.80 TB=36.69 TC=36.69 TD=36.71
 TAV=36.72 T FREE STREAM =27.50 T AMBIENT =27.00 TI=41.90
 VOLTAGES: VA=38.66 VB=39.30 VC=39.99 VD=38.23
 CORR. POWER: PA=17.02 PB=17.49 PC=18.15 PD=16.52 P= 70.15
 PITOT=0.200IN. L/D=2.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.55M/S

POINT # 2
 TA=36.86 TB=36.70 TC=36.77 TD=36.79
 TAV=36.78 T FREE STREAM =27.20 T AMBIENT =26.70 TI=41.90
 VOLTAGES: VA=39.33 VB=39.20 VC=40.16 VD=38.46
 CORR. POWER: PA=17.61 PB=17.39 PC=18.29 PD=16.71 P= 71.03
 PITOT=0.200IN. L/D=2.50 FREQ= 1.9HZ 0-P AMPLITUDE= 26.2% VEL= 9.55M/S

POINT # 3
 TA=36.89 TB=36.61 TC=36.71 TD=36.71
 TAV=36.73 T FREE STREAM =27.40 T AMBIENT =27.10 TI=42.00
 VOLTAGES: VA=39.86 VB=39.02 VC=40.05 VD=38.89
 CORR. POWER: PA=18.11 PB=17.24 PC=18.20 PD=17.11 P= 71.63
 PITOT=0.200IN. L/D=2.50 FREQ= 7.0HZ 0-P AMPLITUDE= 16.8% VEL= 9.55M/S

POINT # 4
 TA=36.85 TB=36.75 TC=36.69 TD=36.60
 TAV=36.72 T FREE STREAM =27.60 T AMBIENT =27.40 TI=42.00
 VOLTAGES: VA=40.49 VB=39.38 VC=39.81 VD=39.56
 CORR. POWER: PA=18.71 PB=17.57 PC=17.99 PD=17.73 P= 72.92
 PITOT=0.200IN. L/D=2.50 FREQ= 13.0HZ 0-P AMPLITUDE= 13.8% VEL= 9.56M/S

POINT # 5
 TA=36.81 TB=36.65 TC=36.76 TD=36.60
 TAV=36.71 T FREE STREAM =27.70 T AMBIENT =27.30 TI=42.40
 VOLTAGES: VA=41.50 VB=39.33 VC=40.19 VD=40.28
 CORR. POWER: PA=19.67 PB=17.53 PC=18.34 PD=18.39 P= 74.84
 PITOT=0.200IN. L/D=2.50 FREQ= 18.0HZ 0-P AMPLITUDE= 12.4% VEL= 9.56M/S

POINT # 6
 TA=36.77 TB=36.61 TC=36.77 TD=36.60
 TAV=36.69 T FREE STREAM =27.90 T AMBIENT =27.50 TI=41.70
 VOLTAGES: VA=40.11 VB=38.84 VC=39.71 VD=39.09
 CORR. POWER: PA=18.36 PB=17.09 PC=17.90 PD=17.31 P= 71.57
 PITOT=0.200IN. L/D=2.50 FREQ= 22.8HZ 0-P AMPLITUDE= 6.7% VEL= 9.56M/S

REDUCED DATA FOR: CX004

#	NUA	NUB	NUC	MUD	NU	RE	L/D	FREQ.	AMP
1	241.8	234.4	248.0	236.7	240.2	48841.	3.00	0.00	0.00
2	237.5	229.5	241.7	231.2	235.0	48813.	3.00	1.90	26.20
3	247.2	241.4	249.3	241.8	244.9	48819.	3.00	7.00	16.80
4	260.1	245.6	258.2	254.3	254.6	48811.	3.00	13.10	13.80
5	260.0	248.0	259.8	255.1	255.7	48815.	3.00	18.10	12.40
6	254.4	244.0	256.5	251.7	251.6	48853.	3.00	23.00	6.70

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	241.209	239.218	240.213	48841.	3.00	.0000	0.00
2	235.613	234.349	234.981	48813.	3.00	.0177	26.20
3	245.328	244.500	244.914	48819.	3.00	.0653	16.80
4	251.917	257.201	254.559	48811.	3.00	.1222	13.80
5	253.871	257.535	255.703	48815.	3.00	.1689	12.40
6	250.245	253.021	251.633	48853.	3.00	.2149	6.70

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.0914	1.0824	1.0869	48841.	3.00	.0000	0.00
2	1.0664	1.0607	1.0636	48813.	3.00	.0177	26.20
3	1.1103	1.1066	1.1085	48819.	3.00	.0653	16.80
4	1.1402	1.1642	1.1522	48811.	3.00	.1222	13.80
5	1.1490	1.1656	1.1573	48815.	3.00	.1689	12.40
6	1.1322	1.1448	1.1385	48853.	3.00	.2149	6.70

NUF/NUS FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48841.	3.00	.0000	0.00
2	0.9769	0.9796	0.9782	48813.	3.00	.0177	26.20
3	1.0174	1.0221	1.0196	48819.	3.00	.0653	16.80
4	1.0445	1.0752	1.0597	48811.	3.00	.1222	13.80
5	1.0526	1.0766	1.0645	48815.	3.00	.1689	12.40
6	1.0376	1.0578	1.0475	48853.	3.00	.2149	6.70

(NUF/NUS-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.0883	-.0778	-.0831	48813.	3.00	.0177
3	0.1037	0.1314	0.1165	48819.	3.00	.0653
4	0.3224	0.5447	0.4327	48811.	3.00	.1222
5	0.4245	0.6176	0.5200	48815.	3.00	.1689
6	0.5606	0.8621	0.7095	48853.	3.00	.2149

9485 CX004
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS RE=50K 3CYL AR2=2.78 AR1=3 PT FRONT CORR VARY F
 9489 ATMOSPHERIC PRESSURE=, 27.88
 POINT # 1
 TA=36.67 TB=36.51 TC=36.56 TD=36.57
 TAV=36.58 T FREE STREAM =27.20 T AMBIENT =26.80 TI=43.00
 VOLTAGES: VA=43.15 VB=42.26 VC=43.54 VD=42.62
 CORR. POWER: PA=21.28 PB=20.28 PC=21.57 PD=20.61 P= 84.65
 PITOT=0.200IN. L/D=3.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 2
 TA=36.84 TB=36.75 TC=36.74 TD=36.79
 TAV=36.78 T FREE STREAM =27.20 T AMBIENT =26.60 TI=43.10
 VOLTAGES: VA=43.15 VB=42.37 VC=43.40 VD=42.62
 CORR. POWER: PA=21.27 PB=20.37 PC=21.42 PD=20.60 P= 84.62
 PITOT=0.200IN. L/D=3.00 FREQ= 1.9HZ 0-P AMPLITUDE= 26.2% VEL= 9.52M/S

POINT # 3
 TA=36.74 TB=36.74 TC=36.65 TD=36.66
 TAV=36.70 T FREE STREAM =27.30 T AMBIENT =26.80 TI=43.20
 VOLTAGES: VA=43.55 VB=43.17 VC=43.63 VD=43.05
 CORR. POWER: PA=21.68 PB=21.17 PC=21.66 PD=21.03 P= 86.46
 PITOT=0.200IN. L/D=3.00 FREQ= 7.0HZ 0-P AMPLITUDE= 16.8% VEL= 9.52M/S

POINT # 4
 TA=36.71 TB=36.72 TC=36.65 TD=36.59
 TAV=36.67 T FREE STREAM =27.50 T AMBIENT =27.10 TI=43.30
 VOLTAGES: VA=44.12 VB=43.05 VC=43.92 VD=43.48
 CORR. POWER: PA=22.27 PB=21.06 PC=21.96 PD=21.48 P= 87.63
 PITOT=0.200IN. L/D=3.00 FREQ= 13.1HZ 0-P AMPLITUDE= 13.8% VEL= 9.53M/S

POINT # 5
 TA=36.69 TB=36.65 TC=36.62 TD=36.59
 TAV=36.64 T FREE STREAM =27.50 T AMBIENT =27.00 TI=43.40
 VOLTAGES: VA=44.05 VB=43.08 VC=43.99 VD=43.55
 CORR. POWER: PA=22.20 PB=21.09 PC=22.03 PD=21.54 P= 87.73
 PITOT=0.200IN. L/D=3.00 FREQ= 18.1HZ 0-P AMPLITUDE= 12.4% VEL= 9.53M/S

POINT # 6
 TA=36.71 TB=36.71 TC=36.64 TD=36.59
 TAV=36.66 T FREE STREAM =26.80 T AMBIENT =26.80 TI=43.70
 VOLTAGES: VA=45.23 VB=44.45 VC=45.35 VD=44.86
 CORR. POWER: PA=23.41 PB=22.46 PC=23.43 PD=22.87 P= 93.05
 PITOT=0.200IN. L/D=3.00 FREQ= 23.0HZ 0-P AMPLITUDE= 6.7% VEL= 9.52M/S

REDUCED DATA FOR: CX006

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	228.3	272.0	289.0	226.7	254.0	48765.	5.00	0.00	0.00
2	227.7	266.4	279.4	221.5	248.7	48752.	5.00	1.90	26.20
3	231.9	270.8	287.1	221.9	252.9	48748.	5.00	7.00	16.80
4	234.1	272.4	285.7	225.7	254.4	48760.	5.00	13.00	13.80
5	235.4	272.6	284.7	227.4	255.0	48754.	5.00	18.00	12.40
6	231.0	272.6	283.6	223.6	252.7	48776.	5.00	0.00	0.00
7	233.2	277.6	288.8	226.3	256.5	48777.	5.00	23.00	6.70

NUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	280.503	227.502	254.002	48765.	5.00	.0000	0.00
2	272.906	224.590	248.748	48752.	5.00	.0177	26.20
3	278.948	226.897	252.922	48748.	5.00	.0653	16.80
4	279.019	229.853	254.436	48760.	5.00	.1212	13.80
5	278.639	231.375	255.007	48754.	5.00	.1677	12.40
6	278.115	227.320	252.717	48776.	5.00	.0000	0.00
7	283.217	229.721	256.469	48777.	5.00	.2145	6.70

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.2702	1.0302	1.1502	48765.	5.00	.0000	0.00
2	1.2360	1.0172	1.1266	48752.	5.00	.0177	26.20
3	1.2634	1.0277	1.1455	48748.	5.00	.0653	16.80
4	1.2636	1.0409	1.1522	48760.	5.00	.1212	13.80
5	1.2619	1.0479	1.1549	48754.	5.00	.1677	12.40
6	1.2593	1.0293	1.1443	48776.	5.00	.0000	0.00
7	1.2824	1.0401	1.1613	48777.	5.00	.2145	6.70

NUF/NUB FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.	AMP
1	1.0000	1.0000	1.0000	48765.	5.00	.0000	0.00
2	0.9731	0.9872	0.9793	48752.	5.00	.0177	26.20
3	0.9945	0.9973	0.9957	48748.	5.00	.0653	16.80
4	0.9949	1.0103	1.0017	48760.	5.00	.1212	13.80
5	0.9936	1.0170	1.0040	48754.	5.00	.1677	12.40
6	0.9918	0.9992	0.9949	48776.	5.00	.0000	0.00
7	1.0100	1.0097	1.0097	48777.	5.00	.2145	6.70

(NUF/NUB-1)/AMP FOR FRONT AND BACK

#	FRONT	BACK	TOTAL	RE	L/D	RED FREQ.
2	-.1026	-.0490	-.0790	48752.	5.00	.0177
3	-.0328	-.0162	-.0253	48748.	5.00	.0653
4	-.0370	0.0745	0.0124	48760.	5.00	.1212
5	-.0515	0.1369	0.0319	48754.	5.00	.1677
7	0.1491	0.1450	0.1449	48777.	5.00	.2145

9485 CX006
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS RE=50K AR2=2.78 3 CYL AR1=5 PITOT FRONT CORR
 9489 ATMOSPHERIC PRESSURE=, 27.77
 POINT # 1
 TA=36.81 TB=36.59 TC=36.51 TD=36.66
 TAV=36.64 T FREE STREAM =26.70 T AMBIENT =26.40 TI=43.60
 VOLTAGES: VA=43.32 VB=46.84 VC=48.04 VD=43.00
 CORR. POWER: PA=21.43 PB=24.97 PC=26.32 PD=20.97 P= 94.62
 PITOT=0.200IN. L/D=5.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.53M/S

POINT # 2
 TA=36.82 TB=36.59 TC=36.61 TD=36.74
 TAV=36.69 T FREE STREAM =26.80 T AMBIENT =26.20 TI=43.50
 VOLTAGES: VA=43.09 VB=46.14 VC=47.26 VD=42.47
 CORR. POWER: PA=21.19 PB=24.21 PC=25.46 PD=20.44 P= 92.27
 PITOT=0.200IN. L/D=5.00 FREQ= 1.9HZ 0-P AMPLITUDE= 26.2% VEL= 9.54M/S

POINT # 3
 TA=36.80 TB=36.60 TC=36.65 TD=36.66
 TAV=36.68 T FREE STREAM =26.90 T AMBIENT =26.40 TI=43.50
 VOLTAGES: VA=43.21 VB=46.30 VC=47.75 VD=42.13
 CORR. POWER: PA=21.32 PB=24.39 PC=26.00 PD=20.12 P= 92.76
 PITOT=0.200IN. L/D=5.00 FREQ= 7.0HZ 0-P AMPLITUDE= 16.8% VEL= 9.54M/S

POINT # 4
 TA=36.65 TB=36.52 TC=36.46 TD=36.56
 TAV=36.55 T FREE STREAM =27.00 T AMBIENT =26.60 TI=43.40
 VOLTAGES: VA=42.85 VB=46.01 VC=46.92 VD=42.04
 CORR. POWER: PA=20.97 PB=24.09 PC=25.10 PD=20.04 P= 91.11
 PITOT=0.200IN. L/D=5.00 FREQ= 13.0HZ 0-P AMPLITUDE= 13.8% VEL= 9.54M/S

POINT # 5
 TA=36.64 TB=36.55 TC=36.45 TD=36.59
 TAV=36.56 T FREE STREAM =27.10 T AMBIENT =26.80 TI=43.30
 VOLTAGES: VA=42.72 VB=45.85 VC=46.56 VD=42.03
 CORR. POWER: PA=20.85 PB=23.93 PC=24.72 PD=20.03 P= 90.41
 PITOT=0.200IN. L/D=5.00 FREQ= 18.0HZ 0-P AMPLITUDE= 12.4% VEL= 9.54M/S

POINT # 6
 TA=36.82 TB=36.60 TC=36.60 TD=36.72
 TAV=36.69 T FREE STREAM =26.40 T AMBIENT =26.20 TI=43.90
 VOLTAGES: VA=44.23 VB=47.61 VC=48.52 VD=43.47
 CORR. POWER: PA=22.35 PB=25.80 PC=26.85 PD=21.43 P= 97.37
 PITOT=0.200IN. L/D=5.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.53M/S

POINT # 7
 TA=36.74 TB=36.65 TC=36.52 TD=36.66
 TAV=36.64 T FREE STREAM =26.50 T AMBIENT =26.50 TI=43.80
 VOLTAGES: VA=44.03 VB=47.92 VC=48.53 VD=43.37
 CORR. POWER: PA=22.16 PB=26.15 PC=26.87 PD=21.34 P= 97.42
 PITOT=0.200IN. L/D=5.00 FREQ= 23.0HZ 0-P AMPLITUDE= 6.7% VEL= 9.53M/S

REDUCED DATA FOR: cX001

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	162.9	213.2	217.5	150.7	186.1	48795.	1.50	0.00	0.00
2	153.0	199.5	205.9	146.2	176.1	48807.	2.00	0.00	0.00
3	154.6	193.0	200.3	144.7	173.2	48807.	2.20	0.00	0.00
4	148.3	191.1	201.6	143.0	171.0	48805.	2.50	0.00	0.00
5	179.1	198.8	208.9	168.6	188.9	48794.	3.00	0.00	0.00
6	202.2	209.0	218.7	191.6	205.4	48791.	3.50	0.00	0.00
7	208.9	215.6	222.5	203.3	212.6	48786.	5.00	0.00	0.00

FROSSLING NO.:

#	FRA	FRB	FRC	FRD	FR	RE	L/D	FREQ.	AMP
1	0.738	0.965	0.985	0.682	0.842	48795.	1.50	0.00	0.00
2	0.692	0.903	0.932	0.662	0.797	48807.	2.00	0.00	0.00
3	0.700	0.874	0.907	0.655	0.784	48807.	2.20	0.00	0.00
4	0.671	0.865	0.912	0.647	0.774	48805.	2.50	0.00	0.00
5	0.811	0.900	0.946	0.763	0.855	48794.	3.00	0.00	0.00
6	0.916	0.946	0.990	0.868	0.930	48791.	3.50	0.00	0.00
7	0.946	0.976	1.007	0.920	0.962	48786.	5.00	0.00	0.00

935 CX001
 936 A POSITION=,180
 937 TEMP CONFIG,1
 938 COMMENTS FRONT CYL PERPINDICULAR AR>=1.5 RE-50K
 939 ATMOSPHERIC PRESSURE=, 27.78
 POINT # 1
 TA=36.95 TB=36.72 TC=36.95 TD=36.85
 TAV=36.87 T FREE STREAM =25.80 T AMBIENT =26.00 TI=42.50
 VOLTAGES: VA=38.52 VB=43.64 VC=44.49 VD=37.04
 CORR. POWER: PA=16.85 PB=21.61 PC=22.49 PD=15.45 P= 77.51
 PITOT=0.200IN. L/D=1.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 2
 TA=36.91 TB=36.63 TC=36.81 TD=36.77
 TAV=36.78 T FREE STREAM =25.80 T AMBIENT =24.60 TI=42.10
 VOLTAGES: VA=37.33 VB=42.08 VC=43.08 VD=36.41
 CORR. POWER: PA=15.76 PB=20.03 PC=21.03 PD=14.88 P= 72.98
 PITOT=0.200IN. L/D=2.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 3
 TA=36.89 TB=36.64 TC=36.86 TD=36.72
 TAV=36.78 T FREE STREAM =25.80 T AMBIENT =24.80 TI=42.00
 VOLTAGES: VA=37.48 VB=41.42 VC=42.59 VD=36.14
 CORR. POWER: PA=15.90 PB=19.40 PC=20.55 PD=14.66 P= 71.77
 PITOT=0.200IN. L/D=2.20 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 4
 TA=36.86 TB=36.63 TC=36.81 TD=36.71
 TAV=36.75 T FREE STREAM =25.90 T AMBIENT =25.00 TI=41.70
 VOLTAGES: VA=36.52 VB=41.00 VC=42.43 VD=35.75
 CORR. POWER: PA=15.08 PB=19.00 PC=20.40 PD=14.34 P= 70.07
 PITOT=0.200IN. L/D=2.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 5
 TA=37.13 TB=36.72 TC=36.93 TD=36.89
 TAV=36.92 T FREE STREAM =25.70 T AMBIENT =25.00 TI=42.80
 VOLTAGES: VA=40.87 VB=42.38 VC=43.79 VD=39.40
 CORR. POWER: PA=18.98 PB=20.33 PC=21.75 PD=17.49 P= 79.78
 PITOT=0.200IN. L/D=3.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 6
 TA=37.10 TB=36.71 TC=36.94 TD=36.84
 TAV=36.90 T FREE STREAM =25.80 T AMBIENT =25.00 TI=43.20
 VOLTAGES: VA=43.14 VB=43.22 VC=44.61 VD=41.67
 CORR. POWER: PA=21.19 PB=21.16 PC=22.59 PD=19.62 P= 85.75
 PITOT=0.200IN. L/D=3.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

POINT # 7
 TA=37.10 TB=36.67 TC=36.91 TD=36.86
 TAV=36.89 T FREE STREAM =25.90 T AMBIENT =25.10 TI=43.40
 VOLTAGES: VA=43.64 VB=43.61 VC=44.74 VD=42.75
 CORR. POWER: PA=21.70 PB=21.55 PC=22.73 PD=20.67 P= 87.82
 PITOT=0.200IN. L/D=5.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.52M/S

REDUCED DATA FOR: CS006

#	NUA	NUB	NUC	NUD	NU	RE	L/D	FREQ.	AMP
1	170.3	238.7	266.6	167.7	210.8	48959.	1.25	0.00	0.00
2	170.2	253.2	271.0	166.2	215.1	48942.	1.50	0.00	0.00
3	183.0	254.5	269.5	180.1	221.8	48938.	2.00	0.00	0.00
4	179.5	255.8	265.2	177.8	219.6	48930.	3.00	0.00	0.00
5	179.9	242.9	256.1	178.0	214.3	48937.	3.50	0.00	0.00
6	213.3	236.7	246.1	205.0	225.3	48923.	4.76	0.00	0.00

MUSSELT NUMBER FOR FRONT AND BACK

#	NU FRONT	NU BACK	NU	RE	L/D	RED FREQ.	AMP
1	252.659	169.013	210.836	48959.	1.25	.0000	0.00
2	262.076	168.172	215.124	48942.	1.50	.0000	0.00
3	262.016	181.561	221.788	48938.	2.00	.0000	0.00
4	260.496	178.640	219.568	48930.	3.00	.0000	0.00
5	249.545	178.985	214.265	48937.	3.50	.0000	0.00
6	241.447	209.133	225.290	48923.	4.76	.0000	0.00

FROSSLING NUMBER FOR FRONT AND BACK

#	FR FRONT	FR BACK	FR	RE	L/D	RED FREQ.	AMP
1	1.1419	0.7638	0.9529	48959.	1.25	.0000	0.00
2	1.1846	0.7602	0.9724	48942.	1.50	.0000	0.00
3	1.1844	0.8207	1.0026	48938.	2.00	.0000	0.00
4	1.1776	0.8076	0.9926	48930.	3.00	.0000	0.00
5	1.1281	0.8091	0.9686	48937.	3.50	.0000	0.00
6	1.0916	0.9455	1.0186	48923.	4.76	.0000	0.00

9485 CS006
 9486 A POSITION=,180
 9487 TEMP CONFIG,1
 9488 COMMENTS 2 CYL RE=50K PITOT BACK UNCOR SET BEGIN TEST
 9489 ATMOSPHERIC PRESSURE=, 28.02
 POINT # 1
 TA=36.94 TB=36.86 TC=36.91 TD=36.74
 TAV=36.86 T FREE STREAM =26.60 T AMBIENT =26.20 TI=42.00
 VOLTAGES: VA=37.95 VB=44.75 VC=47.34 VD=37.42
 CORR. POWER: PA=16.35 PB=22.74 PC=25.53 PD=15.78 P= 81.47
 PITOT=0.200IN. L/D=1.25 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.49M/S

POINT # 2
 TA=36.85 TB=36.85 TC=36.91 TD=36.81
 TAV=36.86 T FREE STREAM =26.90 T AMBIENT =26.50 TI=42.10
 VOLTAGES: VA=37.22 VB=45.37 VC=47.03 VD=36.85
 CORR. POWER: PA=15.73 PB=23.40 PC=25.20 PD=15.30 P= 80.66
 PITOT=0.200IN. L/D=1.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.49M/S

POINT # 3
 TA=36.86 TB=36.86 TC=36.87 TD=36.77
 TAV=36.84 T FREE STREAM =27.00 T AMBIENT =26.70 TI=42.40
 VOLTAGES: VA=38.40 VB=45.29 VC=46.58 VD=38.06
 CORR. POWER: PA=16.77 PB=23.32 PC=24.72 PD=16.36 P= 82.16
 PITOT=0.200IN. L/D=2.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 4
 TA=36.82 TB=36.79 TC=36.76 TD=36.90
 TAV=36.82 T FREE STREAM =27.20 T AMBIENT =26.90 TI=42.70
 VOLTAGES: VA=37.58 VB=44.77 VC=45.48 VD=37.68
 CORR. POWER: PA=16.05 PB=22.79 PC=23.56 PD=16.03 P= 79.40
 PITOT=0.200IN. L/D=3.00 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 5
 TA=36.84 TB=36.75 TC=36.74 TD=36.75
 TAV=36.77 T FREE STREAM =27.20 T AMBIENT =26.90 TI=42.60
 VOLTAGES: VA=37.65 VB=43.56 VC=44.65 VD=37.41
 CORR. POWER: PA=16.11 PB=21.56 PC=22.70 PD=15.80 P= 77.14
 PITOT=0.200IN. L/D=3.50 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

POINT # 6
 TA=36.85 TB=36.76 TC=36.85 TD=36.84
 TAV=36.82 T FREE STREAM =27.30 T AMBIENT =26.90 TI=42.70
 VOLTAGES: VA=40.74 VB=42.82 VC=43.82 VD=40.07
 CORR. POWER: PA=18.93 PB=20.82 PC=21.85 PD=18.17 P= 80.73
 PITOT=0.200IN. L/D=4.76 FREQ= 0.0HZ 0-P AMPLITUDE= 0.0% VEL= 9.50M/S

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