NUMERICAL PREDICTION OF LAMINAR FLOW AND HEAT TRANSFER IN INTERNALLY FINNED TUBES

By

Ibrahim Mahmoud Rustum

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ABSTRACT

The objective of this investigation is to provide a detailed analysis of laminar fluid flow and heat transfer in internally finned tubes. Three mathematical models were formulated for this purpose. These models are shown to be capable of simulating the actual situation of pressure drop and heat transfer in such tubes. A summary of the analysis and results associated with these models is presented in the following :

1. Steady, laminar, forced convection heat transfer in the thermal entrance region of internally finned tubes was investigated numerically for the case of fully developed hydrodynamics using the (H1) and (T) thermal boundary conditions. The governing equations were solved numerically using the finite difference method. Results are presented for the smooth tube geometry and sixteen internally finned tube geometries including the local Nusselt number and thermal developing length corresponding to each boundary condition. Values of Nusselt number provide a reasonable approximation of the actual values near the tube entrance where free convection is insignificant. Moreover, the entrance length is expected to be shortened considerably if significant free convection exists in the fully developed region.

2. Steady, laminar fluid flow in the hydrodynamic entrance region of internally finned tubes was investigated numerically. The parabolized Navier-Stokes's equations were solved using a control-volume based finite difference method following the " SIMPLER " algorithm. Results are presented for the smooth tube geometry and sixteen geometries corresponding to various combinations of relative fin heights and number of fins. For each geometry, the results include the local and fully developed friction factors, local and limiting incremental pressure drop number, and estimates of the hydrodynamic entrance length. These results, as well as those of the previous model, indicate that internal finning influences the development of velocity, temper-

ature and pressure along the entrance region in a complicated way which could not have been predicted by extending the smooth tube results to internally finned tubes on a hydraulic diameter basis.

3. Steady, laminar, mixed convection in the fully developed region of horizontal internally finned tubes was investigated for the case of uniform heat input axially and uniform wall temperature circumferentially. The fluid flow and heat transfer characteristics were found to be dependent on a modified Grashof number, Prandtl number, relative fin height, and number of fins. Governing differential equations were solved numerically for the smooth tube geometry and for six internally finned tube geometries for $Pr = 7$ and modified Grashof number $= 0$ to 2×10^6. Computed results include the secondary flow components, axial velocity and temperature distributions, wall heat flux, friction factor, and average Nusselt number. Internal finning was found to retard the onset of significant free convective effects and to suppress the enhancement in friction factor and Nusselt number compared to smooth tubes.

Comparisons were made between segments of the present analysis and existing experimental data. Such comparisons were not possible before due to lack of equivalence between experimental and analytical conditions. The present comparisons showed good agreement, thus enhancing the confidence in both types of results and improving our understanding of the fluid flow and heat transfer phenomena in the augmenting tool of internally finned tubes.

The major findings from this investigation has been reported in four recent publications by Rustum and Soliman (1988a, 1988b, 1989, 1990).

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NOMENCLATURE

A	= surface area of fins and tube wall = $(\pi D_i + 2Ml)$, [m^2]
A_f	= surface area of fins = $2Ml$, [m^2]
c_p	= specific heat, [$J/kg \cdot K$]
D_i	= inside tube diameter = $2r_o$, [m]
f_{app}	= apparent friction factor = $D_i\left[(\bar{p}_o - \bar{p})/x\right]/(2\rho u_b^2)$
f_{fd}	= circumferential average friction factor in the fully developed region = $-(d\bar{p}/dx\Big\|_{fd})/(2\rho u_b^2/D_i)$
$f_{fd,0}$	= value of f_{fd} at $Gr^+ = 0$
f_x	= circumferential average friction factor at any axial location = $(-d\bar{p}/dx)/(2\rho u_b^2/D_i)$
g	= gravitational acceleration, $[m/s^2]$
Gr	= Grashof number $=\left(gD_i^3\beta(t_w - t_b)\right)/\nu^2$
Gr^+	= modified Grashof number = $(gD_i^3\beta Q')/(\nu^2\pi k)$
Gz	= overall Graetz number = $(Re \cdot Pr)/(S/D_i)$
Gz_x	= local Graetz number = $(Re \cdot Pr)/(x/D_i)$
h	= local heat transfer coefficient, [$W/m^2 \cdot K$]
$\overline{h}$	= circumferential average heat transfer coefficient in the fully developed region, [$W/m^2 \cdot K$]
h_x	= circumferential average heat transfer coefficient at any axial location $=Q'/\left(\pi D_i(t_w - t_b)\right)$, [$W/m^2 \cdot K$]
$h_{x,H1}$	= value of h_x for the (H1) boundary condition, [$W/m^2 \cdot K$]
$h_{x,T}$	= value of h_x for the (T) boundary condition, [$W/m^2 \cdot K$]
H	= relative fin height, l/r_o
k	= fluid thermal conductivity, [$W/m \cdot K$]
K	= incremental pressure drop number = $4X\left[f_{app}Re - f_{fd}Re\right]$

K_∞	=limiting value of incremental pressure drop number
l	= fin height, [m]
$L_{H,1\%}$	= dimensionless hydrodynamic entrance length, (value of X corresponding to $f_x = 1.01 f_{fd}$)
$L_{H,5\%}$	= dimensionless hydrodynamic entrance length, (value of X corresponding to $f_x = 1.05 f_{fd}$)
L^+	= dimensionless thermal entrance length, (value of X^+ corresponding to $Nu_x = 1.05 Nu_{fd}$)
L^+_{H1}	= value of L^+ for the (H1) boundary condition
L^+_T	= value of L^+ for the (T) boundary condition
M	= number of fins
Nu_{fd}	= circumferential average Nusselt number in the fully developed region =$(\overline{h}D_i)/k$
$Nu_{fd,0}$	= value of Nu_{fd} at $Gr^+ = 0$
$Nu_{fd,H1}$	= value of Nu_{fd} for the (H1) boundary condition
$Nu_{fd,T}$	= value of Nu_{fd} for the (T) boundary condition
$\overline{Nu}$	= overall Nusselt number for the whole test section
Nu_x	= circumferential average Nusselt number at any axial location = $(h_x D_i)/k$
$Nu_{x,H1}$	= value of Nu_x for the (H1) boundary condition
$Nu_{x,T}$	= value of Nu_x for the (T) boundary condition
p	= pressure, [N/m^2]
$\overline{p}$	= cross sectional average pressure, [N/m^2]
$\overline{P}$	= dimensionless cross sectional average pressure = $\overline{p}/(\rho u_b^2)$
p'	= cross sectional excess pressure driving the secondary flow, [N/m^2]
P'	= dimensionless cross sectional excess pressure driving the secondary flow = $(p'D_i^2)/(\rho\nu^2)$ for the developing isothermal flow, and $\left((p'D_i^2)/(\rho\nu^2)\right) + \left((gD_i^2)r cos\theta\right)/\nu^2$ for the fully developed mixed convection

$\overline{p}_o$	= uniform pressure at the tube inlet, [N/m^2]
$\overline{P}_o$	= dimensionless inlet pressure = $\overline{p}_o/(\rho u_b^2)$
Pr	= Prandtl number =$(\mu c_p)/k$
Q'	= rate of heat input per unit tube length, [W/m]
Q'_f	= rate of heat transfer from the fins per unit tube length, [W/m]
r	= radial coordinate, [m]
r_i	= radius at fin tips, [m]
r_o	= tube inside radius, [m]
R	= dimensionless radial coordinate = r/r_o
Ra	= Rayleigh number = $\left(g\rho^2 D_i^3 \beta(t_w - t_b)c_p\right)/(\mu k)$
Ra^+	= modified Rayleigh number =$\left(g\rho^2 D_i^3 \beta Q' c_p\right)/(\pi\mu k^2)$
Ra_m^+	= mean value of Ra^+ over the whole test section
Re	= Reynolds number = $(\rho u_b D_i)/\mu$
S	= length of test section, [m]
t	= local fluid temperature, [K]
t_b	= fluid bulk temperature, [K]
t_e	= fluid temperature at the tube inlet, [K]
t_w	= wall temperature, [K]
T	= dimensionless local fluid temperature = $(t - t_e)/(Q'/\pi k)$ for the developing forced convection (H1) boundary condition, = $(t - t_w)/(t_e - t_w)$ for the developing forced convection (T) boundary condition, and = $(t - t_w)/(Q'/\pi k)$ for the fully developed mixed convection
T'	= transformed dimensionless local temperature = $T \cdot R$
T_b	= dimensionless fluid bulk temperature
T_w	= dimensionless wall temperature
u	= axial velocity, [m/s]
u_b	= mean axial velocity, [m/s]

U = dimensionless axial velocity $= u/\left[(r_o^2/\mu)(-dp/dx)\right]$ for the developing forced convection, and $= u/u_b$ for the developing isothermal flow and for the fully developed mixed convection

U' = transformed dimensionless axial velocity $= U \cdot R$

U_b = dimensionless mean axial velocity

v = radial velocity, [m/s]

V = dimensionless radial velocity $= (vD_i)/\nu$

V' = transformed dimensionless radial velocity $= V \cdot R$

w = angular velocity, [m/s]

W = dimensionless angular velocity $= (wD_i)/\nu$

x = axial coordinate, [m]

X = dimensionless axial coordinate for the developing isothermal flow and fully developed mixed convection $= (x/D_i)/Re$

X^+ = dimensionless axial coordinate for the developing forced convection $= (x/r_o)/(Re \cdot Pr)$

Greek Symbols

α = half the angle between two adjacent fins

β = coefficient of thermal expansion, [K^{-1}]

θ = angular coordinate

μ = viscosity, [$N \cdot s/m^2$]

ν = kinematic viscosity, [m^2/s]

ρ = density, [kg/m^3]

ρ_w = density at wall temperature, [kg/m^3]

CHAPTER 1

INTRODUCTION

During the past 30 years, a great amount of effort was directed towards the development of compact and more efficient heat exchangers. The reduction in weight and size of heat exchangers is desirable in many areas. In the area of transportation, compact heat exchangers are desirable in order to reduce the dead weight that has to be carried around as part of the transporting machine. In other industrial applications where weight and size do not cause any problem, highly efficient heat exchangers which are capable of the same heat duty at reduced pumping power or increased heat duty at the same pumping power are desirable for obvious economical benefits.

Techniques developed to enhance the standard heat transfer performance of smooth tubes include surface promoters, vortex generators, tube or fluid vibration, electrostatic fields, and fluid additives. Techniques such as vortex generators, tube or fluid vibration, and electrostatic fields require auxiliary power and hence may be uneconomical. Fluid additives is undesirable for many industrial applications where the purity of the working fluid is essential. On the other hand, surface promoters gained a lot of interest due to their simplicity and suitability to a wide range of engineering applications. The internally finned tubes belong to this class and have become extremely popular in recent years.

Before using any enhanced surface in the design of compact heat exchangers, the heat transfer and pressure drop characteristics of this surface must be studied thoroughly. The performance of internally finned tubes as enhanced surfaces was investigated experimentally and analytically in recent years covering the single-phase laminar and turbulent regimes, as well as two-phase boiling and condensation. These studies have shown that the performance enhancement due to internal finning is particularly significant in the laminar flow regime.

In the laminar and turbulent flow regimes, experiments (with the exception of only one or two works that reported local measurements) produced data for the mean values of the friction factor and Nusselt number corresponding to test sections of given lengths, which included developing and fully developed regions. Analytically, most of the mathematical models assumed fully developed conditions with pure forced convection. Comparing the analytical predictions with experimental data, agreement was found to be good in the case of turbulent flow where developing lengths are known to be short and free convection is insignificant. However, the analytical predictions deviated considerably from the experimental data in the case of laminar flow (even when both corresponded to fully developed conditions) because free convection is known to have significant effects on the velocity and temperature distributions within the flow cross section, and hence cannot be ignored in the analysis of fully developed laminar flow situations.

Compact heat exchangers frequently involve short passages, therefore, the flow may remain in the developing mode over the whole, or a major portion of the heat exchanger. Significant amounts of heat transfer and pressure drop occur in the developing region and the accurate evaluation of these amounts cannot be made without detailed knowledge of the friction factor and Nusselt number in that region. A careful review of the literature revealed that there is a serious lack of such information. As well, there has been no analytical studies of laminar mixed convection in the fully developed region of horizontal internally finned tubes reported in the literature.

The objective of this investigation is to provide a detailed study of heat transfer and pressure drop in the laminar flow regime for internally finned tubes. This study is useful for providing design data and improved understanding of the performance of these tubes. Results of this investigation will also make possible the comparison with previously reported experimental data, and thus, improving the confidence in both theory and experiment. A wide range of geometric parameters is to be covered in this investigation which uses an analytical approach for solving the relevant governing equations. Three mathematical models were identified to describe the desired flow situations. These include fully developed hydrodynamically and thermally developing flow using two limiting thermal boundary conditions, a hydrodynamically developing isothermal flow, and a fully developed mixed convection flow. The three models can be used to simulate the actual situation of pressure drop and heat transfer in the developing and fully developed regions for a wide range of heating loads and a wide range of geometric parameters.

CHAPTER 2

LITERATURE REVIEW

Since the present analysis deals with laminar heat transfer and pressure drop characteristics of internally finned tubes, a review of relevant research efforts reported in the literature, either experimental or analytical, is presented in this chapter. Due to the small amount of research papers dealing with internally finned tubes, this review is extended to include selected and widely recognized papers dealing with the smooth tube geometry as well. Both limiting thermal boundary conditions of constant heat input axially and constant wall temperature circumferentially and constant wall temperature both axially and circumferentially are considered in this review. This review includes both developing and fully developed flow (hydrodynamically or thermally). However, it is limited to laminar flow only.

Horizontal, vertical, and inclined tube orientations were covered in the literature. However, the emphasis is placed here on horizontally oriented tubes since it relates directly to this present work.

2.1 Smooth tubes

2.1.1 Experimental Studies

Ede (1961) tested seven horizontally oriented metal tubes with diameters ranging from 1.27 to 5.08 cm. Alternating electrical current was passed directly through the tube walls generating a uniform heat input both axially and circumferentially. Water and air were used as the working fluids. The experiment covered a range of Reynolds number from 300 to 100,000 , obviously including both laminar and turbulent flow regimes, and Grashof numbers of up to 10^7. The heated section was reported to be remote from the entrance of the tube indicating a hydrodynamically fully developed flow. Values of Nu_{fd} were presented as a function of Re in the laminar and turbulent flow regimes for both water and air. Interestingly, Nu_{fd} did not show any dependance on Re in the laminar flow regime but the dependance was strong in the turbulent flow regime. Peripheral variation of wall temperature was reported to be substantial in the laminar flow regime, thus reflecting a strong effect of free convection. Values of Nu_{fd} for water were presented as a function of Gr for low values of Re, and correlated using the following relation:

$$Nu_{fd}/Nu_{fd,0} = \left(1 + 0.06Gr^{0.3}\right) \tag{2.1}$$

Substituting the cited average value of $Pr = 8$, equation (2.1) can be written in the following form:

$$Nu_{fd}/Nu_{fd,0} = \left(1 + 0.0322Ra^{0.3}\right) \tag{2.2}$$

Equation (2.2) will be compared with relevant results from the present analysis.

Mc Comas and Eckert (1966) tested a horizontal tube in the laminar flow region using air as the working fluid. The test section was heated uniformally by passing a direct current through the tube wall. The heated section was reported to be preceeded by a calming section to ensure a fully developed hydrodynamic flow. The testing was noted to cover very low heating loads giving a maximum Gr of 1000 down to an order of one. Temperature measurements were gathered in the thermally developing and fully developed regions. Values of Nu_x were compared with analytical predictions of pure forced convection and found to agree within $\pm 8\%$ at low values of Gr. Free convection was noted to increase the value of Nu_x at points remote from the beginning of heating as Gr was increased. No appreciable effect of free convection was found in the thermal development region.

Petukhov and Polyakov (1967a and 1967b), experimentally tested a horizontal stainless steel tube with an inside diameter of 18.8 mm, wall thickness of 0.36 mm, and a heated length equivalent to 99 diameters. Alternating electrical current was passed directly through the tube wall generating a uniform heat flux at the fluid-wall interface. Distilled water was used as the working fluid throughout the experiment. A calming section equivalent to 96 diameters in length preceeded the heated test section to ensure a fully developed velocity profile. The experiment covered a range of Re from 50 to 2400, and Ra^+ from 2×10^5 to 4×10^7. Values of Nu_x were presented as a function of the reduced length X^+ at different values of Ra^+, and compared with the pure forced convection prediction. The agreement between experimental Nu_x and the theoretical prediction for pure forced convection was found to be good at low values of X^+ and deviated only at high values of X^+, thus showing the insignificant effect of free convection in the initial portion of the thermally developing region. The critical value of Ra^+ at which free convection became significant in the fully developed region was reported as 1.8×10^4. Free convection was reported to create a substantial peripheral wall temperature variation, especially at high values of Ra^+. Values of Nu_{fd} were found to be dependent on Ra^+ alone. The following correlation fitted all experimental data with a maximum deviation of $\pm 5\%$:

$$Nu_{fd}/Nu_{fd,0} = \left[1 + \left(Ra^+/1.8 \times 10^4\right)^4\right]^{0.045} \tag{2.3}$$

This correlation will be used for comparisons with relevant portions of the present analysis.

Shannon and Depew (1968) tested water in a stainless steel tube heated uniformly by passing a direct electrical current through the tube wall. The flow was laminar and the heated test section was reported to be remote from the tube entrance. Measurements of temperature were taken in the thermal entrance region as well as in the fully developed region. The testing covered a range of Re from 120 to 2300, Gz_x from 1.5 to 1000, and Gr up to 2.5×10^5. Values of Nu_x were presented as a function of Gz_x at different values of Gr and compared with the analytical prediction of pure forced convection. The experimental values of Nu_x agreed very well with the analytical prediction at the beginning of heating and departed to higher values at locations remote from the beginning of heating. The value of Nu_x at $x/D \simeq 700$ was reported to be up to two and a half times the analytical pure forced convection value. These findings confirm the weak effect of free convection in the early stages of the thermally developing region and its strong effect on the heat transfer in the thermally fully developed region.

Bergles and Simonds (1971) investigated the heat transfer performance of a glass tube. The flow was laminar with a fully developed velocity profile. Heating was supplied uniformly over the tube wall by an electric heater, and water was used as the working fluid. The experiment was carried out within a Re range of 300 to 800, and Ra of up to 10^6. Values of Nu_x were presented against the dimensionless tube length X^+ showing no significant variation with the tube length. In comparing their results with other analytical and experimental results, they concluded the following: 1) The value of Nu_{fd} at $Ra = 10^6$ is over three times the forced convective value indicating a strong effect of free convection in the fully developed region. 2) Entry length is short when free convection is significant. 3) The available data for various tube sizes and materials fall into a sufficiently narrow band so that drawing a general correlation for practical purposes is possible.

Morcos and Bergles (1975) extended the previous work of Bergles and Simonds (1971) to include a wider range of Pr and also to investigate the effect of wall conductance. A glass and a stainless steel tube were used in this work, and distilled water and ethylene glycol were used as the working fluids providing a range of Pr from 4 to 175. The flow was laminar and the tubes were heated electrically to ensure a uniform heat supply to the tube wall. The heated test section was preceded by a sufficient length of similar diameter pipe to ensure a fully developed velocity profile. Values of Nu_{fd} for the glass tube and the metal tube were presented together against Ra for both water and ethylene glycol. The results were in close agreement with each others for Ra up to 10^5. However, at higher values of Ra, the effect of wall conductance and

Pr became more noticeable. Consequently a correlation was developed using Gr, Pr, and a dimensionless wall conductance parameter as the independent variables. The pressure drop measurements were taken for the case of ethylene glycol only because of the associated large pressure drop compared to the pressure drop in the case of water which was reported to be very difficult to measure. At Ra of 10^6 the increase in the diabatic friction factor over the isothermal friction factor was found to be 50%. The wall conductance apparently played an insignificant role in the increase of the friction factor.

Brown and Thomas (1965) tested three tubes during cooling. The tube diameters were 1.27, 2.54, and 1.27 cms and their lengths were 91.44, 137.16, and 91.44 cms, respectively. Hot water was flowing in the test section and cold water was flowing at a very high flowrate in the surrounding annulus. The cooling water in the annulus showed a negligible change in temperature which simulated a constant wall temperature along the wall of the test section. The test section was reportedly preceded by a calming section to develop the velocity profile. The testing covered a range of Re from 200 to 1500 which indicated a laminar flow, and covered a range of Gr from 4×10^4 to 4.8×10^6. Results of $\overline{Nu}$ were presented at different values of Gz and Gr. At higher values of Gr, $\overline{Nu}$ showed a significant increase due to free convection. A correlation was introduced relating $\overline{Nu}$ to Gz and Gr, which was reported to fit all their data to within $\pm 8\%$.

Depew and August (1971) tested a copper tube with a heated length to diameter ratio, $S/D = 28.4$. The test section, 19.1 mm in diameter, was surrounded by a 3.18 cm diameter annulus. Freon-12 was passed through the annulus thus cooling the test fluid at a constant wall temperature. The test fluids used were water, ethylene glycol, and mixtures of water and ethylene glycol. The experiment covered a range of Re up to a maximum of 1800, Gz from 25 to 700, and Gr from 7×10^4 to 9.9×10^6. Values of $\overline{Nu}$ were presented and correlated as a function of Gz, Gr, and Pr. Their correlation was reported to agree with their data and many other data of constant wall temperature heating or cooling for various fluids to within ±40%. Obviously, for such a small ratio of S/D, the flow is mostly in the thermally developing region, hence $\overline{Nu}$ was expected to be influnced by Gz which is in turn a function of Re.

Yousef and Tarasuk (1981a) studied the formation and structure of secondary flow vortices of air in the entrance region of simultaneously developing flow with constant wall temperature heating. The test section was an aluminum tube with a 25.1 mm inside diameter and 25.0 mm wall thickness. Different tests were conducted covering a ratio S/D ranging from 2 to 48. The testing covered a range of Re from 120 to 1200 and Gr from 0.8×10^4 to 8.7×10^4. The researchers used the Schlieren optical visualization system which they reported to be sensitive in detecting the minor vortices which had not been visualized by smoke or dye lines. Two major vortices were found to form in the lower half of the flow cross section. These two vortices reverted to four vortices with two major vortices in the lower half and two minor vortices in the upper half of the cross section when $S/D \geq 18$ and the wall temperature exceeded the ambient temperature by $20°C$.

Later, the same researchers, Yousef and Tarasuk (1981b), extended their previous work to study the temperature field and the heat transfer performance of the same type of flow and boundary condition, and covering the same ranges of operation as their previous work. For this experiment, the researchers used the Mach-Zender interferometer to determine the three-dimensional temperature field and the circumferential average Nusselt number, Nu_x. Around the circumference, at a certain axial location in the thermally developing region, the local Nusselt number at the bottom was found to be up to five times higher than the top value due to the high intensity of free convection. The secondary flow was reported to be very active in the entry region, while far from the entrance of the tube it decreased substantially. This is expected since the wall temperature was constant and the fluid temperature increased gradually approaching the wall temperature. This in turn was reflected on the values of Nu_x which were up to two times higher than the pure forced convective analytical predictions at the tube inlet and dropped to the analytical value far away from the tube inlet.

Finally, the same researchers, Yousef and Tarasuk (1982), concluded their previous two works by introducing a correlation for $\overline{Nu}$. Their correlation was reported as a function of Gz and Gr. The researchers claimed that their correlation fitted their own data to within +3% to −11%, and fitted other data of other works to within +3% to −30%.

2.1.2 Analytical Studies

Many studies were reported dealing with the mixed convection problem analytically. The complexity of the governing equations forced these studies to simplify the governing equations by some sort of approximations, thus sometimes limiting their applicability. However, many of these approximations became unnecessary with the introduction of advanced numerical techniques that could handle complicated models and with the introduction of faster computers. In this section, a brief discussion of selected papers from the literature is presented. Different types of thermal boundary conditions at the wall are considered.

Faris and Viskanta (1969) solved the problem of laminar fully developed mixed convection in horizontal tubes with constant heat flux axially and circumferentially. The circumferential variation of wall temperature was also neglected in this study. The properties were assumed to be constant except for the density which was taken to vary linearly with temperature in the buoyancy term, thus creating the secondary flow. Approximate solutions were assumed for the governing equations with coefficients that were determined by perturbation. The effect of secondary flow on velocity, temperature, and Nu_{fd} was studied. The results of Nu_{fd} for fluids with Pr ranging from 0.003 (potassium) to 40 (light oil) were presented as a function of ($Gr^{+}/\sqrt{Re}$). The dependence of Nu_{fd} on Re in the fully developed region of horizontal tubes is surprising, however, this appears to be a result of assuming a solution for the governing equations.

Newell and Bergles (1970) presented an analytical investigation of the effects of free convection on fully developed laminar flow of water in horizontal tubes with uniform heat flux axially. Two limiting cases; infinite wall conductivity and zero wall conductivity were considered. The governing equations were solved using the finite difference method with truncated Taylor's series approximations for the derivatives. Results for heat transfer and pressure drop with both heating and cooling were presented for both limiting cases of wall conductivity as a function of Gr. Higher values of Nu_{fd} and $f_{fd}Re$ were reported for the case of infinite conductivity, where Nu_{fd} at $Gr = 10^6$ was found to be five times the value of pure forced convection. For zero conductivity Nu_{fd} and $f_{fd}Re$ were less than those of infinite conductivity at similar Gr. Higher circumferential temperature variations were reported for the case of zero conductivity. In comparing results with existing experimental data, the two limiting cases of wall conductivity were found to bracket the experimental data of heat transfer and pressure drop.

Hwang and Cheng (1970) adopted a boundary vorticity method to solve the Navier Stokes equations with biharmonic functions. The solution was for laminar fully developed mixed convection in horizontal tubes with uniform heat flux axially and uniform wall temperature circumferentially. The researchers intended to bridge a gap which existed between two methods of solution, namely, the perturbation method which was for low values of Gr and the boundary layer approximation method which was for high values of Gr. Convergence failed for Gr^+ higher than 4×10^5 which was attributed to the nonlinearity of the system of equations. At the maximum Gr^+ attained, Nu_{fd} was found to be about twice its value of pure forced convection for the case of $Pr = 1$. Results of Nu_{fd} and $f_{fd}Re$ were presented graphically as functions of Gr^+ and Pr, and compared with existing solutions. This work will be referred to further in this thesis.

The problem of fully developed flow in a horizontal circular tube with large Pr fluids and temperature dependent viscosity and density has been theoretically investigated by Hong and Bergles (1976). In their investigation, two types of boundary conditions were considered . The first type, which represents metal tubes, is a constant wall heat flux axially and constant wall temperature circumferentially, i.e., (H1) . The second type, which represents tubes with very low wall conductivity such as glass tubes, is a constant heat flux axially and circumferentially, i.e., (H2) . In formulating the problem, the inertia term was dropped , thus restricting the analysis to fluids with high Pr. The solution was carried out using the boundary layer approximation which divides the fluid into two regions; a core region and a thin boundary layer near the wall. Values of Nu_{fd} were presented for Ra up to 10^6 and compared with existing experimental data. Results of the (H1) boundary condition showed good agreement (within 10 %) when compared with experimental data for a metal tube. Results of the (H2) boundary condition showed a deviation of 20% at low Ra and a deviation of 10% at moderate Ra when compared with experimental data for a glass tube. Finally, the authors presented correlations for Nu_{fd} as a function of a viscosity parameter and Ra. Use of these correlations requires iterations due to the temperature dependancy of the viscosity. These correlations are not valid for low values of Ra since they yield values of Nu_{fd} less than the asymptotic forced convection value.

The effect of nonuniform circumferential heating on fully developed laminar combined convection in a horizontal tube was studied numerically by Patankar et al. (1978). Two cases of thermal boundary conditions were studied; one in which the tube was uniformally heated over the top half and insulated over the bottom half, and the other in which the heated and insulated portions were reversed. Results were obtained by the finite difference method for Pr of 0.7 and 5 and Gr^+ of up to 6×10^6. The bottom heating was found to give rise to a vigorous buoyancy induced secondary flow resulting in a much higher Nu_{fd} compared to its equivalent value for pure forced convection. The top heating gave rise to less secondary flow and consequently Nu_{fd} showed a lower degree of enhancement compared to bottom heating. Similar results were also noted for the pressure drop, however, for both types of heating the rise in pressure drop due to secondary flow was less profound compared to the rise in heat transfer.

Nguyen and Galanis (1986) solved numerically (finite difference) the governing equations for simultaneous development of velocity and temperature in the laminar flow regime adopting the (H1) boundary condition. The system of equations was solved in its elliptical form using a three dimensional mesh. Boundary conditions downstream were implemented by imposing a zero derivative with respect to x for all components of velocity and the dimensionless temperature. The solution was obtained for Ra^+ up to 10^6 and $Pr = 7$. Values of Nu_x were presented against X^+ at $Ra^+ = 10^6$ and compared with the predictions of simultaneous development of pure forced convection. The two values were shown to coincide for most of the developing region, and begin to separate at values of $X^+ > 5 \times 10^{-3}$. A significant difference was shown in the fully developed region between the two values of Nusselt number due to the apparent effect of free convection.

All the above investigations correspond to the case of uniform heat flux axially with different wall conditions circumferentially. The second important limiting condition is that of uniform wall temperature both axially and circumferentially, normally referred to as the (T) boundary condition. The following papers correspond to this type of boundary condition.

A theoretical investigation was conducted by Hieber and Sreenivasan (1974) for laminar flow of large Pr fluids through an isothermally heated horizontal pipe. The solution was carried out for Re ranging from 200 to 2000 and Gr of up to 10^5. The flow domain was divided axially into four regions; namely, a near region where secondary flow was neglected and Blasius flow was assumed, an intermediate region where pure free convection was assumed, a near-intermediate region with mixed convection , and a far region with pure forced convection. Results thus obtained expressed $\overline{Nu}$ (which is an overall average value that includes both developing and fully developed regions) as a function of Gr, Pr, Re, and S/D. As the result of comparing the theoretical analysis with existing experimental data, the theory was claimed to be successful.

Ou and Cheng (1977) studied the problem of mixed convection in the entrance region of horizontal isothermal tubes. The problem was formulated based on the assumption of large Pr which renders the inertia terms negligible. Solution of the system of equations was performed numerically using a marching technique in the axial direction. For any given value of Ra, the value of Nu_x starts out identical to the forced convection value, then deviates at a certain X^+ and then again approaches the forced convective curve asymptotically. The solution was marched in the axial direction until Nu_x approached the fully developed value of pure forced convection to within 2%. Value of the entrance length was presented as a function of Ra, and was shown to decrease monotonically with Ra.

Hieber (1981) extended his previous work to elucidate and further substantiate the theory developed. Basically, the same analysis was used and the results were rescaled to be comparable with a wider range of existing results and data. Such comparisons showed very close agreements. Although his analysis was developed for high Pr fluids, the author noted that his results are capable of good agreement with data obtained for air.

The problem of mixed convection in the entrance region of an isothermally heated horizontal pipe with no aid of the large Pr assumption has been addressed by Hishida et al. (1982). In their analysis, Pr was taken to be 0.71 which corresponds to air, however, Gr did not exceed the value of 10^4. The governing system of equations was solved numerically using the finite difference method. Secondary flow was found to intensify gradually until it reached a maximum at a certain location depending on Gr, and then diminished gradually, and ultimately vanished altogether downstream.

As a result, variation of Nu_x along X^+ was found to be identical qualitatively to the pattern described by Ou and Cheng (1977). Increasing Gr was found to increase the value of Nu_x and decrease the entrance length.

2.2 Internally Finned Tubes

In this section, a brief review of experimental and analytical efforts done in the past concerning the internally finned tubes is discussed. This review is limited to laminar flow. Both limiting thermal boundary conditions of (H1) and (T) are considered.

2.2.1 Experimental Studies

One of the earliest works conducted on internally finned tubes was done by Hilding and Coogan (1964). Ten internally finned tubes and a smooth tube were tested. The relative fin height of these tubes ranged from 0.36 to 1.0, and the number of fins ranged from 2 to 8. The tubes were made of copper, the working fluid was air, and the heating was applied at constant wall temperature. The test covered a range of Re from 1000 to 100,000 (based on the hydraulic diameter) encompassing the laminar, transitional, and turbulent flow regimes. All gathered data were average values over the whole test section which was approximately 33 tube diameters for each tested tube. The internally finned tubes showed an increase in the friction factor due to heating that exceeded the smooth tube increase at similar heating loads. This increase was more noticeable in the turbulent flow region. Based on the hydraulic diameter, $\overline{Nu}$ showed an increase due to finning at various heating loads in the laminar flow and the transitional flow. However, this trend reversed in the turbulent flow and the presence of fins was reported to decrease the enhancement of $\overline{Nu}$ when compared with smooth tube results at similar heating loads. The final conclusion of this work was that the presence of fins enhanced $\overline{Nu}$ by 200 to 300%, however, this was accompanied by an increase in the pumping losses as well which was higher in the turbulent flow region.

The use of internally finned tubes instead of smooth tubes in the design of condensers for power plants has been studied by Heeren and Wegscheider (1967). They reported that after six years of laboratory testing and measurements they came up with an optimum configuration for the finned tube whose type was refered to by a code. In a plotted graph, the overall heat transfer coefficient for a condenser built with internally finned tubes was compared with a similar one built with smooth tubes. The internally finned condenser showed a higher heat-transfer performance ranging from 40% to 100% over the smooth condenser depending on the velocity of water in the tubes. The maximum increase was found at low to moderate flow velocities, while at higher flow velocities the increase in performance remained steady at 40%. The researchers commented that greater enhancements can be achieved at low to moderate flow velocities and at higher water temperature, since the water viscosity drops with temperature and eventually less pumping powers are required. As a final conclusion the researchers reported that using internally finned tubes they constructed a condenser carrying the same heat duty of a conventional smooth tube condenser with only 59% of external surface area. This finding is quite interesting in illustrating the fact that internally finned tubes can be very useful components in constructing compact heat exchangers.

Eighteen internally finned tubes with straight and spiral fins, as well as two smooth tubes were tested by Watkinson et al. (1975). The testing was carried out with laminar motor oil flow. The motor oil provided a Pr range of 180 to 250. The heated section was surrounded by a steam jacket to ensure an isothermal wall boundary condition, and the flow was developed hydrodynamically before entering the heated section. The operational range of Re was from 50 to 3000 based on the inside diameter. The geometrical parameters of the tested tubes covered a relative fin height range of 0.05 to 0.31, and a fin number range of 6 to 50. The data for heat transfer and pressure drop were taken across the whole heated section without separating the thermally developing flow from the thermally fully developed flow. Values of $\overline{Nu}$ and the overall friction factor in finned tubes were shown to be consistently higher than for smooth tubes. At $Re = 500$, the enhancement of $\overline{Nu}$ over the smooth tube ranged from 8 to 224% and the increase in the overall friction factor at the same Re ranged from 18 to 131% depending on geometry. For straight finned tubes, the highest degree of enhancement of $\overline{Nu}$ was shown by tubes with fewer and longer fins. This degree of enhancement decreased by increasing the number of fins and by decreasing the height of fins. The $\overline{Nu}$ was correlated as a function of Pr, Gr, Re, and geometrical parameters such as number of fins, relative fin height, and length to diameter ratio, S/D. Their correlation fitted their data with a standard deviation of $\pm$ 17%. In an attempt to correlate the friction factor, no simple relation was found.

Marner and Bergles (1978) conducted an experiment with five different kinds of augmented tubes in laminar flow with constant heat input axially. Among these tubes, one was an internally finned tube with ten fins and a relative fin height of 0.22. A limited amount of data was reported for the axial variation of Nu_x using two fluids (water and ethylene glycol). This data deviated considerably from the analytical predictions of developing forced convection in smooth tubes and fully developed forced convection in internally finned tubes. The discrepancy was attributed to a Prandtl number effect and the possible effect of free convection was not considered. Values of Grashof number were not reported in this study.

Rustum (1984) conducted an experimental study using a smooth tube and five different internally finned tubes. The study was conducted using water as the working fluid in the laminar flow regime with heat being supplied uniformly along the tube axis. Fluid flow was first developed before entering the heated test section. The geometric parameters ranged from a relative fin height of 0.216 to 0.325, and the number of fins from 10 to 16. Local measurements of Nusselt number were recorded and analyzed at different levels of heating loads. The range of operating conditions varied from one tube to another covering an Ra^+ of up to 7.4×10^7, Re from 215 to 1600, and Pr from 3.4 to 6.2. Variation of Nu_x was presented for the entire thermal entry region and the fully developed region. Comparisons were not possible since no similar data existed in the literature dealing with mixed convection in the thermal entrance region or in the fully developed region of internally finned tubes. The effect of secondary flow was found to be much more profound in the fully developed region. The existence of fins was found to delay the onset of secondary flow to higher values of Ra^+ when compared to smooth tubes. This study provides a major source of experimental data against which the theoretical results of the present investigation can be compared.

Marner and Bergles (1989) conducted an experiment investigation using three tubes with heating and cooling under constant wall temperature. A high viscosity fluid with Pr ranging from 1260 to 8130 was used as the working fluid. Their investigation covered Reynolds numbers ranging from 15.1 to 575. The three tubes used were a smooth tube, a tube with a twisted-tape insert, and a spiral internally finned tube. The heated section was preceded by a calming length thus ensuring a fully developed velocity profile at the test section inlet. The effects of free convection were found to be negligible due to the high viscosity of the working fluid. Isothermal friction factors for the internally finned tube and the tube with a twisted-tape insert were found to be 1.7 and 3.4 times those of the smooth tube for the range of Re tested. The $\overline{Nu}$ was also found to be above those of a smooth tube during both heating and cooling with the greatest improvement for heating was for the internally finned tube where $\overline{Nu}$ ranged from 3 to 4 times the smooth tube value. For cooling, the twisted-tape $\overline{Nu}$ was 1.5 to 2.25 that of a smooth tube.

2.2.2 Analytical Studies

The hydrodynamic problem of fully developed laminar flow in internally finned tubes was investigated analytically by Nandakumar and Masliyah (1975). The governing momentum equation was solved numerically using the finite element technique. The fins were assumed to have a triangular cross section so that elements of triangular shape could be easily implemented. The geometric parameters involved in the analysis were, number of fins M, relative fin height H, and thickness of fins. The number of fins covered a range of 6 to 24, the relative fin height covered a range of 0.1 to 0.2 only, and the thickness of fins was represented by the half fin angle which covered the range of 3 to 12 degrees. Results of $f_{fd,0}Re$ were correlated as function of the ratio of hydraulic to inside diameters of the tube, the circumferential arc length between any two adjacent fins, and the relative fin height H. It was reported that the correlation fitted all their numerical data with an average error of 2% and a maximum error of 4%.

Soliman and Feingold (1977) developed a series solution to the problem of fully developed laminar flow in internally finned tubes. The shape of the fins was assumed to be trapezoidal which is reasonably close to the real fin configuration. Values of $f_{fd,0}Re$ were presented for a wide range of geometric parameters, namely, number of fins M, relative fin height H, and fin thickness represented by the half fin angle. The number of fins and the relative fin height were found to have the dominant effect on $f_{fd,0}Re$, while the fin half angle had significant effect only for high number of long fins.

The forced convection heat transfer of fully developed laminar flow in internally finned tubes was investigated analytically by Hu and Chang (1973). The heat flux was assumed to be uniform axially, circumferentially, and along each fin. The momentum and energy equations were solved using the generalized Green's function by the method of partial eigenfunction expansion. Results were presented for a wide range of geometric parameters. Secondary loops of equi-velocity lines and isotherms were found to form in the bay areas between adjacent fins. These secondary loops were reported to be influenced by H alone. For $H < 0.32$, no secondary loops were noticed. However, for $H \geq 0.32$, the researchers reported that the secondary loops appeared in the equi-velocity lines as well as in the isotherms, irrespective of the value of M. The value of $Nu_{fd,0}$ was presented as a function of H and M, and for the particular boundary condition considered, an optimum value of $Nu_{fd,0}$ was found in the neighbourhood of $H = 0.8$.

The work of Nandakumar and Masliyah (1975) was extended by the same researchers, Masliyah, and Nandakumar (1976), to include the heat transfer case. The same geometry, method of solution and flow conditions were assumed. A fully developed pure forced convection with constant heat input axially and constant wall temperature circumferentially were adopted. Results of $Nu_{fd,0}$ based on the inside diameter were presented for a half fin angle ranging from 0 to 3.0 degrees, a number of fins M from 6 to 24, and a relative fin height H ranging from 0 to 0.8.The results showed that $Nu_{fd,0}$ increases monotonically with H for any value of M, however, $Nu_{fd,0}$ increases by increasing M until it reaches a maximum at a certain number of fins, then decreases. This critical number of fins increased by increasing the relative fin height. A very interesting feature of the presented results is the effect of fin thickness on Nu_{fd}. This effect appeared to be insignificant for low number of short fins, and its effect started to appear at high numbers of long fins.

The same problem was investigated by Soliman and Feingold (1978), who developed a series solution for the velocity and temperature distributions and Nusselt number. The fins were assumed to be trapezoidal in shape. Comparison of the results with those of Masliyah and Nandakumar (1976) was possible only for zero-thickness fins due to the difference in fin shapes. The comparison showed good agreement (within 5%).

The case of a finite fin conductance, which would result in a nonuniform temperature along the fins, was investigated for the case of constant heat flux axially and uniform tube wall temperature circumferentially by Soliman (1981). Again, a series solution was obtained using the method of separation of variables. It was shown that the fin conductance can have a serious effect on the overall heat transfer performance of tubes with long fins ($H > 0.4$). However, the assumption of perfect conductance was found to be reasonable when the ratio of tube thermal conductivity to fluid thermal conductivity was high.

The influence of the thermal boundary condition on the performance of internally finned tubes was investigated by Soliman et al. (1980). In their study, uniform wall temperature axially and circumferentially was assumed and the solution was carried out using the finite difference technique. Results of $Nu_{fd,0}$ for a wide range of geometric parameters were presented, and for any geometry, $Nu_{fd,0}$ was found to be consistently lower than that for the constant heat flux boundary condition.

One of the very few works dealing with mixed convection in internally finned tubes was conducted by Prakash and Patankar (1981). In the analysis, the complexity of the problem was reduced substantially by adopting a vertical tube orientation. In vertical tubes, secondary flow is unidirectional with the main flow thus reducing the problem by eliminating the radial and angular momentum equations. The solution domain also reduced to half the sector between any two adjacent fins because of the symmetry of the flow. The problem was solved numerically using the finite difference method for fully developed, laminar flow with constant heat flux axially and uniform temperature circumferentially and along the fins. Results of $f_{fd}Re$ and Nu_{fd} were presented as functions of the single parameter (Gr^+/Re) ranging from 0 to 10^5, assuming $Pr = 0.7$. Both $f_{fd}Re$ and Nu_{fd} increased with (Gr^+/Re) for any geometry. At a given (Gr^+/Re), shorter fins showed higher augmentation due to free convection than longer fins. The presence of the fins suppressed and delayed the onset of free convection.

The effect of free convection on a shrouded fin array was studied analytically by Acharya and Patankar (1981). In their study, a horizontal, laminar, fully developed flow with two types of thermal boundary conditions (a hot fin and base with cold fluid, and a cold fin and base with hot fluid) was considered. The problem was solved numerically by the finite difference method for different geometric parameters and different values of Gr^+ using $Pr = 0.71$. For the case of hot fin and base, which is the most related to the present work, both Nu_{fd} and $f_{fd}Re$ were found to increase with Gr^+ and with fin tip clearance indicating that shorter fins allowed free convection to be stronger while longer fins suppressed the effect of free convection. This finding is very interesting, although the geometry is not exactly that of internally finned tubes.

Prakash and Ranzoni (1985) studied the effect of buoyancy on laminar, fully developed flow in vertical annular passages with radial internal fins attached to the inner tube. The outer tube was insulated, while the inner tube was supplied with a uniform heat flux axially. The problem was solved numerically using the finite difference method. Results presented showed that both Nu_{fd} and $f_{fd}Re$ increased with (Gr^+/Re) over their corresponding values for pure forced convection. This increase was shown to be strongly dependent on the number and length of fins. Similar to what was reported before by Prakash and Patankar (1981), and Acharya and Patankar (1981), longer fins suppressed the buoyancy effect on Nu_{fd} and $f_{fd}Re$, and the highest increase in Nu_{fd} and $f_{fd}Re$ due to free convection corresponded to fewer and shorter fins.

Mirza and Soliman (1985) made an initial effort at investigating the problem of mixed convection in horizontal internally finned tubes. The flow was assumed to be fully developed, laminar, and heating was assumed to be uniform axially with uniform wall temperature circumferentially and along the fins. The geometry was simplified by considering only two vertically oriented fins; one being at the top of the tube, and the other being at the bottom. The problem was solved using the technique of false transients in conjunction with a marker-and-cell type of finite difference mesh. Results were obtained for relative fin heights ranging from 0 to 1, $Pr = 0.7$, and a Gr^{+} ranging from 0 to 10^6. Although the geometry was constructed with only two fins, the presence of fins was found to suppress the effect of free convection and to delay its effect to higher values of Gr^{+} compared to smooth tubes. The enhancement of Nu_{fd} compared to the forced convective value was found to be consistently higher than the enhancement of $f_{fd}Re$ for all values of fin heights and Gr^{+}.

The problem of simultaneous development of velocity and temperature in the entrance region of internally finned tubes was analytically investigated by Prakash and Liu (1985) assuming pure forced convection. In their study, the limiting thermal boundary conditions of constant heat flux axially and constant wall temperature circumferentially and the constant wall temperature both axially and circumferentially were considered. The flow was assumed to be laminar and steady. The system of equations was parabolized, and a marching finite difference technique in the axial direction was adopted. Results of $Nu_{x,H1}$ and $Nu_{x,T}$ were presented in the developing region and in the fully developed region. Estimates of the hydrodynamic and thermal entrance lengths were presented for different values of number of fins and relative fin heights. No simple trend could be found in terms of the effect of geometric parameters on the entrance length, and no firm conclusion was drawn on whether fins will shorten or increase the entrance length. This study will be referred to further in later parts of the present investigation.

From the above review of experimental and analytical research efforts on the heat transfer and pressure drop characteristics of internally finned tubes, the following observations were drawn:

1. Mixed convection was considered analytically only for the case of vertical tube orientation. No analysis is available yet for the horizontal orientation.

2. The free convection effects on pressure drop and heat transfer in tubes appear to be insignificant in much of the thermally developing region with the

(H1) boundary condition. However, these effects cannot be ignored in the fully developed region.

3. Very little information exists in the literature regarding the local pressure drop and heat transfer in the developing region. Such information is necessary for the design of compact heat exchangers involving short passages. One analysis (Prakash and Liu, 1985) involved simultaneous development of velocity and temperature, however, no results are available yet for the individual growth of hydrodynamic and thermal boundary layers.

4. Most experimental data reported average values of friction factor and Nusselt number over a certain test section length which often included both developing and fully developed regions. This fact coupled with the current state of analysis where most available results for horizontal tubes correspond to fully developed forced convection has made it nearly impossible to compare experiment with theory. Such comparisons, when successful, increase the confidence in both sets of results.

The present analyses were carried out to address the above apparent deficiencies.

2.3 Numerical Techniques

There are many approximate numerical techniques reported in the literature. A detailed discussion of such numerical techniques is beyond the scope of this work. However, a good reference on these techniques was reported by Roache (1982). In this section, the emphasis is placed on the most commonly used technique in solving heat transfer and fluid flow problems, i.e., the finite difference method. Basically, there are two powerful techniques that can handle nonlinear systems of partial differential equations that are coupled together through their pressure terms. The first technique is called " The False Transient ". In this technique, a steady state situation is assumed transient temporarily. The solution starts by assuming initial conditions, and then marching in time until steady state conditions are reached and the time derivatives vanish. At this point, the solution is considered complete and the results correspond to the steady state solution. A detailed discussion of this technique was reported by Harlow and Welch (1965).

The second technique treats steady state systems of equations as they are and could be direct (non-iterative) if the equations are linear and unlinked, or iterative to handle linked systems of equations. In this class, the " Semi-Implicit Method for Pressure-Linked Equations " technique, or as abreviated by " SIMPLE ", was developed by Patankar and Spalding (1972). This technique was later revised by Patankar et al. (1975), and reported in detail by Patankar (1980) under the name " SIMPLER " which stands for a revised version of " SIMPLE ". This scheme is very widely used in the area of fluid flow and heat transfer, and has proven to be capable of handling strongly linked nonlinear systems of equations. This technique was adopted as a solution tool in this present analyses.

The above mentioned numerical techniques can be used in solving the governing equations using the primitive variables, such as the components of velocity and the pressure, or by means of vorticity and stream functions. The vorticity and stream functions approach involves cross-differentiation of the momentum equations and eliminating the pressure, thus decreasing the number of equations. The disadvantage of such an approach lies in the difficulty in evaluating the primitive variables after a solution is obtained, which requires numerical integration of the vorticity and stream functions. In this study, the approach of solving directly for the primitive variables was adopted.

CHAPTER 3

STATEMENT OF THE PROBLEM

3.1 Physical Models

The geometry under consideration is that of a horizontal tube with a variable number of straight longitudinal fins, evenly distributed around the inner wall of the tube, as shown in Figure 3.1. Fins are assumed to be of negligible thickness with sides oriented radially within the tube cross section. The fins and the tube wall are assumed to be of negligible thermal resistance, resulting in a circumferentially uniform wall and fins temperature. This assumption closely approximates the real situation when the internally finned tubes are made of highly conductive metals such as copper (which is normally the case), particularly when the fins are short.

To represent an actual physical situation mathematically, it is necessary sometimes to subdivide the actual situation into individual cases, each of which could be represented by a different mathematical model. The value of $Nu_{x,H1}$ during laminar flow in tubes (as shown in Figure 3.2) is normally very high near the entrance and it decreases monotonically until it reaches an asymptotic value in the fully developed region. Dividing this situation into a thermally developing region and a thermally fully developed region, the two cases can be analytically studied separately. In the developing region, previous studies (e.g. Nguyen and Galanis, 1986) have shown that free convection may have insignificant effect on heat transfer due to the small wall-to-bulk temperature difference. Therefore, the thermally developing region can be described by a developing forced convection model which represents the actual situation with acceptable accuracy. This assumption is further justified by the fact that free convection shortens the thermally developing region considerably as shown

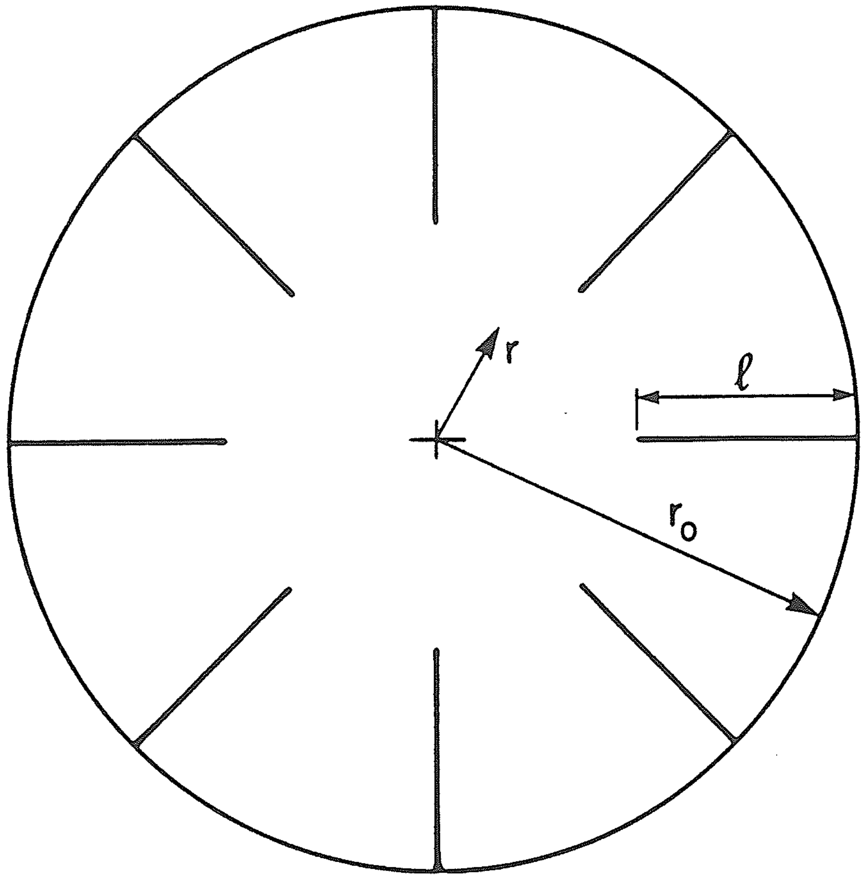


Figure 3.1 Geometry under consideration

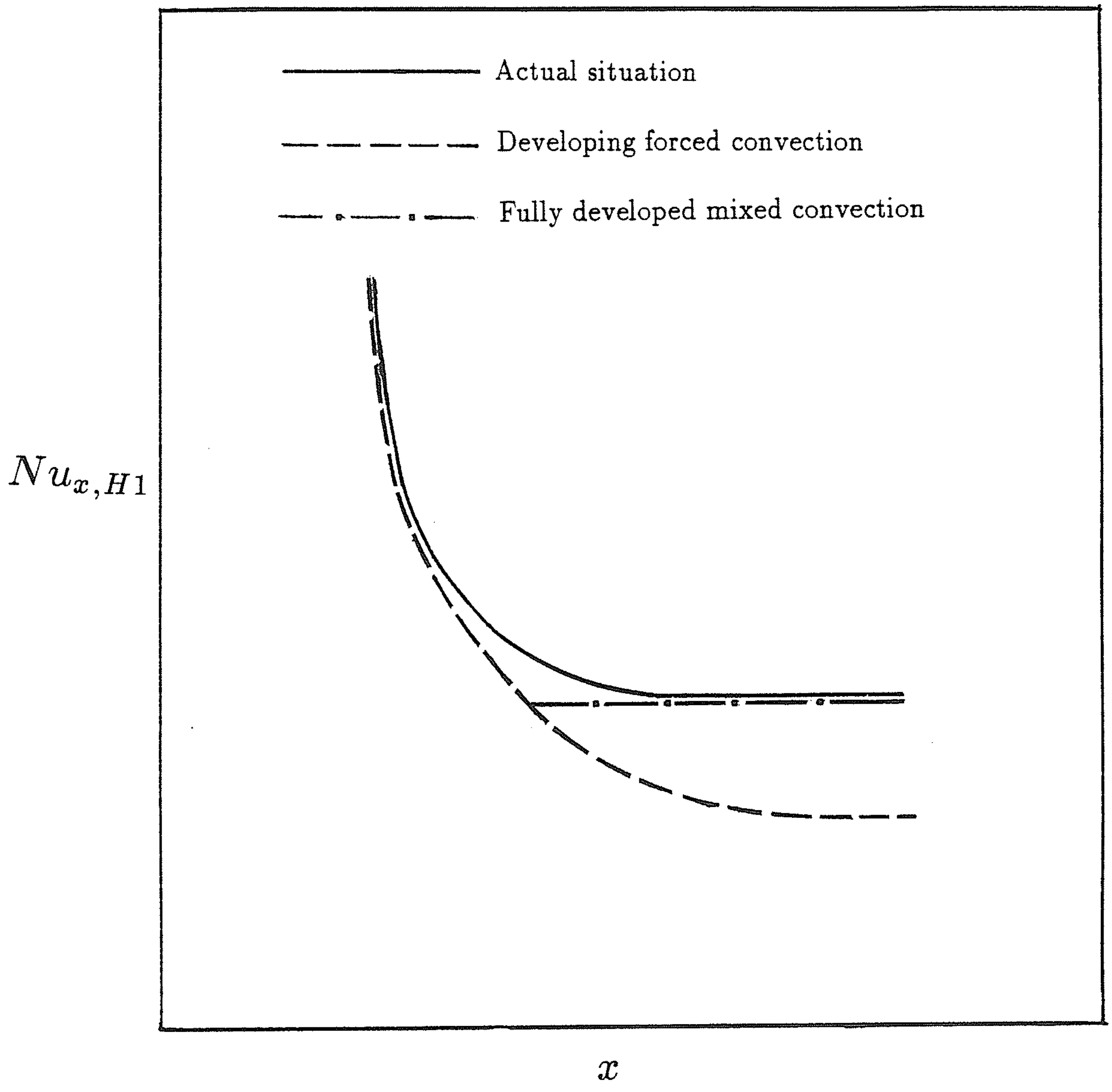


Figure 3.2 Schematic diagram of actual and modeled heat-transfer behaviour

experimentally by Petukhov and Polyakov (1967), and Rustum and Soliman (1988).

On the other hand, free convection is known to have a strong influence on heat transfer in the fully developed region. Therefore, a fully-developed, mixed-convection model is necessary in this region. Hence, the actual situation of hydrodynamically developed but thermally developing flow can be represented with reasonable accuracy by two models assuming forced convection in the thermally developing region and mixed convection in the thermally developed region, as shown in Figure 3.2.

A third model is needed for hydrodynamic development. This model will assume isothermal flow and should provide information about the variation of friction factor and pressure gradient in the hydrodynamic entrance length. Results of these three models should provide a design tool for many applications of compact heat exchangers where internally finned tubes are used.

3.1.1 Developing Forced Convection

The problem of hydrodynamically fully developed flow and thermally developing forced convection heat transfer is considered in this case. Two types of thermal boundary conditions are studied; a constant heat input axially and uniform wall temperature circumferentially, and a constant wall temperature axially and circumferentially. These two thermal boundary conditions are known as the (H1) and (T) boundary conditions, respectively, and they represent limiting conditions for many industrial applications.

In this situation, no radial or angular components of the velocity exist. The pressure is independent of r and θ, and its axial gradient is constant. The temperature is a function of r, θ, and x in the thermally developing region. In the fully developed region, a nondimensional temperature profile becomes invariant with the axial location, x.

Using this model, the fully developed axial velocity distribution can be generated, from which the value of $f_{fd,0}Re$ can be calculated. The temperature distribution can also be generated in the developing and in the fully developed regions, from which Nu_x, $Nu_{fd,0}$ and L^+ can be evaluated. All of these parameters are to be calculated for each tube geometry covered in this investigation using two limiting boundary conditions, the (H1) boundary condition and the (T) boundary condition.

The solution of this problem has the advantage of being applicable to the case of simultaneous development of velocity and temperature for $Pr > 5$. The Prandtl number is a nondimensional group of fluid transport properties, and can be written in the form of the ratio of diffusivity for momentum to diffusivity for heat. If $Pr = 1$, the velocity and temperature profiles develop at about the same rate. If $Pr > 1$, the velocity profile develops more rapidly than the temperature profile, and if $Pr < 1$, the temperature profile develops faster than the velocity profile. For $Pr > 5$, the velocity profile leads the temperature profile sufficiently that a solution based on an already fully developed velocity profile will apply quite accurately even though the hydrodynamic starting length was ignored (Kays and Crawford, 1980). In other words, the present model may be valid for simultaneously developing flow of fluids such as water or oils. However, it is not applicable to simultaneously developing flow of fluids such as gases and liquid metals.

3.1.2 Developing Isothermal Flow

The case of hydrodynamically developing flow is considered in this part. In the developing region, the velocity is three dimensional, and each component is a function of r, θ, and x. The pressure is also a function of r, θ, and x. The intensity of the secondary flow first increases and then decreases until it vanishes in the fully developed region. The pressure in the fully developed region is independent of r and θ, and its axial gradient is invariant with x.

This model can produce the axial velocity distribution in the fully developed region and consequently $f_{fd,0}Re$. In the developing region, the three components of velocity can be generated, and the axial velocity distribution can be used to calculate

$f_x Re$, $f_{app} Re$, and K at each axial station. The hydrodynamic entrance length L_H, and the value of K_∞ can also be calculated. All of these parameters are to be calculated for each geometry considered in this investigation.

3.1.3 Fully-Developed Mixed Convection

In this case, the flow is assumed to be fully developed hydrodynamically and thermally. The density is assumed to be temperature dependent only where buoyancy effects are considered. Heat input is applied at a constant rate axially and the wall temperature is assumed uniform circumferentially.

The application of heat at the tube wall creates a temperature gradient, and consequently, a density gradient. This in turn causes the lighter fluid to move upwards and the heavier fluid to move downwards to replace it. This kind of motion is called free convection or secondary flow. In smooth tubes, this motion usually takes the shape of two loops within the cross section of the tube, with the fluid moving upwards near the wall and downwards at the core. In internally finned tubes, the pattern of the free convection motion is expected to be complicated by the presence of the fins, as shown later in this work.

The intensity of the secondary flow increases the mixing of the fluid and is expected to enhance the heat transfer performance. At the same time, the interaction of the secondary flow with the main flow increases the pressure drop. The presence of fins increases the surface area, which has the effect of increasing heat transfer and the frictional forces. However, the fins may suppress the intensity of secondary flow, thus delaying its effect on heat transfer and pressure drop to higher heating loads compared to smooth tubes.

For a given finned tube geometry, the solution of this model generates the three components of velocity and the temperature distribution for given values of Prandtl and Grashof numbers. From the axial velocity distribution, the value of $f_{fd} Re$ can be calculated, and from the temperature distribution, Nu_{fd} can be calculated. All of these parameters are to be evaluated for all tube geometries considered in this investigation, over a wide range of Grashof number.

3.2 Mathematical Models

3.2.1 Developing Forced Convection

This model is valid for steady, laminar, forced convection flow of incompressible, Newtonian fluids with constant properties. Axial conduction and viscous dissipation within the fluid are assumed negligible. Due to geometric symmetry of the flow domain, solutions of the governing equations are necessary only within $0 \leq r \leq r_o$ and $0 \leq \theta \leq \alpha$, as shown in Figure 3.3.

Based on the above assumptions, the applicable governing equations are as follows:

Momentum Equation

The dimensional momentum equation reduces to

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2} = \frac{1}{\mu}\frac{dp}{dx} \tag{3.1}$$

This equation is subject to the following boundary conditions

$$u = 0 \qquad \text{at} \qquad \left\{ \begin{array}{lcl} r = r_o & , & 0 \leq \theta \leq \alpha \\ r_i \leq r \leq r_o & , & \theta = 0 \end{array} \right\} \tag{3.2a}$$

$$\frac{\partial u}{\partial r} = 0 \qquad \text{at} \qquad r = 0 \quad , \quad \text{for all } \theta \tag{3.2b}$$

and

$$\frac{\partial u}{\partial \theta} = 0 \qquad \text{at} \qquad \left\{ \begin{array}{lcl} 0 < r < r_o & , & \theta = \alpha \\ 0 < r < r_i & , & \theta = 0 \end{array} \right\} \tag{3.2c}$$

Normalizing the above equation and boundary conditions using the dimensionless parameters defined in the Nomenclature, we get

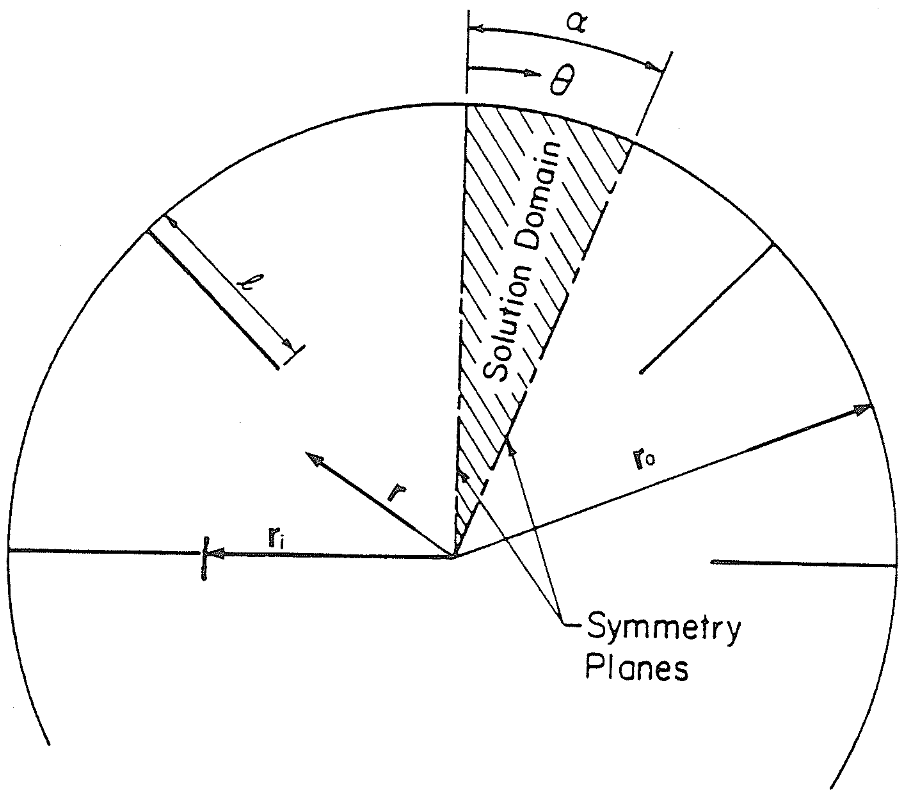


Figure 3.3 Solution domain and coordinate system for developing forced convection and developing isothermal flow

$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial U}{\partial R}\right)+\frac{1}{R^2}\frac{\partial^2 U}{\partial \theta^2}=-1 \tag{3.3}$$

$$U=0 \qquad \text{at} \qquad \left\{\begin{array}{lcc} R=1 & , & 0\le\theta\le\alpha \\ (1-H)\le R\le 1 & , & \theta=0 \end{array}\right\} \tag{3.4a}$$

$$\frac{\partial U}{\partial R}=0 \qquad \text{at} \qquad R=0\,, \qquad \text{for all } \theta \tag{3.4b}$$

and

$$\frac{\partial U}{\partial \theta}=0 \qquad \text{at} \qquad \left\{\begin{array}{lcc} 0<R<1 & , & \theta=\alpha \\ 0<R<(1-H) & , & \theta=0 \end{array}\right\} \tag{3.4c}$$

Boundary condition (3.4b) is difficult to implement numerically. In order to establish a well defined boundary condition at the tube centerline, the transformation $U'=U\cdot R$ was introduced. The final form of the momentum equation becomes

$$\frac{1}{R}\frac{\partial^2 U'}{\partial R^2}-\frac{1}{R^2}\frac{\partial U'}{\partial R}+\frac{1}{R^3}\left(U'+\frac{\partial^2 U'}{\partial \theta^2}\right)=-1 \tag{3.5}$$

subject to these boundary conditions

$$U'=0 \qquad \text{at} \qquad \left\{\begin{array}{lcc} R=1 & , & 0\le\theta\le\alpha \\ (1-H)\le R\le 1 & , & \theta=0 \\ R=0 & & \end{array}\right\} \tag{3.6a}$$

and

$$\frac{\partial U'}{\partial \theta}=0 \qquad \text{at} \qquad \left\{\begin{array}{lcc} 0<R<1 & , & \theta=\alpha \\ 0<R<(1-H) & , & \theta=0 \end{array}\right\} \tag{3.6b}$$

The following definitions were adopted for the fully developed friction factor $f_{fd,0}$ and Reynolds number Re based on the inside diameter D_i :

$$f_{fd,0}=D_i\left(-dp/dx\right)/\left(2\rho u_b^2\right) \tag{3.7}$$

and

$$Re = \rho u_b D_i / \mu \tag{3.8}$$

Consequently, the product $f_{fd,0}Re$ can be reduced to this dimensionless form

$$f_{fd,0}Re = 2/U_b \tag{3.9}$$

where the dimensionless mean velocity is given by

$$U_b = \left[\int_{\theta=0}^{\alpha} \int_{R=0}^{1} U' dR \, d\theta \right] / (\alpha/2) \tag{3.10}$$

Energy Equation: (H1) Boundary Condition

The applicable energy equation has the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 t}{\partial \theta^2} = \frac{\rho c_p}{k} u \frac{\partial t}{\partial x} \tag{3.11}$$

This equation is subject to the following initial and boundary conditions :

at $x = 0$

$$t = t_e \quad \text{for all } r, \text{ and all } \theta \tag{3.12a}$$

for $x > 0$

$$t = t_w \quad \text{at} \quad \left\{ \begin{array}{ll} r = r_0 , & 0 \le \theta \le \alpha \\ r_i \le r \le r_o , & \theta = 0 \end{array} \right\} \tag{3.12b}$$

$$\frac{\partial t}{\partial \theta} = 0 \quad \text{at} \quad \left\{ \begin{array}{ll} 0 < r < r_i , & \theta = 0 \\ 0 < r < r_o , & \theta = \alpha \end{array} \right\} \tag{3.12c}$$

and

$$\frac{\partial t}{\partial r} = 0 \quad \text{at} \quad r = 0 , \quad \text{for all } \theta \tag{3.12d}$$

Normalizing the energy equation and boundary conditions, we get

$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial T}{\partial R}\right) + \frac{1}{R^2}\frac{\partial^2 T}{\partial \theta^2} = \frac{f_{fd,0}Re}{4} U \frac{\partial T}{\partial X^+} \tag{3.13}$$

at $X^+ = 0$

$$T = 0 \qquad \text{for all} \quad R, \qquad \text{and} \quad \text{all} \;\; \theta \tag{3.14a}$$

for $X^+ > 0$

$$T = T_w \qquad \text{at} \qquad \left\{ \begin{array}{ccc} R = 1 & , & 0 \leq \theta \leq \alpha \\ (1-H) \leq R \leq 1 & , & \theta = 0 \end{array} \right\} \tag{3.14b}$$

$$\frac{\partial T}{\partial \theta} = 0 \qquad \text{at} \qquad \left\{ \begin{array}{ccc} 0 < R < (1-H) & , & \theta = 0 \\ 0 < R < 1 & , & \theta = \alpha \end{array} \right\} \tag{3.14c}$$

and

$$\frac{\partial T}{\partial R} = 0 \qquad \text{at} \qquad R = 0, \qquad \text{for} \quad \text{all} \;\; \theta \tag{3.14d}$$

To insure a well defined boundary condition at the centreline, the transformations $T' = T \cdot R$ and $U' = U \cdot R$ were introduced. The final form of the energy equation, initial and boundary conditions become

$$R\frac{\partial^2 T'}{\partial R^2} - \frac{\partial T'}{\partial R} + \frac{1}{R}\left(T' + \frac{\partial^2 T'}{\partial \theta^2}\right) = \frac{f_{fd,0}Re}{4}U'\frac{\partial T'}{\partial X^+} \tag{3.15}$$

at $X^+ = 0$

$$T' = 0 \qquad \text{for} \quad \text{all} \;\; R \;, \qquad \text{and} \quad \text{all} \;\; \theta \tag{3.16a}$$

for $X^+ > 0$

$$T' = T_w \cdot R \qquad \text{at} \qquad \left\{ \begin{array}{ccc} R = 1 & , & 0 \leq \theta \leq \alpha \\ (1-H) \leq R \leq 1 & , & \theta = 0 \end{array} \right\} \tag{3.16b}$$

$$\frac{\partial T'}{\partial \theta} = 0 \qquad \text{at} \qquad \left\{ \begin{array}{ccc} 0 < R < (1-H) & , & \theta = 0 \\ 0 < R < 1 & , & \theta = \alpha \end{array} \right\} \tag{3.16c}$$

and

$$T' = 0 \qquad \text{at} \qquad R = 0 \tag{3.16d}$$

In the fully developed region, energy equation (3.11) would still apply subject to the condition,

$$\frac{\partial t}{\partial x} = \frac{dt}{dx} = \frac{dt_b}{dx} = \frac{Q'}{\rho\ c_p\ u_b\ \pi\ r_o^2}$$

Using this relation and the transformations $U' = U \cdot R$ and $T' = T \cdot R$, the normalized form of the fully developed energy equation can be written as

$$R\frac{\partial^2 T'}{\partial R^2} - \frac{\partial T'}{\partial R} + \frac{1}{R}\left(T' + \frac{\partial^2 T'}{\partial \theta^2}\right) = U'R(\frac{f_{fd,0}Re}{2}) \tag{3.17}$$

Equation (3.17) is subject to boundary conditions (3.16b) to (3.16d).

The following definitions were adopted for the circumferentially averaged values of the heat transfer coefficient $h_{x,H1}$ and Nusselt number $Nu_{x,H1}$ at any axial location

$$h_{x,H1} = Q'/\left[\pi\ D_i\ (t_w - t_b)\right] \tag{3.18a}$$

and

$$Nu_{x,H1} = h_{x,H1} D_i / k \tag{3.18b}$$

In nondimensional form, we have

$$Nu_{x,H1} = 1/\left(T_w - T_b\right) \tag{3.19}$$

where

$$T_b = \left[\int_{\theta=0}^{\alpha} \int_{R=0}^{1} \left(U'T'/R\right) dR\ d\theta\right] / (U_b \alpha/2) \tag{3.20}$$

In the fully developed region, the definition of $Nu_{fd,H1}$ is similar to $Nu_{x,H1}$, given by equation (3.19) above. Additional relations are needed for the evalution of the dimensionless wall temperature T_w. These relations were obtained from the application of an overall energy balance, as shown later.

Energy Equation: (T) Boundary Condition

Equation (3.11) is valid for this condition subject to the following initial and boundary conditions :

at $x = 0$

$$\left\{ \begin{array}{ll} t = t_e & \text{within the fluid} \\ t = t_w & \text{at all solid boundaries} \end{array} \right\} \tag{3.21a}$$

for $x > 0$

$$t = t_w \quad \text{at} \quad \left\{ \begin{array}{ll} r = r_o & , \quad 0 \le \theta \le \alpha \\ r_i \le r \le r_o & , \quad \theta = 0 \end{array} \right\} \tag{3.21b}$$

$$\frac{\partial t}{\partial \theta} = 0 \quad \text{at} \quad \left\{ \begin{array}{ll} 0 < r < r_i & , \quad \theta = 0 \\ 0 < r < r_o & , \quad \theta = \alpha \end{array} \right\} \tag{3.21c}$$

and

$$\frac{\partial t}{\partial r} = 0 \quad \text{at} \quad r = 0, \quad \text{for all } \theta \tag{3.21d}$$

Normalizing using the appropriate definition of T given in the Nomenclature, we get

$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial T}{\partial R}\right) + \frac{1}{R^2}\frac{\partial^2 T}{\partial \theta^2} = \frac{f_{fd,0}Re}{4} U \frac{\partial T}{\partial X^+} \tag{3.22}$$

at $X^+ = 0$

$$\left\{ \begin{array}{ll} T = 1 & \text{within the fluid} \\ T = 0 & \text{at all solid boundaries} \end{array} \right\} \tag{3.23a}$$

for $X^+ > 0$

$$T = 0 \qquad \text{at} \qquad \left\{ \begin{array}{cc} R = 1 & , \quad 0 \le \theta \le \alpha \\ (1-H) \le R \le 1 & , \quad \theta = 0 \end{array} \right\} \tag{3.23b}$$

$$\frac{\partial T}{\partial \theta} = 0 \qquad \text{at} \qquad \left\{ \begin{array}{cc} 0 < R < (1-H) & , \quad \theta = 0 \\ 0 < R < 1 & , \quad \theta = \alpha \end{array} \right\} \tag{3.23c}$$

and

$$\frac{\partial T}{\partial R} = 0 \qquad \text{at} \qquad R = 0 \, , \quad \text{for all} \quad \theta \tag{3.23d}$$

Using the same transformations $T' = T \cdot R$ and $U' = U \cdot R$, the above system becomes

$$R \frac{\partial^2 T'}{\partial R^2} - \frac{\partial T'}{\partial R} + \frac{1}{R}\left(T' + \frac{\partial^2 T'}{\partial \theta^2} \right) = \frac{f_{fd,0} Re}{4} U' \frac{\partial T'}{\partial X^+} \tag{3.24}$$

at $X^+ = 0$

$$\left\{ \begin{array}{ll} T' = R & \text{within the fluid} \\ T' = 0 & \text{at all solid boundaries} \end{array} \right\} \tag{3.25a}$$

for $X^+ > 0$

$$T' = 0 \qquad \text{at} \qquad \left\{ \begin{array}{cc} R = 1 & , \quad 0 \le \theta \le \alpha \\ (1-H) \le R \le 1 & , \quad \theta = 0 \end{array} \right\} \tag{3.25b}$$

$$\frac{\partial T'}{\partial \theta} = 0 \qquad \text{at} \qquad \left\{ \begin{array}{cc} 0 < R < (1-H) & , \quad \theta = 0 \\ 0 < R < 1 & , \quad \theta = \alpha \end{array} \right\} \tag{3.25c}$$

and

$$T' = 0 \qquad \text{at} \qquad R = 0 \tag{3.25d}$$

Similarly, equation (3.11) applies in the fully developed region subject to the condition

$$\frac{\partial t}{\partial x} = \frac{t - t_w}{t_b - t_w}\frac{dt_b}{dx} = -\frac{Nu_{fd,T}\ (t - t_w)k}{\rho\ r_o^2\ u_b\ c_p} \tag{3.26}$$

Using this relation and the transformations $U' = U \cdot R$ and $T' = T \cdot R$, the normalized form of the fully developed energy equation takes the form,

$$R\frac{\partial^2 T'}{\partial R^2} - \frac{\partial T'}{\partial R} + \frac{1}{R}\left(T' + \frac{\partial^2 T'}{\partial \theta^2}\right) = -\frac{f_{fd,0}Re}{2}\ U'\ T'\ Nu_{fd,T} \tag{3.27}$$

Subject to boundary conditions (3.25b) to (3.25d).

The circumferentially averaged values of the heat transfer coefficient $h_{x,T}$ and Nusselt number $Nu_{x,T}$ at any axial location were calculated based on definitions (3.18a) and (3.18b), respectively. In nondimensional form, $Nu_{x,T}$ is given by

$$Nu_{x,T} = -\left[\int_{\theta=0}^{\alpha} \left.\frac{\partial T'}{\partial R}\right|_{R=1} d\theta\ -\ \int_{R=(1-H)}^{1} \frac{1}{R^2}\left.\frac{\partial T'}{\partial \theta}\right|_{\theta=0} dR\right]\Big(T_b\alpha/2\Big) \tag{3.28}$$

Equation (3.28) was also used in the fully developed region. Value of $Nu_{fd,T}$ used in equation (3.27) is not known apriori. Consequently, an iterative procedure was required for solving this equation, as described later.

3.2.2 Developing Isothermal Flow

This model is valid for steady, laminar flow of incompressible, Newtonian fluids. Properties are assumed to be constant throughout the flow domain. Axial mass diffusion and body forces are assumed to be negligible. Due to geometric symmetry of the flow domain, solutions of the governing equations are necessary only within $0 \leq r \leq r_o$ and $0 \leq \theta \leq \alpha$, as shown in Figure 3.3.

Based on the above assumptions, the applicable governing equations are as follows :

Axial Momentum

$$\rho\left[v\frac{\partial u}{\partial r}+\frac{w}{r}\frac{\partial u}{\partial \theta}+u\frac{\partial u}{\partial x}\right]=-\frac{\partial p}{\partial x}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial u}{\partial r})+\frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2}\right] \tag{3.29}$$

Radial Momentum

$$\rho\left[v\frac{\partial v}{\partial r}+\frac{w}{r}\frac{\partial v}{\partial \theta}-\frac{w^2}{r}+u\frac{\partial v}{\partial x}\right]=-\frac{\partial p}{\partial r}$$

$$+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(rv)\right)+\frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial w}{\partial \theta}\right] \tag{3.30}$$

Angular Momentum

$$\rho\left[v\frac{\partial w}{\partial r}+\frac{w}{r}\frac{\partial w}{\partial \theta}+\frac{vw}{r}+u\frac{\partial w}{\partial x}\right]=-\frac{1}{r}\frac{\partial p}{\partial \theta}$$

$$+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(rw)\right)+\frac{1}{r^2}\frac{\partial^2 w}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v}{\partial \theta}\right] \tag{3.31}$$

Continuity

$$\frac{1}{r}\frac{\partial}{\partial r}(rv)+\frac{1}{r}\frac{\partial w}{\partial \theta}+\frac{\partial u}{\partial x}=0 \tag{3.32}$$

To use the marching solution technique in the axial direction, the above set of elliptic equations must be parabolized. To parabolize these equations, two steps must be done; mass diffusion in the axial direction must be neglected ($\frac{\partial^2 u}{\partial x^2}=\frac{\partial^2 v}{\partial x^2}=\frac{\partial^2 w}{\partial x^2}=0$), which has already been assumed, and the pressure is subdivided into two parts. The first part of the pressure is a function of r and θ only and it is the driving force for the radial and angular velocities. The second part is a function of x only and it is the driving force for the main stream flow. The two parts are independent of each other and can be written as follows

$$p(x,r,\theta) = p'(r,\theta) + \bar{p}(x) \tag{3.33}$$

using relation (3.33), the governing equations reduce to

Axial Momentum

$$\rho\left[v\frac{\partial u}{\partial r} + \frac{w}{r}\frac{\partial u}{\partial \theta} + u\frac{\partial u}{\partial x}\right] = -\frac{d\bar{p}}{dx} + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial u}{\partial r}) + \frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2}\right] \tag{3.34}$$

Radial Momentum

$$\rho\left[v\frac{\partial v}{\partial r} + \frac{w}{r}\frac{\partial v}{\partial \theta} - \frac{w^2}{r} + u\frac{\partial v}{\partial x}\right] = -\frac{\partial p'}{\partial r}$$

$$+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(rv)\right) + \frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2} - \frac{2}{r^2}\frac{\partial w}{\partial \theta}\right] \tag{3.35}$$

Angular Momentum

$$\rho\left[v\frac{\partial w}{\partial r} + \frac{w}{r}\frac{\partial w}{\partial \theta} + \frac{vw}{r} + u\frac{\partial w}{\partial x}\right] = -\frac{1}{r}\frac{\partial p'}{\partial \theta}$$

$$+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(rw)\right) + \frac{1}{r^2}\frac{\partial^2 w}{\partial \theta^2} + \frac{2}{r^2}\frac{\partial v}{\partial \theta}\right] \tag{3.36}$$

Continuity

$$\frac{1}{r}\frac{\partial}{\partial r}(rv) + \frac{1}{r}\frac{\partial w}{\partial \theta} + \frac{\partial u}{\partial x} = 0 \qquad (3.37)$$

These equations are subject to the following initial and boundary conditions

at $x = 0$

$$\left\{ \begin{array}{ll} u = u_b & \text{within the fluid} \\ u = 0 & \text{at all solid boundaries} \end{array} \right\} \qquad (3.38a)$$

$$\bar{p} = \bar{p}_o \qquad \text{within the fluid} \qquad (3.38b)$$

and

$$v = w = p' = 0 \qquad \text{for all } r \text{ and all } \theta \qquad (3.38c)$$

where $\bar{p}_o$ could assume any value without influencing the solution.

For $x > 0$

$$u = v = w = 0 \qquad \text{at} \qquad \left\{ \begin{array}{ll} r = r_o & , \quad 0 \le \theta \le \alpha \\ r_i \le r \le r_o & , \quad \theta = 0 \end{array} \right\} \qquad (3.39a)$$

$$\frac{\partial u}{\partial \theta} = \frac{\partial v}{\partial \theta} = w = 0 \qquad \text{at} \qquad \left\{ \begin{array}{ll} 0 < r < r_o & , \quad \theta = \alpha \\ 0 < r < r_i & , \quad \theta = 0 \end{array} \right\} \qquad (3.39b)$$

$$\frac{\partial u}{\partial r} = v = w = 0 \qquad \text{at} \qquad r = 0 \,, \quad \text{for all } \theta \qquad (3.39c)$$

Normalizing the governing equations and the applicable initial and boundary conditions using the dimensionless quantities given in the Nomenclature, we get

Axial Momentum

$$V\frac{\partial U}{\partial R} + \frac{W}{R}\frac{\partial U}{\partial \theta} + \frac{U}{2}\frac{\partial U}{\partial X} = \frac{2}{R}\frac{\partial}{\partial R}\left(R\frac{\partial U}{\partial R}\right) + \frac{2}{R^2}\frac{\partial^2 U}{\partial \theta^2} - \frac{1}{2}\frac{d\bar{P}}{dX} \qquad (3.40)$$

Radial Momentum

$$V\frac{\partial V}{\partial R} + \frac{W}{R}\frac{\partial V}{\partial \theta} - \frac{W^2}{R} + \frac{U}{2}\frac{\partial V}{\partial X} = 2\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial}{\partial R}(RV)\right) + \frac{2}{R^2}\frac{\partial^2 V}{\partial \theta^2} - \frac{4}{R^2}\frac{\partial W}{\partial \theta} - \frac{\partial P'}{\partial R} \tag{3.41}$$

Angular Momentum

$$V\frac{\partial W}{\partial R} + \frac{W}{R}\frac{\partial W}{\partial \theta} + \frac{VW}{R} + \frac{U}{2}\frac{\partial W}{\partial X} = 2\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial}{\partial R}(RW)\right) + \frac{2}{R^2}\frac{\partial^2 W}{\partial \theta^2} + \frac{4}{R^2}\frac{\partial V}{\partial \theta} - \frac{1}{R}\frac{\partial P'}{\partial \theta} \tag{3.42}$$

Continuity

$$\frac{\partial}{\partial R}(RV) + \frac{\partial W}{\partial \theta} + \frac{R}{2}\frac{\partial U}{\partial X} = 0 \tag{3.43}$$

at $X = 0$

$$\left\{\begin{array}{ll} U = 1 & \text{within the fluid} \\ U = 0 & \text{at all solid boundaries} \end{array}\right\} \tag{3.44a}$$

$$\bar{P} = \bar{P}_o \qquad \text{within the fluid} \tag{3.44b}$$

and

$$V = W = P' = 0 \qquad \text{for all } R \text{ and } \theta \tag{3.44c}$$

For $X > 0$

$$U = V = W = 0 \qquad \text{at} \quad \left\{\begin{array}{ll} R = 1 & , \quad 0 \le \theta \le \alpha \\ (1-H) \le R \le 1 & , \quad \theta = 0 \end{array}\right\} \tag{3.45a}$$

$$\frac{\partial U}{\partial \theta} = \frac{\partial V}{\partial \theta} = W = 0 \qquad \text{at} \quad \left\{\begin{array}{ll} 0 < R < 1 & , \quad \theta = \alpha \\ 0 < R < (1-H) & , \quad \theta = 0 \end{array}\right\} \tag{3.45b}$$

$$\frac{\partial U}{\partial R} = V = W = 0 \qquad \text{at} \qquad R = 0\,, \qquad \text{for all } \theta \tag{3.45c}$$

In the fully developed flow region, $V = W = P' = \frac{\partial U}{\partial X} = 0$, and $d\bar{P}/dX$ becomes constant along X. Consequently equations (3.41) to (3.43) vanish and equation (3.40) reduces to

$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial U}{\partial R}\right) + \frac{1}{R^2}\frac{\partial^2 U}{\partial \theta^2} = \frac{1}{4}\frac{d\bar{P}}{dX} \tag{3.46}$$

The boundary conditions applicable to equation (3.46) are similar to equations (3.45a) to (3.45c).

Some of the very important parameters that are calculated after the solution of the above model, such as the local friction factor f_x, Reynolds number Re, the apparent friction factor f_{app} and the incremental pressure drop number K are defined as follows :

$$f_x = D_i(-d\bar{p}/dx)/(2\rho u_b^2) \tag{3.47a}$$

$$Re = \rho u_b D_i/\mu \tag{3.47b}$$

Therefore, the product $f_x Re$ in dimensionless form is expressed by

$$f_x Re = -\frac{1}{2}\frac{d\bar{P}}{dX} \tag{3.48}$$

The apparent friction factor is given by

$$f_{app} = D_i\left[(\bar{p}_o - \bar{p})/x\right]/\left(2\rho u_b^2\right) \tag{3.49}$$

in dimensionless form, $f_{app}Re$ can be written as

$$f_{app}Re = \left(\bar{P}_o - \bar{P}\right)/(2X) \tag{3.50}$$

The pressure drop can be treated as the sum of two components; one is based on the fully developed conditions and the other is a consequence of the change of momentum in the entrance region, thus

$$\frac{\bar{p}_o - \bar{p}}{\rho u_b^2/2} = \frac{4\, f_{fd}\, x}{D_i} + K \tag{3.51}$$

Substituting from equations (3.47) and (3.49) into equation (3.51) and reducing we get

$$K = 4X\left[f_{app}Re - f_{fd}Re\right] \tag{3.52}$$

Normally, the value of K increases gradually in the entrance region and asymptotically reaches a limiting value K_∞ which remains constant in the fully developed region.

3.2.3 Fully-Developed Mixed Convection

This model is applicable to steady, laminar flow of incompressible, Newtonian fluids. Properties are assumed to be constant, except for the density which is temperature dependent where buoyancy effects are considered. Axial conduction and viscous dissipation within the fluid are assumed negligible. The flow is assumed to be fully developed hydrodynamically and thermally with uniform heat input axially and uniform wall temperature circumferentially. Consequently, the three velocity components, the axial pressure gradient and the axial temperature gradient are all invariant in the flow direction. This analysis assumes that each tube is always oriented with the uppermost fin in the vertical direction. Due to the flow symmetry, the solution is necessary only for $0 \leq r \leq r_o$ and $0 \leq \theta \leq \pi$, as shown in Figure 3.4. As well, this analysis considers the case of heating, i.e. situations where the wall temperature is higher than the fluid temperature.

The applicable momentum, energy, and continuity equations under the above assumptions and conditions are

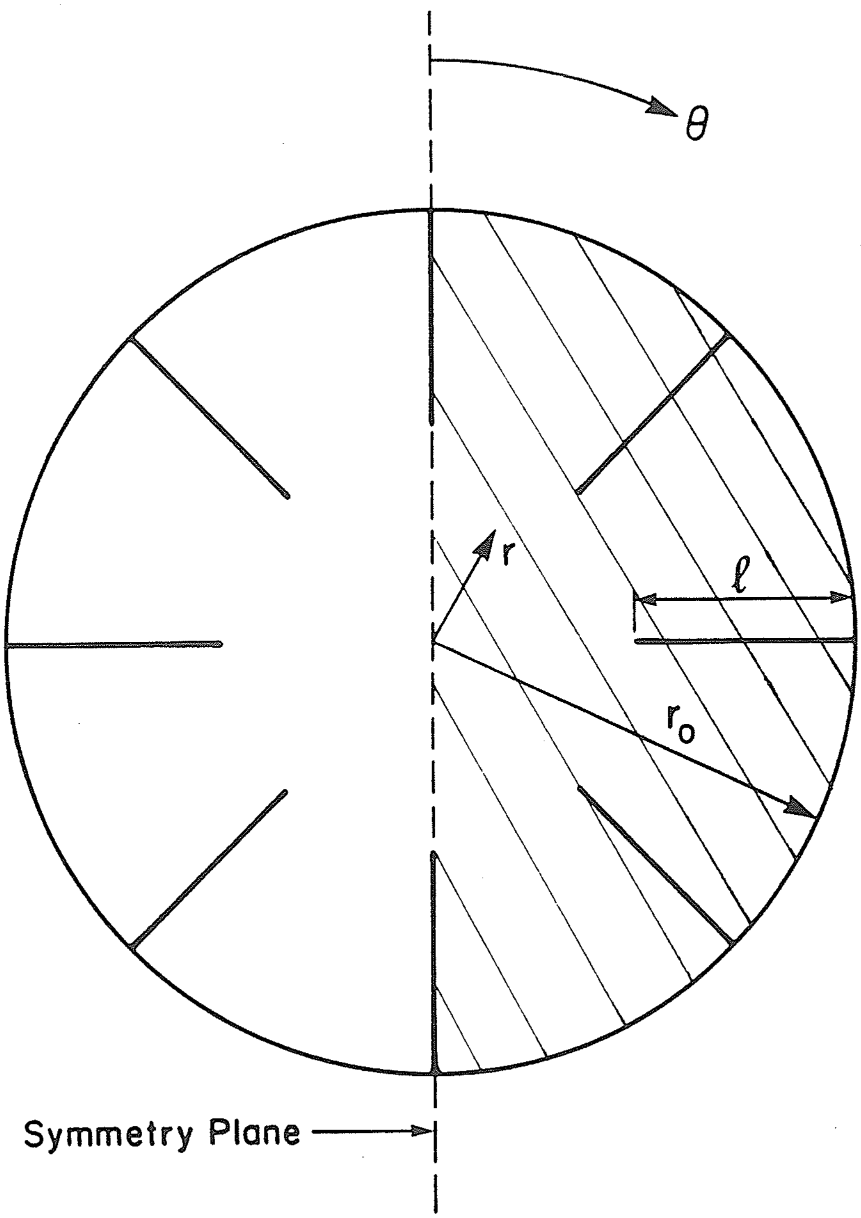


Figure 3.4 Solution domain for fully-developed mixed convection

Axial Momentum

$$\rho\left[v\frac{\partial u}{\partial r}+\frac{w}{r}\frac{\partial u}{\partial \theta}\right]=-\frac{\partial p}{\partial x}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial u}{\partial r})+\frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2}\right] \tag{3.53}$$

Radial Momentum

$$\rho\left[v\frac{\partial v}{\partial r}+\frac{w}{r}\frac{\partial v}{\partial \theta}-\frac{w^2}{r}\right]=\rho\; g_r-\frac{\partial p}{\partial r}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(rv)\right)+\frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial w}{\partial \theta}\right] \tag{3.54}$$

Angular Momentum

$$\rho\left[v\frac{\partial w}{\partial r}+\frac{w}{r}\frac{\partial w}{\partial \theta}+\frac{vw}{r}\right]=\rho\; g_\theta-\frac{1}{r}\frac{\partial p}{\partial \theta}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(rw)\right)+\frac{1}{r^2}\frac{\partial^2 w}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v}{\partial \theta}\right] \tag{3.55}$$

Continuity

$$\frac{\partial}{\partial r}(rv)+\frac{\partial w}{\partial \theta}=0 \tag{3.56}$$

Energy

$$\rho c_p\left[v\frac{\partial t}{\partial r}+\frac{w}{r}\frac{\partial t}{\partial \theta}+u\frac{\partial t}{\partial x}\right]=k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 t}{\partial \theta^2}\right] \tag{3.57}$$

The momentum equations were parabolized by introducing the approximate representation of the pressure given by equation (3.33). The Boussinesq approximation was used in formulating the body force terms in the momentum equations, which basically states that the density changes linearly with temperature as follows

$$\rho=\rho_w\left[1+\beta\left(t_w-t\right)\right] \tag{3.58}$$

Nondimensionlizing, we get

Axial Momentum

$$V\frac{\partial U}{\partial R}+\frac{W}{R}\frac{\partial U}{\partial \theta}=-\frac{1}{2}\frac{d\bar{P}}{\partial X}+2\left[\frac{\partial^2 U}{\partial R^2}+\frac{1}{R}\frac{\partial U}{\partial R}+\frac{1}{R^2}\frac{\partial^2 U}{\partial \theta^2}\right] \tag{3.59}$$

Radial Momentum

$$V\frac{\partial V}{\partial R}+\frac{W}{R}\frac{\partial V}{\partial \theta}-\frac{W^2}{R}=\frac{Gr^+\,T}{2}cos\theta-\frac{\partial P'}{\partial R}$$

$$+2\left[\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial}{\partial R}(RV)\right)+\frac{1}{R^2}\frac{\partial^2 V}{\partial \theta^2}-\frac{2}{R^2}\frac{\partial W}{\partial \theta}\right] \tag{3.60}$$

Angular Momentum

$$V\frac{\partial W}{\partial R}+\frac{W}{R}\frac{\partial W}{\partial \theta}+\frac{VW}{R}=-\frac{Gr^+\,T}{2}sin\theta-\frac{1}{R}\frac{\partial P'}{\partial \theta}$$

$$+2\left[\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial}{\partial R}(RW)\right)+\frac{1}{R^2}\frac{\partial^2 W}{\partial \theta^2}+\frac{2}{R^2}\frac{\partial V}{\partial \theta}\right] \tag{3.61}$$

Continuity

$$\frac{\partial}{\partial R}(RV)+\frac{\partial W}{\partial \theta}=0 \tag{3.62}$$

Energy

$$\frac{Pr}{2}\left(V\frac{\partial T}{\partial R}+\frac{W}{R}\frac{\partial T}{\partial \theta}+\frac{2U}{Pr}\right)=\frac{\partial^2 T}{\partial R^2}+\frac{1}{R}\frac{\partial T}{\partial R}+\frac{1}{R^2}\frac{\partial^2 T}{\partial \theta^2} \tag{3.63}$$

Introducing the transformation $V' = V \cdot R$, the mathematical model takes the following final form

Axial Momentum

$$\frac{V'}{R}\frac{\partial U}{\partial R} + \frac{W}{R}\frac{\partial U}{\partial \theta} = -\frac{1}{2}\frac{d\bar{P}}{dX} + 2\left[\frac{\partial^2 U}{\partial R^2} + \frac{1}{R}\frac{\partial U}{\partial R} + \frac{1}{R^2}\frac{\partial^2 U}{\partial \theta^2}\right] \tag{3.64}$$

Radial Momentum

$$\frac{V'}{R}\frac{\partial V}{\partial R} + \frac{W}{R^2}\frac{\partial V'}{\partial \theta} - \frac{W^2}{R} = \frac{Gr^+T}{2}cos\theta - \frac{\partial P'}{\partial R}$$
$$+2\left[\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial V'}{\partial R}\right) + \frac{1}{R^3}\frac{\partial^2 V'}{\partial \theta^2} - \frac{2}{R^2}\frac{\partial W}{\partial \theta}\right] \tag{3.65}$$

Angular Momentum

$$\frac{V'}{R}\frac{\partial W}{\partial R} + \frac{W}{R}\frac{\partial W}{\partial \theta} + \frac{V'W}{R^2} = -\frac{Gr^+\ T}{2}sin\theta - \frac{1}{R}\frac{\partial P'}{\partial \theta}$$
$$+2\left[\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial}{\partial R}(RW)\right) + \frac{1}{R^2}\frac{\partial^2 W}{\partial \theta^2} + \frac{2}{R^3}\frac{\partial V'}{\partial \theta}\right] \tag{3.66}$$

Continuity

$$\frac{\partial V'}{\partial R} + \frac{\partial W}{\partial \theta} = 0 \tag{3.67}$$

Energy

$$\frac{Pr}{2}\left(\frac{V'}{R}\frac{\partial T}{\partial R} + \frac{W}{R}\frac{\partial T}{\partial \theta} + \frac{2U}{Pr}\right) = \frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} + \frac{1}{R^2}\frac{\partial^2 T}{\partial \theta^2} \tag{3.68}$$

It must be pointed out that a transformed radial velocity V' is used in equations (3.64) to (3.68) instead of the velocity V in order to invoke a strong boundary condition ($V' = 0$) at the centerline of the tube. Along the solid boundaries, the three velocity components and temperature are equal to zero, while at the symmetry plane, the normal velocity component is equal to zero and the normal gradients of the other two velocity components and the temperature are equal to zero.

Definitions (3.19) and (3.48) were used in calculating Nu_{fd} and $f_{fd}Re$, respectively.

The mathematical formulation, equations (3.64) to (3.68), indicates that the velocity, pressure, and temperature distributions for a particular finned tube geometry (i.e. given H and M) are functions of the two independent parameters Pr and Gr^+. Therefore, overall quantities such as Nu_{fd} and $f_{fd}Re$ would also be dependent on Pr and Gr^+ beside the geometric parameters H and M. The axial pressure gradient term ($d\bar{P}/dX$) that appears in equation (3.64) is calculated from a global mass balance, as shown later.

CHAPTER 4

SOLUTION PROCEDURE AND ACCURACY ASSESSMENT

4.1 Developing Forced Convection

The governing equations for this model consist of a fully developed momentum equation and two energy equations for each thermal boundary condition. One energy equation applies in the fully developed region and the other in the thermally developing region. The sequence of solving this system of equations started by solving the momentum equation, thus providing the axial velocity distribution which was required for solving the energy equations. The next step for each B.C. was to solve the energy equation in the fully developed region, thus yielding a temperature distribution from which $Nu_{fd,0}$ was calculated. After solving the fully developed energy equation, the developing energy equation was solved using a marching technique, starting from the tube entrance and proceeding by a certain axial step ΔX^+. At each axial location, the temperature distribution was generated and the circumferential average local Nusselt number was calculated. At the cross-section where the local value of Nusselt number reached 1.05 times the fully developed value the solution was stopped and the value X^+ at this cross-section was considered the thermal entrance length L^+. Tube geometry (H and M) is the only necessary input information required for the solution.

4.1.1 Solution Procedure

Momentum Equation

The momentum equation in its nondimensional form (3.5) and the applicable boundary conditions (3.6) were solved numerically using a finite-difference approach. All derivatives were approximated by second order central differences.

The resulting set of algebraic finite difference equations were then solved using Gauss Seidel point by point iterative method with overrelaxation factors ranging from 1.90 to 1.99. The iterating process was continued until the velocity at each single nodal point has converged. The criteria used to judge the convergence was by comparing the velocity at each nodal point with its value from the previous iteration. If the change was within $\pm\ 10^{-3}\%$ at all mesh points, then the solution was considered to be converged. The velocity field was then integrated over the solution domain using equation (3.10) to get U_b. The dimensionless parameter $f_{fd,0}Re$ was then calculated from equation (3.9) and the solution was progressed to the next step which deals with the energy equation.

Energy Equation : (H1) Boundary Condition

The nondimensional fully developed energy equation (3.17) was solved numerically subject to boundary conditions (3.16). Values of U' and $f_{fd,0}Re$ are known from the solution of the momentum equation, and T_w can assume any value without influencing the solution. Equation (3.17) was discretized and solved using similar procedure to the one used in solving the momentum equation. Once a converged solution was established, the bulk temperature was evaluated using equation (3.20). The fully developed Nusselt number was then calculated using equation (3.19).

In the developing region, energy equation (3.15) and the applicable initial and boundary conditions (3.16) were discretized using a finite difference approach. In the R and θ directions, differential terms were discretized using second order central differences, while in the axial direction, terms were discretized using first order backward differences to facilitate the use of the marching technique in the axial direction.

The procedure required solving simultanously for all the temperatures at any axial location X^+ provided that the previous station ($X^+ - \Delta X^+$) was solved for. The iteration technique at any axial location was similar to that used in solving the momentum and the fully-developed energy equations. To determine the wall temperature at any axial location, an iterative procedure was necessary. Using an overall energy balance between the tube inlet and any axial location, we get

$$Q' = \frac{\dot{m}c_p(t_b - t_e)}{x} \quad , \tag{4.1}$$

which reduces to the following nondimensional form

$$T_b = 2 \cdot X^+ \tag{4.2}$$

The energy equation was solved using an initial guess for T_w and the bulk temperature was calculated using equation (3.20) and compared with the value from equation (4.2). If the two values deviate, the wall temperature was corrected as follows

$$T_w^{n+1} = T_w^n \cdot \frac{2X^+}{T_b^n} \tag{4.3}$$

where n indicates the present iteration, and $n+1$ the next iteration. This procedure was repeated until both values of T_b agreed to four significant figures. The local Nusselt number was then calculated using equation (3.19) and the solution was marched to the next axial station. The solution was terminated at the axial distance where the local Nusselt number approached the fully developed Nusselt number by 5% and the value of X^+ there was taken as the thermal entrance length L_{H1}^+.

Energy Equation: (T) Boundary Condition

The nondimensional fully developed energy equation (3.27) was solved with initial and boundary conditions (3.25). The appearance of $Nu_{fd,T}$ in the right hand side of the energy equation caused the solution to be iterative. An initial value of $Nu_{fd,T}$ was guessed and the solution was carried out following similar procedure to the one used in solving the momentum equation and the fully developed energy equation with (H1) boundary condition. $Nu_{fd,T}$ was calculated from the resulting T' using equation (3.28) and substituted into the right hand side of the energy equation. This iterating procedure was continued until $Nu_{fd,T}$ converged to five significant figures.

The solution procedure in the developing region was similar to the one used for the (H1) boundary condition. No iteration was necessary since the wall temperature was known apriori. The solution was terminated at the axial station where $Nu_{x,T} = 1.05\ Nu_{fd,T}$ and the value of X^+ there represented L_T^+.

4.1.2 Selection of Grid Size

The solution domain in the R, θ, and X^+ directions was discretized by an uneven three dimensional mesh. At any cross section, higher concentrations of mesh points were used near the solid boundaries (tube wall and fin side), under the fin, and near the tube centerline due to the steep gradients of U' and T' at these locations. Similarly, in the X^+ direction, very small values of ΔX^+ were used near the beginning of heating, increasing gradually in the flow direction. In the R and θ directions, the mesh was basically of uniform divisions in both directions of R and θ, with the first division near the wall, beside the fin, under the fin, and at the centerline subdivided into six subdivisions (Figure 4.1).

The decision about the grid size in the R and θ directions was guided by the accuracy of the results in the fully developed region. Solutions were obtained for the four extreme geometries covered in this problem. These geometries are ($H = 0.2$, $M = 4$), ($H = 0.8$, $M = 4$), ($H = 0.2$, $M = 24$), and ($H = 0.8$, $M = 24$).

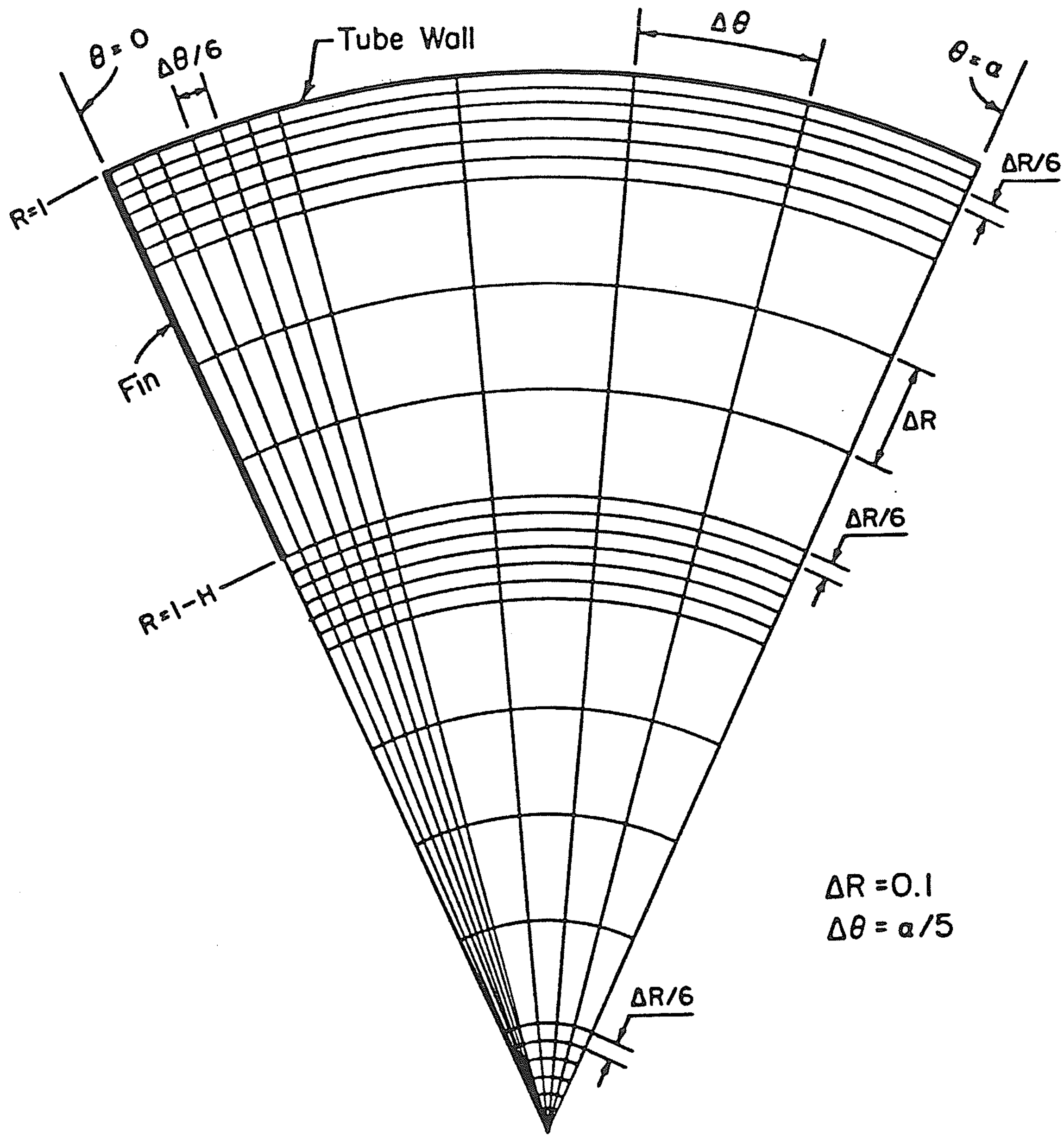


Figure 4.1 Appearance of the mesh for $\Delta R = 0.1$ and $\Delta\theta = \alpha/5$

Results of $f_{fd,0}Re$ and $Nu_{fd,H1}$ were obtained for different grid sizes in the radial and angular directions, as shown in Table 4.1. A grid size of 35×20 (Radial $\times$ Angular) was found to be a good compromise between accuracy and computer time.

The decision about the grid size in the X^+ direction was guided by the accuracy of the results in the developing region for the smooth tube and two internally finned tubes. The first trial of mesh selection was made by taking the first ten steps with $\Delta X^+ = 10^{-6}$, followed by another ten steps with $\Delta X^+ = 10^{-5}$, followed by a gradual increase of ΔX^+ starting with a value of $\Delta X^+ = 10^{-4}$ and increasing gradually by a factor of 20% in each step over the previous step (i.e. $\Delta X^+\Big|_{X^+ + \Delta X^+} = 1.2 * \Delta X^+\Big|_{X^+}$) to a maximum $\Delta X^+ = 10^{-3}$ where it was kept constant for the rest of the steps. This grid size was used to calculate the thermal entrance lengths of the smooth tube and two internally finned tubes ($H = 0.2$, $M = 4$ and $H = 0.8$, $M = 4$). The results of L^+_{H1} and L^+_T for these geometries are shown in Table 4.2. A second trial was carried out using the first ten steps with $\Delta X^+ = 10^{-6}$, followed by another ten steps with $\Delta X^+ = 10^{-5}$ followed by a gradual increase of ΔX^+ starting with a value of $\Delta X^+ = 10^{-4}$ and increasing it gradually by a factor of 5% in each step over the previous step (i.e. $\Delta X^+\Big|_{X^+ + \Delta X^+} = 1.05 * \Delta X^+\Big|_{X^+}$) to a maximum ($\Delta X^+ = 10^{-3}$) where it was kept constant for the rest of the steps. This grid was different from the previous one only in the rate of the gradual increase of ΔX^+ from 10^{-4} to 10^{-3}. The results of L^+_{H1} and L^+_T for the same geometries of the previous trial are also shown in Table 4.2. A further refining of the axial grid size (trial 3) was carried out by taking the first ten steps with $\Delta X^+ = 10^{-7}$, followed by another ten steps with $\Delta X^+ = 10^{-6}$, followed by a gradual increase of ΔX^+ starting with a value of $\Delta X^+ = 10^{-5}$ and increasing gradually by a factor of 5% in each step over the previous step to a maximum $\Delta X^+ = 10^{-3}$ which was kept constant for the rest of the steps. The results, as shown in Table 4.2, do not show significant difference between trials 2 and 3; however, the computer time required with trial 3 was found to be over 50% higher than that with trial 2. The axial step

Table 4.1 Effect of mesh size on the value of $f_{fd,0}Re$ and $Nu_{fd,H1}$ for some selected geometries

	Mesh Size $(R \times \theta)$	$H = 0.2$ $M = 4$	$H = 0.8$ $M = 4$	$H = 0.2$ $M = 24$	$H = 0.8$ $M = 24$
$f_{fd,0}Re$	35 × 15	18.587	71.195	30.266	853.054
	35 × 20	18.574	71.169	30.253	852.816
	35 × 25	18.568	71.161	30.239	852.868
	35 × 45	18.558	71.145	30.212	852.751
	30 × 20	18.571	71.182	30.413	856.865
	40 × 20	18.568	71.167	30.151	852.219
	45 × 20	18.567	71.156	30.080	851.108
	50 × 20	18.563	71.148	30.026	850.613
	50 × 45	18.543	71.125	30.014	850.536
$Nu_{fd,H1}$	35 × 15	4.547	19.406	4.621	153.667
	35 × 20	4.545	19.399	4.621	153.678
	35 × 25	4.544	19.399	4.622	153.686
	35 × 45	4.542	19.399	4.624	153.740
	30 × 20	4.543	19.334	4.618	159.290
	40 × 20	4.551	19.426	4.625	152.801
	45 × 20	4.553	19.441	4.628	151.234
	50 × 20	4.556	19.448	4.631	150.812
	50 × 45	4.553	19.448	4.636	150.869

Table 4.2 The effect of the axial step size on the values of L^+_{H1} and L^+_T for some selected geometries

	Mesh Size	$H = 0.2 \quad M = 4$	$H = 0.8 \quad M = 4$	Smooth Tube
L^+_{H1}	Trial 1	0.09878	0.02348	0.09681
	Trial 2	0.09029	0.02180	0.08831
	Trial 3	0.09004	0.02171	0.08806
L^+_T	Trial 1	0.05817	0.01984	0.08276
	Trial 2	0.05180	0.01764	0.07136
	Trial 3	0.05175	0.01749	0.07132

sizes of trial 2 were used to generate all the results as a reasonable compromise between accuracy and computer time.

4.1.3 Validation of Accuracy

One way to substantiate the accuracy of the numerical solution is by comparing the generated results with existing data. In the developing region, results of L^+_{H1}, L^+_T, $Nu_{x,H1}$, and $Nu_{x,T}$ exist only for the limiting case of smooth tubes; figure 4.2 shows $Nu_{x,H1}$ and $Nu_{x,T}$ as compared with the theoretical results reported by Shah and London (1978). The agreement is shown to be very good. The values of L^+_{H1} of 0.08840 and L^+_T of 0.06880 reported by Shah and London (1978) compares very well with L^+_{H1} of 0.08831 and L^+_T of 0.07136 of the present analysis. For the case of internally finned tubes, data of fRe and Nu are available only for the fully developed region. Therefore, comparisons are made for the case of $Nu_{fd,H1}$ and $f_{fd,0}Re$ with Hu and Chang (1973), Masliyah and Nandakumar (1976), and Soliman and Feingold (1978). These comparisons, as shown in Table 4.3, are in good agreement.

4.2 Developing Isothermal Flow

The system of governing equations of this model consists of a single axial momentum equation in the fully developed region, and a set four equations in the developing region (axial momentum, radial momentum, angular momentum, and continuity). The sequence of solving these equations starts by solving the momentum equation in the fully developed region, thus providing a velocity distribution and consequently the parameter $f_{fd,0}Re$ was calculated. The value of $f_{fd,0}Re$ served as a guide for determining the axial location where the marching solution in the developing region was terminated.

The system of equations in the developing region is nonlinear and coupled, therefore, an iterative technique was necessary to solve all four equations simultaneously. The solution technique selected to solve these equations was a revised version of a

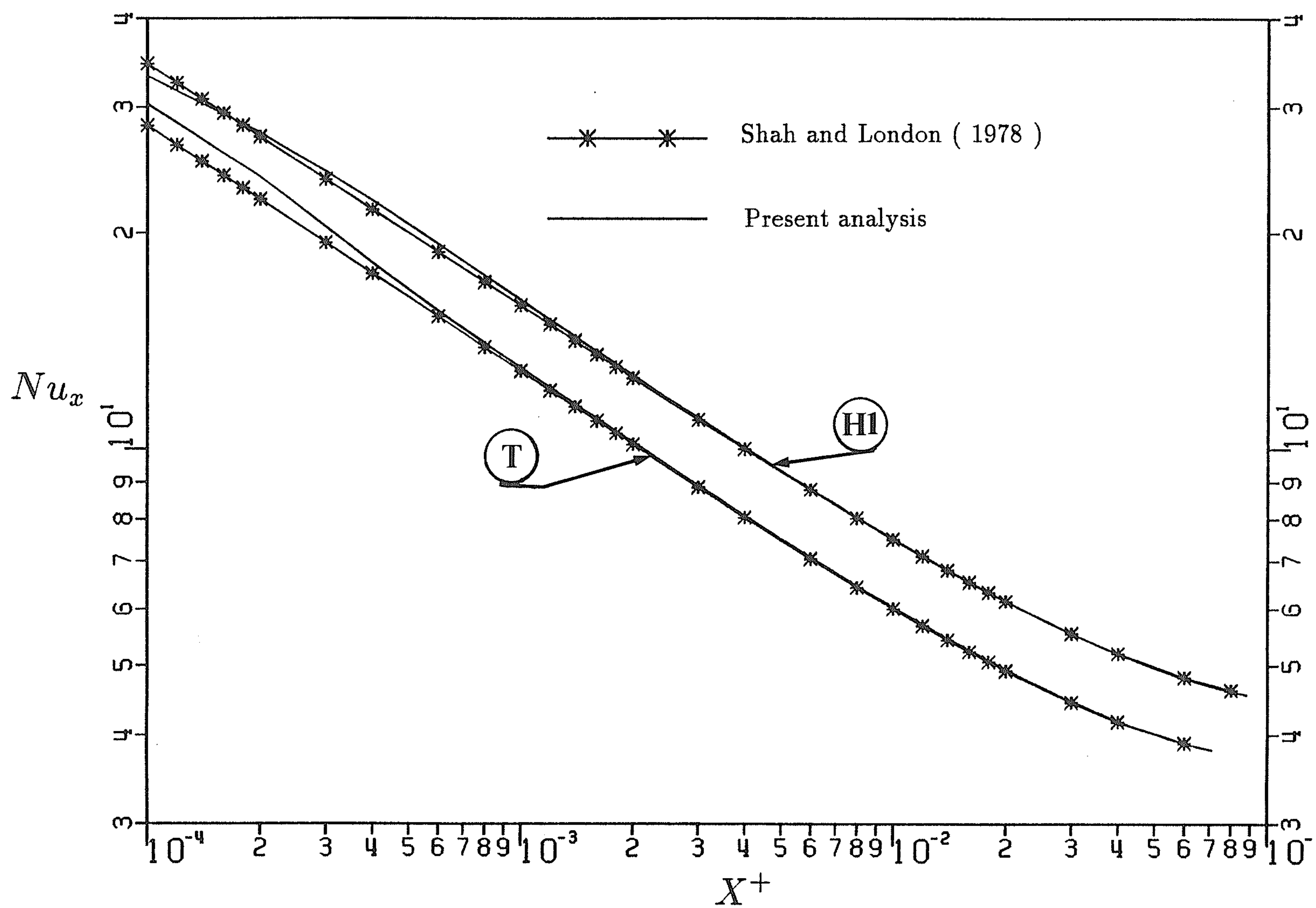


Figure 4.2 Comparison between the present results of $Nu_{x,H1}$ and $Nu_{x,T}$ and existing results for smooth tubes

Table 4.3 Comparisons of $f_{fd,0}Re$ and $Nu_{fd,H1}$ with results from three other sources.

Tube Geometry		Present Results		Hu and Chang (1973)	Masliyah and Nandakumar (1975, 1976)		Soliman and Feingold (1977, 1978)	
H	M	$f_{fd,0}Re$	$Nu_{fd,H1}$	$f_{fd,0}Re$	$f_{fd,0}Re$	$Nu_{fd,H1}$	$f_{fd,0}Re$	$Nu_{fd,H1}$
0.2	4	18.57	4.54	—	19.13	4.58	19.15	4.63
	8	21.50	4.69	21.22	22.39	4.74	22.08	4.75
	16	26.71	4.72	25.99	28.20	4.74	26.77	4.74
	24	30.25	4.62	—	32.01	4.62	29.92	4.64
0.4	4	27.67	5.88	—	29.04	6.05	28.63	6.07
	8	44.11	6.77	42.87	47.02	6.98	44.40	6.82
	16	72.33	6.03	69.57	77.86	6.09	71.15	6.03
	24	88.98	5.32	—	95.57	5.32	87.07	5.33
0.6	4	47.64	11.17	—	50.31	11.82	48.16	11.38
	8	103.9	19.36	101.1	110.8	21.10	103.1	19.12
	16	227.9	15.17	219.5	246.1	16.22	224.1	14.85
	24	328.5	10.16	—	356.0	10.41	321.0	9.99
0.8	4	71.17	19.39	—	73.43	19.30	71.12	19.47
	8	166.0	43.46	164.8	170.50	42.58	165.6	43.73
	16	453.4	107.6	448.4	469.90	106.5	451.2	107.4
	24	852.8	153.7	838.2	894.20	156.9	846.4	147.9

semi implicit technique called "SIMPLER". This technique was found to be powerful in handling nonlinear coupled systems of partial differential equations of this kind. The solution was carried out in the developing region using a marching technique, starting at the tube entrance and progressing in the direction of flow with a step equal to ΔX. At each axial station, the local value of $f_x Re$ was calculated and compared with $f_{fd,0} Re$. The solution was stopped and considered complete for any particular geometry as $f_x Re$ approached $f_{fd,0} Re$ by 1%, and the corresponding value of X was called the hydrodynamic entrance length "$L_{H,1\%}$". At each axial station some other engineering parameters were calculated from the resulting velocity distribution, such as $f_{app} Re$ and K.

This model was used to generate data for sixteen different geometries of internally finned tubes plus the geometry of the smooth tube. The internally finned tubes correspond to combinations of the geometric parameters H = 0.2, 0.4, 0.6, and 0.8 and M = 4, 8, 16, and 24.

4.2.1 Solution Procedure

The momentum equation in the fully developed region (3.46) was discretized using the control volume based finite difference method. The equation was integrated over a control volume resulting in an algebraic equation for each mesh point. The coefficients were all constants and the solution was iterative only due to the presence of $\frac{d\bar{P}}{dX}$ in the right hand side of the momentum equation. A line by line sweeping technique was used to solve the system of algebraic equations. The solution was assumed converged if the percentage change in the velocity at every mesh point came within $\pm\ 10^{-3}\%$. A global mass balance must be satisfied at the correct value of $\frac{d\bar{P}}{dX}$, as follows :

$$\int_0^{\alpha} \int_0^1 U\ R\ dR\ d\theta = (\pi/2M) \tag{4.4}$$

If equation (4.4) was not satisfied, the iterative procedure was continued until the pressure gradient term $\frac{d\bar{P}}{dX}$ converged to five significant figures.

In the developing region, the applicable momentum and continuity equations in their nondimensional form, (3.40) to (3.43), and their applicable initial and boundary conditions (3.44) and (3.45) were solved using a control volume based finite difference approach. The solution domain was discretized using a three dimensional mesh. The governing equations were integrated each over its corresponding control volume resulting in a system of algebraic equations coupled by variable coefficients. The "SIMPLER" technique as discussed by Patankar (1980) was followed closely. The continuity equation was used to construct a pressure equation and a pressure correction equation. The pressure equation was used in this technique to generate a pressure distribution that was used to solve the radial and angular momentum equations. The pressure correction equation was used to correct the computed radial and angular velocities and bring them into conformity with the continuity equation. The "SIMPLER" scheme follows these steps, at each axial station

1) Start with a guessed velocity field.
2) Calculate the variable coefficients of the momentum equations.
3) Calculate the coefficients for the pressure equation and solve it.
4) Assume a value for the axial pressure gradient $\frac{d\bar{P}}{dX}$.
5) Solve the three momentum equations separately using the pressure distribution P' from step 3 and the assumed value of $\frac{d\bar{P}}{dX}$ from step 4.
6) Solve the pressure correction equation.
7) Correct the velocity field using the pressure correction from step 6 above.
8) Correct the term $\frac{d\bar{P}}{dX}$ using the global mass balance, given by equation (4.4).
9) Return to step 2 and repeat until convergence.

Each of the momentum equations, the pressure, and the pressure correction equations were solved using a line by line sweep until converged to five significant figures. The global convergence of the scheme was checked by more than one criteria as follows :

1) The absolute value of the continuity equation residual must be less than 10^{-6} for each control volume.

2) The axial pressure gradient $\frac{d\bar{P}}{dX}$ must converge to five significant figures.

3) The average change in the radial and angular velocities must converge to five significant figures, (i.e. $\left[\sum \left|V^{n-1}(I,J) - V^{n}(I,J)\right| / \sum \left|V^{n}(I,J)\right|\right] < 10^{-3}\%$, and $\left[\sum \left|W^{n-1}(I,J) - W^{n}(I,J)\right| / \sum \left|W^{n}(I,J)\right|\right] < 10^{-3}\%$ where n indicates the present global iteration and $n-1$, indicates the previous global iteration.

Knowing the initial conditions at $X = 0$, the solution was progressed in the flow direction using finite axial steps ΔX. The parameters $f_x Re$, $f_{app} Re$ and K were calculated at each station using equations (3.48), (3.50), and (3.52), respectively. All these parameters, as well as the dimensionless velocities and pressure distributions are functions only of the geometrical parameters H and M.

4.2.2 Selection of Grid Size

The mesh used to solve this model was a three dimensional one, staggered in the directions of R and θ. This mesh had uniform divisions in the radial and angular directions and nonuniform divisions in the axial direction.

The decision about the mesh size in the R and θ directions was guided by the accuracy of the results in the fully developed region. The smooth tube and the four extreme geometries covered in this solution were tested using different mesh sizes. Values of $f_{fd,0}Re$ are reported in Table 4.4. Based on these results and the computer time used with each mesh size, a mesh of 30×20 (Radial $\times$ Angular) subdivisions was found to be a reasonable compromise between accuracy and computer time.

In the axial direction, smaller divisions were used near the tube entrance. These divisions were enlarged gradually until a certain maximum size was reached where it was kept constant for the rest of the flow domain. An attempt was made where the first ΔX was taken equal to 10^{-6}, and a gradual increase of 10% was incorporated until ΔX reached the value of 10^{-3}. This kind of axial mesh was tested for the case of the smooth tube and the results were found to be in good accuracy, as seen in

Table 4.4 Effect of mesh size on the value of $f_{fd,0}Re$ for some selected geometries

Mesh Size $R \times \theta$	$H = 0.2$ $M = 4$	$H = 0.8$ $M = 4$	$H = 0.2$ $M = 24$	$H = 0.8$ $M = 24$
20 × 20	18.71	71.54	31.30	852.5
30 × 20	18.60	71.38	30.76	852.7
35 × 20	18.56	71.32	30.60	852.4
30 × 15	18.54	71.30	30.74	851.9
30 × 25	18.63	71.42	30.76	853.0

the next section. Prakash and Liu (1985) used an axial mesh starting with $\Delta X = 10^{-4}$ and increasing gradually by a factor of 10% without imposing any restriction on the maximum value for ΔX. The present mesh is certainly finer than the one used by Prakash and Liu, and based on the experience with the previous model, should produce more accurate results. An even finer mesh was used in the present investigation for tubes with long fins due to the short entrance lengths associated with these tubes. For fin heights $H = 0.6$ and $H = 0.8$, the axial step size started with the value $\Delta X = 10^{-7}$ and increased gradually by 10% until $\Delta X = 10^{-3}$.

4.2.3 Validation of Accuracy

To validate the accuracy of the generated results, comparisons with existing published results is necessary. Results for smooth tubes exist for the two conditions of developing and fully developed flow. However, for the case of internally finned tubes, comparisons are possible only in the fully developed region. For the smooth tube geometry, a value of 15.98 was obtained for $f_{fd,0}Re$, which compares very well with the exact value of 16, and a value of 1.258 was obtained for K_∞, which approximates a mean of the previously reported theoretical values (1.08 to 1.41) and a mean of the previously reported experimental values (1.20 to 1.32) as reported by Shah and London (1978). Prakash and Liu (1985) reported $f_{fd,0}Re = 15.96$ and $K_\infty = 1.25$ which are very close to the present values. In the developing region, the smooth tube results of $f_{app}Re$ and K, shown in Figure 4.3, are in good agreement with the finite difference results of Hornbeck (1964) and Liu (1974) as reported by Shah and London (1978). For the case of internally finned tubes, values of $f_{fd,0}Re$ for all considered geometries are compared with results from Hu and Chang (1973), Nandakumar and Masliyah (1975), and Soliman and Feingold (1977). The agreement is seen to be very good, as shown in Table 4.5. As well, values of $f_{fd,0}Re$ from this model agree to within 2% with the corresponding values listed in Table 4.3 for the previous model.

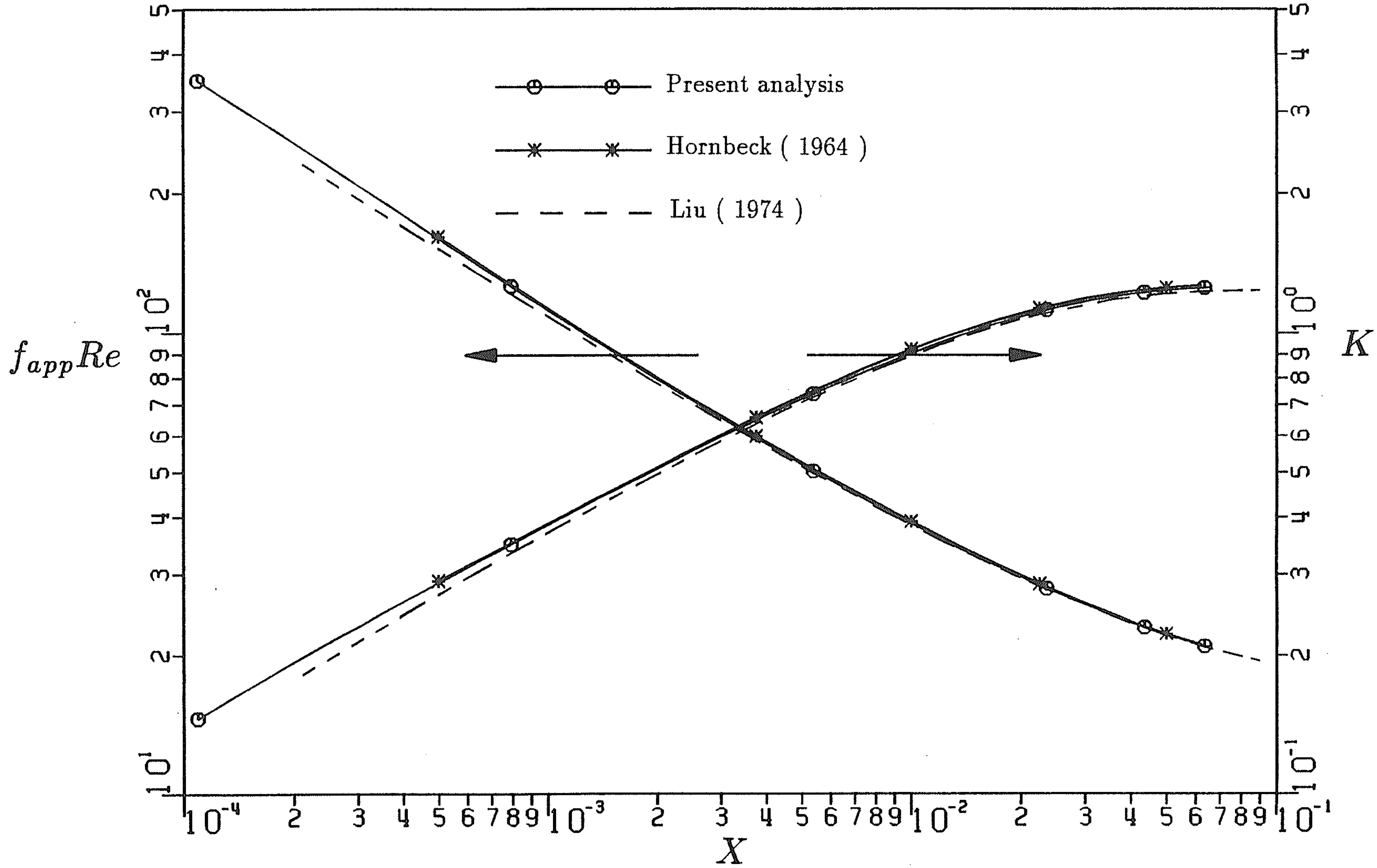


Figure 4.3 Comparison between the present results of $f_{app}Re$ and K and existing results for smooth tubes

Table 4.5 Comparison between the present values of $f_{fd,0}Re$ and existing values.

Tube Geometry H	Tube Geometry M	Present Results	Hu and Chang (1973)	Nandakumar and Masliyah (1975)	Soliman and Feingold (1977)
0.2	4	18.60	—	19.13	19.15
	8	21.66	21.22	22.39	22.08
	16	27.10	25.99	28.20	26.77
	24	30.76	—	32.01	29.92
0.4	4	27.79	—	29.04	28.63
	8	44.73	42.87	47.02	44.40
	16	73.89	69.57	77.86	71.15
	24	90.95	—	95.57	87.07
0.6	4	47.99	—	50.31	48.16
	8	105.40	101.10	110.80	103.18
	16	232.50	219.50	246.10	224.10
	24	335.90	—	356.00	321.00
0.8	4	71.38	—	73.43	71.12
	8	166.00	164.80	170.50	165.60
	16	453.00	448.40	469.90	451.20
	24	852.70	838.20	894.20	846.40

4.3 Fully-Developed Mixed Convection

In this model, the flow is hydrodynamically and thermally fully developed, and hence the problem is two dimensional. The solution was carried out using the "SIMPLER" technique for a wide range of Gr^+. For each geometry, the solution was first obtained at $Gr^+ = 0$. The value of Gr^+ was then increased gradually and corresponding solutions were obtained until $Gr^+ = 2 \times 10^6$. Divergence was encountered sometimes if the step size of Gr^+ was large. For some geometries (short fins), it was not possible to progress the solution beyond $Gr^+ = 2 \times 10^6$.

Another independent parameter that appeared in the system of equations is Prandtl number. In this investigation, Prandtl number was taken to be equal to 7, which approximates the value for water. Thus, the present results cover the range $0 \leq Ra^+ \leq 1 \times 10^7$.

For this model, the geometries covered consist of the smooth tube and six different internally finned tubes with $H = 0.2$, 0.5 and 0.8 and $M = 4$ and 16. The decreased number of finned tubes was adopted due to the very high computation cost associated with this model compared with the two previous models.

4.3.1 Solution Procedure

The system of equations (3.64) to (3.68) was solved numerically using a control volume based finite difference approach. Each equation was integrated over its corresponding control volume, thus converting the three momentum equations and the energy equation into a system of algebraic equations. This system of algebraic equations was coupled by their variable coefficients. Following the procedure of the "SIMPLER" technique, as discussed by Patankar (1980), the continuity equation was used to construct a pressure equation and a pressure correction equation. In using the "SIMPLER" algorithm to solve the system of the governing equations, it was found out that this algorithm converges for very low values of Gr^+ only. For $Gr^+ > 10^3$, the coupling of the equations became very strong and the algorithm diverged. A slight modification to the algorithm, as suggested by Prakash and Patankar (1981) was found to be helpful in getting convergence at higher values of Gr^+. The modified version of the "SIMPLER" algorithm works as follows :

1) Start with a guessed velocity field.
2) Calculate the variable coefficients of the momentum and energy equations.
3) Calculate the coefficients of the pressure equation and solve it.
4) Assume a value for the axial pressure gradient $\frac{d\bar{P}}{dX}$.
5) The three momentum equations and the energy equation are swept simultaneously in the angular direction. After solving for each radial line the variable coefficients are updated before moving to the next radial line during the sweeping process.
6) Solve the pressure correction equation.
7) Correct the velocity field using the pressure correction from step 6 above.
8) Correct the axial pressure gradient $\frac{d\bar{P}}{dX}$ using the global mass balance, equation (4.4).
9) Return to step 2 and repeat until convergence.

The global convergence of the scheme was checked by more than one criteria as follows :

1) The absolute value of the residual of the continuity equation must be less than 10^{-3} at each control volume.
2) The axial pressure gradient $\frac{d\bar{P}}{dX}$ must converge to five significant figures.
3) The average change in the radial and angular velocities must converge to five significant figures, (i.e. $\left[\sum \left|V^{n-1}(I,J) - V^n(I,J)\right| / \sum \left|V^n(I,J)\right|\right] < 10^{-3}\%$, and $\left[\sum \left|W^{n-1}(I,J) - W^n(I,J)\right| / \sum \left|W^n(I,J)\right|\right] < 10^{-3}\%$ where n indicates the present global iteration and $n-1$, indicates the previous global iteration.

Values of Nu_{fd} and $f_{fd}Re$ were calculated using equations (3.19) and (3.48), respectively. The converged values of velocities, temperature and pressure at a particular

Gr^+ were used as an initial guess for the next value of Gr^+. The solution for each particular geometry was carried out at six values of Gr^+. These values of Gr^+ are 0, 10^3, 10^4, 10^5, 10^6 and 2×10^6, except for the geometry of $H = 0.2$ and $M = 4$, where the maximum Gr^+ reached was 1.3×10^6 after which the solution diverged.

4.3.2 Selection of Grid Size

The mesh used to solve this model was a two-dimensional staggered, uniform mesh. The decision about the mesh size was guided by the results of the smooth tube geometry. Using a 30×40 (Radial $\times$ Angular) mesh produced very good results for the case of smooth tubes, as shown in the next section. For the case of internally finned tubes, the number of subdivisions in the angular direction were increased with the number of fins to insure accuracy. For the case of $M = 4$, the mesh size used for all fin heights and all values of Gr^+ was 30×60. For the case of $M = 16$, the mesh size was refined to 30×64.

4.3.3 Validation of Accuracy

Accuracy of the present results was assessed by comparing the predictions of this model with previous results of some limiting cases. These limiting cases include forced and mixed convection in smooth tubes and only forced convection in internally finned tubes. The comparisons involve values of $f_{fd}Re$ and Nu_{fd} for all geometries, and velocity and temperature profiles for smooth tubes only.

For forced convection in smooth tubes this model predicted $f_{fd}Re = 15.98$ and $Nu_{fd} = 4.367$, compared to the exact values of 16 and 4.365, respectively. Results of $f_{fd}Re$ and Nu_{fd} for mixed convection in horizontal smooth tubes are presented in Figures 4.4 and 4.5 for $Pr = 1$ along with results from Hwang and Cheng (1970). The results show very good agreement over the range $0 \leq Gr^+ \leq 2.6 \times 10^5$ covered by Hwang and Cheng. Comparisons were also made between results of the velocity and temperature distributions reported by Hwang and Cheng (1970) and the present

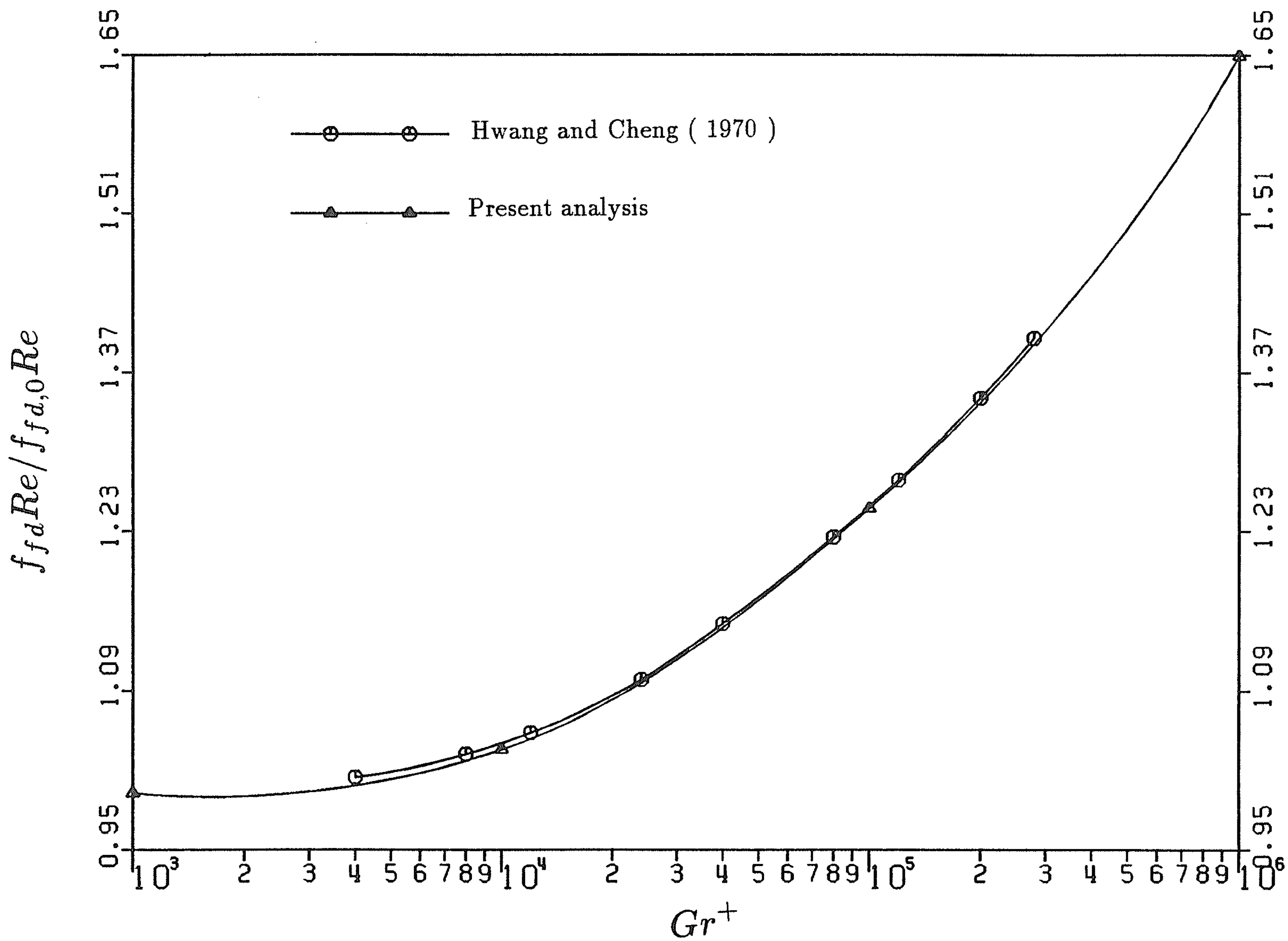


Figure 4.4 Comparison between the present values of $f_{fd}Re/f_{fd,0}Re$ and Hwang and Cheng (1970) for smooth tubes ($Pr = 1$)

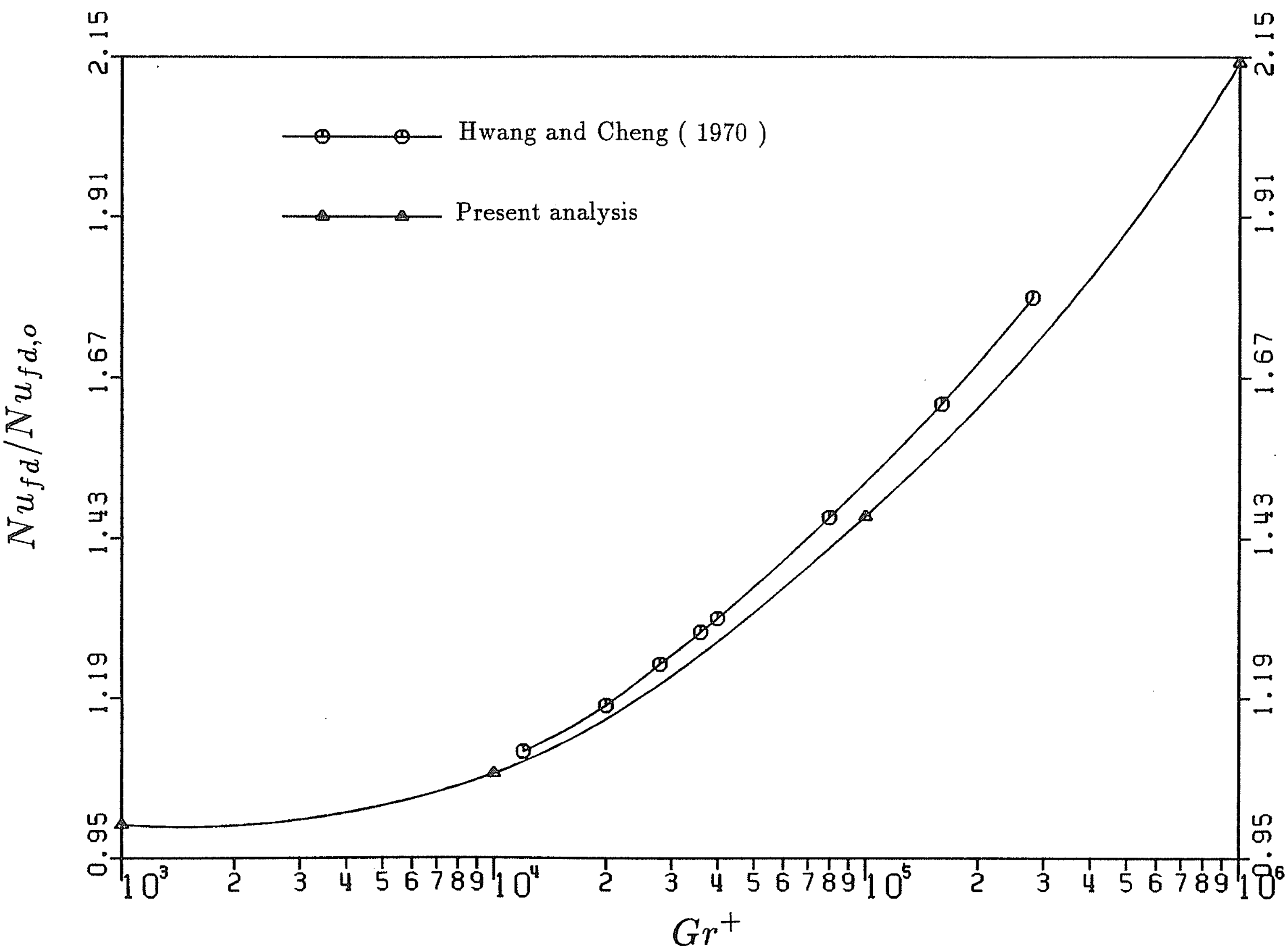


Figure 4.5 Comparisons between the present results of $Nu_{fd}/Nu_{fd,0}$ and Hwang and Cheng (1970) for smooth tubes ($Pr = 1$)

predictions at $Gr^+ = 2.6 \times 10^5$. Excellent agreement was found in magnitude and trend, as shown in Figure 4.6. In this figure, u_c and t_c correspond to the velocity and temperature at the tube centreline, respectively. For the case of internally finned tubes, values of $f_{fd,0}Re$ and $Nu_{fd,0}$ were compared with results from Masliyah and Nandakumar (1976) and Soliman and Feingold (1978). The results were found in good agreement, as shown in Table 4.6.

Computer programs developed in this analysis which were used in solving the three models of the developing forced convection, the developing isothermal flow, and the fully-developed mixed convection are listed in Appendix C.

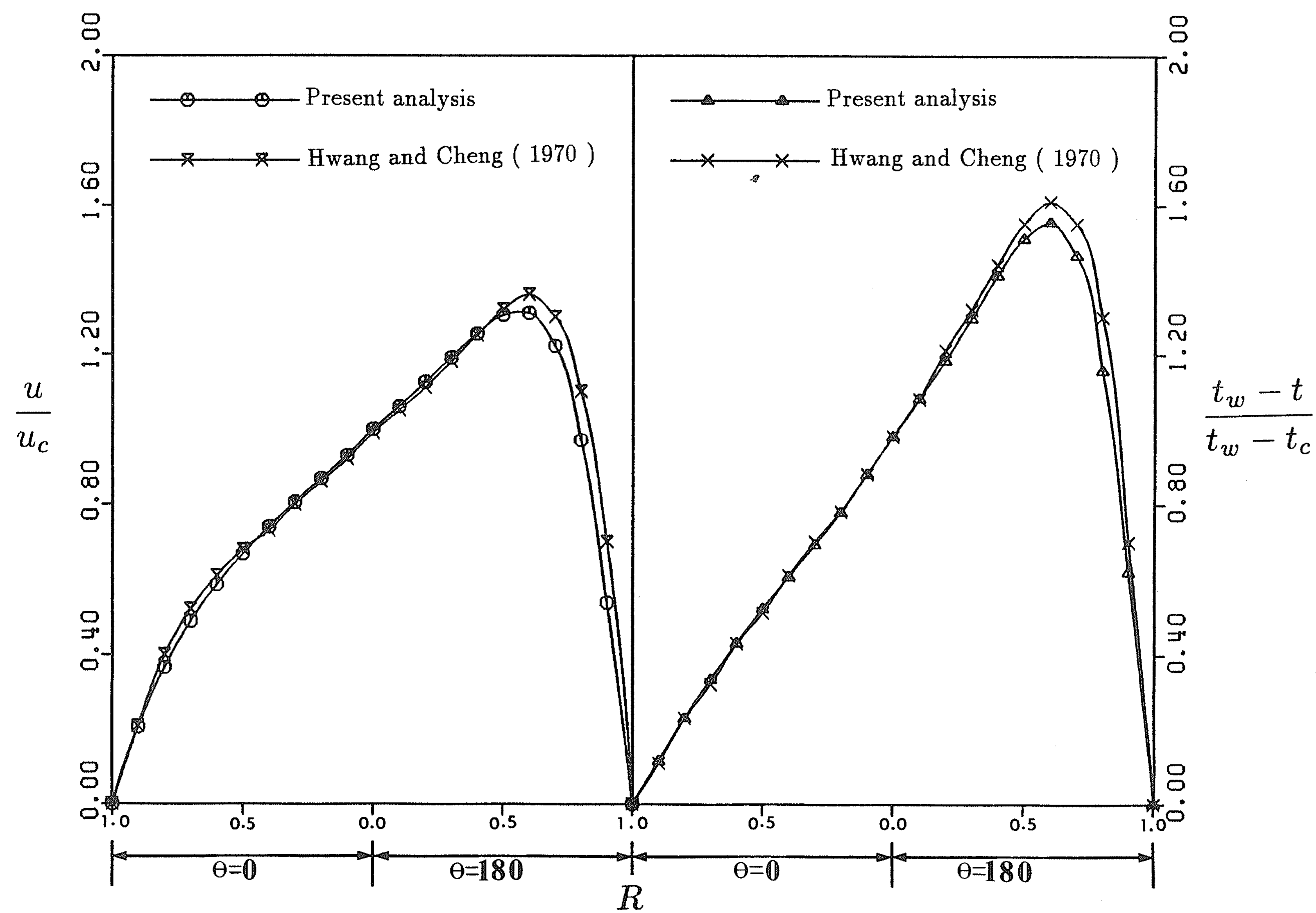


Figure 4.6 Comparison of axial velocity and temperature distributions with Hwang and Cheng (1970) at $Gr^{+} = 2.6 \times 10^{5}$ and $Pr = 1$

Table 4.6 Values of $f_{fd,0}Re$ and $Nu_{fd,0}$ for finned tubes as compared with existing values.

Geometry		Present Results		Masliyah and Nanadkumar (1975, 1976)		Soliman and Feingold (1977, 1978)	
M	H	$f_{fd,0}Re$	$Nu_{fd,0}$	$f_{fd,0}Re$	$Nu_{fd,0}$	$f_{fd,0}Re$	$Nu_{fd,0}$
4	0.2	18.54	4.570	19.13	4.58	19.11	4.62
	0.5	36.21	7.763	—	—	36.90	7.89
	0.8	71.30	19.60	73.43	19.30	71.09	19.47
16	0.2	26.55	4.747	28.20	4.74	26.73	4.74
	0.5	129.20	8.326	—	—	126.29	8.04
	0.8	440.70	110.20	469.9	106.50	451.12	107.35

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Developing Forced Convection

Velocity and temperature distributions were obtained for sixteen different combinations of the geometric parameters H and M, in addition to the smooth tube geometry. For each geometry, the temperature distributions were obtained for the two limiting thermal boundary conditions (H1) and (T). The geometries covered in this model correspond to the smooth tube and combinations of H = 0.2, 0.4, 0.6, and 0.8, and M = 4, 8, 16, and 24. Based on the velocity and temperature distributions, some very important engineering parameters were calculated. These parameters are, $f_{fd}Re$, $Nu_{fd,H1}$, $Nu_{fd,T}$, $Nu_{x,H1}$, and $Nu_{x,T}$. The influence of the geometric parameters H and M on the velocity and temperature distributions was studied and sample results of some selected geometries are presented. The effect of the geometric parameters H and M on the global parameters is presented for all geometries and boundary conditions. The local values of $Nu_{x,H1}$ and $Nu_{x,T}$ are presented graphically for all geometries, and the corresponding numerical values are tabulated in Appendix A.

5.1.1 Fully-Developed Velocity Fields

Figures 5.1 to 5.4 show samples of the dimensionless equi-velocity lines (u/u_b) for all considered fin heights and the lowest and highest number of fins (M = 4 and 24). Results for other geometries are presented in section 5.2. It is clear from these figures that the velocity gradient in both the radial and the angular directions becomes steeper as we approach solid boundaries. Another aspect of the flow pattern

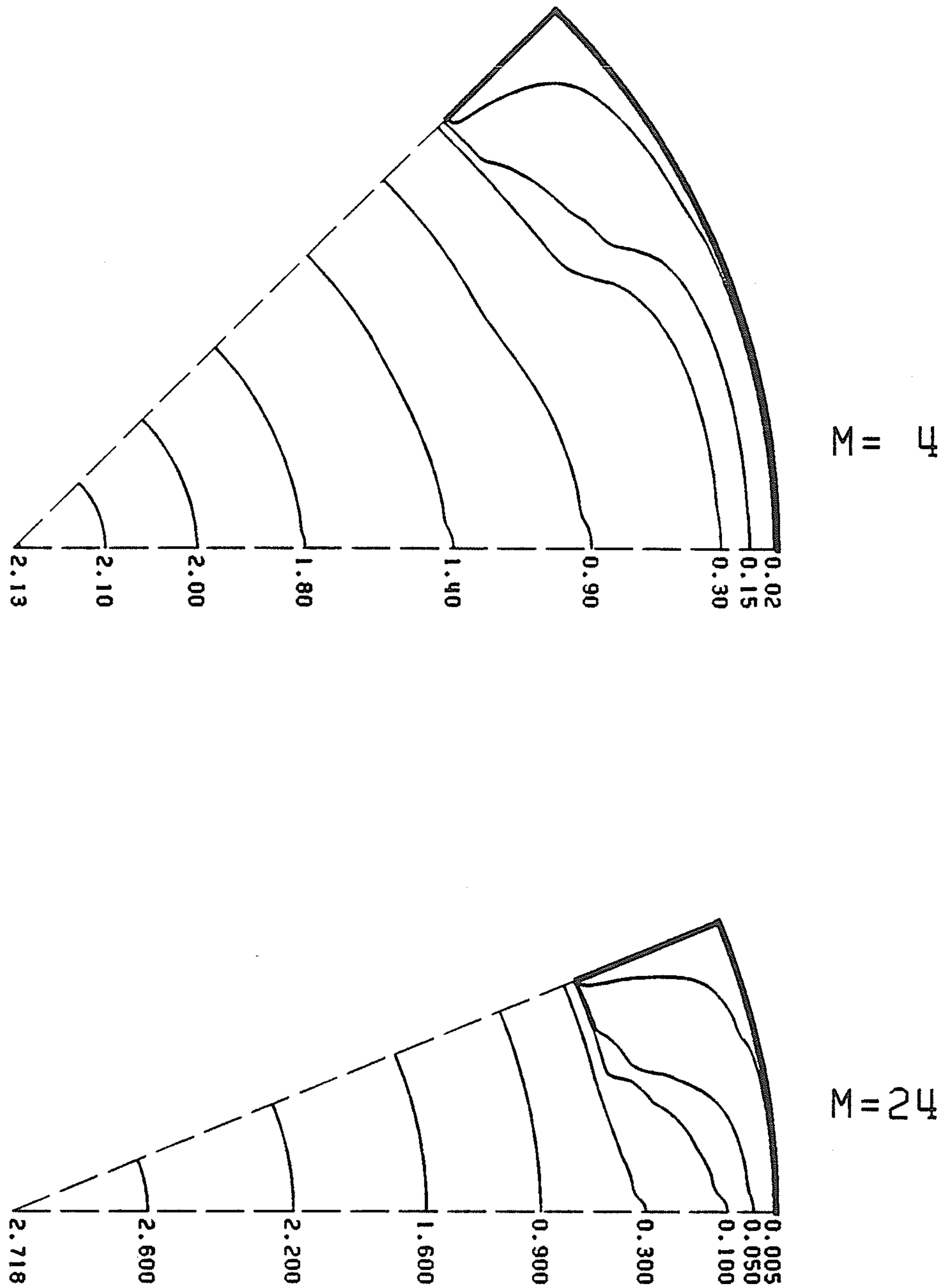


Figure 5.1 Equi-velocity lines (u/u_b) for $H = 0.2$.

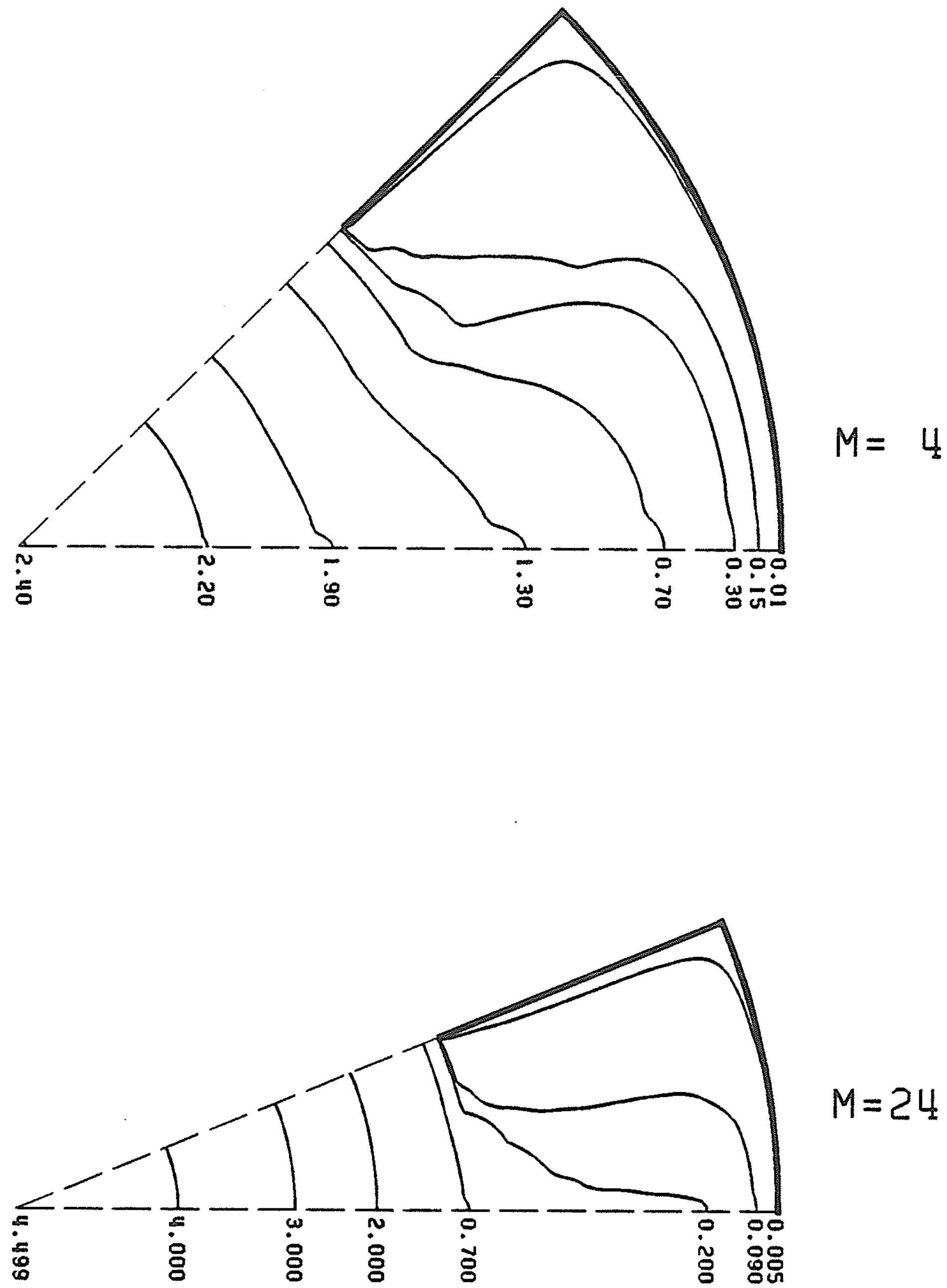


Figure 5.2 Equi-velocity lines (u/u_b) for $H = 0.4$.

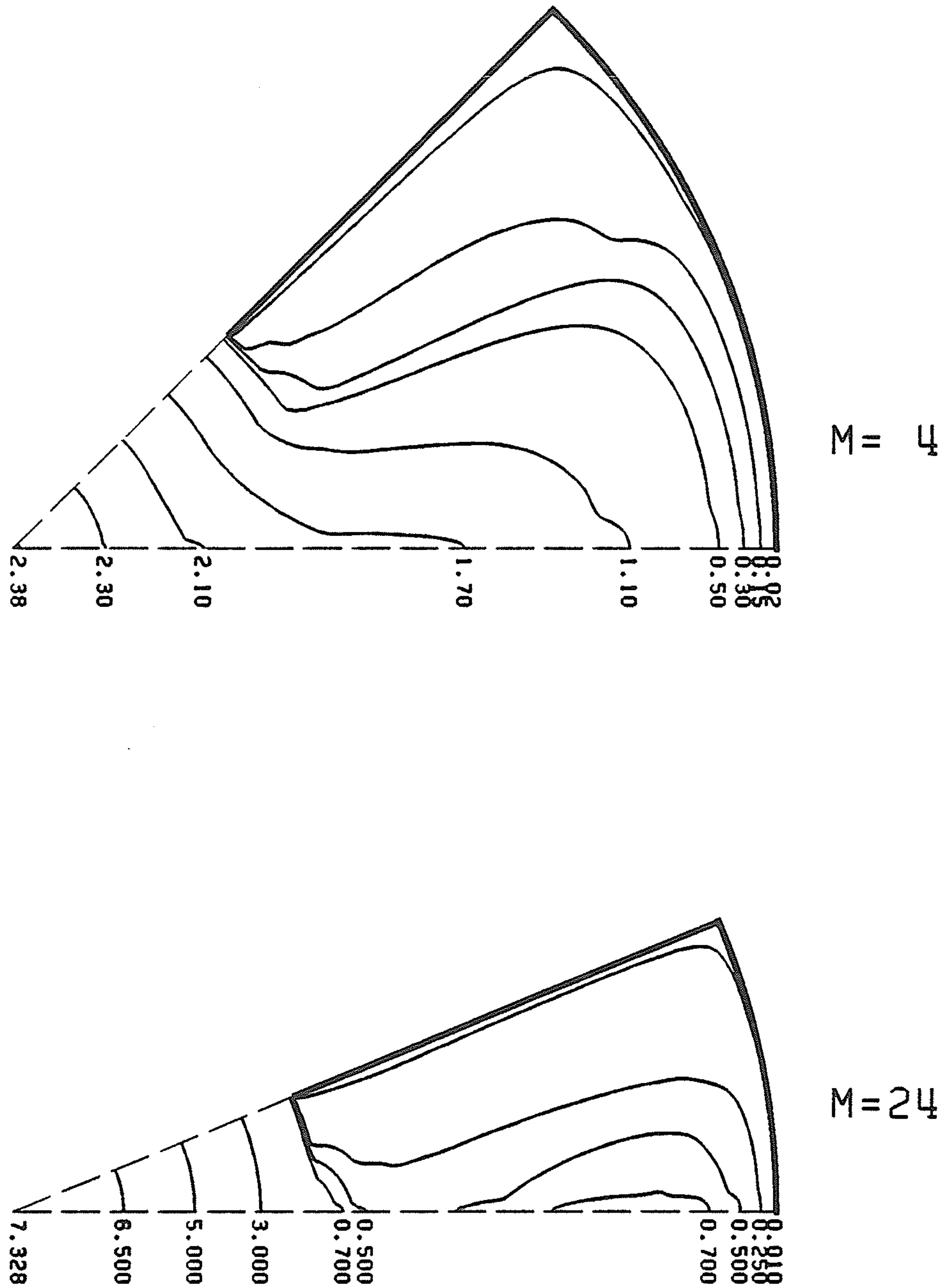


Figure 5.3 Equi-velocity lines (u/u_b) for $H = 0.6$.

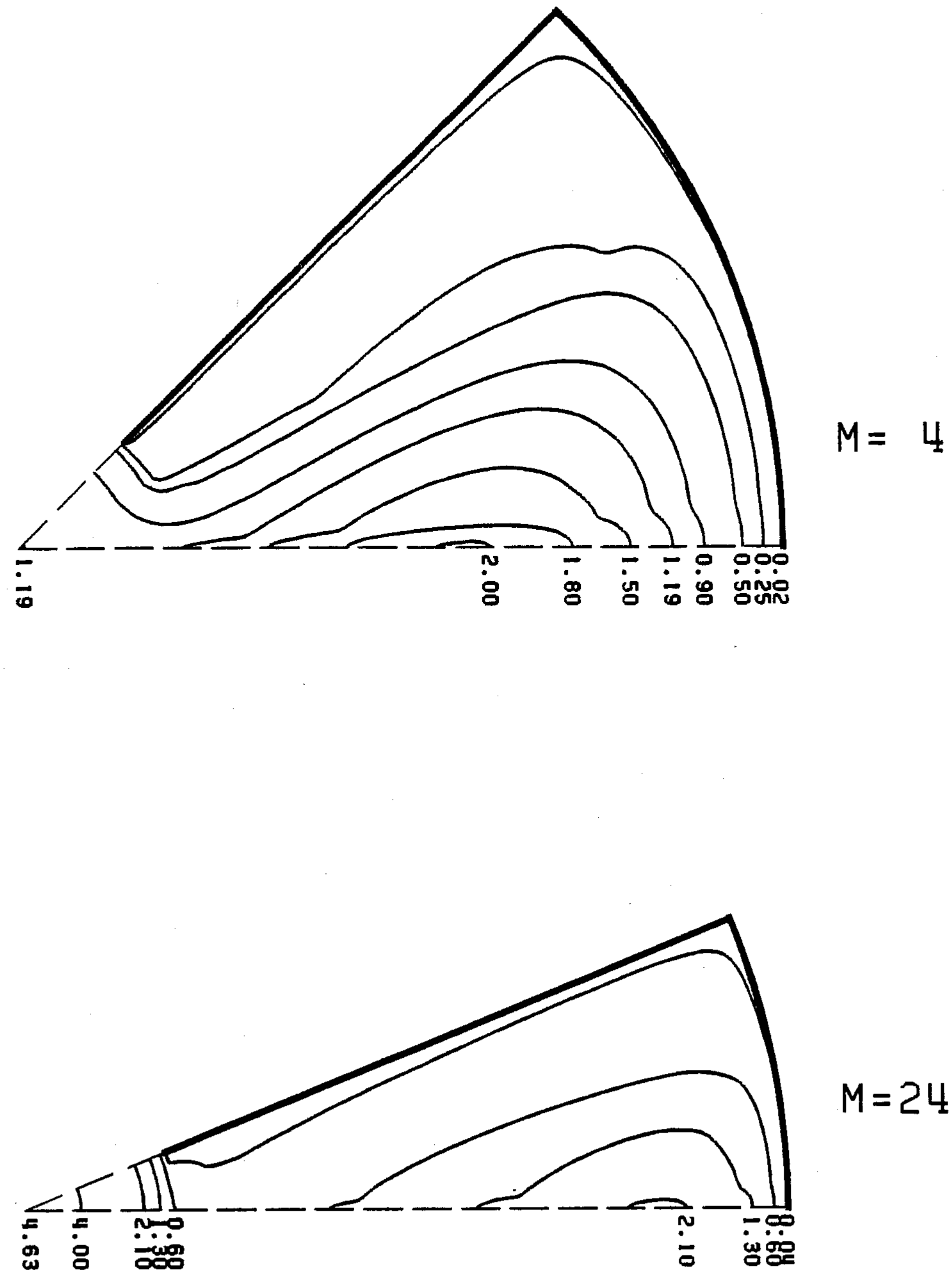


Figure 5.4 Equi-velocity lines (u/u_b) for $H = 0.8$.

associated with long fins is the existence of closed loop equi-velocity lines within the bays formed by any two adjacent fins. Similar observations were reported by Hu and Chang (1973) and Soliman and Feingold (1977). Hu and Chang reported that the existence of the closed loops depends only on H. However, Soliman and Feingold reported that the presence of closed loops is a function of H, M, and β (the fin thickness). In the present analysis, no closed loops can be noticed for the case of short fins $H = 0.2$ and 0.4 for any value of M. The formation of closed loops started at $H = 0.6$ and $M = 8$. No closed loops are noticed for $H = 0.6$ and $M = 4$. For the case of long fins $H = 0.8$, the closed loops are noticed for all values of M considered. Secondary loops are one of the important features of the flow in internally finned tubes because their existence affects the temperature distribution and consequently the rate of heat transfer from these tubes.

5.1.2 Temperature Fields

The fully developed temperature profile is presented for all H and for $M = 4$ and 24 for both thermal boundary conditions (H1) and (T) in Figures 5.5 to 5.12. It is clear from these figures that the temperature gradient in both the radial and the angular directions becomes steeper as we approach solid boundaries. The (H1) boundary condition temperature fields resemble the equi-velocity lines in terms of trend. The formation of closed loops is noticed to occur at $H = 0.6$ and $M = 8$. No closed loops for $H = 0.2$ and 0.4 are noticed at any value of M. For $H = 0.8$ the closed loops are noticed at all values of M from 4 to 24.

The isotherms for the (T) boundary condition resemble those of the (H1) boundary condition and the equi-velocity lines for all geometries except for the cases of high number of long fins, i.e. $H = 0.6$ and 0.8, and $M = 24$. At $M = 24$ the isotherms of the (T) boundary condition did not show any formation of closed loops at $H = 0.6$ and 0.8, contrary to the (H1) and velocity distributions. To explore what is happening in the thermally developing region, the case of $H = 0.6$

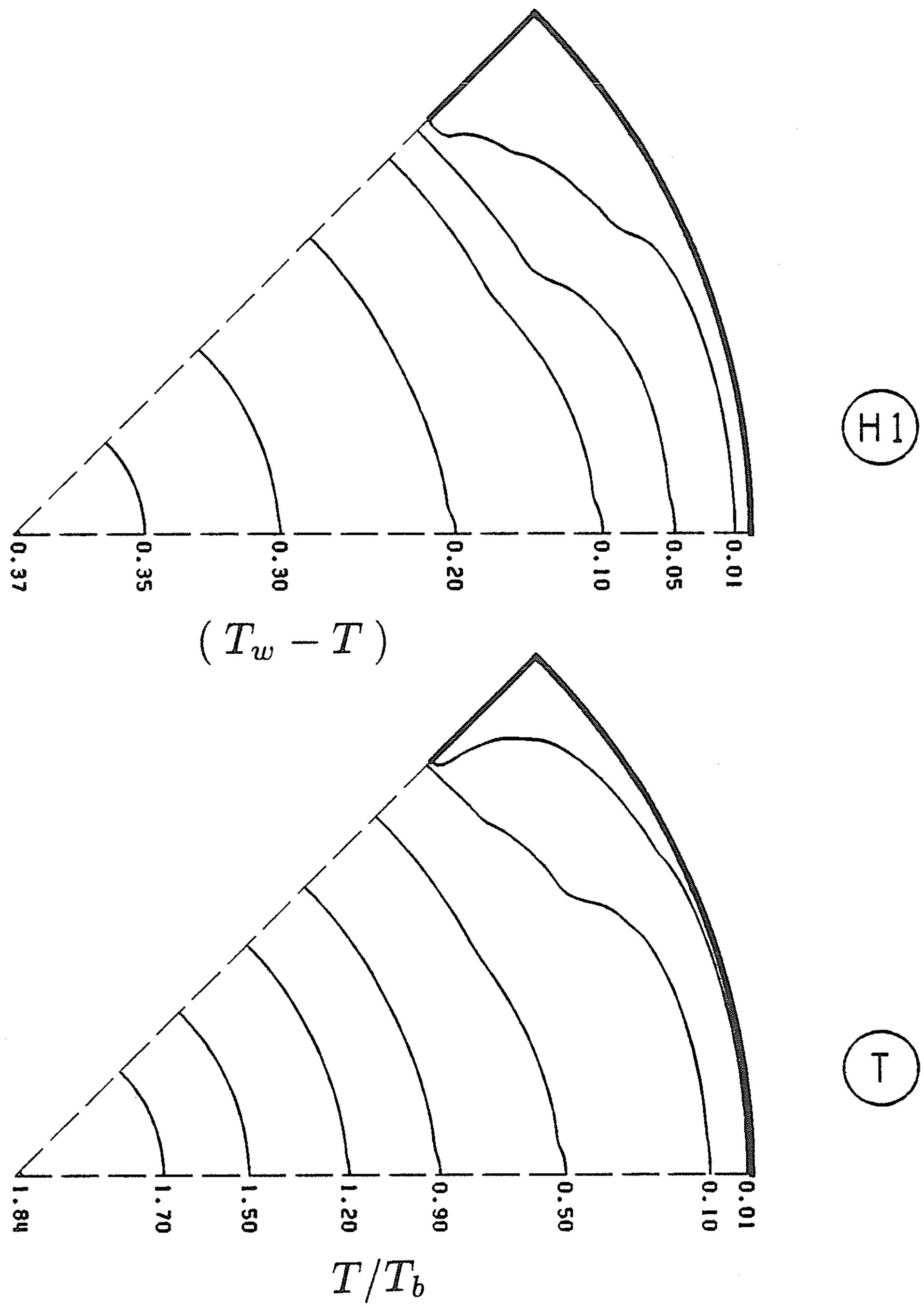
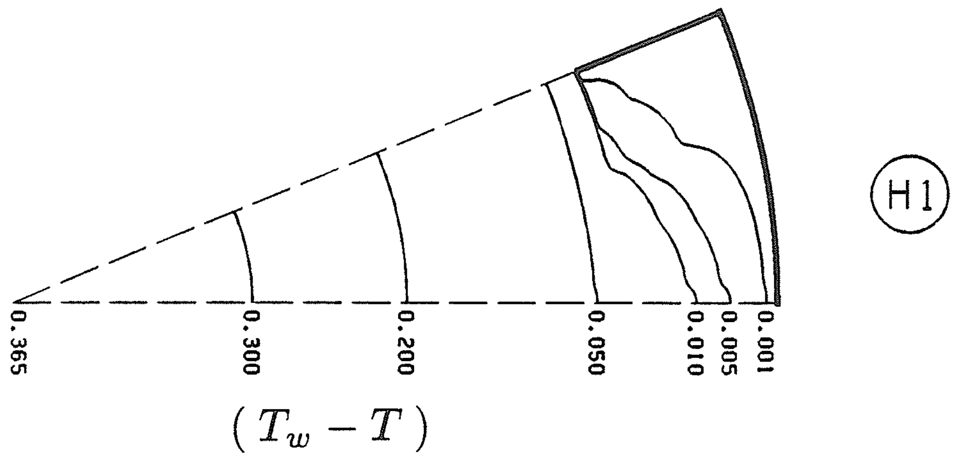


Figure 5.5 Isotherms for $H = 0.2$ and $M = 4$ (Fully Developed).



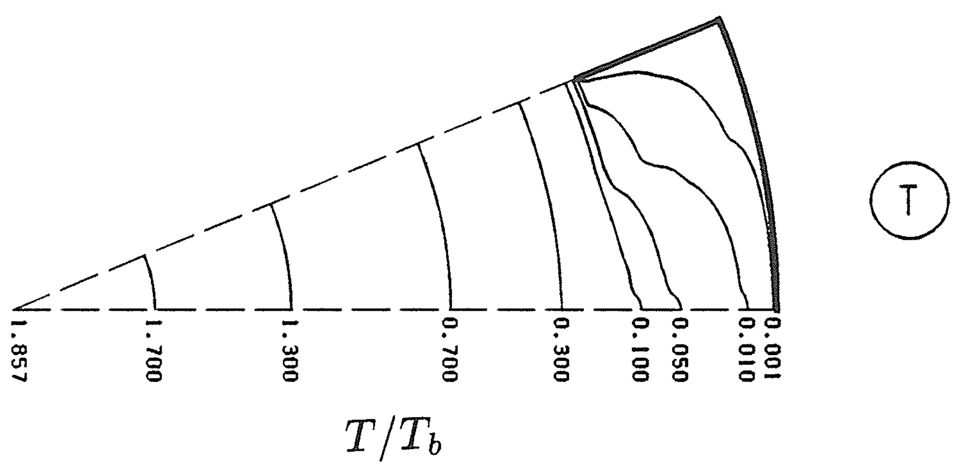


Figure 5.6 Isotherms for $H = 0.2$ and $M = 24$ (Fully Developed).

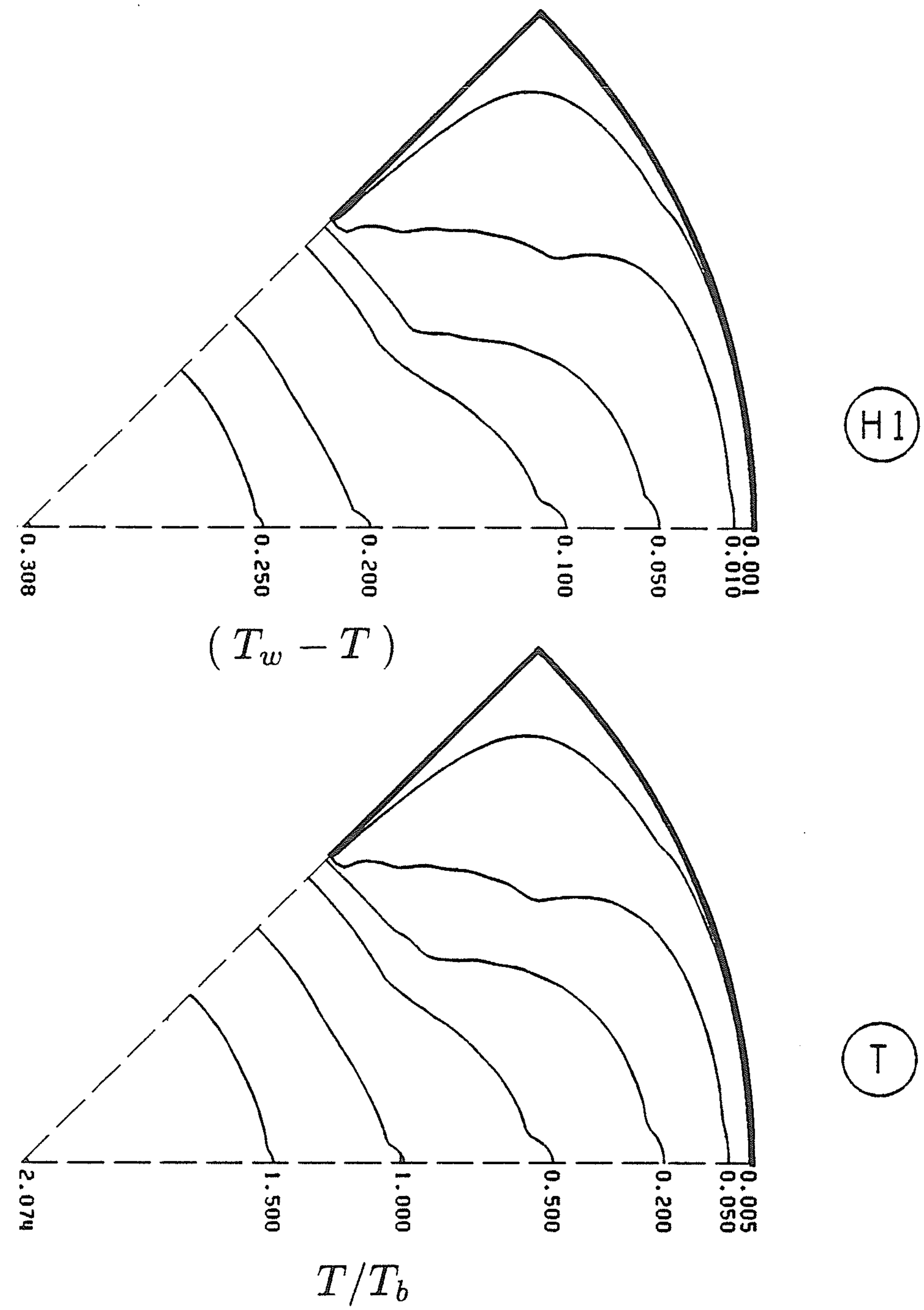
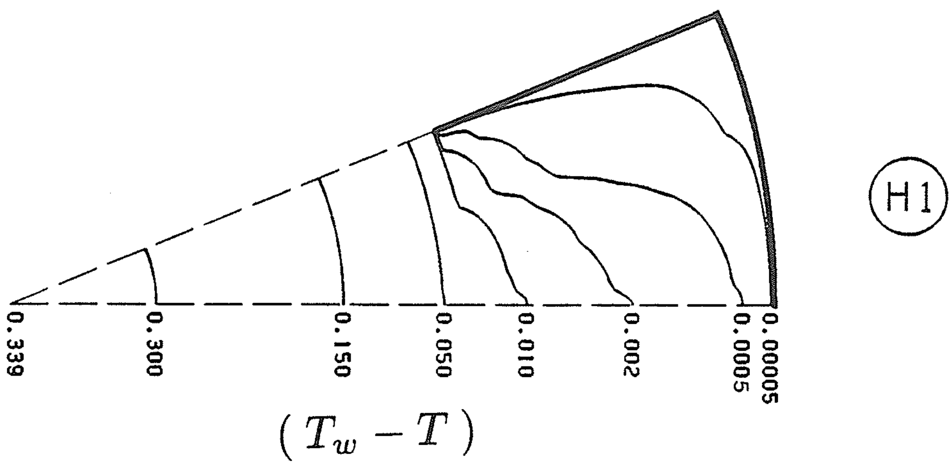


Figure 5.7 Isotherms for $H = 0.4$ and $M = 4$ (Fully Developed).



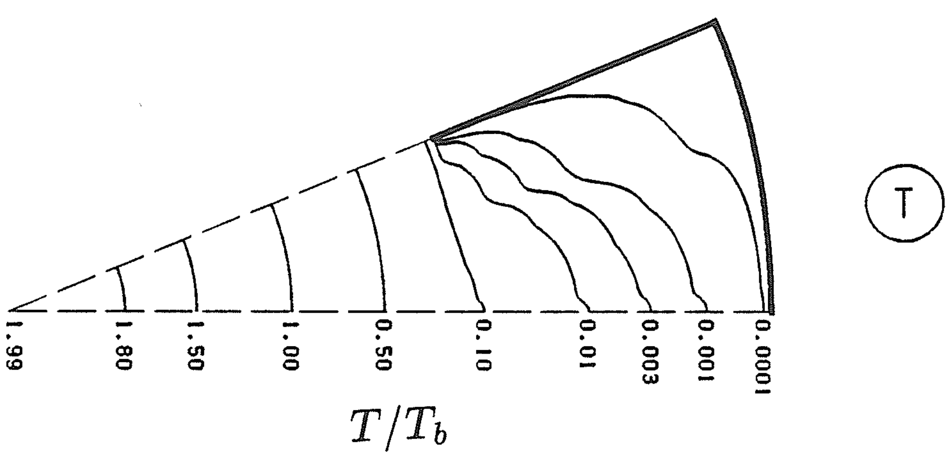


Figure 5.8 Isotherms for $H = 0.4$ and $M = 24$ (Fully Developed).

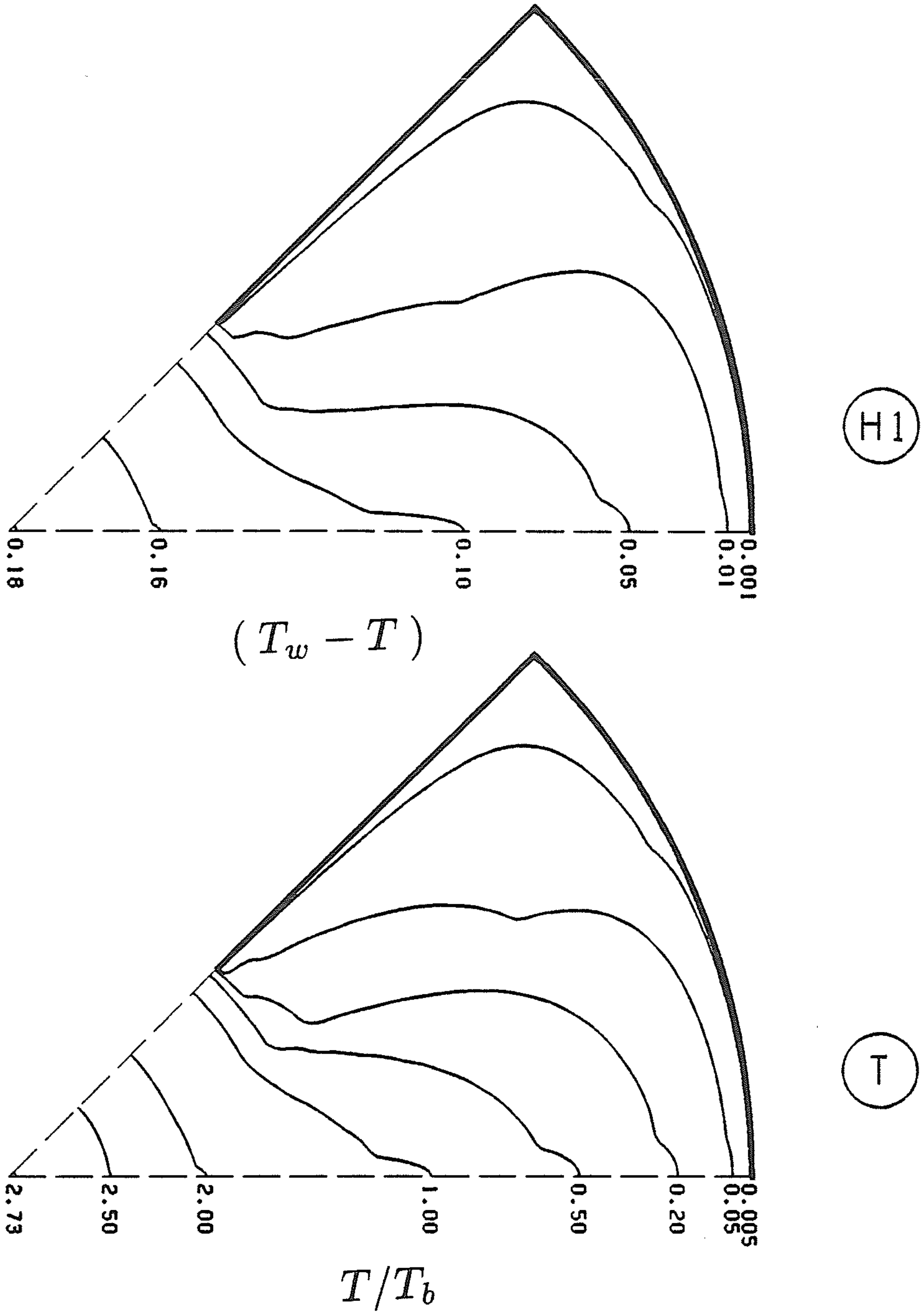


Figure 5.9 Isotherms for $H = 0.6$ and $M = 4$ (Fully Developed).

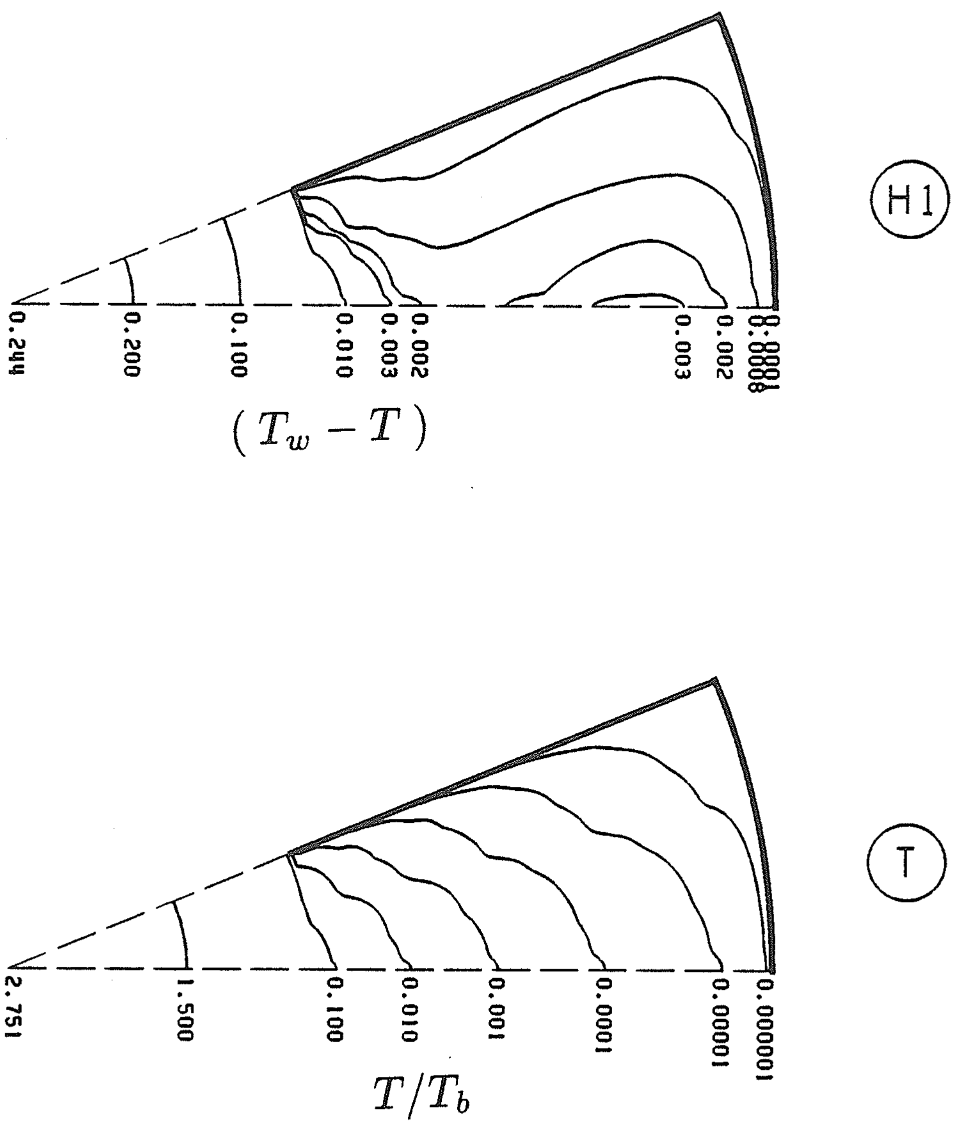


Figure 5.10 Isotherms for $H = 0.6$ and $M = 24$ (Fully Developed).

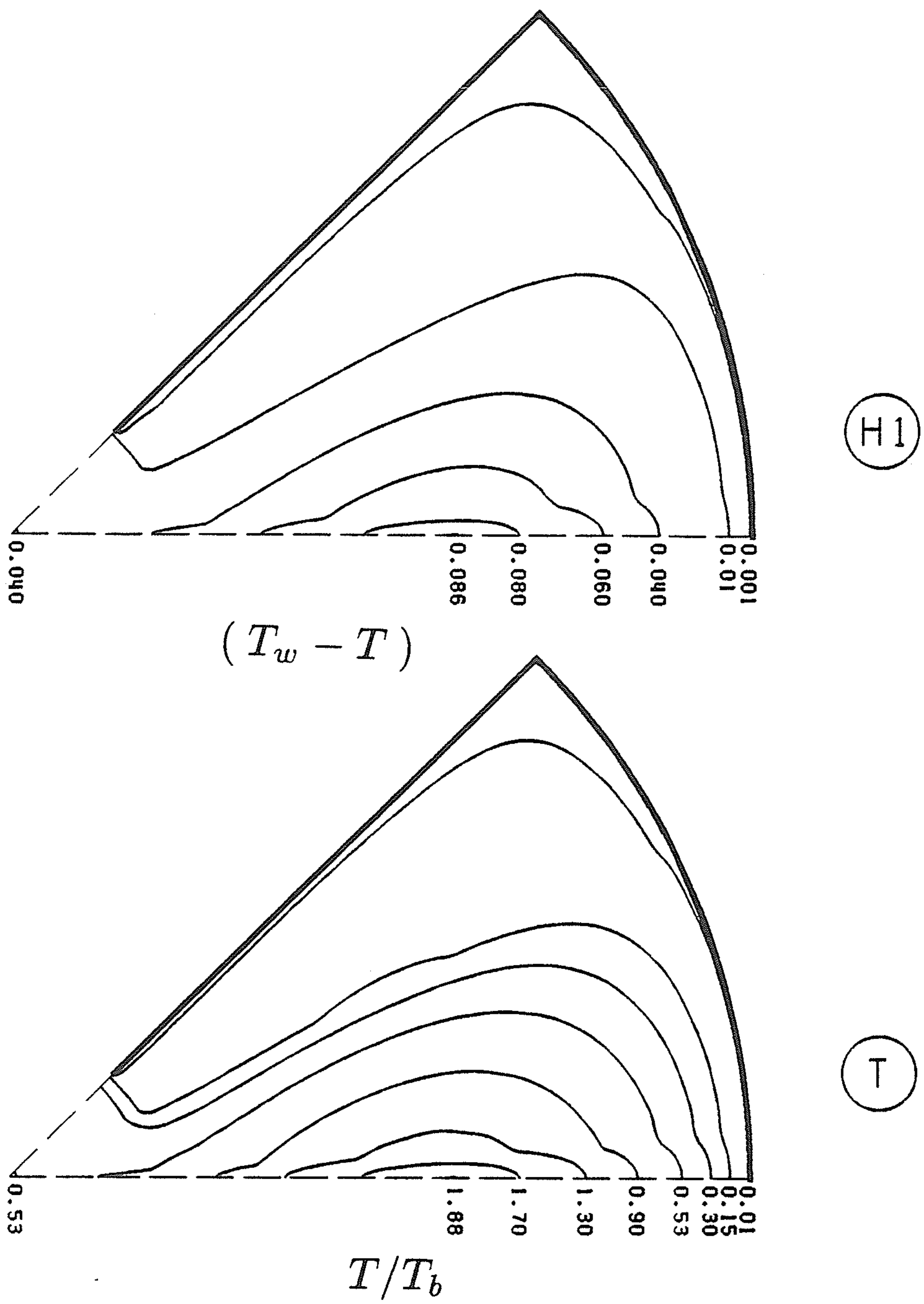


Figure 5.11 Isotherms for $H = 0.8$ and $M = 4$ (Fully Developed).

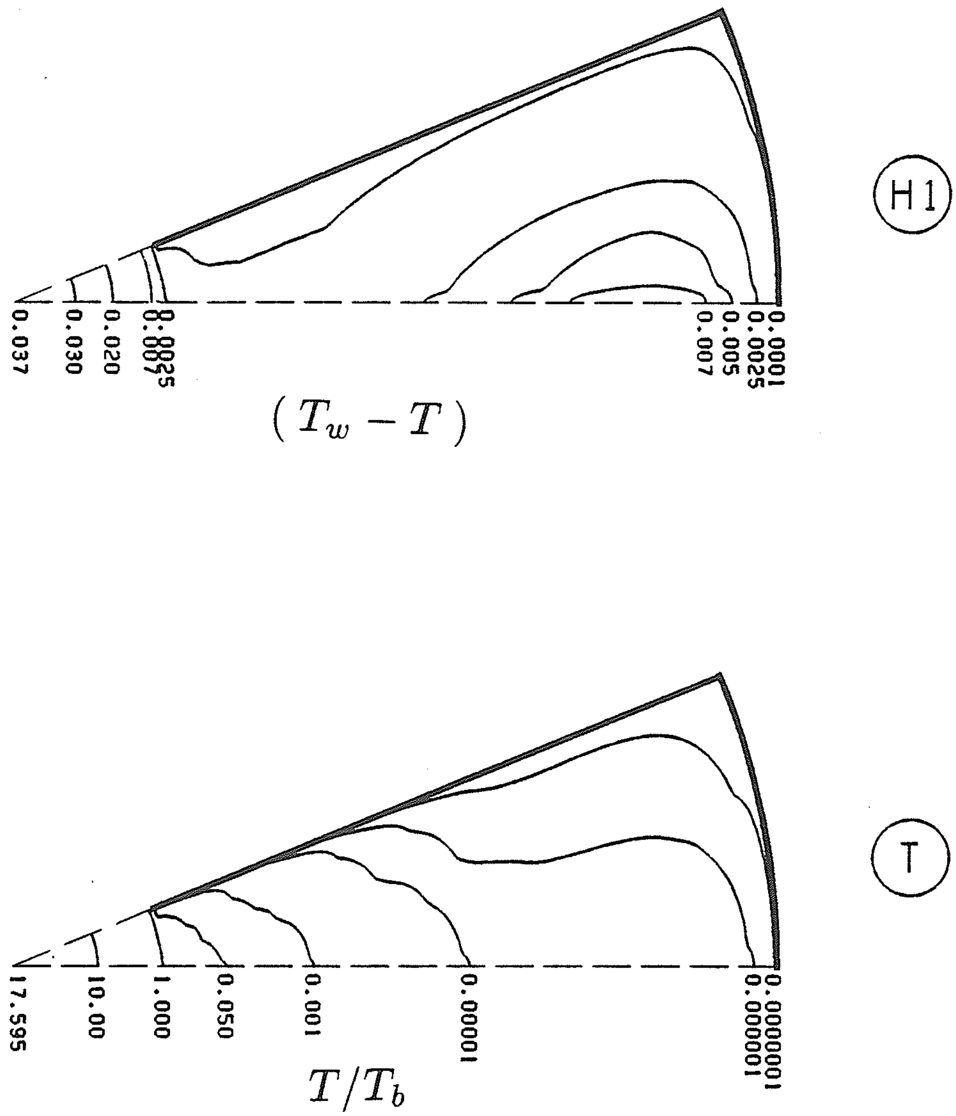


Figure 5.12 Isotherms for $H = 0.8$ and $M = 24$ (Fully Developed).

and $M = 24$ was studied for the two thermal boundary conditions (H1) and (T). Figures 5.13 and 5.14 show the results for the (T) boundary condition at four stations in the developing region Closed loops are noticed to form right at the start of heating and continues until the fully developed region is approached, where the closed loops start to disappear. Figures 5.15 and 5.16 are for the same geometry using the (H1) boundary condition. The closed loops are shown to form right at the start and continues throughout the whole entry region.

It is evident that the presence of fins inside tubes influences the velocity and temperature distributions in a very complicated way. This in turn is reflected on the behaviour of the local values of Nusselt number and consequently the entrance lengths, as will be seen later. More details on the developing temperature profiles are presented in a later section in an attempt to shed more light on the complicated way by which the presence of fins affects the Nusselt numbers and the entrance lengths.

5.1.3 Fully-Developed Pressure Drop

For the present conditions, $f_{fd}Re$, which is indicative of the fully developed pressure drop, is a function of the geometric parameters H and M. The computed values of $f_{fd}Re$ for the internally finned tubes with $H = 0.2$, 0.4, 0.6, and 0.8 and $M = 4$, 8, 16, and 24 are listed in Table 4.3. Both H and M are found to have pronounced effect on $f_{fd}Re$. At any value of M, $f_{fd}Re$ increases monotonically with H. Similarly, at any value of H, $f_{fd}Re$ is found to increase monotonically with M for the range covered ($M = 4$ to 24). However, it is expected that $f_{fd}Re$ will reach a maximum value at a high M and then start to decrease. As $M \rightarrow \infty$, the tube becomes full of fins and approaches the geometry of a smooth tube, and consequently $f_{fd}Re$ is expected to drop to 16, which is the value for smooth tubes.

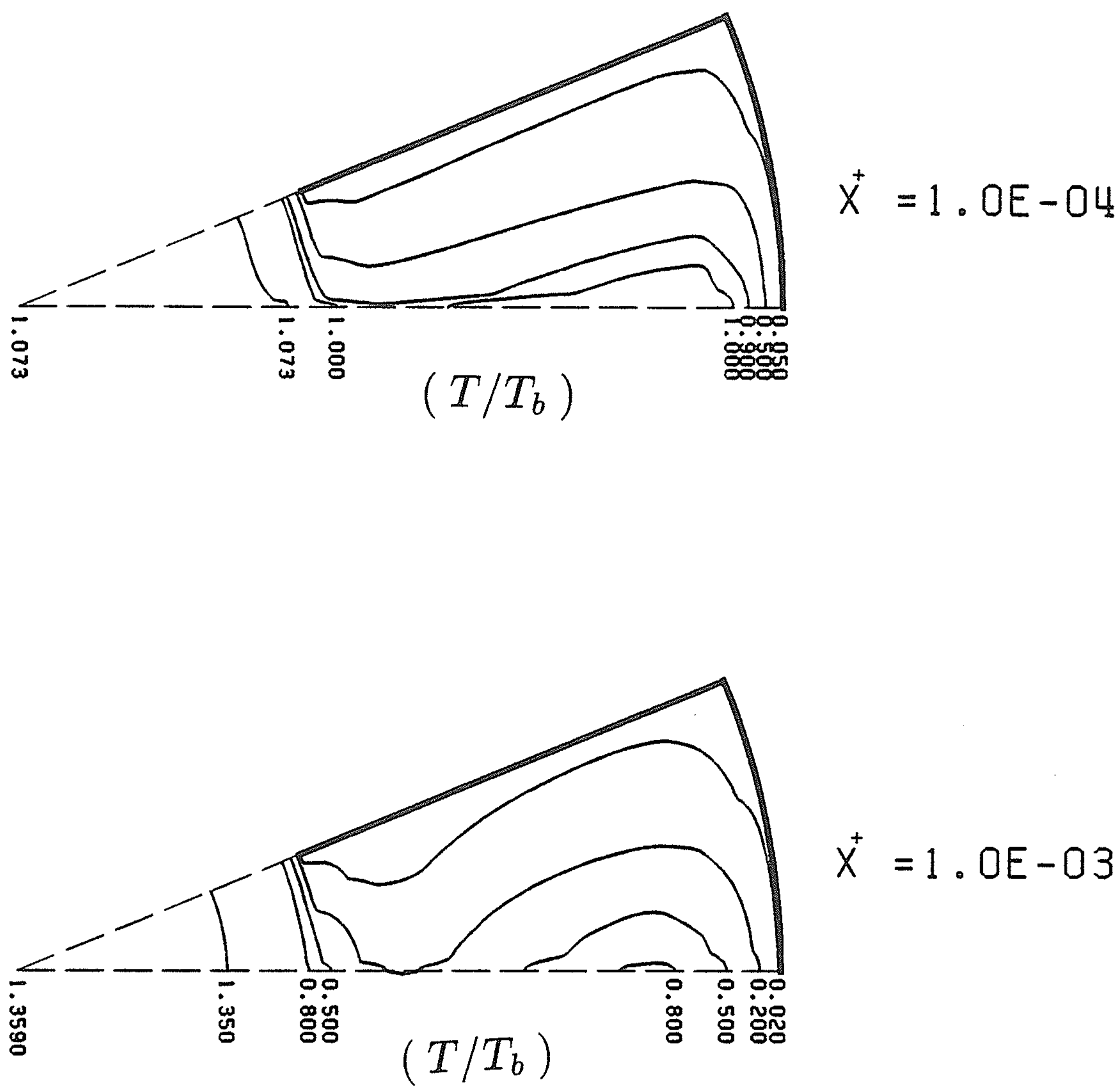
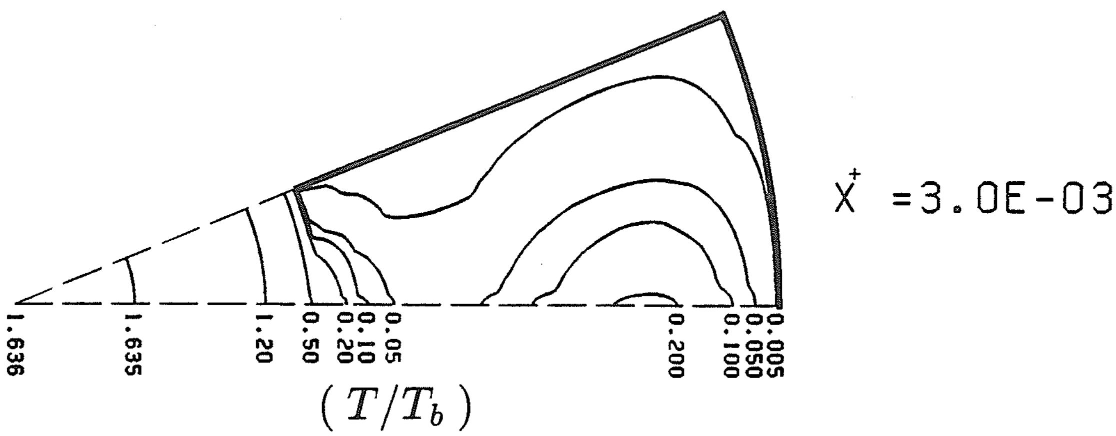


Figure 5.13 Isotherms for $H = 0.6$ and $M = 24$ in the thermally developing region ((T) boundary condition).



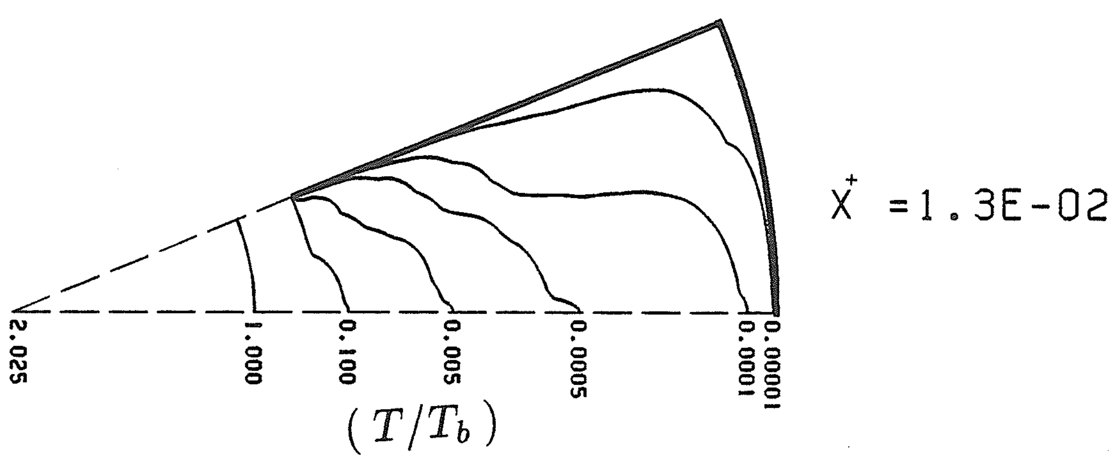


Figure 5.14 Isotherms for $H = 0.6$ and $M = 24$ in the thermally developing region ((T) boundary condition).

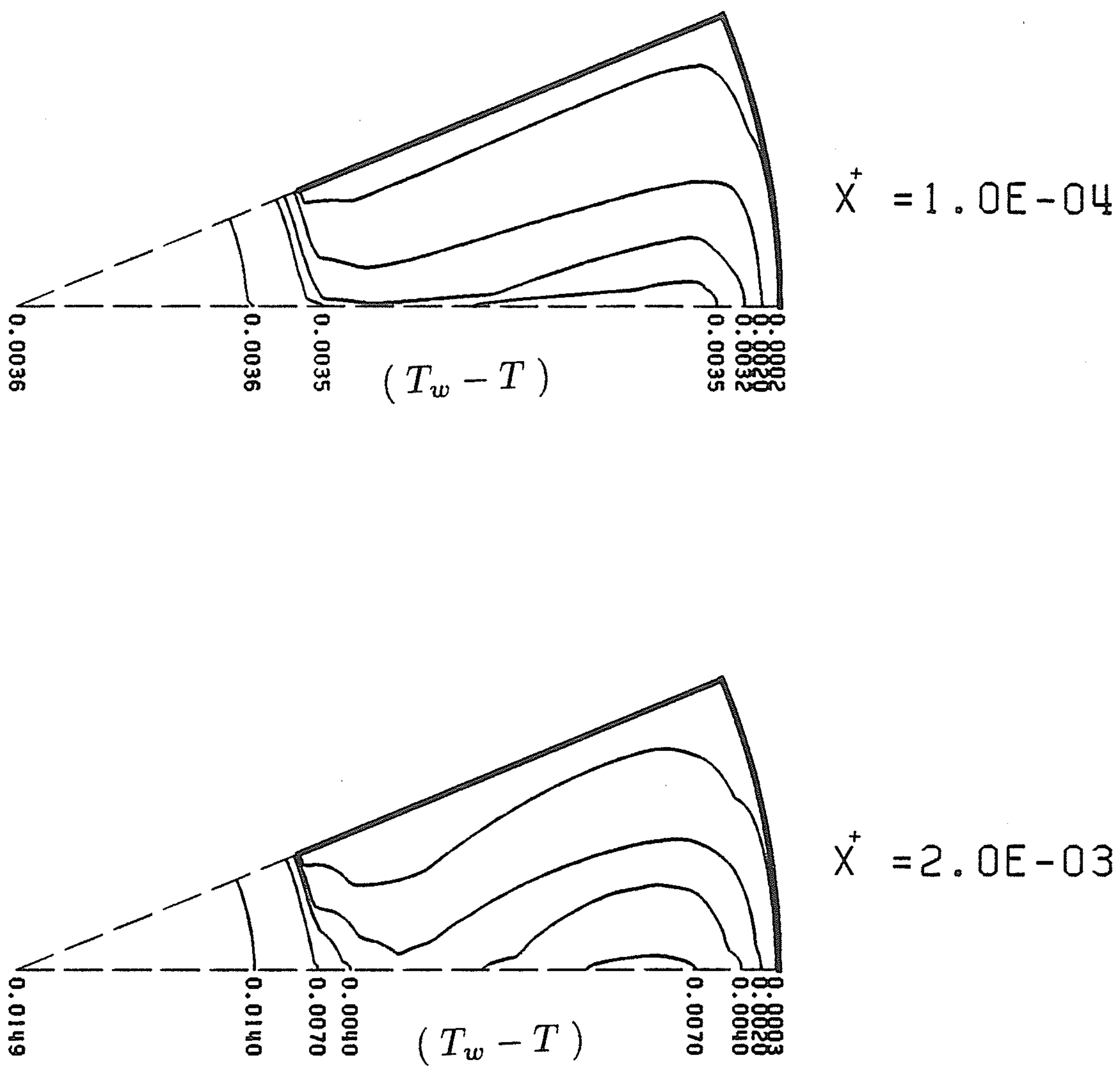
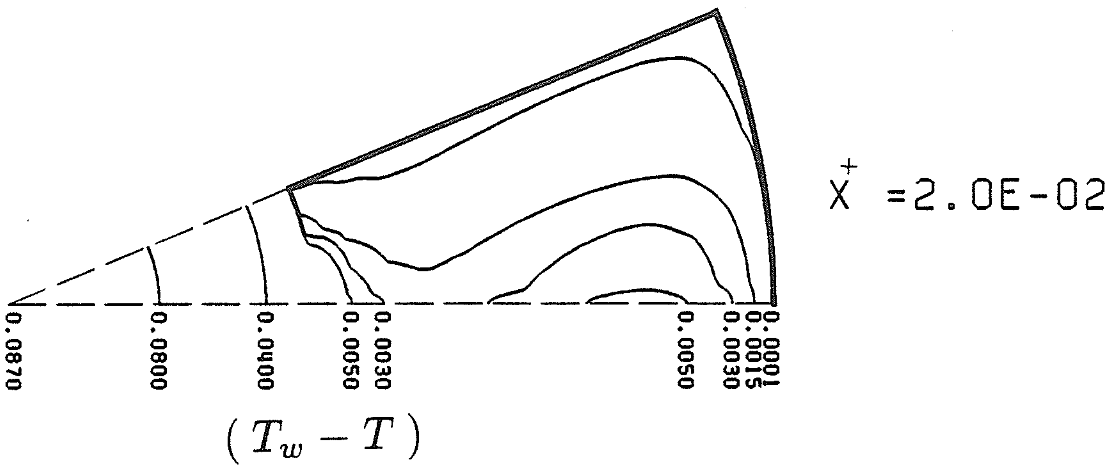


Figure 5.15 Isotherms for $H = 0.6$ and $M = 24$ in the thermally developing region ((H1) boundary condition).



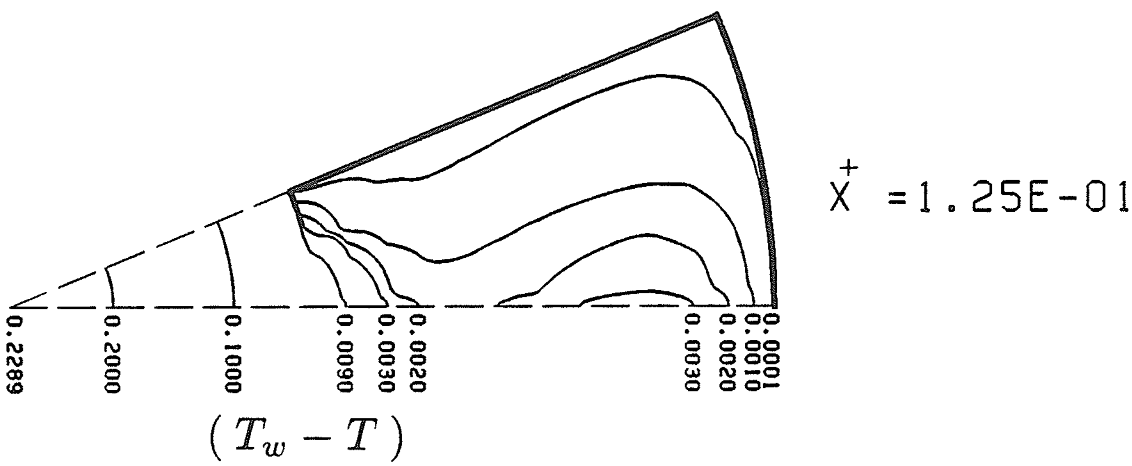


Figure 5.16 Isotherms for $H = 0.6$ and $M = 24$ in the thermally developing region ((H1) boundary condition).

5.1.4 Heat Transfer

A) Fully-Developed Heat Transfer

$Nu_{fd,H1}$ and $Nu_{fd,T}$ for all geometries studied are presented in Table 5.1. The effect of H and M on the fully developed Nusselt number is somewhat mixed. Nu_{fd} for both (H1) and (T) increases monotonically with H at any value of M. However, at any value of H, $Nu_{fd,H1}$ and $Nu_{fd,T}$ increase to a certain maximum value after which they start to decrease. The value of M at which Nusselt number reaches its maximum increases with H. The values of $Nu_{fd,H1}$ and $Nu_{fd,T}$ are expected to decrease to the values corresponding to the smooth tube geometry as $M \to \infty$. At very high values of M, the resistance to fluid flow in the bays between the fin increases and most the flow is pushed to the core, thus approaching the smooth tube situation. For any combination of H and M, $Nu_{fd,H1}$ is found to be consistently higher than $Nu_{fd,T}$.

B) Developing Heat Transfer: (H1) Boundary Condition

Figures 5.17 to 5.20 show the devlopment of the local Nusselt number $Nu_{x,H1}$ over the range $10^{-4} \leq X^+ \leq L^+_{H1}$ for M = 4, 8, 16, and 24, respectively. In each figure, the influence of fin height is illustrated by showing results for $H = 0$ (smooth tube), 0.2, 0.4, 0.6, and 0.8. Both $Nu_{x,H1}$ and X^+ are based on the inside diameter rather than the hydraulic diameter in order to show the effect of internal finning in a manner easy to visualize.

For all geometries, $Nu_{x,H1}$ follows the expected behaviour of monotonic decrease along the developing region down to the fully developed value. An interesting feature of the results in Figures 5.17 to 5.20 is that all finned tubes appear to have approximately the same rate of decrease of $Nu_{x,H1}$ with respect to X^+ near the beginning of heating and this rate is approximately equal to the rate for smooth tubes. However, sharp changes in this rate occur later in the developing region and this is particularly

Table 5.1 Values of $Nu_{fd,H1}$ and $Nu_{fd,T}$ for all geometries

	$Nu_{fd,H1}$				$Nu_{fd,T}$			
H \ M	4	8	16	24	4	8	16	24
0.0	4.336	—	—	—	3.630	—	—	—
0.2	4.540	4.69	4.72	4.62	3.750	3.82	3.81	3.76
0.4	5.880	6.77	6.03	5.32	4.560	4.80	4.34	4.04
0.6	11.17	19.36	15.17	10.16	8.180	9.60	7.03	5.61
0.8	19.39	43.46	107.6	153.7	16.030	34.38	60.97	37.21

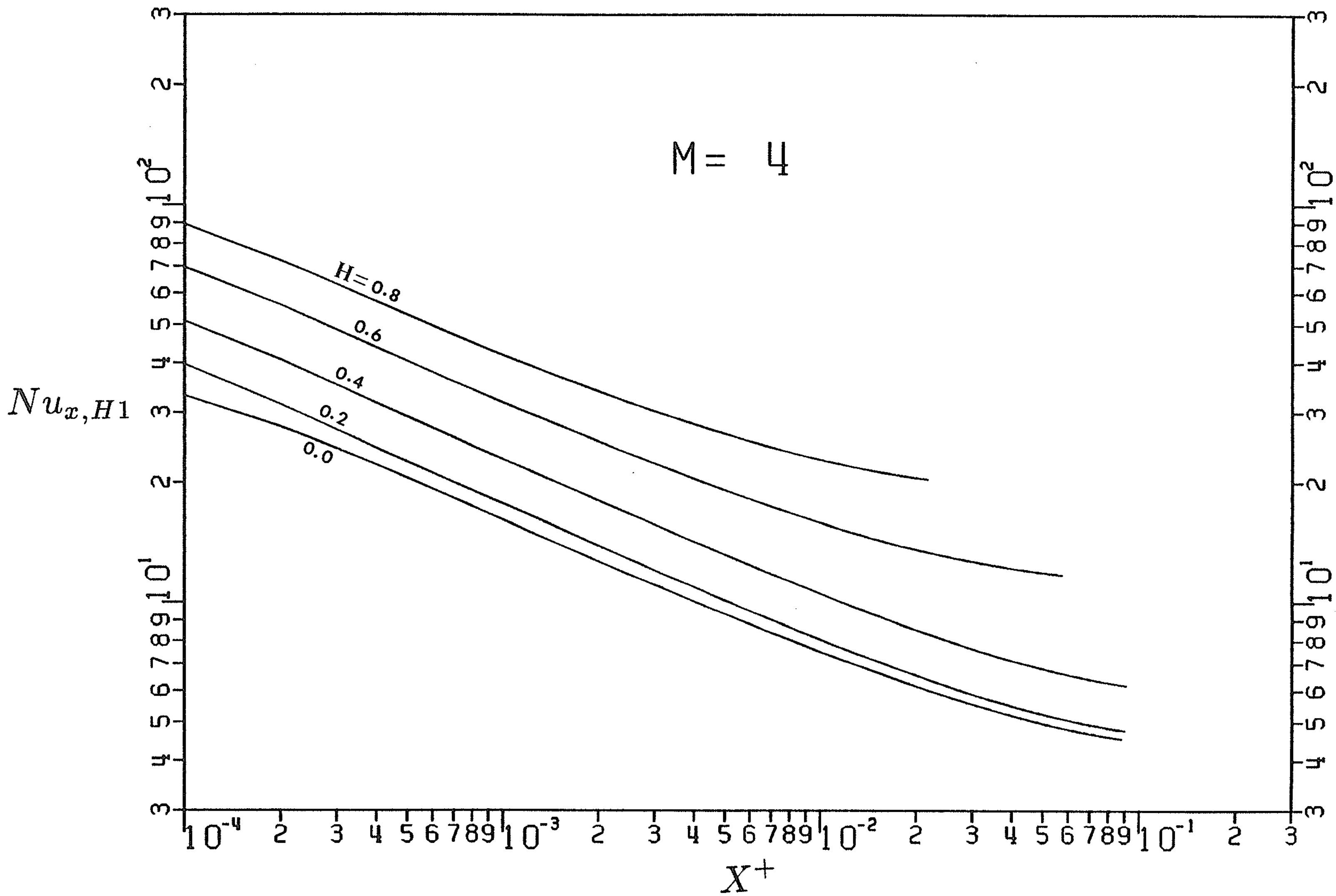


Figure 5.17 $Nu_{x,H1}$ versus X^+ for $M = 4$.

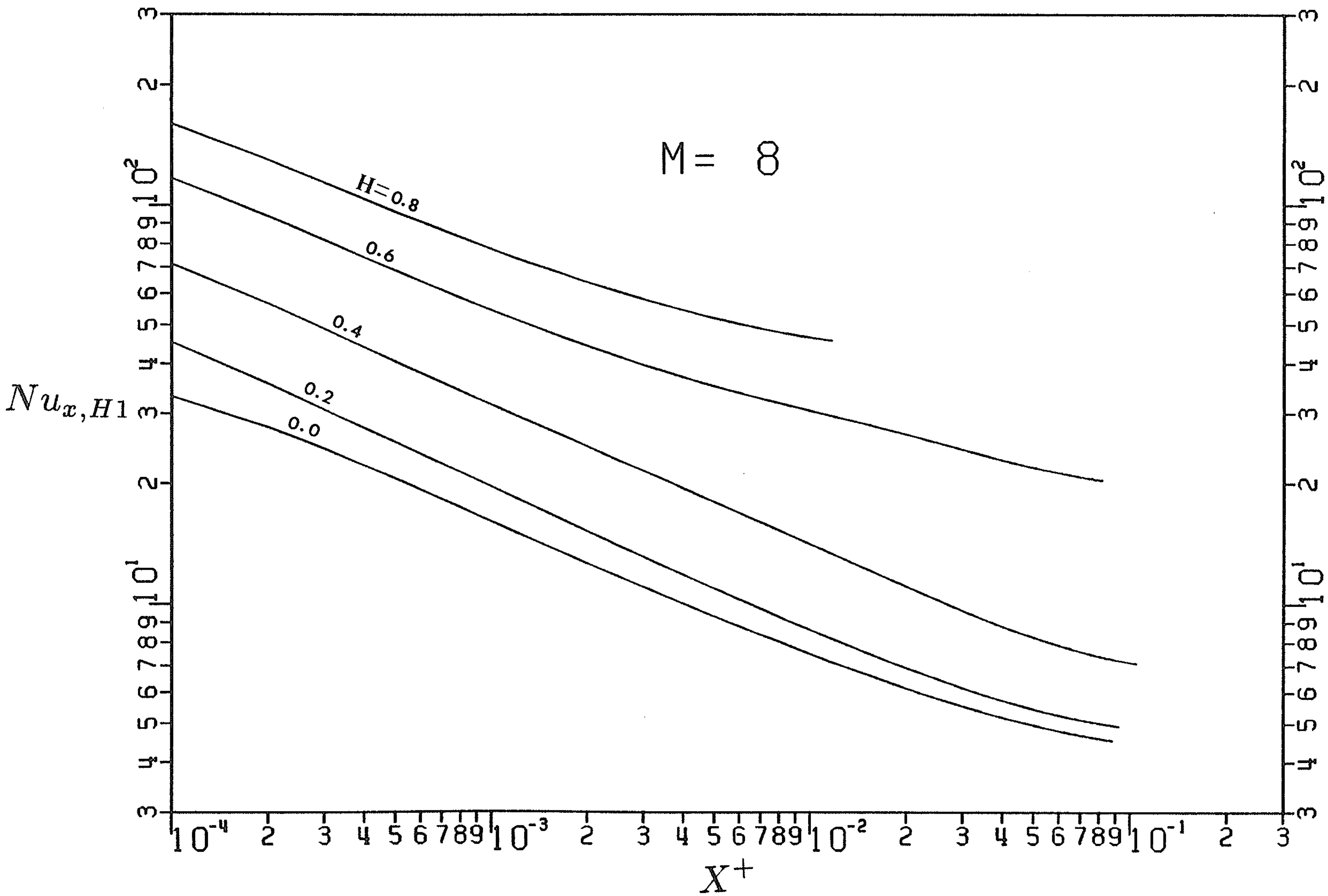


Figure 5.18 $Nu_{x,H1}$ versus X^+ for $M = 8$.

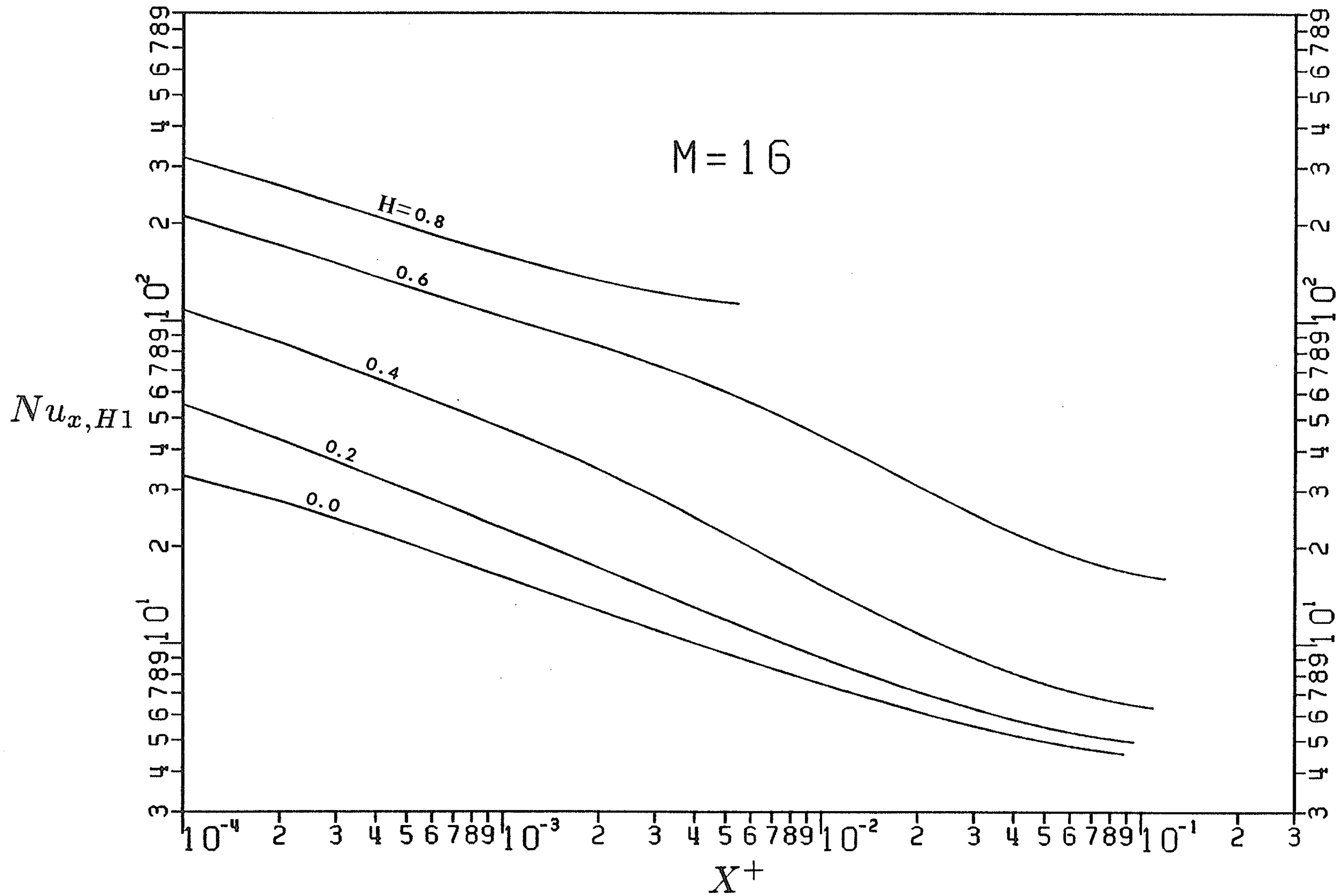


Figure 5.19 $Nu_{x,H1}$ versus X^+ for $M = 16$.

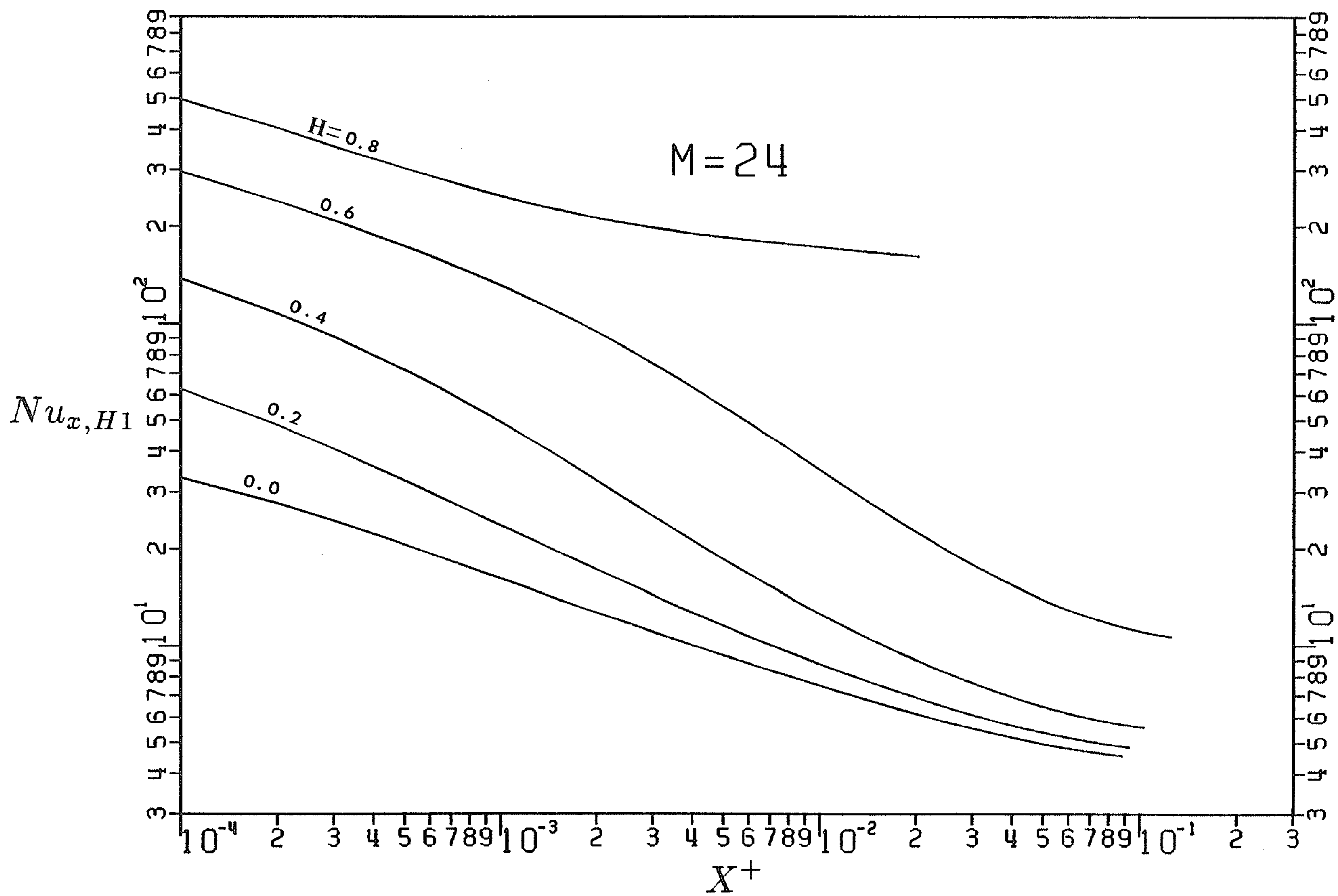


Figure 5.20 $Nu_{x,H1}$ versus X^+ for $M = 24$.

noticeable for large numbers ($M = 16$ and 24) of medium height fins ($H = 0.4$ and 0.6). As a consequence, this behaviour is expected to have effects on the length of the developing region (L^+_{H1}) as presented shortly.

In an attempt to explain this behaviour, the temperature development at some cross sectional locations of particular tubes was studied. For smooth tubes (Figure 5.21), $(T_w - T)$ can be seen to increase monotonically in the axial direction for all radial locations within the tube cross section. On the other hand, for some internally finned tubes (e.g., $H = 0.6$ and $M = 24$ shown in Figure 5.22), $(T_w - T)$ was found to increase monotonically at some locations within the core ($R = 0.2$), while at other locations within the bays formed by the fins ($R = 0.7$), $(T_w - T)$ starts out increasing, reaches a maximum and then drops toward the fully developed value. This unconventional manner of temperature development is probably caused by the complex velocity distribution (as seen in section 5.1.1), and the irregular shape of the wall-fluid interface where heat transfer takes place. Interestingly, when any geometry for which $Nu_{x,H1}$ behaves similar to smooth tubes (e.g., $H = 0.2$ and $M = 8$), the form of the temperature development was also found to be similar to smooth tubes as seen in Figure 5.23. The $Nu_{x,H1}$ results of Prakash and Liu (1985) for simultaneous development of velocities and temperature showed trends quite similar to those in Figures 5.17 to 5.20.

Table 5.2 provides values of the entrance length L^+_{H1} for the whole range of tube geometries considered in this investigation. These results contain maxima and minima that are not easy to explain, but which can be attributed to the complicated way by which the geometry influences the velocity distribution and in turn the temperature and local Nusselt number development. Two important observations can be drawn from the results in Table 5.2.

1) The value of L^+_{H1} for some finned tube geometries exceeds the value for smooth tubes, which is contrary to expectations.

2) The assumption that the entrance length for finned tubes based on the

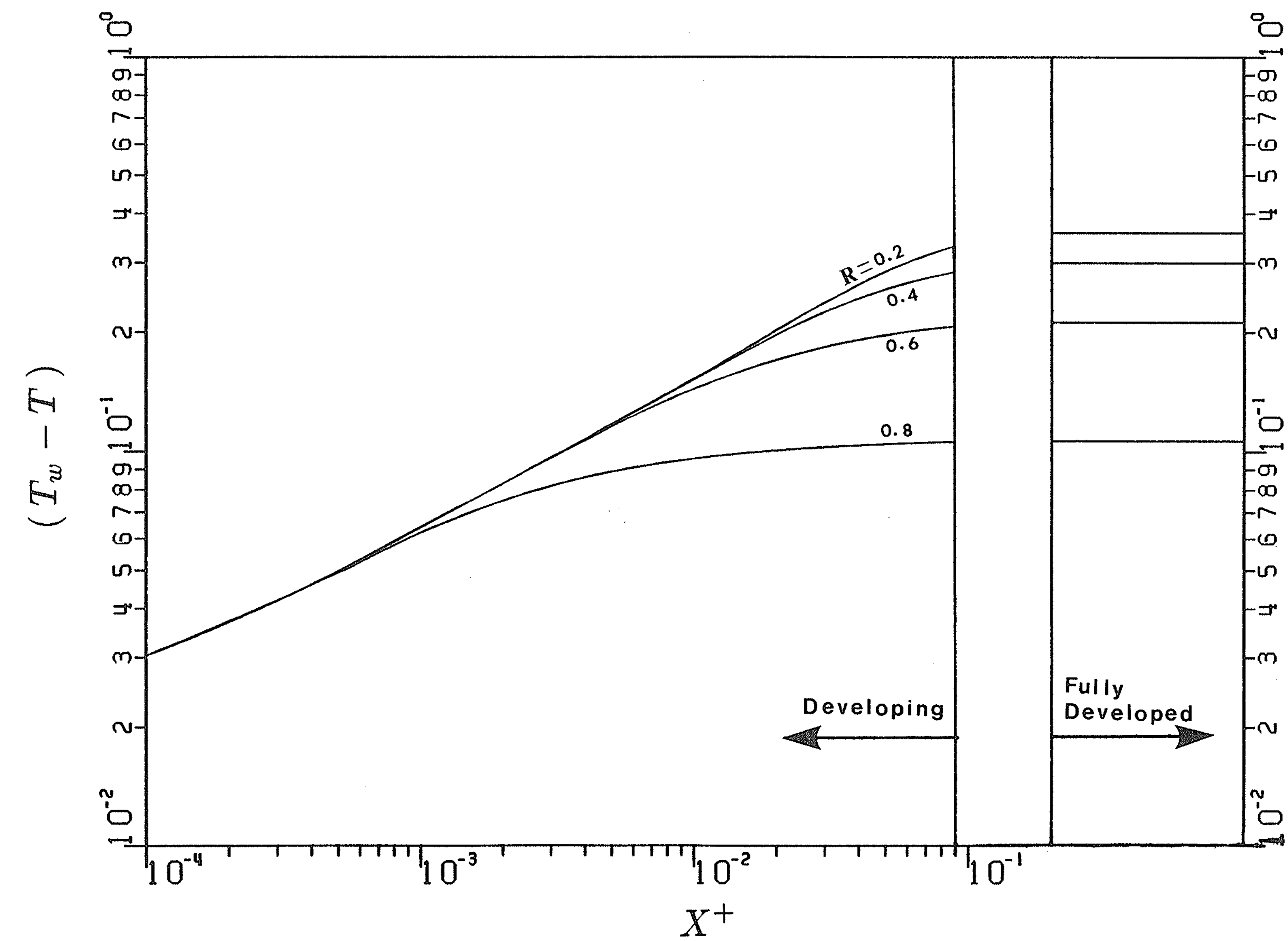


Figure 5.21 The development of temperature for smooth tubes at particular radial locations.

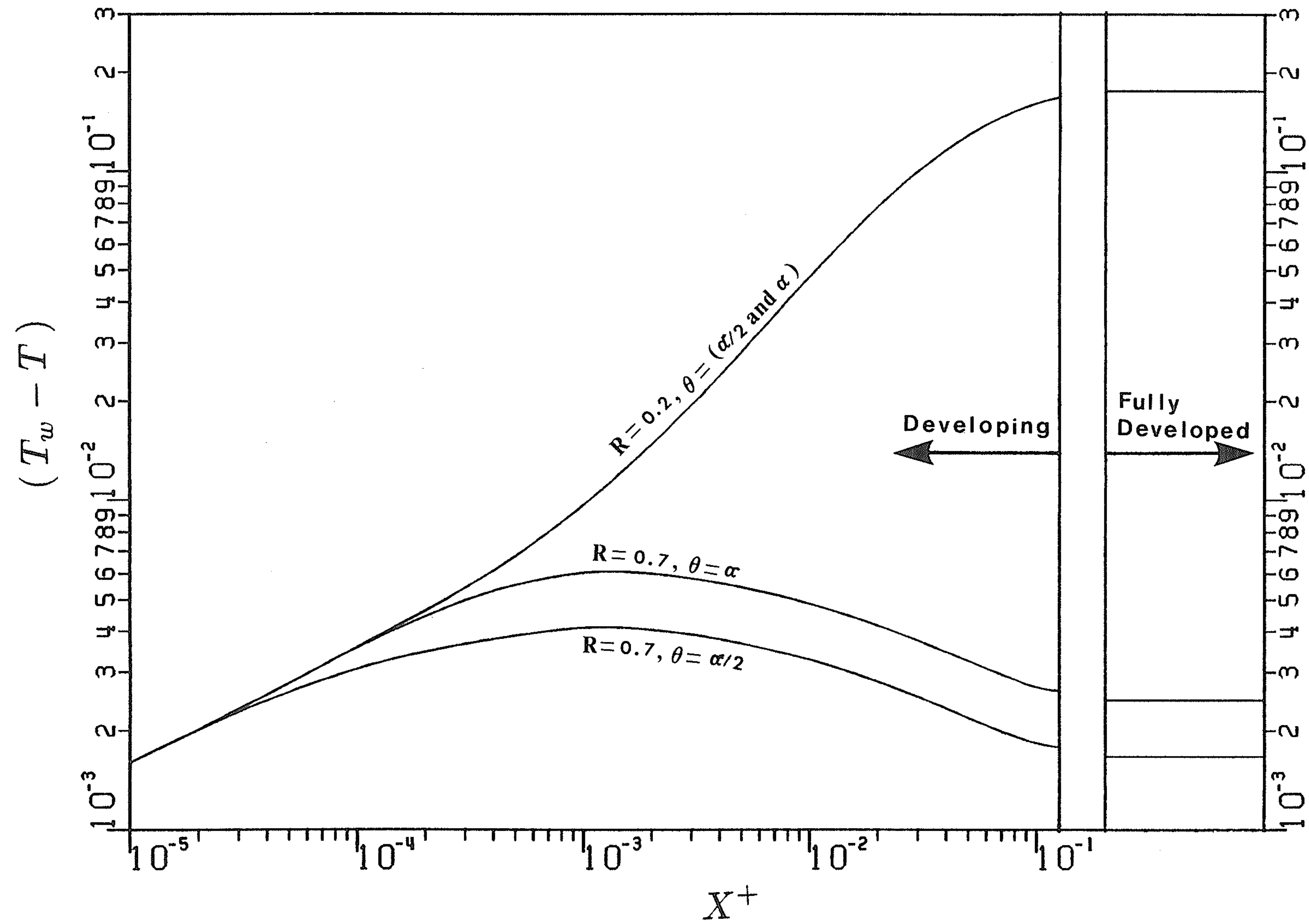


Figure 5.22 The development of temperature for $H = 0.6$ and $M = 24$ at particular locations.

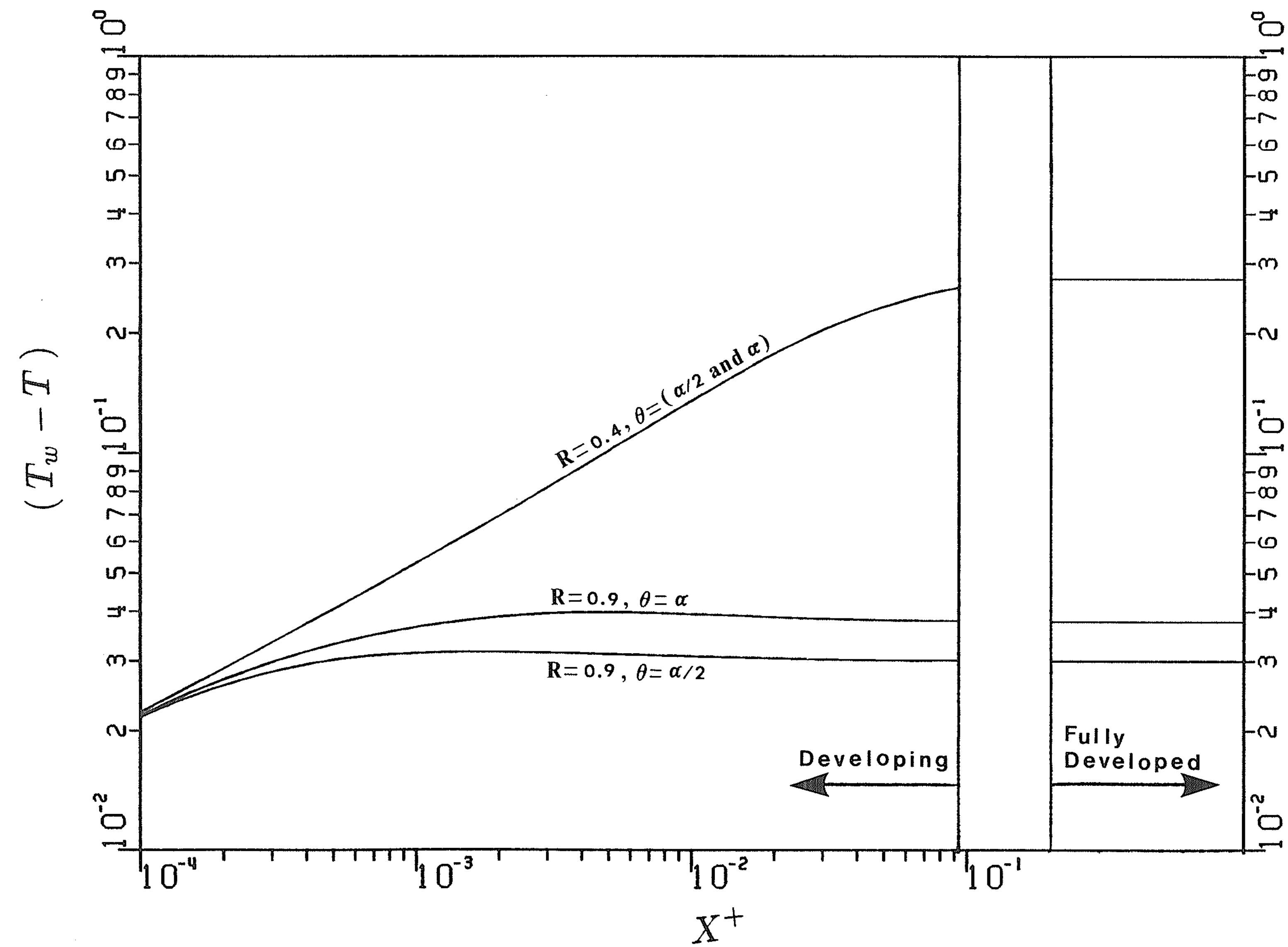


Figure 5.23 The development of temperature for $H = 0.2$ and $M = 8$ at particular locations.

Table 5.2 Values of L^{+}_{H1} for all geometries.

M / H	4	8	16	24
0.0 (smooth tube)	0.08831	—	—	—
0.2	0.09029	0.09250	0.09500	0.09324
0.4	0.09152	0.1049	0.1089	0.1035
0.6	0.05739	0.08233	0.1192	0.1260
0.8	0.02180	0.01176	0.005502	0.02043

hydraulic diameter may be equated to the entrance length for smooth tube appears to be invalid.

Both of the above observations, as well as the existence of local maxima and minima are consistent with the trends in the results of Prakash and Liu (1985). In terms of magnitudes, the present results for $H = 0.6$ are consistently lower by 45 to 50% than the predictions of Parakash and Liu, however, their flow situation is different from the present situation.

C) Developing Heat Transfer: (T) Boundary Condition

Figures 5.24 to 5.27 show the development of the local Nusselt number $Nu_{x,T}$ over the range $10^{-4} \leq X^+ \leq L_T^+$ for $M = 4$, 8, 16, and 24, respectively. The influence of fin height H is illustrated in each figure by presenting $Nu_{x,T}$ for $H = 0$ (smooth tube), 0.2, 0.4, 0.6, and 0.8. Similar observations to $Nu_{x,H1}$ in terms of trends are noted. Comparing $Nu_{x,T}$ to $Nu_{x,H1}$ for any geometry, $Nu_{x,T}$ is found to be consistently lower than $Nu_{x,H1}$ at any axial location X^+. Also, $Nu_{x,T}$ shows an irregular rate of development along X^+ as was noted for the case of (H1) boundary condition. This irregular rate of development is reflected on the values of L_T^+, which contain local maxima and minima similar to the L_{H1}^+ results, as shown in Table 5.3. For $H = 0.6$, the present results of L_T^+ are 44 to 77 % lower than those predicted by Prakash and Liu (1985), however, their flow situation is different from this present sitution.

Establishing general trends from the present results was found to be a difficult task. For example, values of L_T^+ are generally lower than L_{H1}^+, however, for the case of $H = 0.8$ and $M = 16$, L_T^+ is more than 10 times that of L_{H1}^+. Also, the ratio L_{H1}^+/L_T^+ varies significantly among different geometries. While it is unfortunate that simple but accurate correlations cannot be developed for $Nu_{x,H1}$, $Nu_{x,T}$, L_{H1}^+, and L_T^+, the results are useful in their present form and should serve as a warning against extending smooth tube results to other geometries on hydraulic diameter basis.

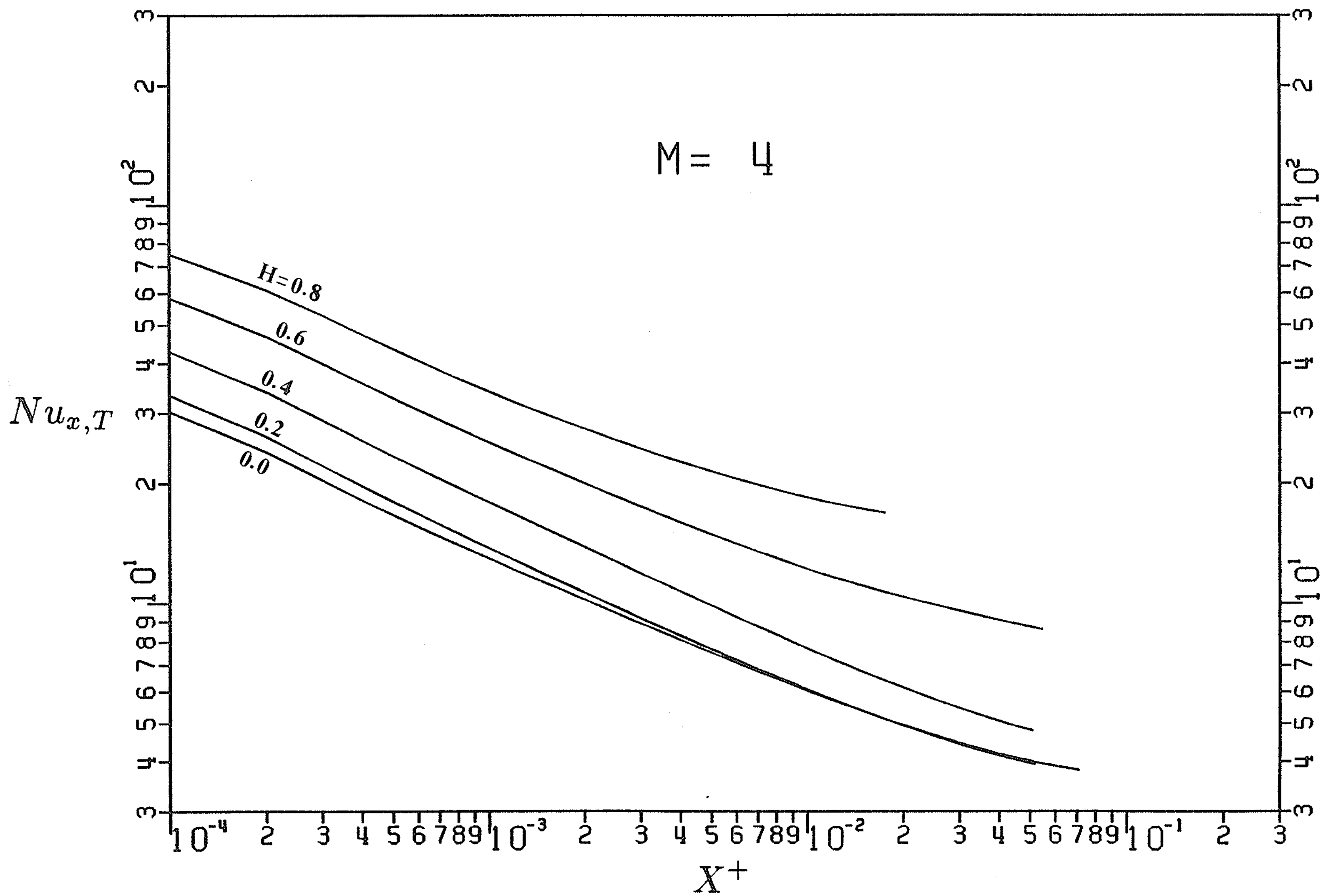


Figure 5.24 $Nu_{x,T}$ versus X^+ for $M = 4$.

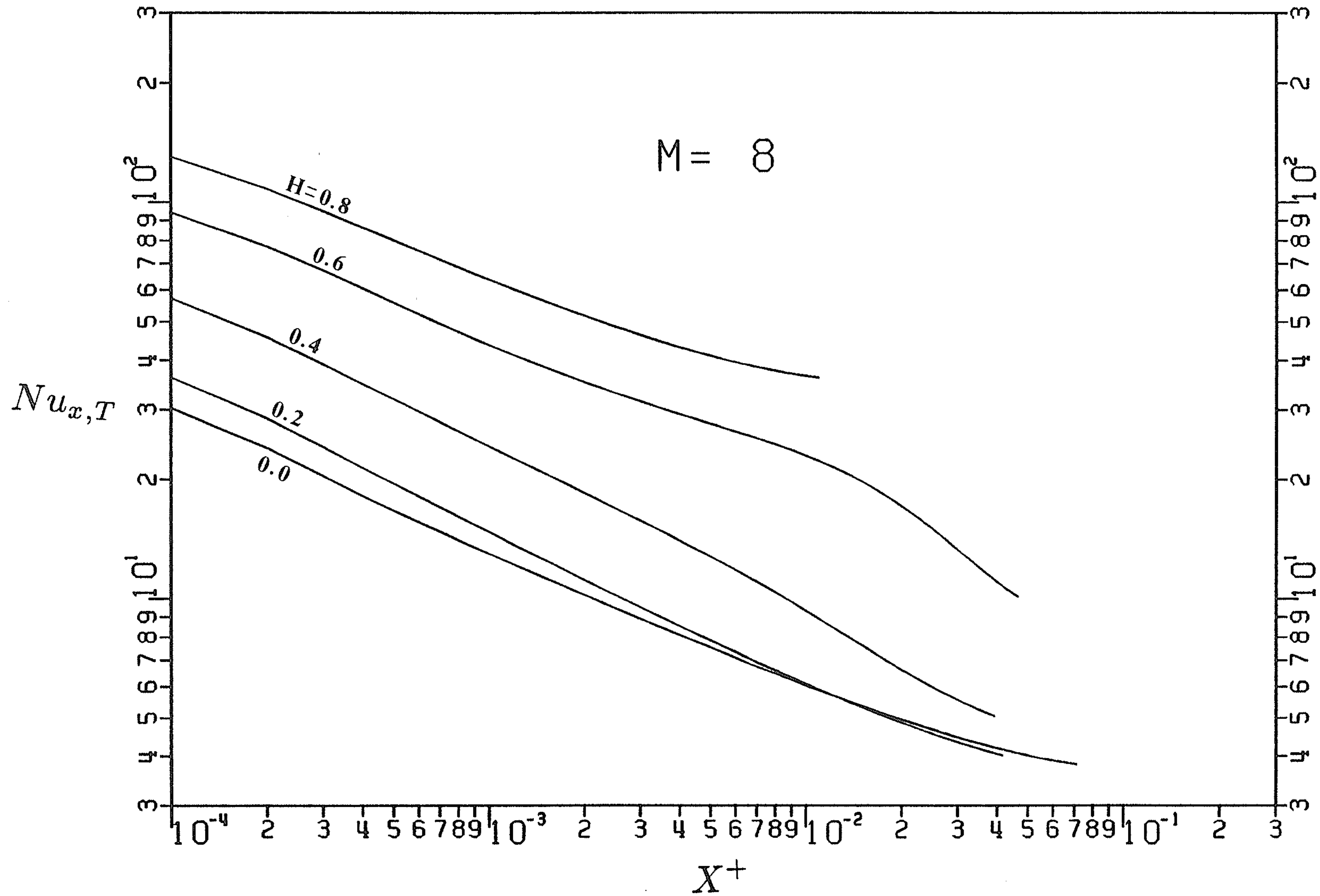


Figure 5.25 $Nu_{x,T}$ versus X^+ for $M = 8$.

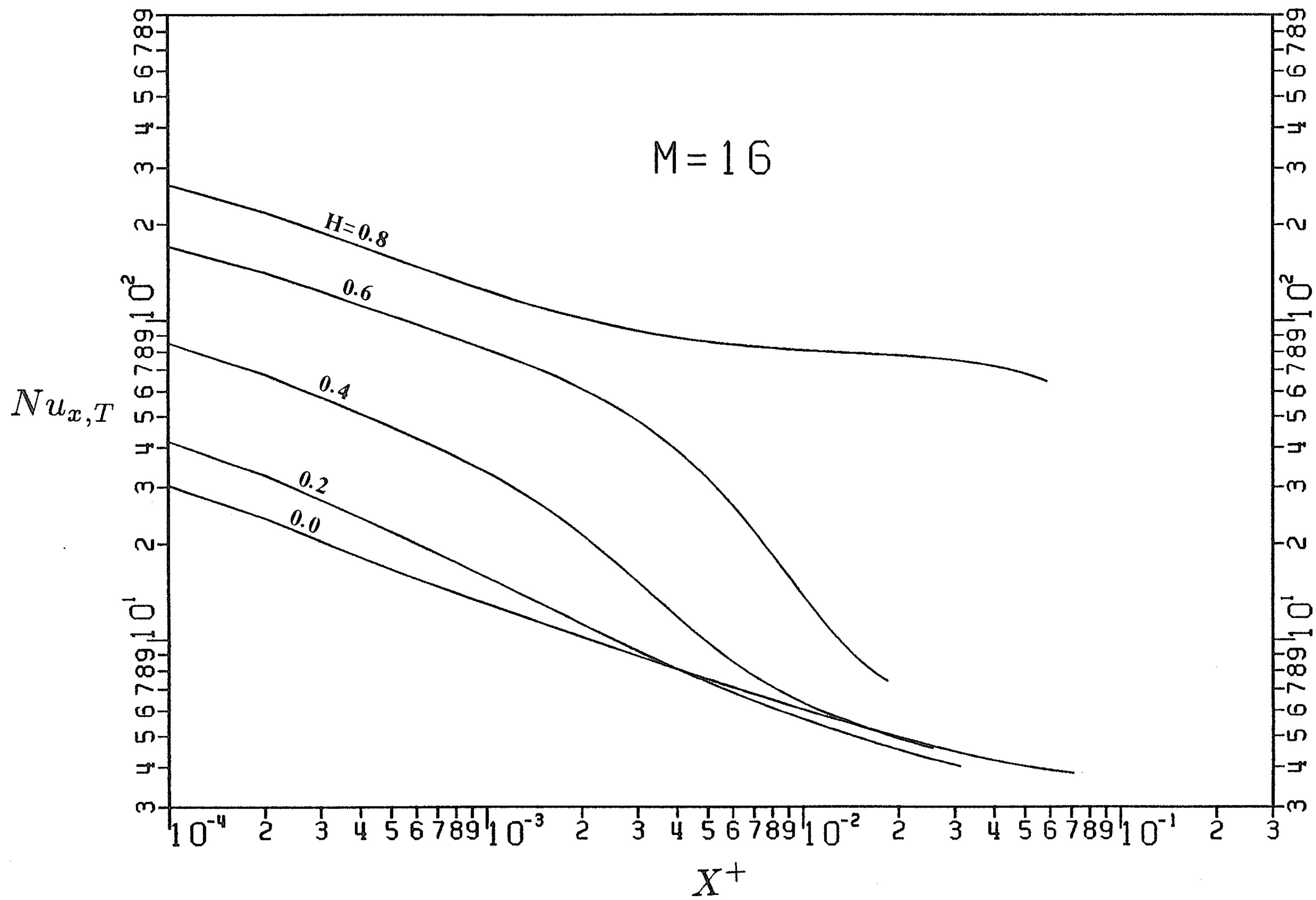


Figure 5.26 $Nu_{x,T}$ versus X^+ for $M = 16$.

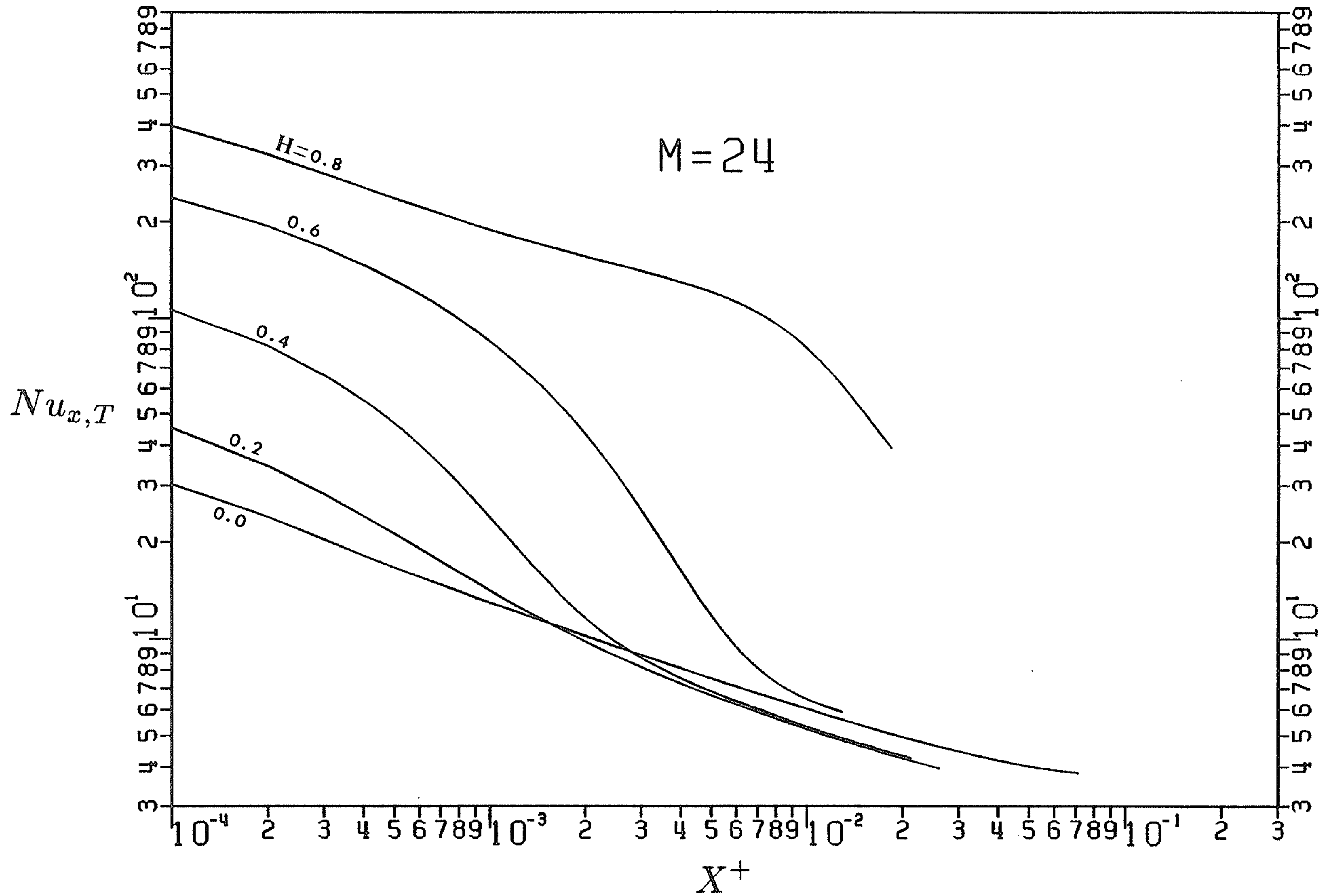


Figure 5.27 $Nu_{x,T}$ versus X^+ for $M = 24$.

Table 5.3 Values of L_T^+ for all geometries.

H \ M	4	8	16	24
0.0 (smooth tube)	0.07136	—	—	–
0.2	0.05180	0.04174	0.03135	0.02621
0.4	0.05107	0.03945	0.02566	0.02135
0.6	0.05473	0.04679	0.01858	0.01298
0.8	0.01764	0.01101	0.05919	0.01850

5.2 Developing Isothermal Flow

The velocity and pressure distributions in the solution domain were obtained for sixteen different geometries of internally finned tubes and the smooth tube geometry. The geometries covered in this model correspond to $H = 0$ (smooth tube), and a combination of the geometric parameters $H = 0.2$, 0.4, 0.6, and 0.8 and $M = 4$, 8, 16, and 24. Based on the velocity distributions, very important engineering parameters were calculated. These parameters are, fRe, $f_{app}Re$, $f_{fd}Re$, K, K_{∞}, $L_{H,1\%}$, and $L_{H,5\%}$. Influence of the geometric parameters H and M on the velocity distributions was studied and an adequate sample of results for some selected geometries is presented. The effect of H and M on the global parameters is presented for all geometries in graphical form in this chapter and in detailed tabulated form in Appendix B.

5.2.1 Velocity Fields

A) Fully-Developed Velocity Fields

In the previous section, results of fully developed equi-velocity (u/u_b) lines were presented for all considered fin heights ($H = 0.2$, 0.4, 0.6, and 0.8) and for the highest and lowest values of number of fins ($M = 4$ and 24). To avoid duplication, the fully developed equi-velocity (u/u_b) lines of this model are presented for the geometries that were not presented in the previous section (i.e., $H = 0.2$, 0.4, 0.6, and 0.8 $M = 8$ and 16), thus covering all geometries among the two models. Figures 5.28 to 5.31 show that the velocity gradient in both the radial and the angular directions becomes steeper as we approach solid boundaries. The other aspect of the flow pattern shown in these figures is the formation of closed loop equi-velocity lines within the bays formed by any two adjacent fins. As mentioned in section 5.1.1, the formation of these loops is found to be a function of the two geometrical parameters, H and M. For short fins (H=0.2 and 0.4), no loops are formed for any value of M.

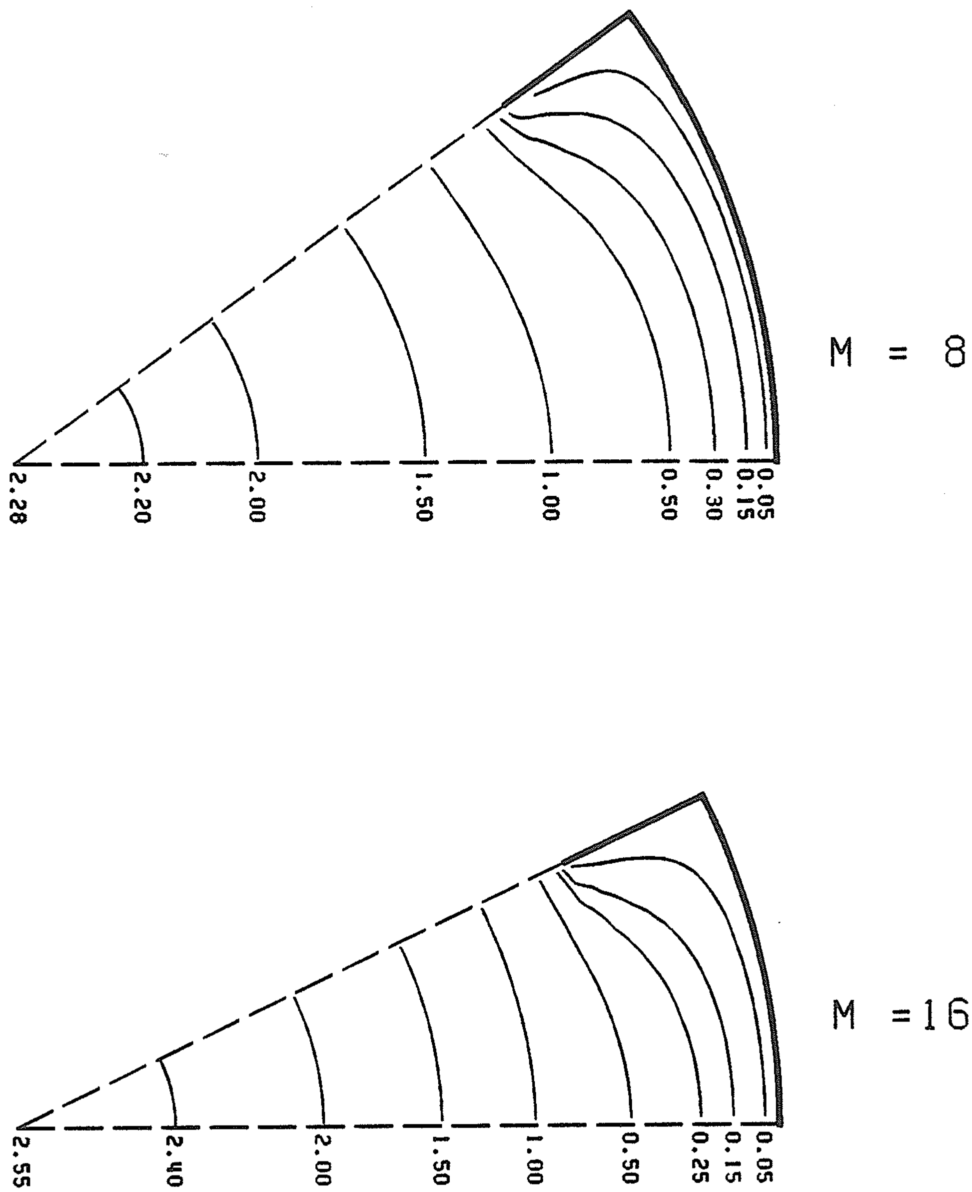


Figure 5.28 Equi-velocity lines (u/u_b) for $H = 0.2$.

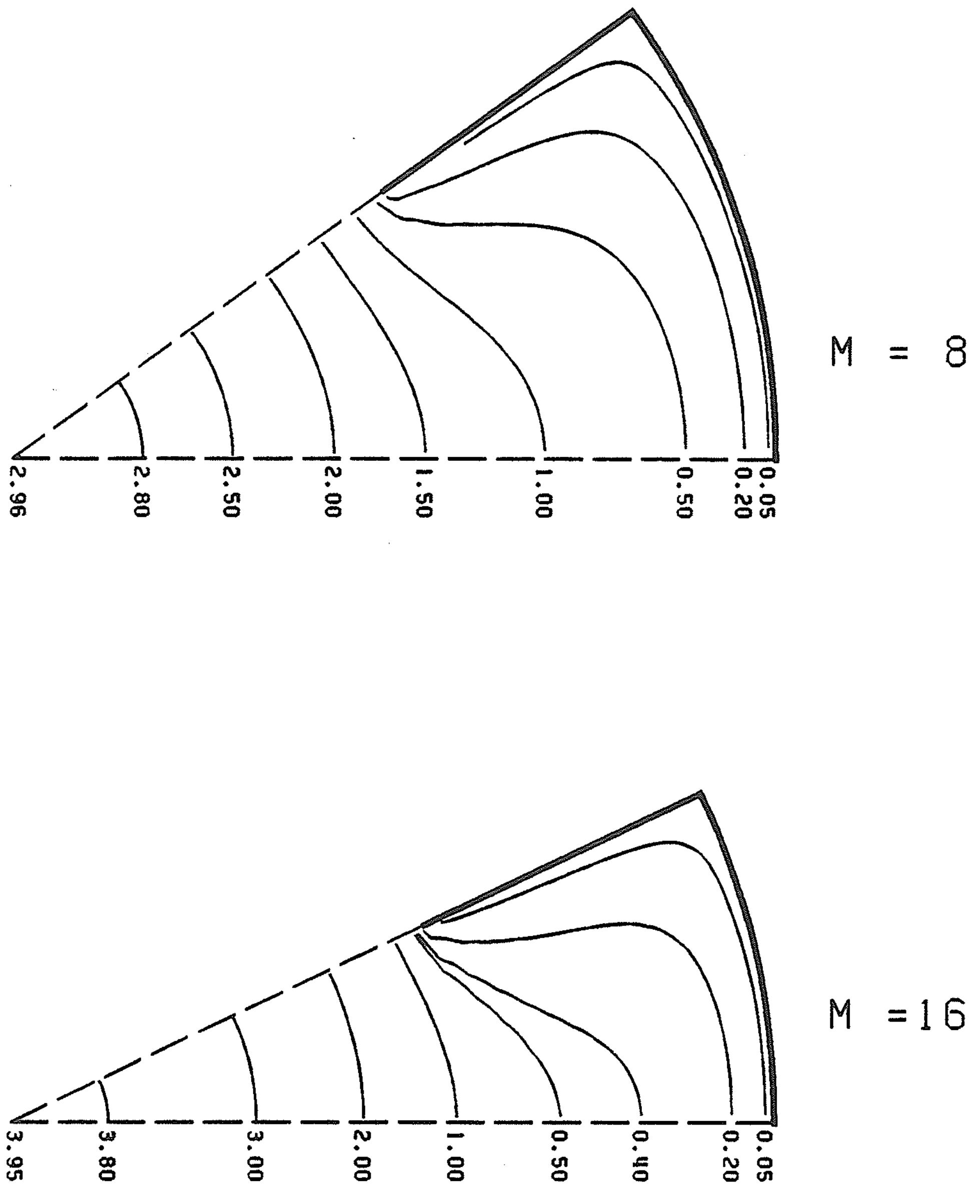


Figure 5.29 Equi-velocity lines (u/u_b) for $H = 0.4$.

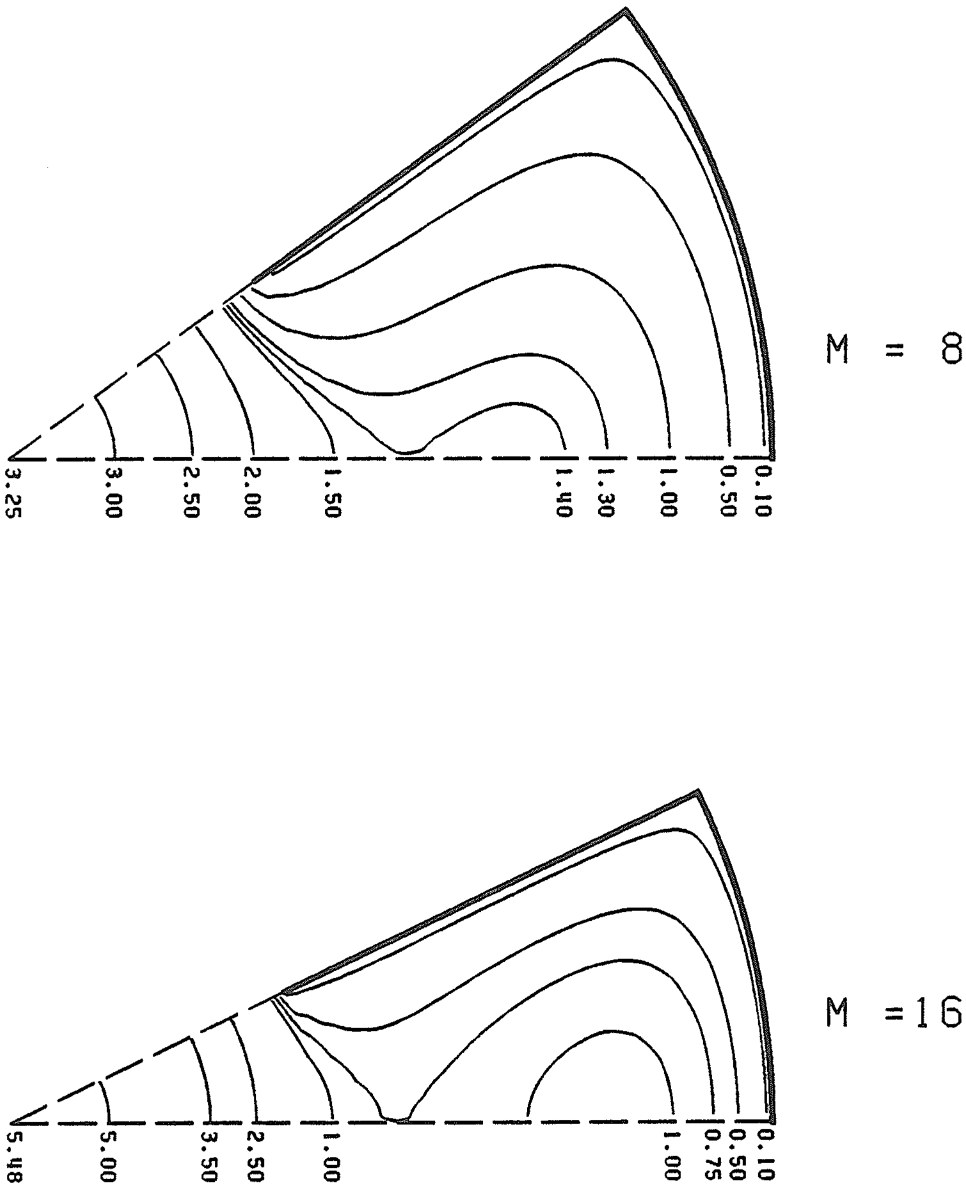


Figure 5.30 Equi-velocity lines (u/u_b) for $H = 0.6$.

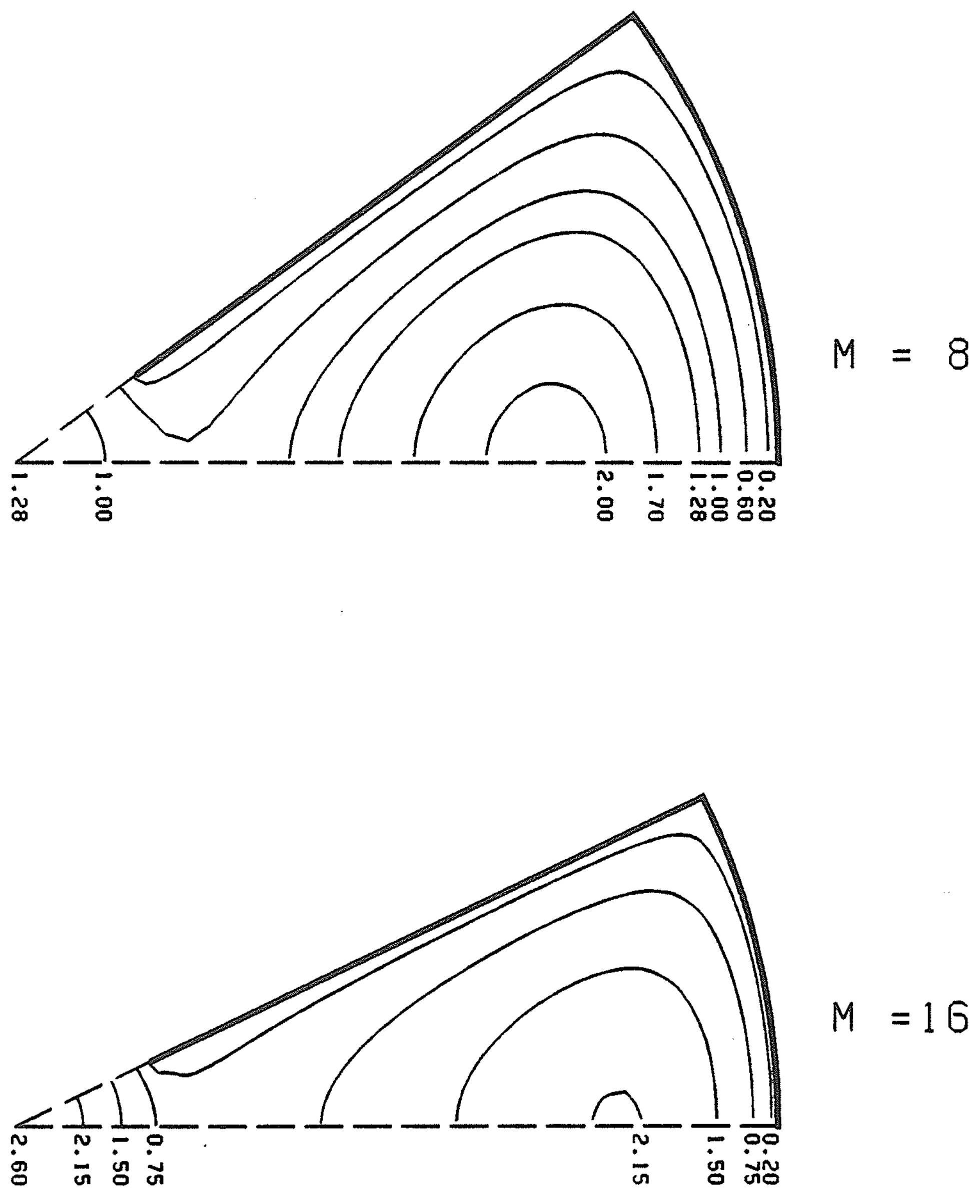


Figure 5.31 Equi-velocity lines (u/u_b) for $H = 0.8$.

However, for $H = 0.6$, the loops started to form for values of $M = 8$ and higher. For long fins of $H = 0.8$, the closed loops are shown to form for all values of M considered in this investigation (i.e. M=4, 8, 16, and 24).

B) Developing Velocity Fields

In the developing region, the velocity starts with a uniform profile at $X = 0$. As the flow progresses along the tube ($X > 0$), a boundary layer starts to develop along the solid boundaries (tube wall and fin side). This boundary layer continues to grow until the fully developed region is reached. For the smooth-tube case, the boundary layer grows symmetrically from the wall towards the tube centreline. For the case of internally finned tubes, the boundary layer grows towards the points where the axial velocity is maximum. As indicated before, the location of the maximum axial velocity depends on the geometry of the tube. Results for the four corners of the covered geometries ($H = 0.2$ and $M = 4$, $H = 0.2$ and $M = 24$, $H = 0.8$ and $M = 4$, and $H = 0.8$ and $M = 24$) were chosen to be presented to shed some light on the development of the velocity fields.

Figure 5.32 illustrates the boundary layer growth as evidence by the axial shift in the equi-velocity lines for the case of low number of short fins ($H = 0.2$ and $M = 4$). The axial velocity is shown to accelerate at the tube centre and retards near the solid boundaries. A secondary flow is generated due to the boundary layer mass displacement effect. For smooth tubes, the secondary flow has a radial component only, and it is in the negative direction for the entire developing region (i.e., the fluid is pushed towards the tube centre at all cross-sections). For finned tubes, the secondary flow generally has two components (radial and angular). The fluid movement cannot be defined in a general way for all geometries, however, for each geometry the secondary flow appears to move the fluid from the retarding areas (near solid boundaries) to the accelerating areas (tube centre, the central area between adjacent fins, or both). Figure 5.33 shows the secondary flow pattern for the

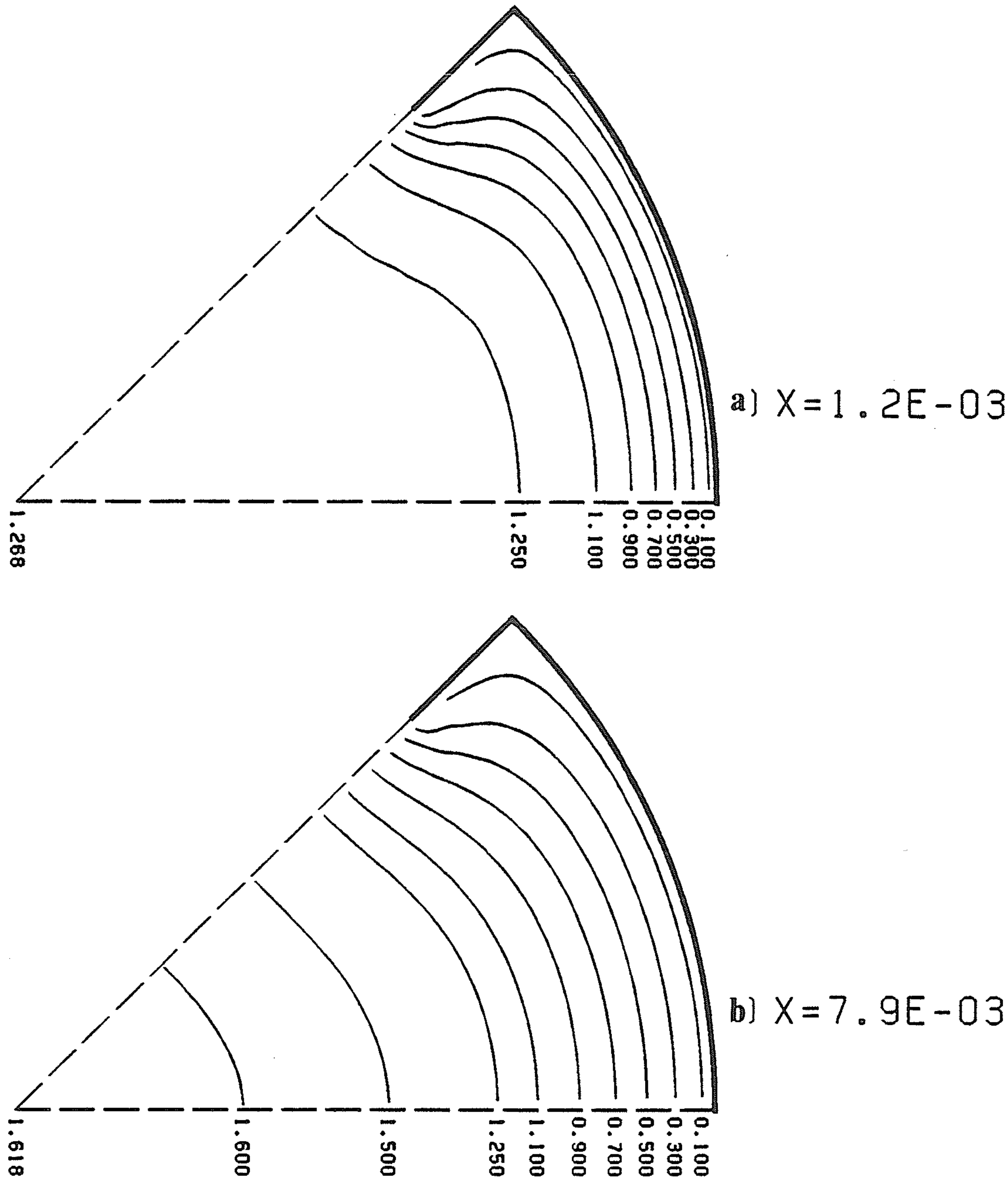


Figure 5.32 Development of the equi-velocity (u/u_b) lines for $H = 0.2$ and $M = 4$.

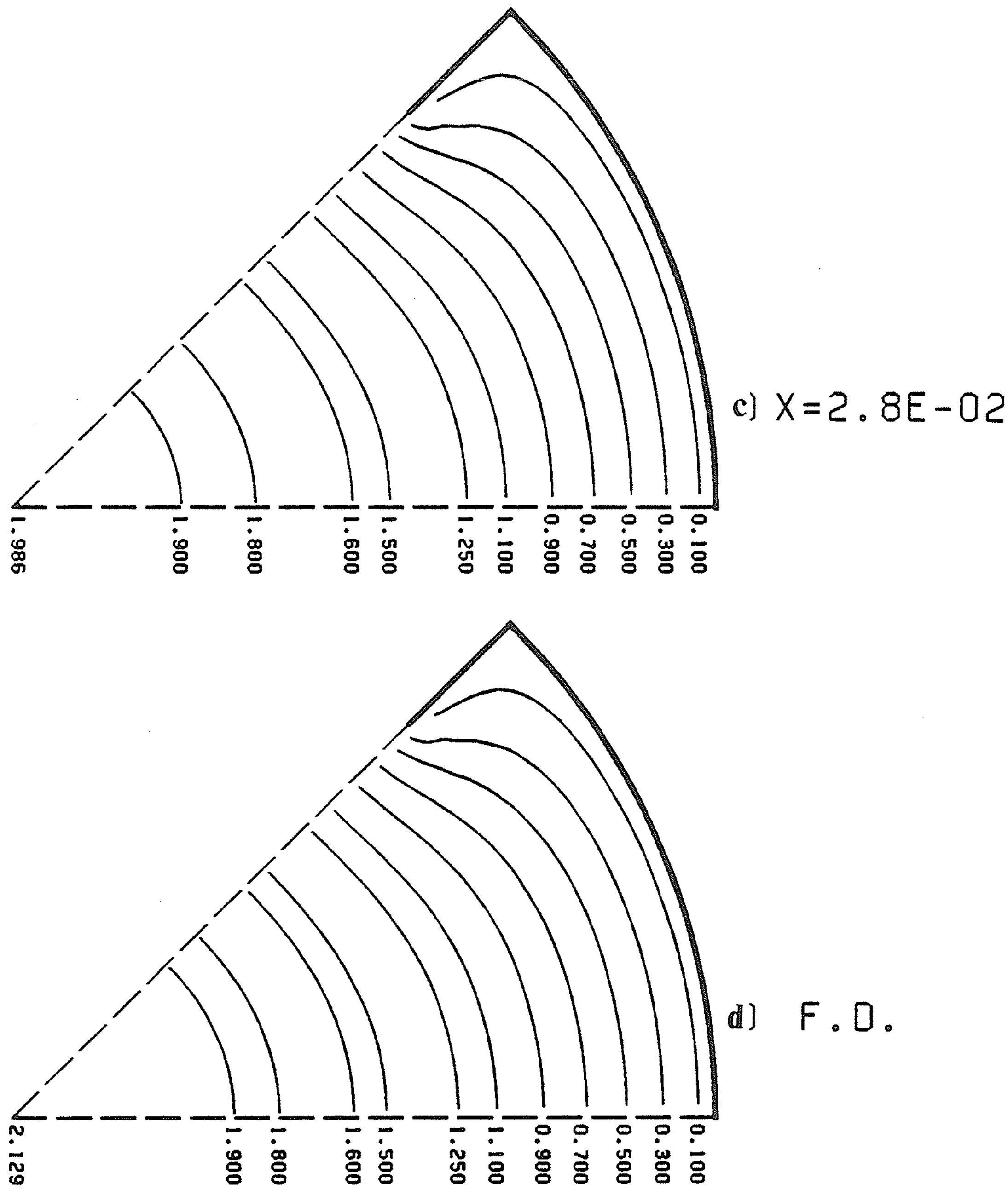


Figure 5.32 Development of the equi-velocity (u/u_b) lines for $H = 0.2$ and $M = 4$.

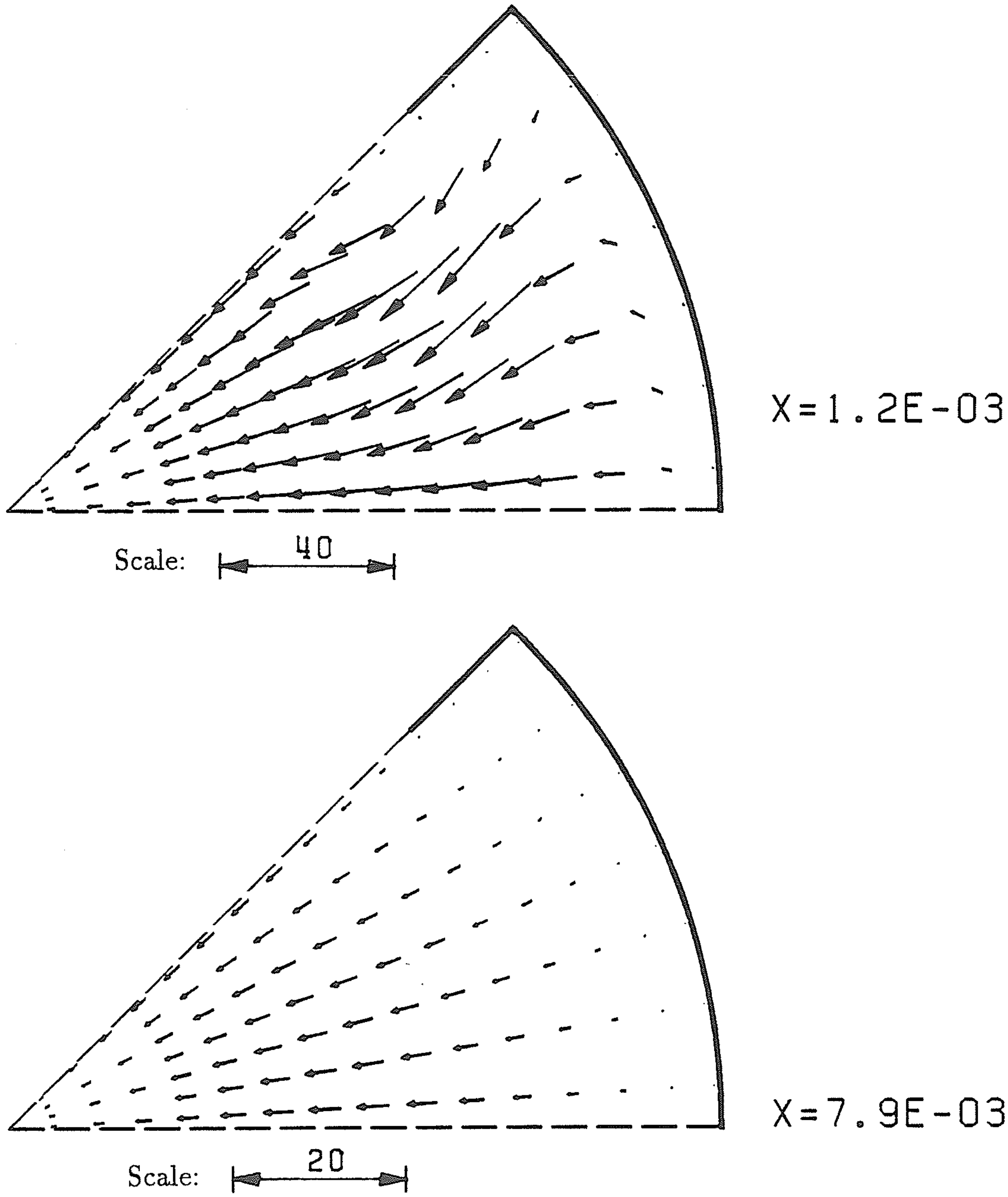


Figure 5.33 Secondary flow pattern at two axial locations for $H = 0.2$ and $M = 4$.

geometry of $H = 0.2$ and $M = 4$. At an early station in the entrance region, the secondary flow is shown to be very active and mostly moves the fluid radially towards the tube centre and away from the wall and fin side. At a later station downstream, the secondary flow is shown to be decaying. Similar results for $H = 0.2$ and $M = 24$ are shown in Figures 5.34 and 5.35. It may be noted that for short fins ($H = 0.2$), the pattern of flow development resembles that of smooth tubes for most of the cross sectional area except near the wall where the effect of the fins is noticeable.

Figure 5.36 shows the development of the boundary layer for the case of low number of long fins ($H = 0.8$ and $M = 4$). For this geometry the axial velocity is known to have two maxima, one at the tube centreline and the other within the bay between the fins. The global maximum depends on the number of fins. If the number of fins is low (e.g., $M = 4$), the fluid finds the bay area to have less resistance than the tube core area. This in turn causes the global maximum axial velocity to occur in the bay area as shown in Figure 5.36. As a result of the boundary layer mass displacement effect, the fluid moves from the retarding area near the solid boundaries towards the accelerating areas (bay and centreline areas). This in turn created a secondary flow in the form of radial and angular components, as shown in Figure 5.37 Another interesting feature of Figure 5.37 is the appearance of a small eddy near the corner formed by the tube wall and fin side. One possible explanation for this behaviour could be attributed to the fluid moving away from that area causing a suction effect in that corner.

Figures 5.38 and 5.39 show similar results for the case of high number of long fins ($H = 0.8$ and $M = 24$). For this geometry, the axial velocity has two maxima, with the global maximum occuring at the tube centreline. The secondary flow, shown in Figure 5.39, appears to be moving the fluid into the two maxima areas, and away from the solid boundaries.

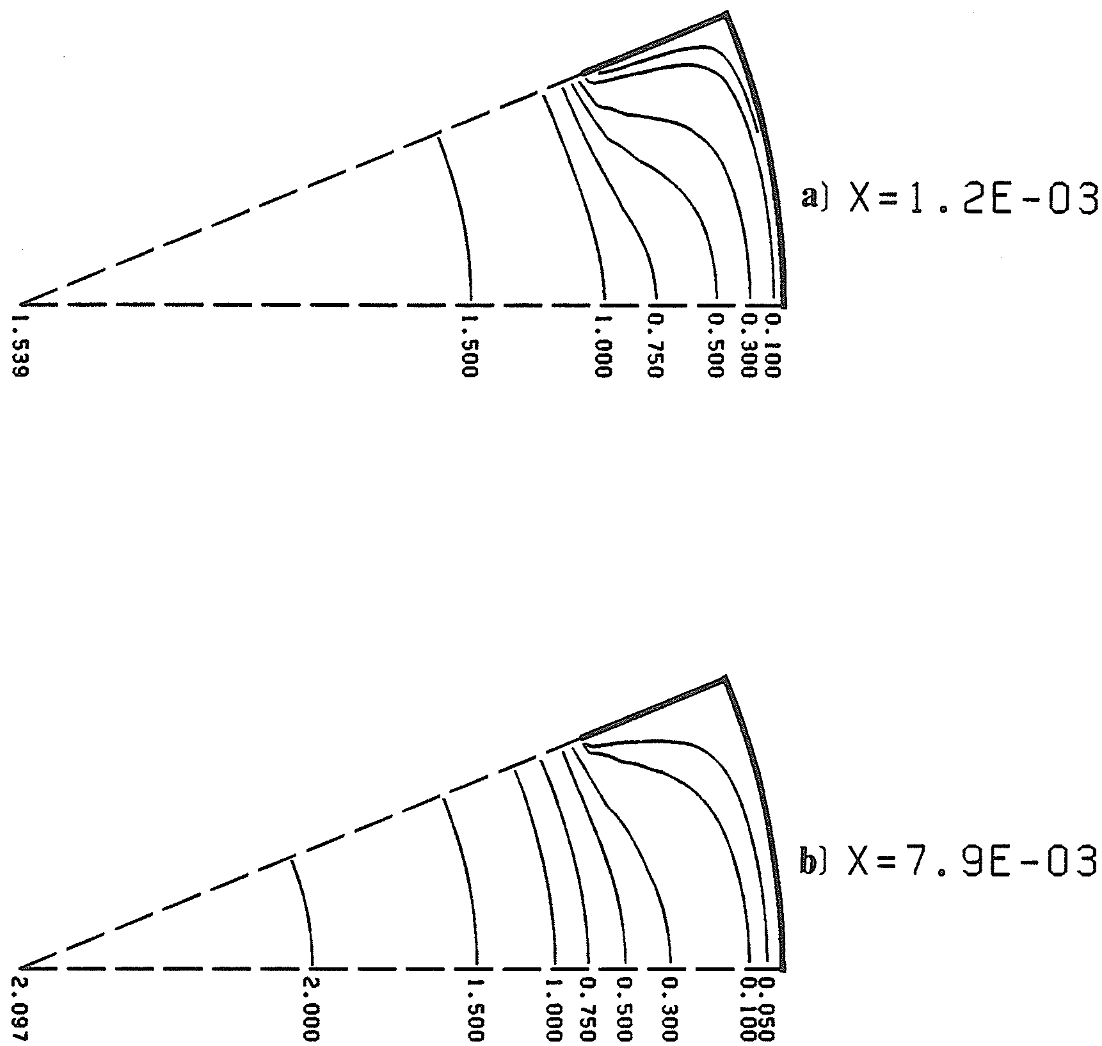


Figure 5.34 Development of the equi-velocity (u/u_b) lines for $H = 0.2$ and $M = 24$.

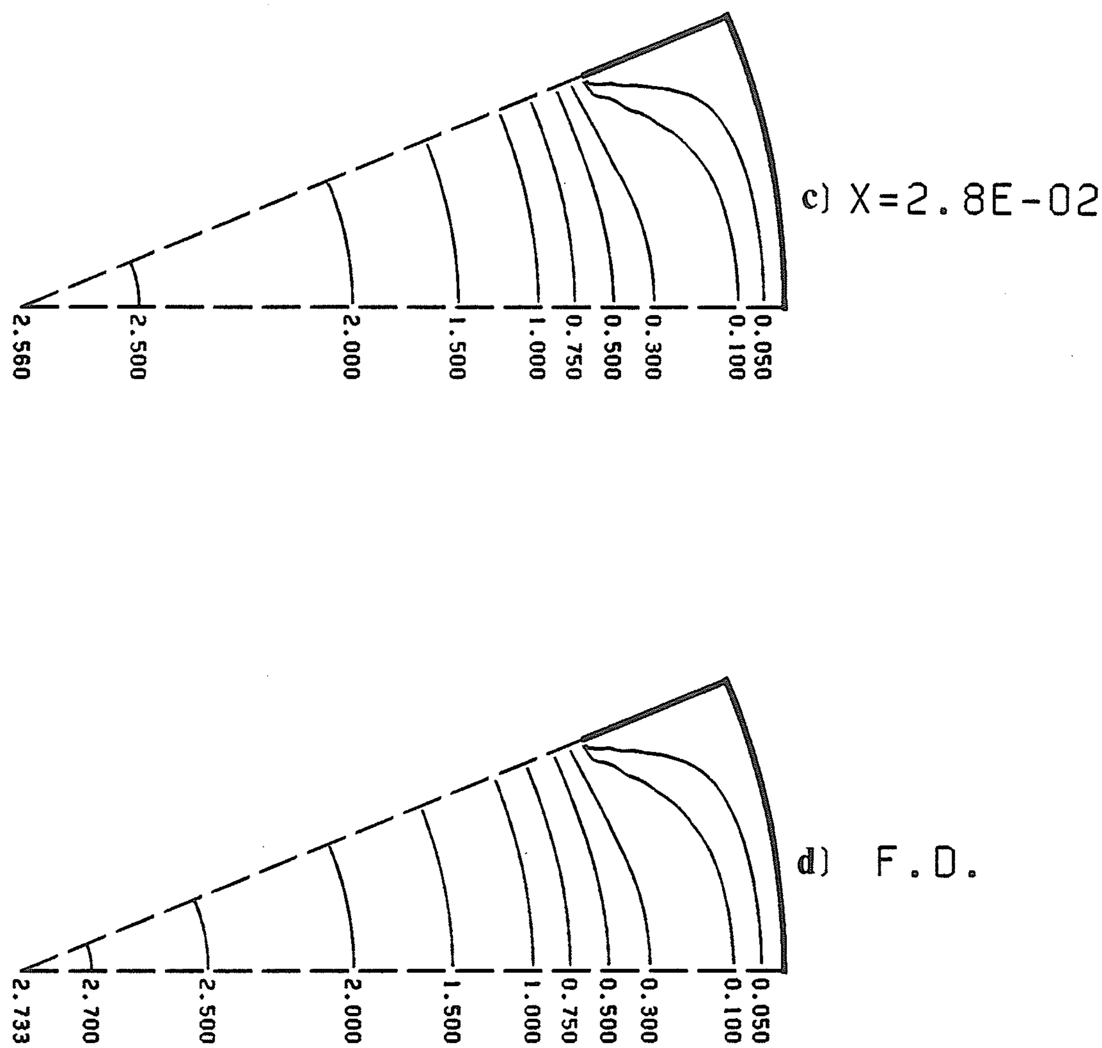
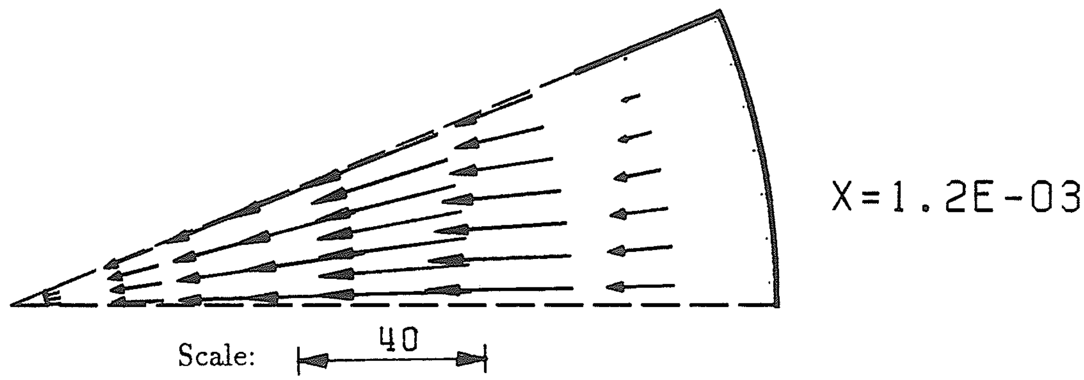


Figure 5.34 Development of the equi-velocity (u/u_b) lines for $H = 0.2$ and $M = 24$.



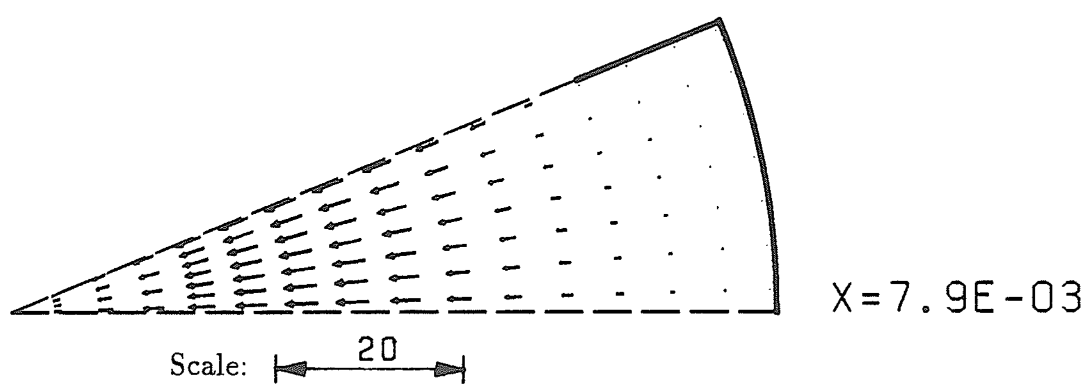


Figure 5.35 Secondary flow pattern at two axial locations for $H = 0.2$ and $M = 24$.

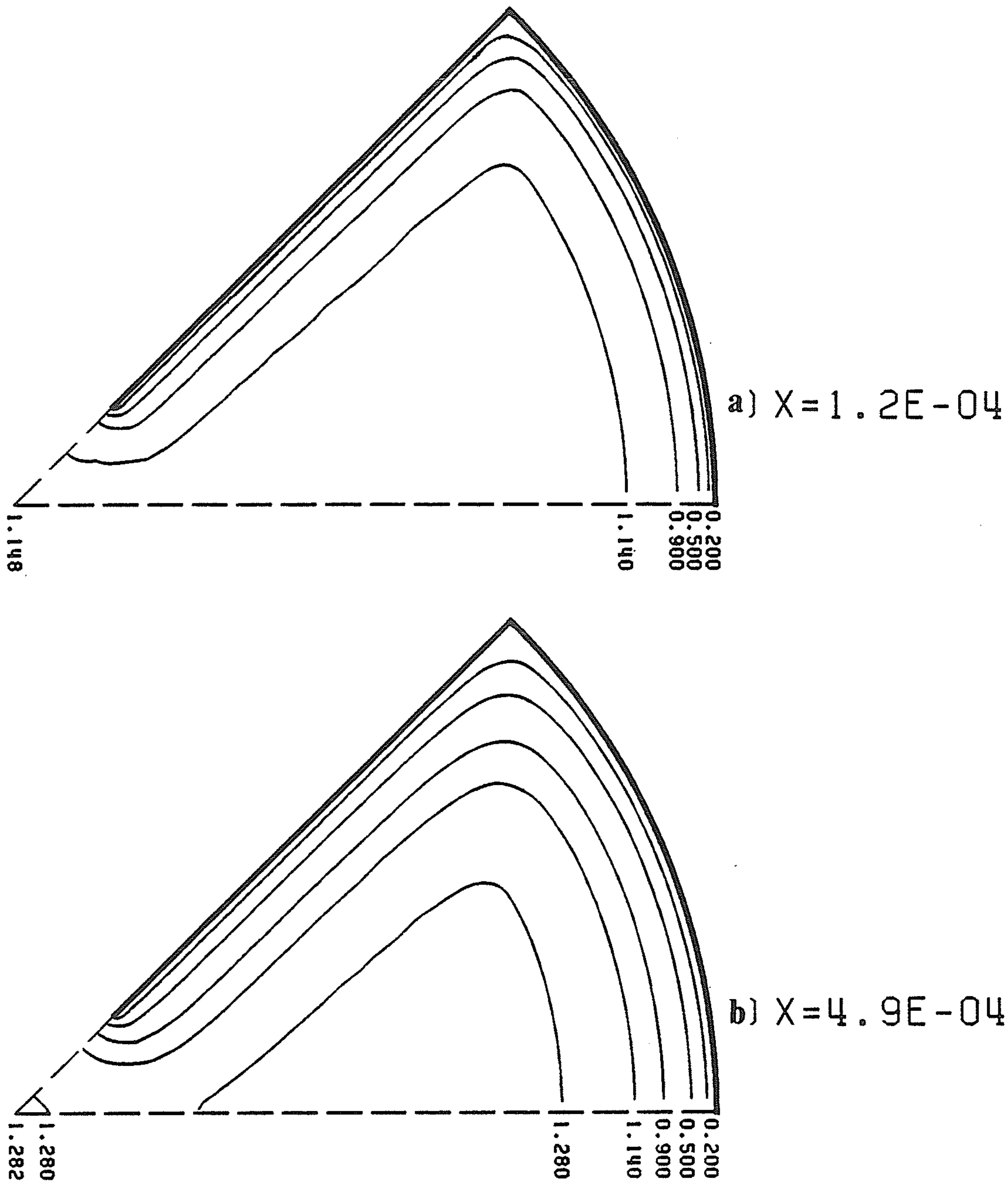


Figure 5.36 Development of the equi-velocity (u/u_b) lines for $H = 0.8$ and $M = 4$.

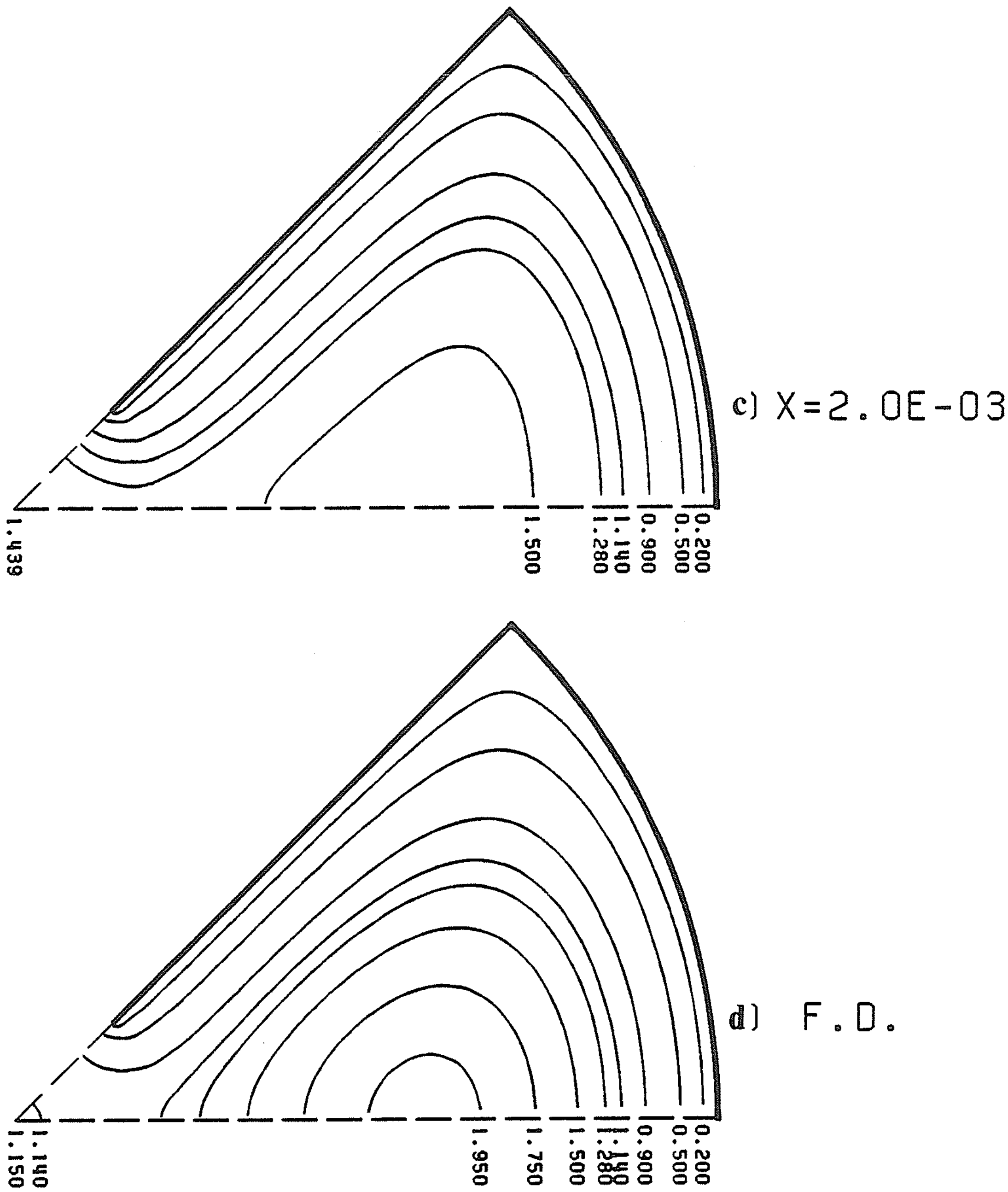


Figure 5.36 Development of the equi-velocity (u/u_b) lines for $H = 0.8$ and $M = 4$.

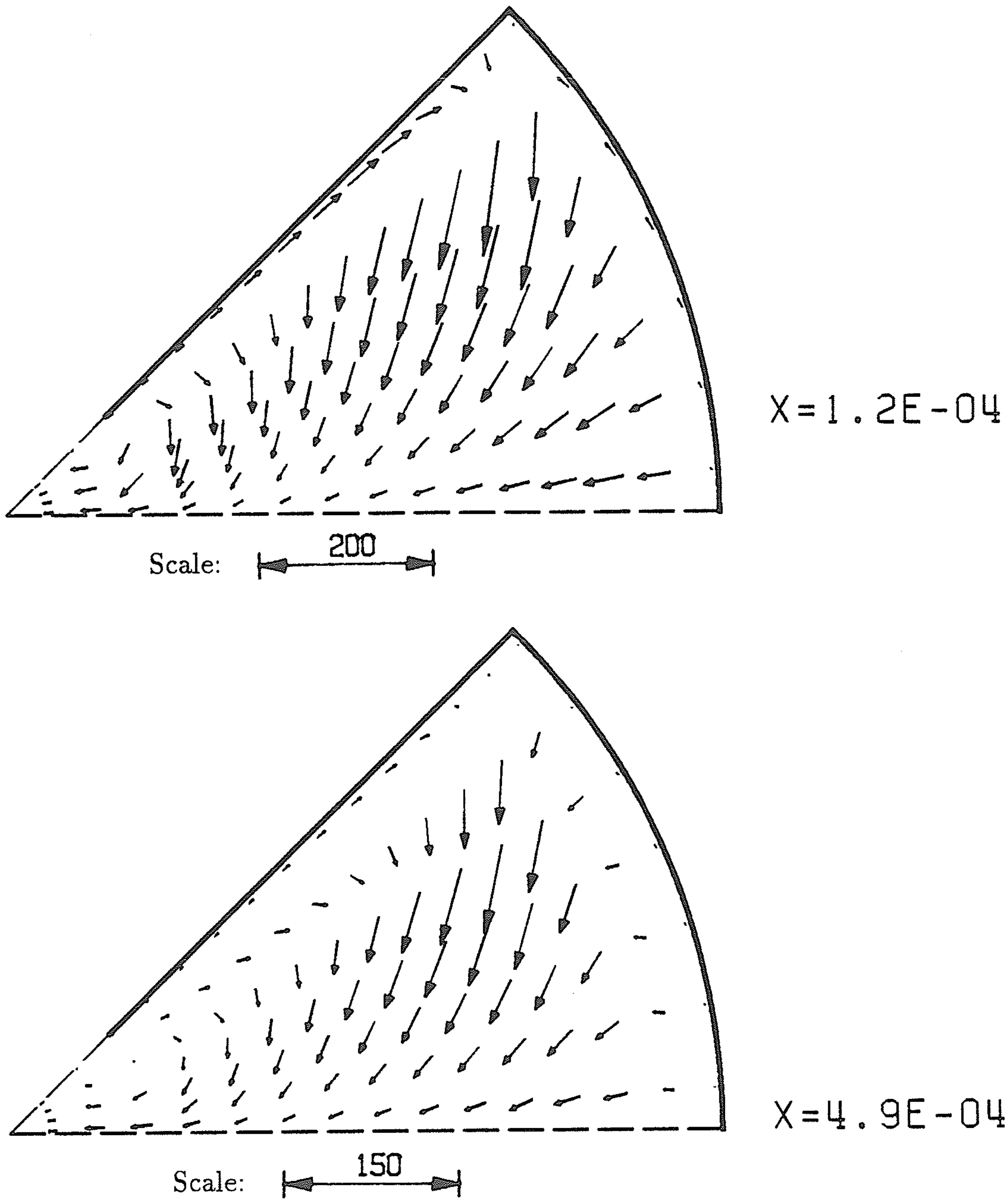


Figure 5.37 Secondary flow pattern at two axial locations for $H = 0.8$ and $M = 4$.

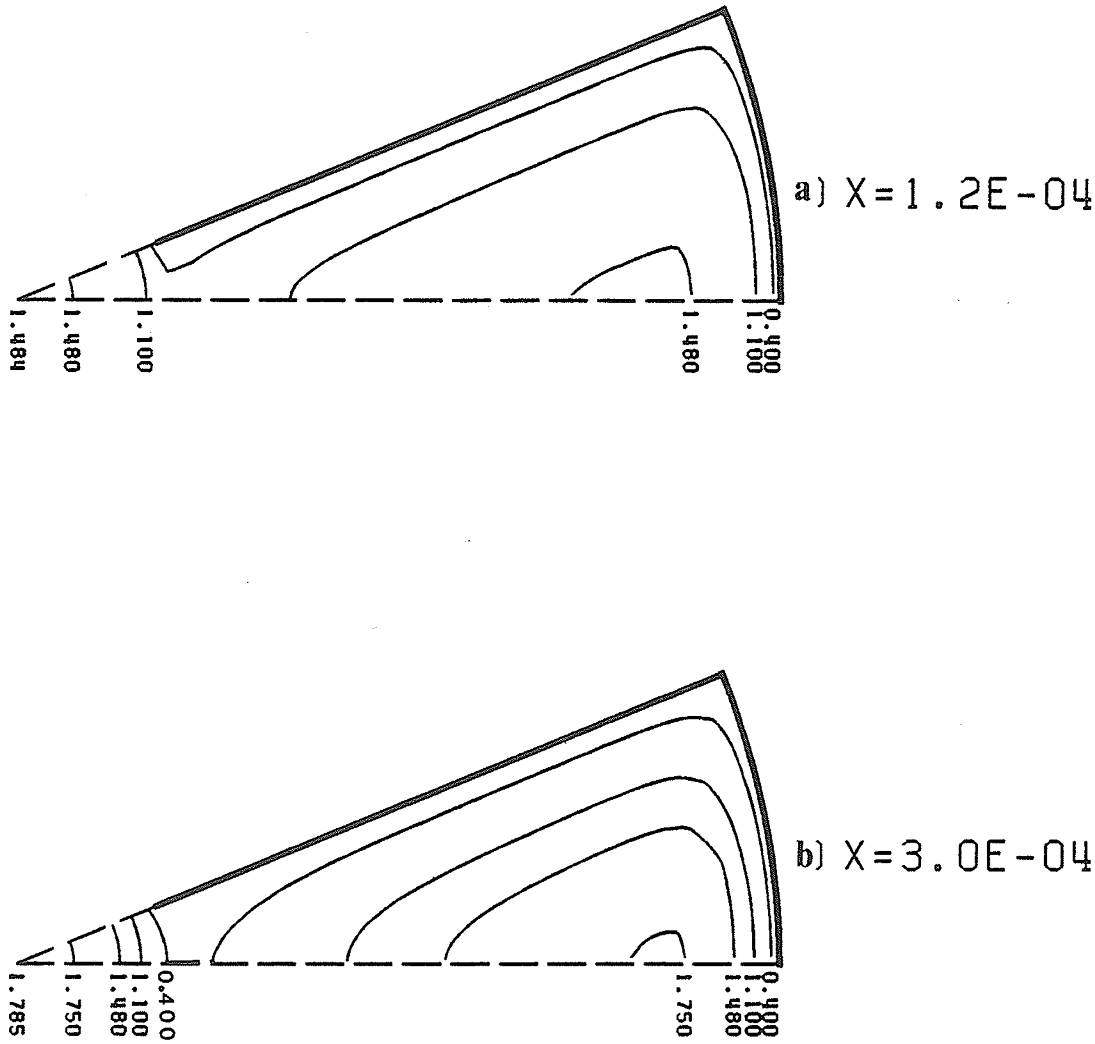


Figure 5.38 Development of the equi-velocity (u/u_b) lines for $H = 0.8$ and $M = 24$.

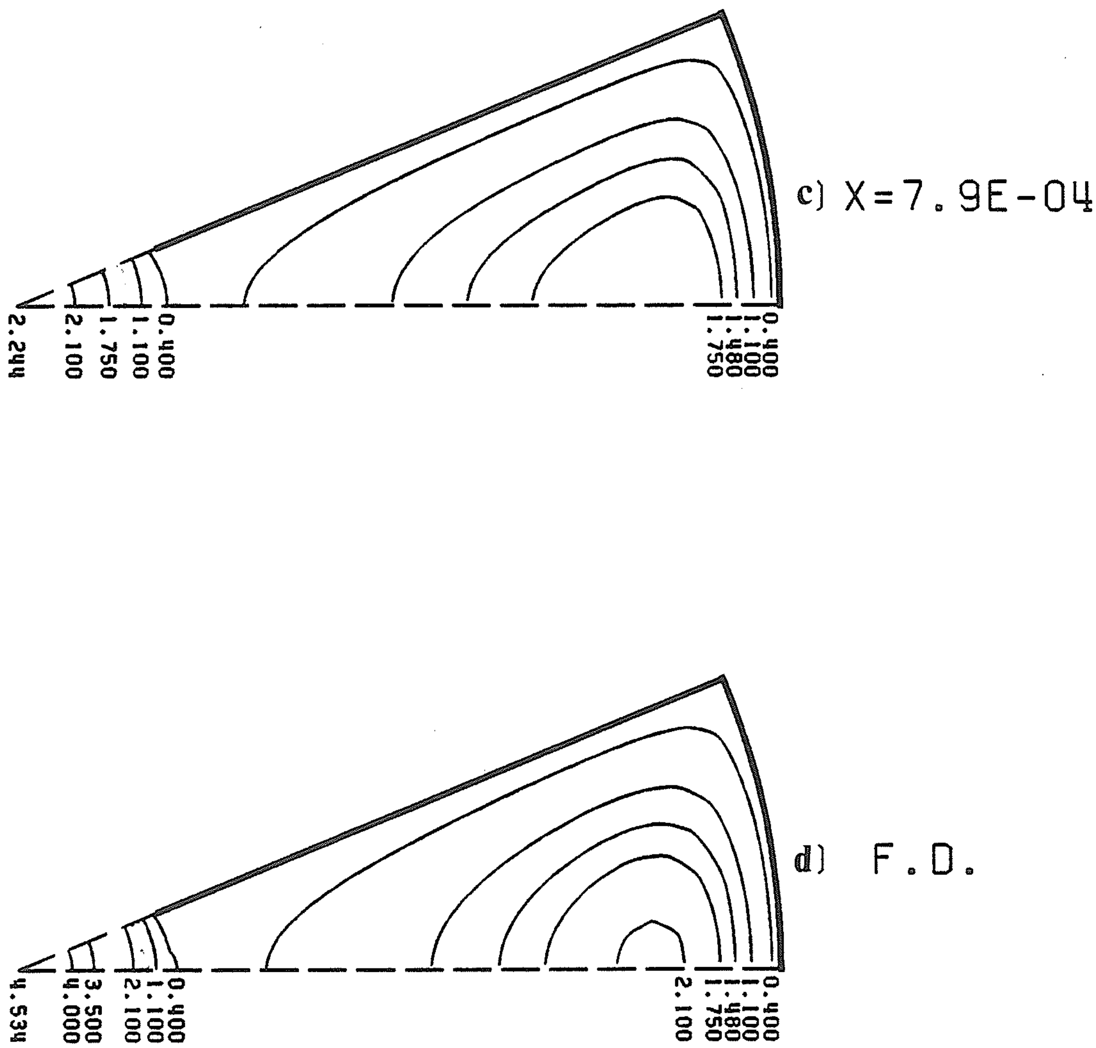
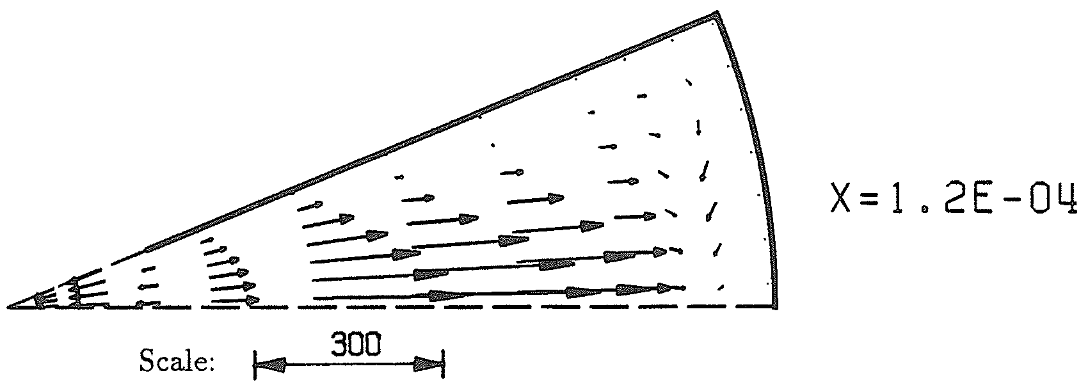


Figure 5.38 Development of the equi-velocity (u/u_b) lines for $H = 0.8$ and $M = 24$.



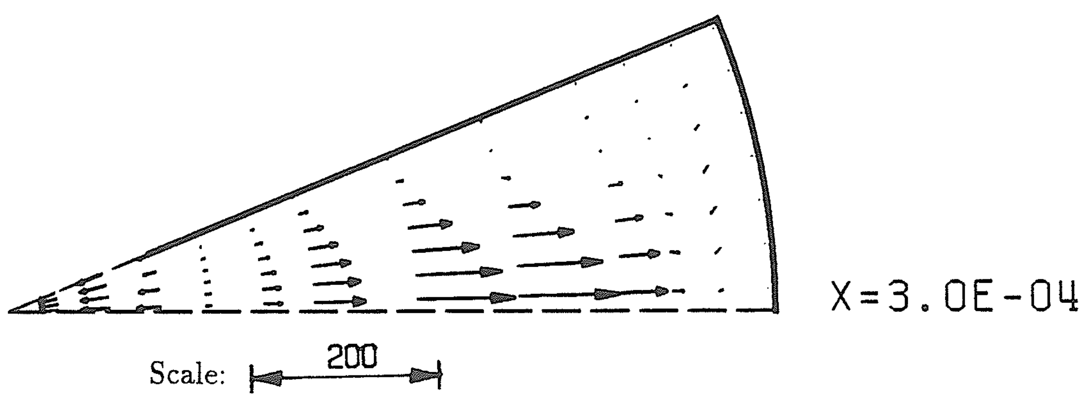


Figure 5.39 Secondary flow pattern at two axial locations for $H = 0.8$ and $M = 24$.

5.2.2 Values of $f_x Re$ and K

Figures 5.40 to 5.43 show the development of $f_x Re$ and K in the flow direction from $X = 10^{-4}$ to the value of X at which $f_x Re = 1.01(f_{fd} Re)$ for $M = 4$, 8, 16, and 24, respectively. In each figure, the influence of fin height is illustrated by showing results for $H = 0$ (smooth tube), 0.2, 0.4, 0.6, and 0.8. The inside tube diameter is used as the characteristic dimension in $f_x Re$, and K, rather than the hydraulic diameter, in order to show the influence of internal finning in a direct manner.

For all geometries, $f_x Re$ follows the expected behaviour of monotonic decrease along the entrance region down to the fully developed value. For any value of M, $f_x Re$ at any X increases as H increases. An interesting feature of the results in Figures 5.40 to 5.43 is that all finned tubes appear to have approximately the same rate of decrease of $f_x Re$ with respect to X near the inlet of the tube (small values of X), and this rate is approximately equal to the rate for smooth tubes. However, for some geometries, sharp changes in this rate occur later in the entrance region and this is particularly noticeable for large numbers ($M = 16$ and 24) of medium height fins ($H = 0.4$). These abrupt changes in the slope are attributed to the complicated pattern of flow development discussed earlier. Naturally, this behaviour is expected to influence the remaining hydrodynamic results, such as K, K_∞, and the hydrodynamic entrance length.

Values of K presented in Figures 5.40 to 5.43 follow the expected trend of monotonic increase with X towards the limiting value K_∞ in the fully developed region. For any value of M, K can be seen to increase with H at small values of X (near the inlet of the tube). However, this trend may change at larger values of X as the K lines in Figures 5.40 to 5.43 start crossing. This line crossing is, of course, a consequence of the change in the slope of the $f_x Re$ curves along X which was pointed out earlier. Similar trends were reported by Prakash and Liu (1985).

Values of the limiting incremental pressure drop number K_∞ are listed in

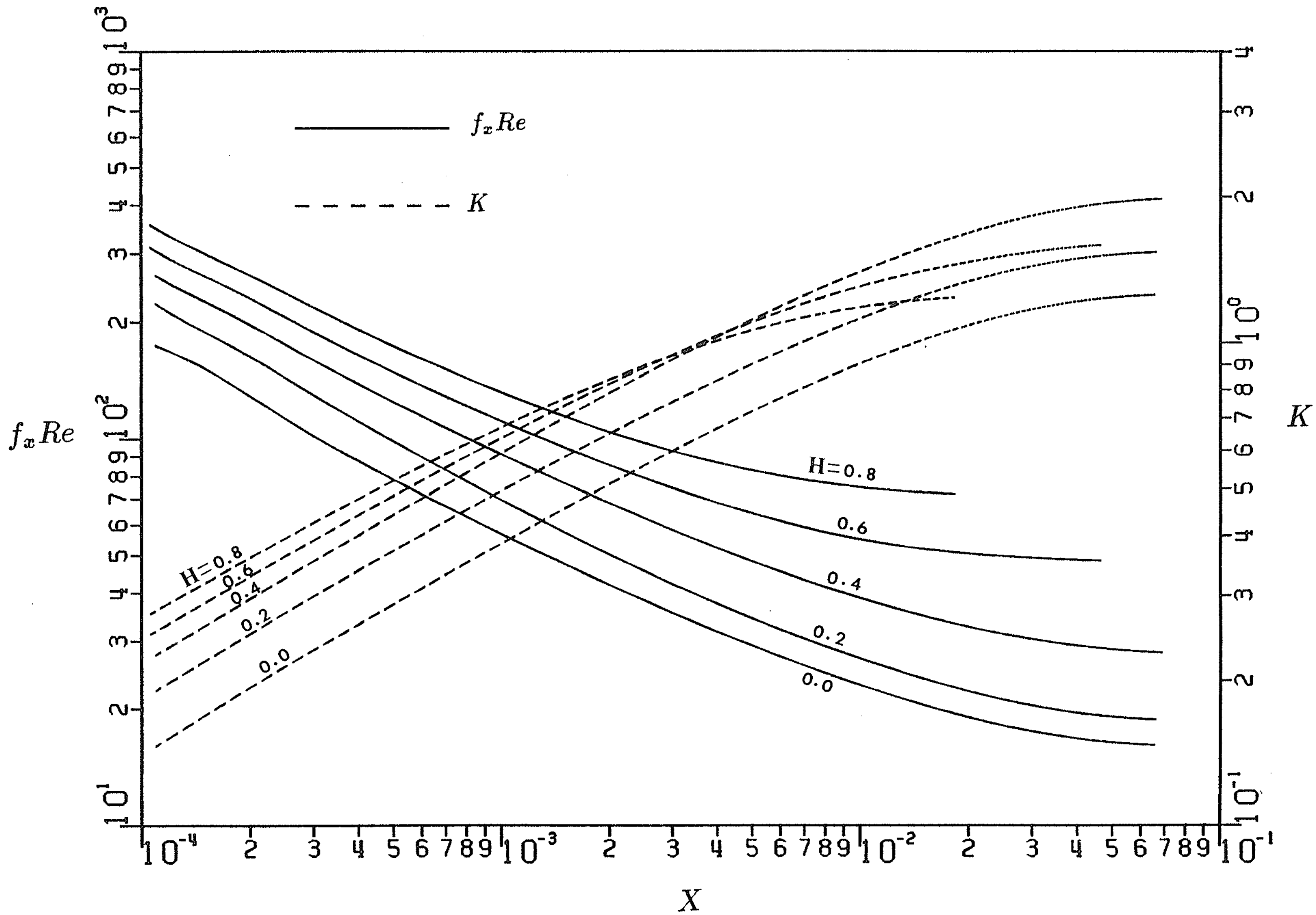


Figure 5.40 Values of $f_x Re$ and K in the hydrodynamic entrance region for $M = 4$.

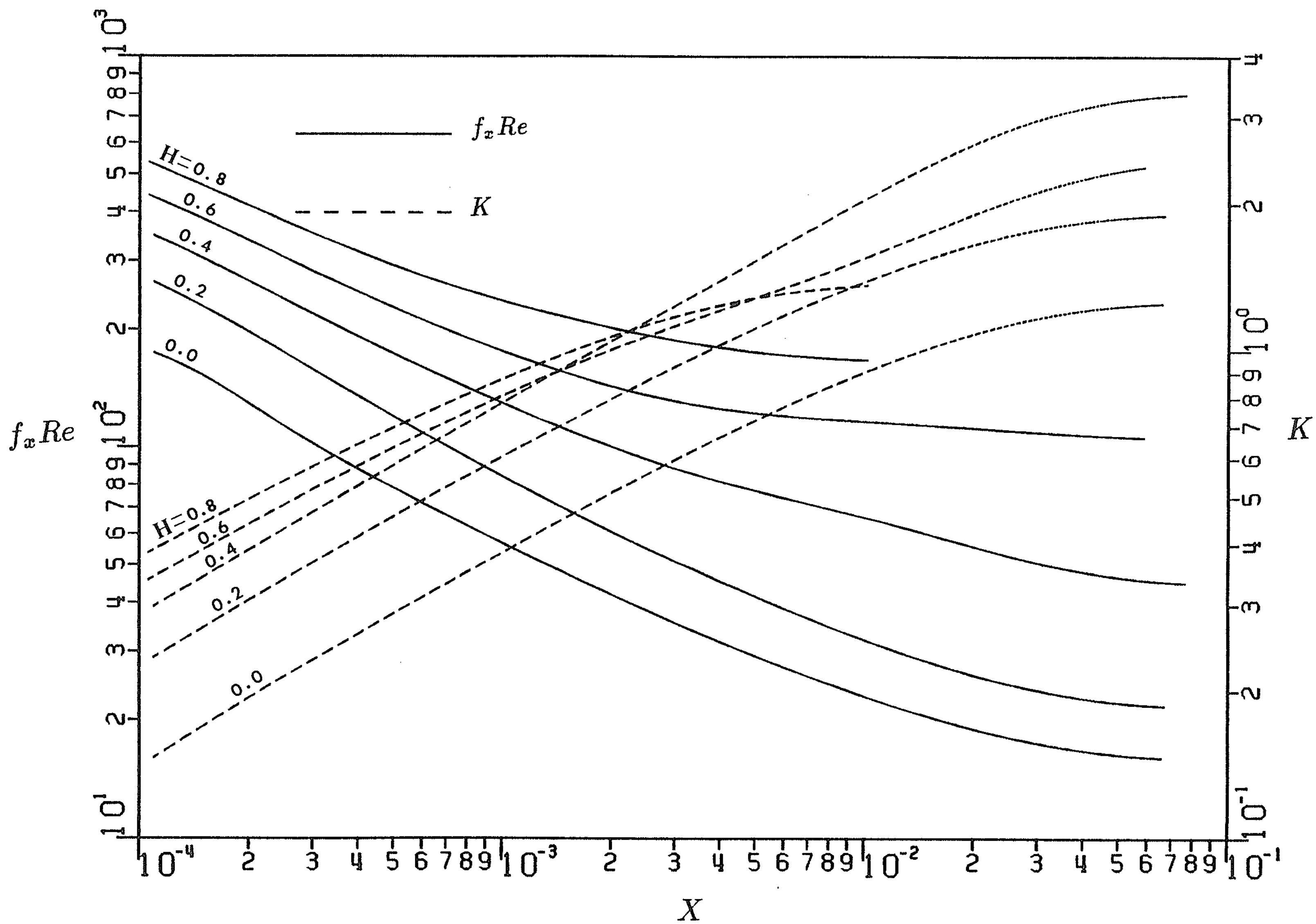


Figure 5.41 Values of $f_x Re$ and K in the hydrodynamic entrance region for $M = 8$.

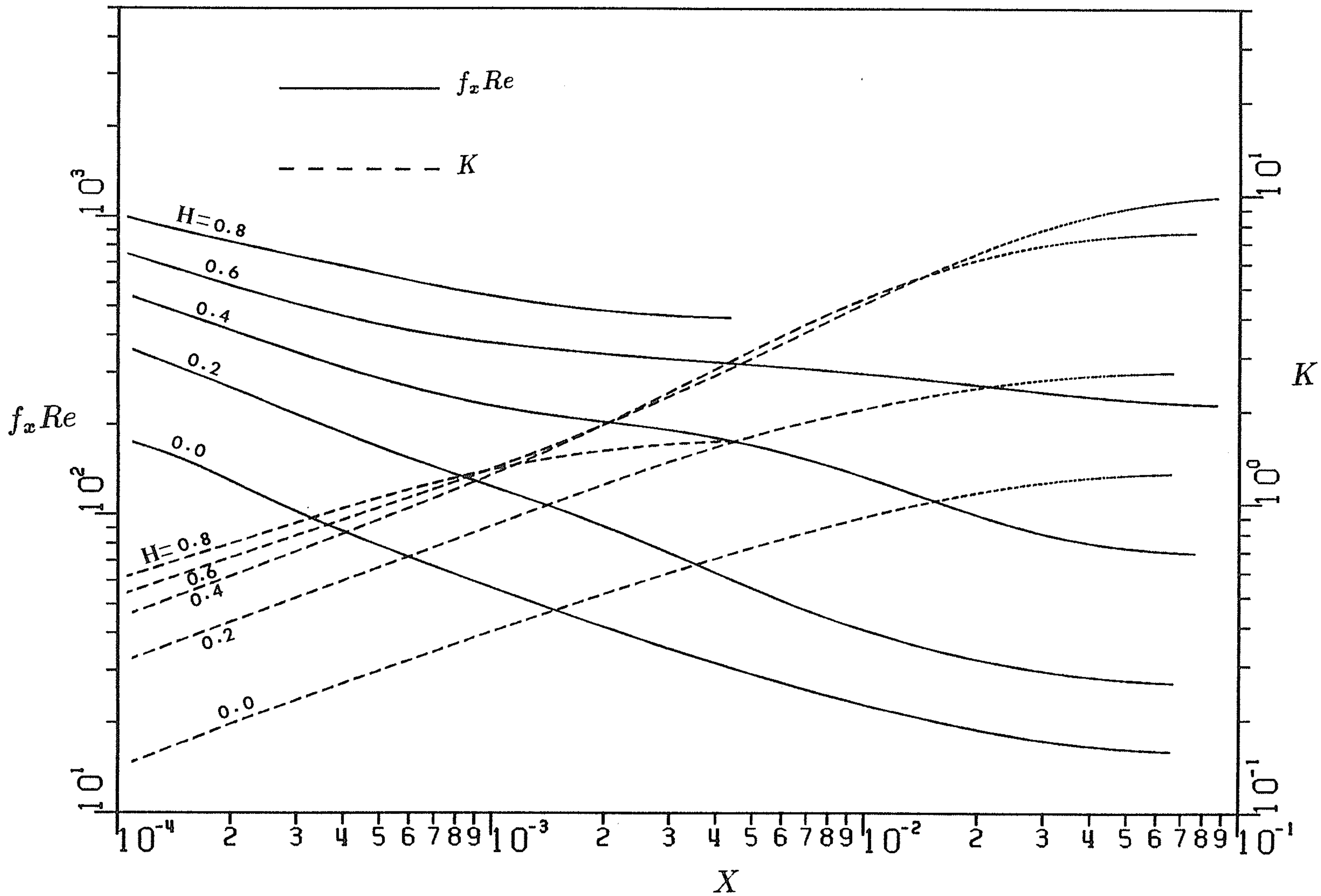


Figure 5.42 Values of $f_x Re$ and K in the hydrodynamic entrance region for $M = 16$.

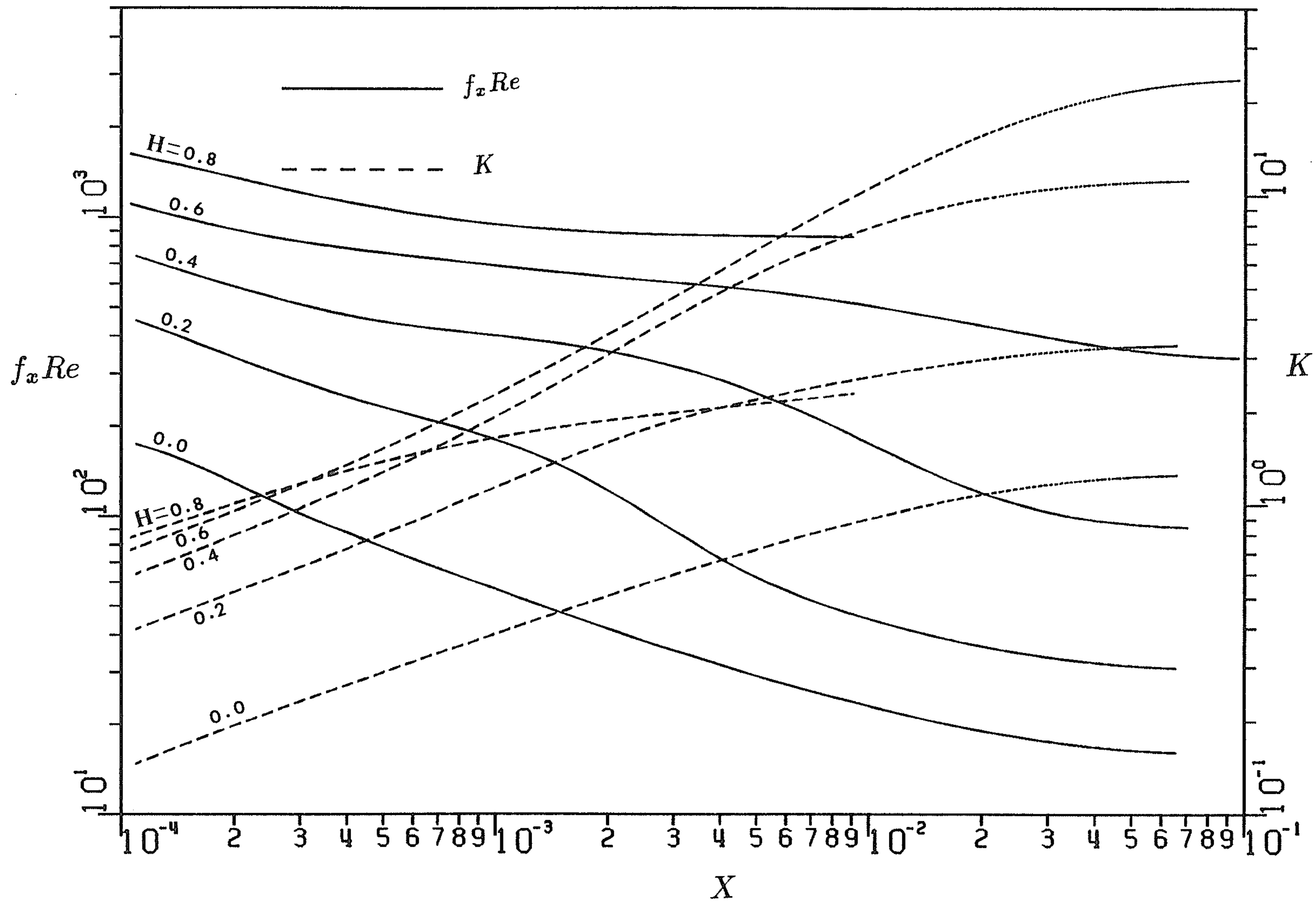


Figure 5.43 Values of $f_x Re$ and K in the hydrodynamic entrance region for $M = 24$.

Table 5.4. These values were calculated by numerically extrapolating the values of K near the end of the entrance region assuming exponential behaviour. For any given H, the value of K_∞ increases as M increases. However, for a fixed M, K_∞ starts out increasing with H and then decreases. For $H = 0.6$, the deviation between the present results and those of Prakash and Liu (1985) ranges from 1.3% at $M = 24$ to 16.8% at $M = 8$. Using K_∞ and f_{fd}, it is possible to calculate the overall pressure drop in the entrance region using equation (3.51) provided that the hydrodynamic entrance length is known.

5.2.3 Estimates of the Hydrodynamic Entrance Length

Several definitions were reported in the literature for the hydrodynamic entrance length. The one frequently used defines this length as the distance from inlet required to achieve a cross-sectional maximum velocity of 99% of the corresponding fully developed value. This definition is easy to adopt when the location of the maximum velocity is known apriori (e.g. the centre line for circular, rectangular, or square ducts). For internally finned tubes, the cross sectional maximum velocity may occur at the centre line or somewhere within the bays between the fins depending on the value of H and M. Hence, for convenience and for more practical significance, it was decided to use the following definitions for the hydrodynamic entrance length.

$L_{H,1\%}=$ the value of X at which the local friction factor drops to 1.01 times the fully developed friction factor.

$L_{H,5\%}=$ the value of X at which the local friction factor drops to 1.05 times the fully developed friction factor. This definition was used by Prakash and Liu (1985).

For the smooth tube case, the present model produced $L_{H,1\%} = 0.06585$ and $L_{H,5\%} = 0.04018$. This value of $L_{H,5\%}$ is in good agreement with results of Prakash and Liu (1985) who reported 0.0415. Values of $L_{H,1\%}$ and $L_{H,5\%}$ for the smooth and finned tubes are listed in Table 5.5 from which some irregular and unexpected

Table 5.4 Values of K_∞

Tube Geometry		K_∞
H	M	
0.0 (smooth tube)	—	1.258
0.2	4	1.543
	8	1.904
	16	2.678
	24	3.289
0.4	4	1.989
	8	3.370
	16	7.595
	24	11.17
0.6	4	1.605
	8	2.442
	16	10.02
	24	23.83
0.8	4	1.235
	8	1.370
	16	1.603
	24	2.356

Table 5.5 Values of $L_{H,1\%}$ and $L_{H,5\%}$

H		$M = 4$	8	16	24
0.0 (smooth tube)	$L_{H,1\%}$	0.06585	—	—	—
	$L_{H,5\%}$	0.04018	—	—	—
0.2	$L_{H,1\%}$	0.06658	0.06704	0.06665	0.06589
	$L_{H,5\%}$	0.04066	0.04123	0.04099	0.04026
0.4	$L_{H,1\%}$	0.06890	0.07637	0.07636	0.07048
	$L_{H,5\%}$	0.04081	0.04734	0.04910	0.04467
0.6	$L_{H,1\%}$	0.04669	0.05886	0.08737	0.09652
	$L_{H,5\%}$	0.02096	0.02583	0.04824	0.05855
0.8	$L_{H,1\%}$	0.01836	0.01024	0.004377	0.009079
	$L_{H,5\%}$	0.01010	0.00533	0.002326	0.001837

trends are evident. For example, several finned tube geometries have longer entrance lengths than the smooth tube. Also, for the same H, the hydrodynamic entrance length does not always increase with increasing M as would have been expected if the smooth tube results did apply to finned tubes on a hydraulic diameter basis. The trends in Table 5.5 are direct consequences of the irregular manner by which $f_x Re$ is shown to develop along X (Figures 5.40 to 5.43). Qualitatively, the present trends are consistent with those in Prakash and Liu (1985), however, for $H = 0.6$, values of $L_{H,5\%}$ reported by Prakash and Liu are higher than the present values by 6.2% at $M = 24$ and by 23.9% at $M = 8$.

5.3 Fully-Developed Mixed Convection

The velocity and temperature distributions were obtained for $Pr = 7$ at various values of Gr^+. The values of Gr^+ ranged from 0 (pure forced convection) to the highest value of 2×10^6. The geometries covered in this investigation are the smooth tube plus six different geometries of internally finned tubes. The internally finned tubes correspond to a combination of $H = 0.2$, 0.5, and 0.8 and $M = 4$ and 16. For the smooth tube geometry, the results were obtained for $Pr = 1$ as well as $Pr = 7$ to facilitate comparisons with existing data. Results in terms of velocity and temperature contour lines are presented for all geometries at the highest value of Gr^+ to show the effect of free convection. The global parameters, such as $f_{fd}Re$ and Nu_{fd}, were calculated from the velocity and temperature distributions and the effect of free convection on these parameters was studied for all considered geometries.

5.3.1 Velocity Distribution

A) Axial Velocity Distribution

For all geometries, the influence of free convection on the axial velocity distribution was found to be less profound than the influence on the temperature distribution (presented later).

Figures 5.44 to 5.50 show the axial velocity distribution for the smooth tube geometry and all internally finned tubes considered in this investigation at the highest Gr^+. The general trend in these results is for more mass concentration in the lower part of the tube. For very long fins ($H = 0.8$), the effect of free convection on the axial velocity distribution is seen to be insignificant up to $Gr^+ = 2 \times 10^6$. This trend would in turn reflect on the friction results, which are presented later.

B) Secondary Flow Pattern

The pattern of the bouyancy induced secondary flow is presented for the smooth tube and all internally finned tubes considered in this investigation in Figures 5.51 to 5.57. These results correspond to the highest Gr^+. Figure 5.51 in which the smooth tube case is considered, provides a reference for studying the influence of internal finning on the secondary flow pattern. These results show a single cell with upward flow along the heated wall and downward flow in the core. The absolute value of the secondary velocity vector along any radial line reaches a maximum near the wall.

Figure 5.52 shows the secondary flow pattern for a tube with a small number of short fins ($H = 0.2$ and $M = 4$). Two counter rotating secondary flow cells appear in the lower part of the tube, while in the upper part, the flow pattern is close to the smooth tube behaviour. An exchange of fluid exists between the top and bottom parts by upward moving flow around the tip of the horizontal fin and downward moving flow in the core. Higher secondary flow intensity can be seen in the lower part than the upper part of the tube .

Figure 5.53 shows the secondary flow pattern for a tube with a small number of medium height fins ($H = 0.5$ and $M = 4$). Two counter rotating secondary flow cells appear in the lower part of the tube, while in the upper part, another cell is starting to form right above the horizontal fin. An exchange of fluid still exists between the top and bottom parts by upward moving flow around the tip of the horizontal fin and downward moving flow in the core. The lower part of the tube is still more active

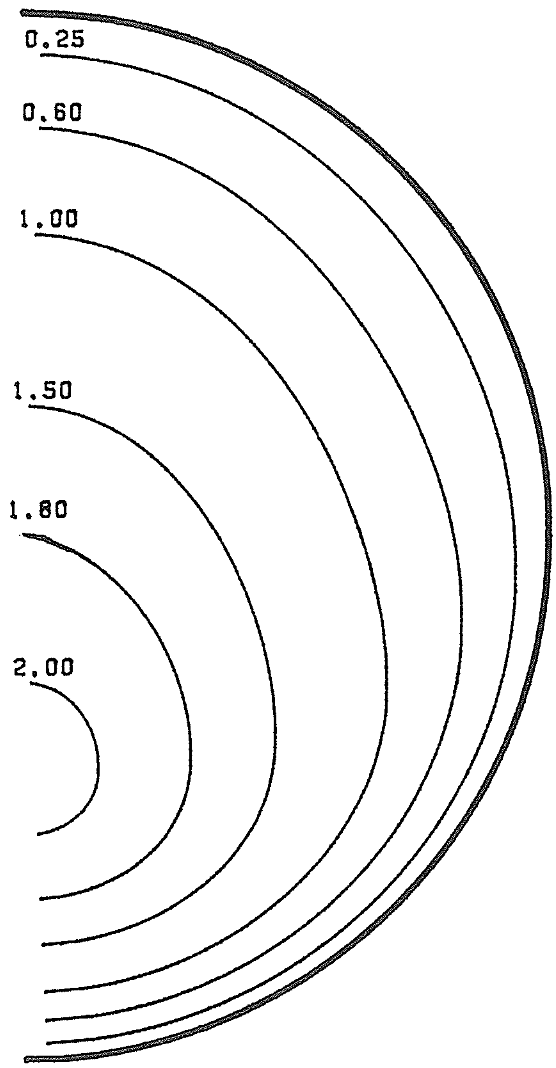


Figure 5.44 Equi-velocity lines (u/u_b) at $Gr^+ = 2 \times 10^6$ for the smooth tube geometry.

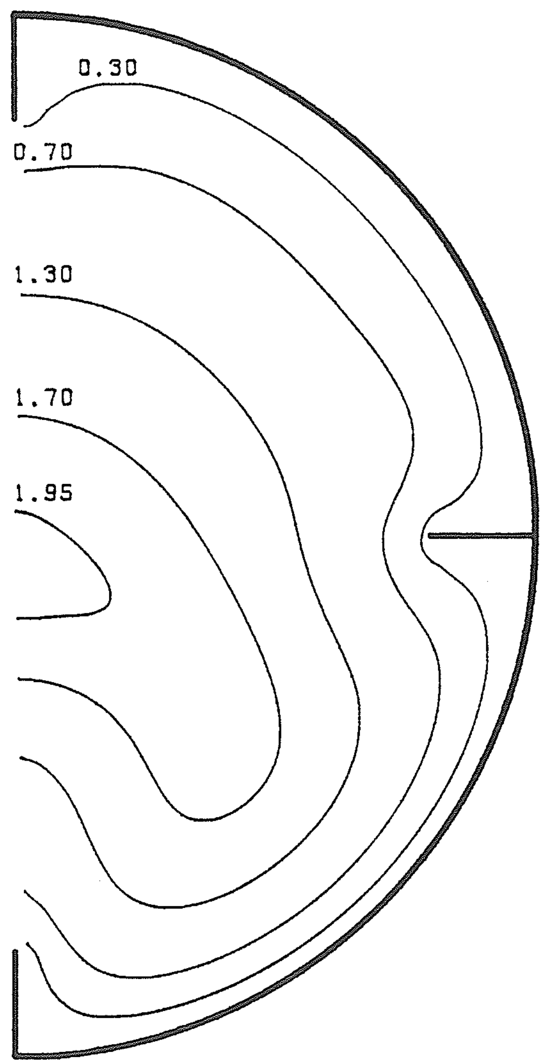


Figure 5.45 Equi-velocity lines (u/u_b) at $Gr^+ = 1.3 \times 10^6$ for $H = 0.2$ and $M = 4$.

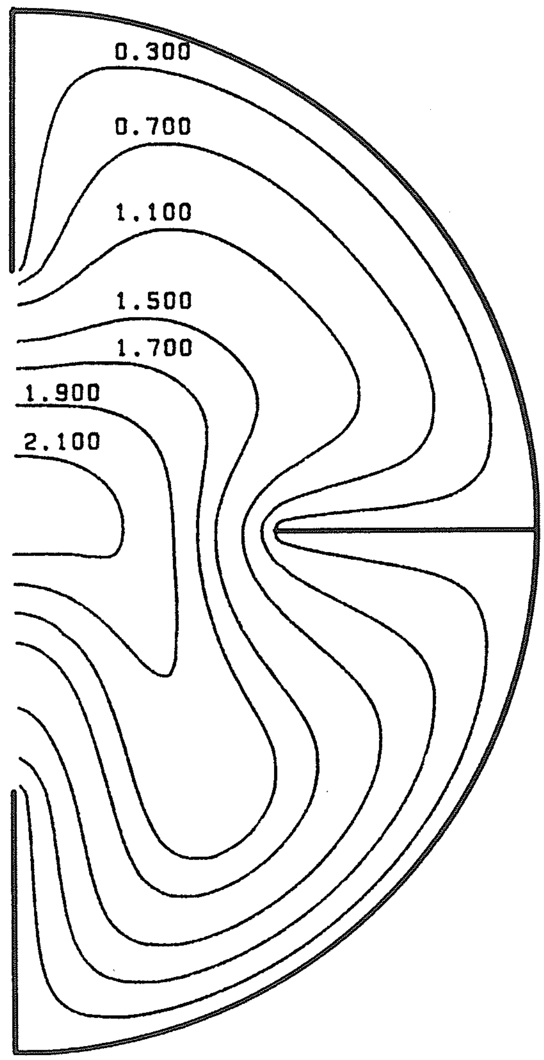


Figure 5.46 Equi-velocity lines (u/u_b) at $Gr^+ = 2 \times 10^6$ for $H = 0.5$ and $M = 4$.

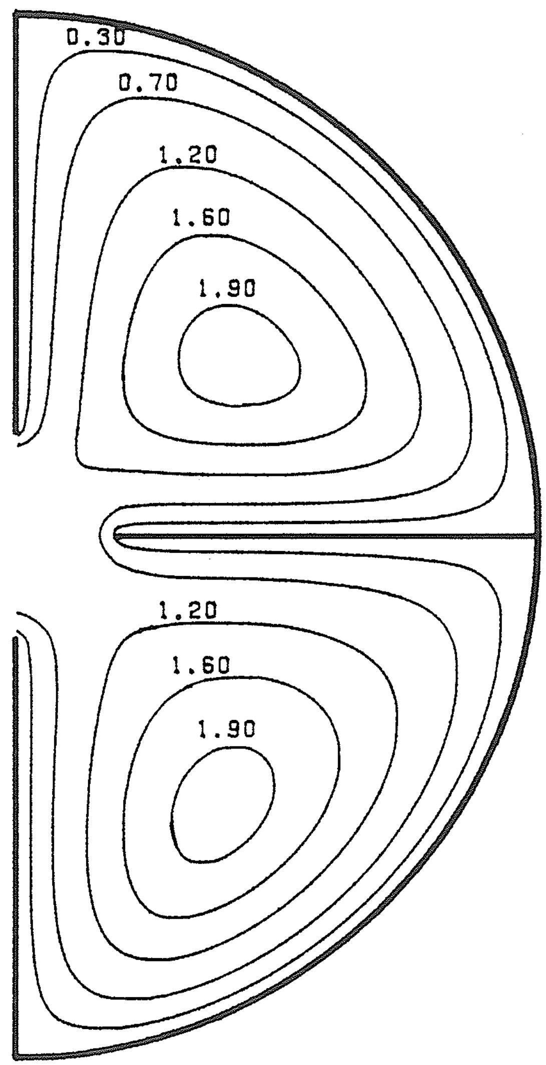


Figure 5.47 Equi-velocity lines (u/u_b) at $Gr^+ = 2 \times 10^6$ for $H = 0.8$ and $M = 4$.

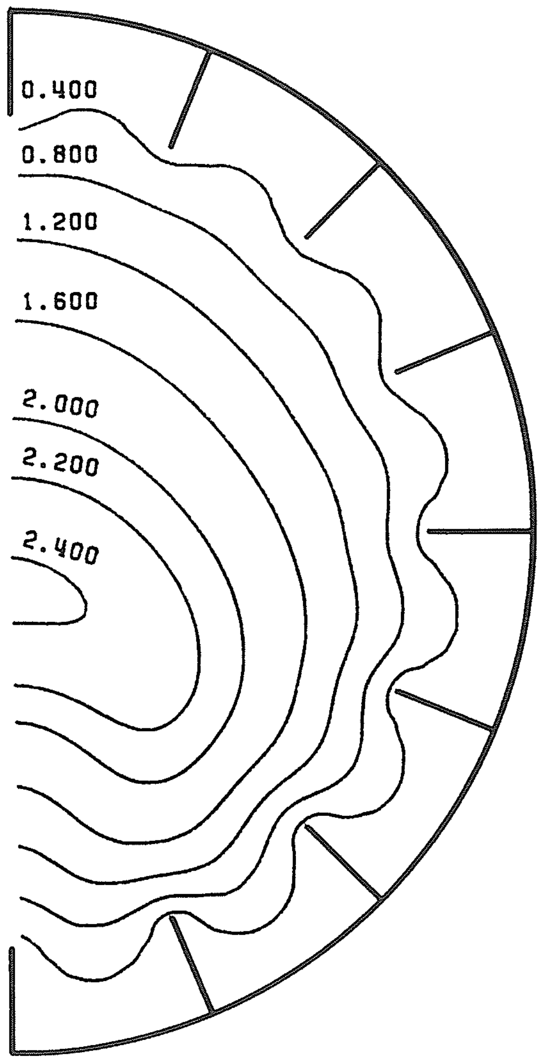


Figure 5.48 Equi-velocity lines (u/u_b) at $Gr^+ = 2 \times 10^6$ for $H = 0.2$ and $M = 16$.

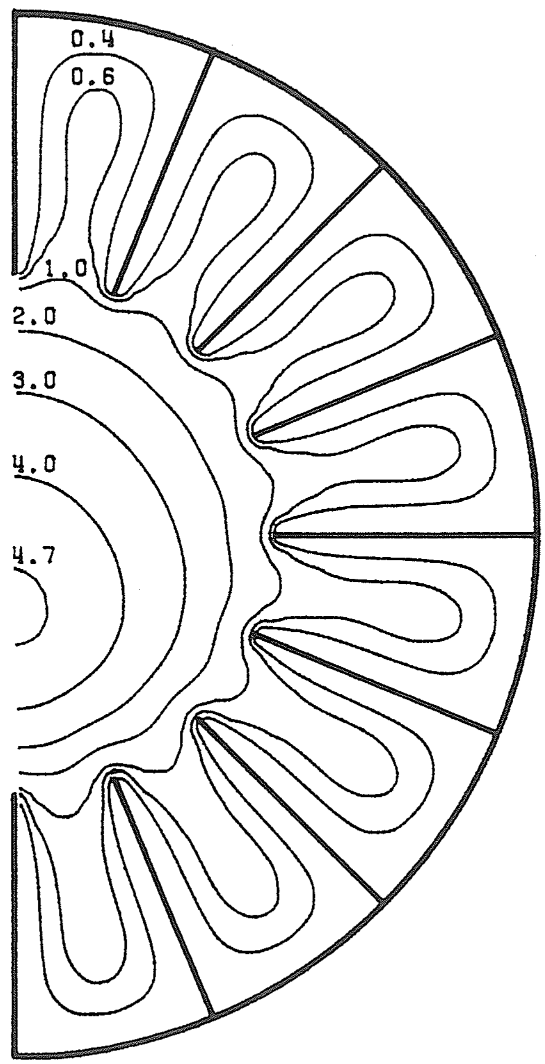


Figure 5.49 Equi-velocity lines (u/u_b) at $Gr^+ = 2 \times 10^6$ for $H = 0.5$ and $M = 16$.

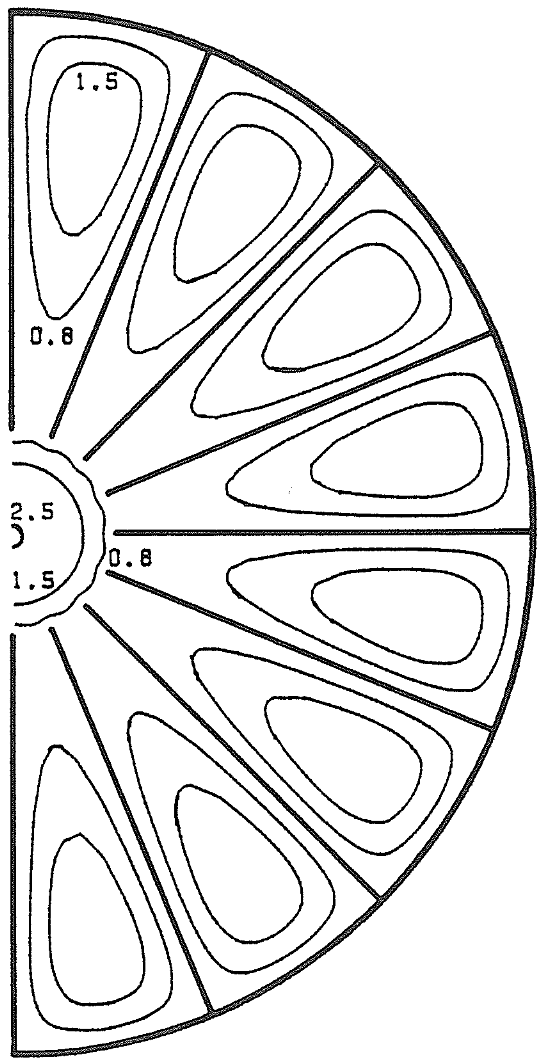


Figure 5.50 Equi-velocity lines (u/u_b) at $Gr^+ = 2 \times 10^6$ for $H = 0.8$ and $M = 16$.

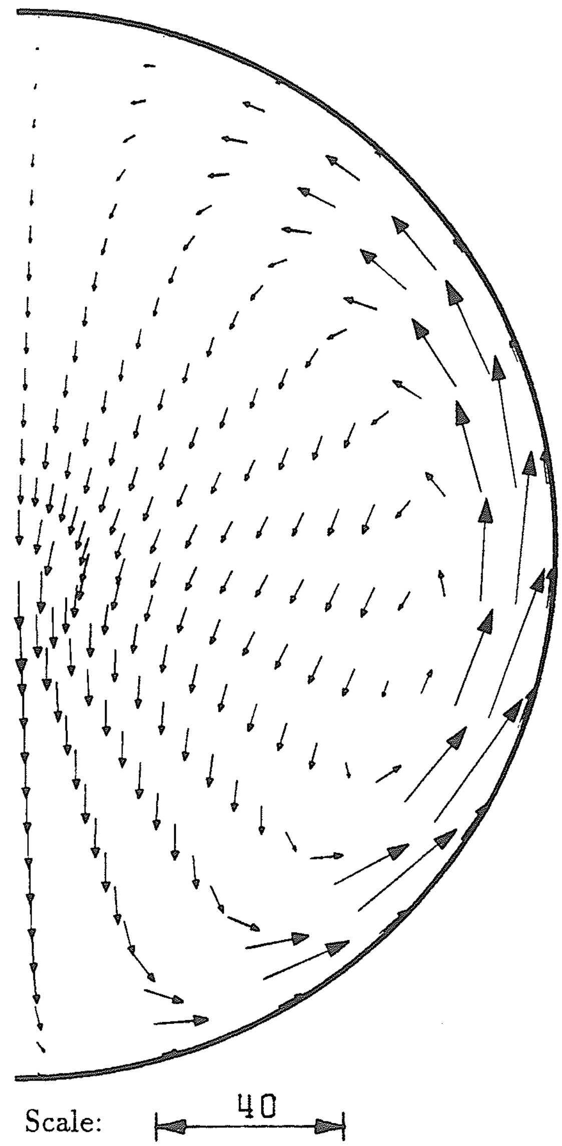


Figure 5.51 Secondary flow pattern for the smooth tube geometry at $Gr^+ = 2 \times 10^6$.

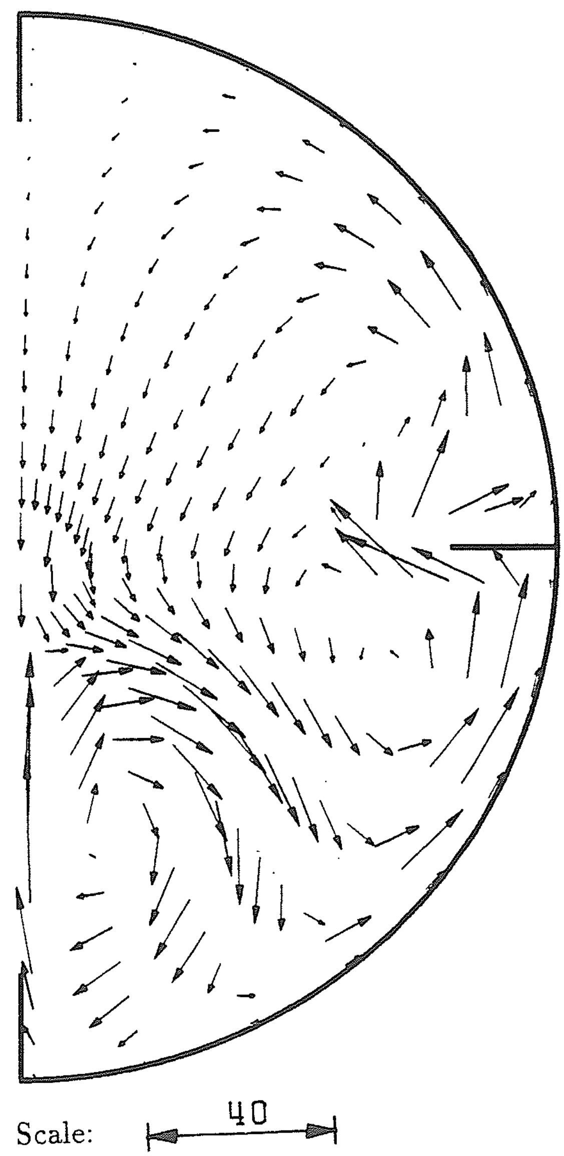


Figure 5.52 Secondary flow pattern for $H = 0.2$ and $M = 4$ at $Gr^{+} = 1.3 \times 10^{6}$.

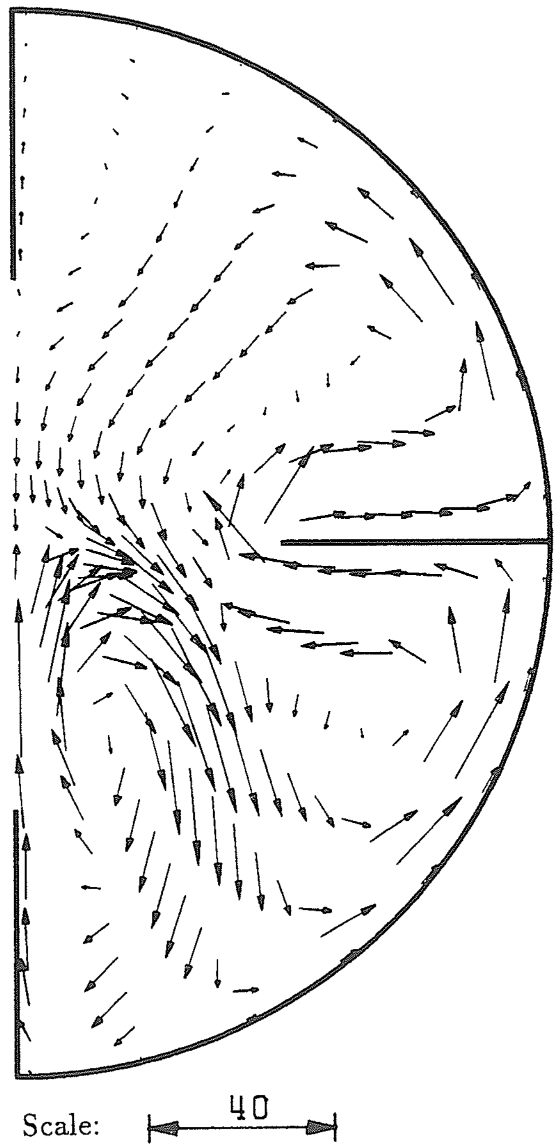


Figure 5.53 Secondary flow pattern for $H = 0.5$ and $M = 4$ at $Gr^{+} = 2 \times 10^{6}$.

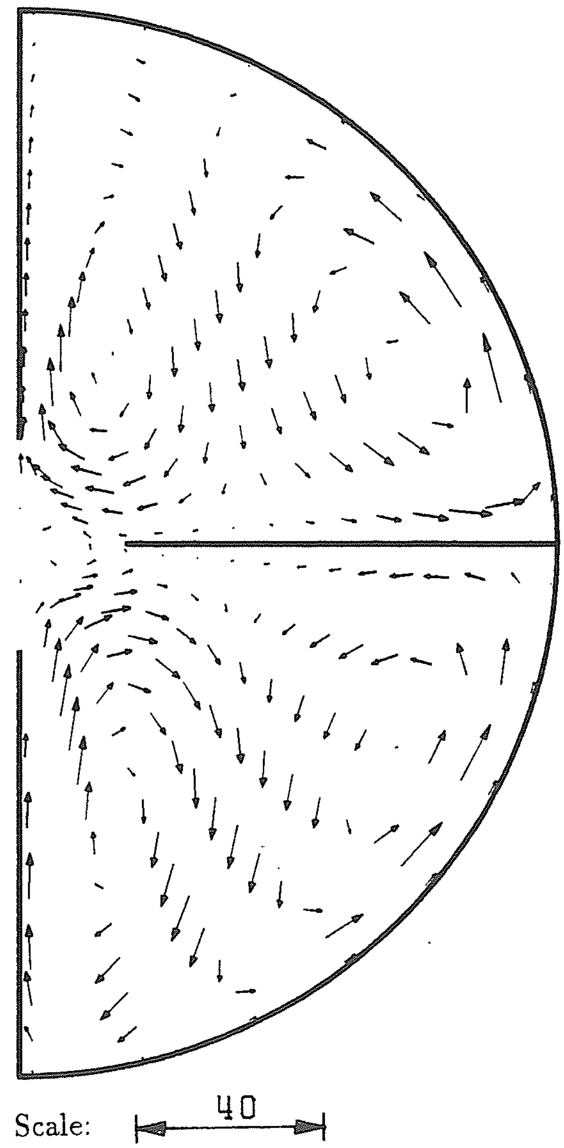


Figure 5.54 Secondary flow pattern for $H = 0.8$ and $M = 4$ at $Gr^+ = 2 \times 10^6$.

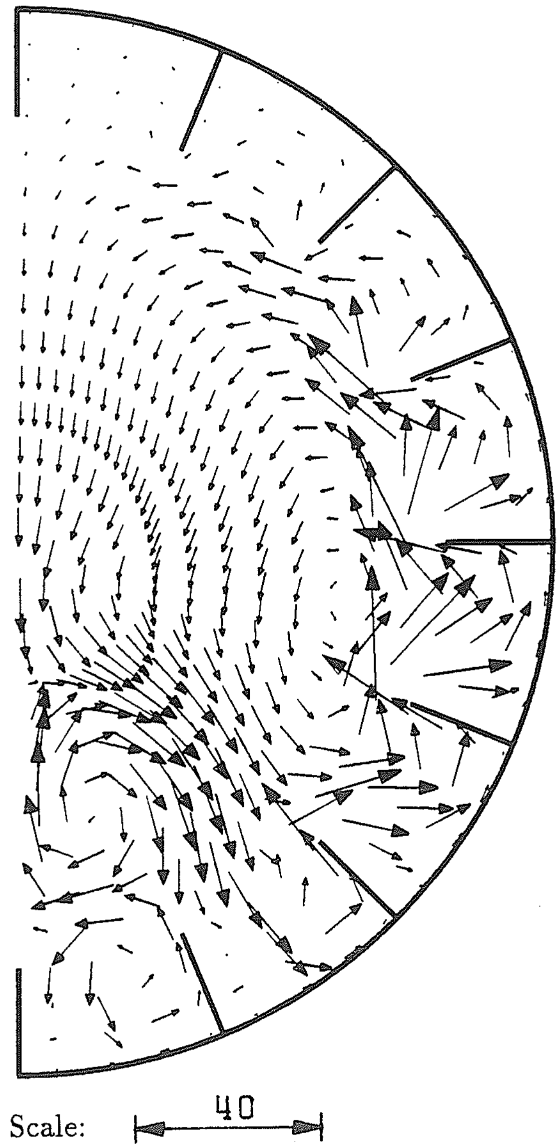


Figure 5.55 Secondary flow pattern for $H = 0.2$ and $M = 16$ at $Gr^{+} = 2 \times 10^{6}$.

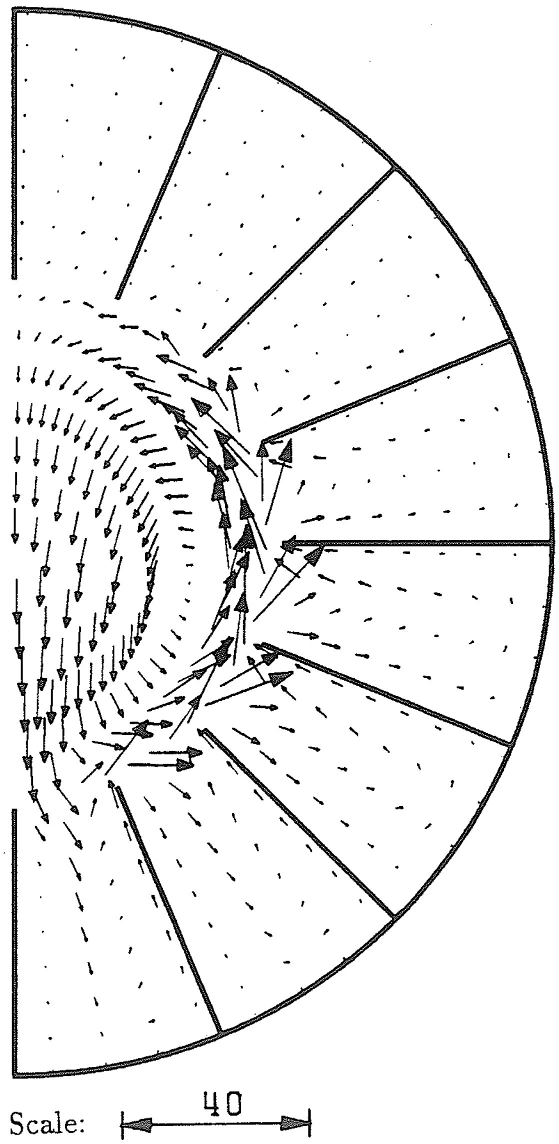


Figure 5.56 Secondary flow pattern for $H = 0.5$ and $M = 16$ at $Gr^{+} = 2 \times 10^{6}$.

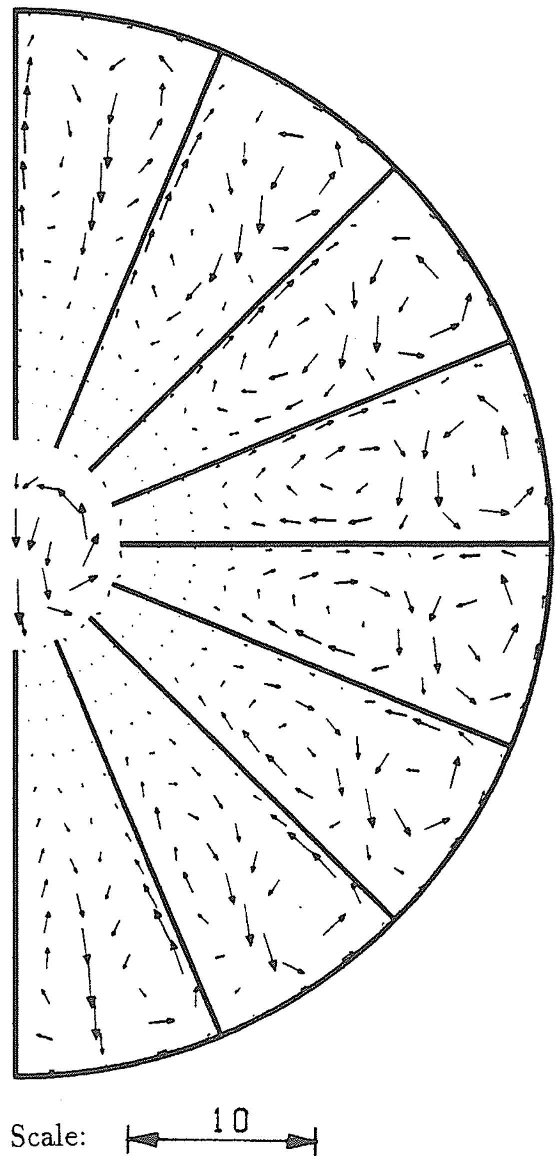


Figure 5.57 Secondary flow pattern for $H = 0.8$ and $M = 16$ at $Gr^{+} = 2 \times 10^{6}$.

than the upper part in terms of secondary flow intensity.

Figure 5.54 shows the secondary flow pattern for a tube with a small number of long fins ($H = 0.8$ and $M = 4$). Two counter rotating secondary flow cells appear in the lower part of the tube, and another two counter rotating cells appear in the upper part as well. An exchange of fluid between the top and bottom parts seems to be happening with a small amount of flow moving upwards near the tip of the horizontal fin and a small amount of flow moving downwards in the core of the tube. The upper and lower parts of the tube appear to have about the same level of secondary flow intensity.

For the case of high number of fins, Figures 5.55 to 5.57 show the secondary flow pattern for short , medium, and long fins respectively. Figure 5.55 shows the secondary flow pattern for a tube with a large number of short fins ($H = 0.2$ and $M = 16$). The secondary flow is shown to have a complicated pattern with two counter rotating cells in the core of the tube and fluid exchange between core flow and each of the bays formed by two consecutive fins. In each bay, the exchange flow enters along the lower fin and exits along the upper fin. The intensity of secondary flow is always minimum in the uppermost bay and maximum in one of the lower bays.

Figure 5.56 shows the secondary flow pattern for a tube with a large number of medium height fins ($H = 0.5$ and $M = 16$). For this geometry, the secondary flow is severly suppressed in the bays formed by the fins. In the core section, only one secondary flow cell exist and the second cell that existed for short fins has disappeared.

Figure 5.57 shows that the secondary flow for a tube with a large number of long fins ($H = 0.8$ and $M = 16$) contains two weak counter-acting cells in the bay areas. In the core area, a weak singular cell is shown to exist.

The results shown in Figures 5.51 to 5.57 demonstrate that internal finning has a strong influence on secondary flow in both magnitude and structure. These influences depend in a complicated way on the geometrical parameters H and M, and would naturally reflect on the remaining results.

5.3.2 Temperature Distribution

The isotherms for all geometries are presented in Figures 5.58 to 5.64 corresponding to the maximum Gr^+ considered in this investigation. Figure 5.58 shows significant free convective effects for the smooth tube case. The secondary flow circulation causes a large shift in the location of the minimum temperature from the tube centreline (at $Gr^+ = 0$) downward along the symmetry plane. The local heat flux at the tube wall, which can be inferred from Figure 5.58, is found to vary from a minimum at the top of the tube to a maximum at the bottom. As well, the absolute values of temperature are considerably lower than their forced convection values due to the cross sectional circulation.

The case of a tube with a small number of short fins is exemplified in Figure 5.59 for $H = 0.2$ and $M = 4$. During pure forced convection ($Gr^+ = 0$) in this geometry, the temperature profile is identical in the upper and lower quarters separated by the horizontal fin plane and the minimum temperature exists at the tube centre. The presence of natural circulation gives rise to a second minimum temperature in the lower quarter and it destroys the symmetry between the two quarters. It is also clear from Figure 5.59 that the lower part of the tube wall becomes a much more effective heat transfer surface than the upper part. The case of $H = 0.5$ and $M = 4$, shown in Figure 5.60, shows similar features to those in Figure 5.59.

For a low number of long fins ($H = 0.8$ and $M = 4$), Figure 5.61 shows the effect of free convection on the isotherms. Minimum temperatures exist in the upper part of the tube, the lower part, as well as the symmetry plane. The intensity of free convection for this geometry appears to be strong at both halfs of the tube.

For the case of large number of short fins ($H = 0.2$ and $M = 16$), the isotherms are shown in Figure 5.62. The interaction between the tube core and the bays formed between the fins is shown to exist for this geometry. The minimum temperature zone is shown at the bottom of the tube core, and right at the second bay from the bottom. This indicates that the second bay from the bottom is providing the best heat

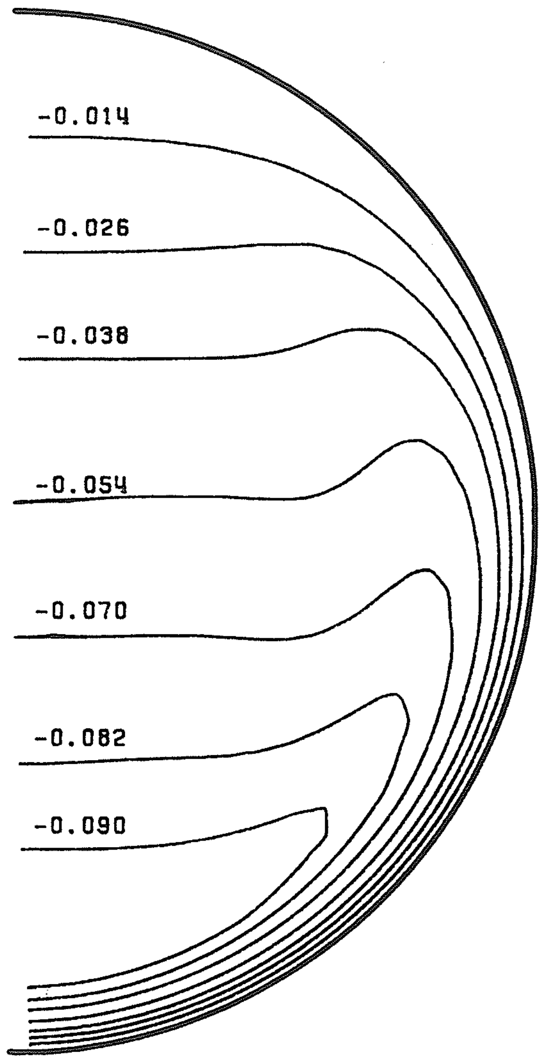


Figure 5.58 Isotherms for a smooth tube at $Gr^{+} = 2 \times 10^{6}$.

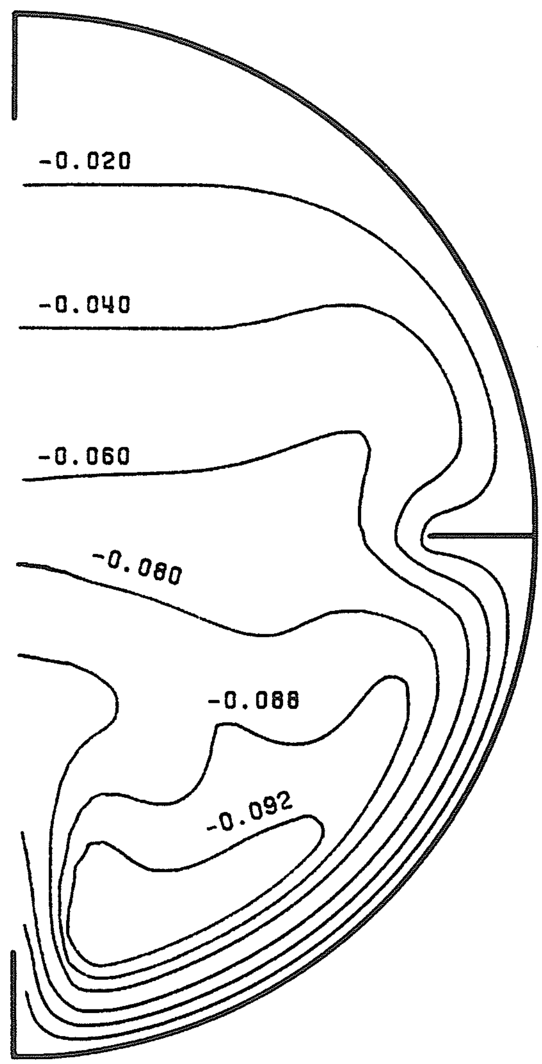


Figure 5.59 Isotherms for $H = 0.2$ and $M = 4$ at $Gr^{+} = 1.3 \times 10^{6}$.

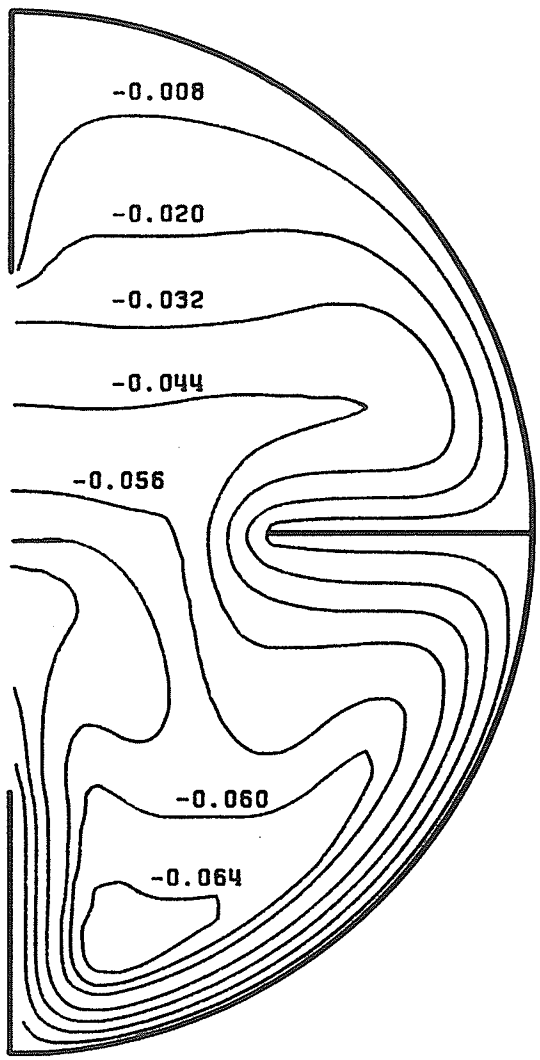


Figure 5.60 Isotherms for $H = 0.5$ and $M = 4$ at $Gr^{+} = 2 \times 10^{6}$.

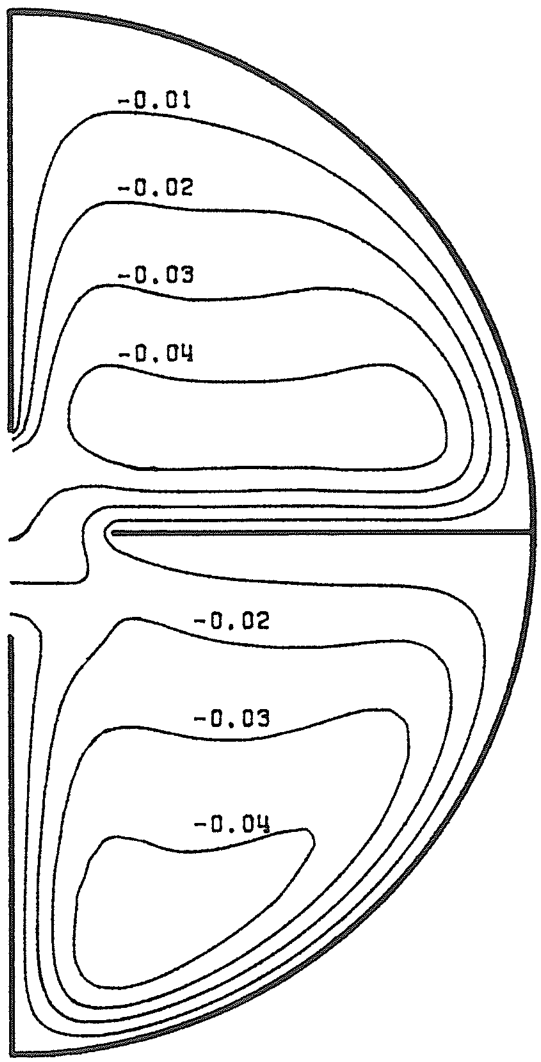


Figure 5.61 Isotherms for $H = 0.8$ and $M = 4$ at $Gr^{+} = 2 \times 10^{6}$.

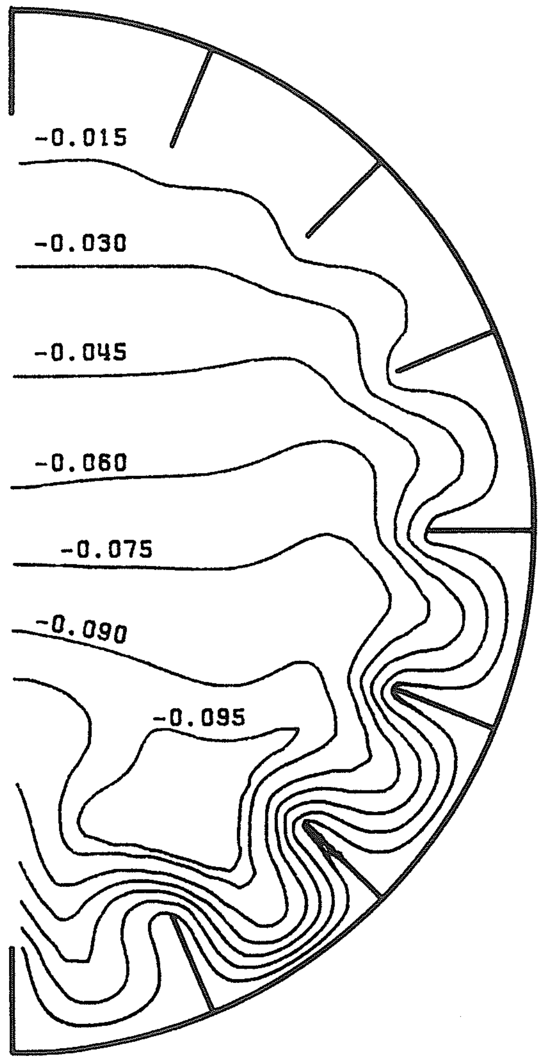


Figure 5.62 Isotherms for $H = 0.2$ and $M = 16$ at $Gr^+ = 2 \times 10^6$.

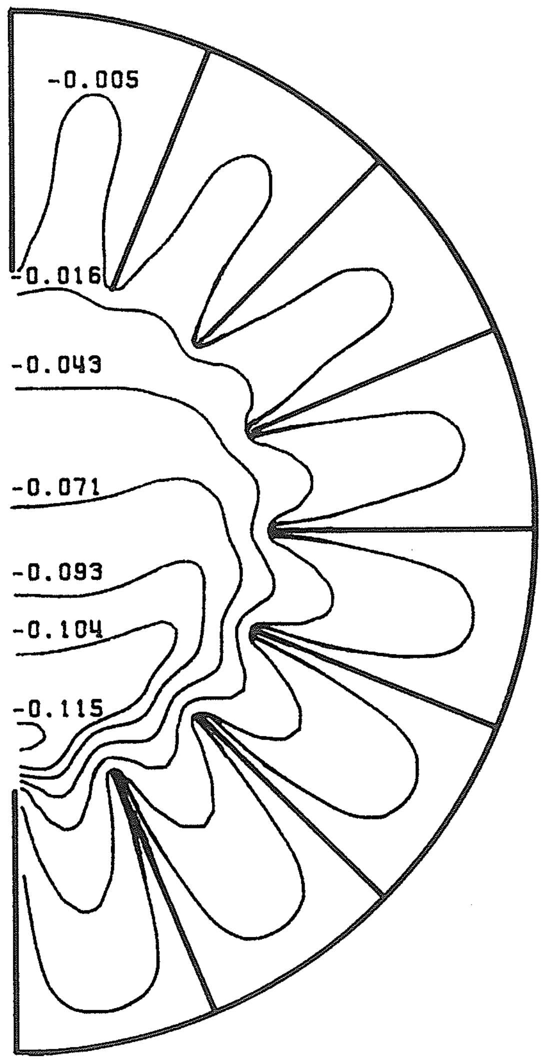


Figure 5.63 Isotherms for $H = 0.5$ and $M = 16$ at $Gr^{+} = 2 \times 10^{6}$.

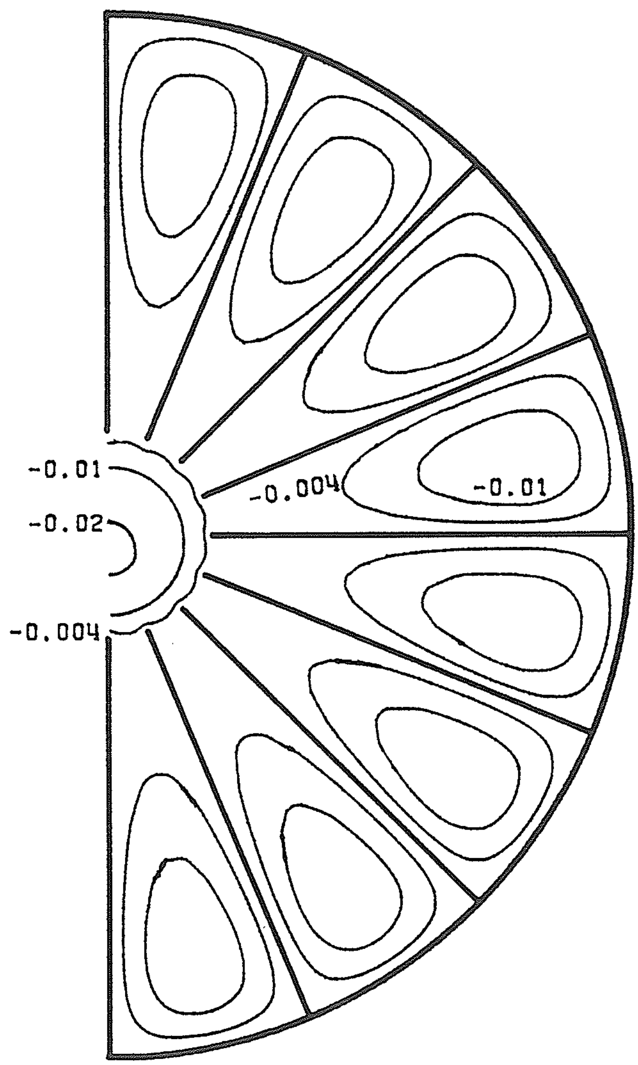


Figure 5.64 Isotherms for $H = 0.8$ and $M = 16$ at $Gr^+ = 2 \times 10^6$.

transfer performance. As shown before, this finding is consistent with the activity of the secondary flow for this geometry.

For large number of medium height fins ($H = 0.5$ and $M = 16$), Figure 5.63 shows the effect of free convection on the isotherms. The core area isotherms are similar to those of a smooth tube. The bays area has nearly similar temperature structure. The interaction between the core and the bays is weaker than the case of Figure 5.62. The heat-transfer performance of the bays is maximum at the first bay from the bottom and decreases to a minimum in the last bay at the top of the tube.

The case of large number of long fins ($H = 0.8$ and $M = 16$) Figure 5.64 shows that the structure of the isotherms is similar to the case of pure forced convection. In the bays area, the structure of isotherms is identical in all bays, and the interaction between the bays and the core area almost does not exist. This finding is consistent with the secondary flow pattern which is shown to be severly suppressed for this geometry. The minimum temperature is located slightly below the tube centre, and each bay has its own minimum temperature at a point about half the distance between the two fins and closer to the wall than the fin tip.

5.3.3 Distribution of Wall Heat Flux

Figures 5.65 to 5.70 show the trend in the present results of local heat flux distribution at the solid wall (tube and fins). These results are presented in terms of $h/\bar{h}$, where h is the local heat transfer coefficient evaluated from the temperature gradient normal to the wall and $\bar{h}$ is the average heat transfer coefficient over the whole solid surface.

Figures 5.65 to 5.67 corresponds to finned tubes with (H = 0.2, 0.5, and 0.8 and $M = 4$) and they show the behaviour of the local heat flux at $Gr^+ = 0$, 10^5 and 2×10^6. The abscissa is proportional to distance along the wall from the tip of the upper fin to the tip of the bottom fin in the direction shown in the inset of each figure. At $Gr^+ = 0$, similarity exists between bay 1 and bay 2 of each geometry, as

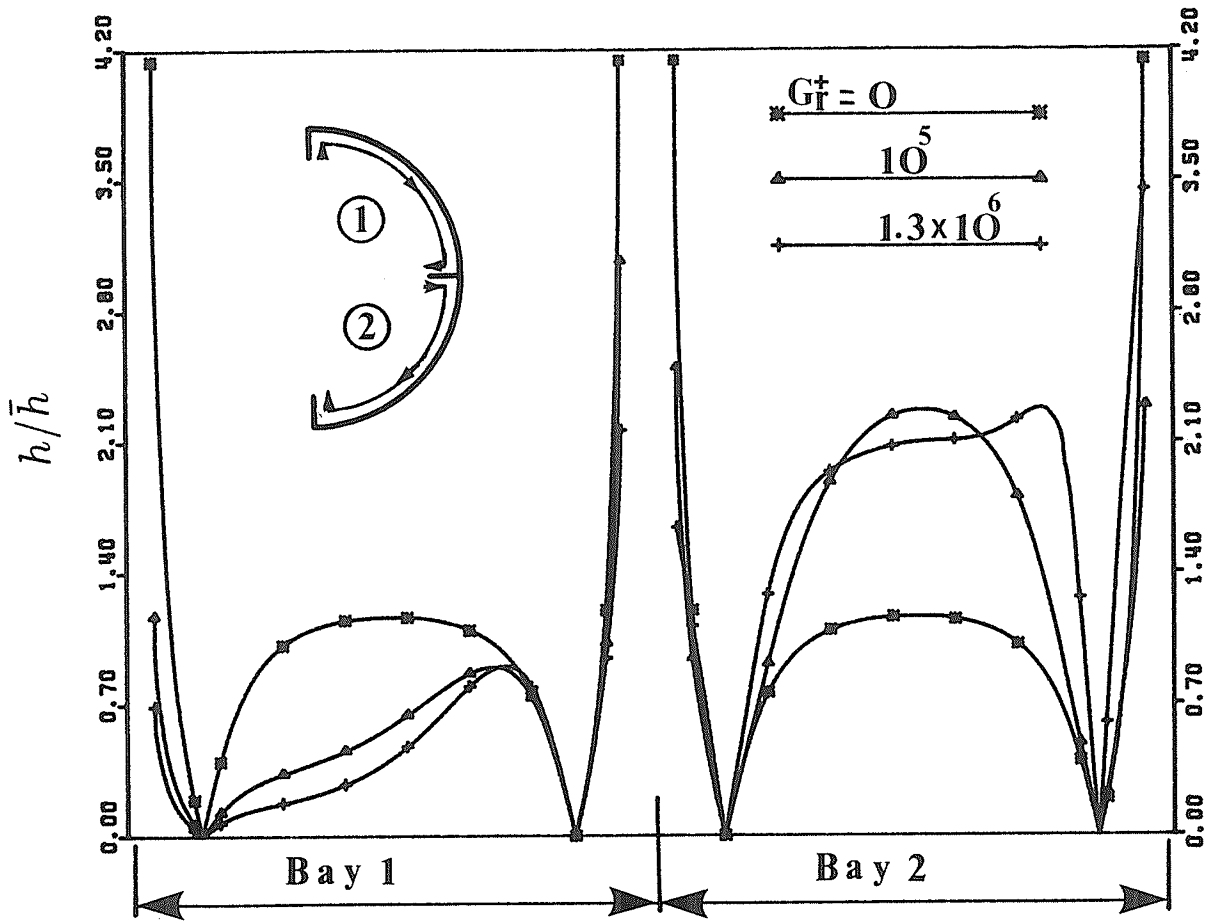


Figure 5.65 Distribution of wall heat flux for $H = 0.2$ and $M = 4$.

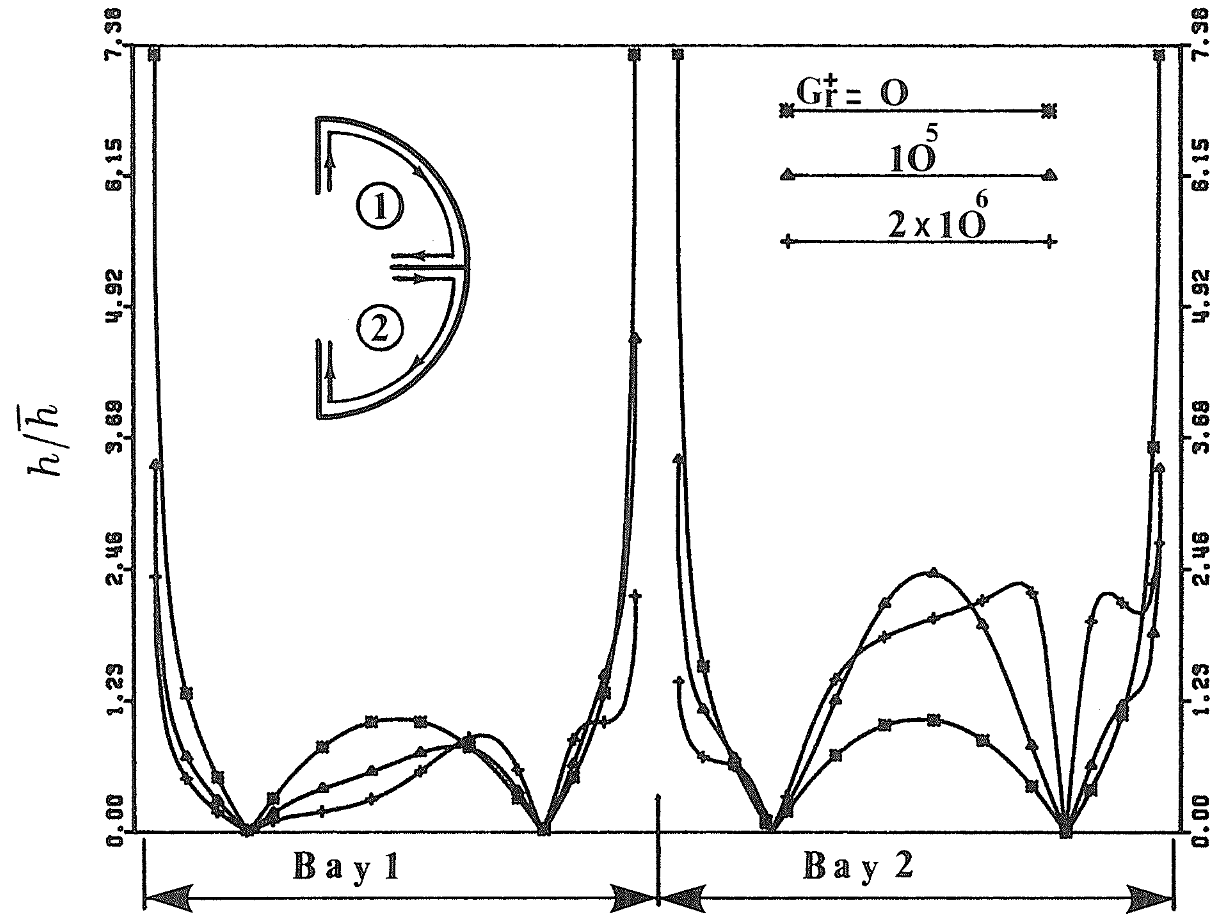


Figure 5.66 Distribution of wall heat flux for $H = 0.5$ and $M = 4$.

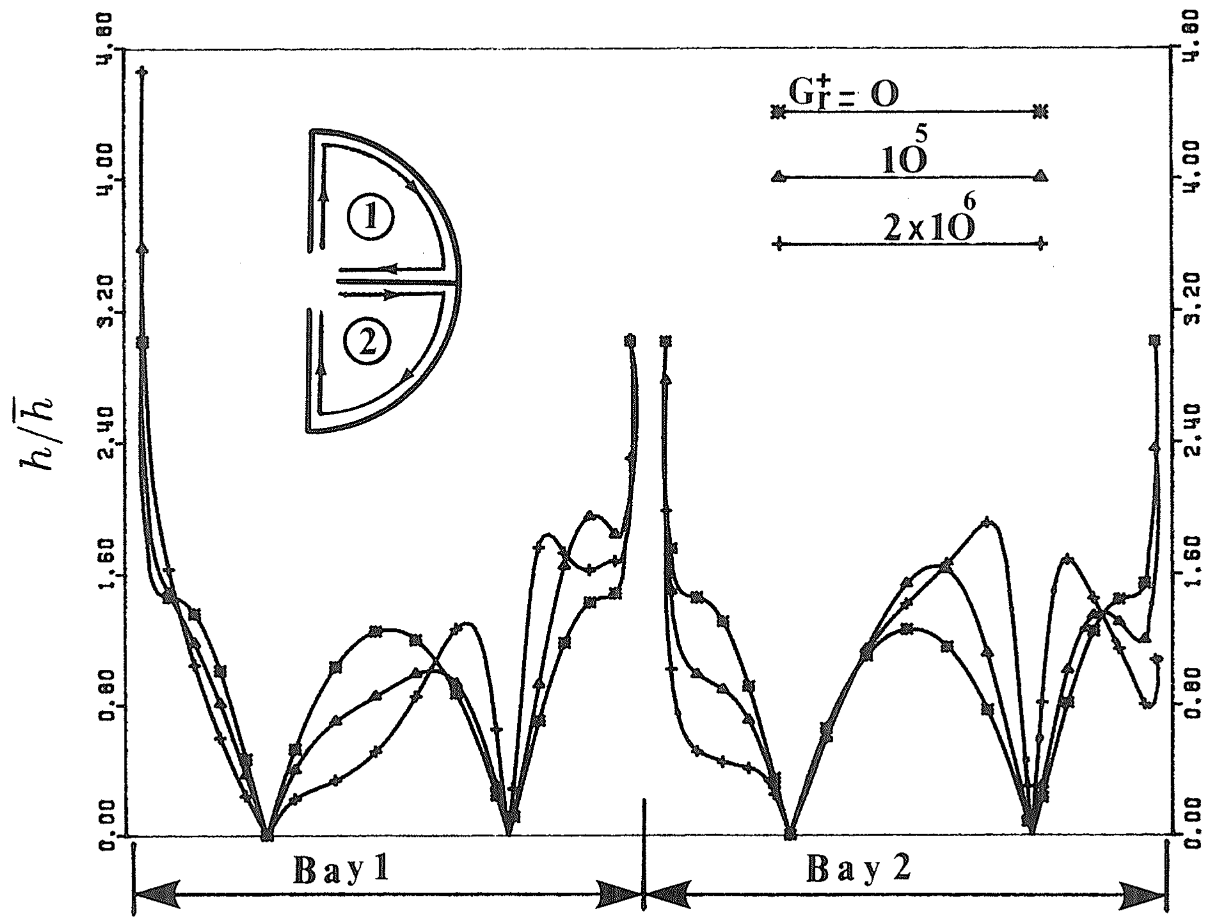


Figure 5.67 Distribution of wall heat flux for $H = 0.8$ and $M = 4$.

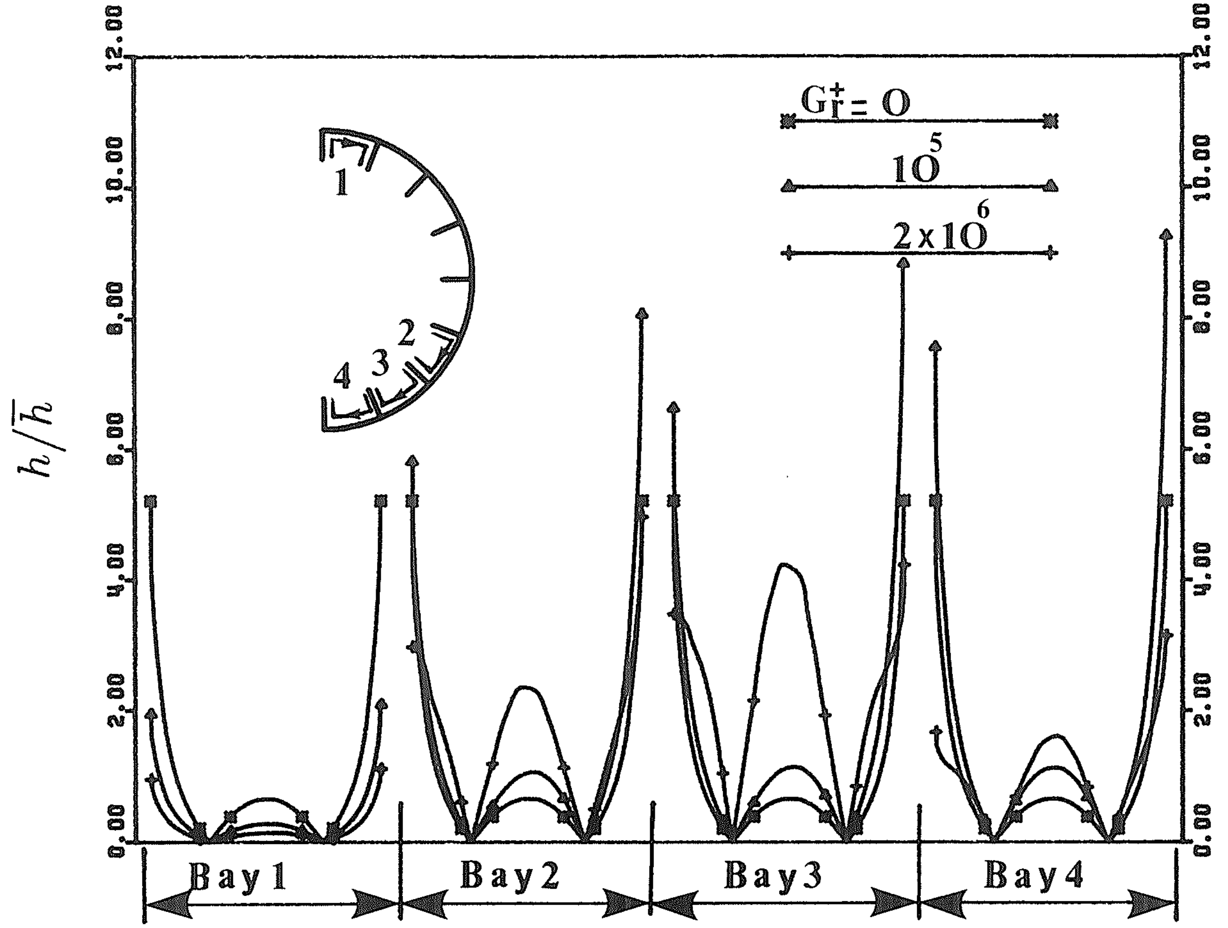


Figure 5.68 Distribution of wall heat flux for $H = 0.2$ and $M = 16$.

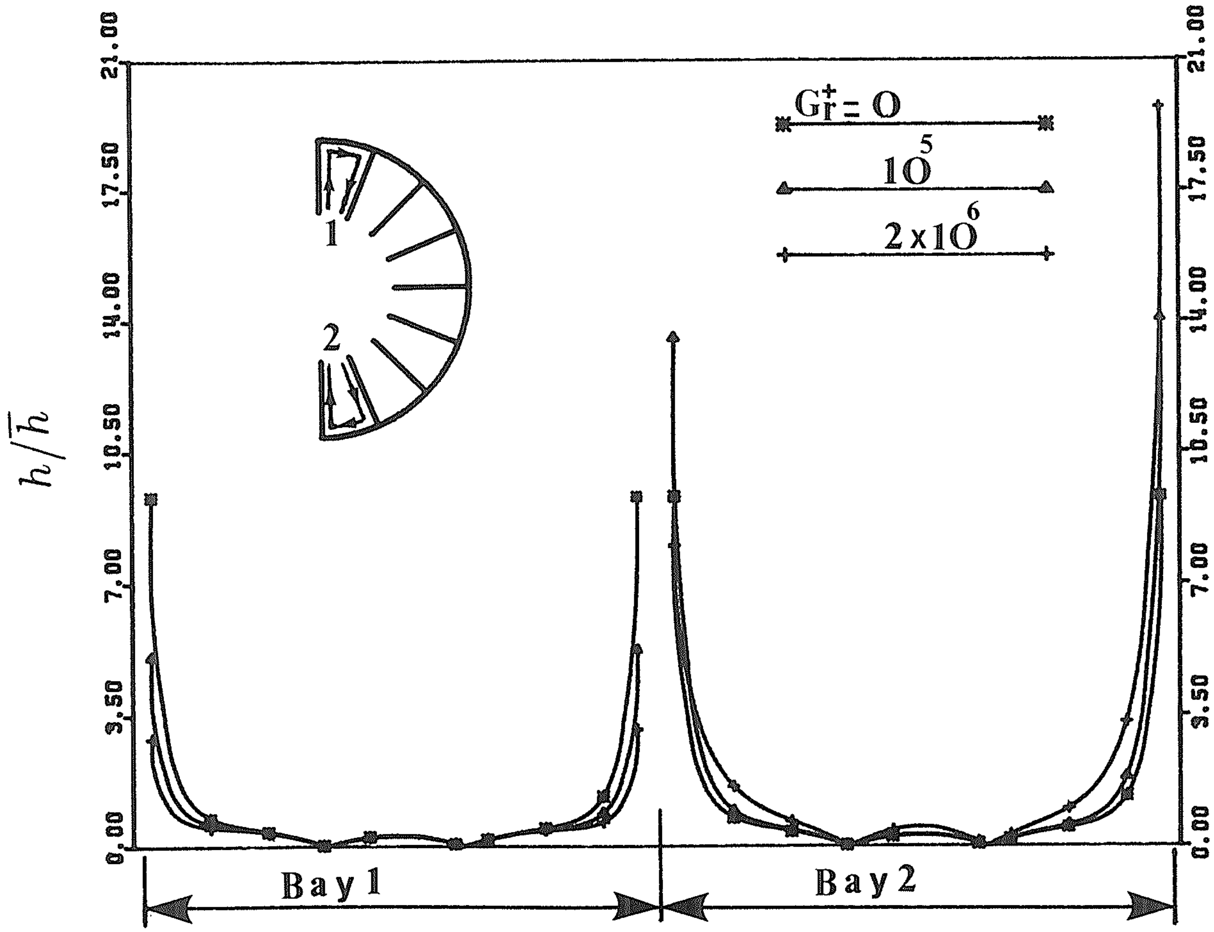


Figure 5.69 Distribution of wall heat flux for $H = 0.5$ and $M = 16$.

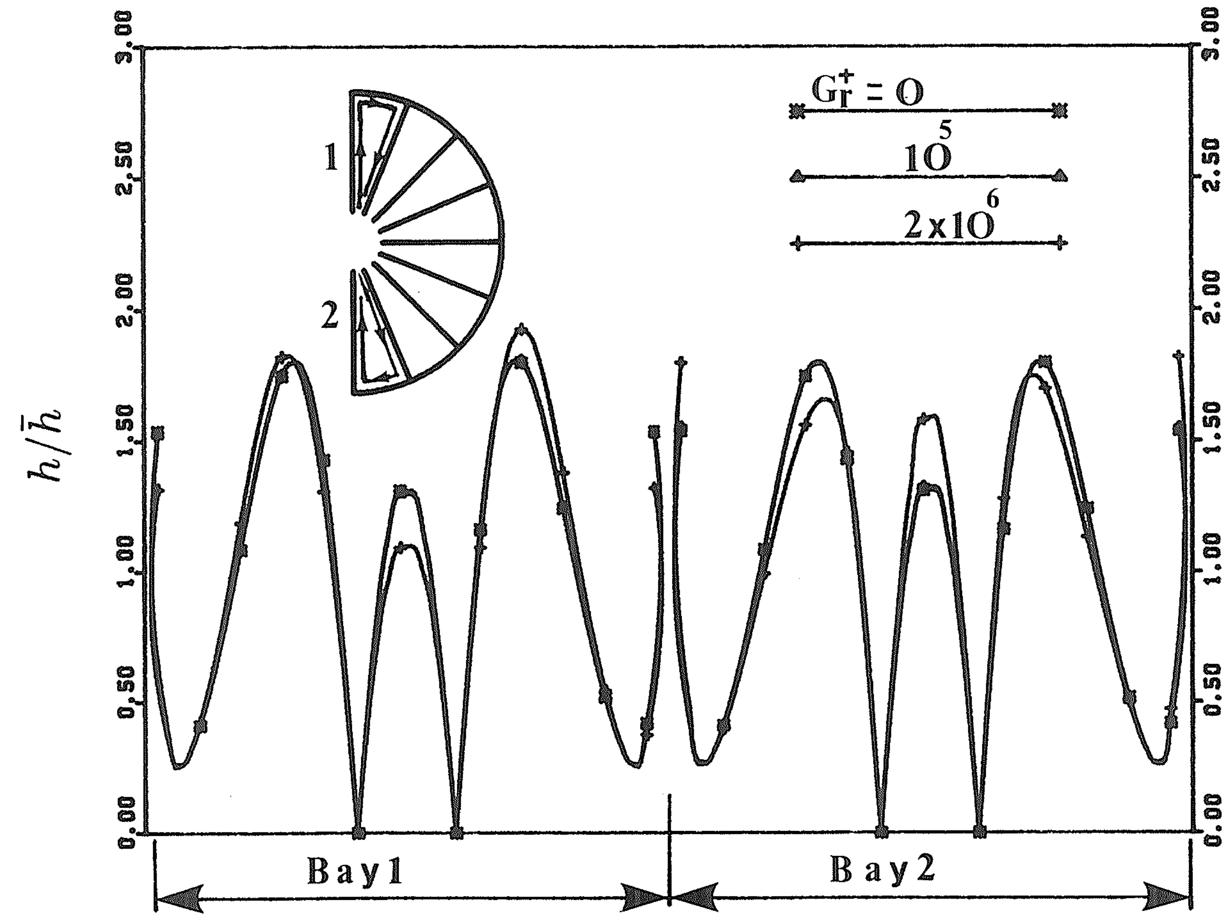


Figure 5.70 Distribution of wall heat flux for $H = 0.8$ and $M = 16$.

expected, and the areas near the tips of the fins are the most effective heat transfer surfaces. As Gr^+ increases, a higher proportion of the heat dissipation occurs in bay 2, which is consistant with the previous results of secondary flow and temperature distribution for all fins heights 0.2, 0.5, and 0.8 and $M = 4$. Figure 5.65 for the case of $H = 0.2$ and $M = 4$ shows that a gradual decrease in relative heat transfer effectiveness with Gr^+ can be seen at all surfaces of bay 1. In bay 2, significant enhances in heat transfer effectiveness are evident at the circular wall and the bases of the fins, while decreases in effectiveness occur near the fin tips. Similar findings can be seen in Figures 5.66 and 5.67. Bay 1 shows a gradual decrease in relative heat transfer effectiveness with Gr^+ at all surfaces except for the area near the junction of the horizontal fin and the circular wall where some increase occurs.

A second set of heat transfer distribution results is shown in Figures 5.68 to 5.70. This set is for high number of fins ($M = 16$), and different values of fin heights $H = 0.2$, 0.5, and 0.8, respectively, and each figure presents the heat transfer distribution at $Gr^+ = 0$, 10^5, and 2×10^6. Figure 5.68 ($H = 0.2$ and $M = 16$) is simplified by including only the top bay and the bottom three bays since the behaviour at any point within the excluded bays is found to be consistent with a gradual monotonic change between the corresponding points in bays 1 and 2. As expected from the previous results, bay 3 (the second from the bottom) gets to be the most active at $Gr^+ = 2 \times 10^6$ while the top bay becomes the least active. The modified Grashof number can be seen to have a strong influence on the relative heat transfer effectiveness of different parts of the solid wall. Figures 5.69 and 5.70 show the heat transfer distribution for $H = 0.5$ and 0.8, respectively. For both cases, the effect of Gr^+ is only noticeable at the fin tips where it reduces the effectiveness of the fin tips at the top bay and increase the effectiveness of the fin tips at the bottom bay.

Another way of presenting the heat flux characteristics is shown in Figure 5.71 in terms of Q'_f/Q', where Q'_f is the integrated sum of the heat transfer rate from

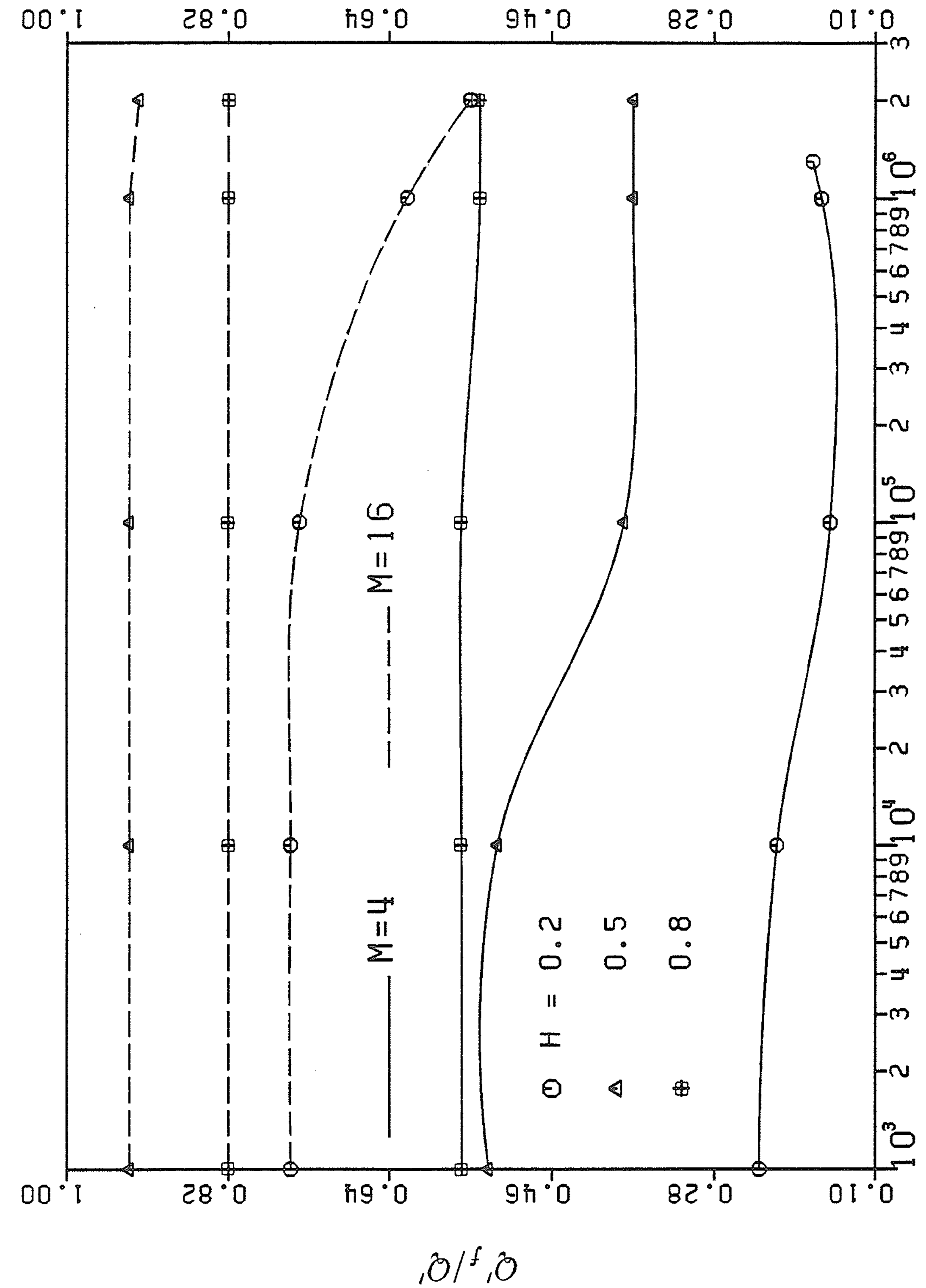


Figure 5.71 Fractional fin heat dissipation versus Gr^+.

the sides of the fins per unit axial length. For $H = 0.2$ and $M = 4$, Q'_f/Q first decreases with Gr^+ and then increases gradually. An increase in either H or M causes an increase in the value of Gr^+ at which Q'_f/Q' starts decreasing. This is due to the fact that secondary flow is retarded within the bays by increases in either H or M, as shown earlier. Comparing Q'_f/Q' to A_f/A which is the ratio of the total surface area of the fins to the total surface area of the solid wall, we find that the fins are more effective heat transfer surfaces for all the geometries in Figure 5.71 at low Gr^+. With decrease in Q'_f/Q' at high Gr^+, Q'_f/Q' becomes smaller than A_f/A for some geometries (e.g. $H = 0.2$ and 0.5 and $M = 4$) which indicate that, on average, the circular wall becomes more effective than the fins. This trend may again reverse at Gr^+ higher than the values covered in this investigation, as suggested by the behaviour with $H = 0.2$ and $M = 4$ (where there is a gradual increase in Q'_f/Q' at high Gr^+).

5.3.4 Friction Factor and Nusselt Numbers

The case of horizontal smooth tubes is presented in Table 5.6 for two values of Prandtl number ($Pr = 1$ for air and $Pr = 7$ for water). These results were used in the previous chapter in comparisons with existing solutions and showed a very good agreement.

Values of $f_{fd}Re/f_{fd,0}Re$, where $f_{fd,0}Re$ corresponds to pure forced convection for the same geometry, are presented in Figures 5.72 and 5.73 for $M = 4$ and 16, respectively, with the smooth tube case included for reference. These results show that $f_{fd}Re/f_{fd,0}Re$ remain equal to unity up to a critical Grashof number beyond which $f_{fd}Re/f_{fd,0}Re$ increases with Gr^+. This critical Gr^+ increases as H or M increases, which can be attributed to the earlier observation that internal finning retards the onset of secondary flow. Also, due to the fact that the presence of fins generally suppresses the values of the secondary velocities, we find that the ratio $f_{fd}Re/f_{fd,0}Re$ decreases with increases in either H or M at any given Gr^+. For

Table 5.6 Values of $f_{fd}Re$ and Nu_{fd} for Horizontal Smooth Tube

Gr^+	$Pr = 1$		$Pr = 7$	
	$f_{fd}Re$	Nu_{fd}	$f_{fd}Re$	Nu_{fd}
0.0	15.98	4.367	15.98	4.367
10^4	16.59	4.705	16.15	6.007
10^5	19.97	6.388	16.90	9.076
10^6	26.35	9.350	18.67	13.93
2×10^6	—	—	19.52	16.04
10^7	37.22	14.33	—	—

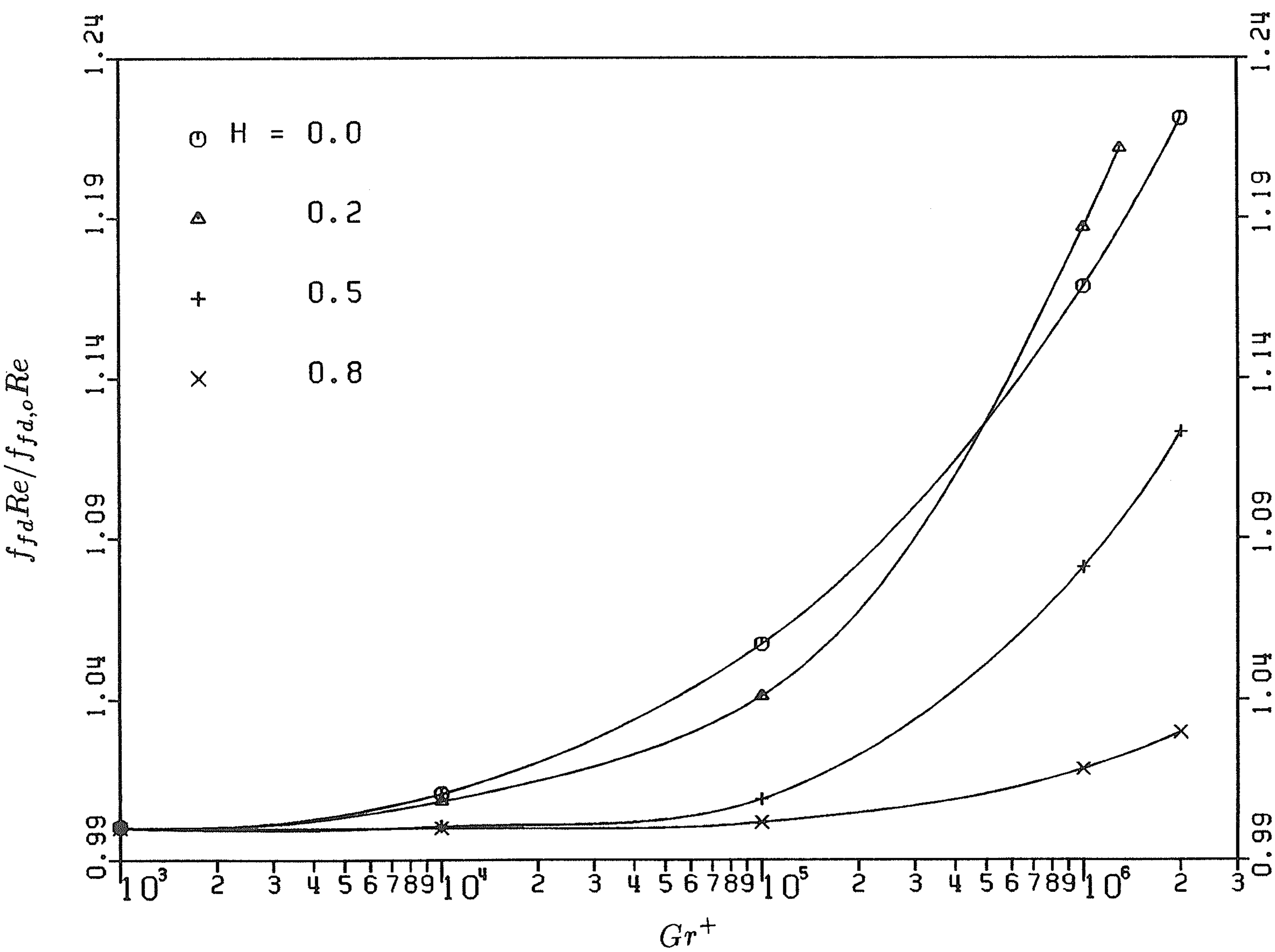


Figure 5.72 The friction factor ratio versus Gr^+ for $M = 4$.

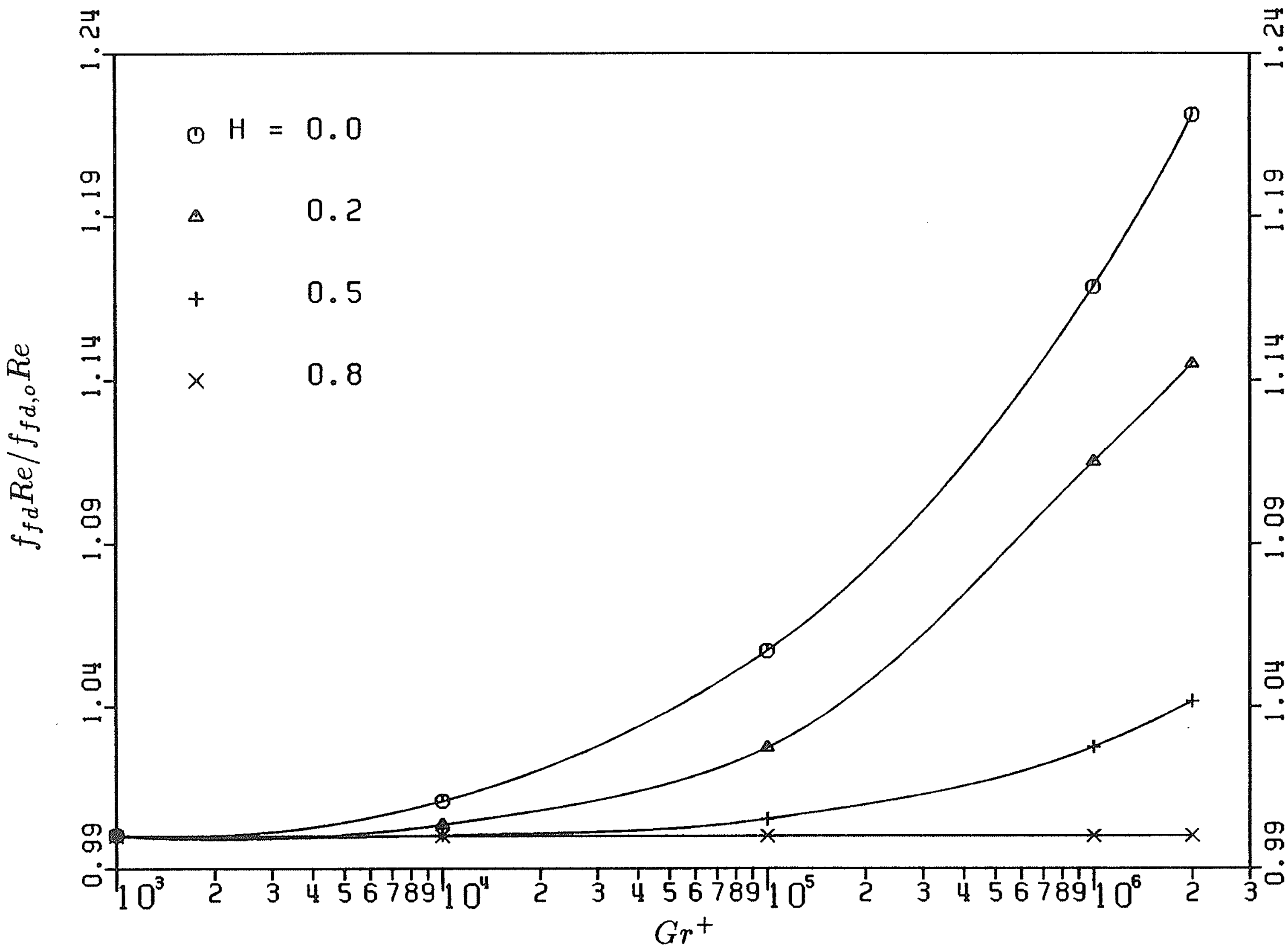


Figure 5.73 The friction factor ratio versus Gr^+ for $M = 16$.

smooth tubes, the enhancement in the friction factor due to free convection exceeds that of finned tubes except for the geometry $H = 0.2$ and $M = 4$ at high Gr^+.

Figures 5.74 and 5.75 show the variation of $Nu_{fd}/Nu_{fd,0}$ with Gr^+, for the cases of $M = 4$ and 16, respectively. The prevailing trends are similar to the ones discussed above in connection with the friction factor results. However, it must be noted that for any geometry, $Nu_{fd}/Nu_{fd,0}$ far exceeds $f_{fd}Re/f_{fd,0}Re$ at any Gr^+. This is consistent with the earlier results where it was shown that the influence of the free convection currents on the temperature distribution is much stronger than their influence on the axial velocity distribution. The manner by which variations in M and H influence $Nu_{fd}/Nu_{fd,0}$ is consistent with previously published experimental and theoretical results [Prakash and Patankar (1981), Mirza and Soliman (1985), and Rustum and Soliman (1988a)].

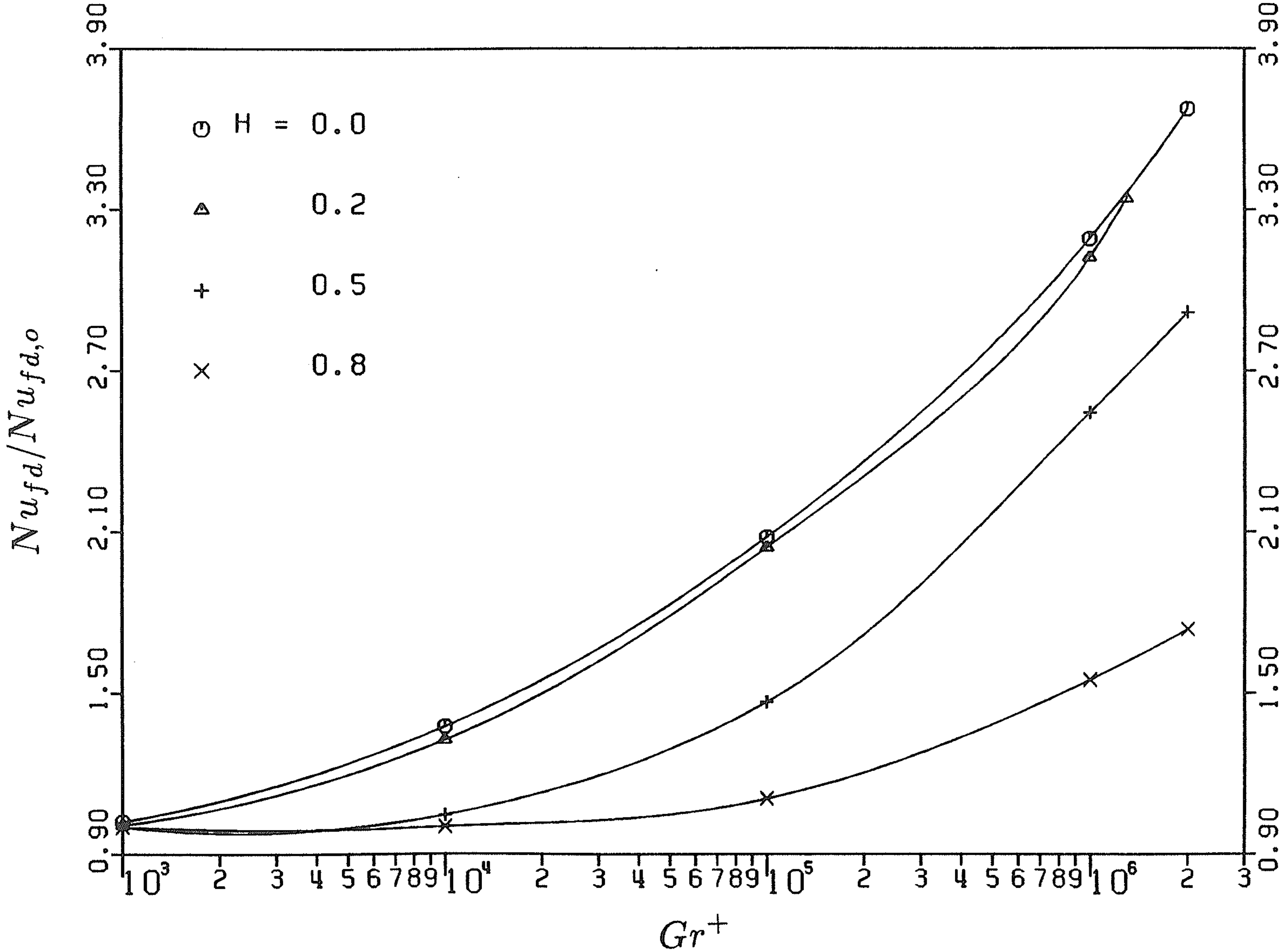


Figure 5.74 The Nusselt number ratio versus Gr^+ for $M = 4$.

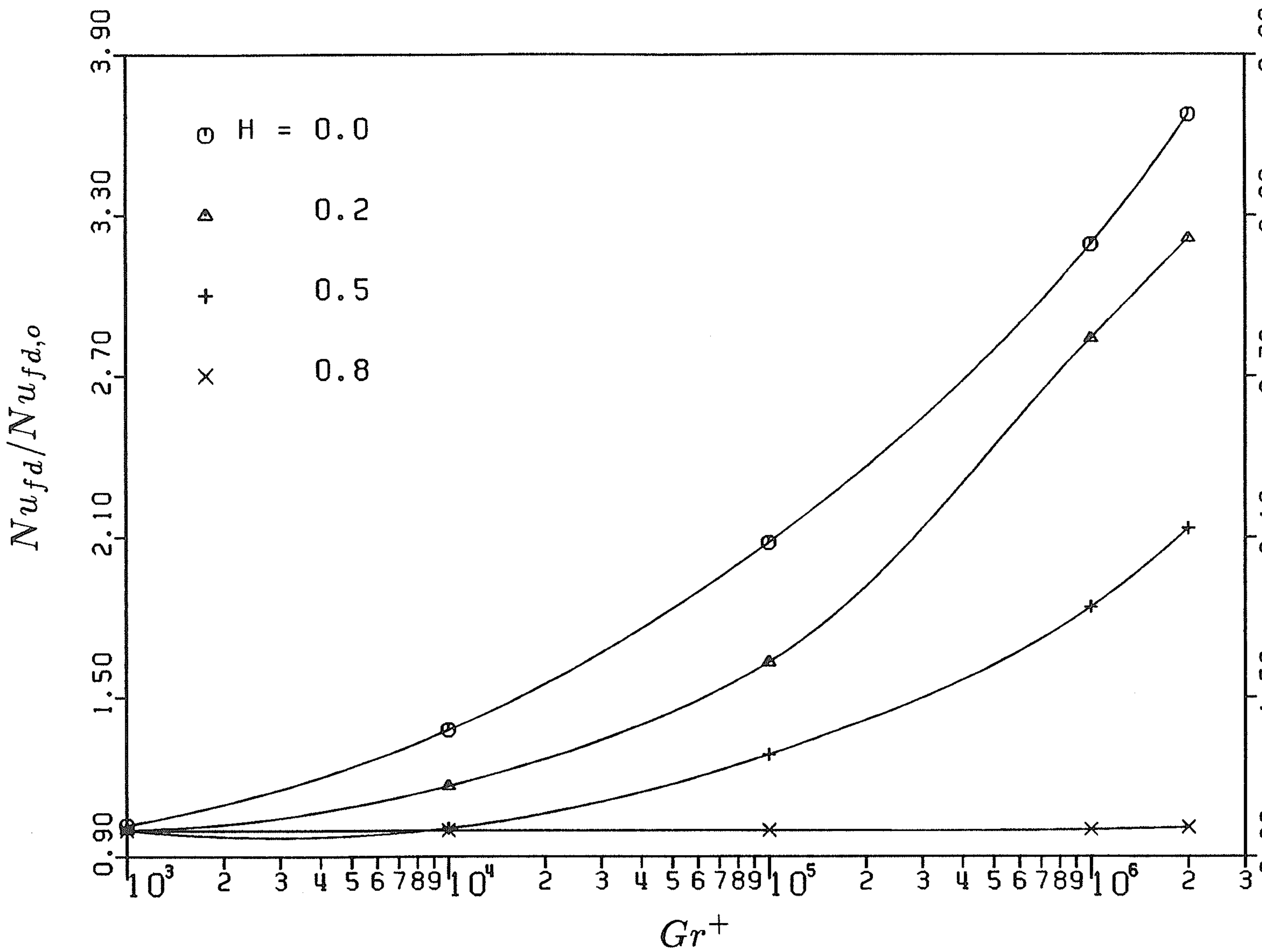


Figure 5.75 The Nusselt number ratio versus Gr^+ for $M = 16$.

CHAPTER 6

COMPARISONS WITH EXPERIMENTAL RESULTS

An interesting feature of the literature on laminar flow and heat transfer in internally finned tubes is that there has been very little (if any) correlation between experimental and analytical results. This is basically due to the fact that the experimental conditions did not correspond to the situations assumed in the analysis. In some cases, this lack of correlation gave rise to misconceptions, such as the proposition by Marner and Bergles (1978) that Prandtl number has a much stronger influence on heat transfer in internally finned tubes than in smooth tubes.

Only two experimental investigations reported data on local heat transfer in internally finned tubes with laminar flow. The more extensive of the two is the work of Rustum (1984). This data set is compared here with different results from the present analysis. As is normally the case with analytical studies, not all the results can be confirmed experimentally. Fortunately, segments from all three models considered in this investigation can be used in this comparison.

6.1 Model I

Figure 6.1 shows experimental data of the local values of Nusselt number in the thermally developing region of a smooth tube at four different values of Ra_m^+. The effect of free convection is apparent in the fully developed region. However, in the early part of the developing region where the effect of free convection is weak due to the small wall to bulk temperature difference, values of the local Nusselt numbers seem to be approaching the analytical value for pure forced convection of Model I, thus indicating the success of the analysis of Model I in defining a lower bound for $Ra_m^+ = 0$. This fact is substantiated by similar results for two internally finned tubes,

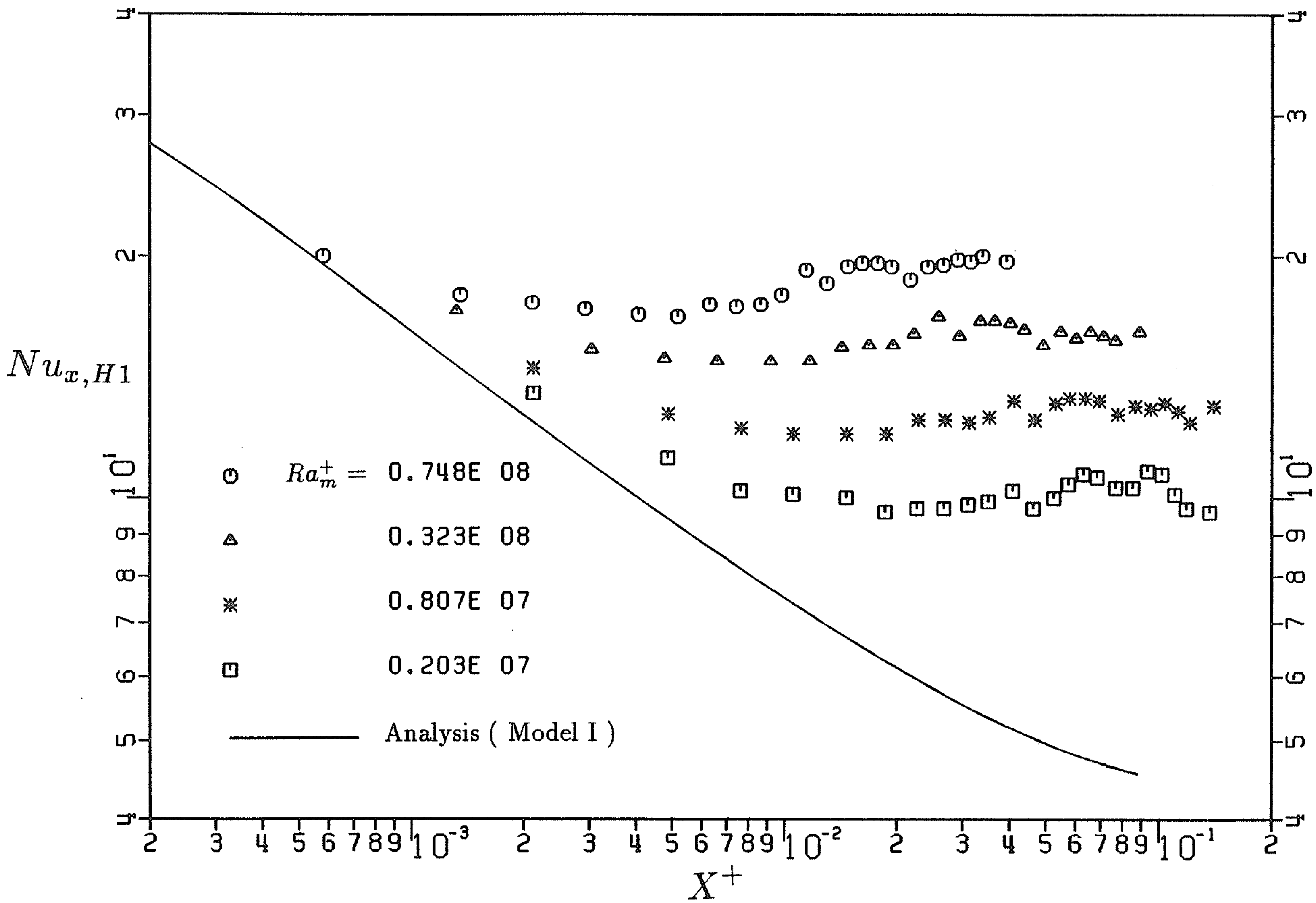


Figure 6.1 Comparison between Model I ($Ra_m^+ = 0$) and the experimental data of Rustum (1984) for a smooth tube

as presented in Figures 6.2 and 6.3. It is obvious from these results that the entrance length decreases as Ra_m^+ increases. However the actual heat transfer performance measured experimentally can be reasonably approximated at any value of Ra_m^+ by a horizontal line representing mixed convection in the fully developed region and the forced convective line in the thermally developing region as it is apparent from Figures 6.1 to 6.3.

The experimental values of $f_{fd,0}$ for an internally finned tube with $H = 0.216$ and $M = 10$, reported by Rustum (1984), are presented in Figure 6.4. This data is compared with the analytical results for the same geometry which were generated using Model I (Models II and III gave practically identical values). The agreement can be seen to be excellent. Other equally successfull comparisons between experimental and analytical predictions of fully developed friction factors were reported by Rustum and Soliman (1988a). No data exist in the literature on the axial development of f_x.

6.2 Model II

For the case of developing isothermal flow, no experimental data exist yet for internally finned tubes. For the case of the smooth tube geometry ($H = 0$), the only experimental data found is the value of K_∞, which is the limiting incremental pressure drop number. For smooth tubes, Shah and London (1978) reported experimental values of K_∞ ranging from 1.20 to 1.32. These values compare very well with the value of K_∞ at ($H = 0$) generated by this model which is 1.258.

6.3 Model III

Predictions of the present analysis are compared with the experimental data of the fully developed Nusselt number ratio $Nu_{fd}/Nu_{fd,0}$ of Rustum (1984). This comparison is shown in Figure 6.5 for a tube with $H = 0.318$ and $M = 16$, and in Figure 6.6 for a tube with $H = 0.325$ and $M = 10$. In both cases, the theoretical

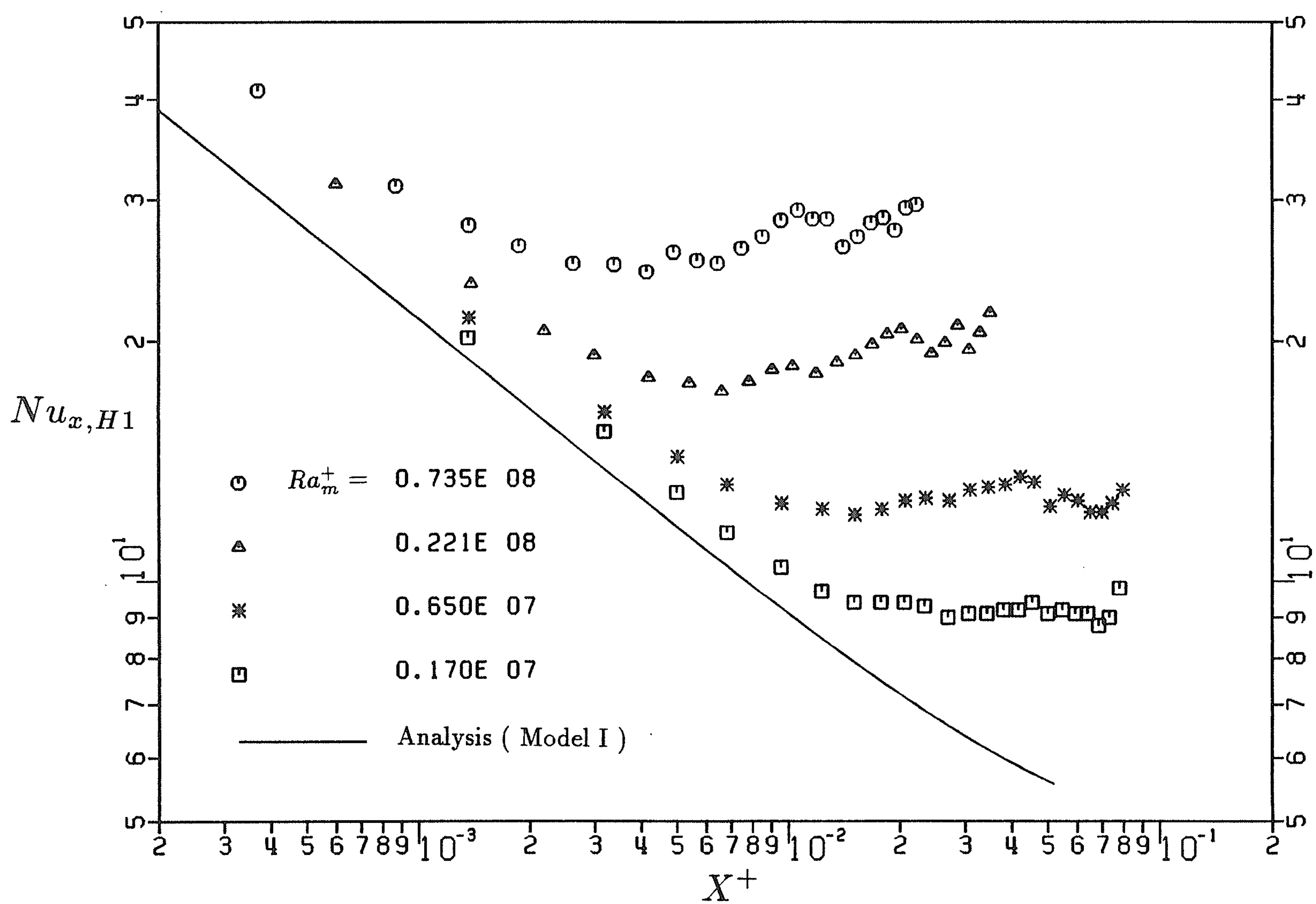


Figure 6.2 Comparison between Model I ($Ra_m^+ = 0$) and the experimental data of Rustum (1984) for $H = 0.216$ and $M = 10$

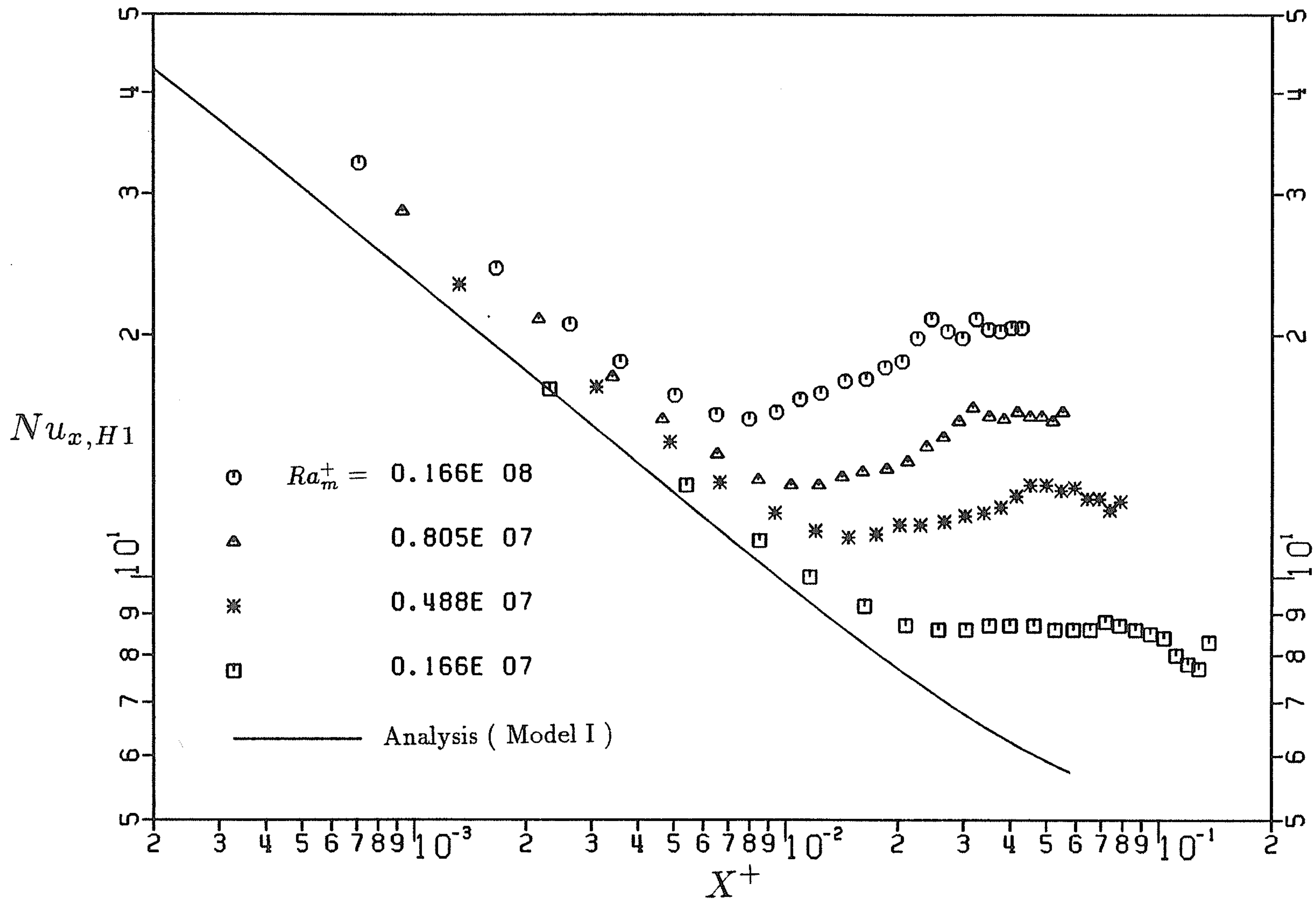


Figure 6.3 Comparison between Model I ($Ra_m^+ = 0$) and the experimental data of Rustum (1984) for $H = 0.248$ and $M = 10$

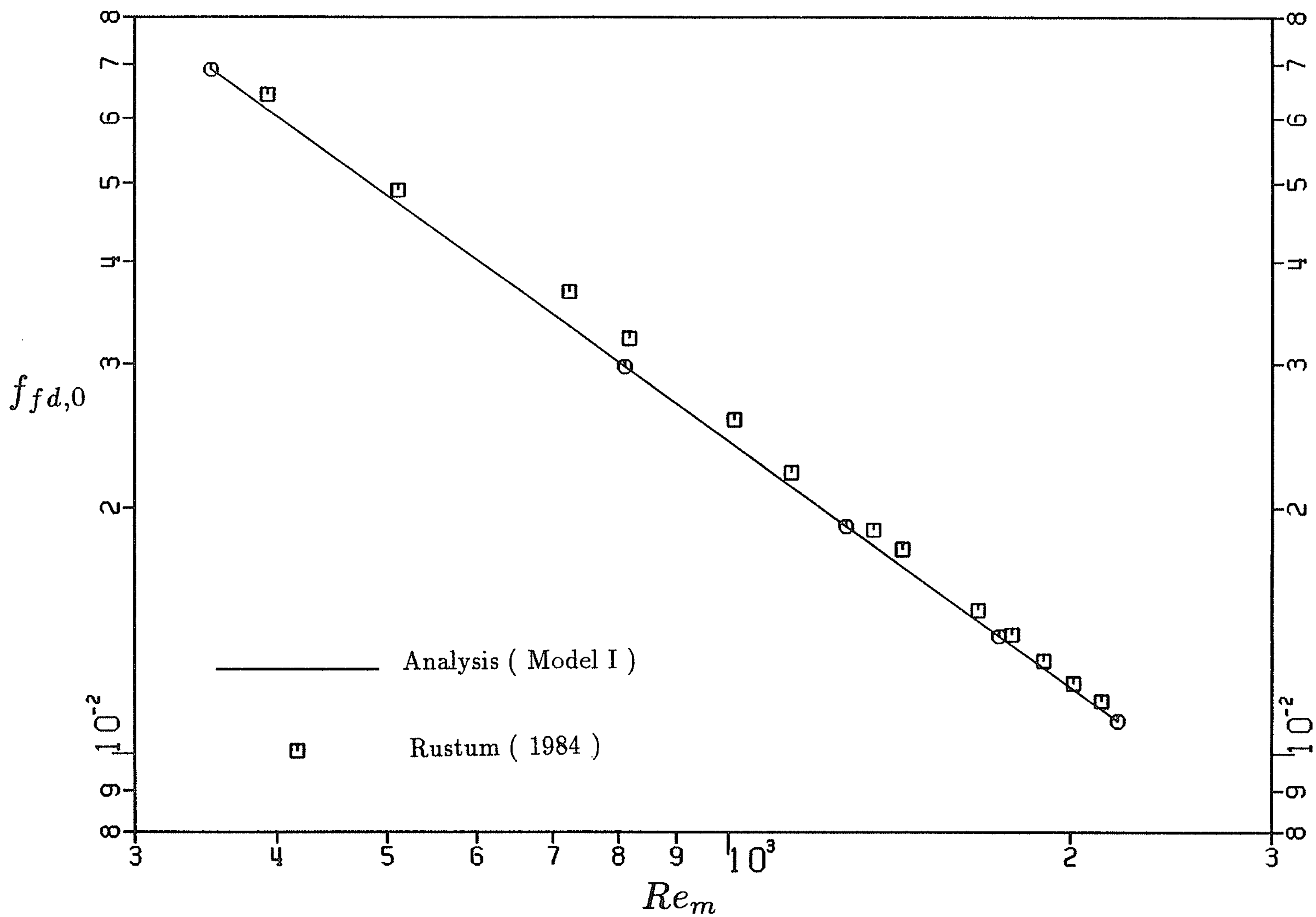


Figure 6.4 Comparison between Model I and the experimental data of Rustum (1984) for $H = 0.216$ and $M = 10$

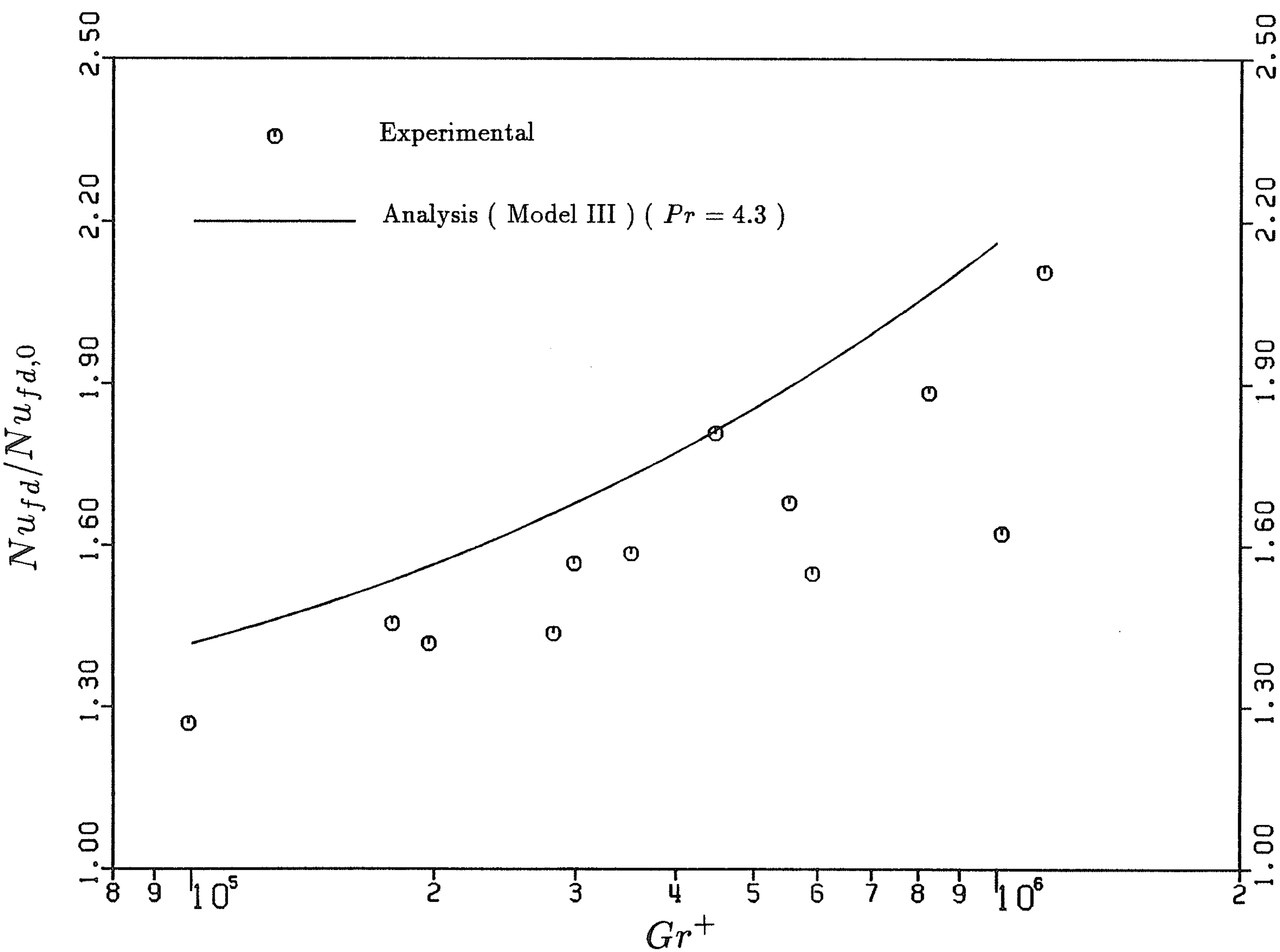


Figure 6.5 Comparison of $Nu_{fd}/Nu_{fd,0}$ with the experimental data of Rustum (1984) for $H = 0.318$ and $M = 16$

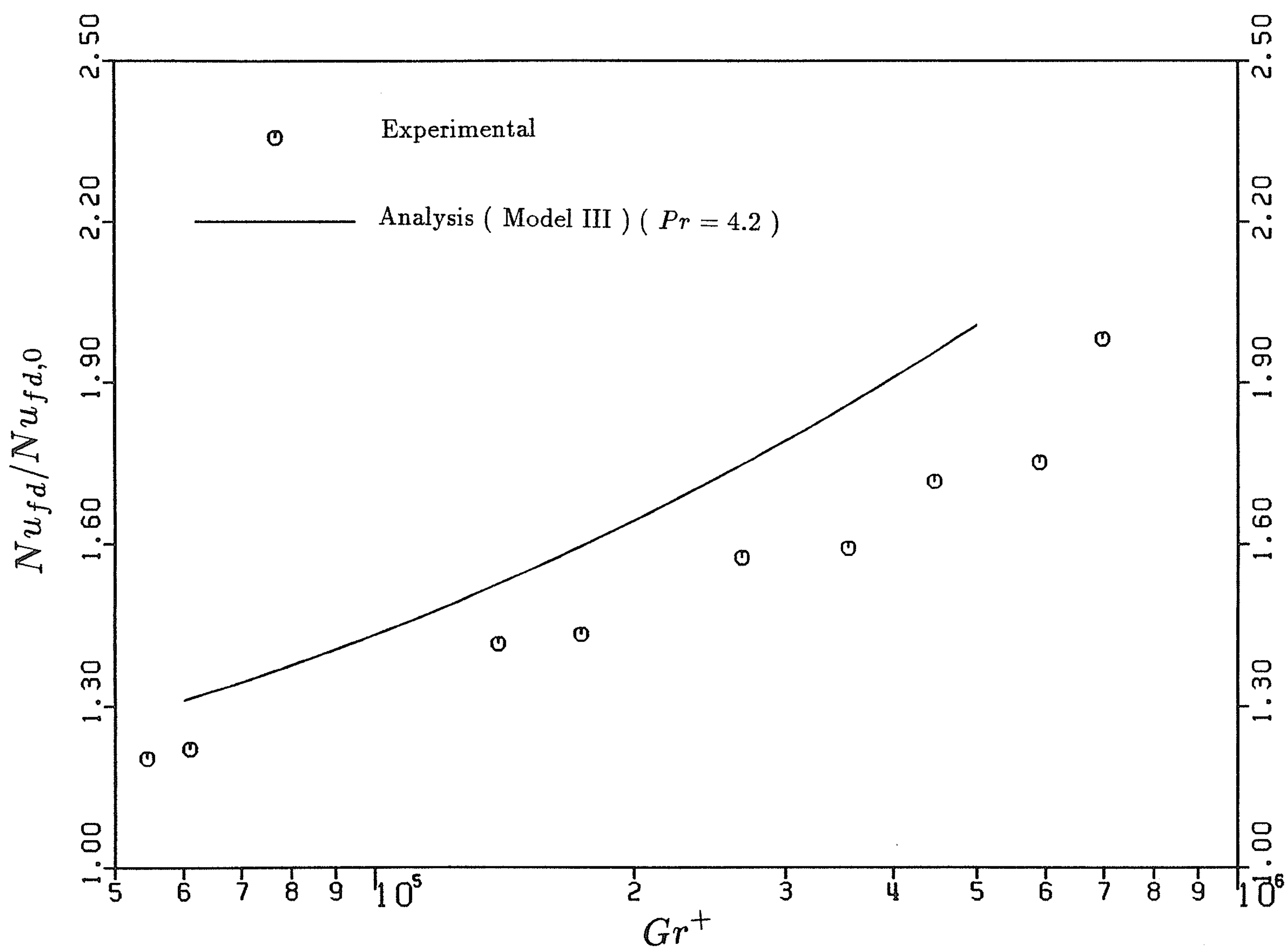


Figure 6.6 Comparison of $Nu_{fd}/Nu_{fd,0}$ with the experimental data of Rustum (1984) for $H = 0.325$ and $M = 10$

predictions of Model III are generated at a Prandtl number equal to the mean value for the respective data set. Figures 6.5 and 6.6 show that the experimental data are overpredicted by about 10 to 15%. It should be recalled that the present analysis assumes negligible fin thickness and uniform fin temperature (i.e 100% fin efficiency). Both of these assumptions result in slight overestimation of Nusselt number for the geometries considered in Figures 6.5 and 6.6, as reported by Soliman (1981). Another factor that could have contributed to this deviation in the results is the dependence of properties on temperature, whereas the properties are assumed to be constant in the theoretical analysis except for the density in the body force term. Taking these factors into account, it can be concluded that the comparisons shown in Figures 6.5 and 6.6 are quite satisfactory.

For the case of smooth tubes, the analytical results of $Nu_{fd}/Nu_{fd,0}$ from Model III are compared with three different independent experimental results. Figure 6.7 shows the experimental data of Rustum (1984), the empirical correlation generated by Ede (1961), and another empirical correlation generated by Petukhov and Polyakov (1967) for smooth tubes. The results indicate that the theoretical analysis slightly overpredicts the empirical correlations at high Ra^+. However, the difference is within an acceptable range especially if we considered an average of $\pm 15\%$ uncertainty in the experimental results.

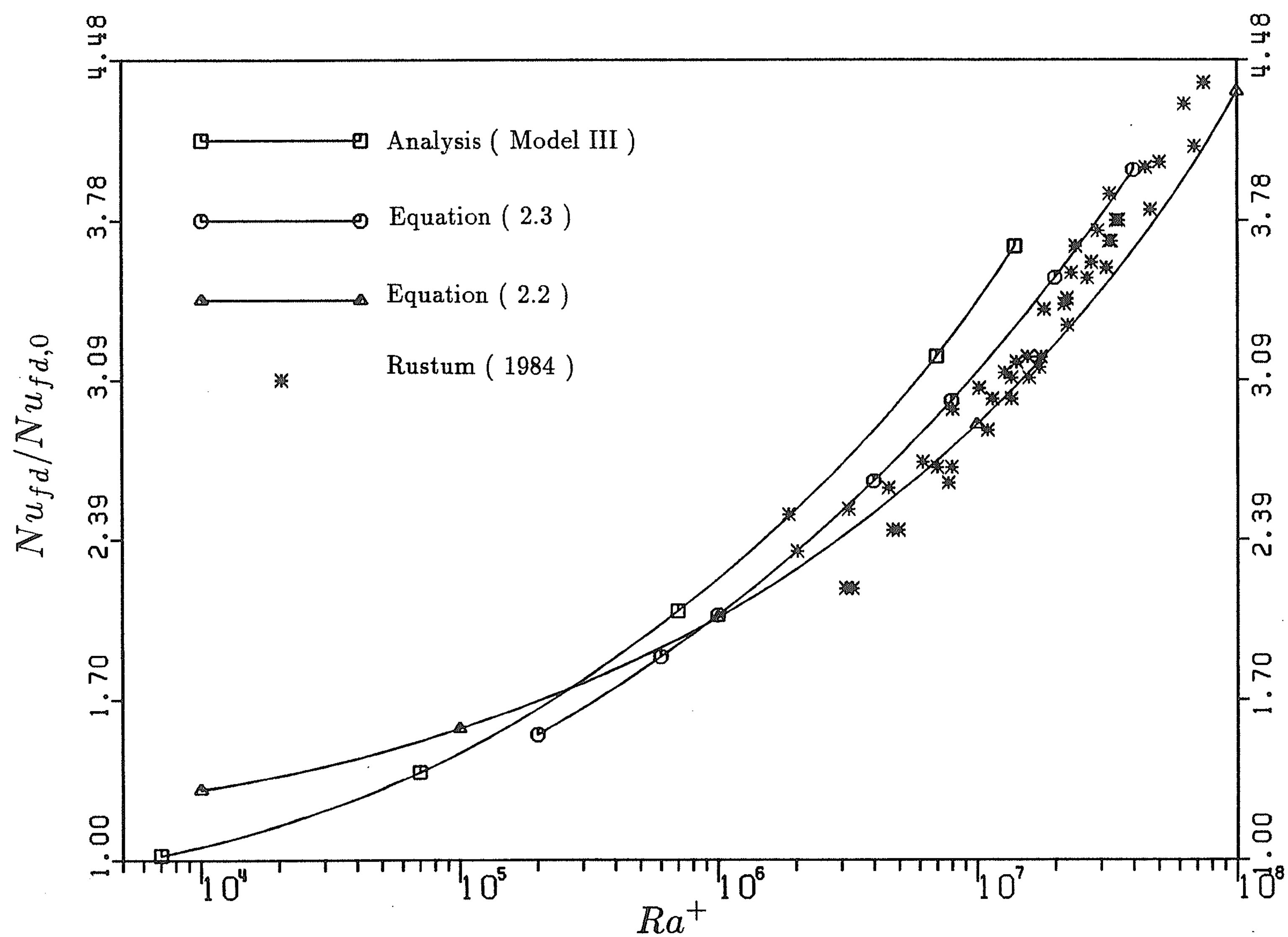


Figure 6.7 Comparison of $Nu_{fd}/Nu_{fd,0}$ of Model III with three different sources of experimental data for the case of smooth tubes

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

7.1.1 Model I

The local values of Nusselt number in the entrance region of internally finned tubes for both (H1) and (T) boundary conditions exhibited some unconventional behaviour. At very low values of X^+, the rate of decrease of local Nusselt number for all finned tube geometries was found to be almost equal to that of smooth tubes. However, sharp changes occured in this rate later in the developing region, which resulted in unexpected trends in the magnitudes of the entrance length. This behaviour is attributed to the fact that internal finning influences the velocity distribution and results in a complex geometry for the wall-fluid interface (where heat transfer takes place), which may cause the form of temperature development to be different from that of smooth tubes.

Results generated by this model in the developing region for the (H1) boundary condition were found to serve well as the lower bound for experimental results where free convection effect took place. In the fully developed region, values of $Nu_{fd,H1}$ are compared with other analytical results and shown to be very accurate. In general, extreme care was taken about numerical accuracy. However, it must be emphasized that all results of this model correspond to pure forced convection, i.e., flows with low Grashof number. Free convective currents superimposed on the main flow may have substantial effects on the heat transfer characteristics in the fully developed region, but not much in the developing region, as shown in the experimental results that were used for comparisons.

7.1.2 Model II

Laminar fluid flow in the entrance region of internally finned tubes has been investigated theoretically. The appropriate continuity and momentum equations have been solved numerically using the finite difference method. Results for the fully developed and developing regions were obtained for sixteen finned tube geometries as well as the smooth tube geometry. The fully developed results of the finned tubes and all results of the smooth tube agree well with previously published results, which indicates satisfactory numerical accuracy.

In the entrance region of internally finned tubes, the local friction factor exhibited some sharp changes in the slope for some geometries. This resulted in unexpected trends in the magnitude of K, K_∞ and L_H which are attributed to the complicated secondary flow field. Comparisons between predictions and experiments for f_x were not possible due to lack of experimental data.

7.1.3 Model III

A numerical analysis of laminar, fully developed mixed convection in horizontal internally finned tubes has been presented covering a wide range of geometric parameters. The results show that tube geometry (H and M) has a strong influence on the pattern and intensity of the secondary flow currents, which is in turn reflected on the axial velocity and temperature distributions, wall heat flux, friction factor and Nusselt number. In general, an increase in either H or M suppresses secondary flow in the bays formed by the fins at any given Grashof number. Consequently, the departure of $f_{fd}Re$ and Nu_{fd} from their respective forced convection value begins at higher Grashof numbers as H or M increases. This trend in the overall performance is consistent with previously reported experimental data and is now justified by the detailed fluid flow and heat transfer characteristics presented in this investigation.

7.2 RECOMMENDATIONS

7.2.1 Model I

For the case of this model, the free convection effect could be added to study the effect of secondary flow on heat transfer and pressure drop and on the thermal entrance lengths. We know from experimental results that free convection plays a small role in the early stages of the thermal entrance region; nonetheless, the effect of free convection on the thermal entrance length should be studied. Another factor that will arise in the mathematical model once free convection is considered is the appearance of Prandtl number, which could then be studied to investigate its effect. A tremendous amount of work and computer time are required and it is only through the use of superfast computers that this type of work might be accomplished.

7.2.2 Model II

This work could be extended to other geometries. For example, if the fin height H is set equal to 1.0, the results will be for flow in circular sectors where M will specify the angle of the sector. Another improvement could be made to this work by assuming a finite fin thickness which in turn increases the wetted area and decreases the flow area and thus may have an impact on the results of $f_x Re$ and L_H in the case of large number of long fins. What is more important is the generation of experimental results of f_x, K and K_∞ for internally finned tubes.

7.2.3 Model III

For the case of this model, there are few possible steps that could be taken further. The tremendous amount of computer time needed for producing data using this model is a major obstacle, however, with the aid of a superfast computer the following steps could be pursued further:

1) The effect of finite fin conductance, rather than 100% efficiency, and of fin thickness could be added to investigate these effects on the heat transfer and pressure drop, especially for the case of large number of long fins.

2) Different values of Prandtl numbers could be explored to study the effect of different types of fluids on the heat transfer and pressure drop in internally finned tubes. This should be coupled with the generation of corresponding experimental data.

3) Some of the fluid properties that are known to be strongly temperature dependent (like the fluid viscosity) could be modeled as variables in order to investigate such effects on the results especially at high axial temperature gradients (i.e., high heat input rates).

4) The present results correspond to hot walls and cold fluids. The analysis could be repeated for the case of cooling (i.e., hot fluids and cold walls) in order to cover this type of applications.

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APPENDIX A

Numerical Values of $Nu_{x,H1}$ and $Nu_{x,T}$ for all Geometries

(H1) BOUNDARY CONDITION

The Smooth Tube Geometry

$f_{fd,0}Re = 15.934$ $Nu_{fd,0} = 4.3364$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.1764D 03	0.5940D-02	0.8832D 01	0.4490D-01	0.5071D 01
0.2000D-05	0.1358D 03	0.6332D-02	0.8654D 01	0.4590D-01	0.5048D 01
0.3000D-05	0.1163D 03	0.6744D-02	0.8484D 01	0.4690D-01	0.5026D 01
0.4000D-05	0.1045D 03	0.7176D-02	0.8320D 01	0.4790D-01	0.5006D 01
0.5000D-05	0.9633D 02	0.7630D-02	0.8162D 01	0.4890D-01	0.4986D 01
0.6000D-05	0.9021D 02	0.8106D-02	0.8010D 01	0.4990D-01	0.4966D 01
0.7000D-05	0.8535D 02	0.8607D-02	0.7863D 01	0.5090D-01	0.4948D 01
0.8000D-05	0.8133D 02	0.9132D-02	0.7722D 01	0.5190D-01	0.4930D 01
0.9000D-05	0.7794D 02	0.9684D-02	0.7585D 01	0.5290D-01	0.4912D 01
0.1000D-04	0.7496D 02	0.1026D-01	0.7453D 01	0.5390D-01	0.4896D 01
0.2000D-04	0.5871D 02	0.1087D-01	0.7325D 01	0.5490D-01	0.4880D 01
0.3000D-04	0.5022D 02	0.1151D-01	0.7202D 01	0.5590D-01	0.4864D 01
0.4000D-04	0.4501D 02	0.1218D-01	0.7082D 01	0.5690D-01	0.4849D 01
0.5000D-04	0.4146D 02	0.1288D-01	0.6966D 01	0.5790D-01	0.4834D 01
0.6000D-04	0.3891D 02	0.1362D-01	0.6854D 01	0.5890D-01	0.4820D 01
0.7000D-04	0.3698D 02	0.1440D-01	0.6746D 01	0.5990D-01	0.4806D 01
0.8000D-04	0.3545D 02	0.1521D-01	0.6640D 01	0.6090D-01	0.4793D 01
0.9000D-04	0.3422D 02	0.1607D-01	0.6538D 01	0.6190D-01	0.4780D 01
0.1000D-03	0.3317D 02	0.1697D-01	0.6440D 01	0.6290D-01	0.4768D 01
0.2000D-03	0.2762D 02	0.1791D-01	0.6344D 01	0.6390D-01	0.4756D 01
0.3050D-03	0.2427D 02	0.1890D-01	0.6251D 01	0.6490D-01	0.4744D 01
0.4152D-03	0.2191D 02	0.1990D-01	0.6164D 01	0.6590D-01	0.4733D 01
0.5310D-03	0.2013D 02	0.2090D-01	0.6084D 01	0.6690D-01	0.4722D 01
0.6526D-03	0.1872D 02	0.2190D-01	0.6009D 01	0.6790D-01	0.4712D 01
0.7802D-03	0.1757D 02	0.2290D-01	0.5938D 01	0.6890D-01	0.4702D 01
0.9142D-03	0.1661D 02	0.2390D-01	0.5873D 01	0.6990D-01	0.4692D 01
0.1055D-02	0.1579D 02	0.2490D-01	0.5811D 01	0.7090D-01	0.4682D 01
0.1203D-02	0.1508D 02	0.2590D-01	0.5753D 01	0.7190D-01	0.4681D 01
0.1358D-02	0.1446D 02	0.2690D-01	0.5699D 01	0.7290D-01	0.4658D 01
0.1521D-02	0.1390D 02	0.2790D-01	0.5647D 01	0.7390D-01	0.4658D 01
0.1692D-02	0.1340D 02	0.2890D-01	0.5599D 01	0.7490D-01	0.4643D 01
0.1871D-02	0.1294D 02	0.2990D-01	0.5552D 01	0.7590D-01	0.4643D 01
0.2060D-02	0.1253D 02	0.3090D-01	0.5509D 01	0.7690D-01	0.4626D 01
0.2258D-02	0.1214D 02	0.3190D-01	0.5467D 01	0.7790D-01	0.4625D 01
0.2466D-02	0.1179D 02	0.3290D-01	0.5428D 01	0.7890D-01	0.4611D 01
0.2684D-02	0.1146D 02	0.3390D-01	0.5390D 01	0.7990D-01	0.4611D 01
0.2913D-02	0.1115D 02	0.3490D-01	0.5354D 01	0.8090D-01	0.4596D 01
0.3154D-02	0.1086D 02	0.3590D-01	0.5320D 01	0.8190D-01	0.4596D 01
0.3407D-02	0.1058D 02	0.3690D-01	0.5287D 01	0.8290D-01	0.4583D 01
0.3672D-02	0.1032D 02	0.3790D-01	0.5256D 01	0.8390D-01	0.4583D 01
0.3951D-02	0.1008D 02	0.3890D-01	0.5226D 01	0.8490D-01	0.4570D 01
0.4243D-02	0.9844D 01	0.3990D-01	0.5197D 01	0.8590D-01	0.4570D 01
0.4550D-02	0.9623D 01	0.4090D-01	0.5170D 01	0.8690D-01	0.4558D 01
0.4873D-02	0.9411D 01	0.4190D-01	0.5143D 01	0.8790D-01	0.4558D 01
0.5211D-02	0.9210D 01	0.4290D-01	0.5118D 01	0.8831D-01	0.4553D 01
0.5567D-02	0.9017D 01	0.4390D-01	0.5094D 01		

(H1) BOUNDARY CONDITION

$H = 0.2 \qquad M = 4$

$f_{fd,0}Re = 18.574 \qquad Nu_{fd,0} = 4.5448$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.2068D 03	0.6332D-02	0.9333D 01	0.4690D-01	0.5304D 01
0.2000D-05	0.2586D 03	0.6744D-02	0.9142D 01	0.4790D-01	0.5281D 01
0.3000D-05	0.1358D 03	0.7176D-02	0.8958D 01	0.4890D-01	0.5259D 01
0.4000D-05	0.1221D 03	0.7630D-02	0.8782D 01	0.4990D-01	0.5238D 01
0.5000D-05	0.1126D 03	0.8106D-02	0.8612D 01	0.5090D-01	0.5217D 01
0.6000D-05	0.1055D 03	0.8607D-02	0.8448D 01	0.5190D-01	0.5198D 01
0.7000D-05	0.9987D 02	0.9132D-02	0.8290D 01	0.5290D-01	0.5179D 01
0.8000D-05	0.9526D 02	0.9684D-02	0.8137D 01	0.5390D-01	0.5160D 01
0.9000D-05	0.9141D 02	0.1026D-01	0.7990D 01	0.5490D-01	0.5142D 01
0.1000D-04	0.8805D 02	0.1087D-01	0.7848D 01	0.5590D-01	0.5125D 01
0.2000D-04	0.7035D 02	0.1151D-01	0.7710D 01	0.5690D-01	0.5109D 01
0.3000D-04	0.6100D 02	0.1218D-01	0.7577D 01	0.5790D-01	0.5093D 01
0.4000D-04	0.5505D 02	0.1288D-01	0.7449D 01	0.5890D-01	0.5077D 01
0.5000D-04	0.5084D 02	0.1362D-01	0.7324D 01	0.5990D-01	0.5062D 01
0.6000D-04	0.4766D 02	0.1440D-01	0.7203D 01	0.6090D-01	0.5048D 01
0.7000D-04	0.4512D 02	0.1521D-01	0.7087D 01	0.6190D-01	0.5034D 01
0.8000D-04	0.4303D 02	0.1607D-01	0.6974D 01	0.6290D-01	0.5020D 01
0.9000D-04	0.4125D 02	0.1697D-01	0.6864D 01	0.6390D-01	0.5007D 01
0.1000D-03	0.3973D 02	0.1791D-01	0.6758D 01	0.6490D-01	0.4994D 01
0.2000D-03	0.3146D 02	0.1890D-01	0.6655D 01	0.6590D-01	0.4982D 01
0.3050D-03	0.2698D 02	0.1990D-01	0.6559D 01	0.6690D-01	0.4970D 01
0.4152D-03	0.2412D 02	0.2090D-01	0.6470D 01	0.6790D-01	0.4958D 01
0.5310D-03	0.2208D 02	0.2190D-01	0.6387D 01	0.6890D-01	0.4947D 01
0.6526D-03	0.2053D 02	0.2290D-01	0.6309D 01	0.6990D-01	0.4936D 01
0.7802D-03	0.1929D 02	0.2390D-01	0.6237D 01	0.7090D-01	0.4925D 01
0.9142D-03	0.1825D 02	0.2490D-01	0.6169D 01	0.7190D-01	0.4915D 01
0.1055D-02	0.1736D 02	0.2590D-01	0.6105D 01	0.7290D-01	0.4905D 01
0.1203D-02	0.1659D 02	0.2690D-01	0.6044D 01	0.7390D-01	0.4904D 01
0.1358D-02	0.1589D 02	0.2790D-01	0.5988D 01	0.7490D-01	0.4880D 01
0.1521D-02	0.1528D 02	0.2890D-01	0.5934D 01	0.7590D-01	0.4880D 01
0.1692D-02	0.1471D 02	0.2990D-01	0.5883D 01	0.7690D-01	0.4865D 01
0.1871D-02	0.1419D 02	0.3090D-01	0.5835D 01	0.7790D-01	0.4865D 01
0.2060D-02	0.1372D 02	0.3190D-01	0.5789D 01	0.7890D-01	0.4847D 01
0.2258D-02	0.1328D 02	0.3290D-01	0.5745D 01	0.7990D-01	0.4847D 01
0.2466D-02	0.1288D 02	0.3390D-01	0.5704D 01	0.8090D-01	0.4832D 01
0.2684D-02	0.1250D 02	0.3490D-01	0.5664D 01	0.8190D-01	0.4832D 01
0.2913D-02	0.1215D 02	0.3590D-01	0.5627D 01	0.8290D-01	0.4816D 01
0.3154D-02	0.1182D 02	0.3690D-01	0.5591D 01	0.8390D-01	0.4816D 01
0.3407D-02	0.1151D 02	0.3790D-01	0.5556D 01	0.8490D-01	0.4803D 01
0.3672D-02	0.1121D 02	0.3890D-01	0.5523D 01	0.8590D-01	0.4803D 01
0.3951D-02	0.1094D 02	0.3990D-01	0.5492D 01	0.8690D-01	0.4789D 01
0.4243D-02	0.1067D 02	0.4090D-01	0.5462D 01	0.8790D-01	0.4789D 01
0.4550D-02	0.1042D 02	0.4190D-01	0.5433D 01	0.8890D-01	0.4777D 01
0.4873D-02	0.1018D 02	0.4290D-01	0.5405D 01	0.8990D-01	0.4777D 01
0.5211D-02	0.9957D 01	0.4390D-01	0.5378D 01	0.9029D-01	0.4772D 01
0.5567D-02	0.9740D 01	0.4490D-01	0.5352D 01		
0.5940D-02	0.9532D 01	0.4590D-01	0.5328D 01		

(H1) BOUNDARY CONDITION

$$H = 0.4 \qquad M = 4$$

$$f_{fd,0}Re = 27.673 \qquad Nu_{fd,0} = 5.8815$$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.2644D 03	0.6332D-02	0.1217D 02	0.4690D-01	0.6891D 01
0.2000D-05	0.2029D 03	0.6744D-02	0.1192D 02	0.4790D-01	0.6861D 01
0.3000D-05	0.1737D 03	0.7176D-02	0.1168D 02	0.4890D-01	0.6832D 01
0.4000D-05	0.1561D 03	0.7630D-02	0.1145D 02	0.4990D-01	0.6804D 01
0.5000D-05	0.1438D 03	0.8106D-02	0.1123D 02	0.5090D-01	0.6777D 01
0.6000D-05	0.1347D 03	0.8607D-02	0.1101D 02	0.5190D-01	0.6751D 01
0.7000D-05	0.1274D 03	0.9132D-02	0.1081D 02	0.5290D-01	0.6726D 01
0.8000D-05	0.1214D 03	0.9684D-02	0.1061D 02	0.5390D-01	0.6702D 01
0.9000D-05	0.1165D 03	0.1026D-01	0.1041D 02	0.5490D-01	0.6678D 01
0.1000D-04	0.1121D 03	0.1087D-01	0.1023D 02	0.5590D-01	0.6656D 01
0.2000D-04	0.8931D 02	0.1151D-01	0.1005D 02	0.5690D-01	0.6634D 01
0.3000D-04	0.7744D 02	0.1218D-01	0.9870D 01	0.5790D-01	0.6613D 01
0.4000D-04	0.7000D 02	0.1288D-01	0.9701D 01	0.5890D-01	0.6592D 01
0.5000D-04	0.6476D 02	0.1362D-01	0.9537D 01	0.5990D-01	0.6573D 01
0.6000D-04	0.6083D 02	0.1440D-01	0.9379D 01	0.6090D-01	0.6553D 01
0.7000D-04	0.5772D 02	0.1521D-01	0.9226D 01	0.6190D-01	0.6535D 01
0.8000D-04	0.5515D 02	0.1607D-01	0.9077D 01	0.6290D-01	0.6517D 01
0.9000D-04	0.5300D 02	0.1697D-01	0.8933D 01	0.6390D-01	0.6499D 01
0.1000D-03	0.5111D 02	0.1791D-01	0.8794D 01	0.6490D-01	0.6483D 01
0.2000D-03	0.4079D 02	0.1890D-01	0.8659D 01	0.6590D-01	0.6467D 01
0.3050D-03	0.3505D 02	0.1990D-01	0.8533D 01	0.6690D-01	0.6451D 01
0.4152D-03	0.3131D 02	0.2090D-01	0.8416D 01	0.6790D-01	0.6435D 01
0.5310D-03	0.2863D 02	0.2190D-01	0.8308D 01	0.6890D-01	0.6420D 01
0.6526D-03	0.2659D 02	0.2290D-01	0.8206D 01	0.6990D-01	0.6406D 01
0.7802D-03	0.2496D 02	0.2390D-01	0.8111D 01	0.7090D-01	0.6392D 01
0.9142D-03	0.2361D 02	0.2490D-01	0.8022D 01	0.7190D-01	0.6378D 01
0.1055D-02	0.2246D 02	0.2590D-01	0.7939D 01	0.7290D-01	0.6365D 01
0.1203D-02	0.2146D 02	0.2690D-01	0.7860D 01	0.7390D-01	0.6351D 01
0.1358D-02	0.2057D 02	0.2790D-01	0.7786D 01	0.7490D-01	0.6351D 01
0.1521D-02	0.1979D 02	0.2890D-01	0.7715D 01	0.7590D-01	0.6320D 01
0.1692D-02	0.1906D 02	0.2990D-01	0.7649D 01	0.7690D-01	0.6319D 01
0.1871D-02	0.1841D 02	0.3090D-01	0.7586D 01	0.7790D-01	0.6301D 01
0.2060D-02	0.1781D 02	0.3190D-01	0.7526D 01	0.7890D-01	0.6300D 01
0.2258D-02	0.1726D 02	0.3290D-01	0.7469D 01	0.7990D-01	0.6276D 01
0.2466D-02	0.1674D 02	0.3390D-01	0.7415D 01	0.8090D-01	0.6276D 01
0.2684D-02	0.1626D 02	0.3490D-01	0.7363D 01	0.8190D-01	0.6258D 01
0.2913D-02	0.1581D 02	0.3590D-01	0.7314D 01	0.8290D-01	0.6258D 01
0.3154D-02	0.1539D 02	0.3690D-01	0.7267D 01	0.8390D-01	0.6237D 01
0.3407D-02	0.1499D 02	0.3790D-01	0.7222D 01	0.8490D-01	0.6237D 01
0.3672D-02	0.1461D 02	0.3890D-01	0.7179D 01	0.8590D-01	0.6220D 01
0.3951D-02	0.1425D 02	0.3990D-01	0.7137D 01	0.8690D-01	0.6219D 01
0.4243D-02	0.1391D 02	0.4090D-01	0.7098D 01	0.8790D-01	0.6202D 01
0.4550D-02	0.1359D 02	0.4190D-01	0.7060D 01	0.8890D-01	0.6202D 01
0.4873D-02	0.1328D 02	0.4290D-01	0.7023D 01	0.8990D-01	0.6186D 01
0.5211D-02	0.1299D 02	0.4390D-01	0.6989D 01	0.9090D-01	0.6186D 01
0.5567D-02	0.1270D 02	0.4490D-01	0.6955D 01	0.9152D-01	0.6176D 01
0.5940D-02	0.1243D 02	0.4590D-01	0.6922D 01		

(H1) BOUNDARY CONDITION

$H = 0.6 \qquad M = 4$

$f_{fd,0}Re = 47.639 \qquad Nu_{fd,0} = 11.172$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.3531D 03	0.2913D-02	0.2252D 02	0.2490D-01	0.1305D 02
0.2000D-05	0.2724D 03	0.3154D-02	0.2197D 02	0.2590D-01	0.1296D 02
0.3000D-05	0.2335D 03	0.3407D-02	0.2146D 02	0.2690D-01	0.1288D 02
0.4000D-05	0.2097D 03	0.3672D-02	0.2097D 02	0.2790D-01	0.1281D 02
0.5000D-05	0.1931D 03	0.3951D-02	0.2052D 02	0.2890D-01	0.1274D 02
0.6000D-05	0.1806D 03	0.4243D-02	0.2008D 02	0.2990D-01	0.1267D 02
0.7000D-05	0.1707D 03	0.4550D-02	0.1967D 02	0.3090D-01	0.1261D 02
0.8000D-05	0.1626D 03	0.4873D-02	0.1928D 02	0.3190D-01	0.1255D 02
0.9000D-05	0.1559D 03	0.5211D-02	0.1891D 02	0.3290D-01	0.1250D 02
0.1000D-04	0.1500D 03	0.5567D-02	0.1855D 02	0.3390D-01	0.1245D 02
0.2000D-04	0.1196D 03	0.5940D-02	0.1821D 02	0.3490D-01	0.1240D 02
0.3000D-04	0.1039D 03	0.6332D-02	0.1789D 02	0.3590D-01	0.1235D 02
0.4000D-04	0.9417D 02	0.6744D-02	0.1757D 02	0.3690D-01	0.1231D 02
0.5000D-04	0.8733D 02	0.7176D-02	0.1728D 02	0.3790D-01	0.1227D 02
0.6000D-04	0.8220D 02	0.7630D-02	0.1699D 02	0.3890D-01	0.1223D 02
0.7000D-04	0.7814D 02	0.8106D-02	0.1672D 02	0.3990D-01	0.1219D 02
0.8000D-04	0.7481D 02	0.8607D-02	0.1646D 02	0.4090D-01	0.1215D 02
0.9000D-04	0.7201D 02	0.9132D-02	0.1621D 02	0.4190D-01	0.1212D 02
0.1000D-03	0.6955D 02	0.9684D-02	0.1596D 02	0.4290D-01	0.1208D 02
0.2000D-03	0.5602D 02	0.1026D-01	0.1573D 02	0.4390D-01	0.1205D 02
0.3050D-03	0.4832D 02	0.1087D-01	0.1551D 02	0.4490D-01	0.1202D 02
0.4152D-03	0.4326D 02	0.1151D-01	0.1530D 02	0.4590D-01	0.1199D 02
0.5310D-03	0.3960D 02	0.1218D-01	0.1509D 02	0.4690D-01	0.1196D 02
0.6526D-03	0.3682D 02	0.1288D-01	0.1489D 02	0.4790D-01	0.1194D 02
0.7802D-03	0.3460D 02	0.1362D-01	0.1470D 02	0.4890D-01	0.1191D 02
0.9142D-03	0.3278D 02	0.1440D-01	0.1452D 02	0.4990D-01	0.1189D 02
0.1055D-02	0.3123D 02	0.1521D-01	0.1435D 02	0.5090D-01	0.1188D 02
0.1203D-02	0.2990D 02	0.1607D-01	0.1418D 02	0.5190D-01	0.1183D 02
0.1358D-02	0.2874D 02	0.1697D-01	0.1402D 02	0.5290D-01	0.1183D 02
0.1521D-02	0.2769D 02	0.1791D-01	0.1387D 02	0.5390D-01	0.1179D 02
0.1692D-02	0.2675D 02	0.1890D-01	0.1372D 02	0.5490D-01	0.1179D 02
0.1871D-02	0.2589D 02	0.1990D-01	0.1358D 02	0.5590D-01	0.1175D 02
0.2060D-02	0.2511D 02	0.2090D-01	0.1346D 02	0.5690D-01	0.1175D 02
0.2258D-02	0.2439D 02	0.2190D-01	0.1334D 02	0.5738D-01	0.1173D 02
0.2466D-02	0.2372D 02	0.2290D-01	0.1324D 02		
0.2684D-02	0.2310D 02	0.2390D-01	0.1314D 02		

(H1) BOUNDARY CONDITION

$$H = 0.8 \qquad M = 4$$

$$f_{fd,0}Re = 71.169 \qquad Nu_{fd,0} = 19.399$$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.4453D 03	0.7802D-03	0.4545D 02	0.6744D-02	0.2474D 02
0.2000D-05	0.3451D 03	0.9142D-03	0.4313D 02	0.7176D-02	0.2441D 02
0.3000D-05	0.2962D 03	0.1055D-02	0.4118D 02	0.7630D-02	0.2409D 02
0.4000D-05	0.2661D 03	0.1203D-02	0.3952D 02	0.8106D-02	0.2379D 02
0.5000D-05	0.2451D 03	0.1358D-02	0.3805D 02	0.8607D-02	0.2350D 02
0.6000D-05	0.2294D 03	0.1521D-02	0.3676D 02	0.9132D-02	0.2323D 02
0.7000D-05	0.2171D 03	0.1692D-02	0.3560D 02	0.9684D-02	0.2297D 02
0.8000D-05	0.2071D 03	0.1871D-02	0.3455D 02	0.1026D-01	0.2272D 02
0.9000D-05	0.1988D 03	0.2060D-02	0.3360D 02	0.1087D-01	0.2248D 02
0.1000D-04	0.1915D 03	0.2258D-02	0.3273D 02	0.1151D-01	0.2225D 02
0.2000D-04	0.1539D 03	0.2466D-02	0.3192D 02	0.1218D-01	0.2204D 02
0.3000D-04	0.1341D 03	0.2684D-02	0.3117D 02	0.1288D-01	0.2184D 02
0.4000D-04	0.1215D 03	0.2913D-02	0.3048D 02	0.1362D-01	0.2164D 02
0.5000D-04	0.1125D 03	0.3154D-02	0.2983D 02	0.1440D-01	0.2146D 02
0.6000D-04	0.1058D 03	0.3407D-02	0.2922D 02	0.1521D-01	0.2129D 02
0.7000D-04	0.1005D 03	0.3672D-02	0.2865D 02	0.1607D-01	0.2113D 02
0.8000D-04	0.9614D 02	0.3951D-02	0.2812D 02	0.1697D-01	0.2097D 02
0.9000D-04	0.9251D 02	0.4243D-02	0.2761D 02	0.1791D-01	0.2083D 02
0.1000D-03	0.8933D 02	0.4550D-02	0.2713D 02	0.1890D-01	0.2069D 02
0.2000D-03	0.7239D 02	0.4873D-02	0.2668D 02	0.1990D-01	0.2057D 02
0.3050D-03	0.6279D 02	0.5211D-02	0.2625D 02	0.2090D-01	0.2046D 02
0.4152D-03	0.5643D 02	0.5567D-02	0.2584D 02	0.2180D-01	0.2037D 02
0.5310D-03	0.5181D 02	0.5940D-02	0.2546D 02		
0.6526D-03	0.4827D 02	0.6332D-02	0.2509D 02		

(H1) BOUNDARY CONDITION

$$H = 0.2 \qquad M = 8$$

$$f_{fd,0}Re = 21.497 \qquad Nu_{fd,0} = 4.6923$$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.2394D 03	0.6332D-02	0.1008D 02	0.4690D-01	0.5530D 01
0.2000D-05	0.1808D 03	0.6744D-02	0.9867D 01	0.4790D-01	0.5505D 01
0.3000D-05	0.1543D 03	0.7176D-02	0.9658D 01	0.4890D-01	0.5481D 01
0.4000D-05	0.1386D 03	0.7630D-02	0.9458D 01	0.4990D-01	0.5457D 01
0.5000D-05	0.1277D 03	0.8106D-02	0.9265D 01	0.5090D-01	0.5434D 01
0.6000D-05	0.1197D 03	0.8607D-02	0.9079D 01	0.5190D-01	0.5412D 01
0.7000D-05	0.1134D 03	0.9132D-02	0.8899D 01	0.5290D-01	0.5391D 01
0.8000D-05	0.1083D 03	0.9684D-02	0.8726D 01	0.5390D-01	0.5371D 01
0.9000D-05	0.1040D 03	0.1026D-01	0.8559D 01	0.5490D-01	0.5352D 01
0.1000D-04	0.1003D 03	0.1087D-01	0.8398D 01	0.5590D-01	0.5332D 01
0.2000D-04	0.8072D 02	0.1151D-01	0.8242D 01	0.5690D-01	0.5313D 01
0.3000D-04	0.7018D 02	0.1218D-01	0.8091D 01	0.5790D-01	0.5296D 01
0.4000D-04	0.6337D 02	0.1288D-01	0.7945D 01	0.5890D-01	0.5279D 01
0.5000D-04	0.5847D 02	0.1362D-01	0.7803D 01	0.5990D-01	0.5263D 01
0.6000D-04	0.5472D 02	0.1440D-01	0.7667D 01	0.6090D-01	0.5247D 01
0.7000D-04	0.5172D 02	0.1521D-01	0.7534D 01	0.6190D-01	0.5231D 01
0.8000D-04	0.4923D 02	0.1607D-01	0.7406D 01	0.6290D-01	0.5216D 01
0.9000D-04	0.4712D 02	0.1697D-01	0.7282D 01	0.6390D-01	0.5201D 01
0.1000D-03	0.4531D 02	0.1791D-01	0.7162D 01	0.6490D-01	0.5187D 01
0.2000D-03	0.3561D 02	0.1890D-01	0.7046D 01	0.6590D-01	0.5174D 01
0.3050D-03	0.3042D 02	0.1990D-01	0.6937D 01	0.6690D-01	0.5161D 01
0.4152D-03	0.2711D 02	0.2090D-01	0.6837D 01	0.6790D-01	0.5147D 01
0.5310D-03	0.2475D 02	0.2190D-01	0.6743D 01	0.6890D-01	0.5136D 01
0.6526D-03	0.2295D 02	0.2290D-01	0.6656D 01	0.6990D-01	0.5123D 01
0.7802D-03	0.2150D 02	0.2390D-01	0.6574D 01	0.7090D-01	0.5112D 01
0.9142D-03	0.2029D 02	0.2490D-01	0.6497D 01	0.7190D-01	0.5100D 01
0.1055D-02	0.1926D 02	0.2590D-01	0.6426D 01	0.7290D-01	0.5089D 01
0.1203D-02	0.1836D 02	0.2690D-01	0.6358D 01	0.7390D-01	0.5078D 01
0.1358D-02	0.1756D 02	0.2790D-01	0.6294D 01	0.7490D-01	0.5068D 01
0.1521D-02	0.1685D 02	0.2890D-01	0.6234D 01	0.7590D-01	0.5058D 01
0.1692D-02	0.1620D 02	0.2990D-01	0.6177D 01	0.7690D-01	0.5048D 01
0.1871D-02	0.1561D 02	0.3090D-01	0.6123D 01	0.7790D-01	0.5047D 01
0.2060D-02	0.1507D 02	0.3190D-01	0.6071D 01	0.7890D-01	0.5024D 01
0.2258D-02	0.1457D 02	0.3290D-01	0.6023D 01	0.7990D-01	0.5024D 01
0.2466D-02	0.1411D 02	0.3390D-01	0.5976D 01	0.8090D-01	0.5010D 01
0.2684D-02	0.1368D 02	0.3490D-01	0.5932D 01	0.8190D-01	0.5010D 01
0.2913D-02	0.1328D 02	0.3590D-01	0.5890D 01	0.8290D-01	0.4990D 01
0.3154D-02	0.1290D 02	0.3690D-01	0.5850D 01	0.8390D-01	0.4990D 01
0.3407D-02	0.1255D 02	0.3790D-01	0.5811D 01	0.8490D-01	0.4978D 01
0.3672D-02	0.1222D 02	0.3890D-01	0.5775D 01	0.8590D-01	0.4977D 01
0.3951D-02	0.1190D 02	0.3990D-01	0.5739D 01	0.8690D-01	0.4960D 01
0.4243D-02	0.1160D 02	0.4090D-01	0.5706D 01	0.8790D-01	0.4960D 01
0.4550D-02	0.1132D 02	0.4190D-01	0.5673D 01	0.8890D-01	0.4948D 01
0.4873D-02	0.1105D 02	0.4290D-01	0.5642D 01	0.8990D-01	0.4948D 01
0.5211D-02	0.1079D 02	0.4390D-01	0.5613D 01	0.9090D-01	0.4935D 01
0.5567D-02	0.1055D 02	0.4490D-01	0.5584D 01	0.9190D-01	0.4935D 01
0.5940D-02	0.1031D 02	0.4590D-01	0.5557D 01	0.9250D-01	0.4927D 01

(H1) BOUNDARY CONDITION

$H = 0.4 \qquad M = 8$

$f_{fd,0} Re = 44.106 \qquad Nu_{fd,0} = 6.7694$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.3686D 03	0.8106D-02	0.1523D 02	0.5490D-01	0.8059D 01
0.2000D-05	0.2773D 03	0.8607D-02	0.1492D 02	0.5590D-01	0.8023D 01
0.3000D-05	0.2360D 03	0.9132D-02	0.1461D 02	0.5690D-01	0.7987D 01
0.4000D-05	0.2115D 03	0.9684D-02	0.1431D 02	0.5790D-01	0.7953D 01
0.5000D-05	0.1949D 03	0.1026D-01	0.1402D 02	0.5890D-01	0.7920D 01
0.6000D-05	0.1827D 03	0.1087D-01	0.1374D 02	0.5990D-01	0.7887D 01
0.7000D-05	0.1733D 03	0.1151D-01	0.1347D 02	0.6090D-01	0.7856D 01
0.8000D-05	0.1657D 03	0.1218D-01	0.1320D 02	0.6190D-01	0.7826D 01
0.9000D-05	0.1595D 03	0.1288D-01	0.1294D 02	0.6290D-01	0.7797D 01
0.1000D-04	0.1541D 03	0.1362D-01	0.1269D 02	0.6390D-01	0.7769D 01
0.2000D-04	0.1254D 03	0.1440D-01	0.1244D 02	0.6490D-01	0.7742D 01
0.3000D-04	0.1096D 03	0.1521D-01	0.1220D 02	0.6590D-01	0.7715D 01
0.4000D-04	0.9917D 02	0.1607D-01	0.1197D 02	0.6690D-01	0.7689D 01
0.5000D-04	0.9162D 02	0.1697D-01	0.1174D 02	0.6790D-01	0.7665D 01
0.6000D-04	0.8583D 02	0.1791D-01	0.1152D 02	0.6890D-01	0.7641D 01
0.7000D-04	0.8120D 02	0.1890D-01	0.1130D 02	0.6990D-01	0.7617D 01
0.8000D-04	0.7738D 02	0.1990D-01	0.1110D 02	0.7090D-01	0.7595D 01
0.9000D-04	0.7418D 02	0.2090D-01	0.1091D 02	0.7190D-01	0.7572D 01
0.1000D-03	0.7137D 02	0.2190D-01	0.1073D 02	0.7290D-01	0.7551D 01
0.2000D-03	0.5654D 02	0.2290D-01	0.1057D 02	0.7390D-01	0.7530D 01
0.3050D-03	0.4849D 02	0.2390D-01	0.1041D 02	0.7490D-01	0.7510D 01
0.4152D-03	0.4329D 02	0.2490D-01	0.1027D 02	0.7590D-01	0.7491D 01
0.5310D-03	0.3956D 02	0.2590D-01	0.1013D 02	0.7690D-01	0.7473D 01
0.6526D-03	0.3671D 02	0.2690D-01	0.1000D 02	0.7790D-01	0.7454D 01
0.7802D-03	0.3443D 02	0.2790D-01	0.9879D 01	0.7890D-01	0.7436D 01
0.9142D-03	0.3254D 02	0.2890D-01	0.9763D 01	0.7990D-01	0.7419D 01
0.1055D-02	0.3093D 02	0.2990D-01	0.9654D 01	0.8090D-01	0.7402D 01
0.1203D-02	0.2954D 02	0.3090D-01	0.9550D 01	0.8190D-01	0.7385D 01
0.1358D-02	0.2830D 02	0.3190D-01	0.9451D 01	0.8290D-01	0.7370D 01
0.1521D-02	0.2721D 02	0.3290D-01	0.9357D 01	0.8390D-01	0.7354D 01
0.1692D-02	0.2621D 02	0.3390D-01	0.9268D 01	0.8490D-01	0.7339D 01
0.1871D-02	0.2530D 02	0.3490D-01	0.9183D 01	0.8590D-01	0.7337D 01
0.2060D-02	0.2447D 02	0.3590D-01	0.9102D 01	0.8690D-01	0.7303D 01
0.2258D-02	0.2370D 02	0.3690D-01	0.9024D 01	0.8790D-01	0.7302D 01
0.2466D-02	0.2298D 02	0.3790D-01	0.8950D 01	0.8890D-01	0.7277D 01
0.2684D-02	0.2232D 02	0.3890D-01	0.8878D 01	0.8990D-01	0.7276D 01
0.2913D-02	0.2169D 02	0.3990D-01	0.8811D 01	0.9090D-01	0.7252D 01
0.3154D-02	0.2110D 02	0.4090D-01	0.8746D 01	0.9190D-01	0.7251D 01
0.3407D-02	0.2055D 02	0.4190D-01	0.8683D 01	0.9290D-01	0.7227D 01
0.3672D-02	0.2002D 02	0.4290D-01	0.8623D 01	0.9390D-01	0.7227D 01
0.3951D-02	0.1953D 02	0.4390D-01	0.8566D 01	0.9490D-01	0.7205D 01
0.4243D-02	0.1905D 02	0.4490D-01	0.8510D 01	0.9590D-01	0.7204D 01
0.4550D-02	0.1860D 02	0.4590D-01	0.8457D 01	0.9690D-01	0.7184D 01
0.4873D-02	0.1816D 02	0.4690D-01	0.8406D 01	0.9790D-01	0.7183D 01
0.5211D-02	0.1775D 02	0.4790D-01	0.8357D 01	0.9890D-01	0.7163D 01
0.5567D-02	0.1735D 02	0.4890D-01	0.8310D 01	0.9990D-01	0.7162D 01
0.5940D-02	0.1697D 02	0.4990D-01	0.8265D 01	0.1009D 00	0.7144D 01
0.6332D-02	0.1660D 02	0.5090D-01	0.8220D 01	0.1019D 00	0.7143D 01
0.6744D-02	0.1624D 02	0.5190D-01	0.8178D 01	0.1029D 00	0.7125D 01
0.7176D-02	0.1589D 02	0.5290D-01	0.8137D 01	0.1039D 00	0.7125D 01
0.7630D-02	0.1556D 02	0.5390D-01	0.8097D 01	0.1049D 00	0.7108D 01

(H1) BOUNDARY CONDITION

$H = 0.6 \qquad M = 8$

$f_{fd,0} Re = 103.94 \qquad Nu_{fd,0} = 19.367$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.5812D 03	0.5211D-02	0.3479D 02	0.4090D-01	0.2278D 02
0.2000D-05	0.4411D 03	0.5567D-02	0.3429D 02	0.4190D-01	0.2267D 02
0.3000D-05	0.3766D 03	0.5940D-02	0.3382D 02	0.4290D-01	0.2257D 02
0.4000D-05	0.3375D 03	0.6332D-02	0.3336D 02	0.4390D-01	0.2247D 02
0.5000D-05	0.3107D 03	0.6744D-02	0.3293D 02	0.4490D-01	0.2237D 02
0.6000D-05	0.2911D 03	0.7176D-02	0.3251D 02	0.4590D-01	0.2227D 02
0.7000D-05	0.2760D 03	0.7630D-02	0.3211D 02	0.4690D-01	0.2218D 02
0.8000D-05	0.2639D 03	0.8106D-02	0.3172D 02	0.4790D-01	0.2209D 02
0.9000D-05	0.2540D 03	0.8607D-02	0.3135D 02	0.4890D-01	0.2201D 02
0.1000D-04	0.2454D 03	0.9132D-02	0.3098D 02	0.4990D-01	0.2193D 02
0.2000D-04	0.2011D 03	0.9684D-02	0.3063D 02	0.5090D-01	0.2185D 02
0.3000D-04	0.1766D 03	0.1026D-01	0.3028D 02	0.5190D-01	0.2177D 02
0.4000D-04	0.1604D 03	0.1087D-01	0.2994D 02	0.5290D-01	0.2170D 02
0.5000D-04	0.1486D 03	0.1151D-01	0.2961D 02	0.5390D-01	0.2162D 02
0.6000D-04	0.1395D 03	0.1218D-01	0.2929D 02	0.5490D-01	0.2156D 02
0.7000D-04	0.1322D 03	0.1288D-01	0.2897D 02	0.5590D-01	0.2149D 02
0.8000D-04	0.1262D 03	0.1362D-01	0.2865D 02	0.5690D-01	0.2142D 02
0.9000D-04	0.1211D 03	0.1440D-01	0.2833D 02	0.5790D-01	0.2136D 02
0.1000D-03	0.1167D 03	0.1521D-01	0.2802D 02	0.5890D-01	0.2130D 02
0.2000D-03	0.9377D 02	0.1607D-01	0.2772D 02	0.5990D-01	0.2124D 02
0.3050D-03	0.8117D 02	0.1697D-01	0.2741D 02	0.6090D-01	0.2123D 02
0.4152D-03	0.7296D 02	0.1791D-01	0.2711D 02	0.6190D-01	0.2110D 02
0.5310D-03	0.6705D 02	0.1890D-01	0.2681D 02	0.6290D-01	0.2110D 02
0.6526D-03	0.6254D 02	0.1990D-01	0.2652D 02	0.6390D-01	0.2101D 02
0.7802D-03	0.5896D 02	0.2090D-01	0.2625D 02	0.6490D-01	0.2101D 02
0.9142D-03	0.5601D 02	0.2190D-01	0.2600D 02	0.6590D-01	0.2091D 02
0.1055D-02	0.5353D 02	0.2290D-01	0.2575D 02	0.6690D-01	0.2090D 02
0.1203D-02	0.5142D 02	0.2390D-01	0.2552D 02	0.6790D-01	0.2082D 02
0.1358D-02	0.4955D 02	0.2490D-01	0.2530D 02	0.6890D-01	0.2082D 02
0.1521D-02	0.4790D 02	0.2590D-01	0.2508D 02	0.6990D-01	0.2074D 02
0.1692D-02	0.4643D 02	0.2690D-01	0.2488D 02	0.7090D-01	0.2073D 02
0.1871D-02	0.4511D 02	0.2790D-01	0.2469D 02	0.7190D-01	0.2066D 02
0.2060D-02	0.4391D 02	0.2890D-01	0.2450D 02	0.7290D-01	0.2065D 02
0.2258D-02	0.4281D 02	0.2990D-01	0.2432D 02	0.7390D-01	0.2058D 02
0.2466D-02	0.4180D 02	0.3090D-01	0.2415D 02	0.7490D-01	0.2058D 02
0.2684D-02	0.4086D 02	0.3190D-01	0.2399D 02	0.7590D-01	0.2057D 02
0.2913D-02	0.4000D 02	0.3290D-01	0.2383D 02	0.7690D-01	0.2046D 02
0.3154D-02	0.3919D 02	0.3390D-01	0.2368D 02	0.7790D-01	0.2046D 02
0.3407D-02	0.3844D 02	0.3490D-01	0.2354D 02	0.7890D-01	0.2045D 02
0.3672D-02	0.3774D 02	0.3590D-01	0.2340D 02	0.7990D-01	0.2038D 02
0.3951D-02	0.3708D 02	0.3690D-01	0.2327D 02	0.8090D-01	0.2037D 02
0.4243D-02	0.3645D 02	0.3790D-01	0.2314D 02	0.8190D-01	0.2037D 02
0.4550D-02	0.3587D 02	0.3890D-01	0.2302D 02	0.8233D-01	0.2034D 02
0.4873D-02	0.3531D 02	0.3990D-01	0.2290D 02		

(H1) BOUNDARY CONDITION

$H = 0.8 \qquad M = 8$

$f_{fd,0}Re = 166.01 \qquad Nu_{fd,0} = 43.468$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.7787D 03	0.3050D-03	0.1130D 03	0.3951D-02	0.5448D 02
0.2000D-05	0.5984D 03	0.4152D-03	0.1022D 03	0.4243D-02	0.5366D 02
0.3000D-05	0.5152D 03	0.5310D-03	0.9437D 02	0.4550D-02	0.5289D 02
0.4000D-05	0.4636D 03	0.6526D-03	0.8841D 02	0.4873D-02	0.5216D 02
0.5000D-05	0.4272D 03	0.7802D-03	0.8364D 02	0.5211D-02	0.5149D 02
0.6000D-05	0.4000D 03	0.9142D-03	0.7972D 02	0.5567D-02	0.5085D 02
0.7000D-05	0.3786D 03	0.1055D-02	0.7641D 02	0.5940D-02	0.5025D 02
0.8000D-05	0.3612D 03	0.1203D-02	0.7358D 02	0.6332D-02	0.4969D 02
0.9000D-05	0.3469D 03	0.1358D-02	0.7108D 02	0.6744D-02	0.4916D 02
0.1000D-04	0.3345D 03	0.1521D-02	0.6889D 02	0.7176D-02	0.4867D 02
0.2000D-04	0.2722D 03	0.1692D-02	0.6693D 02	0.7630D-02	0.4820D 02
0.3000D-04	0.2391D 03	0.1871D-02	0.6516D 02	0.8106D-02	0.4777D 02
0.4000D-04	0.2176D 03	0.2060D-02	0.6356D 02	0.8607D-02	0.4737D 02
0.5000D-04	0.2021D 03	0.2258D-02	0.6210D 02	0.9132D-02	0.4699D 02
0.6000D-04	0.1901D 03	0.2466D-02	0.6075D 02	0.9684D-02	0.4664D 02
0.7000D-04	0.1805D 03	0.2684D-02	0.5951D 02	0.1026D-01	0.4631D 02
0.8000D-04	0.1725D 03	0.2913D-02	0.5836D 02	0.1087D-01	0.4601D 02
0.9000D-04	0.1659D 03	0.3154D-02	0.5728D 02	0.1151D-01	0.4574D 02
0.1000D-03	0.1600D 03	0.3407D-02	0.5628D 02	0.1176D-01	0.4564D 02
0.2000D-03	0.1296D 03	0.3672D-02	0.5535D 02		

(H1) BOUNDARY CONDITION

$H = 0.2 \qquad M = 16$

$f_{fd,0}Re = 26.707 \qquad Nu_{fd,0} = 4.7183$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.3000D 03	0.6744D-02	0.1052D 02	0.4890D-01	0.5545D 01
0.2000D-05	0.2270D 03	0.7176D-02	0.1027D 02	0.4990D-01	0.5520D 01
0.3000D-05	0.1952D 03	0.7630D-02	0.1003D 02	0.5090D-01	0.5496D 01
0.4000D-05	0.1759D 03	0.8106D-02	0.9795D 01	0.5190D-01	0.5473D 01
0.5000D-05	0.1624D 03	0.8607D-02	0.9574D 01	0.5290D-01	0.5450D 01
0.6000D-05	0.1522D 03	0.9132D-02	0.9362D 01	0.5390D-01	0.5429D 01
0.7000D-05	0.1440D 03	0.9684D-02	0.9158D 01	0.5490D-01	0.5408D 01
0.8000D-05	0.1372D 03	0.1026D-01	0.8962D 01	0.5590D-01	0.5388D 01
0.9000D-05	0.1316D 03	0.1087D-01	0.8774D 01	0.5690D-01	0.5369D 01
0.1000D-04	0.1266D 03	0.1151D-01	0.8593D 01	0.5790D-01	0.5349D 01
0.2000D-04	0.1007D 03	0.1218D-01	0.8419D 01	0.5890D-01	0.5333D 01
0.3000D-04	0.8694D 02	0.1288D-01	0.8251D 01	0.5990D-01	0.5315D 01
0.4000D-04	0.7815D 02	0.1362D-01	0.8090D 01	0.6090D-01	0.5298D 01
0.5000D-04	0.7185D 02	0.1440D-01	0.7935D 01	0.6190D-01	0.5282D 01
0.6000D-04	0.6704D 02	0.1521D-01	0.7785D 01	0.6290D-01	0.5265D 01
0.7000D-04	0.6320D 02	0.1607D-01	0.7641D 01	0.6390D-01	0.5251D 01
0.8000D-04	0.6004D 02	0.1697D-01	0.7501D 01	0.6490D-01	0.5236D 01
0.9000D-04	0.5736D 02	0.1791D-01	0.7367D 01	0.6590D-01	0.5221D 01
0.1000D-03	0.5508D 02	0.1890D-01	0.7238D 01	0.6690D-01	0.5208D 01
0.2000D-03	0.4298D 02	0.1990D-01	0.7118D 01	0.6790D-01	0.5194D 01
0.3050D-03	0.3653D 02	0.2090D-01	0.7007D 01	0.6890D-01	0.5181D 01
0.4152D-03	0.3238D 02	0.2190D-01	0.6904D 01	0.6990D-01	0.5168D 01
0.5310D-03	0.2938D 02	0.2290D-01	0.6808D 01	0.7090D-01	0.5156D 01
0.6526D-03	0.2708D 02	0.2390D-01	0.6719D 01	0.7190D-01	0.5143D 01
0.7802D-03	0.2522D 02	0.2490D-01	0.6635D 01	0.7290D-01	0.5133D 01
0.9142D-03	0.2367D 02	0.2590D-01	0.6557D 01	0.7390D-01	0.5121D 01
0.1055D-02	0.2234D 02	0.2690D-01	0.6484D 01	0.7490D-01	0.5112D 01
0.1203D-02	0.2119D 02	0.2790D-01	0.6415D 01	0.7590D-01	0.5101D 01
0.1358D-02	0.2017D 02	0.2890D-01	0.6349D 01	0.7690D-01	0.5090D 01
0.1521D-02	0.1926D 02	0.2990D-01	0.6288D 01	0.7790D-01	0.5080D 01
0.1692D-02	0.1844D 02	0.3090D-01	0.6229D 01	0.7890D-01	0.5070D 01
0.1871D-02	0.1770D 02	0.3190D-01	0.6174D 01	0.7990D-01	0.5069D 01
0.2060D-02	0.1701D 02	0.3290D-01	0.6122D 01	0.8090D-01	0.5047D 01
0.2258D-02	0.1638D 02	0.3390D-01	0.6072D 01	0.8190D-01	0.5047D 01
0.2466D-02	0.1580D 02	0.3490D-01	0.6025D 01	0.8290D-01	0.5031D 01
0.2684D-02	0.1526D 02	0.3590D-01	0.5980D 01	0.8390D-01	0.5030D 01
0.2913D-02	0.1476D 02	0.3690D-01	0.5937D 01	0.8490D-01	0.5015D 01
0.3154D-02	0.1428D 02	0.3790D-01	0.5895D 01	0.8590D-01	0.5014D 01
0.3407D-02	0.1384D 02	0.3890D-01	0.5856D 01	0.8690D-01	0.4999D 01
0.3672D-02	0.1342D 02	0.3990D-01	0.5819D 01	0.8790D-01	0.4999D 01
0.3951D-02	0.1303D 02	0.4090D-01	0.5783D 01	0.8890D-01	0.4985D 01
0.4243D-02	0.1266D 02	0.4190D-01	0.5749D 01	0.8990D-01	0.4985D 01
0.4550D-02	0.1230D 02	0.4290D-01	0.5716D 01	0.9090D-01	0.4972D 01
0.4873D-02	0.1197D 02	0.4390D-01	0.5684D 01	0.9190D-01	0.4972D 01
0.5211D-02	0.1165D 02	0.4490D-01	0.5655D 01	0.9290D-01	0.4957D 01
0.5567D-02	0.1135D 02	0.4590D-01	0.5625D 01	0.9390D-01	0.4957D 01
0.5940D-02	0.1106D 02	0.4690D-01	0.5597D 01	0.9490D-01	0.4956D 01
0.6332D-02	0.1078D 02	0.4790D-01	0.5570D 01	0.9500D-01	0.4954D 01

(H1) BOUNDARY CONDITION

$H = 0.4 \qquad M = 16$

$f_{fd,0} Re = 72.332 \qquad Nu_{fd,0} = 6.0251$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.5628D 03	0.9132D-02	0.1594D 02	0.5890D-01	0.7174D 01
0.2000D-05	0.4284D 03	0.9684D-02	0.1545D 02	0.5990D-01	0.7141D 01
0.3000D-05	0.3703D 03	0.1026D-01	0.1499D 02	0.6090D-01	0.7109D 01
0.4000D-05	0.3348D 03	0.1087D-01	0.1455D 02	0.6190D-01	0.7078D 01
0.5000D-05	0.3095D 03	0.1151D-01	0.1413D 02	0.6290D-01	0.7048D 01
0.6000D-05	0.2902D 03	0.1218D-01	0.1373D 02	0.6390D-01	0.7020D 01
0.7000D-05	0.2747D 03	0.1288D-01	0.1334D 02	0.6490D-01	0.6992D 01
0.8000D-05	0.2619D 03	0.1362D-01	0.1297D 02	0.6590D-01	0.6965D 01
0.9000D-05	0.2512D 03	0.1440D-01	0.1262D 02	0.6690D-01	0.6938D 01
0.1000D-04	0.2418D 03	0.1521D-01	0.1228D 02	0.6790D-01	0.6914D 01
0.2000D-04	0.1929D 03	0.1607D-01	0.1196D 02	0.6890D-01	0.6889D 01
0.3000D-04	0.1671D 03	0.1697D-01	0.1165D 02	0.6990D-01	0.6866D 01
0.4000D-04	0.1506D 03	0.1791D-01	0.1135D 02	0.7090D-01	0.6843D 01
0.5000D-04	0.1389D 03	0.1890D-01	0.1107D 02	0.7190D-01	0.6821D 01
0.6000D-04	0.1300D 03	0.1990D-01	0.1081D 02	0.7290D-01	0.6799D 01
0.7000D-04	0.1229D 03	0.2090D-01	0.1057D 02	0.7390D-01	0.6779D 01
0.8000D-04	0.1171D 03	0.2190D-01	0.1035D 02	0.7490D-01	0.6759D 01
0.9000D-04	0.1122D 03	0.2290D-01	0.1014D 02	0.7590D-01	0.6738D 01
0.1000D-03	0.1080D 03	0.2390D-01	0.9953D 01	0.7690D-01	0.6721D 01
0.2000D-03	0.8548D 02	0.2490D-01	0.9777D 01	0.7790D-01	0.6702D 01
0.3050D-03	0.7323D 02	0.2590D-01	0.9613D 01	0.7890D-01	0.6684D 01
0.4152D-03	0.6525D 02	0.2690D-01	0.9460D 01	0.7990D-01	0.6666D 01
0.5310D-03	0.5947D 02	0.2790D-01	0.9317D 01	0.8090D-01	0.6650D 01
0.6526D-03	0.5500D 02	0.2890D-01	0.9183D 01	0.8190D-01	0.6633D 01
0.7802D-03	0.5136D 02	0.2990D-01	0.9056D 01	0.8290D-01	0.6617D 01
0.9142D-03	0.4829D 02	0.3090D-01	0.8937D 01	0.8390D-01	0.6602D 01
0.1055D-02	0.4563D 02	0.3190D-01	0.8825D 01	0.8490D-01	0.6587D 01
0.1203D-02	0.4327D 02	0.3290D-01	0.8719D 01	0.8590D-01	0.6573D 01
0.1358D-02	0.4115D 02	0.3390D-01	0.8618D 01	0.8690D-01	0.6558D 01
0.1521D-02	0.3922D 02	0.3490D-01	0.8523D 01	0.8790D-01	0.6545D 01
0.1692D-02	0.3744D 02	0.3590D-01	0.8433D 01	0.8890D-01	0.6531D 01
0.1871D-02	0.3579D 02	0.3690D-01	0.8348D 01	0.8990D-01	0.6518D 01
0.2060D-02	0.3427D 02	0.3790D-01	0.8266D 01	0.9090D-01	0.6506D 01
0.2258D-02	0.3283D 02	0.3890D-01	0.8189D 01	0.9190D-01	0.6493D 01
0.2466D-02	0.3148D 02	0.3990D-01	0.8114D 01	0.9290D-01	0.6482D 01
0.2684D-02	0.3021D 02	0.4090D-01	0.8044D 01	0.9390D-01	0.6470D 01
0.2913D-02	0.2902D 02	0.4190D-01	0.7977D 01	0.9490D-01	0.6459D 01
0.3154D-02	0.2789D 02	0.4290D-01	0.7912D 01	0.9590D-01	0.6448D 01
0.3407D-02	0.2682D 02	0.4390D-01	0.7851D 01	0.9690D-01	0.6437D 01
0.3672D-02	0.2581D 02	0.4490D-01	0.7792D 01	0.9790D-01	0.6427D 01
0.3951D-02	0.2485D 02	0.4590D-01	0.7734D 01	0.9890D-01	0.6416D 01
0.4243D-02	0.2394D 02	0.4690D-01	0.7681D 01	0.9990D-01	0.6407D 01
0.4550D-02	0.2308D 02	0.4790D-01	0.7629D 01	0.1009D 00	0.6396D 01
0.4873D-02	0.2226D 02	0.4890D-01	0.7579D 01	0.1019D 00	0.6395D 01
0.5211D-02	0.2148D 02	0.4990D-01	0.7531D 01	0.1029D 00	0.6375D 01
0.5567D-02	0.2074D 02	0.5090D-01	0.7485D 01	0.1039D 00	0.6374D 01
0.5940D-02	0.2003D 02	0.5190D-01	0.7441D 01	0.1049D 00	0.6358D 01
0.6332D-02	0.1936D 02	0.5290D-01	0.7399D 01	0.1059D 00	0.6357D 01
0.6744D-02	0.1872D 02	0.5390D-01	0.7358D 01	0.1069D 00	0.6341D 01
0.7176D-02	0.1811D 02	0.5490D-01	0.7318D 01	0.1079D 00	0.6341D 01
0.7630D-02	0.1753D 02	0.5590D-01	0.7280D 01	0.1089D 00	0.6326D 01
0.8106D-02	0.1697D 02	0.5690D-01	0.7243D 01		
0.8607D-02	0.1644D 02	0.5790D-01	0.7208D 01		

(H1) BOUNDARY CONDITION

$H = 0.6 \qquad M = 16$

$f_{fd,0}Re = 227.93 \qquad Nu_{fd,0} = 15.175$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.1033D 04	0.1087D-01	0.4230D 02	0.6490D-01	0.1836D 02
0.2000D-05	0.7902D 03	0.1151D-01	0.4111D 02	0.6590D-01	0.1827D 02
0.3000D-05	0.6853D 03	0.1218D-01	0.3995D 02	0.6690D-01	0.1818D 02
0.4000D-05	0.6215D 03	0.1288D-01	0.3883D 02	0.6790D-01	0.1810D 02
0.5000D-05	0.5764D 03	0.1362D-01	0.3774D 02	0.6890D-01	0.1802D 02
0.6000D-05	0.5420D 03	0.1440D-01	0.3668D 02	0.6990D-01	0.1794D 02
0.7000D-05	0.5145D 03	0.1521D-01	0.3566D 02	0.7090D-01	0.1786D 02
0.8000D-05	0.4917D 03	0.1607D-01	0.3467D 02	0.7190D-01	0.1779D 02
0.9000D-05	0.4725D 03	0.1697D-01	0.3371D 02	0.7290D-01	0.1772D 02
0.1000D-04	0.4557D 03	0.1791D-01	0.3278D 02	0.7390D-01	0.1765D 02
0.2000D-04	0.3665D 03	0.1890D-01	0.3188D 02	0.7490D-01	0.1758D 02
0.3000D-04	0.3190D 03	0.1990D-01	0.3105D 02	0.7590D-01	0.1752D 02
0.4000D-04	0.2886D 03	0.2090D-01	0.3028D 02	0.7690D-01	0.1745D 02
0.5000D-04	0.2669D 03	0.2190D-01	0.2956D 02	0.7790D-01	0.1739D 02
0.6000D-04	0.2506D 03	0.2290D-01	0.2890D 02	0.7890D-01	0.1733D 02
0.7000D-04	0.2376D 03	0.2390D-01	0.2828D 02	0.7990D-01	0.1728D 02
0.8000D-04	0.2270D 03	0.2490D-01	0.2771D 02	0.8090D-01	0.1722D 02
0.9000D-04	0.2182D 03	0.2590D-01	0.2717D 02	0.8190D-01	0.1717D 02
0.1000D-03	0.2105D 03	0.2690D-01	0.2666D 02	0.8290D-01	0.1711D 02
0.2000D-03	0.1710D 03	0.2790D-01	0.2618D 02	0.8390D-01	0.1706D 02
0.3050D-03	0.1493D 03	0.2890D-01	0.2574D 02	0.8490D-01	0.1701D 02
0.4152D-03	0.1352D 03	0.2990D-01	0.2531D 02	0.8590D-01	0.1696D 02
0.5310D-03	0.1251D 03	0.3090D-01	0.2492D 02	0.8690D-01	0.1692D 02
0.6526D-03	0.1173D 03	0.3190D-01	0.2454D 02	0.8790D-01	0.1687D 02
0.7802D-03	0.1110D 03	0.3290D-01	0.2419D 02	0.8890D-01	0.1683D 02
0.9142D-03	0.1058D 03	0.3390D-01	0.2385D 02	0.8990D-01	0.1678D 02
0.1055D-02	0.1013D 03	0.3490D-01	0.2353D 02	0.9090D-01	0.1674D 02
0.1203D-02	0.9741D 02	0.3590D-01	0.2323D 02	0.9190D-01	0.1670D 02
0.1358D-02	0.9391D 02	0.3690D-01	0.2294D 02	0.9290D-01	0.1666D 02
0.1521D-02	0.9075D 02	0.3790D-01	0.2266D 02	0.9390D-01	0.1663D 02
0.1692D-02	0.8785D 02	0.3890D-01	0.2240D 02	0.9490D-01	0.1659D 02
0.1871D-02	0.8516D 02	0.3990D-01	0.2215D 02	0.9590D-01	0.1655D 02
0.2060D-02	0.8264D 02	0.4090D-01	0.2191D 02	0.9690D-01	0.1652D 02
0.2258D-02	0.8026D 02	0.4190D-01	0.2168D 02	0.9790D-01	0.1648D 02
0.2466D-02	0.7800D 02	0.4290D-01	0.2147D 02	0.9890D-01	0.1645D 02
0.2684D-02	0.7584D 02	0.4390D-01	0.2126D 02	0.9990D-01	0.1644D 02
0.2913D-02	0.7376D 02	0.4490D-01	0.2106D 02	0.1009D 00	0.1637D 02
0.3154D-02	0.7176D 02	0.4590D-01	0.2087D 02	0.1019D 00	0.1637D 02
0.3407D-02	0.6982D 02	0.4690D-01	0.2068D 02	0.1029D 00	0.1632D 02
0.3672D-02	0.6795D 02	0.4790D-01	0.2051D 02	0.1039D 00	0.1631D 02
0.3951D-02	0.6612D 02	0.4890D-01	0.2034D 02	0.1049D 00	0.1626D 02
0.4243D-02	0.6435D 02	0.4990D-01	0.2018D 02	0.1059D 00	0.1625D 02
0.4550D-02	0.6261D 02	0.5090D-01	0.2002D 02	0.1069D 00	0.1620D 02
0.4873D-02	0.6092D 02	0.5190D-01	0.1987D 02	0.1079D 00	0.1620D 02
0.5211D-02	0.5927D 02	0.5290D-01	0.1973D 02	0.1089D 00	0.1615D 02
0.5567D-02	0.5766D 02	0.5390D-01	0.1959D 02	0.1099D 00	0.1615D 02
0.5940D-02	0.5609D 02	0.5490D-01	0.1946D 02	0.1109D 00	0.1610D 02
0.6332D-02	0.5455D 02	0.5590D-01	0.1933D 02	0.1119D 00	0.1610D 02
0.6744D-02	0.5305D 02	0.5690D-01	0.1921D 02	0.1129D 00	0.1606D 02
0.7176D-02	0.5159D 02	0.5790D-01	0.1909D 02	0.1139D 00	0.1606D 02
0.7630D-02	0.5016D 02	0.5890D-01	0.1897D 02	0.1149D 00	0.1601D 02
0.8106D-02	0.4876D 02	0.5990D-01	0.1886D 02	0.1159D 00	0.1601D 02
0.8607D-02	0.4740D 02	0.6090D-01	0.1875D 02	0.1169D 00	0.1598D 02
0.9132D-02	0.4607D 02	0.6190D-01	0.1865D 02	0.1179D 00	0.1597D 02
0.9684D-02	0.4478D 02	0.6290D-01	0.1855D 02	0.1189D 00	0.1593D 02
0.1026D-01	0.4352D 02	0.6390D-01	0.1846D 02	0.1191D 00	0.1593D 02

(H1) BOUNDARY CONDITION

$H = 0.8 \qquad M = 16$

$f_{fd,0}Re = 453.40 \qquad Nu_{fd,0} = 107.65$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.1530D 04	0.8000D-04	0.3452D 03	0.2060D-02	0.1322D 03
0.2000D-05	0.1169D 04	0.9000D-04	0.3321D 03	0.2258D-02	0.1297D 03
0.3000D-05	0.1011D 04	0.1000D-03	0.3207D 03	0.2466D-02	0.1273D 03
0.4000D-05	0.9159D 03	0.2000D-03	0.2617D 03	0.2684D-02	0.1253D 03
0.5000D-05	0.8496D 03	0.3050D-03	0.2291D 03	0.2913D-02	0.1234D 03
0.6000D-05	0.7998D 03	0.4152D-03	0.2077D 03	0.3154D-02	0.1217D 03
0.7000D-05	0.7602D 03	0.5310D-03	0.1922D 03	0.3407D-02	0.1201D 03
0.8000D-05	0.7276D 03	0.6526D-03	0.1804D 03	0.3672D-02	0.1188D 03
0.9000D-05	0.7003D 03	0.7802D-03	0.1709D 03	0.3951D-02	0.1175D 03
0.1000D-04	0.6763D 03	0.9142D-03	0.1632D 03	0.4243D-02	0.1164D 03
0.2000D-04	0.5491D 03	0.1055D-02	0.1567D 03	0.4550D-02	0.1154D 03
0.3000D-04	0.4801D 03	0.1203D-02	0.1511D 03	0.4873D-02	0.1145D 03
0.4000D-04	0.4357D 03	0.1358D-02	0.1463D 03	0.5211D-02	0.1136D 03
0.5000D-04	0.4040D 03	0.1521D-02	0.1421D 03	0.5502D-02	0.1130D 03
0.6000D-04	0.3799D 03	0.1692D-02	0.1384D 03		
0.7000D-04	0.3608D 03	0.1871D-02	0.1351D 03		

(H1) BOUNDARY CONDITION

$H = 0.2 \qquad M = 24$

$f_{fd,0}Re = 30.253 \qquad Nu_{fd,0} = 4.6211$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.3589D 03	0.6744D-02	0.1020D 02	0.4890D-01	0.5410D 01
0.2000D-05	0.2701D 03	0.7176D-02	0.9953D 01	0.4990D-01	0.5387D 01
0.3000D-05	0.2309D 03	0.7630D-02	0.9717D 01	0.5090D-01	0.5364D 01
0.4000D-05	0.2072D 03	0.8106D-02	0.9491D 01	0.5190D-01	0.5341D 01
0.5000D-05	0.1906D 03	0.8607D-02	0.9275D 01	0.5290D-01	0.5320D 01
0.6000D-05	0.1781D 03	0.9132D-02	0.9069D 01	0.5390D-01	0.5299D 01
0.7000D-05	0.1683D 03	0.9684D-02	0.8871D 01	0.5490D-01	0.5279D 01
0.8000D-05	0.1602D 03	0.1026D-01	0.8682D 01	0.5590D-01	0.5260D 01
0.9000D-05	0.1534D 03	0.1087D-01	0.8500D 01	0.5690D-01	0.5242D 01
0.1000D-04	0.1476D 03	0.1151D-01	0.8325D 01	0.5790D-01	0.5224D 01
0.2000D-04	0.1168D 03	0.1218D-01	0.8158D 01	0.5890D-01	0.5207D 01
0.3000D-04	0.1006D 03	0.1288D-01	0.7997D 01	0.5990D-01	0.5191D 01
0.4000D-04	0.9010D 02	0.1362D-01	0.7842D 01	0.6090D-01	0.5174D 01
0.5000D-04	0.8260D 02	0.1440D-01	0.7693D 01	0.6190D-01	0.5158D 01
0.6000D-04	0.7689D 02	0.1521D-01	0.7549D 01	0.6290D-01	0.5144D 01
0.7000D-04	0.7234D 02	0.1607D-01	0.7411D 01	0.6390D-01	0.5129D 01
0.8000D-04	0.6859D 02	0.1697D-01	0.7278D 01	0.6490D-01	0.5115D 01
0.9000D-04	0.6543D 02	0.1791D-01	0.7150D 01	0.6590D-01	0.5102D 01
0.1000D-03	0.6272D 02	0.1890D-01	0.7026D 01	0.6690D-01	0.5088D 01
0.2000D-03	0.4823D 02	0.1990D-01	0.6911D 01	0.6790D-01	0.5075D 01
0.3050D-03	0.4037D 02	0.2090D-01	0.6805D 01	0.6890D-01	0.5062D 01
0.4152D-03	0.3524D 02	0.2190D-01	0.6707D 01	0.6990D-01	0.5050D 01
0.5310D-03	0.3155D 02	0.2290D-01	0.6615D 01	0.7090D-01	0.5039D 01
0.6526D-03	0.2871D 02	0.2390D-01	0.6530D 01	0.7190D-01	0.5028D 01
0.7802D-03	0.2645D 02	0.2490D-01	0.6451D 01	0.7290D-01	0.5017D 01
0.9142D-03	0.2459D 02	0.2590D-01	0.6376D 01	0.7390D-01	0.5006D 01
0.1055D-02	0.2302D 02	0.2690D-01	0.6306D 01	0.7490D-01	0.4996D 01
0.1203D-02	0.2167D 02	0.2790D-01	0.6240D 01	0.7590D-01	0.4985D 01
0.1358D-02	0.2050D 02	0.2890D-01	0.6178D 01	0.7690D-01	0.4975D 01
0.1521D-02	0.1946D 02	0.2990D-01	0.6119D 01	0.7790D-01	0.4966D 01
0.1692D-02	0.1854D 02	0.3090D-01	0.6063D 01	0.7890D-01	0.4957D 01
0.1871D-02	0.1771D 02	0.3190D-01	0.6011D 01	0.7990D-01	0.4948D 01
0.2060D-02	0.1695D 02	0.3290D-01	0.5961D 01	0.8090D-01	0.4947D 01
0.2258D-02	0.1627D 02	0.3390D-01	0.5913D 01	0.8190D-01	0.4928D 01
0.2466D-02	0.1565D 02	0.3490D-01	0.5868D 01	0.8290D-01	0.4927D 01
0.2684D-02	0.1506D 02	0.3590D-01	0.5825D 01	0.8390D-01	0.4911D 01
0.2913D-02	0.1453D 02	0.3690D-01	0.5784D 01	0.8490D-01	0.4911D 01
0.3154D-02	0.1403D 02	0.3790D-01	0.5745D 01	0.8590D-01	0.4896D 01
0.3407D-02	0.1356D 02	0.3890D-01	0.5708D 01	0.8690D-01	0.4896D 01
0.3672D-02	0.1313D 02	0.3990D-01	0.5672D 01	0.8790D-01	0.4882D 01
0.3951D-02	0.1272D 02	0.4090D-01	0.5637D 01	0.8890D-01	0.5882D 01
0.4243D-02	0.1234D 02	0.4190D-01	0.5605D 01	0.8990D-01	0.4868D 01
0.4550D-02	0.1198D 02	0.4290D-01	0.5574D 01	0.9090D-01	0.4868D 01
0.4873D-02	0.1165D 02	0.4390D-01	0.5544D 01	0.9190D-01	0.4857D 01
0.5211D-02	0.1133D 02	0.4490D-01	0.5515D 01	0.9290D-01	0.4857D 01
0.5567D-02	0.1102D 02	0.4590D-01	0.5487D 01	0.9324D-01	0.4852D 01
0.5940D-02	0.1073D 02	0.4690D-01	0.5460D 01		
0.6332D-02	0.1046D 02	0.4790D-01	0.5434D 01		

(H1) BOUNDARY CONDITION

$H = 0.4 \qquad M = 24$

$f_{fd,0}Re = 88.975 \qquad Nu_{fd,0} = 5.3207$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.7461D 03	0.8106D-02	0.1406D 02	0.5490D-01	0.6320D 01
0.2000D-05	0.5644D 03	0.8607D-02	0.1361D 02	0.5590D-01	0.6291D 01
0.3000D-05	0.4829D 03	0.9132D-02	0.1318D 02	0.5690D-01	0.6262D 01
0.4000D-05	0.4334D 03	0.9684D-02	0.1278D 02	0.5790D-01	0.6235D 01
0.5000D-05	0.3990D 03	0.1026D-01	0.1239D 02	0.5890D-01	0.6208D 01
0.6000D-05	0.3732D 03	0.1087D-01	0.1203D 02	0.5990D-01	0.6183D 01
0.7000D-05	0.3529D 03	0.1151D-01	0.1169D 02	0.6090D-01	0.6158D 01
0.8000D-05	0.3363D 03	0.1218D-01	0.1136D 02	0.6190D-01	0.6134D 01
0.9000D-05	0.3224D 03	0.1288D-01	0.1105D 02	0.6290D-01	0.6111D 01
0.1000D-04	0.3104D 03	0.1362D-01	0.1075D 02	0.6390D-01	0.6089D 01
0.2000D-04	0.2475D 03	0.1440D-01	0.1047D 02	0.6490D-01	0.6067D 01
0.3000D-04	0.2143D 03	0.1521D-01	0.1020D 02	0.6590D-01	0.6046D 01
0.4000D-04	0.1930D 03	0.1607D-01	0.9941D 01	0.6690D-01	0.6026D 01
0.5000D-04	0.1778D 03	0.1697D-01	0.9696D 01	0.6790D-01	0.6007D 01
0.6000D-04	0.1663D 03	0.1791D-01	0.9462D 01	0.6890D-01	0.5988D 01
0.7000D-04	0.1571D 03	0.1890D-01	0.9239D 01	0.6990D-01	0.5969D 01
0.8000D-04	0.1495D 03	0.1990D-01	0.9034D 01	0.7090D-01	0.5952D 01
0.9000D-04	0.1431D 03	0.2090D-01	0.8846D 01	0.7190D-01	0.5935D 01
0.1000D-03	0.1377D 03	0.2190D-01	0.8673D 01	0.7290D-01	0.5917D 01
0.2000D-03	0.1074D 03	0.2290D-01	0.8513D 01	0.7390D-01	0.5902D 01
0.3050D-03	0.9021D 02	0.2390D-01	0.8366D 01	0.7490D-01	0.5886D 01
0.4152D-03	0.7843D 02	0.2490D-01	0.8229D 01	0.7590D-01	0.5871D 01
0.5310D-03	0.6959D 02	0.2590D-01	0.8101D 01	0.7690D-01	0.5856D 01
0.6526D-03	0.6255D 02	0.2690D-01	0.7982D 01	0.7790D-01	0.5842D 01
0.7802D-03	0.5678D 02	0.2790D-01	0.7871D 01	0.7890D-01	0.5828D 01
0.9142D-03	0.5194D 02	0.2890D-01	0.7766D 01	0.7990D-01	0.5814D 01
0.1055D-02	0.4781D 02	0.2990D-01	0.7668D 01	0.8090D-01	0.5801D 01
0.1203D-02	0.4424D 02	0.3090D-01	0.7576D 01	0.8190D-01	0.5789D 01
0.1358D-02	0.4113D 02	0.3190D-01	0.7489D 01	0.8290D-01	0.5776D 01
0.1521D-02	0.3839D 02	0.3290D-01	0.7406D 01	0.8390D-01	0.5764D 01
0.1692D-02	0.3596D 02	0.3390D-01	0.7329D 01	0.8490D-01	0.5753D 01
0.1871D-02	0.3379D 02	0.3490D-01	0.7255D 01	0.8590D-01	0.5742D 01
0.2060D-02	0.3184D 02	0.3590D-01	0.7185D 01	0.8690D-01	0.5731D 01
0.2258D-02	0.3008D 02	0.3690D-01	0.7118D 01	0.8790D-01	0.5720D 01
0.2466D-02	0.2848D 02	0.3790D-01	0.7055D 01	0.8890D-01	0.5710D 01
0.2684D-02	0.2702D 02	0.3890D-01	0.6995D 01	0.8990D-01	0.5700D 01
0.2913D-02	0.2568D 02	0.3990D-01	0.6938D 01	0.9090D-01	0.5690D 01
0.3154D-02	0.2445D 02	0.4090D-01	0.6883D 01	0.9190D-01	0.5680D 01
0.3407D-02	0.2332D 02	0.4190D-01	0.6831D 01	0.9290D-01	0.5671D 01
0.3672D-02	0.2228D 02	0.4290D-01	0.6781D 01	0.9390D-01	0.5662D 01
0.3951D-02	0.2131D 02	0.4390D-01	0.6733D 01	0.9490D-01	0.5653D 01
0.4243D-02	0.2041D 02	0.4490D-01	0.6688D 01	0.9590D-01	0.5645D 01
0.4550D-02	0.1958D 02	0.4590D-01	0.6644D 01	0.9690D-01	0.5637D 01
0.4873D-02	0.1879D 02	0.4690D-01	0.6602D 01	0.9790D-01	0.5628D 01
0.5211D-02	0.1806D 02	0.4790D-01	0.6561D 01	0.9890D-01	0.5621D 01
0.5567D-02	0.1738D 02	0.4890D-01	0.6523D 01	0.9990D-01	0.5612D 01
0.5940D-02	0.1674D 02	0.4990D-01	0.6486D 01	0.1009D 00	0.5612D 01
0.6332D-02	0.1614D 02	0.5090D-01	0.6450D 01	0.1019D 00	0.5595D 01
0.6744D-02	0.1557D 02	0.5190D-01	0.6416D 01	0.1029D 00	0.5595D 01
0.7176D-02	0.1504D 02	0.5290D-01	0.6383D 01	0.1035D 00	0.5587D 01
0.7630D-02	0.1453D 02	0.5390D-01	0.6351D 01		

(H1) BOUNDARY CONDITION

$H = 0.6 \qquad M = 24$

$f_{fd,0}Re = 328.55 \qquad Nu_{fd,0} = 10.155$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.1473D 04	0.1288D-01	0.2969D 02	0.7090D-01	0.1218D 02
0.2000D-05	0.1130D 04	0.1362D-01	0.2864D 02	0.7190D-01	0.1213D 02
0.3000D-05	0.9757D 03	0.1440D-01	0.2764D 02	0.7290D-01	0.1207D 02
0.4000D-05	0.8801D 03	0.1521D-01	0.2669D 02	0.7390D-01	0.1202D 02
0.5000D-05	0.8122D 03	0.1607D-01	0.2579D 02	0.7490D-01	0.1197D 02
0.6000D-05	0.7609D 03	0.1697D-01	0.2492D 02	0.7590D-01	0.1192D 02
0.7000D-05	0.7202D 03	0.1791D-01	0.2410D 02	0.7690D-01	0.1188D 02
0.8000D-05	0.6869D 03	0.1890D-01	0.2332D 02	0.7790D-01	0.1183D 02
0.9000D-05	0.6591D 03	0.1990D-01	0.2260D 02	0.7890D-01	0.1179D 02
0.1000D-04	0.6350D 03	0.2090D-01	0.2194D 02	0.7990D-01	0.1174D 02
0.2000D-04	0.5105D 03	0.2190D-01	0.2134D 02	0.8090D-01	0.1170D 02
0.3000D-04	0.4448D 03	0.2290D-01	0.2078D 02	0.8190D-01	0.1166D 02
0.4000D-04	0.4029D 03	0.2390D-01	0.2027D 02	0.8290D-01	0.1162D 02
0.5000D-04	0.3731D 03	0.2490D-01	0.1979D 02	0.8390D-01	0.1159D 02
0.6000D-04	0.3506D 03	0.2590D-01	0.1935D 02	0.8490D-01	0.1155D 02
0.7000D-04	0.3327D 03	0.2690D-01	0.1894D 02	0.8590D-01	0.1151D 02
0.8000D-04	0.3181D 03	0.2790D-01	0.1856D 02	0.8690D-01	0.1148D 02
0.9000D-04	0.3058D 03	0.2890D-01	0.1820D 02	0.8790D-01	0.1145D 02
0.1000D-03	0.2952D 03	0.2990D-01	0.1787D 02	0.8890D-01	0.1141D 02
0.2000D-03	0.2394D 03	0.3090D-01	0.1755D 02	0.8990D-01	0.1138D 02
0.3050D-03	0.2076D 03	0.3190D-01	0.1725D 02	0.9090D-01	0.1135D 02
0.4152D-03	0.1860D 03	0.3290D-01	0.1697D 02	0.9190D-01	0.1132D 02
0.5310D-03	0.1696D 03	0.3390D-01	0.1671D 02	0.9290D-01	0.1129D 02
0.6526D-03	0.1565D 03	0.3490D-01	0.1646D 02	0.9390D-01	0.1126D 02
0.7802D-03	0.1455D 03	0.3590D-01	0.1623D 02	0.9490D-01	0.1123D 02
0.9142D-03	0.1361D 03	0.3690D-01	0.1600D 02	0.9590D-01	0.1121D 02
0.1055D-02	0.1279D 03	0.3790D-01	0.1579D 02	0.9690D-01	0.1118D 02
0.1203D-02	0.1205D 03	0.3890D-01	0.1559D 02	0.9790D-01	0.1116D 02
0.1358D-02	0.1139D 03	0.3990D-01	0.1540D 02	0.9890D-01	0.1113D 02
0.1521D-02	0.1078D 03	0.4090D-01	0.1522D 02	0.9990D-01	0.1111D 02
0.1692D-02	0.1023D 03	0.4190D-01	0.1504D 02	0.1009D 00	0.1108D 02
0.1871D-02	0.9718D 02	0.4290D-01	0.1488D 02	0.1019D 00	0.1106D 02
0.2060D-02	0.9243D 02	0.4390D-01	0.1472D 02	0.1029D 00	0.1104D 02
0.2258D-02	0.8801D 02	0.4490D-01	0.1457D 02	0.1039D 00	0.1102D 02
0.2466D-02	0.8387D 02	0.4590D-01	0.1442D 02	0.1049D 00	0.1100D 02
0.2684D-02	0.8002D 02	0.4690D-01	0.1429D 02	0.1059D 00	0.1098D 02
0.2913D-02	0.7635D 02	0.4790D-01	0.1415D 02	0.1069D 00	0.1096D 02
0.3154D-02	0.7291D 02	0.4890D-01	0.1403D 02	0.1079D 00	0.1094D 02
0.3407D-02	0.6967D 02	0.4990D-01	0.1391D 02	0.1089D 00	0.1092D 02
0.3672D-02	0.6660D 02	0.5090D-01	0.1379D 02	0.1099D 00	0.1090D 02
0.3951D-02	0.6371D 02	0.5190D-01	0.1368D 02	0.1109D 00	0.1088D 02
0.4243D-02	0.6096D 02	0.5290D-01	0.1357D 02	0.1119D 00	0.1086D 02
0.4550D-02	0.5837D 02	0.5390D-01	0.1347D 02	0.1129D 00	0.1085D 02
0.4873D-02	0.5590D 02	0.5490D-01	0.1337D 02	0.1139D 00	0.1083D 02
0.5211D-02	0.5357D 02	0.5590D-01	0.1327D 02	0.1149D 00	0.1081D 02
0.5567D-02	0.5135D 02	0.5690D-01	0.1318D 02	0.1159D 00	0.1080D 02
0.5940D-02	0.4925D 02	0.5790D-01	0.1309D 02	0.1169D 00	0.1078D 02
0.6332D-02	0.4725D 02	0.5890D-01	0.1300D 02	0.1179D 00	0.1078D 02
0.6744D-02	0.4535D 02	0.5990D-01	0.1292D 02	0.1189D 00	0.1075D 02
0.7176D-02	0.4355D 02	0.6090D-01	0.1284D 02	0.1199D 00	0.1075D 02
0.7630D-02	0.4183D 02	0.6190D-01	0.1277D 02	0.1209D 00	0.1072D 02
0.8106D-02	0.4020D 02	0.6290D-01	0.1269D 02	0.1219D 00	0.1072D 02
0.8607D-02	0.3865D 02	0.6390D-01	0.1262D 02	0.1229D 00	0.1069D 02
0.9132D-02	0.3717D 02	0.6490D-01	0.1255D 02	0.1239D 00	0.1069D 02
0.9684D-02	0.3577D 02	0.6590D-01	0.1248D 02	0.1249D 00	0.1067D 02
0.1026D-01	0.3443D 02	0.6690D-01	0.1242D 02	0.1259D 00	0.1067D 02
0.1087D-01	0.3316D 02	0.6790D-01	0.1236D 02	0.1261D 00	0.1066D 02
0.1151D-01	0.3194D 02	0.6890D-01	0.1230D 02		
0.1218D-01	0.3079D 02	0.6990D-01	0.1224D 02		

(H1) BOUNDARY CONDITION

$H = 0.8 \qquad M = 24$

$f_{fd,0}Re = 852.82 \qquad Nu_{fd,0} = 153.68$

X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$	X^+	$Nu_{x,H1}$
0.1000D-05	0.2374D 04	0.6526D-03	0.2795D 03	0.5940D-02	0.1816D 03
0.2000D-05	0.1817D 04	0.7802D-03	0.2656D 03	0.6332D-02	0.1804D 03
0.3000D-05	0.1579D 04	0.9142D-03	0.2544D 03	0.6744D-02	0.1792D 03
0.4000D-05	0.1434D 04	0.1055D-02	0.2450D 03	0.7176D-02	0.1780D 03
0.5000D-05	0.1332D 04	0.1203D-02	0.2371D 03	0.7630D-02	0.1769D 03
0.6000D-05	0.1253D 04	0.1358D-02	0.2304D 03	0.8106D-02	0.1759D 03
0.7000D-05	0.1190D 04	0.1521D-02	0.2246D 03	0.8607D-02	0.1748D 03
0.8000D-05	0.1138D 04	0.1692D-02	0.2195D 03	0.9132D-02	0.1738D 03
0.9000D-05	0.1094D 04	0.1871D-02	0.2150D 03	0.9684D-02	0.1728D 03
0.1000D-04	0.1055D 04	0.2060D-02	0.2110D 03	0.1026D-01	0.1718D 03
0.2000D-04	0.8529D 03	0.2258D-02	0.2075D 03	0.1087D-01	0.1708D 03
0.3000D-04	0.7452D 03	0.2466D-02	0.2043D 03	0.1151D-01	0.1699D 03
0.4000D-04	0.6764D 03	0.2684D-02	0.2015D 03	0.1218D-01	0.1689D 03
0.5000D-04	0.6274D 03	0.2913D-02	0.1989D 03	0.1288D-01	0.1680D 03
0.6000D-04	0.5901D 03	0.3154D-02	0.1965D 03	0.1362D-01	0.1672D 03
0.7000D-04	0.5604D 03	0.3407D-02	0.1943D 03	0.1440D-01	0.1663D 03
0.8000D-04	0.5359D 03	0.3672D-02	0.1923D 03	0.1521D-01	0.1655D 03
0.9000D-04	0.5154D 03	0.3951D-02	0.1905D 03	0.1607D-01	0.1647D 03
0.1000D-03	0.4975D 03	0.4243D-02	0.1888D 03	0.1697D-01	0.1639D 03
0.2000D-03	0.4043D 03	0.4550D-02	0.1872D 03	0.1791D-01	0.1631D 03
0.3050D-03	0.3533D 03	0.4873D-02	0.1857D 03	0.1890D-01	0.1624D 03
0.4152D-03	0.3204D 03	0.5211D-02	0.1842D 03	0.1990D-01	0.1617D 03
0.5310D-03	0.2971D 03	0.5567D-02	0.1829D 03	0.2043D-01	0.1614D 03

(T) BOUNDARY CONDITION

The Smooth Tube Geometry

$f_{fd,0}Re = 15.934 \qquad Nu_{fd,0} = 3.6294$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.2243D 03	0.3951D-02	0.8118D 01	0.3290D-01	0.4364D 01
0.2000D-05	0.1316D 03	0.4243D-02	0.7929D 01	0.3390D-01	0.4335D 01
0.3000D-05	0.9810D 02	0.4550D-02	0.7749D 01	0.3490D-01	0.4307D 01
0.4000D-05	0.8430D 02	0.4873D-02	0.7577D 01	0.3590D-01	0.4281D 01
0.5000D-05	0.7727D 02	0.5211D-02	0.7414D 01	0.3690D-01	0.4255D 01
0.6000D-05	0.7278D 02	0.5567D-02	0.7257D 01	0.3790D-01	0.4231D 01
0.7000D-05	0.6938D 02	0.5940D-02	0.7107D 01	0.3890D-01	0.4208D 01
0.8000D-05	0.6659D 02	0.6332D-02	0.6962D 01	0.3990D-01	0.4186D 01
0.9000D-05	0.6418D 02	0.6744D-02	0.6824D 01	0.4090D-01	0.4165D 01
0.1000D-04	0.6206D 02	0.7176D-02	0.6691D 01	0.4190D-01	0.4145D 01
0.2000D-04	0.5137D 02	0.7630D-02	0.6563D 01	0.4290D-01	0.4126D 01
0.3000D-04	0.4519D 02	0.8106D-02	0.6439D 01	0.4390D-01	0.4108D 01
0.4000D-04	0.4119D 02	0.8607D-02	0.6320D 01	0.4490D-01	0.4090D 01
0.5000D-04	0.3835D 02	0.9132D-02	0.6205D 01	0.4590D-01	0.4073D 01
0.6000D-04	0.3616D 02	0.9684D-02	0.6094D 01	0.4690D-01	0.4057D 01
0.7000D-04	0.3436D 02	0.1026D-01	0.5987D 01	0.4790D-01	0.4042D 01
0.8000D-04	0.3283D 02	0.1087D-01	0.5884D 01	0.4890D-01	0.4027D 01
0.9000D-04	0.3148D 02	0.1151D-01	0.5784D 01	0.4990D-01	0.4013D 01
0.1000D-03	0.3028D 02	0.1218D-01	0.5687D 01	0.5090D-01	0.3999D 01
0.2000D-03	0.2398D 02	0.1288D-01	0.5594D 01	0.5190D-01	0.3986D 01
0.3050D-03	0.2025D 02	0.1362D-01	0.5503D 01	0.5290D-01	0.3974D 01
0.4152D-03	0.1789D 02	0.1440D-01	0.5416D 01	0.5390D-01	0.3961D 01
0.5310D-03	0.1627D 02	0.1521D-01	0.5331D 01	0.5490D-01	0.3950D 01
0.6526D-03	0.1508D 02	0.1607D-01	0.5249D 01	0.5590D-01	0.3939D 01
0.7802D-03	0.1414D 02	0.1697D-01	0.5169D 01	0.5690D-01	0.3928D 01
0.9142D-03	0.1337D 02	0.1791D-01	0.5092D 01	0.5790D-01	0.3918D 01
0.1055D-02	0.1272D 02	0.1890D-01	0.5018D 01	0.5890D-01	0.3908D 01
0.1203D-02	0.1215D 02	0.1990D-01	0.4948D 01	0.5990D-01	0.3898D 01
0.1358D-02	0.1165D 02	0.2090D-01	0.4884D 01	0.6090D-01	0.3889D 01
0.1521D-02	0.1121D 02	0.2190D-01	0.4824D 01	0.6190D-01	0.3880D 01
0.1692D-02	0.1080D 02	0.2290D-01	0.4768D 01	0.6290D-01	0.3872D 01
0.1871D-02	0.1044D 02	0.2390D-01	0.4716D 01	0.6390D-01	0.3863D 01
0.2060D-02	0.1010D 02	0.2490D-01	0.4667D 01	0.6490D-01	0.3855D 01
0.2258D-02	0.9791D 01	0.2590D-01	0.4621D 01	0.6590D-01	0.3848D 01
0.2466D-02	0.9503D 01	0.2690D-01	0.4578D 01	0.6690D-01	0.3841D 01
0.2684D-02	0.9235D 01	0.2790D-01	0.4537D 01	0.6790D-01	0.3833D 01
0.2913D-02	0.8985D 01	0.2890D-01	0.4499D 01	0.6890D-01	0.3827D 01
0.3154D-02	0.8749D 01	0.2990D-01	0.4462D 01	0.6990D-01	0.3820D 01
0.3407D-02	0.8527D 01	0.3090D-01	0.4428D 01	0.7090D-01	0.3814D 01
0.3672D-02	0.8317D 01	0.3190D-01	0.4395D 01	0.7138D-01	0.3811D 01

(T) BOUNDARY CONDITION

$H = 0.2 \qquad M = 4$

$f_{fd,0}Re = 18.574 \qquad Nu_{fd,0} = 3.7498$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.2556D 03	0.2466D-02	0.9842D 01	0.2090D-01	0.4868D 01
0.2000D-05	0.1495D 03	0.2684D-02	0.9544D 01	0.2190D-01	0.4805D 01
0.3000D-05	0.1130D 03	0.2913D-02	0.9267D 01	0.2290D-01	0.4747D 01
0.4000D-05	0.9765D 02	0.3154D-02	0.9007D 01	0.2390D-01	0.4692D 01
0.5000D-05	0.8948D 02	0.3407D-02	0.8763D 01	0.2490D-01	0.4641D 01
0.6000D-05	0.8407D 02	0.3672D-02	0.8534D 01	0.2590D-01	0.4593D 01
0.7000D-05	0.7995D 02	0.3951D-02	0.8318D 01	0.2690D-01	0.4548D 01
0.8000D-05	0.7655D 02	0.4243D-02	0.8113D 01	0.2790D-01	0.4506D 01
0.9000D-05	0.7366D 02	0.4550D-02	0.7918D 01	0.2890D-01	0.4466D 01
0.1000D-04	0.7114D 02	0.4873D-02	0.7733D 01	0.2990D-01	0.4428D 01
0.2000D-04	0.5857D 02	0.5211D-02	0.7557D 01	0.3090D-01	0.4392D 01
0.3000D-04	0.5128D 02	0.5567D-02	0.7388D 01	0.3190D-01	0.4359D 01
0.4000D-04	0.4650D 02	0.5940D-02	0.7227D 01	0.3290D-01	0.4327D 01
0.5000D-04	0.4305D 02	0.6332D-02	0.7072D 01	0.3390D-01	0.4296D 01
0.6000D-04	0.4038D 02	0.6744D-02	0.6924D 01	0.3490D-01	0.4267D 01
0.7000D-04	0.3819D 02	0.7176D-02	0.6782D 01	0.3590D-01	0.4240D 01
0.8000D-04	0.3634D 02	0.7630D-02	0.6645D 01	0.3690D-01	0.4214D 01
0.9000D-04	0.3474D 02	0.8106D-02	0.6513D 01	0.3790D-01	0.4189D 01
0.1000D-03	0.3332D 02	0.8607D-02	0.6386D 01	0.3890D-01	0.4165D 01
0.2000D-03	0.2620D 02	0.9132D-02	0.6264D 01	0.3990D-01	0.4142D 01
0.3050D-03	0.2205D 02	0.9684D-02	0.6146D 01	0.4090D-01	0.4121D 01
0.4152D-03	0.1940D 02	0.1026D-01	0.6032D 01	0.4190D-01	0.4100D 01
0.5310D-03	0.1757D 02	0.1087D-01	0.5923D 01	0.4290D-01	0.4080D 01
0.6526D-03	0.1620D 02	0.1151D-01	0.5817D 01	0.4390D-01	0.4061D 01
0.7802D-03	0.1513D 02	0.1218D-01	0.5714D 01	0.4490D-01	0.4043D 01
0.9142D-03	0.1424D 02	0.1288D-01	0.5615D 01	0.4590D-01	0.4026D 01
0.1055D-02	0.1349D 02	0.1362D-01	0.5519D 01	0.4690D-01	0.4009D 01
0.1203D-02	0.1284D 02	0.1440D-01	0.5427D 01	0.4790D-01	0.3993D 01
0.1358D-02	0.1227D 02	0.1521D-01	0.5337D 01	0.4890D-01	0.3978D 01
0.1521D-02	0.1176D 02	0.1607D-01	0.5251D 01	0.4990D-01	0.3963D 01
0.1692D-02	0.1130D 02	0.1697D-01	0.5167D 01	0.5090D-01	0.3949D 01
0.1871D-02	0.1089D 02	0.1791D-01	0.5087D 01	0.5180D-01	0.3937D 01
0.2060D-02	0.1051D 02	0.1890D-01	0.5008D 01		
0.2258D-02	0.1016D 02	0.1990D-01	0.4936D 01		

(T) BOUNDARY CONDITION

$H = 0.4 \qquad M = 4$

$f_{fd,0}Re = 27.673 \qquad Nu_{fd,0} = 4.5631$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.3274D 03	0.2466D-02	0.1279D 02	0.2090D-01	0.6060D 01
0.2000D-05	0.1921D 03	0.2684D-02	0.1240D 02	0.2190D-01	0.5975D 01
0.3000D-05	0.1454D 03	0.2913D-02	0.1202D 02	0.2290D-01	0.5896D 01
0.4000D-05	0.1256D 03	0.3154D-02	0.1168D 02	0.2390D-01	0.5822D 01
0.5000D-05	0.1149D 03	0.3407D-02	0.1135D 02	0.2490D-01	0.5753D 01
0.6000D-05	0.1079D 03	0.3672D-02	0.1104D 02	0.2590D-01	0.5688D 01
0.7000D-05	0.1026D 03	0.3951D-02	0.1074D 02	0.2690D-01	0.5627D 01
0.8000D-05	0.9825D 02	0.4243D-02	0.1046D 02	0.2790D-01	0.5569D 01
0.9000D-05	0.9456D 02	0.4550D-02	0.1020D 02	0.2890D-01	0.5515D 01
0.1000D-04	0.9135D 02	0.4873D-02	0.9948D 01	0.2990D-01	0.5463D 01
0.2000D-04	0.7540D 02	0.5211D-02	0.9707D 01	0.3090D-01	0.5414D 01
0.3000D-04	0.6609D 02	0.5567D-02	0.9477D 01	0.3190D-01	0.5368D 01
0.4000D-04	0.5995D 02	0.5940D-02	0.9257D 01	0.3290D-01	0.5324D 01
0.5000D-04	0.5548D 02	0.6332D-02	0.9046D 01	0.3390D-01	0.5282D 01
0.6000D-04	0.5201D 02	0.6744D-02	0.8844D 01	0.3490D-01	0.5242D 01
0.7000D-04	0.4918D 02	0.7176D-02	0.8650D 01	0.3590D-01	0.5204D 01
0.8000D-04	0.4679D 02	0.7630D-02	0.8464D 01	0.3690D-01	0.5167D 01
0.9000D-04	0.4473D 02	0.8106D-02	0.8284D 01	0.3790D-01	0.5133D 01
0.1000D-03	0.4292D 02	0.8607D-02	0.8112D 01	0.3890D-01	0.5099D 01
0.2000D-03	0.3390D 02	0.9132D-02	0.7945D 01	0.3990D-01	0.5068D 01
0.3050D-03	0.2863D 02	0.9684D-02	0.7785D 01	0.4090D-01	0.5037D 01
0.4152D-03	0.2523D 02	0.1026D-01	0.7631D 01	0.4190D-01	0.5008D 01
0.5310D-03	0.2286D 02	0.1087D-01	0.7482D 01	0.4290D-01	0.4980D 01
0.6526D-03	0.2109D 02	0.1151D-01	0.7338D 01	0.4390D-01	0.4954D 01
0.7802D-03	0.1970D 02	0.1218D-01	0.7200D 01	0.4490D-01	0.4928D 01
0.9142D-03	0.1855D 02	0.1288D-01	0.7066D 01	0.4590D-01	0.4903D 01
0.1055D-02	0.1757D 02	0.1362D-01	0.6937D 01	0.4690D-01	0.4880D 01
0.1203D-02	0.1673D 02	0.1440D-01	0.6812D 01	0.4790D-01	0.4857D 01
0.1358D-02	0.1598D 02	0.1521D-01	0.6691D 01	0.4890D-01	0.4835D 01
0.1521D-02	0.1532D 02	0.1607D-01	0.6575D 01	0.4990D-01	0.4815D 01
0.1692D-02	0.1472D 02	0.1697D-01	0.6462D 01	0.5090D-01	0.4795D 01
0.1871D-02	0.1418D 02	0.1791D-01	0.6354D 01	0.5107D-01	0.4791D 01
0.2060D-02	0.1368D 02	0.1890D-01	0.6249D 01		
0.2258D-02	0.1322D 02	0.1990D-01	0.6150D 01		

(T) BOUNDARY CONDITION

$H = 0.6 \qquad M = 4$

$f_{fd,0}Re = 47.639 \qquad Nu_{fd,0} = 8.1846$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.4423D 03	0.2684D-02	0.1812D 02	0.2290D-01	0.1008D 02
0.2000D-05	0.2654D 03	0.2913D-02	0.1764D 02	0.2390D-01	0.9993D 01
0.3000D-05	0.2007D 03	0.3154D-02	0.1720D 02	0.2490D-01	0.9914D 01
0.4000D-05	0.1715D 03	0.3407D-02	0.1677D 02	0.2590D-01	0.9839D 01
0.5000D-05	0.1555D 03	0.3672D-02	0.1638D 02	0.2690D-01	0.9768D 01
0.6000D-05	0.1452D 03	0.3951D-02	0.1600D 02	0.2790D-01	0.9700D 01
0.7000D-05	0.1378D 03	0.4243D-02	0.1565D 02	0.2890D-01	0.9636D 01
0.8000D-05	0.1319D 03	0.4550D-02	0.1531D 02	0.2990D-01	0.9575D 01
0.9000D-05	0.1270D 03	0.4873D-02	0.1499D 02	0.3090D-01	0.9517D 01
0.1000D-04	0.1229D 03	0.5211D-02	0.1469D 02	0.3190D-01	0.9461D 01
0.2000D-04	0.1020D 03	0.5567D-02	0.1440D 02	0.3290D-01	0.9407D 01
0.3000D-04	0.8959D 02	0.5940D-02	0.1412D 02	0.3390D-01	0.9356D 01
0.4000D-04	0.8127D 02	0.6332D-02	0.1386D 02	0.3490D-01	0.9306D 01
0.5000D-04	0.7519D 02	0.6744D-02	0.1360D 02	0.3590D-01	0.9258D 01
0.6000D-04	0.7047D 02	0.7176D-02	0.1336D 02	0.3690D-01	0.9212D 01
0.7000D-04	0.6666D 02	0.7630D-02	0.1313D 02	0.3790D-01	0.9168D 01
0.8000D-04	0.6348D 02	0.8106D-02	0.1291D 02	0.3890D-01	0.9125D 01
0.9000D-04	0.6077D 02	0.8607D-02	0.1269D 02	0.3990D-01	0.9083D 01
0.1000D-03	0.5841D 02	0.9132D-02	0.1249D 02	0.4090D-01	0.9043D 01
0.2000D-03	0.4678D 02	0.9684D-02	0.1230D 02	0.4190D-01	0.9004D 01
0.3050D-03	0.3983D 02	0.1026D-01	0.1211D 02	0.4290D-01	0.8966D 01
0.4152D-03	0.3525D 02	0.1087D-01	0.1193D 02	0.4390D-01	0.8929D 01
0.5310D-03	0.3202D 02	0.1151D-01	0.1176D 02	0.4490D-01	0.8894D 01
0.6526D-03	0.2961D 02	0.1218D-01	0.1159D 02	0.4590D-01	0.8859D 01
0.7802D-03	0.2772D 02	0.1288D-01	0.1143D 02	0.4690D-01	0.8826D 01
0.9142D-03	0.2617D 02	0.1362D-01	0.1128D 02	0.4790D-01	0.8793D 01
0.1055D-02	0.2488D 02	0.1440D-01	0.1113D 02	0.4890D-01	0.8761D 01
0.1203D-02	0.2376D 02	0.1521D-01	0.1099D 02	0.4990D-01	0.8731D 01
0.1358D-02	0.2279D 02	0.1607D-01	0.1086D 02	0.5090D-01	0.8701D 01
0.1521D-02	0.2192D 02	0.1697D-01	0.1073D 02	0.5190D-01	0.8672D 01
0.1692D-02	0.2114D 02	0.1791D-01	0.1060D 02	0.5290D-01	0.8643D 01
0.1871D-02	0.2043D 02	0.1890D-01	0.1048D 02	0.5390D-01	0.8616D 01
0.2060D-02	0.1978D 02	0.1990D-01	0.1037D 02	0.5473D-01	0.8594D 01
0.2258D-02	0.1919D 02	0.2090D-01	0.1026D 02		
0.2466D-02	0.1863D 02	0.2190D-01	0.1017D 02		

(T) BOUNDARY CONDITION

$H = 0.8 \qquad M = 4$

$f_{fd,0}Re = 71.169 \qquad Nu_{fd,0} = 16.033$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.5598D 03	0.5310D-03	0.4261D 02	0.5211D-02	0.2118D 02
0.2000D-05	0.3501D 03	0.6526D-03	0.3949D 02	0.5567D-02	0.2085D 02
0.3000D-05	0.2671D 03	0.7802D-03	0.3704D 02	0.5940D-02	0.2054D 02
0.4000D-05	0.2261D 03	0.9142D-03	0.3506D 02	0.6332D-02	0.2024D 02
0.5000D-05	0.2026D 03	0.1055D-02	0.3342D 02	0.6744D-02	0.1996D 02
0.6000D-05	0.1876D 03	0.1203D-02	0.3202D 02	0.7176D-02	0.1969D 02
0.7000D-05	0.1771D 03	0.1358D-02	0.3081D 02	0.7630D-02	0.1943D 02
0.8000D-05	0.1691D 03	0.1521D-02	0.2974D 02	0.8106D-02	0.1919D 02
0.9000D-05	0.1626D 03	0.1692D-02	0.2878D 02	0.8607D-02	0.1896D 02
0.1000D-04	0.1572D 03	0.1871D-02	0.2793D 02	0.9132D-02	0.1873D 02
0.2000D-04	0.1303D 03	0.2060D-02	0.2715D 02	0.9684D-02	0.1852D 02
0.3000D-04	0.1142D 03	0.2258D-02	0.2643D 02	0.1026D-01	0.1832D 02
0.4000D-04	0.1035D 03	0.2466D-02	0.2578D 02	0.1087D-01	0.1813D 02
0.5000D-04	0.9576D 02	0.2684D-02	0.2517D 02	0.1151D-01	0.1795D 02
0.6000D-04	0.8984D 02	0.2913D-02	0.2460D 02	0.1218D-01	0.1777D 02
0.7000D-04	0.8512D 02	0.3154D-02	0.2408D 02	0.1288D-01	0.1761D 02
0.8000D-04	0.8124D 02	0.3407D-02	0.2359D 02	0.1362D-01	0.1745D 02
0.9000D-04	0.7796D 02	0.3672D-02	0.2313D 02	0.1440D-01	0.1731D 02
0.1000D-03	0.7513D 02	0.3951D-02	0.2269D 02	0.1521D-01	0.1717D 02
0.2000D-03	0.6112D 02	0.4243D-02	0.2228D 02	0.1607D-01	0.1704D 02
0.3050D-03	0.5253D 02	0.4550D-02	0.2190D 02	0.1697D-01	0.1692D 02
0.4152D-03	0.4676D 02	0.4873D-02	0.2153D 02	0.1764D-01	0.1683D 02

(T) BOUNDARY CONDITION

$H = 0.2 \qquad M = 8$

$f_{fd,0}Re = 21.497 \qquad Nu_{fd,0} = 3.8172$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.2776D 03	0.1692D-02	0.1189D 02	0.1362D-01	0.5480D 01
0.2000D-05	0.1646D 03	0.1871D-02	0.1143D 02	0.1440D-01	0.5381D 01
0.3000D-05	0.1294D 03	0.2060D-02	0.1100D 02	0.1521D-01	0.5285D 01
0.4000D-05	0.1137D 03	0.2258D-02	0.1061D 02	0.1607D-01	0.5193D 01
0.5000D-05	0.1044D 03	0.2466D-02	0.1025D 02	0.1697D-01	0.5105D 01
0.6000D-05	0.9791D 02	0.2684D-02	0.9923D 01	0.1791D-01	0.5019D 01
0.7000D-05	0.9279D 02	0.2913D-02	0.9613D 01	0.1890D-01	0.4937D 01
0.8000D-05	0.8855D 02	0.3154D-02	0.9325D 01	0.1990D-01	0.4860D 01
0.9000D-05	0.8493D 02	0.3407D-02	0.9054D 01	0.2090D-01	0.4789D 01
0.1000D-04	0.8178D 02	0.3672D-02	0.8799D 01	0.2190D-01	0.4724D 01
0.2000D-04	0.6631D 02	0.3951D-02	0.8558D 01	0.2290D-01	0.4663D 01
0.3000D-04	0.5742D 02	0.4243D-02	0.8331D 01	0.2390D-01	0.4607D 01
0.4000D-04	0.5166D 02	0.4550D-02	0.8115D 01	0.2490D-01	0.4554D 01
0.5000D-04	0.4754D 02	0.4873D-02	0.7910D 01	0.2590D-01	0.4504D 01
0.6000D-04	0.4438D 02	0.5211D-02	0.7714D 01	0.2690D-01	0.4458D 01
0.7000D-04	0.4182D 02	0.5567D-02	0.7527D 01	0.2790D-01	0.4415D 01
0.8000D-04	0.3968D 02	0.5940D-02	0.7349D 01	0.2890D-01	0.4374D 01
0.9000D-04	0.3785D 02	0.6332D-02	0.7178D 01	0.2990D-01	0.4335D 01
0.1000D-03	0.3625D 02	0.6744D-02	0.7014D 01	0.3090D-01	0.4299D 01
0.2000D-03	0.2847D 02	0.7176D-02	0.6857D 01	0.3190D-01	0.4265D 01
0.3050D-03	0.2396D 02	0.7630D-02	0.6707D 01	0.3290D-01	0.4232D 01
0.4152D-03	0.2105D 02	0.8106D-02	0.6562D 01	0.3390D-01	0.4201D 01
0.5310D-03	0.1901D 02	0.8607D-02	0.6423D 01	0.3490D-01	0.4172D 01
0.6526D-03	0.1747D 02	0.9132D-02	0.6289D 01	0.3590D-01	0.4145D 01
0.7802D-03	0.1624D 02	0.9684D-02	0.6160D 01	0.3690D-01	0.4118D 01
0.9142D-03	0.1523D 02	0.1026D-01	0.6036D 01	0.3790D-01	0.4093D 01
0.1055D-02	0.1437D 02	0.1087D-01	0.5916D 01	0.3890D-01	0.4069D 01
0.1203D-02	0.1363D 02	0.1151D-01	0.5801D 01	0.3990D-01	0.4047D 01
0.1358D-02	0.1299D 02	0.1218D-01	0.5690D 01	0.4090D-01	0.4025D 01
0.1521D-02	0.1241D 02	0.1288D-01	0.5583D 01	0.4173D-01	0.4008D 01

Ⓣ BOUNDARY CONDITION

$H = 0.4 \qquad M = 8$

$f_{fd,0}Re = 44.106 \qquad Nu_{fd,0} = 4.8041$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.4226D 03	0.1692D-02	0.1970D 02	0.1362D-01	0.7991D 01
0.2000D-05	0.2574D 03	0.1871D-02	0.1893D 02	0.1440D-01	0.7772D 01
0.3000D-05	0.2049D 03	0.2060D-02	0.1823D 02	0.1521D-01	0.7561D 01
0.4000D-05	0.1799D 03	0.2258D-02	0.1758D 02	0.1607D-01	0.7358D 01
0.5000D-05	0.1651D 03	0.2466D-02	0.1698D 02	0.1697D-01	0.7162D 01
0.6000D-05	0.1547D 03	0.2684D-02	0.1642D 02	0.1791D-01	0.6975D 01
0.7000D-05	0.1467D 03	0.2913D-02	0.1589D 02	0.1890D-01	0.6795D 01
0.8000D-05	0.1401D 03	0.3154D-02	0.1540D 02	0.1990D-01	0.6630D 01
0.9000D-05	0.1344D 03	0.3407D-02	0.1493D 02	0.2090D-01	0.6478D 01
0.1000D-04	0.1294D 03	0.3672D-02	0.1448D 02	0.2190D-01	0.6339D 01
0.2000D-04	0.1041D 03	0.3951D-02	0.1406D 02	0.2290D-01	0.6211D 01
0.3000D-04	0.8967D 02	0.4243D-02	0.1365D 02	0.2390D-01	0.6094D 01
0.4000D-04	0.8046D 02	0.4550D-02	0.1326D 02	0.2490D-01	0.5985D 01
0.5000D-04	0.7405D 02	0.4873D-02	0.1289D 02	0.2590D-01	0.5884D 01
0.6000D-04	0.6923D 02	0.5211D-02	0.1253D 02	0.2690D-01	0.5791D 01
0.7000D-04	0.6541D 02	0.5567D-02	0.1218D 02	0.2790D-01	0.5705D 01
0.8000D-04	0.6226D 02	0.5940D-02	0.1185D 02	0.2890D-01	0.5625D 01
0.9000D-04	0.5958D 02	0.6332D-02	0.1152D 02	0.2990D-01	0.5551D 01
0.1000D-03	0.5725D 02	0.6744D-02	0.1120D 02	0.3090D-01	0.5481D 01
0.2000D-03	0.4572D 02	0.7176D-02	0.1089D 02	0.3190D-01	0.5416D 01
0.3050D-03	0.3883D 02	0.7630D-02	0.1059D 02	0.3290D-01	0.5356D 01
0.4152D-03	0.3430D 02	0.8106D-02	0.1030D 02	0.3390D-01	0.5299D 01
0.5310D-03	0.3107D 02	0.8607D-02	0.1001D 02	0.3490D-01	0.5247D 01
0.6526D-03	0.2863D 02	0.9132D-02	0.9734D 01	0.3590D-01	0.5197D 01
0.7802D-03	0.2668D 02	0.9684D-02	0.9463D 01	0.3690D-01	0.5150D 01
0.9142D-03	0.2507D 02	0.1026D-01	0.9200D 01	0.3790D-01	0.5107D 01
0.1055D-02	0.2370D 02	0.1087D-01	0.8943D 01	0.3890D-01	0.5066D 01
0.1203D-02	0.2252D 02	0.1151D-01	0.8694D 01	0.3945D-01	0.5044D 01
0.1358D-02	0.2147D 02	0.1218D-01	0.8452D 01		
0.1521D-02	0.2054D 02	0.1288D-01	0.8218D 01		

(T) BOUNDARY CONDITION

$H = 0.6 \qquad M = 8$

$f_{fd,0}Re = 103.94 \qquad Nu_{fd,0} = 9.6035$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.6776D 03	0.2060D-02	0.3490D 02	0.1697D-01	0.1865D 02
0.2000D-05	0.4313D 03	0.2258D-02	0.3399D 02	0.1791D-01	0.1815D 02
0.3000D-05	0.3440D 03	0.2466D-02	0.3317D 02	0.1890D-01	0.1765D 02
0.4000D-05	0.2974D 03	0.2684D-02	0.3240D 02	0.1990D-01	0.1717D 02
0.5000D-05	0.2689D 03	0.2913D-02	0.3170D 02	0.2090D-01	0.1670D 02
0.6000D-05	0.2497D 03	0.3154D-02	0.3104D 02	0.2190D-01	0.1626D 02
0.7000D-05	0.2357D 03	0.3407D-02	0.3042D 02	0.2290D-01	0.1583D 02
0.8000D-05	0.2247D 03	0.3672D-02	0.2984D 02	0.2390D-01	0.1542D 02
0.9000D-05	0.2156D 03	0.3951D-02	0.2929D 02	0.2490D-01	0.1503D 02
0.1000D-04	0.2079D 03	0.4243D-02	0.2877D 02	0.2590D-01	0.1465D 02
0.2000D-04	0.1688D 03	0.4550D-02	0.2828D 02	0.2690D-01	0.1430D 02
0.3000D-04	0.1458D 03	0.4873D-02	0.2780D 02	0.2790D-01	0.1396D 02
0.4000D-04	0.1308D 03	0.5211D-02	0.2734D 02	0.2890D-01	0.1364D 02
0.5000D-04	0.1204D 03	0.5567D-02	0.2690D 02	0.2990D-01	0.1333D 02
0.6000D-04	0.1126D 03	0.5940D-02	0.2647D 02	0.3090D-01	0.1304D 02
0.7000D-04	0.1066D 03	0.6332D-02	0.2605D 02	0.3190D-01	0.1276D 02
0.8000D-04	0.1017D 03	0.6744D-02	0.2564D 02	0.3290D-01	0.1250D 02
0.9000D-04	0.9766D 02	0.7176D-02	0.2523D 02	0.3390D-01	0.1226D 02
0.1000D-03	0.9420D 02	0.7630D-02	0.2482D 02	0.3490D-01	0.1202D 02
0.2000D-03	0.7725D 02	0.8106D-02	0.2441D 02	0.3590D-01	0.1180D 02
0.3050D-03	0.6679D 02	0.8607D-02	0.2401D 02	0.3690D-01	0.1159D 02
0.4152D-03	0.5968D 02	0.9132D-02	0.2360D 02	0.3790D-01	0.1140D 02
0.5310D-03	0.5451D 02	0.9684D-02	0.2318D 02	0.3890D-01	0.1121D 02
0.6526D-03	0.5059D 02	0.1026D-01	0.2276D 02	0.3990D-01	0.1104D 02
0.7802D-03	0.4750D 02	0.1087D-01	0.2234D 02	0.4090D-01	0.1087D 02
0.9142D-03	0.4499D 02	0.1151D-01	0.2190D 02	0.4190D-01	0.1072D 02
0.1055D-02	0.4289D 02	0.1218D-01	0.2146D 02	0.4290D-01	0.1057D 02
0.1203D-02	0.4110D 02	0.1288D-01	0.2101D 02	0.4390D-01	0.1043D 02
0.1358D-02	0.3955D 02	0.1362D-01	0.2056D 02	0.4490D-01	0.1031D 02
0.1521D-02	0.3819D 02	0.1440D-01	0.2009D 02	0.4590D-01	0.1018D 02
0.1692D-02	0.3698D 02	0.1521D-01	0.1962D 02	0.4679D-01	0.1008D 02
0.1871D-02	0.3588D 02	0.1607D-01	0.1913D 02		

(T) BOUNDARY CONDITION

$H = 0.8 \qquad M = 8$

$f_{fd,0}Re = 166.01 \qquad Nu_{fd,0} = 34.381$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.9125D 03	0.3050D-03	0.9437D 02	0.3951D-02	0.4325D 02
0.2000D-05	0.5976D 03	0.4152D-03	0.8521D 02	0.4243D-02	0.4254D 02
0.3000D-05	0.4817D 03	0.5310D-03	0.7844D 02	0.4550D-02	0.4187D 02
0.4000D-05	0.4154D 03	0.6526D-03	0.7319D 02	0.4873D-02	0.4125D 02
0.5000D-05	0.3723D 03	0.7802D-03	0.6897D 02	0.5211D-02	0.4066D 02
0.6000D-05	0.3423D 03	0.9142D-03	0.6549D 02	0.5567D-02	0.4012D 02
0.7000D-05	0.3205D 03	0.1055D-02	0.6256D 02	0.5940D-02	0.3961D 02
0.8000D-05	0.3038D 03	0.1203D-02	0.6005D 02	0.6332D-02	0.3914D 02
0.9000D-05	0.2906D 03	0.1358D-02	0.5786D 02	0.6744D-02	0.3869D 02
0.1000D-04	0.2797D 03	0.1521D-02	0.5592D 02	0.7176D-02	0.3828D 02
0.2000D-04	0.2297D 03	0.1692D-02	0.5420D 02	0.7630D-02	0.3790D 02
0.3000D-04	0.2002D 03	0.1871D-02	0.5265D 02	0.8106D-02	0.3755D 02
0.4000D-04	0.1804D 03	0.2060D-02	0.5123D 02	0.8607D-02	0.3722D 02
0.5000D-04	0.1662D 03	0.2258D-02	0.4994D 02	0.9132D-02	0.3691D 02
0.6000D-04	0.1554D 03	0.2466D-02	0.4876D 02	0.9684D-02	0.3664D 02
0.7000D-04	0.1470D 03	0.2684D-02	0.4766D 02	0.1026D-01	0.3638D 02
0.8000D-04	0.1403D 03	0.2913D-02	0.4665D 02	0.1087D-01	0.3615D 02
0.9000D-04	0.1346D 03	0.3154D-02	0.4571D 02	0.1101D-01	0.3610D 02
0.1000D-03	0.1299D 03	0.3407D-02	0.4483D 02		
0.2000D-03	0.1078D 03	0.3672D-02	0.4401D 02		

(T) BOUNDARY CONDITION

$H = 0.2 \qquad M = 16$

$f_{fd,0}Re = 26.707 \qquad Nu_{fd,0} = 3.8115$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.3256D 03	0.1203D-02	0.1435D 02	0.9684D-02	0.5690D 01
0.2000D-05	0.1993D 03	0.1358D-02	0.1353D 02	0.1026D-01	0.5575D 01
0.3000D-05	0.1602D 03	0.1521D-02	0.1280D 02	0.1087D-01	0.5465D 01
0.4000D-05	0.1409D 03	0.1692D-02	0.1215D 02	0.1151D-01	0.5360D 01
0.5000D-05	0.1285D 03	0.1871D-02	0.1156D 02	0.1218D-01	0.5260D 01
0.6000D-05	0.1197D 03	0.2060D-02	0.1104D 02	0.1288D-01	0.5163D 01
0.7000D-05	0.1128D 03	0.2258D-02	0.1056D 02	0.1362D-01	0.5070D 01
0.8000D-05	0.1072D 03	0.2466D-02	0.1012D 02	0.1440D-01	0.4981D 01
0.9000D-05	0.1025D 03	0.2684D-02	0.9720D 01	0.1521D-01	0.4895D 01
0.1000D-04	0.9854D 02	0.2913D-02	0.9352D 01	0.1607D-01	0.4813D 01
0.2000D-04	0.7969D 02	0.3154D-02	0.9013D 01	0.1697D-01	0.4734D 01
0.3000D-04	0.6877D 02	0.3407D-02	0.8699D 01	0.1791D-01	0.4658D 01
0.4000D-04	0.6151D 02	0.3672D-02	0.8408D 01	0.1890D-01	0.4584D 01
0.5000D-04	0.5621D 02	0.3951D-02	0.8137D 01	0.1990D-01	0.4516D 01
0.6000D-04	0.5211D 02	0.4243D-02	0.7885D 01	0.2090D-01	0.4453D 01
0.7000D-04	0.4880D 02	0.4550D-02	0.7649D 01	0.2190D-01	0.4395D 01
0.8000D-04	0.4606D 02	0.4873D-02	0.7428D 01	0.2290D-01	0.4341D 01
0.9000D-04	0.4375D 02	0.5211D-02	0.7222D 01	0.2390D-01	0.4291D 01
0.1000D-03	0.4176D 02	0.5567D-02	0.7027D 01	0.2490D-01	0.4243D 01
0.2000D-03	0.3252D 02	0.5940D-02	0.6844D 01	0.2590D-01	0.4199D 01
0.3050D-03	0.2719D 02	0.6332D-02	0.6672D 01	0.2690D-01	0.4158D 01
0.4152D-03	0.2369D 02	0.6744D-02	0.6509D 01	0.2790D-01	0.4119D 01
0.5310D-03	0.2118D 02	0.7176D-02	0.6354D 01	0.2890D-01	0.4083D 01
0.6526D-03	0.1924D 02	0.7630D-02	0.6208D 01	0.2990D-01	0.4048D 01
0.7802D-03	0.1768D 02	0.8106D-02	0.6069D 01	0.3090D-01	0.4016D 01
0.9142D-03	0.1639D 02	0.8607D-02	0.5936D 01	0.3134D-01	0.4002D 01
0.1055D-02	0.1530D 02	0.9132D-02	0.5810D 01		

(T) BOUNDARY CONDITION

$H = 0.4 \qquad M = 16$

$f_{fd,0}Re = 72.332 \qquad Nu_{fd,0} = 4.3378$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.6172D 03	0.9142D-03	0.3498D 02	0.7630D-02	0.7292D 01
0.2000D-05	0.3906D 03	0.1055D-02	0.3242D 02	0.8106D-02	0.7045D 01
0.3000D-05	0.3129D 03	0.1203D-02	0.3008D 02	0.8607D-02	0.6821D 01
0.4000D-05	0.2726D 03	0.1358D-02	0.2794D 02	0.9132D-02	0.6616D 01
0.5000D-05	0.2476D 03	0.1521D-02	0.2596D 02	0.9684D-02	0.6430D 01
0.6000D-05	0.2302D 03	0.1692D-02	0.2412D 02	0.1026D-01	0.6258D 01
0.7000D-05	0.2170D 03	0.1871D-02	0.2241D 02	0.1087D-01	0.6100D 01
0.8000D-05	0.2066D 03	0.2060D-02	0.2083D 02	0.1151D-01	0.5954D 01
0.9000D-05	0.1979D 03	0.2258D-02	0.1936D 02	0.1218D-01	0.5817D 01
0.1000D-04	0.1905D 03	0.2466D-02	0.1800D 02	0.1288D-01	0.5690D 01
0.2000D-04	0.1550D 03	0.2684D-02	0.1675D 02	0.1362D-01	0.5571D 01
0.3000D-04	0.1345D 03	0.2913D-02	0.1560D 02	0.1440D-01	0.5458D 01
0.4000D-04	0.1209D 03	0.3154D-02	0.1455D 02	0.1521D-01	0.5352D 01
0.5000D-04	0.1112D 03	0.3407D-02	0.1359D 02	0.1607D-01	0.5252D 01
0.6000D-04	0.1037D 03	0.3672D-02	0.1272D 02	0.1697D-01	0.5157D 01
0.7000D-04	0.9776D 02	0.3951D-02	0.1193D 02	0.1791D-01	0.5066D 01
0.8000D-04	0.9280D 02	0.4243D-02	0.1121D 02	0.1890D-01	0.4980D 01
0.9000D-04	0.8861D 02	0.4550D-02	0.1057D 02	0.1990D-01	0.4901D 01
0.1000D-03	0.8499D 02	0.4873D-02	0.9988D 01	0.2090D-01	0.4829D 01
0.2000D-03	0.6754D 02	0.5211D-02	0.9468D 01	0.2190D-01	0.4762D 01
0.3050D-03	0.5717D 02	0.5567D-02	0.9001D 01	0.2290D-01	0.4701D 01
0.4152D-03	0.5025D 02	0.5940D-02	0.8582D 01	0.2390D-01	0.4644D 01
0.5310D-03	0.4518D 02	0.6332D-02	0.8206D 01	0.2490D-01	0.4592D 01
0.6526D-03	0.4118D 02	0.6744D-02	0.7869D 01	0.2566D-01	0.4555D 01
0.7802D-03	0.3786D 02	0.7176D-02	0.7565D 01		

(T) BOUNDARY CONDITION

$H = 0.6 \qquad M = 16$

$f_{fd,0}Re = 227.93 \qquad Nu_{fd,0} = 7.0331$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.1158D 04	0.6526D-03	0.9458D 02	0.5940D-02	0.2651D 02
0.2000D-05	0.7709D 03	0.7802D-03	0.8888D 02	0.6332D-02	0.2463D 02
0.3000D-05	0.6232D 03	0.9142D-03	0.8403D 02	0.6744D-02	0.2285D 02
0.4000D-05	0.5380D 03	0.1055D-02	0.7978D 02	0.7176D-02	0.2117D 02
0.5000D-05	0.4827D 03	0.1203D-02	0.7595D 02	0.7630D-02	0.1958D 02
0.6000D-05	0.4440D 03	0.1358D-02	0.7243D 02	0.8106D-02	0.1811D 02
0.7000D-05	0.4155D 03	0.1521D-02	0.6914D 02	0.8607D-02	0.1674D 02
0.8000D-05	0.3935D 03	0.1692D-02	0.6602D 02	0.9132D-02	0.1548D 02
0.9000D-05	0.3759D 03	0.1871D-02	0.6303D 02	0.9684D-02	0.1433D 02
0.1000D-04	0.3614D 03	0.2060D-02	0.6016D 02	0.1026D-01	0.1329D 02
0.2000D-04	0.2960D 03	0.2258D-02	0.5736D 02	0.1087D-01	0.1234D 02
0.3000D-04	0.2586D 03	0.2466D-02	0.5464D 02	0.1151D-01	0.1150D 02
0.4000D-04	0.2341D 03	0.2684D-02	0.5198D 02	0.1218D-01	0.1074D 02
0.5000D-04	0.2164D 03	0.2913D-02	0.4938D 02	0.1288D-01	0.1008D 02
0.6000D-04	0.2030D 03	0.3154D-02	0.4683D 02	0.1362D-01	0.9494D 01
0.7000D-04	0.1924D 03	0.3407D-02	0.4433D 02	0.1440D-01	0.8984D 01
0.8000D-04	0.1837D 03	0.3672D-02	0.4188D 02	0.1521D-01	0.8542D 01
0.9000D-04	0.1765D 03	0.3951D-02	0.3948D 02	0.1607D-01	0.8159D 01
0.1000D-03	0.1702D 03	0.4243D-02	0.3715D 02	0.1697D-01	0.7830D 01
0.2000D-03	0.1406D 03	0.4550D-02	0.3487D 02	0.1791D-01	0.7548D 01
0.3050D-03	0.1227D 03	0.4873D-02	0.3267D 02	0.1858D-01	0.7385D 01
0.4152D-03	0.1105D 03	0.5211D-02	0.3054D 02		
0.5310D-03	0.1016D 03	0.5567D-02	0.2848D 02		

(T) BOUNDARY CONDITION

$H = 0.8 \qquad M = 16$

$f_{fd,0}Re = 453.40 \qquad Nu_{fd,0} = 60.970$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.1889D 04	0.2913D-02	0.9327D 02	0.2490D-01	0.7640D 02
0.2000D-05	0.1224D 04	0.3154D-02	0.9188D 02	0.2590D-01	0.7613D 02
0.3000D-05	0.9579D 03	0.3407D-02	0.9063D 02	0.2690D-01	0.7586D 02
0.4000D-05	0.8177D 03	0.3672D-02	0.8950D 02	0.2790D-01	0.7557D 02
0.5000D-05	0.7316D 03	0.3951D-02	0.8847D 02	0.2890D-01	0.7529D 02
0.6000D-05	0.6731D 03	0.4243D-02	0.8755D 02	0.2990D-01	0.7500D 02
0.7000D-05	0.6303D 03	0.4550D-02	0.8671D 02	0.3090D-01	0.7470D 02
0.8000D-05	0.5972D 03	0.4873D-02	0.8594D 02	0.3190D-01	0.7439D 02
0.9000D-05	0.5707D 03	0.5211D-02	0.8525D 02	0.3290D-01	0.7408D 02
0.1000D-04	0.5488D 03	0.5567D-02	0.8462D 02	0.3390D-01	0.7377D 02
0.2000D-04	0.4517D 03	0.5940D-02	0.8404D 02	0.3490D-01	0.7344D 02
0.3000D-04	0.3969D 03	0.6332D-02	0.8351D 02	0.3590D-01	0.7312D 02
0.4000D-04	0.3610D 03	0.6744D-02	0.8303D 02	0.3690D-01	0.7278D 02
0.5000D-04	0.3351D 03	0.7176D-02	0.8258D 02	0.3790D-01	0.7244D 02
0.6000D-04	0.3153D 03	0.7630D-02	0.8218D 02	0.3890D-01	0.7209D 02
0.7000D-04	0.2995D 03	0.8106D-02	0.8180D 02	0.3990D-01	0.7174D 02
0.8000D-04	0.2864D 03	0.8607D-02	0.8145D 02	0.4090D-01	0.7138D 02
0.9000D-04	0.2753D 03	0.9132D-02	0.8113D 02	0.4190D-01	0.7102D 02
0.1000D-03	0.2657D 03	0.9684D-02	0.8083D 02	0.4290D-01	0.7065D 02
0.2000D-03	0.2181D 03	0.1026D-01	0.8055D 02	0.4390D-01	0.7028D 02
0.3050D-03	0.1886D 03	0.1087D-01	0.8029D 02	0.4490D-01	0.6990D 02
0.4152D-03	0.1686D 03	0.1151D-01	0.8003D 02	0.4590D-01	0.6952D 02
0.5310D-03	0.1541D 03	0.1218D-01	0.7979D 02	0.4690D-01	0.6913D 02
0.6526D-03	0.1431D 03	0.1288D-01	0.7956D 02	0.4790D-01	0.6874D 02
0.7802D-03	0.1345D 03	0.1362D-01	0.7933D 02	0.4890D-01	0.6835D 02
0.9142D-03	0.1275D 03	0.1440D-01	0.7910D 02	0.4990D-01	0.6795D 02
0.1055D-02	0.1217D 03	0.1521D-01	0.7888D 02	0.5090D-01	0.6755D 02
0.1203D-02	0.1168D 03	0.1607D-01	0.7865D 02	0.5190D-01	0.6715D 02
0.1358D-02	0.1126D 03	0.1697D-01	0.7842D 02	0.5290D-01	0.6674D 02
0.1521D-02	0.1090D 03	0.1791D-01	0.7818D 02	0.5390D-01	0.6633D 02
0.1692D-02	0.1058D 03	0.1890D-01	0.7793D 02	0.5490D-01	0.6592D 02
0.1871D-02	0.1031D 03	0.1990D-01	0.7768D 02	0.5590D-01	0.6551D 02
0.2060D-02	0.1006D 03	0.2090D-01	0.7743D 02	0.5690D-01	0.6509D 02
0.2258D-02	0.9848D 02	0.2190D-01	0.7718D 02	0.5790D-01	0.6468D 02
0.2466D-02	0.9655D 02	0.2290D-01	0.7693D 02	0.5890D-01	0.6426D 02
0.2684D-02	0.9482D 02	0.2390D-01	0.7667D 02	0.5910D-01	0.6418D 02

(T) BOUNDARY CONDITION

$H = 0.2 \qquad M = 24$

$f_{fd,0}Re = 30.253 \qquad Nu_{fd,0} = 3.7606$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.3679D 03	0.9142D-03	0.1486D 02	0.7630D-02	0.5717D 01
0.2000D-05	0.2273D 03	0.1055D-02	0.1369D 02	0.8106D-02	0.5601D 01
0.3000D-05	0.1851D 03	0.1203D-02	0.1273D 02	0.8607D-02	0.5489D 01
0.4000D-05	0.1635D 03	0.1358D-02	0.1191D 02	0.9132D-02	0.5382D 01
0.5000D-05	0.1493D 03	0.1521D-02	0.1122D 02	0.9684D-02	0.5280D 01
0.6000D-05	0.1388D 03	0.1692D-02	0.1063D 02	0.1026D-01	0.5181D 01
0.7000D-05	0.1307D 03	0.1871D-02	0.1011D 02	0.1087D-01	0.5086D 01
0.8000D-05	0.1240D 03	0.2060D-02	0.9650D 01	0.1151D-01	0.4995D 01
0.9000D-05	0.1185D 03	0.2258D-02	0.9242D 01	0.1218D-01	0.4907D 01
0.1000D-04	0.1137D 03	0.2466D-02	0.8877D 01	0.1288D-01	0.4822D 01
0.2000D-04	0.9104D 02	0.2684D-02	0.8548D 01	0.1362D-01	0.4741D 01
0.3000D-04	0.7772D 02	0.2913D-02	0.8249D 01	0.1440D-01	0.4662D 01
0.4000D-04	0.6882D 02	0.3154D-02	0.7975D 01	0.1521D-01	0.4586D 01
0.5000D-04	0.6237D 02	0.3407D-02	0.7724D 01	0.1607D-01	0.4513D 01
0.6000D-04	0.5743D 02	0.3672D-02	0.7492D 01	0.1697D-01	0.4442D 01
0.7000D-04	0.5351D 02	0.3951D-02	0.7277D 01	0.1791D-01	0.4373D 01
0.8000D-04	0.5030D 02	0.4243D-02	0.7076D 01	0.1890D-01	0.4307D 01
0.9000D-04	0.4762D 02	0.4550D-02	0.6889D 01	0.1990D-01	0.4246D 01
0.1000D-03	0.4534D 02	0.4873D-02	0.6713D 01	0.2090D-01	0.4189D 01
0.2000D-03	0.3449D 02	0.5211D-02	0.6547D 01	0.2190D-01	0.4136D 01
0.3050D-03	0.2799D 02	0.5567D-02	0.6390D 01	0.2290D-01	0.4087D 01
0.4152D-03	0.2362D 02	0.5940D-02	0.6242D 01	0.2390D-01	0.4041D 01
0.5310D-03	0.2048D 02	0.6332D-02	0.6101D 01	0.2490D-01	0.3998D 01
0.6526D-03	0.1813D 02	0.6744D-02	0.5967D 01	0.2590D-01	0.3958D 01
0.7802D-03	0.1631D 02	0.7176D-02	0.5839D 01	0.2615D-01	0.3949D 01

(T) BOUNDARY CONDITION

$H = 0.4 \qquad M = 24$

$f_{fd,0}Re = 88.975 \qquad Nu_{fd,0} = 4.0372$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.7769D 03	0.7802D-03	0.3110D 02	0.6744D-02	0.6100D 01
0.2000D-05	0.4889D 03	0.9142D-03	0.2629D 02	0.7176D-02	0.5964D 01
0.3000D-05	0.3958D 03	0.1055D-02	0.2245D 02	0.7630D-02	0.5835D 01
0.4000D-05	0.3490D 03	0.1203D-02	0.1938D 02	0.8106D-02	0.5712D 01
0.5000D-05	0.3193D 03	0.1358D-02	0.1695D 02	0.8607D-02	0.5595D 01
0.6000D-05	0.2977D 03	0.1521D-02	0.1502D 02	0.9132D-02	0.5484D 01
0.7000D-05	0.2810D 03	0.1692D-02	0.1349D 02	0.9684D-02	0.5377D 01
0.8000D-05	0.2673D 03	0.1871D-02	0.1226D 02	0.1026D-01	0.5275D 01
0.9000D-05	0.2558D 03	0.2060D-02	0.1128D 02	0.1087D-01	0.5177D 01
0.1000D-04	0.2460D 03	0.2258D-02	0.1049D 02	0.1151D-01	0.5083D 01
0.2000D-04	0.1990D 03	0.2466D-02	0.9845D 01	0.1218D-01	0.4992D 01
0.3000D-04	0.1717D 03	0.2684D-02	0.9308D 01	0.1288D-01	0.4905D 01
0.4000D-04	0.1538D 03	0.2913D-02	0.8856D 01	0.1362D-01	0.4822D 01
0.5000D-04	0.1408D 03	0.3154D-02	0.8470D 01	0.1440D-01	0.4741D 01
0.6000D-04	0.1309D 03	0.3407D-02	0.8134D 01	0.1521D-01	0.4664D 01
0.7000D-04	0.1230D 03	0.3672D-02	0.7838D 01	0.1607D-01	0.4589D 01
0.8000D-04	0.1164D 03	0.3951D-02	0.7574D 01	0.1697D-01	0.4517D 01
0.9000D-04	0.1109D 03	0.4243D-02	0.7336D 01	0.1791D-01	0.4448D 01
0.1000D-03	0.1061D 03	0.4550D-02	0.7118D 01	0.1890D-01	0.4381D 01
0.2000D-03	0.8180D 02	0.4873D-02	0.6917D 01	0.1990D-01	0.4319D 01
0.3050D-03	0.6576D 02	0.5211D-02	0.6732D 01	0.2090D-01	0.4262D 01
0.4152D-03	0.5386D 02	0.5567D-02	0.6559D 01	0.2133D-01	0.4239D 01
0.5310D-03	0.4455D 02	0.5940D-02	0.6397D 01		
0.6526D-03	0.3709D 02	0.6332D-02	0.6244D 01		

(T) BOUNDARY CONDITION

$H = 0.6 \qquad M = 24$

$f_{fd,0}Re = 328.55 \qquad Nu_{fd,0} = 5.6103$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.1587D 04	0.4152D-03	0.1439D 03	0.4550D-02	0.1344D 02
0.2000D-05	0.1047D 04	0.5310D-03	0.1269D 03	0.4873D-02	0.1220D 02
0.3000D-05	0.8459D 03	0.6526D-03	0.1128D 03	0.5211D-02	0.1114D 02
0.4000D-05	0.7343D 03	0.7802D-03	0.1008D 03	0.5567D-02	0.1025D 02
0.5000D-05	0.6633D 03	0.9142D-03	0.9021D 02	0.5940D-02	0.9498D 01
0.6000D-05	0.6141D 03	0.1055D-02	0.8089D 02	0.6332D-02	0.8871D 01
0.7000D-05	0.5776D 03	0.1203D-02	0.7257D 02	0.6744D-02	0.8347D 01
0.8000D-05	0.5492D 03	0.1358D-02	0.6509D 02	0.7176D-02	0.7909D 01
0.9000D-05	0.5261D 03	0.1521D-02	0.5834D 02	0.7630D-02	0.7544D 01
0.1000D-04	0.5068D 03	0.1692D-02	0.5223D 02	0.8106D-02	0.7238D 01
0.2000D-04	0.4159D 03	0.1871D-02	0.4670D 02	0.8607D-02	0.6980D 01
0.3000D-04	0.3630D 03	0.2060D-02	0.4170D 02	0.9132D-02	0.6760D 01
0.4000D-04	0.3282D 03	0.2258D-02	0.3718D 02	0.9684D-02	0.6571D 01
0.5000D-04	0.3032D 03	0.2466D-02	0.3312D 02	0.1026D-01	0.6406D 01
0.6000D-04	0.2843D 03	0.2684D-02	0.2947D 02	0.1087D-01	0.6261D 01
0.7000D-04	0.2693D 03	0.2913D-02	0.2622D 02	0.1151D-01	0.6130D 01
0.8000D-04	0.2570D 03	0.3154D-02	0.2333D 02	0.1218D-01	0.6012D 01
0.9000D-04	0.2467D 03	0.3407D-02	0.2078D 02	0.1288D-01	0.5904D 01
0.1000D-03	0.2379D 03	0.3672D-02	0.1854D 02	0.1298D-01	0.5891D 01
0.2000D-03	0.1940D 03	0.3951D-02	0.1658D 02		
0.3050D-03	0.1653D 03	0.4243D-02	0.1489D 02		

(T) BOUNDARY CONDITION

$H = 0.8 \qquad M = 24$

$f_{fd,0}Re = 852.82 \qquad Nu_{fd,0} = 37.212$

X^+	$Nu_{x,T}$	X^+	$Nu_{x,T}$	X^+	Nu_T
0.1000D-05	0.2570D 04	0.6526D-03	0.2163D 03	0.5940D-02	0.1121D 03
0.2000D-05	0.1753D 04	0.7802D-03	0.2040D 03	0.6332D-02	0.1089D 03
0.3000D-05	0.1458D 04	0.9142D-03	0.1941D 03	0.6744D-02	0.1055D 03
0.4000D-05	0.1281D 04	0.1055D-02	0.1858D 03	0.7176D-02	0.1020D 03
0.5000D-05	0.1158D 04	0.1203D-02	0.1787D 03	0.7630D-02	0.9839D 02
0.6000D-05	0.1068D 04	0.1358D-02	0.1726D 03	0.8106D-02	0.9463D 02
0.7000D-05	0.9976D 03	0.1521D-02	0.1673D 03	0.8607D-02	0.9073D 02
0.8000D-05	0.9419D 03	0.1692D-02	0.1625D 03	0.9132D-02	0.8672D 02
0.9000D-05	0.8965D 03	0.1871D-02	0.1582D 03	0.9684D-02	0.8260D 02
0.1000D-04	0.8589D 03	0.2060D-02	0.1543D 03	0.1026D-01	0.7841D 02
0.2000D-04	0.6979D 03	0.2258D-02	0.1507D 03	0.1087D-01	0.7416D 02
0.3000D-04	0.6094D 03	0.2466D-02	0.1473D 03	0.1151D-01	0.6991D 02
0.4000D-04	0.5520D 03	0.2684D-02	0.1442D 03	0.1218D-01	0.6568D 02
0.5000D-04	0.5106D 03	0.2913D-02	0.1411D 03	0.1288D-01	0.6153D 02
0.6000D-04	0.4786D 03	0.3154D-02	0.1382D 03	0.1362D-01	0.5750D 02
0.7000D-04	0.4528D 03	0.3407D-02	0.1353D 03	0.1440D-01	0.5363D 02
0.8000D-04	0.4314D 03	0.3672D-02	0.1325D 03	0.1521D-01	0.4997D 02
0.9000D-04	0.4132D 03	0.3951D-02	0.1297D 03	0.1607D-01	0.4655D 02
0.1000D-03	0.3976D 03	0.4243D-02	0.1269D 03	0.1697D-01	0.4340D 02
0.2000D-03	0.3245D 03	0.4550D-02	0.1241D 03	0.1791D-01	0.4054D 02
0.3050D-03	0.2810D 03	0.4873D-02	0.1212D 03	0.1848D-01	0.3907D 02
0.4152D-03	0.2522D 03	0.5211D-02	0.1183D 03		
0.5310D-03	0.2317D 03	0.5567D-02	0.1152D 03		

APPENDIX B

Numerical Values of $f_x Re$, $f_{app} Re$ and K for all Geometries

The Smooth Tube Geometry

$f_{fd,0} Re = 15.98$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.975130D 03	0.975127D 03	0.383658D-02
0.210000D-05	0.101690D 04	0.997034D 03	0.824083D-02
0.331000D-05	0.106230D 04	0.102090D 04	0.133051D-01
0.464100D-05	0.111030D 04	0.104654D 04	0.191313D-01
0.610511D-05	0.115880D 04	0.107346D 04	0.258241D-01
0.771562D-05	0.120250D 04	0.110039D 04	0.334675D-01
0.948719D-05	0.123000D 04	0.112459D 04	0.420703D-01
0.114359D-04	0.121830D 04	0.114056D 04	0.514422D-01
0.135795D-04	0.113020D 04	0.113892D 04	0.609957D-01
0.159375D-04	0.936590D 03	0.110898D 04	0.696786D-01
0.185312D-04	0.676170D 03	0.104840D 04	0.765277D-01
0.213843D-04	0.449970D 03	0.968560D 03	0.814808D-01
0.245228D-04	0.312270D 03	0.884567D 03	0.852004D-01
0.279751D-04	0.246370D 03	0.805809D 03	0.883818D-01
0.317726D-04	0.218970D 03	0.735669D 03	0.914652D-01
0.359499D-04	0.208320D 03	0.674392D 03	0.946790D-01
0.405449D-04	0.204050D 03	0.621088D 03	0.981357D-01
0.455994D-04	0.201890D 03	0.574621D 03	0.101894D 00
0.511593D-04	0.200180D 03	0.533927D 03	0.105991D 00
0.572753D-04	0.198300D 03	0.498088D 03	0.110451D 00
0.640028D-04	0.196000D 03	0.466335D 03	0.115295D 00
0.714031D-04	0.193130D 03	0.438020D 03	0.120539D 00
0.795435D-04	0.189600D 03	0.412597D 03	0.126192D 00
0.884978D-04	0.185320D 03	0.389601D 03	0.132257D 00
0.983477D-04	0.180260D 03	0.368635D 03	0.138730D 00
0.109182D-03	0.174400D 03	0.349359D 03	0.145595D 00
0.121101D-03	0.167770D 03	0.331488D 03	0.152832D 00
0.134211D-03	0.160500D 03	0.314785D 03	0.160410D 00
0.148632D-03	0.152720D 03	0.299061D 03	0.168298D 00
0.164495D-03	0.144680D 03	0.284173D 03	0.176464D 00
0.181945D-03	0.136600D 03	0.270020D 03	0.184883D 00
0.201139D-03	0.128720D 03	0.256536D 03	0.193538D 00
0.222253D-03	0.121240D 03	0.243682D 03	0.202427D 00
0.245479D-03	0.114280D 03	0.231439D 03	0.211560D 00
0.271027D-03	0.107910D 03	0.219795D 03	0.220954D 00
0.299130D-03	0.102110D 03	0.208739D 03	0.230636D 00
0.330043D-03	0.968360D 02	0.198258D 03	0.240634D 00
0.364047D-03	0.920130D 02	0.188334D 03	0.250975D 00
0.401452D-03	0.875760D 02	0.178946D 03	0.261687D 00
0.442597D-03	0.834310D 02	0.170066D 03	0.272787D 00
0.487857D-03	0.795630D 02	0.161670D 03	0.284298D 00
0.537643D-03	0.759370D 02	0.153731D 03	0.296237D 00
0.592408D-03	0.724890D 02	0.146221D 03	0.308616D 00
0.652649D-03	0.692460D 02	0.139116D 03	0.321451D 00
0.718914D-03	0.661790D 02	0.132393D 03	0.334755D 00
0.791805D-03	0.632760D 02	0.126030D 03	0.348543D 00
0.871986D-03	0.605270D 02	0.120007D 03	0.362830D 00
0.960185D-03	0.579240D 02	0.114304D 03	0.377625D 00
0.105720D-02	0.554560D 02	0.108904D 03	0.392944D 00
0.116392D-02	0.531160D 02	0.103789D 03	0.408797D 00
0.128132D-02	0.508970D 02	0.989429D 02	0.425193D 00
0.141045D-02	0.487920D 02	0.943513D 02	0.442138D 00
0.155250D-02	0.467930D 02	0.900000D 02	0.459646D 00
0.170875D-02	0.448970D 02	0.858758D 02	0.477717D 00
0.188062D-02	0.430970D 02	0.819661D 02	0.496357D 00
0.206968D-02	0.413890D 02	0.782594D 02	0.515569D 00
0.227765D-02	0.397670D 02	0.747447D 02	0.535354D 00
0.250642D-02	0.382270D 02	0.714117D 02	0.555710D 00
0.275806D-02	0.367660D 02	0.682506D 02	0.576629D 00
0.303487D-02	0.353790D 02	0.652525D 02	0.598106D 00
0.333936D-02	0.340630D 02	0.624086D 02	0.620127D 00
0.367429D-02	0.328150D 02	0.597109D 02	0.642676D 00
0.404273D-02	0.316310D 02	0.571518D 02	0.665737D 00
0.444800D-02	0.305080D 02	0.547242D 02	0.689283D 00
0.489380D-02	0.294430D 02	0.524212D 02	0.713285D 00
0.538418D-02	0.284340D 02	0.502365D 02	0.737708D 00
0.592360D-02	0.274790D 02	0.481641D 02	0.762512D 00
0.651697D-02	0.265740D 02	0.461983D 02	0.787649D 00

0.716966D-02	0.257180D 02	0.443338D 02	0.813062D 00
0.788763D-02	0.249080D 02	0.425656D 02	0.838695D 00
0.867740D-02	0.241430D 02	0.408889D 02	0.864474D 00
0.954614D-02	0.234200D 02	0.392992D 02	0.890319D 00
0.105018D-01	0.227390D 02	0.377922D 02	0.916143D 00
0.115018D-01	0.221240D 02	0.364300D 02	0.940709D 00
0.125018D-01	0.215880D 02	0.352428D 02	0.963129D 00
0.135018D-01	0.211160D 02	0.341965D 02	0.983660D 00
0.145018D-01	0.206990D 02	0.332657D 02	0.100252D 01
0.155018D-01	0.203260D 02	0.324310D 02	0.101989D 01
0.165018D-01	0.199930D 02	0.316773D 02	0.103594D 01
0.175018D-01	0.196920D 02	0.309925D 02	0.105077D 01
0.185018D-01	0.194190D 02	0.303669D 02	0.106451D 01
0.195018D-01	0.191720D 02	0.297929D 02	0.107727D 01
0.205018D-01	0.189460D 02	0.292638D 02	0.108912D 01
0.215018D-01	0.187400D 02	0.287744D 02	0.110015D 01
0.225018D-01	0.185500D 02	0.283200D 02	0.111042D 01
0.235018D-01	0.183760D 02	0.278969D 02	0.111999D 01
0.245018D-01	0.182160D 02	0.275018D 02	0.112893D 01
0.255018D-01	0.180680D 02	0.271319D 02	0.113727D 01
0.265018D-01	0.179300D 02	0.267847D 02	0.114506D 01
0.275018D-01	0.178030D 02	0.264581D 02	0.115234D 01
0.285018D-01	0.176860D 02	0.261503D 02	0.115915D 01
0.295018D-01	0.175760D 02	0.258597D 02	0.116552D 01
0.305018D-01	0.174740D 02	0.255848D 02	0.117149D 01
0.315018D-01	0.173800D 02	0.253243D 02	0.117707D 01
0.325018D-01	0.172910D 02	0.250771D 02	0.118230D 01
0.335018D-01	0.172090D 02	0.248423D 02	0.118721D 01
0.345018D-01	0.171320D 02	0.246188D 02	0.119180D 01
0.355018D-01	0.170600D 02	0.244059D 02	0.119611D 01
0.365018D-01	0.169930D 02	0.242028D 02	0.120015D 01
0.375018D-01	0.169310D 02	0.240089D 02	0.120394D 01
0.385018D-01	0.168720D 02	0.238235D 02	0.120749D 01
0.395018D-01	0.168170D 02	0.236462D 02	0.121084D 01
0.405018D-01	0.167660D 02	0.234763D 02	0.121397D 01
0.415018D-01	0.167170D 02	0.233134D 02	0.121690D 01
0.425018D-01	0.166720D 02	0.231572D 02	0.121967D 01
0.435018D-01	0.166300D 02	0.230071D 02	0.122224D 01
0.445018D-01	0.165910D 02	0.228629D 02	0.122467D 01
0.455018D-01	0.165530D 02	0.227243D 02	0.122697D 01
0.465018D-01	0.165190D 02	0.225908D 02	0.122910D 01
0.475018D-01	0.164860D 02	0.224623D 02	0.123111D 01
0.485018D-01	0.164550D 02	0.223385D 02	0.123301D 01
0.495018D-01	0.164270D 02	0.222190D 02	0.123477D 01
0.505018D-01	0.164000D 02	0.221038D 02	0.123645D 01
0.515018D-01	0.163740D 02	0.219926D 02	0.123802D 01
0.525018D-01	0.163510D 02	0.218851D 02	0.123948D 01
0.535018D-01	0.163280D 02	0.217812D 02	0.124086D 01
0.545018D-01	0.163070D 02	0.216808D 02	0.124216D 01
0.555018D-01	0.162880D 02	0.215836D 02	0.124337D 01
0.565018D-01	0.162690D 02	0.214896D 02	0.124453D 01
0.575018D-01	0.162520D 02	0.213985D 02	0.124560D 01
0.585018D-01	0.162360D 02	0.213102D 02	0.124660D 01
0.595018D-01	0.162200D 02	0.212247D 02	0.124756D 01
0.605018D-01	0.162060D 02	0.211417D 02	0.124844D 01
0.615018D-01	0.161920D 02	0.210613D 02	0.124930D 01
0.625018D-01	0.161800D 02	0.209832D 02	0.125009D 01
0.635018D-01	0.161680D 02	0.209073D 02	0.125081D 01
0.645018D-01	0.161570D 02	0.208337D 02	0.125152D 01
0.655018D-01	0.161460D 02	0.207621D 02	0.125216D 01
0.658471D-01	0.161428D 02	0.207382D 02	0.125246D 01

$H = 0.2 \qquad M = 4$

$f_{fd,0}Re = 18.60$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.975130D 03	0.975127D 03	0.383658D-02
0.210000D-05	0.101690D 04	0.997034D 03	0.824083D-02
0.100000D-05	0.108920D 04	0.108918D 04	0.428233D-02
0.210000D-05	0.113290D 04	0.111210D 04	0.918542D-02
0.331000D-05	0.118040D 04	0.113705D 04	0.148083D-01
0.464100D-05	0.123040D 04	0.116383D 04	0.212601D-01
0.610511D-05	0.128070D 04	0.119186D 04	0.286516D-01
0.771562D-05	0.132520D 04	0.121969D 04	0.370687D-01
0.948719D-05	0.135100D 04	0.124422D 04	0.465108D-01
0.114359D-04	0.133220D 04	0.125921D 04	0.567501D-01
0.135795D-04	0.123030D 04	0.125465D 04	0.671399D-01
0.159375D-04	0.102830D 04	0.122116D 04	0.766633D-01
0.185312D-04	0.778470D 03	0.115920D 04	0.845469D-01
0.213843D-04	0.568910D 03	0.108044D 04	0.908270D-01
0.245228D-04	0.440290D 03	0.998513D 03	0.961210D-01
0.279751D-04	0.377770D 03	0.921910D 03	0.101081D 00
0.317726D-04	0.352230D 03	0.853821D 03	0.106149D 00
0.359499D-04	0.343450D 03	0.794517D 03	0.111577D 00
0.405449D-04	0.340900D 03	0.743108D 03	0.117501D 00
0.455994D-04	0.339490D 03	0.698369D 03	0.123989D 00
0.511593D-04	0.336460D 03	0.659037D 03	0.131058D 00
0.572753D-04	0.329860D 03	0.623887D 03	0.138672D 00
0.640028D-04	0.318290D 03	0.591764D 03	0.146737D 00
0.714031D-04	0.301480D 03	0.561679D 03	0.155111D 00
0.795435D-04	0.280930D 03	0.532947D 03	0.163652D 00
0.884978D-04	0.259420D 03	0.505272D 03	0.172278D 00
0.983477D-04	0.239700D 03	0.478674D 03	0.180990D 00
0.109182D-03	0.223240D 03	0.453325D 03	0.189857D 00
0.121101D-03	0.210050D 03	0.429383D 03	0.198986D 00
0.134211D-03	0.199240D 03	0.406902D 03	0.208459D 00
0.148632D-03	0.189720D 03	0.385829D 03	0.218329D 00
0.164495D-03	0.180690D 03	0.366046D 03	0.228614D 00
0.181945D-03	0.171750D 03	0.347413D 03	0.239305D 00
0.201139D-03	0.162840D 03	0.329799D 03	0.250379D 00
0.222253D-03	0.154070D 03	0.313105D 03	0.261820D 00
0.245479D-03	0.145610D 03	0.297258D 03	0.273621D 00
0.271027D-03	0.137610D 03	0.282209D 03	0.285783D 00
0.299130D-03	0.130140D 03	0.267923D 03	0.298322D 00
0.330043D-03	0.123220D 03	0.254369D 03	0.311258D 00
0.364047D-03	0.116800D 03	0.241519D 03	0.324615D 00
0.401452D-03	0.110830D 03	0.229343D 03	0.338416D 00
0.442597D-03	0.105270D 03	0.217808D 03	0.352679D 00
0.487857D-03	0.100050D 03	0.206883D 03	0.367425D 00
0.537643D-03	0.951420D 02	0.196536D 03	0.382668D 00
0.592408D-03	0.905190D 02	0.186735D 03	0.398423D 00
0.652649D-03	0.861590D 02	0.177452D 03	0.414704D 00
0.718914D-03	0.820420D 02	0.168657D 03	0.431518D 00
0.791805D-03	0.781570D 02	0.160326D 03	0.448884D 00
0.871986D-03	0.744890D 02	0.152433D 03	0.466809D 00
0.960185D-03	0.710280D 02	0.144956D 03	0.485308D 00
0.105720D-02	0.677620D 02	0.137872D 03	0.504386D 00
0.116392D-02	0.646800D 02	0.131161D 03	0.524057D 00
0.128132D-02	0.617730D 02	0.124804D 03	0.544335D 00
0.141045D-02	0.590300D 02	0.118782D 03	0.565218D 00
0.155250D-02	0.564430D 02	0.113078D 03	0.586721D 00
0.170875D-02	0.540010D 02	0.107676D 03	0.608848D 00
0.188062D-02	0.516970D 02	0.102560D 03	0.631602D 00
0.206968D-02	0.495230D 02	0.977151D 02	0.654988D 00
0.227765D-02	0.474710D 02	0.931274D 02	0.679007D 00
0.250642D-02	0.455340D 02	0.887834D 02	0.703656D 00
0.275806D-02	0.437050D 02	0.846704D 02	0.728926D 00
0.303487D-02	0.419770D 02	0.807765D 02	0.754815D 00
0.333936D-02	0.403460D 02	0.770900D 02	0.781303D 00
0.367429D-02	0.388060D 02	0.736001D 02	0.808375D 00
0.404273D-02	0.373510D 02	0.702966D 02	0.836014D 00
0.444800D-02	0.359780D 02	0.671697D 02	0.864188D 00
0.489380D-02	0.346810D 02	0.642101D 02	0.892866D 00
0.538418D-02	0.334560D 02	0.614091D 02	0.922011D 00
0.592360D-02	0.323000D 02	0.587583D 02	0.951574D 00

0.651697D-02	0.312100D 02	0.562501D 02	0.981510D 00
0.716966D-02	0.301810D 02	0.538768D 02	0.101175D 01
0.788763D-02	0.292110D 02	0.516316D 02	0.104223D 01
0.867740D-02	0.282970D 02	0.495078D 02	0.107287D 01
0.954614D-02	0.274350D 02	0.474991D 02	0.110358D 01
0.105018D-01	0.266240D 02	0.455996D 02	0.113426D 01
0.115018D-01	0.258930D 02	0.438862D 02	0.116344D 01
0.125018D-01	0.252560D 02	0.423960D 02	0.119007D 01
0.135018D-01	0.246970D 02	0.410852D 02	0.121447D 01
0.145018D-01	0.242020D 02	0.399209D 02	0.123688D 01
0.155018D-01	0.237600D 02	0.388784D 02	0.125753D 01
0.165018D-01	0.233650D 02	0.379383D 02	0.127660D 01
0.175018D-01	0.230080D 02	0.370853D 02	0.129424D 01
0.185018D-01	0.226850D 02	0.363070D 02	0.131059D 01
0.195018D-01	0.223920D 02	0.355934D 02	0.132576D 01
0.205018D-01	0.221250D 02	0.349365D 02	0.133987D 01
0.215018D-01	0.218800D 02	0.343292D 02	0.135300D 01
0.225018D-01	0.216550D 02	0.337660D 02	0.136523D 01
0.235018D-01	0.214490D 02	0.332419D 02	0.137663D 01
0.245018D-01	0.212590D 02	0.327528D 02	0.138727D 01
0.255018D-01	0.210830D 02	0.322952D 02	0.139721D 01
0.265018D-01	0.209200D 02	0.318660D 02	0.140650D 01
0.275018D-01	0.207700D 02	0.314625D 02	0.141519D 01
0.285018D-01	0.206300D 02	0.310825D 02	0.142332D 01
0.295018D-01	0.205000D 02	0.307238D 02	0.143093D 01
0.305018D-01	0.203790D 02	0.303846D 02	0.143805D 01
0.315018D-01	0.202670D 02	0.300634D 02	0.144472D 01
0.325018D-01	0.201620D 02	0.297588D 02	0.145098D 01
0.335018D-01	0.200640D 02	0.294694D 02	0.145684D 01
0.345018D-01	0.199730D 02	0.291942D 02	0.146235D 01
0.355018D-01	0.198880D 02	0.289320D 02	0.146750D 01
0.365018D-01	0.198080D 02	0.286821D 02	0.147235D 01
0.375018D-01	0.197330D 02	0.284434D 02	0.147688D 01
0.385018D-01	0.196640D 02	0.282154D 02	0.148115D 01
0.395018D-01	0.195980D 02	0.279973D 02	0.148516D 01
0.405018D-01	0.195370D 02	0.277884D 02	0.148891D 01
0.415018D-01	0.194800D 02	0.275882D 02	0.149244D 01
0.425018D-01	0.194260D 02	0.273961D 02	0.149574D 01
0.435018D-01	0.193760D 02	0.272118D 02	0.149886D 01
0.445018D-01	0.193290D 02	0.270346D 02	0.150177D 01
0.455018D-01	0.192840D 02	0.268643D 02	0.150452D 01
0.465018D-01	0.192430D 02	0.267004D 02	0.150710D 01
0.475018D-01	0.192040D 02	0.265426D 02	0.150953D 01
0.485018D-01	0.191670D 02	0.263905D 02	0.151180D 01
0.495018D-01	0.191330D 02	0.262439D 02	0.151394D 01
0.505018D-01	0.191010D 02	0.261025D 02	0.151596D 01
0.515018D-01	0.190700D 02	0.259659D 02	0.151784D 01
0.525018D-01	0.190420D 02	0.258340D 02	0.151961D 01
0.535018D-01	0.190150D 02	0.257066D 02	0.152129D 01
0.545018D-01	0.189900D 02	0.255834D 02	0.152287D 01
0.555018D-01	0.189670D 02	0.254642D 02	0.152434D 01
0.565018D-01	0.189450D 02	0.253488D 02	0.152573D 01
0.575018D-01	0.189240D 02	0.252370D 02	0.152702D 01
0.585018D-01	0.189040D 02	0.251288D 02	0.152825D 01
0.595018D-01	0.188860D 02	0.250239D 02	0.152941D 01
0.605018D-01	0.188690D 02	0.249221D 02	0.153048D 01
0.615018D-01	0.188530D 02	0.248234D 02	0.153149D 01
0.625018D-01	0.188370D 02	0.247277D 02	0.153247D 01
0.635018D-01	0.188230D 02	0.246347D 02	0.153336D 01
0.645018D-01	0.188100D 02	0.245444D 02	0.153421D 01
0.655018D-01	0.187970D 02	0.244566D 02	0.153499D 01
0.665018D-01	0.187850D 02	0.243713D 02	0.153574D 01
0.665841D-01	0.187841D 02	0.243645D 02	0.153583D 01

$H = 0.4 \qquad M = 4$

$f_{fd,0}Re = 27.79$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.122930D 04	0.122926D 04	0.480589D-02
0.210000D-05	0.127240D 04	0.125188D 04	0.102824D-01
0.331000D-05	0.131870D 04	0.127630D 04	0.165303D-01
0.464100D-05	0.136660D 04	0.130220D 04	0.236582D-01
0.610511D-05	0.141350D 04	0.132889D 04	0.317735D-01
0.771562D-05	0.145320D 04	0.135484D 04	0.409561D-01
0.948719D-05	0.147300D 04	0.137691D 04	0.511975D-01
0.114359D-04	0.144910D 04	0.138922D 04	0.622768D-01
0.135795D-04	0.134830D 04	0.138275D 04	0.735989D-01
0.159375D-04	0.115730D 04	0.134939D 04	0.842522D-01
0.185312D-04	0.923070D 03	0.128972D 04	0.935405D-01
0.213843D-04	0.724330D 03	0.121429D 04	0.101490D 00
0.245228D-04	0.599270D 03	0.113558D 04	0.108665D 00
0.279751D-04	0.535700D 03	0.106155D 04	0.115678D 00
0.317726D-04	0.506200D 03	0.995172D 03	0.122945D 00
0.359499D-04	0.490350D 03	0.936512D 03	0.130674D 00
0.405449D-04	0.476830D 03	0.884416D 03	0.138928D 00
0.455994D-04	0.460360D 03	0.837411D 03	0.147673D 00
0.511593D-04	0.439280D 03	0.794142D 03	0.156825D 00
0.572753D-04	0.414060D 03	0.753557D 03	0.166275D 00
0.640028D-04	0.386050D 03	0.714927D 03	0.175916D 00
0.714031D-04	0.356870D 03	0.677817D 03	0.185657D 00
0.795435D-04	0.328430D 03	0.642061D 03	0.195446D 00
0.884978D-04	0.302720D 03	0.607726D 03	0.205293D 00
0.983477D-04	0.281070D 03	0.575010D 03	0.215272D 00
0.109182D-03	0.263650D 03	0.544112D 03	0.225494D 00
0.121101D-03	0.249630D 03	0.515130D 03	0.236071D 00
0.134211D-03	0.237770D 03	0.488036D 03	0.247082D 00
0.148632D-03	0.227000D 03	0.462709D 03	0.258573D 00
0.164495D-03	0.216680D 03	0.438982D 03	0.270558D 00
0.181945D-03	0.206530D 03	0.416689D 03	0.283035D 00
0.201139D-03	0.196550D 03	0.395681D 03	0.295991D 00
0.222253D-03	0.186800D 03	0.375837D 03	0.309421D 00
0.245479D-03	0.177430D 03	0.357065D 03	0.323323D 00
0.271027D-03	0.168530D 03	0.339293D 03	0.337706D 00
0.299130D-03	0.160180D 03	0.322466D 03	0.352589D 00
0.330043D-03	0.152390D 03	0.306536D 03	0.367997D 00
0.364047D-03	0.145140D 03	0.291461D 03	0.383959D 00
0.401452D-03	0.138380D 03	0.277198D 03	0.400506D 00
0.442597D-03	0.132070D 03	0.263706D 03	0.417668D 00
0.487857D-03	0.126150D 03	0.250944D 03	0.435475D 00
0.537643D-03	0.120580D 03	0.238872D 03	0.453953D 00
0.592408D-03	0.115320D 03	0.227451D 03	0.473130D 00
0.652649D-03	0.110350D 03	0.216642D 03	0.493024D 00
0.718914D-03	0.105650D 03	0.206412D 03	0.513664D 00
0.791805D-03	0.101200D 03	0.196726D 03	0.535067D 00
0.871986D-03	0.969760D 02	0.187554D 03	0.557258D 00
0.960185D-03	0.929710D 02	0.178866D 03	0.580255D 00
0.105720D-02	0.891700D 02	0.170635D 03	0.604076D 00
0.116392D-02	0.855600D 02	0.162834D 03	0.628736D 00
0.128132D-02	0.821320D 02	0.155440D 03	0.654257D 00
0.141045D-02	0.788740D 02	0.148430D 03	0.680644D 00
0.155250D-02	0.757770D 02	0.141783D 03	0.707915D 00
0.170875D-02	0.728330D 02	0.135478D 03	0.736068D 00
0.188062D-02	0.700330D 02	0.129497D 03	0.765111D 00
0.206968D-02	0.673720D 02	0.123822D 03	0.795047D 00
0.227765D-02	0.648400D 02	0.118436D 03	0.825867D 00
0.250642D-02	0.624340D 02	0.113325D 03	0.857577D 00
0.275806D-02	0.601460D 02	0.108473D 03	0.890147D 00
0.303487D-02	0.579720D 02	0.103867D 03	0.923572D 00
0.333940D-02	0.559060D 02	0.994940D 02	0.957833D 00
0.367430D-02	0.539440D 02	0.953410D 02	0.992855D 00
0.404270D-02	0.520820D 02	0.913990D 02	0.102866D 01
0.444800D-02	0.503170D 02	0.876560D 02	0.106519D 01
0.489380D-02	0.486450D 02	0.841020D 02	0.110238D 01
0.538420D-02	0.470620D 02	0.807290D 02	0.114020D 01
0.592360D-02	0.455670D 02	0.775270D 02	0.117856D 01
0.651700D-02	0.441560D 02	0.744880D 02	0.121740D 01
0.716970D-02	0.428260D 02	0.716060D 02	0.125668D 01

0.788760D-02	0.415740D 02	0.688720D 02	0.129625D 01
0.867740D-02	0.403980D 02	0.662810D 02	0.133611D 01
0.954610D-02	0.392940D 02	0.638250D 02	0.137609D 01
0.105020D-01	0.382590D 02	0.614980D 02	0.141613D 01
0.115020D-01	0.373300D 02	0.593970D 02	0.145431D 01
0.125020D-01	0.365230D 02	0.575680D 02	0.148929D 01
0.135020D-01	0.358170D 02	0.559570D 02	0.152141D 01
0.145020D-01	0.351920D 02	0.545250D 02	0.155102D 01
0.155020D-01	0.346370D 02	0.532420D 02	0.157841D 01
0.165020D-01	0.341390D 02	0.520840D 02	0.160380D 01
0.175020D-01	0.336900D 02	0.510330D 02	0.162741D 01
0.185018D-01	0.332840D 02	0.500738D 02	0.164938D 01
0.195018D-01	0.329140D 02	0.491939D 02	0.166989D 01
0.205018D-01	0.325760D 02	0.483833D 02	0.168904D 01
0.215018D-01	0.322660D 02	0.476337D 02	0.170696D 01
0.225018D-01	0.319810D 02	0.469381D 02	0.172374D 01
0.235018D-01	0.317180D 02	0.462905D 02	0.173946D 01
0.245018D-01	0.314750D 02	0.456858D 02	0.175421D 01
0.255018D-01	0.312490D 02	0.451197D 02	0.176806D 01
0.265018D-01	0.310400D 02	0.445884D 02	0.178107D 01
0.275018D-01	0.308450D 02	0.440887D 02	0.179330D 01
0.285018D-01	0.306630D 02	0.436176D 02	0.180480D 01
0.295018D-01	0.304930D 02	0.431727D 02	0.181562D 01
0.305018D-01	0.303350D 02	0.427519D 02	0.182583D 01
0.315018D-01	0.301860D 02	0.423530D 02	0.183542D 01
0.325018D-01	0.300470D 02	0.419744D 02	0.184446D 01
0.335018D-01	0.299170D 02	0.416144D 02	0.185297D 01
0.345018D-01	0.297950D 02	0.412719D 02	0.186101D 01
0.355018D-01	0.296800D 02	0.409453D 02	0.186857D 01
0.365018D-01	0.295720D 02	0.406337D 02	0.187571D 01
0.375018D-01	0.294700D 02	0.403361D 02	0.188245D 01
0.385018D-01	0.293750D 02	0.400514D 02	0.188881D 01
0.395018D-01	0.292850D 02	0.397788D 02	0.189479D 01
0.405018D-01	0.292000D 02	0.395176D 02	0.190044D 01
0.415018D-01	0.291210D 02	0.392671D 02	0.190578D 01
0.425018D-01	0.290460D 02	0.390266D 02	0.191081D 01
0.435018D-01	0.289750D 02	0.387955D 02	0.191556D 01
0.445018D-01	0.289080D 02	0.385734D 02	0.192006D 01
0.455018D-01	0.288450D 02	0.383596D 02	0.192429D 01
0.465018D-01	0.287860D 02	0.381537D 02	0.192828D 01
0.475018D-01	0.287300D 02	0.379553D 02	0.193205D 01
0.485018D-01	0.286780D 02	0.377640D 02	0.193561D 01
0.495018D-01	0.286280D 02	0.375795D 02	0.193898D 01
0.505018D-01	0.285810D 02	0.374013D 02	0.194216D 01
0.515018D-01	0.285370D 02	0.372292D 02	0.194516D 01
0.525018D-01	0.284850D 02	0.370628D 02	0.194798D 01
0.535018D-01	0.284560D 02	0.369019D 02	0.195065D 01
0.545018D-01	0.284180D 02	0.367463D 02	0.195319D 01
0.555018D-01	0.283830D 02	0.365956D 02	0.195557D 01
0.565018D-01	0.283500D 02	0.364497D 02	0.195783D 01
0.575018D-01	0.283190D 02	0.363083D 02	0.195996D 01
0.585018D-01	0.282890D 02	0.361712D 02	0.196196D 01
0.595018D-01	0.282610D 02	0.360383D 02	0.196387D 01
0.605018D-01	0.282350D 02	0.359093D 02	0.196565D 01
0.615018D-01	0.282100D 02	0.357841D 02	0.196734D 01
0.625018D-01	0.281870D 02	0.356625D 02	0.196893D 01
0.635018D-01	0.281650D 02	0.355445D 02	0.197046D 01
0.645018D-01	0.281440D 02	0.354297D 02	0.197187D 01
0.655018D-01	0.281240D 02	0.353182D 02	0.197323D 01
0.665018D-01	0.281050D 02	0.352097D 02	0.197449D 01
0.675018D-01	0.280870D 02	0.351042D 02	0.197570D 01
0.685018D-01	0.280710D 02	0.350015D 02	0.197682D 01
0.688975D-01	0.280646D 02	0.349620D 02	0.197736D 01

$H = 0.6 \qquad M = 4$

$f_{fd,0}Re = 47.99$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-06	0.139553D 04	0.139553D 04	0.539016D-03
0.210000D-06	0.139955D 04	0.139763D 04	0.113370D-02
0.331000D-06	0.140475D 04	0.140023D 04	0.179037D-02
0.464100D-06	0.141041D 04	0.140315D 04	0.251572D-02
0.610511D-06	0.141663D 04	0.140639D 04	0.331728D-02
0.771562D-06	0.142344D 04	0.140995D 04	0.420335D-02
0.948718D-06	0.143089D 04	0.141386D 04	0.518331D-02
0.114359D-05	0.143904D 04	0.141815D 04	0.626761D-02
0.135795D-05	0.144794D 04	0.142285D 04	0.746797D-02
0.159375D-05	0.145765D 04	0.142800D 04	0.879757D-02
0.185312D-05	0.146823D 04	0.143363D 04	0.102710D-01
0.213843D-05	0.147972D 04	0.143978D 04	0.119050D-01
0.245228D-05	0.149219D 04	0.144649D 04	0.137181D-01
0.279751D-05	0.150566D 04	0.145379D 04	0.157310D-01
0.317726D-05	0.152017D 04	0.146172D 04	0.179672D-01
0.359499D-05	0.153569D 04	0.147032D 04	0.204531D-01
0.405449D-05	0.155217D 04	0.147960D 04	0.232178D-01
0.455994D-05	0.156949D 04	0.148956D 04	0.262939D-01
0.511593D-05	0.158740D 04	0.150019D 04	0.297174D-01
0.572753D-05	0.160547D 04	0.151143D 04	0.335276D-01
0.640028D-05	0.162302D 04	0.152316D 04	0.377660D-01
0.714031D-05	0.163894D 04	0.153516D 04	0.424754D-01
0.795435D-05	0.165145D 04	0.154706D 04	0.476965D-01
0.884978D-05	0.165780D 04	0.155827D 04	0.534626D-01
0.983476D-05	0.165377D 04	0.156783D 04	0.597891D-01
0.109182D-04	0.163317D 04	0.157432D 04	0.666591D-01
0.121101D-04	0.158775D 04	0.157564D 04	0.740000D-01
0.134211D-04	0.150873D 04	0.156910D 04	0.816599D-01
0.148632D-04	0.139168D 04	0.155189D 04	0.894111D-01
0.164495D-04	0.124315D 04	0.152211D 04	0.969942D-01
0.181945D-04	0.108262D 04	0.147996D 04	0.104216D 00
0.201139D-04	0.934821D 03	0.142794D 04	0.111025D 00
0.222253D-04	0.817011D 03	0.136990D 04	0.117519D 00
0.245479D-04	0.732116D 03	0.130956D 04	0.123876D 00
0.271027D-04	0.672848D 03	0.124954D 04	0.130261D 00
0.299130D-04	0.629890D 03	0.119133D 04	0.136803D 00
0.330043D-04	0.596247D 03	0.113559D 04	0.143582D 00
0.364047D-04	0.567928D 03	0.108257D 04	0.150654D 00
0.401452D-04	0.542702D 03	0.103226D 04	0.158055D 00
0.442597D-04	0.519209D 03	0.984569D 03	0.165811D 00
0.487857D-04	0.496495D 03	0.939289D 03	0.173931D 00
0.537643D-04	0.473795D 03	0.896184D 03	0.182410D 00
0.592408D-04	0.450515D 03	0.854984D 03	0.191228D 00
0.652649D-04	0.426296D 03	0.815415D 03	0.200344D 00
0.718914D-04	0.401281D 03	0.777243D 03	0.209708D 00
0.791805D-04	0.376206D 03	0.740325D 03	0.219278D 00
0.871986D-04	0.352246D 03	0.704640D 03	0.229036D 00
0.960185D-04	0.330537D 03	0.670276D 03	0.239004D 00
0.105720D-03	0.311691D 03	0.637369D 03	0.249237D 00
0.116392D-03	0.295672D 03	0.606039D 03	0.259810D 00
0.128132D-03	0.281940D 03	0.576345D 03	0.270797D 00
0.141045D-03	0.269763D 03	0.548276D 03	0.282252D 00
0.155250D-03	0.258482D 03	0.521762D 03	0.294213D 00
0.170875D-03	0.247638D 03	0.496695D 03	0.306691D 00
0.188062D-03	0.237000D 03	0.472961D 03	0.319684D 00
0.206968D-03	0.226514D 03	0.450449D 03	0.333185D 00
0.227765D-03	0.216241D 03	0.429063D 03	0.347181D 00
0.250642D-03	0.206291D 03	0.408731D 03	0.361668D 00
0.275806D-03	0.196769D 03	0.389391D 03	0.376643D 00
0.303487D-03	0.187750D 03	0.371000D 03	0.392119D 00
0.333936D-03	0.179265D 03	0.353517D 03	0.408107D 00
0.367429D-03	0.171309D 03	0.336908D 03	0.424629D 00
0.404272D-03	0.163852D 03	0.321136D 03	0.441703D 00
0.444800D-03	0.156853D 03	0.306168D 03	0.459352D 00
0.489380D-03	0.150269D 03	0.291966D 03	0.477590D 00
0.538418D-03	0.144061D 03	0.278495D 03	0.496434D 00
0.592360D-03	0.138196D 03	0.265719D 03	0.515898D 00
0.651696D-03	0.132648D 03	0.253603D 03	0.535991D 00
0.716966D-03	0.127395D 03	0.242114D 03	0.556724D 00

0.788763D-03	0.122418D 03	0.231219D 03	0.578100D 00
0.867740D-03	0.117701D 03	0.220887D 03	0.600122D 00
0.954614D-03	0.113231D 03	0.211090D 03	0.622794D 00
0.105018D-02	0.108993D 03	0.201799D 03	0.646113D 00
0.115529D-02	0.104975D 03	0.192989D 03	0.670068D 00
0.127092D-02	0.101165D 03	0.184635D 03	0.694665D 00
0.139812D-02	0.975534D 02	0.176713D 03	0.719886D 00
0.153803D-02	0.941293D 02	0.169200D 03	0.745705D 00
0.169193D-02	0.908835D 02	0.162076D 03	0.772109D 00
0.186123D-02	0.878073D 02	0.155321D 03	0.799078D 00
0.204745D-02	0.848925D 02	0.148915D 03	0.826564D 00
0.225230D-02	0.821316D 02	0.142841D 03	0.854541D 00
0.247763D-02	0.795173D 02	0.137082D 03	0.882958D 00
0.272549D-02	0.770433D 02	0.131622D 03	0.911764D 00
0.299814D-02	0.747036D 02	0.126446D 03	0.940900D 00
0.329805D-02	0.724931D 02	0.121540D 03	0.970300D 00
0.362796D-02	0.704067D 02	0.116890D 03	0.999880D 00
0.399086D-02	0.684401D 02	0.112484D 03	0.102956D 01
0.439005D-02	0.665895D 02	0.108311D 03	0.105927D 01
0.482915D-02	0.648517D 02	0.104359D 03	0.108888D 01
0.531217D-02	0.632240D 02	0.100619D 03	0.111832D 01
0.584349D-02	0.617039D 02	0.970807D 02	0.114747D 01
0.642794D-02	0.602896D 02	0.937355D 02	0.117622D 01
0.707084D-02	0.589793D 02	0.905754D 02	0.120449D 01
0.777802D-02	0.577714D 02	0.875929D 02	0.123216D 01
0.855593D-02	0.566641D 02	0.847808D 02	0.125915D 01
0.941162D-02	0.556549D 02	0.821327D 02	0.128539D 01
0.103529D-01	0.547410D 02	0.796423D 02	0.131081D 01
0.113529D-01	0.539419D 02	0.773785D 02	0.133462D 01
0.123529D-01	0.532775D 02	0.754275D 02	0.135578D 01
0.133529D-01	0.527201D 02	0.737269D 02	0.137470D 01
0.143529D-01	0.522483D 02	0.722305D 02	0.139174D 01
0.153529D-01	0.518456D 02	0.709027D 02	0.140717D 01
0.163529D-01	0.514991D 02	0.697161D 02	0.142120D 01
0.173529D-01	0.511986D 02	0.686490D 02	0.143404D 01
0.183529D-01	0.509359D 02	0.676839D 02	0.144583D 01
0.193529D-01	0.507047D 02	0.668065D 02	0.145669D 01
0.203529D-01	0.504996D 02	0.660053D 02	0.146674D 01
0.213529D-01	0.503166D 02	0.652706D 02	0.147605D 01
0.223529D-01	0.501522D 02	0.645942D 02	0.148470D 01
0.233529D-01	0.500038D 02	0.639695D 02	0.149276D 01
0.243529D-01	0.498690D 02	0.633905D 02	0.150028D 01
0.253529D-01	0.497460D 02	0.628523D 02	0.150731D 01
0.263529D-01	0.496333D 02	0.623507D 02	0.151389D 01
0.273529D-01	0.495297D 02	0.618819D 02	0.152004D 01
0.283529D-01	0.494340D 02	0.614429D 02	0.152583D 01
0.293529D-01	0.493454D 02	0.610308D 02	0.153126D 01
0.303529D-01	0.492632D 02	0.606431D 02	0.153635D 01
0.313529D-01	0.491867D 02	0.602777D 02	0.154115D 01
0.323529D-01	0.491153D 02	0.599327D 02	0.154565D 01
0.333529D-01	0.490487D 02	0.596063D 02	0.154988D 01
0.343529D-01	0.489864D 02	0.592972D 02	0.155388D 01
0.353529D-01	0.489281D 02	0.590039D 02	0.155763D 01
0.363529D-01	0.488734D 02	0.587252D 02	0.156117D 01
0.373529D-01	0.488220D 02	0.584601D 02	0.156450D 01
0.383529D-01	0.487738D 02	0.582075D 02	0.156764D 01
0.393529D-01	0.487285D 02	0.579667D 02	0.157061D 01
0.403529D-01	0.486859D 02	0.577367D 02	0.157339D 01
0.413529D-01	0.486459D 02	0.575168D 02	0.157601D 01
0.423529D-01	0.486081D 02	0.573065D 02	0.157849D 01
0.433529D-01	0.485726D 02	0.571050D 02	0.158082D 01
0.443530D-01	0.485390D 02	0.569120D 02	0.158387D 01
0.453530D-01	0.485080D 02	0.567270D 02	0.158518D 01
0.463530D-01	0.484780D 02	0.565490D 02	0.158713D 01
0.466859D-01	0.484687D 02	0.564921D 02	0.158790D 01

$H = 0.8$ $M = 4$

$f_{fd,0}Re = 71.38$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-06	0.175239D 04	0.175239D 04	0.672405D-03
0.210000D-06	0.175971D 04	0.175622D 04	0.141527D-02
0.331000D-06	0.176839D 04	0.176067D 04	0.223662D-02
0.464100D-06	0.177793D 04	0.176562D 04	0.314519D-02
0.610511D-06	0.178837D 04	0.177108D 04	0.415075D-02
0.771562D-06	0.179977D 04	0.177707D 04	0.526419D-02
0.948718D-06	0.181222D 04	0.178363D 04	0.649778D-02
0.114359D-05	0.182575D 04	0.179081D 04	0.786531D-02
0.135795D-05	0.184042D 04	0.179864D 04	0.938215D-02
0.159375D-05	0.185620D 04	0.180716D 04	0.110656D-01
0.185312D-05	0.187299D 04	0.181637D 04	0.129347D-01
0.213843D-05	0.189048D 04	0.182626D 04	0.150108D-01
0.245228D-05	0.190799D 04	0.183672D 04	0.173165D-01
0.279751D-05	0.192413D 04	0.184751D 04	0.198750D-01
0.317726D-05	0.193624D 04	0.185811D 04	0.227077D-01
0.359499D-05	0.193999D 04	0.186763D 04	0.258300D-01
0.405449D-05	0.193144D 04	0.187486D 04	0.292488D-01
0.455994D-05	0.191224D 04	0.187900D 04	0.329706D-01
0.511593D-05	0.189071D 04	0.188027D 04	0.370167D-01
0.572753D-05	0.187322D 04	0.187952D 04	0.414248D-01
0.640028D-05	0.185988D 04	0.187746D 04	0.462377D-01
0.714031D-05	0.184787D 04	0.187439D 04	0.514963D-01
0.795435D-05	0.183444D 04	0.187030D 04	0.572371D-01
0.884978D-05	0.181681D 04	0.186489D 04	0.634888D-01
0.983476D-05	0.179159D 04	0.185755D 04	0.702663D-01
0.109182D-04	0.175398D 04	0.184727D 04	0.775582D-01
0.121101D-04	0.169737D 04	0.183252D 04	0.853105D-01
0.134211D-04	0.161412D 04	0.181119D 04	0.934008D-01
0.148632D-04	0.149897D 04	0.178089D 04	0.101635D 00
0.164495D-04	0.135492D 04	0.173981D 04	0.109780D 00
0.181945D-04	0.119679D 04	0.168773D 04	0.117635D 00
0.201139D-04	0.104624D 04	0.162652D 04	0.125120D 00
0.222253D-04	0.920674D 03	0.155946D 04	0.132292D 00
0.245479D-04	0.825663D 03	0.149004D 04	0.139301D 00
0.271027D-04	0.756746D 03	0.142091D 04	0.146304D 00
0.299130D-04	0.706075D 03	0.135375D 04	0.153438D 00
0.330043D-04	0.666742D 03	0.128941D 04	0.160801D 00
0.364047D-04	0.634156D 03	0.122820D 04	0.168455D 00
0.401452D-04	0.605464D 03	0.117018D 04	0.176447D 00
0.442597D-04	0.578972D 03	0.111522D 04	0.184801D 00
0.487857D-04	0.553624D 03	0.106312D 04	0.193532D 00
0.537643D-04	0.528677D 03	0.101363D 04	0.202638D 00
0.592408D-04	0.503574D 03	0.966477D 03	0.212106D 00
0.652649D-04	0.477953D 03	0.921385D 03	0.221903D 00
0.718914D-04	0.451810D 03	0.878102D 03	0.231986D 00
0.791805D-04	0.425646D 03	0.836450D 03	0.242315D 00
0.871986D-04	0.400390D 03	0.796354D 03	0.252868D 00
0.960185D-04	0.377044D 03	0.757837D 03	0.263651D 00
0.105720D-03	0.356272D 03	0.720986D 03	0.274707D 00
0.116392D-03	0.338196D 03	0.685888D 03	0.286097D 00
0.128132D-03	0.322459D 03	0.652591D 03	0.297888D 00
0.141045D-03	0.308458D 03	0.621084D 03	0.310134D 00
0.155250D-03	0.295581D 03	0.591302D 03	0.322873D 00
0.170875D-03	0.283362D 03	0.563144D 03	0.336123D 00
0.188062D-03	0.271521D 03	0.536492D 03	0.349882D 00
0.206968D-03	0.259950D 03	0.511230D 03	0.364142D 00
0.227765D-03	0.248661D 03	0.487255D 03	0.378890D 00
0.250642D-03	0.237726D 03	0.464480D 03	0.394112D 00
0.275806D-03	0.227235D 03	0.442834D 03	0.409800D 00
0.303487D-03	0.217259D 03	0.422260D 03	0.425954D 00
0.333936D-03	0.207843D 03	0.402709D 03	0.442575D 00
0.367429D-03	0.198968D 03	0.384136D 03	0.459667D 00
0.404272D-03	0.190640D 03	0.366502D 03	0.477243D 00
0.444800D-03	0.182814D 03	0.349766D 03	0.495310D 00
0.489380D-03	0.175450D 03	0.333886D 03	0.513867D 00
0.538418D-03	0.168509D 03	0.318824D 03	0.532920D 00
0.592360D-03	0.161956D 03	0.304539D 03	0.552463D 00
0.651696D-03	0.155763D 03	0.290993D 03	0.572491D 00
0.716966D-03	0.149909D 03	0.278150D 03	0.592997D 00

0.788763D-03	0.144372D 03	0.265973D 03	0.613961D 00
0.867740D-03	0.139138D 03	0.254429D 03	0.635366D 00
0.954614D-03	0.134190D 03	0.243486D 03	0.657191D 00
0.105018D-02	0.129516D 03	0.233116D 03	0.679420D 00
0.115529D-02	0.125103D 03	0.223288D 03	0.702005D 00
0.127092D-02	0.120938D 03	0.213976D 03	0.724928D 00
0.139812D-02	0.117012D 03	0.205155D 03	0.748151D 00
0.153803D-02	0.113314D 03	0.196800D 03	0.771617D 00
0.169193D-02	0.109832D 03	0.188889D 03	0.795288D 00
0.186123D-02	0.106560D 03	0.181401D 03	0.819120D 00
0.204745D-02	0.103486D 03	0.174314D 03	0.843033D 00
0.225230D-02	0.100603D 03	0.167610D 03	0.866982D 00
0.247763D-02	0.979024D 02	0.161270D 03	0.890886D 00
0.272549D-02	0.953763D 02	0.155278D 03	0.914685D 00
0.299814D-02	0.930174D 02	0.149616D 03	0.938286D 00
0.329805D-02	0.908185D 02	0.144269D 03	0.961606D 00
0.362796D-02	0.887729D 02	0.139222D 03	0.984556D 00
0.399086D-02	0.868741D 02	0.134462D 03	0.100705D 01
0.439005D-02	0.851160D 02	0.129975D 03	0.102899D 01
0.482915D-02	0.834928D 02	0.125749D 03	0.105028D 01
0.531217D-02	0.819989D 02	0.121771D 03	0.107081D 01
0.584349D-02	0.806292D 02	0.118030D 03	0.109047D 01
0.642794D-02	0.793787D 02	0.114516D 03	0.110918D 01
0.707084D-02	0.782428D 02	0.111218D 03	0.112684D 01
0.777802D-02	0.772168D 02	0.108126D 03	0.114334D 01
0.855593D-02	0.762962D 02	0.105232D 03	0.115864D 01
0.941162D-02	0.754766D 02	0.102527D 03	0.117269D 01
0.103529D-01	0.747530D 02	0.100002D 03	0.118541D 01
0.113529D-01	0.741379D 02	0.977235D 02	0.119644D 01
0.123529D-01	0.736420D 02	0.957741D 02	0.120550D 01
0.133529D-01	0.732397D 02	0.940865D 02	0.121295D 01
0.143529D-01	0.729117D 02	0.926112D 02	0.121909D 01
0.153529D-01	0.726434D 02	0.913106D 02	0.122415D 01
0.163529D-01	0.724232D 02	0.901556D 02	0.122834D 01
0.173529D-01	0.722420D 02	0.891233D 02	0.123180D 01
0.183529D-01	0.720927D 02	0.881953D 02	0.123466D 01
0.183648D-01	0.720912D 02	0.881853D 02	0.123472D 01

$H = 0.2$ $M = 8$

$f_{fd,0}Re = 21.66$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.146760D 04	0.146760D 04	0.578374D-02
0.210000D-05	0.153034D 04	0.150047D 04	0.124220D-01
0.331000D-05	0.159819D 04	0.153619D 04	0.200523D-01
0.464100D-05	0.166904D 04	0.157429D 04	0.288229D-01
0.610511D-05	0.173675D 04	0.161325D 04	0.388672D-01
0.771562D-05	0.178345D 04	0.164878D 04	0.502168D-01
0.948719D-05	0.177001D 04	0.167141D 04	0.626058D-01
0.114359D-04	0.167184D 04	0.167149D 04	0.754690D-01
0.135795D-04	0.151370D 04	0.164658D 04	0.882622D-01
0.159375D-04	0.130422D 04	0.159593D 04	0.100359D 00
0.185312D-04	0.106151D 04	0.152113D 04	0.111148D 00
0.213843D-04	0.832848D 03	0.142930D 04	0.120405D 00
0.245228D-04	0.653364D 03	0.132999D 04	0.128335D 00
0.279751D-04	0.529290D 03	0.123118D 04	0.135345D 00
0.317726D-04	0.453165D 03	0.113819D 04	0.141900D 00
0.359499D-04	0.411601D 03	0.105376D 04	0.148415D 00
0.405449D-04	0.388724D 03	0.978393D 03	0.155162D 00
0.455994D-04	0.372673D 03	0.911251D 03	0.162259D 00
0.511593D-04	0.357864D 03	0.851110D 03	0.169736D 00
0.572753D-04	0.342970D 03	0.796850D 03	0.177596D 00
0.640028D-04	0.328307D 03	0.747600D 03	0.185848D 00
0.714031D-04	0.314307D 03	0.702693D 03	0.194510D 00
0.795435D-04	0.301079D 03	0.661592D 03	0.203608D 00
0.884978D-04	0.288486D 03	0.623841D 03	0.213165D 00
0.983477D-04	0.276325D 03	0.589036D 03	0.223199D 00
0.109182D-03	0.264425D 03	0.556823D 03	0.233719D 00
0.121101D-03	0.252685D 03	0.526891D 03	0.244734D 00
0.134211D-03	0.241064D 03	0.498970D 03	0.256239D 00
0.148632D-03	0.229569D 03	0.472832D 03	0.268232D 00
0.164495D-03	0.218247D 03	0.448280D 03	0.280705D 00
0.181945D-03	0.207175D 03	0.425157D 03	0.293654D 00
0.201139D-03	0.196408D 03	0.403328D 03	0.307070D 00
0.222253D-03	0.186052D 03	0.382687D 03	0.320954D 00
0.245479D-03	0.176172D 03	0.363148D 03	0.335309D 00
0.271027D-03	0.166818D 03	0.344641D 03	0.350142D 00
0.299130D-03	0.158012D 03	0.327107D 03	0.365469D 00
0.330043D-03	0.149752D 03	0.310496D 03	0.381308D 00
0.364047D-03	0.142015D 03	0.294758D 03	0.397676D 00
0.401452D-03	0.134766D 03	0.279851D 03	0.414599D 00
0.442597D-03	0.127964D 03	0.265731D 03	0.432093D 00
0.487857D-03	0.121570D 03	0.252357D 03	0.450181D 00
0.537643D-03	0.115549D 03	0.239689D 03	0.468878D 00
0.592408D-03	0.109873D 03	0.227688D 03	0.488201D 00
0.652649D-03	0.104519D 03	0.216319D 03	0.508166D 00
0.718914D-03	0.994670D 02	0.205548D 03	0.528787D 00
0.791805D-03	0.947011D 02	0.195344D 03	0.550083D 00
0.871986D-03	0.902069D 02	0.185677D 03	0.572068D 00
0.960185D-03	0.859709D 02	0.176518D 03	0.594754D 00
0.105720D-02	0.819806D 02	0.167842D 03	0.618158D 00
0.116392D-02	0.782236D 02	0.159625D 03	0.642302D 00
0.128132D-02	0.746883D 02	0.151843D 03	0.667204D 00
0.141045D-02	0.713623D 02	0.144475D 03	0.692875D 00
0.155250D-02	0.682341D 02	0.137499D 03	0.719335D 00
0.170875D-02	0.652914D 02	0.130897D 03	0.746608D 00
0.188062D-02	0.625221D 02	0.124648D 03	0.774695D 00
0.206968D-02	0.599133D 02	0.118734D 03	0.803615D 00
0.227765D-02	0.574528D 02	0.113139D 03	0.833392D 00
0.250642D-02	0.551286D 02	0.107844D 03	0.864013D 00
0.275806D-02	0.529286D 02	0.102834D 03	0.895487D 00
0.303487D-02	0.508428D 02	0.980915D 02	0.927790D 00
0.333936D-02	0.488628D 02	0.936028D 02	0.960918D 00
0.367429D-02	0.469799D 02	0.893528D 02	0.994833D 00
0.404273D-02	0.451893D 02	0.853280D 02	0.102951D 01
0.444800D-02	0.434865D 02	0.815157D 02	0.106488D 01
0.489380D-02	0.418684D 02	0.779040D 02	0.110091D 01
0.538418D-02	0.403323D 02	0.744820D 02	0.113753D 01
0.592360D-02	0.388760D 02	0.712396D 02	0.117466D 01
0.651697D-02	0.374972D 02	0.681674D 02	0.121225D 01
0.716966D-02	0.361936D 02	0.652566D 02	0.125018D 01

0.788763D-02	0.349620D 02	0.624991D 02	0.128837D 01
0.867740D-02	0.338009D 02	0.598871D 02	0.132671D 01
0.954614D-02	0.327056D 02	0.574135D 02	0.136508D 01
0.105018D-01	0.316744D 02	0.550713D 02	0.140335D 01
0.115018D-01	0.307459D 02	0.529564D 02	0.143968D 01
0.125018D-01	0.299381D 02	0.511152D 02	0.147277D 01
0.135018D-01	0.292293D 02	0.494942D 02	0.150303D 01
0.145018D-01	0.286026D 02	0.480536D 02	0.153079D 01
0.155018D-01	0.280449D 02	0.467629D 02	0.155631D 01
0.165018D-01	0.275459D 02	0.455983D 02	0.157984D 01
0.175018D-01	0.270971D 02	0.445412D 02	0.160157D 01
0.185018D-01	0.266916D 02	0.435765D 02	0.162168D 01
0.195018D-01	0.263240D 02	0.426918D 02	0.164032D 01
0.205018D-01	0.259894D 02	0.418771D 02	0.165762D 01
0.215018D-01	0.256839D 02	0.411240D 02	0.167370D 01
0.225018D-01	0.254042D 02	0.404254D 02	0.168866D 01
0.235018D-01	0.251476D 02	0.397753D 02	0.170259D 01
0.245018D-01	0.249115D 02	0.391687D 02	0.171559D 01
0.255018D-01	0.246938D 02	0.386011D 02	0.172771D 01
0.265018D-01	0.244928D 02	0.380687D 02	0.173902D 01
0.275018D-01	0.243069D 02	0.375683D 02	0.174959D 01
0.285018D-01	0.241347D 02	0.370970D 02	0.175947D 01
0.295018D-01	0.239749D 02	0.366522D 02	0.176872D 01
0.305018D-01	0.238265D 02	0.362317D 02	0.177736D 01
0.315018D-01	0.236884D 02	0.358336D 02	0.178547D 01
0.325018D-01	0.235600D 02	0.354559D 02	0.179305D 01
0.335018D-01	0.234403D 02	0.350973D 02	0.180016D 01
0.345018D-01	0.233286D 02	0.347562D 02	0.180682D 01
0.355018D-01	0.232245D 02	0.344313D 02	0.181305D 01
0.365018D-01	0.231272D 02	0.341217D 02	0.181891D 01
0.375018D-01	0.230364D 02	0.338261D 02	0.182440D 01
0.385018D-01	0.229514D 02	0.335436D 02	0.182954D 01
0.395018D-01	0.228719D 02	0.332735D 02	0.183438D 01
0.405018D-01	0.227976D 02	0.330148D 02	0.183891D 01
0.415018D-01	0.227280D 02	0.327669D 02	0.184316D 01
0.425018D-01	0.226628D 02	0.325292D 02	0.184716D 01
0.435018D-01	0.226017D 02	0.323010D 02	0.185091D 01
0.445018D-01	0.225445D 02	0.320818D 02	0.185444D 01
0.455018D-01	0.224908D 02	0.318710D 02	0.185775D 01
0.465018D-01	0.224405D 02	0.316682D 02	0.186085D 01
0.475018D-01	0.223933D 02	0.314729D 02	0.186376D 01
0.485018D-01	0.223491D 02	0.312848D 02	0.186650D 01
0.495018D-01	0.223075D 02	0.311035D 02	0.186909D 01
0.505018D-01	0.222686D 02	0.309285D 02	0.187150D 01
0.515018D-01	0.222320D 02	0.307597D 02	0.187378D 01
0.525018D-01	0.221977D 02	0.305966D 02	0.187591D 01
0.535018D-01	0.221655D 02	0.304390D 02	0.187791D 01
0.545018D-01	0.221352D 02	0.302866D 02	0.187979D 01
0.555018D-01	0.221068D 02	0.301393D 02	0.188158D 01
0.565018D-01	0.220801D 02	0.299966D 02	0.188323D 01
0.575018D-01	0.220550D 02	0.298585D 02	0.188479D 01
0.585018D-01	0.220315D 02	0.297247D 02	0.188626D 01
0.595018D-01	0.220094D 02	0.295951D 02	0.188766D 01
0.605018D-01	0.219886D 02	0.294693D 02	0.188894D 01
0.615018D-01	0.219691D 02	0.293474D 02	0.189017D 01
0.625018D-01	0.219508D 02	0.292290D 02	0.189130D 01
0.635018D-01	0.219335D 02	0.291142D 02	0.189240D 01
0.645018D-01	0.219173D 02	0.290026D 02	0.189341D 01
0.655018D-01	0.219021D 02	0.288942D 02	0.189436D 01
0.665018D-01	0.218878D 02	0.287888D 02	0.189525D 01
0.670395D-01	0.218806D 02	0.287337D 02	0.189580D 01

$H = 0.4 \qquad M = 8$

$f_{fd,0}Re = 44.73$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.205263D 04	0.205263D 04	0.803158D-02
0.210000D-05	0.213414D 04	0.209533D 04	0.172250D-01
0.331000D-05	0.221504D 04	0.213909D 04	0.277293D-01
0.464100D-05	0.228670D 04	0.218142D 04	0.396654D-01
0.610511D-05	0.233099D 04	0.221729D 04	0.530548D-01
0.771562D-05	0.231377D 04	0.223743D 04	0.676720D-01
0.948719D-05	0.220155D 04	0.223073D 04	0.829558D-01
0.114359D-04	0.201287D 04	0.219361D 04	0.982973D-01
0.135795D-04	0.179514D 04	0.213071D 04	0.113306D 00
0.159375D-04	0.156122D 04	0.204645D 04	0.127609D 00
0.185312D-04	0.131230D 04	0.194369D 04	0.140760D 00
0.213843D-04	0.107243D 04	0.182745D 04	0.152489D 00
0.245228D-04	0.872503D 03	0.170523D 04	0.162880D 00
0.279751D-04	0.725167D 03	0.158429D 04	0.172277D 00
0.317726D-04	0.626067D 03	0.146976D 04	0.181107D 00
0.359499D-04	0.563364D 03	0.136444D 04	0.189773D 00
0.405449D-04	0.523272D 03	0.126911D 04	0.198569D 00
0.455994D-04	0.494788D 03	0.118328D 04	0.207668D 00
0.511593D-04	0.471549D 03	0.110593D 04	0.217160D 00
0.572753D-04	0.450703D 03	0.103596D 04	0.227091D 00
0.640028D-04	0.431233D 03	0.972397D 03	0.237492D 00
0.714031D-04	0.412842D 03	0.914404D 03	0.248389D 00
0.795435D-04	0.395424D 03	0.861292D 03	0.259808D 00
0.884978D-04	0.378871D 03	0.812480D 03	0.271775D 00
0.983477D-04	0.363047D 03	0.767468D 03	0.284317D 00
0.109182D-03	0.347817D 03	0.725824D 03	0.297451D 00
0.121101D-03	0.333068D 03	0.687170D 03	0.311199D 00
0.134211D-03	0.318724D 03	0.651179D 03	0.325566D 00
0.148632D-03	0.304745D 03	0.617566D 03	0.340565D 00
0.164495D-03	0.291131D 03	0.586086D 03	0.356199D 00
0.181945D-03	0.277908D 03	0.556530D 03	0.372475D 00
0.201139D-03	0.265121D 03	0.528721D 03	0.389395D 00
0.222253D-03	0.252829D 03	0.502511D 03	0.406969D 00
0.245479D-03	0.241085D 03	0.477777D 03	0.425212D 00
0.271027D-03	0.229932D 03	0.454414D 03	0.444137D 00
0.299130D-03	0.219394D 03	0.432334D 03	0.463771D 00
0.330043D-03	0.209473D 03	0.411460D 03	0.484141D 00
0.364047D-03	0.200152D 03	0.391723D 03	0.505281D 00
0.401452D-03	0.191399D 03	0.373058D 03	0.527225D 00
0.442597D-03	0.183174D 03	0.355406D 03	0.550010D 00
0.487857D-03	0.175434D 03	0.338709D 03	0.573671D 00
0.537643D-03	0.168137D 03	0.322914D 03	0.598246D 00
0.592408D-03	0.161248D 03	0.307969D 03	0.623770D 00
0.652649D-03	0.154734D 03	0.293825D 03	0.650276D 00
0.718914D-03	0.148571D 03	0.280437D 03	0.677801D 00
0.791805D-03	0.142736D 03	0.267760D 03	0.706372D 00
0.871986D-03	0.137208D 03	0.255756D 03	0.736033D 00
0.960185D-03	0.131972D 03	0.244385D 03	0.766808D 00
0.105720D-02	0.127013D 03	0.233614D 03	0.798736D 00
0.116392D-02	0.122319D 03	0.223409D 03	0.831854D 00
0.128132D-02	0.117879D 03	0.213741D 03	0.866208D 00
0.141045D-02	0.113683D 03	0.204580D 03	0.901819D 00
0.155250D-02	0.109724D 03	0.195901D 03	0.938747D 00
0.170875D-02	0.105993D 03	0.187680D 03	0.977036D 00
0.188062D-02	0.102486D 03	0.179894D 03	0.101674D 01
0.206968D-02	0.991947D 02	0.172522D 03	0.105792D 01
0.227765D-02	0.961137D 02	0.165545D 03	0.110066D 01
0.250642D-02	0.932352D 02	0.158945D 03	0.114504D 01
0.275806D-02	0.905504D 02	0.152705D 03	0.119116D 01
0.303487D-02	0.880491D 02	0.146808D 03	0.123913D 01
0.333936D-02	0.857195D 02	0.141238D 03	0.128905D 01
0.367429D-02	0.835481D 02	0.135979D 03	0.134104D 01
0.404273D-02	0.815205D 02	0.131016D 03	0.139526D 01
0.444800D-02	0.796209D 02	0.126333D 03	0.145181D 01
0.489380D-02	0.778326D 02	0.121915D 03	0.151083D 01
0.538418D-02	0.761380D 02	0.117746D 03	0.157244D 01
0.592360D-02	0.745197D 02	0.113809D 03	0.163669D 01
0.651697D-02	0.729604D 02	0.110090D 03	0.170369D 01
0.716966D-02	0.714437D 02	0.106572D 03	0.177343D 01

0.788763D-02	0.699552D 02	0.103239D 03	0.184586D 01
0.867740D-02	0.684829D 02	0.100076D 03	0.192090D 01
0.954614D-02	0.670187D 02	0.970673D 02	0.199832D 01
0.105018D-01	0.655572D 02	0.942000D 02	0.207793D 01
0.115018D-01	0.641622D 02	0.915884D 02	0.215564D 01
0.125018D-01	0.628814D 02	0.892922D 02	0.222823D 01
0.135018D-01	0.617007D 02	0.872486D 02	0.229609D 01
0.145018D-01	0.606093D 02	0.854117D 02	0.235960D 01
0.155018D-01	0.595984D 02	0.837465D 02	0.241906D 01
0.165018D-01	0.586608D 02	0.822263D 02	0.247476D 01
0.175018D-01	0.577901D 02	0.808301D 02	0.252699D 01
0.185018D-01	0.569806D 02	0.795410D 02	0.257597D 01
0.195018D-01	0.562274D 02	0.783456D 02	0.262195D 01
0.205018D-01	0.555259D 02	0.772325D 02	0.266511D 01
0.215018D-01	0.548720D 02	0.761926D 02	0.270567D 01
0.225018D-01	0.542621D 02	0.752180D 02	0.274378D 01
0.235018D-01	0.536927D 02	0.743021D 02	0.277961D 01
0.245018D-01	0.531608D 02	0.734392D 02	0.281332D 01
0.255018D-01	0.526635D 02	0.726245D 02	0.284503D 01
0.265018D-01	0.521982D 02	0.718538D 02	0.287489D 01
0.275018D-01	0.517627D 02	0.711233D 02	0.290301D 01
0.285018D-01	0.513547D 02	0.704297D 02	0.292950D 01
0.295018D-01	0.509724D 02	0.697701D 02	0.295444D 01
0.305018D-01	0.506138D 02	0.691421D 02	0.297796D 01
0.315018D-01	0.502773D 02	0.685432D 02	0.300013D 01
0.325018D-01	0.499614D 02	0.679715D 02	0.302104D 01
0.335018D-01	0.496647D 02	0.674251D 02	0.304077D 01
0.345018D-01	0.493858D 02	0.669022D 02	0.305937D 01
0.355018D-01	0.491237D 02	0.664015D 02	0.307694D 01
0.365018D-01	0.488772D 02	0.659214D 02	0.309351D 01
0.375018D-01	0.486452D 02	0.654607D 02	0.310916D 01
0.385018D-01	0.484269D 02	0.650183D 02	0.312393D 01
0.395018D-01	0.482214D 02	0.645930D 02	0.313787D 01
0.405018D-01	0.480278D 02	0.641840D 02	0.315104D 01
0.415018D-01	0.478454D 02	0.637904D 02	0.316350D 01
0.425018D-01	0.476735D 02	0.634112D 02	0.317526D 01
0.435018D-01	0.475114D 02	0.630457D 02	0.318637D 01
0.445018D-01	0.473586D 02	0.626932D 02	0.319687D 01
0.455018D-01	0.472145D 02	0.623530D 02	0.320679D 01
0.465018D-01	0.470786D 02	0.620245D 02	0.321616D 01
0.475018D-01	0.469503D 02	0.617072D 02	0.322503D 01
0.485018D-01	0.468293D 02	0.614004D 02	0.323340D 01
0.495018D-01	0.467150D 02	0.611038D 02	0.324134D 01
0.505018D-01	0.466071D 02	0.608167D 02	0.324882D 01
0.515018D-01	0.465052D 02	0.605388D 02	0.325590D 01
0.525018D-01	0.464090D 02	0.602697D 02	0.326261D 01
0.535018D-01	0.463181D 02	0.600089D 02	0.326894D 01
0.545018D-01	0.462323D 02	0.597561D 02	0.327493D 01
0.555018D-01	0.461512D 02	0.595110D 02	0.328060D 01
0.565018D-01	0.460745D 02	0.592732D 02	0.328597D 01
0.575018D-01	0.460021D 02	0.590424D 02	0.329104D 01
0.585018D-01	0.459337D 02	0.588183D 02	0.329583D 01
0.595018D-01	0.458689D 02	0.586007D 02	0.330038D 01
0.605018D-01	0.458078D 02	0.583893D 02	0.330468D 01
0.615018D-01	0.457499D 02	0.581838D 02	0.330875D 01
0.625018D-01	0.456953D 02	0.579839D 02	0.331257D 01
0.635018D-01	0.456436D 02	0.577896D 02	0.331622D 01
0.645018D-01	0.455947D 02	0.576006D 02	0.331968D 01
0.655018D-01	0.455484D 02	0.574166D 02	0.332293D 01
0.665018D-01	0.455047D 02	0.572374D 02	0.332600D 01
0.675018D-01	0.454633D 02	0.570630D 02	0.332892D 01
0.685018D-01	0.454242D 02	0.568931D 02	0.333168D 01
0.695018D-01	0.453872D 02	0.567276D 02	0.333431D 01
0.705018D-01	0.453522D 02	0.565662D 02	0.333677D 01
0.715018D-01	0.453190D 02	0.564089D 02	0.333911D 01
0.725018D-01	0.452877D 02	0.562555D 02	0.334132D 01
0.735018D-01	0.452581D 02	0.561059D 02	0.334342D 01
0.745018D-01	0.452300D 02	0.559599D 02	0.334540D 01
0.755018D-01	0.452035D 02	0.558174D 02	0.334727D 01
0.763719D-01	0.451816D 02	0.556964D 02	0.334888D 01

$H = 0.6 \qquad M = 8$

$f_{fd,0}Re = 105.40$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-06	0.279711D 04	0.279711D 04	0.107668D-02
0.210000D-06	0.281390D 04	0.280591D 04	0.226841D-02
0.331000D-06	0.283294D 04	0.281579D 04	0.358853D-02
0.464100D-06	0.285373D 04	0.282667D 04	0.505173D-02
0.610511D-06	0.287636D 04	0.283859D 04	0.667452D-02
0.771562D-06	0.290092D 04	0.285160D 04	0.847539D-02
0.948718D-06	0.292749D 04	0.286577D 04	0.104752D-01
0.114359D-05	0.295609D 04	0.288116D 04	0.126972D-01
0.135795D-05	0.298663D 04	0.289781D 04	0.151677D-01
0.159375D-05	0.301880D 04	0.291571D 04	0.179156D-01
0.185312D-05	0.305195D 04	0.293478D 04	0.209726D-01
0.213843D-05	0.308474D 04	0.295479D 04	0.243727D-01
0.245228D-05	0.311447D 04	0.297522D 04	0.281502D-01
0.279751D-05	0.313599D 04	0.299506D 04	0.323352D-01
0.317726D-05	0.313985D 04	0.301237D 04	0.369445D-01
0.359499D-05	0.311224D 04	0.302397D 04	0.419686D-01
0.405449D-05	0.304354D 04	0.302619D 04	0.473689D-01
0.455994D-05	0.294516D 04	0.301721D 04	0.531104D-01
0.511593D-05	0.284322D 04	0.299830D 04	0.591991D-01
0.572753D-05	0.275154D 04	0.297195D 04	0.656725D-01
0.640028D-05	0.266878D 04	0.294008D 04	0.725705D-01
0.714031D-05	0.258983D 04	0.290378D 04	0.799246D-01
0.795435D-05	0.250980D 04	0.286346D 04	0.877537D-01
0.884978D-05	0.242360D 04	0.281896D 04	0.960569D-01
0.983476D-05	0.232617D 04	0.276960D 04	0.104806D 00
0.109182D-04	0.221493D 04	0.271456D 04	0.113948D 00
0.121101D-04	0.209230D 04	0.265332D 04	0.123421D 00
0.134211D-04	0.196145D 04	0.258574D 04	0.133154D 00
0.148632D-04	0.182095D 04	0.251153D 04	0.143050D 00
0.164495D-04	0.166727D 04	0.243011D 04	0.152960D 00
0.181945D-04	0.150095D 04	0.234100D 04	0.162701D 00
0.201139D-04	0.133000D 04	0.224452D 04	0.172103D 00
0.222253D-04	0.116731D 04	0.214219D 04	0.181071D 00
0.245479D-04	0.102426D 04	0.203642D 04	0.189608D 00
0.271027D-04	0.906533D 03	0.192991D 04	0.197794D 00
0.299130D-04	0.814604D 03	0.182513D 04	0.205767D 00
0.330043D-04	0.745833D 03	0.172404D 04	0.213686D 00
0.364047D-04	0.695609D 03	0.162798D 04	0.221713D 00
0.401452D-04	0.658328D 03	0.153763D 04	0.229985D 00
0.442597D-04	0.628835D 03	0.145315D 04	0.238601D 00
0.487857D-04	0.603459D 03	0.137432D 04	0.247617D 00
0.537643D-04	0.580109D 03	0.130077D 04	0.257069D 00
0.592408D-04	0.557861D 03	0.123210D 04	0.266982D 00
0.652649D-04	0.536440D 03	0.116789D 04	0.277368D 00
0.718914D-04	0.515832D 03	0.110778D 04	0.288244D 00
0.791805D-04	0.496067D 03	0.105147D 04	0.299635D 00
0.871986D-04	0.477132D 03	0.998658D 03	0.311556D 00
0.960185D-04	0.458961D 03	0.949084D 03	0.324029D 00
0.105720D-03	0.441462D 03	0.902500D 03	0.337069D 00
0.116392D-03	0.424540D 03	0.858675D 03	0.350691D 00
0.128132D-03	0.408116D 03	0.817395D 03	0.364907D 00
0.141045D-03	0.392134D 03	0.778461D 03	0.379716D 00
0.155250D-03	0.376566D 03	0.741690D 03	0.395124D 00
0.170875D-03	0.361407D 03	0.706916D 03	0.411123D 00
0.188062D-03	0.346675D 03	0.673993D 03	0.427708D 00
0.206968D-03	0.332403D 03	0.642789D 03	0.444873D 00
0.227765D-03	0.318632D 03	0.613191D 03	0.462610D 00
0.250642D-03	0.305408D 03	0.585099D 03	0.480911D 00
0.275806D-03	0.292769D 03	0.558427D 03	0.499768D 00
0.303487D-03	0.280742D 03	0.533099D 03	0.519180D 00
0.333936D-03	0.269338D 03	0.509049D 03	0.539145D 00
0.367429D-03	0.258555D 03	0.486215D 03	0.559661D 00
0.404272D-03	0.248374D 03	0.464540D 03	0.580729D 00
0.444800D-03	0.238769D 03	0.443969D 03	0.602346D 00
0.489380D-03	0.229706D 03	0.424450D 03	0.624508D 00
0.538418D-03	0.221152D 03	0.405934D 03	0.647209D 00
0.592360D-03	0.213075D 03	0.388372D 03	0.670438D 00
0.651696D-03	0.205446D 03	0.371717D 03	0.694179D 00
0.716966D-03	0.198240D 03	0.355924D 03	0.718411D 00

0.788763D-03	0.191436D 03	0.340952D 03	0.743116D 00
0.867740D-03	0.185018D 03	0.326759D 03	0.768259D 00
0.954614D-03	0.178967D 03	0.313310D 03	0.793819D 00
0.105018D-02	0.173273D 03	0.300567D 03	0.819758D 00
0.115529D-02	0.167924D 03	0.288498D 03	0.846033D 00
0.127092D-02	0.162909D 03	0.277072D 03	0.872624D 00
0.139812D-02	0.158219D 03	0.266259D 03	0.899489D 00
0.153803D-02	0.153844D 03	0.256033D 03	0.926589D 00
0.169193D-02	0.149778D 03	0.246368D 03	0.953897D 00
0.186123D-02	0.146013D 03	0.237240D 03	0.981389D 00
0.204745D-02	0.142540D 03	0.228626D 03	0.100903D 01
0.225230D-02	0.139354D 03	0.220507D 03	0.103684D 01
0.247763D-02	0.136445D 03	0.212862D 03	0.106481D 01
0.272549D-02	0.133806D 03	0.205672D 03	0.109294D 01
0.299814D-02	0.131427D 03	0.198921D 03	0.112132D 01
0.329805D-02	0.129295D 03	0.192589D 03	0.114995D 01
0.362796D-02	0.127400D 03	0.186661D 03	0.117896D 01
0.399086D-02	0.125727D 03	0.181120D 03	0.120843D 01
0.439005D-02	0.124258D 03	0.175950D 03	0.123852D 01
0.482915D-02	0.122976D 03	0.171133D 03	0.126935D 01
0.531217D-02	0.121859D 03	0.166653D 03	0.130112D 01
0.584349D-02	0.120887D 03	0.162491D 03	0.133398D 01
0.642794D-02	0.120034D 03	0.158631D 03	0.136815D 01
0.707084D-02	0.119277D 03	0.155053D 03	0.140379D 01
0.777802D-02	0.118592D 03	0.151738D 03	0.144105D 01
0.855593D-02	0.117958D 03	0.148666D 03	0.148004D 01
0.941162D-02	0.117354D 03	0.145820D 03	0.152092D 01
0.103529D-01	0.116764D 03	0.143178D 03	0.156362D 01
0.113529D-01	0.116194D 03	0.140801D 03	0.160671D 01
0.123529D-01	0.115666D 03	0.138766D 03	0.164768D 01
0.133529D-01	0.115169D 03	0.136999D 03	0.168669D 01
0.143529D-01	0.114700D 03	0.135445D 03	0.172378D 01
0.153529D-01	0.114254D 03	0.134065D 03	0.175914D 01
0.163529D-01	0.113829D 03	0.132828D 03	0.179280D 01
0.173529D-01	0.113425D 03	0.131710D 03	0.182483D 01
0.183529D-01	0.113040D 03	0.130692D 03	0.185526D 01
0.193529D-01	0.112673D 03	0.129761D 03	0.188428D 01
0.203529D-01	0.112324D 03	0.128904D 03	0.191187D 01
0.213529D-01	0.111991D 03	0.128112D 03	0.193816D 01
0.223529D-01	0.111675D 03	0.127377D 03	0.196321D 01
0.233529D-01	0.111373D 03	0.126692D 03	0.198705D 01
0.243529D-01	0.111087D 03	0.126051D 03	0.200970D 01
0.253529D-01	0.110814D 03	0.125450D 03	0.203127D 01
0.263529D-01	0.110554D 03	0.124885D 03	0.205184D 01
0.273529D-01	0.110307D 03	0.124352D 03	0.207138D 01
0.283529D-01	0.110072D 03	0.123848D 03	0.208995D 01
0.293529D-01	0.109849D 03	0.123371D 03	0.210766D 01
0.303529D-01	0.109636D 03	0.122919D 03	0.212458D 01
0.313529D-01	0.109434D 03	0.122489D 03	0.214065D 01
0.323529D-01	0.109242D 03	0.122079D 03	0.215587D 01
0.333529D-01	0.109059D 03	0.121689D 03	0.217047D 01
0.343529D-01	0.108885D 03	0.121316D 03	0.218430D 01
0.353529D-01	0.108719D 03	0.120960D 03	0.219754D 01
0.363529D-01	0.108561D 03	0.120619D 03	0.221011D 01
0.373529D-01	0.108411D 03	0.120292D 03	0.222205D 01
0.383529D-01	0.108269D 03	0.119978D 03	0.223337D 01
0.393529D-01	0.108133D 03	0.119677D 03	0.224422D 01
0.403529D-01	0.108004D 03	0.119388D 03	0.225460D 01
0.413529D-01	0.107881D 03	0.119110D 03	0.226449D 01
0.423529D-01	0.107764D 03	0.118842D 03	0.227384D 01
0.433529D-01	0.107652D 03	0.118584D 03	0.228279D 01
0.443529D-01	0.107546D 03	0.118335D 03	0.229127D 01
0.453529D-01	0.107445D 03	0.118095D 03	0.229939D 01
0.463529D-01	0.107349D 03	0.117863D 03	0.230708D 01
0.473529D-01	0.107258D 03	0.117639D 03	0.231442D 01
0.483529D-01	0.107171D 03	0.117423D 03	0.232152D 01
0.493529D-01	0.107088D 03	0.117213D 03	0.232808D 01
0.503529D-01	0.107009D 03	0.117010D 03	0.233436D 01
0.513529D-01	0.106934D 03	0.116814D 03	0.234046D 01
0.523529D-01	0.106862D 03	0.116624D 03	0.234625D 01
0.533529D-01	0.106794D 03	0.116440D 03	0.235180D 01
0.543529D-01	0.106729D 03	0.116261D 03	0.235696D 01
0.553529D-01	0.106667D 03	0.116088D 03	0.236202D 01
0.563529D-01	0.106608D 03	0.115920D 03	0.236682D 01
0.573529D-01	0.106552D 03	0.115756D 03	0.237120D 01
0.583529D-01	0.106499D 03	0.115598D 03	0.237566D 01
0.588592D-01	0.106473D 03	0.115520D 03	0.237791D 01

$H = 0.8 \qquad M = 8$

$f_{fd,0}Re = 166.00$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-06	0.426613D 04	0.426613D 04	0.164004D-02
0.210000D-06	0.434617D 04	0.430805D 04	0.347931D-02
0.331000D-06	0.443605D 04	0.435484D 04	0.554600D-02
0.464100D-06	0.453474D 04	0.440644D 04	0.787192D-02
0.610511D-06	0.463498D 04	0.446124D 04	0.104891D-01
0.771562D-06	0.470748D 04	0.451264D 04	0.134147D-01
0.948718D-06	0.467858D 04	0.454363D 04	0.166125D-01
0.114359D-05	0.450307D 04	0.453672D 04	0.199932D-01
0.135795D-05	0.428549D 04	0.449706D 04	0.235253D-01
0.159375D-05	0.411622D 04	0.444071D 04	0.272511D-01
0.185312D-05	0.398703D 04	0.437721D 04	0.312154D-01
0.213843D-05	0.387233D 04	0.430985D 04	0.354452D-01
0.245228D-05	0.376083D 04	0.423959D 04	0.399581D-01
0.279751D-05	0.365011D 04	0.416684D 04	0.447693D-01
0.317726D-05	0.354068D 04	0.409200D 04	0.498954D-01
0.359499D-05	0.343356D 04	0.401549D 04	0.553552D-01
0.405449D-05	0.332942D 04	0.393774D 04	0.611696D-01
0.455994D-05	0.322851D 04	0.385912D 04	0.673613D-01
0.511593D-05	0.313071D 04	0.377996D 04	0.739547D-01
0.572753D-05	0.303556D 04	0.370047D 04	0.809747D-01
0.640028D-05	0.294231D 04	0.362078D 04	0.884457D-01
0.714031D-05	0.284970D 04	0.354086D 04	0.963896D-01
0.795435D-05	0.275589D 04	0.346053D 04	0.104823D 00
0.884978D-05	0.265762D 04	0.337929D 04	0.113747D 00
0.983476D-05	0.255106D 04	0.329634D 04	0.123144D 00
0.109182D-04	0.243331D 04	0.321070D 04	0.132970D 00
0.121101D-04	0.230532D 04	0.312159D 04	0.143169D 00
0.134211D-04	0.216984D 04	0.302862D 04	0.153677D 00
0.148632D-04	0.202679D 04	0.293142D 04	0.164411D 00
0.164495D-04	0.187343D 04	0.282939D 04	0.175244D 00
0.181945D-04	0.170902D 04	0.272194D 04	0.186015D 00
0.201139D-04	0.153892D 04	0.260905D 04	0.196555D 00
0.222253D-04	0.137364D 04	0.249168D 04	0.206754D 00
0.245479D-04	0.122422D 04	0.237176D 04	0.216585D 00
0.271027D-04	0.109742D 04	0.225164D 04	0.226104D 00
0.299130D-04	0.994897D 03	0.213357D 04	0.235421D 00
0.330043D-04	0.914847D 03	0.201942D 04	0.244681D 00
0.364047D-04	0.853456D 03	0.191051D 04	0.254031D 00
0.401452D-04	0.805925D 03	0.180759D 04	0.263605D 00
0.442597D-04	0.767541D 03	0.171091D 04	0.273505D 00
0.487857D-04	0.734690D 03	0.162034D 04	0.283800D 00
0.537643D-04	0.704844D 03	0.153556D 04	0.294529D 00
0.592408D-04	0.676969D 03	0.145619D 04	0.305723D 00
0.652649D-04	0.650476D 03	0.138182D 04	0.317396D 00
0.718914D-04	0.625214D 03	0.131208D 04	0.329567D 00
0.791805D-04	0.601119D 03	0.124663D 04	0.342253D 00
0.871986D-04	0.578165D 03	0.118517D 04	0.355474D 00
0.960185D-04	0.556257D 03	0.112740D 04	0.369241D 00
0.105720D-03	0.535306D 03	0.107306D 04	0.383569D 00
0.116392D-03	0.515209D 03	0.102191D 04	0.398475D 00
0.128132D-03	0.495856D 03	0.973715D 03	0.413966D 00
0.141045D-03	0.477190D 03	0.928257D 03	0.430039D 00
0.155250D-03	0.459146D 03	0.885335D 03	0.446695D 00
0.170875D-03	0.441708D 03	0.844769D 03	0.463925D 00
0.188062D-03	0.424874D 03	0.806394D 03	0.481720D 00
0.206968D-03	0.408642D 03	0.770060D 03	0.500068D 00
0.227765D-03	0.393054D 03	0.735636D 03	0.518954D 00
0.250642D-03	0.378137D 03	0.703006D 03	0.538365D 00
0.275806D-03	0.363922D 03	0.672069D 03	0.558285D 00
0.303487D-03	0.350433D 03	0.642733D 03	0.578705D 00
0.333936D-03	0.337698D 03	0.614919D 03	0.599614D 00
0.367429D-03	0.325681D 03	0.588553D 03	0.621004D 00
0.404272D-03	0.314403D 03	0.563569D 03	0.642872D 00
0.444800D-03	0.303830D 03	0.539903D 03	0.665213D 00
0.489380D-03	0.293928D 03	0.517496D 03	0.688021D 00
0.538418D-03	0.284658D 03	0.496289D 03	0.711291D 00
0.592360D-03	0.275981D 03	0.476227D 03	0.735017D 00
0.651696D-03	0.267857D 03	0.457255D 03	0.759187D 00
0.716966D-03	0.260247D 03	0.439321D 03	0.783790D 00

0.788763D-03	0.253117D 03	0.422371D 03	0.808801D 00
0.867740D-03	0.246432D 03	0.406358D 03	0.834204D 00
0.954614D-03	0.240159D 03	0.391233D 03	0.859966D 00
0.105018D-02	0.234267D 03	0.376950D 03	0.886058D 00
0.115529D-02	0.228727D 03	0.363464D 03	0.912420D 00
0.127092D-02	0.223510D 03	0.350730D 03	0.939007D 00
0.139812D-02	0.218590D 03	0.338709D 03	0.965760D 00
0.153803D-02	0.213945D 03	0.327359D 03	0.992577D 00
0.169193D-02	0.209553D 03	0.316643D 03	0.101937D 01
0.186123D-02	0.205400D 03	0.306525D 03	0.104605D 01
0.204745D-02	0.201473D 03	0.296970D 03	0.107245D 01
0.225230D-02	0.197766D 03	0.287947D 03	0.109846D 01
0.247763D-02	0.194275D 03	0.279428D 03	0.112393D 01
0.272549D-02	0.191002D 03	0.271387D 03	0.114871D 01
0.299814D-02	0.187948D 03	0.263799D 03	0.117262D 01
0.329805D-02	0.185118D 03	0.256644D 03	0.119553D 01
0.362796D-02	0.182514D 03	0.249903D 03	0.121730D 01
0.399086D-02	0.180140D 03	0.243559D 03	0.123779D 01
0.439005D-02	0.177994D 03	0.237597D 03	0.125691D 01
0.482915D-02	0.176075D 03	0.232003D 03	0.127457D 01
0.531217D-02	0.174376D 03	0.226763D 03	0.129071D 01
0.584349D-02	0.172888D 03	0.221865D 03	0.130532D 01
0.642794D-02	0.171601D 03	0.217295D 03	0.131837D 01
0.707084D-02	0.170498D 03	0.213040D 03	0.132988D 01
0.777802D-02	0.169566D 03	0.209087D 03	0.133990D 01
0.855593D-02	0.168787D 03	0.205423D 03	0.134852D 01
0.941162D-02	0.168144D 03	0.202034D 03	0.135580D 01
0.102407D-01	0.167684D 03	0.199278D 03	0.136234D 01

$$H = 0.2 \qquad M = 16$$

$$f_{fd,0}Re = 27.10$$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.319867D 04	0.319867D 04	0.126863D-01
0.210000D-05	0.353150D 04	0.337301D 04	0.281057D-01
0.331000D-05	0.365738D 04	0.347696D 04	0.456762D-01
0.464100D-05	0.307167D 04	0.336073D 04	0.618855D-01
0.610511D-05	0.231554D 04	0.311008D 04	0.752878D-01
0.771562D-05	0.190935D 04	0.285944D 04	0.874131D-01
0.948719D-05	0.174676D 04	0.265167D 04	0.995992D-01
0.114359D-04	0.164774D 04	0.248060D 04	0.112232D 00
0.135795D-04	0.152439D 04	0.232965D 04	0.125070D 00
0.159375D-04	0.135285D 04	0.218513D 04	0.137574D 00
0.185312D-04	0.114760D 04	0.203991D 04	0.149199D 00
0.213843D-04	0.949095D 03	0.189438D 04	0.159722D 00
0.245228D-04	0.793390D 03	0.175347D 04	0.169342D 00
0.279751D-04	0.688693D 03	0.162207D 04	0.178478D 00
0.317726D-04	0.622669D 03	0.150262D 04	0.187525D 00
0.359499D-04	0.579424D 03	0.139535D 04	0.196754D 00
0.405449D-04	0.547602D 03	0.129927D 04	0.206320D 00
0.455994D-04	0.520969D 03	0.121300D 04	0.216305D 00
0.511593D-04	0.496691D 03	0.113515D 04	0.226748D 00
0.572753D-04	0.473723D 03	0.106452D 04	0.237674D 00
0.640028D-04	0.451793D 03	0.100012D 04	0.249104D 00
0.714031D-04	0.430885D 03	0.941121D 03	0.261056D 00
0.795435D-04	0.410991D 03	0.886869D 03	0.273556D 00
0.884978D-04	0.392060D 03	0.836803D 03	0.286628D 00
0.983477D-04	0.373994D 03	0.790451D 03	0.300296D 00
0.109182D-03	0.356683D 03	0.747406D 03	0.314578D 00
0.121101D-03	0.340030D 03	0.707313D 03	0.329498D 00
0.134211D-03	0.323964D 03	0.669867D 03	0.345066D 00
0.148632D-03	0.308448D 03	0.634800D 03	0.361295D 00
0.164495D-03	0.293471D 03	0.601883D 03	0.378196D 00
0.181945D-03	0.279047D 03	0.570921D 03	0.395783D 00
0.201139D-03	0.265203D 03	0.541747D 03	0.414063D 00
0.222253D-03	0.251973D 03	0.514219D 03	0.433056D 00
0.245479D-03	0.239389D 03	0.488216D 03	0.452778D 00
0.271027D-03	0.227477D 03	0.463638D 03	0.473255D 00
0.299130D-03	0.216250D 03	0.440396D 03	0.494518D 00
0.330043D-03	0.205707D 03	0.418414D 03	0.516603D 00
0.364047D-03	0.195836D 03	0.397624D 03	0.539554D 00
0.401452D-03	0.186613D 03	0.377963D 03	0.563420D 00
0.442597D-03	0.178003D 03	0.359374D 03	0.588256D 00
0.487857D-03	0.169969D 03	0.341803D 03	0.614122D 00
0.537643D-03	0.162472D 03	0.325197D 03	0.641081D 00
0.592408D-03	0.155467D 03	0.309506D 03	0.669201D 00
0.652649D-03	0.148909D 03	0.294683D 03	0.698554D 00
0.718914D-03	0.142751D 03	0.280679D 03	0.729209D 00
0.791805D-03	0.136948D 03	0.267447D 03	0.761235D 00
0.871986D-03	0.131453D 03	0.254942D 03	0.794704D 00
0.960185D-03	0.126222D 03	0.243118D 03	0.829673D 00
0.105720D-02	0.121213D 03	0.231931D 03	0.866194D 00
0.116392D-02	0.116392D 03	0.221337D 03	0.904310D 00
0.128132D-02	0.111725D 03	0.211295D 03	0.944056D 00
0.141045D-02	0.107186D 03	0.201763D 03	0.985419D 00
0.155250D-02	0.102753D 03	0.192704D 03	0.102841D 01
0.170875D-02	0.984078D 02	0.184082D 03	0.107298D 01
0.188062D-02	0.941412D 02	0.175862D 03	0.111907D 01
0.206968D-02	0.899466D 02	0.168014D 03	0.116660D 01
0.227765D-02	0.858239D 02	0.160509D 03	0.121545D 01
0.250642D-02	0.817815D 02	0.153323D 03	0.126548D 01
0.275806D-02	0.778330D 02	0.146436D 03	0.131655D 01
0.303487D-02	0.739962D 02	0.139829D 03	0.136848D 01
0.333936D-02	0.702909D 02	0.133488D 03	0.142108D 01
0.367429D-02	0.667381D 02	0.127403D 03	0.147418D 01
0.404273D-02	0.633575D 02	0.121567D 03	0.152763D 01
0.444800D-02	0.601643D 02	0.115972D 03	0.158123D 01
0.489380D-02	0.571702D 02	0.110615D 03	0.163484D 01
0.538418D-02	0.543819D 02	0.105494D 03	0.168837D 01
0.592360D-02	0.518003D 02	0.100604D 03	0.174166D 01
0.651697D-02	0.494217D 02	0.959441D 02	0.179465D 01
0.716966D-02	0.472386D 02	0.915102D 02	0.184723D 01

0.788763D-02	0.452400D 02	0.872984D 02	0.189932D 01
0.867740D-02	0.434133D 02	0.833043D 02	0.195086D 01
0.954614D-02	0.417446D 02	0.795222D 02	0.200176D 01
0.105018D-01	0.402201D 02	0.759458D 02	0.205192D 01
0.115018D-01	0.388837D 02	0.727235D 02	0.209906D 01
0.125018D-01	0.377483D 02	0.699259D 02	0.214165D 01
0.135018D-01	0.367715D 02	0.674703D 02	0.218034D 01
0.145018D-01	0.359223D 02	0.652949D 02	0.221564D 01
0.155018D-01	0.351771D 02	0.633520D 02	0.224795D 01
0.165018D-01	0.345180D 02	0.616047D 02	0.227762D 01
0.175018D-01	0.339311D 02	0.600235D 02	0.230495D 01
0.185018D-01	0.334051D 02	0.585848D 02	0.233018D 01
0.195018D-01	0.329314D 02	0.572694D 02	0.235351D 01
0.205018D-01	0.325028D 02	0.560613D 02	0.237512D 01
0.215018D-01	0.321133D 02	0.549476D 02	0.239518D 01
0.225018D-01	0.317582D 02	0.539170D 02	0.241381D 01
0.235018D-01	0.314334D 02	0.529603D 02	0.243115D 01
0.245018D-01	0.311355D 02	0.520696D 02	0.244730D 01
0.255018D-01	0.308616D 02	0.512380D 02	0.246235D 01
0.265018D-01	0.306091D 02	0.504596D 02	0.247639D 01
0.275018D-01	0.303760D 02	0.497293D 02	0.248950D 01
0.285018D-01	0.301604D 02	0.490427D 02	0.250174D 01
0.295018D-01	0.299606D 02	0.483959D 02	0.251319D 01
0.305018D-01	0.297753D 02	0.477854D 02	0.252389D 01
0.315018D-01	0.296031D 02	0.472083D 02	0.253392D 01
0.325018D-01	0.294430D 02	0.466617D 02	0.254329D 01
0.335018D-01	0.292940D 02	0.461433D 02	0.255207D 01
0.345018D-01	0.291551D 02	0.456509D 02	0.256030D 01
0.355018D-01	0.290256D 02	0.451826D 02	0.256800D 01
0.365018D-01	0.289048D 02	0.447366D 02	0.257522D 01
0.375018D-01	0.287920D 02	0.443115D 02	0.258200D 01
0.385018D-01	0.286865D 02	0.439056D 02	0.258834D 01
0.395018D-01	0.285880D 02	0.435179D 02	0.259430D 01
0.405018D-01	0.284958D 02	0.431470D 02	0.259989D 01
0.415018D-01	0.284095D 02	0.427919D 02	0.260513D 01
0.425018D-01	0.283287D 02	0.424516D 02	0.261005D 01
0.435018D-01	0.282531D 02	0.421252D 02	0.261467D 01
0.445018D-01	0.281823D 02	0.418119D 02	0.261900D 01
0.455018D-01	0.281159D 02	0.415109D 02	0.262307D 01
0.465018D-01	0.280537D 02	0.412215D 02	0.262689D 01
0.475018D-01	0.279954D 02	0.409430D 02	0.263046D 01
0.485018D-01	0.279407D 02	0.406750D 02	0.263384D 01
0.495018D-01	0.278894D 02	0.404167D 02	0.263700D 01
0.505018D-01	0.278413D 02	0.401677D 02	0.263997D 01
0.515018D-01	0.277961D 02	0.399274D 02	0.264274D 01
0.525018D-01	0.277538D 02	0.396956D 02	0.264538D 01
0.535018D-01	0.277140D 02	0.394716D 02	0.264783D 01
0.545018D-01	0.276767D 02	0.392552D 02	0.265014D 01
0.555018D-01	0.276417D 02	0.390460D 02	0.265232D 01
0.565018D-01	0.276088D 02	0.388435D 02	0.265434D 01
0.575018D-01	0.275779D 02	0.386476D 02	0.265626D 01
0.585018D-01	0.275489D 02	0.384579D 02	0.265806D 01
0.595018D-01	0.275217D 02	0.382741D 02	0.265975D 01
0.605018D-01	0.274962D 02	0.380960D 02	0.266135D 01
0.615018D-01	0.274722D 02	0.379232D 02	0.266283D 01
0.625018D-01	0.274496D 02	0.377557D 02	0.266425D 01
0.635018D-01	0.274284D 02	0.375930D 02	0.266555D 01
0.645018D-01	0.274085D 02	0.374351D 02	0.266679D 01
0.655018D-01	0.273898D 02	0.372818D 02	0.266797D 01
0.665018D-01	0.273723D 02	0.371328D 02	0.266906D 01
0.666491D-01	0.273699D 02	0.371114D 02	0.266927D 01

$H = 0.4 \qquad M = 16$

$f_{fd,0}Re = 73.89$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.588617D 04	0.588617D 04	0.232491D-01
0.210000D-05	0.621230D 04	0.605700D 04	0.502582D-01
0.331000D-05	0.515894D 04	0.572870D 04	0.748698D-01
0.464100D-05	0.395067D 04	0.521878D 04	0.955098D-01
0.610511D-05	0.303903D 04	0.469604D 04	0.112875D 00
0.771562D-05	0.250336D 04	0.423835D 04	0.128526D 00
0.948719D-05	0.223724D 04	0.386468D 04	0.143856D 00
0.114359D-04	0.207830D 04	0.356027D 04	0.159480D 00
0.135795D-04	0.193346D 04	0.330347D 04	0.175425D 00
0.159375D-04	0.176393D 04	0.307570D 04	0.191366D 00
0.185312D-04	0.156525D 04	0.286428D 04	0.206837D 00
0.213843D-04	0.136008D 04	0.266359D 04	0.221516D 00
0.245228D-04	0.118029D 04	0.247376D 04	0.235407D 00
0.279751D-04	0.104291D 04	0.229718D 04	0.248788D 00
0.317726D-04	0.945324D 03	0.213561D 04	0.262025D 00
0.359499D-04	0.875654D 03	0.198920D 04	0.275422D 00
0.405449D-04	0.822619D 03	0.185699D 04	0.289183D 00
0.455994D-04	0.778803D 03	0.173748D 04	0.303436D 00
0.511593D-04	0.740191D 03	0.162909D 04	0.318253D 00
0.572753D-04	0.704874D 03	0.153041D 04	0.333692D 00
0.640028D-04	0.672035D 03	0.144018D 04	0.349787D 00
0.714031D-04	0.641281D 03	0.135738D 04	0.366582D 00
0.795435D-04	0.612450D 03	0.128115D 04	0.384120D 00
0.884978D-04	0.585369D 03	0.121075D 04	0.402440D 00
0.983477D-04	0.559869D 03	0.114556D 04	0.421587D 00
0.109182D-03	0.535777D 03	0.108505D 04	0.441604D 00
0.121101D-03	0.512929D 03	0.102874D 04	0.462536D 00
0.134211D-03	0.491189D 03	0.976231D 03	0.484419D 00
0.148632D-03	0.470447D 03	0.927157D 03	0.507294D 00
0.164495D-03	0.450627D 03	0.881202D 03	0.531198D 00
0.181945D-03	0.431679D 03	0.838090D 03	0.556173D 00
0.201139D-03	0.413577D 03	0.797579D 03	0.582252D 00
0.222253D-03	0.396312D 03	0.759459D 03	0.609484D 00
0.245479D-03	0.379885D 03	0.723546D 03	0.637913D 00
0.271027D-03	0.364300D 03	0.689683D 03	0.667592D 00
0.299130D-03	0.349562D 03	0.657729D 03	0.698581D 00
0.330043D-03	0.335669D 03	0.627563D 03	0.730950D 00
0.364047D-03	0.322614D 03	0.599079D 03	0.764781D 00
0.401452D-03	0.310386D 03	0.572180D 03	0.800166D 00
0.442597D-03	0.298965D 03	0.546781D 03	0.837209D 00
0.487857D-03	0.288338D 03	0.522805D 03	0.876035D 00
0.537643D-03	0.278471D 03	0.500180D 03	0.916778D 00
0.592408D-03	0.269357D 03	0.478841D 03	0.959597D 00
0.652649D-03	0.260969D 03	0.458731D 03	0.100468D 01
0.718914D-03	0.253285D 03	0.439794D 03	0.105223D 01
0.791805D-03	0.246277D 03	0.421980D 03	0.110249D 01
0.871986D-03	0.239916D 03	0.405239D 03	0.115574D 01
0.960185D-03	0.234163D 03	0.389524D 03	0.121229D 01
0.105720D-02	0.228978D 03	0.374791D 03	0.127247D 01
0.116392D-02	0.224307D 03	0.360993D 03	0.133668D 01
0.128132D-02	0.220096D 03	0.348084D 03	0.140535D 01
0.141045D-02	0.216282D 03	0.336017D 03	0.147890D 01
0.155250D-02	0.212797D 03	0.324743D 03	0.155783D 01
0.170875D-02	0.209568D 03	0.314211D 03	0.164263D 01
0.188062D-02	0.206522D 03	0.304369D 03	0.173381D 01
0.206968D-02	0.203581D 03	0.295162D 03	0.183189D 01
0.227765D-02	0.200670D 03	0.286535D 03	0.193737D 01
0.250642D-02	0.197717D 03	0.278428D 03	0.205068D 01
0.275806D-02	0.194657D 03	0.270785D 03	0.217225D 01
0.303487D-02	0.191435D 03	0.263547D 03	0.230240D 01
0.333936D-02	0.188007D 03	0.256659D 03	0.244139D 01
0.367429D-02	0.184345D 03	0.250067D 03	0.258938D 01
0.404273D-02	0.180431D 03	0.243721D 03	0.274640D 01
0.444800D-02	0.176263D 03	0.237575D 03	0.291237D 01
0.489380D-02	0.171848D 03	0.231587D 03	0.308705D 01
0.538418D-02	0.167205D 03	0.225724D 03	0.327011D 01
0.592360D-02	0.162358D 03	0.219953D 03	0.346099D 01
0.651697D-02	0.157339D 03	0.214252D 03	0.365907D 01
0.716966D-02	0.152187D 03	0.208602D 03	0.386350D 01

0.788763D-02	0.146941D 03	0.202989D 03	0.407330D 01
0.867740D-02	0.141647D 03	0.197406D 03	0.428736D 01
0.954614D-02	0.136351D 03	0.191850D 03	0.450444D 01
0.105018D-01	0.131100D 03	0.186322D 03	0.472316D 01
0.115018D-01	0.126166D 03	0.181092D 03	0.493229D 01
0.125018D-01	0.121730D 03	0.176344D 03	0.512369D 01
0.135018D-01	0.117736D 03	0.172003D 03	0.529908D 01
0.145018D-01	0.114136D 03	0.168013D 03	0.546010D 01
0.155018D-01	0.110887D 03	0.164327D 03	0.560806D 01
0.165018D-01	0.107948D 03	0.160911D 03	0.574434D 01
0.175018D-01	0.105286D 03	0.157733D 03	0.586996D 01
0.185018D-01	0.102871D 03	0.154767D 03	0.598585D 01
0.195018D-01	0.100676D 03	0.151994D 03	0.609306D 01
0.205018D-01	0.986773D 02	0.149393D 03	0.619220D 01
0.215018D-01	0.968545D 02	0.146950D 03	0.628412D 01
0.225018D-01	0.951892D 02	0.144649D 03	0.636927D 01
0.235018D-01	0.936654D 02	0.142480D 03	0.644842D 01
0.245018D-01	0.922689D 02	0.140431D 03	0.652199D 01
0.255018D-01	0.909871D 02	0.138492D 03	0.659038D 01
0.265018D-01	0.898087D 02	0.136655D 03	0.665407D 01
0.275018D-01	0.887240D 02	0.134912D 03	0.671341D 01
0.285018D-01	0.877241D 02	0.133257D 03	0.676884D 01
0.295018D-01	0.868013D 02	0.131682D 03	0.682046D 01
0.305018D-01	0.859484D 02	0.130183D 03	0.686876D 01
0.315018D-01	0.851593D 02	0.128753D 03	0.691376D 01
0.325018D-01	0.844283D 02	0.127390D 03	0.695604D 01
0.335018D-01	0.837506D 02	0.126087D 03	0.699544D 01
0.345018D-01	0.831214D 02	0.124842D 03	0.703243D 01
0.355018D-01	0.825368D 02	0.123650D 03	0.706699D 01
0.365018D-01	0.819932D 02	0.122509D 03	0.709945D 01
0.375018D-01	0.814871D 02	0.121415D 03	0.712984D 01
0.385018D-01	0.810158D 02	0.120366D 03	0.715841D 01
0.395018D-01	0.805763D 02	0.119358D 03	0.718506D 01
0.405018D-01	0.801662D 02	0.118391D 03	0.721029D 01
0.415018D-01	0.797834D 02	0.117460D 03	0.723376D 01
0.425018D-01	0.794257D 02	0.116566D 03	0.725608D 01
0.435018D-01	0.790914D 02	0.115704D 03	0.727681D 01
0.445018D-01	0.787786D 02	0.114874D 03	0.729634D 01
0.455018D-01	0.784859D 02	0.114075D 03	0.731487D 01
0.465018D-01	0.782118D 02	0.113303D 03	0.733203D 01
0.475018D-01	0.779550D 02	0.112559D 03	0.734834D 01
0.485018D-01	0.777144D 02	0.111841D 03	0.736374D 01
0.495018D-01	0.774887D 02	0.111147D 03	0.737815D 01
0.505018D-01	0.772770D 02	0.110476D 03	0.739165D 01
0.515018D-01	0.770783D 02	0.109828D 03	0.740452D 01
0.525018D-01	0.768918D 02	0.109200D 03	0.741641D 01
0.535018D-01	0.767166D 02	0.108593D 03	0.742776D 01
0.545021D-01	0.765521D 02	0.108005D 03	0.743841D 01
0.555018D-01	0.763975D 02	0.107436D 03	0.744856D 01
0.565018D-01	0.762521D 02	0.106884D 03	0.745801D 01
0.575018D-01	0.761155D 02	0.106349D 03	0.746696D 01
0.585018D-01	0.759870D 02	0.105830D 03	0.747536D 01
0.595018D-01	0.758661D 02	0.105326D 03	0.748319D 01
0.605018D-01	0.757524D 02	0.104837D 03	0.749061D 01
0.615018D-01	0.756454D 02	0.104363D 03	0.749781D 01
0.625018D-01	0.755447D 02	0.103902D 03	0.750447D 01
0.635018D-01	0.754499D 02	0.103454D 03	0.751074D 01
0.645018D-01	0.753606D 02	0.103018D 03	0.751653D 01
0.655018D-01	0.752765D 02	0.102595D 03	0.752223D 01
0.665018D-01	0.751973D 02	0.102183D 03	0.752747D 01
0.675018D-01	0.751227D 02	0.101782D 03	0.753239D 01
0.685024D-01	0.750524D 02	0.101392D 03	0.753712D 01
0.695018D-01	0.749862D 02	0.101012D 03	0.754150D 01
0.705018D-01	0.749238D 02	0.100642D 03	0.754567D 01
0.715018D-01	0.748649D 02	0.100281D 03	0.754945D 01
0.725018D-01	0.748095D 02	0.999298D 02	0.755318D 01
0.735018D-01	0.747572D 02	0.995873D 02	0.755666D 01
0.745018D-01	0.747080D 02	0.992534D 02	0.755997D 01
0.755018D-01	0.746615D 02	0.989277D 02	0.756308D 01
0.763580D-01	0.746240D 02	0.986556D 02	0.756574D 01

$H = 0.6 \qquad M = 16$

$f_{fd,0}Re = 232.50$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-06	0.858579D 04	0.858579D 04	0.334133D-02
0.210000D-06	0.882955D 04	0.871347D 04	0.712405D-02
0.331000D-06	0.909529D 04	0.885305D 04	0.114137D-01
0.464100D-06	0.937480D 04	0.900268D 04	0.162810D-01
0.610511D-06	0.963678D 04	0.915475D 04	0.217886D-01
0.771562D-06	0.977634D 04	0.928450D 04	0.279368D-01
0.948718D-06	0.956115D 04	0.933616D 04	0.345474D-01
0.114359D-05	0.893143D 04	0.926719D 04	0.413281D-01
0.135795D-05	0.824002D 04	0.910505D 04	0.481941D-01
0.159375D-05	0.765837D 04	0.889101D 04	0.551983D-01
0.185312D-05	0.715309D 04	0.864776D 04	0.623782D-01
0.213843D-05	0.668722D 04	0.838618D 04	0.697446D-01
0.245228D-05	0.624560D 04	0.811223D 04	0.772936D-01
0.279751D-05	0.582160D 04	0.782955D 04	0.850117D-01
0.317726D-05	0.541193D 04	0.754059D 04	0.928793D-01
0.359499D-05	0.501303D 04	0.724690D 04	0.100867D 00
0.405449D-05	0.461950D 04	0.694913D 04	0.108931D 00
0.455994D-05	0.422878D 04	0.664759D 04	0.117010D 00
0.511593D-05	0.385146D 04	0.634371D 04	0.125059D 00
0.572753D-05	0.351335D 04	0.604148D 04	0.133085D 00
0.640028D-05	0.323662D 04	0.574665D 04	0.141169D 00
0.714031D-05	0.302516D 04	0.546459D 04	0.149436D 00
0.795435D-05	0.286782D 04	0.519884D 04	0.158017D 00
0.884978D-05	0.274777D 04	0.495084D 04	0.167026D 00
0.983476D-05	0.264883D 04	0.472029D 04	0.176547D 00
0.109182D-04	0.255813D 04	0.450572D 04	0.186625D 00
0.121101D-04	0.246620D 04	0.430500D 04	0.197275D 00
0.134211D-04	0.236616D 04	0.411561D 04	0.208465D 00
0.148632D-04	0.225324D 04	0.393491D 04	0.220121D 00
0.164495D-04	0.212508D 04	0.376038D 04	0.232130D 00
0.181945D-04	0.198291D 04	0.358991D 04	0.244348D 00
0.201139D-04	0.183242D 04	0.342219D 04	0.256632D 00
0.222253D-04	0.168338D 04	0.325701D 04	0.268886D 00
0.245479D-04	0.154613D 04	0.309514D 04	0.281091D 00
0.271027D-04	0.142772D 04	0.293796D 04	0.293305D 00
0.299130D-04	0.132987D 04	0.278688D 04	0.305641D 00
0.330043D-04	0.125011D 04	0.264294D 04	0.318225D 00
0.364047D-04	0.118411D 04	0.250668D 04	0.331169D 00
0.401452D-04	0.112768D 04	0.237819D 04	0.344563D 00
0.442597D-04	0.107766D 04	0.225729D 04	0.358473D 00
0.487857D-04	0.103196D 04	0.214361D 04	0.372947D 00
0.537643D-04	0.989368D 03	0.203673D 04	0.388021D 00
0.592408D-04	0.949228D 03	0.193620D 04	0.403724D 00
0.652649D-04	0.911201D 03	0.184159D 04	0.420079D 00
0.718914D-04	0.875112D 03	0.175250D 04	0.437111D 00
0.791805D-04	0.840851D 03	0.166858D 04	0.454851D 00
0.871986D-04	0.808327D 03	0.158948D 04	0.473321D 00
0.960185D-04	0.777444D 03	0.151489D 04	0.492548D 00
0.105720D-03	0.748097D 03	0.144452D 04	0.512556D 00
0.116392D-03	0.720180D 03	0.137810D 04	0.533373D 00
0.128132D-03	0.693591D 03	0.131539D 04	0.555032D 00
0.141045D-03	0.668238D 03	0.125614D 04	0.577540D 00
0.155250D-03	0.644048D 03	0.120014D 04	0.600929D 00
0.170875D-03	0.620965D 03	0.114718D 04	0.625211D 00
0.188062D-03	0.598954D 03	0.109707D 04	0.650401D 00
0.206968D-03	0.577995D 03	0.104966D 04	0.676537D 00
0.227765D-03	0.558081D 03	0.100477D 04	0.703621D 00
0.250642D-03	0.539218D 03	0.962279D 03	0.731693D 00
0.275806D-03	0.521414D 03	0.922055D 03	0.760778D 00
0.303487D-03	0.504678D 03	0.883986D 03	0.790919D 00
0.333936D-03	0.489017D 03	0.847972D 03	0.822166D 00
0.367429D-03	0.474424D 03	0.813921D 03	0.854583D 00
0.404272D-03	0.460892D 03	0.781748D 03	0.888247D 00
0.444800D-03	0.448397D 03	0.751375D 03	0.923254D 00
0.489380D-03	0.436907D 03	0.722728D 03	0.959709D 00
0.538418D-03	0.426382D 03	0.695738D 03	0.997749D 00
0.592360D-03	0.416773D 03	0.670334D 03	0.103752D 01
0.651696D-03	0.408025D 03	0.646451D 03	0.107919D 01
0.716966D-03	0.400078D 03	0.624022D 03	0.112295D 01

0.788763D-03	0.392868D 03	0.602982D 03	0.116902D 01
0.867740D-03	0.386352D 03	0.583265D 03	0.121763D 01
0.954614D-03	0.380371D 03	0.564801D 03	0.126903D 01
0.105018D-02	0.374948D 03	0.547525D 03	0.132350D 01
0.115529D-02	0.369972D 03	0.531370D 03	0.138131D 01
0.127092D-02	0.365376D 03	0.516268D 03	0.144279D 01
0.139812D-02	0.361094D 03	0.502151D 03	0.150824D 01
0.153803D-02	0.357070D 03	0.488953D 03	0.157798D 01
0.169193D-02	0.353260D 03	0.476610D 03	0.165234D 01
0.186123D-02	0.349630D 03	0.465060D 03	0.173169D 01
0.204745D-02	0.346157D 03	0.454245D 03	0.181637D 01
0.225230D-02	0.342832D 03	0.444112D 03	0.190682D 01
0.247763D-02	0.339629D 03	0.434610D 03	0.200341D 01
0.272549D-02	0.336558D 03	0.425693D 03	0.210662D 01
0.299814D-02	0.333609D 03	0.417319D 03	0.221693D 01
0.329805D-02	0.330769D 03	0.409448D 03	0.233486D 01
0.362796D-02	0.328023D 03	0.402044D 03	0.246098D 01
0.399086D-02	0.325348D 03	0.395070D 03	0.259581D 01
0.439005D-02	0.322721D 03	0.388491D 03	0.273994D 01
0.482915D-02	0.320112D 03	0.382273D 03	0.289388D 01
0.531217D-02	0.317493D 03	0.376383D 03	0.305817D 01
0.584349D-02	0.314838D 03	0.370787D 03	0.323325D 01
0.642794D-02	0.312112D 03	0.365452D 03	0.341946D 01
0.707084D-02	0.309307D 03	0.360347D 03	0.361707D 01
0.777802D-02	0.306404D 03	0.355443D 03	0.382626D 01
0.855593D-02	0.303394D 03	0.350710D 03	0.404695D 01
0.941162D-02	0.300277D 03	0.346125D 03	0.427909D 01
0.103529D-01	0.297055D 03	0.341664D 03	0.452231D 01
0.113529D-01	0.293841D 03	0.337451D 03	0.476781D 01
0.123529D-01	0.290819D 03	0.333676D 03	0.500124D 01
0.133529D-01	0.287973D 03	0.330254D 03	0.522333D 01
0.143529D-01	0.285291D 03	0.327121D 03	0.543464D 01
0.153529D-01	0.282761D 03	0.324232D 03	0.563586D 01
0.163529D-01	0.280373D 03	0.321550D 03	0.582752D 01
0.173529D-01	0.278116D 03	0.319047D 03	0.601014D 01
0.183529D-01	0.275983D 03	0.316700D 03	0.618419D 01
0.193529D-01	0.273965D 03	0.314492D 03	0.635023D 01
0.203529D-01	0.272054D 03	0.312407D 03	0.650861D 01
0.213529D-01	0.270244D 03	0.310432D 03	0.665971D 01
0.223529D-01	0.268528D 03	0.308558D 03	0.680404D 01
0.233529D-01	0.266900D 03	0.306774D 03	0.694179D 01
0.243529D-01	0.265354D 03	0.305073D 03	0.707335D 01
0.253529D-01	0.263887D 03	0.303448D 03	0.719901D 01
0.263529D-01	0.262492D 03	0.301894D 03	0.731915D 01
0.273529D-01	0.261166D 03	0.300405D 03	0.743397D 01
0.283529D-01	0.259905D 03	0.298977D 03	0.754380D 01
0.293529D-01	0.258706D 03	0.297605D 03	0.764878D 01
0.303529D-01	0.257563D 03	0.296286D 03	0.774922D 01
0.313529D-01	0.256475D 03	0.295016D 03	0.784525D 01
0.323529D-01	0.255439D 03	0.293793D 03	0.793720D 01
0.333529D-01	0.254451D 03	0.292613D 03	0.802511D 01
0.343529D-01	0.253509D 03	0.291475D 03	0.810934D 01
0.353529D-01	0.252611D 03	0.290376D 03	0.818999D 01
0.363529D-01	0.251754D 03	0.289313D 03	0.826708D 01
0.373529D-01	0.250936D 03	0.288286D 03	0.834105D 01
0.383529D-01	0.250155D 03	0.287291D 03	0.841171D 01
0.393529D-01	0.249409D 03	0.286329D 03	0.847960D 01
0.403529D-01	0.248697D 03	0.285396D 03	0.854448D 01
0.413529D-01	0.248017D 03	0.284492D 03	0.860670D 01
0.423529D-01	0.247367D 03	0.283616D 03	0.866642D 01
0.433529D-01	0.246745D 03	0.282765D 03	0.872347D 01
0.443529D-01	0.246151D 03	0.281940D 03	0.877832D 01
0.453529D-01	0.245583D 03	0.281138D 03	0.883075D 01
0.463529D-01	0.245039D 03	0.280359D 03	0.888103D 01
0.473529D-01	0.244519D 03	0.279602D 03	0.892924D 01
0.483529D-01	0.244022D 03	0.278867D 03	0.897565D 01
0.493529D-01	0.243546D 03	0.278151D 03	0.901993D 01
0.503529D-01	0.243090D 03	0.277455D 03	0.906251D 01
0.513529D-01	0.242654D 03	0.276777D 03	0.910322D 01
0.523529D-01	0.242237D 03	0.276117D 03	0.914228D 01
0.533529D-01	0.241837D 03	0.275475D 03	0.917990D 01
0.543529D-01	0.241454D 03	0.274849D 03	0.921586D 01
0.553529D-01	0.241087D 03	0.274239D 03	0.925035D 01
0.563529D-01	0.240736D 03	0.273644D 03	0.928335D 01
0.573529D-01	0.240399D 03	0.273065D 03	0.931526D 01
0.583529D-01	0.240077D 03	0.272499D 03	0.934557D 01
0.593529D-01	0.239768D 03	0.271948D 03	0.937491D 01
0.603529D-01	0.239472D 03	0.271410D 03	0.940298D 01
0.613529D-01	0.239188D 03	0.270885D 03	0.942994D 01

0.623529D-01	0.238916D 03	0.270372D 03	0.945569D 01
0.633529D-01	0.238655D 03	0.269871D 03	0.948038D 01
0.643529D-01	0.238405D 03	0.269382D 03	0.950415D 01
0.653529D-01	0.238166D 03	0.268905D 03	0.952714D 01
0.663529D-01	0.237936D 03	0.268438D 03	0.954898D 01
0.673529D-01	0.237715D 03	0.267982D 03	0.957004D 01
0.683529D-01	0.237504D 03	0.267536D 03	0.959018D 01
0.693529D-01	0.237301D 03	0.267100D 03	0.960954D 01
0.703529D-01	0.237107D 03	0.266674D 03	0.962821D 01
0.713529D-01	0.236920D 03	0.266257D 03	0.964605D 01
0.723529D-01	0.236742D 03	0.265849D 03	0.966316D 01
0.733529D-01	0.236570D 03	0.265450D 03	0.967965D 01
0.743529D-01	0.236405D 03	0.265059D 03	0.969532D 01
0.753529D-01	0.236247D 03	0.264677D 03	0.971058D 01
0.763529D-01	0.236096D 03	0.264302D 03	0.972491D 01
0.773529D-01	0.235951D 03	0.263936D 03	0.973904D 01
0.783529D-01	0.235811D 03	0.263577D 03	0.975243D 01
0.793529D-01	0.235677D 03	0.263225D 03	0.976517D 01
0.803529D-01	0.235549D 03	0.262881D 03	0.977766D 01
0.813529D-01	0.235425D 03	0.262543D 03	0.978935D 01
0.823529D-01	0.235307D 03	0.262213D 03	0.980098D 01
0.833529D-01	0.235194D 03	0.261888D 03	0.981163D 01
0.843529D-01	0.235085D 03	0.261571D 03	0.982239D 01
0.853529D-01	0.234980D 03	0.261259D 03	0.983231D 01
0.863529D-01	0.234880D 03	0.260954D 03	0.984216D 01
0.873529D-01	0.234783D 03	0.260654D 03	0.985131D 01
0.873711D-01	0.234782D 03	0.260649D 03	0.985161D 01

$H = 0.8 \qquad M = 16$

$f_{fd,0}Re = 453.00$

X	f_xRe	$f_{app}Re$	K
0.100000D-06	0.152423D 05	0.152423D 05	0.591574D-02
0.210000D-06	0.164832D 05	0.158923D 05	0.129691D-01
0.331000D-06	0.157392D 05	0.158363D 05	0.203676D-01
0.464100D-06	0.138370D 05	0.152629D 05	0.274932D-01
0.610511D-06	0.125823D 05	0.146201D 05	0.345968D-01
0.771562D-06	0.116577D 05	0.140017D 05	0.418148D-01
0.948718D-06	0.108471D 05	0.134127D 05	0.491806D-01
0.114359D-05	0.101097D 05	0.128498D 05	0.567077D-01
0.135795D-05	0.943538D 04	0.123108D 05	0.644095D-01
0.159375D-05	0.881500D 04	0.117936D 05	0.722966D-01
0.185312D-05	0.823944D 04	0.112962D 05	0.803754D-01
0.213843D-05	0.770136D 04	0.108165D 05	0.886469D-01
0.245228D-05	0.719517D 04	0.103531D 05	0.971118D-01
0.279751D-05	0.671641D 04	0.990428D 04	0.105761D 00
0.317726D-05	0.626103D 04	0.946883D 04	0.114583D 00
0.359499D-05	0.582430D 04	0.904535D 04	0.123558D 00
0.405449D-05	0.540099D 04	0.863233D 04	0.132653D 00
0.455994D-05	0.498759D 04	0.822832D 04	0.141821D 00
0.511593D-05	0.458964D 04	0.783288D 04	0.151021D 00
0.572753D-05	0.422497D 04	0.744762D 04	0.160249D 00
0.640028D-05	0.391302D 04	0.707608D 04	0.169560D 00
0.714031D-05	0.366084D 04	0.672212D 04	0.179055D 00
0.795435D-05	0.346210D 04	0.638850D 04	0.188854D 00
0.884978D-05	0.330339D 04	0.607634D 04	0.199063D 00
0.983476D-05	0.317044D 04	0.578531D 04	0.209770D 00
0.109182D-04	0.305115D 04	0.551398D 04	0.221029D 00
0.121101D-04	0.293631D 04	0.526030D 04	0.232870D 00
0.134211D-04	0.281902D 04	0.502182D 04	0.245277D 00
0.148632D-04	0.269444D 04	0.479601D 04	0.258207D 00
0.164495D-04	0.255956D 04	0.458033D 04	0.271573D 00
0.181945D-04	0.241395D 04	0.437257D 04	0.285262D 00
0.201139D-04	0.226031D 04	0.417099D 04	0.299137D 00
0.222253D-04	0.210515D 04	0.397474D 04	0.313091D 00
0.245479D-04	0.195674D 04	0.378381D 04	0.327062D 00
0.271027D-04	0.182235D 04	0.359892D 04	0.341057D 00
0.299130D-04	0.170580D 04	0.342106D 04	0.355140D 00
0.330043D-04	0.160698D 04	0.325115D 04	0.369411D 00
0.364047D-04	0.152325D 04	0.308975D 04	0.383968D 00
0.401452D-04	0.145116D 04	0.293708D 04	0.398904D 00
0.442597D-04	0.138757D 04	0.279303D 04	0.414285D 00
0.487857D-04	0.133026D 04	0.265732D 04	0.430167D 00
0.537643D-04	0.127753D 04	0.252956D 04	0.446590D 00
0.592408D-04	0.122864D 04	0.240929D 04	0.463581D 00
0.652649D-04	0.118299D 04	0.229610D 04	0.481172D 00
0.718914D-04	0.114026D 04	0.218956D 04	0.499389D 00
0.791805D-04	0.110023D 04	0.208928D 04	0.518262D 00
0.871986D-04	0.106272D 04	0.199489D 04	0.537820D 00
0.960185D-04	0.102758D 04	0.190603D 04	0.558090D 00
0.105720D-03	0.994632D 03	0.182240D 04	0.579113D 00
0.116392D-03	0.963727D 03	0.174366D 04	0.600913D 00
0.128132D-03	0.934694D 03	0.166955D 04	0.623542D 00
0.141045D-03	0.907372D 03	0.159977D 04	0.647013D 00
0.155250D-03	0.881602D 03	0.153406D 04	0.671369D 00
0.170875D-03	0.857234D 03	0.147217D 04	0.696637D 00
0.188062D-03	0.834119D 03	0.141386D 04	0.722843D 00
0.206968D-03	0.812116D 03	0.135889D 04	0.750002D 00
0.227765D-03	0.791086D 03	0.130704D 04	0.778127D 00
0.250642D-03	0.770893D 03	0.125811D 04	0.807228D 00
0.275806D-03	0.751410D 03	0.121188D 04	0.837270D 00
0.303487D-03	0.732519D 03	0.116815D 04	0.868216D 00
0.333936D-03	0.714129D 03	0.112676D 04	0.900038D 00
0.367429D-03	0.696170D 03	0.108751D 04	0.932623D 00
0.404272D-03	0.678617D 03	0.105024D 04	0.965871D 00
0.444800D-03	0.661478D 03	0.101482D 04	0.999679D 00
0.489380D-03	0.644801D 03	0.981113D 03	0.103389D 01
0.538418D-03	0.628654D 03	0.949011D 03	0.106835D 01
0.592360D-03	0.613117D 03	0.918424D 03	0.110291D 01
0.651696D-03	0.598270D 03	0.889274D 03	0.113740D 01
0.716966D-03	0.584175D 03	0.861499D 03	0.117166D 01

0.788763D-03	0.570879D 03	0.835045D 03	0.120553D 01
0.867740D-03	0.558407D 03	0.809867D 03	0.123884D 01
0.954614D-03	0.546770D 03	0.785924D 03	0.127145D 01
0.105018D-02	0.535963D 03	0.763179D 03	0.130319D 01
0.115529D-02	0.525973D 03	0.741596D 03	0.133388D 01
0.127092D-02	0.516781D 03	0.721142D 03	0.136340D 01
0.139812D-02	0.508365D 03	0.701785D 03	0.139161D 01
0.153803D-02	0.500699D 03	0.683492D 03	0.141832D 01
0.169193D-02	0.493759D 03	0.666234D 03	0.144345D 01
0.186123D-02	0.487517D 03	0.649978D 03	0.146686D 01
0.204745D-02	0.481946D 03	0.634695D 03	0.148846D 01
0.225230D-02	0.477015D 03	0.620354D 03	0.150818D 01
0.247763D-02	0.472693D 03	0.606925D 03	0.152597D 01
0.272549D-02	0.468945D 03	0.594376D 03	0.154182D 01
0.299814D-02	0.465733D 03	0.582678D 03	0.155577D 01
0.329805D-02	0.463019D 03	0.571796D 03	0.156784D 01
0.362796D-02	0.460760D 03	0.561699D 03	0.157815D 01
0.399086D-02	0.458912D 03	0.552353D 03	0.158681D 01
0.437716D-02	0.457476D 03	0.544000D 03	0.159416D 01

$H = 0.2$ $\qquad M = 24$

$f_{fd,0}Re = 30.76$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.682110D 04	0.682107D 04	0.271613D-01
0.210000D-05	0.644800D 04	0.662566D 04	0.553972D-01
0.331000D-05	0.374560D 04	0.557283D 04	0.733771D-01
0.464100D-05	0.259140D 04	0.471780D 04	0.870103D-01
0.610511D-05	0.229430D 04	0.413660D 04	0.100267D 00
0.771562D-05	0.215290D 04	0.372253D 04	0.113937D 00
0.948719D-05	0.202640D 04	0.340581D 04	0.128079D 00
0.114359D-04	0.189070D 04	0.314763D 04	0.142577D 00
0.135795D-04	0.173120D 04	0.292404D 04	0.157157D 00
0.159375D-04	0.154250D 04	0.271964D 04	0.171416D 00
0.185312D-04	0.133740D 04	0.252618D 04	0.184973D 00
0.213843D-04	0.114450D 04	0.234184D 04	0.197684D 00
0.245228D-04	0.988940D 03	0.216869D 04	0.209713D 00
0.279751D-04	0.877220D 03	0.200932D 04	0.221402D 00
0.317726D-04	0.800560D 03	0.186484D 04	0.233095D 00
0.359499D-04	0.746190D 03	0.173486D 04	0.245050D 00
0.405449D-04	0.704060D 03	0.161804D 04	0.257425D 00
0.455994D-04	0.668170D 03	0.151275D 04	0.270312D 00
0.511593D-04	0.635500D 03	0.141741D 04	0.283761D 00
0.572753D-04	0.604800D 03	0.133064D 04	0.297805D 00
0.640028D-04	0.575670D 03	0.125128D 04	0.312468D 00
0.714031D-04	0.548020D 03	0.117839D 04	0.327779D 00
0.795435D-04	0.521840D 03	0.111120D 04	0.343770D 00
0.884978D-04	0.497080D 03	0.104907D 04	0.360475D 00
0.983477D-04	0.473640D 03	0.991436D 03	0.377923D 00
0.109182D-03	0.451410D 03	0.937846D 03	0.396152D 00
0.121101D-03	0.430260D 03	0.887892D 03	0.415201D 00
0.134211D-03	0.410120D 03	0.841222D 03	0.435094D 00
0.148632D-03	0.390930D 03	0.797532D 03	0.455870D 00
0.164495D-03	0.372660D 03	0.756559D 03	0.477565D 00
0.181945D-03	0.355310D 03	0.718076D 03	0.500218D 00
0.201139D-03	0.338890D 03	0.681891D 03	0.523875D 00
0.222253D-03	0.323440D 03	0.647839D 03	0.548595D 00
0.245479D-03	0.308970D 03	0.615778D 03	0.574443D 00
0.271027D-03	0.295500D 03	0.585587D 03	0.601498D 00
0.299130D-03	0.283020D 03	0.557162D 03	0.629856D 00
0.330043D-03	0.271500D 03	0.530405D 03	0.659624D 00
0.364047D-03	0.260870D 03	0.505229D 03	0.690923D 00
0.401452D-03	0.251080D 03	0.481549D 03	0.723889D 00
0.442597D-03	0.242030D 03	0.459282D 03	0.758659D 00
0.487857D-03	0.233620D 03	0.438347D 03	0.795386D 00
0.537643D-03	0.225750D 03	0.418660D 03	0.834218D 00
0.592408D-03	0.218310D 03	0.400138D 03	0.875302D 00
0.652649D-03	0.211180D 03	0.382697D 03	0.918778D 00
0.718914D-03	0.204250D 03	0.366249D 03	0.964765D 00
0.791805D-03	0.197400D 03	0.350705D 03	0.101335D 01
0.871986D-03	0.190500D 03	0.335974D 03	0.106459D 01
0.960185D-03	0.183460D 03	0.321964D 03	0.111846D 01
0.105720D-02	0.176190D 03	0.308587D 03	0.117490D 01
0.116392D-02	0.168650D 03	0.295756D 03	0.123376D 01
0.128132D-02	0.160810D 03	0.283393D 03	0.129484D 01
0.141045D-02	0.152690D 03	0.271427D 03	0.135782D 01
0.155250D-02	0.144360D 03	0.259800D 03	0.142237D 01
0.170875D-02	0.135880D 03	0.248469D 03	0.148808D 01
0.188062D-02	0.127380D 03	0.237402D 03	0.155450D 01
0.206968D-02	0.118970D 03	0.226583D 03	0.162121D 01
0.227765D-02	0.110770D 03	0.216009D 03	0.168778D 01
0.250642D-02	0.102920D 03	0.205687D 03	0.175381D 01
0.275806D-02	0.955110D 02	0.195634D 03	0.181898D 01
0.303487D-02	0.886330D 02	0.185875D 03	0.188308D 01
0.333936D-02	0.823380D 02	0.176434D 03	0.194590D 01
0.367429D-02	0.766560D 02	0.167339D 03	0.200740D 01
0.404273D-02	0.715850D 02	0.158612D 03	0.206757D 01
0.444800D-02	0.671010D 02	0.150274D 03	0.212648D 01
0.489380D-02	0.631580D 02	0.142339D 03	0.218428D 01
0.538418D-02	0.597040D 02	0.134812D 03	0.224105D 01
0.592360D-02	0.566760D 02	0.127697D 03	0.229698D 01
0.651697D-02	0.540140D 02	0.120988D 03	0.235218D 01
0.716966D-02	0.516620D 02	0.114677D 03	0.240677D 01

0.788763D-02	0.495700D 02	0.108751D 03	0.246081D 01
0.867740D-02	0.476940D 02	0.103194D 03	0.251433D 01
0.954614D-02	0.460010D 02	0.979888D 02	0.256729D 01
0.105018D-01	0.444620D 02	0.931180D 02	0.261969D 01
0.115018D-01	0.431130D 02	0.887704D 02	0.266913D 01
0.125018D-01	0.419630D 02	0.850263D 02	0.271396D 01
0.135018D-01	0.409700D 02	0.817630D 02	0.275480D 01
0.145018D-01	0.401020D 02	0.788900D 02	0.279218D 01
0.155018D-01	0.393360D 02	0.763390D 02	0.282654D 01
0.165018D-01	0.386550D 02	0.740550D 02	0.285811D 01
0.175018D-01	0.380460D 02	0.719980D 02	0.288731D 01
0.185018D-01	0.374980D 02	0.701331D 02	0.291426D 01
0.195018D-01	0.370020D 02	0.684342D 02	0.293925D 01
0.205018D-01	0.365510D 02	0.668791D 02	0.296244D 01
0.215018D-01	0.361410D 02	0.654496D 02	0.298398D 01
0.225018D-01	0.357650D 02	0.641304D 02	0.300403D 01
0.235018D-01	0.354210D 02	0.629088D 02	0.302269D 01
0.245018D-01	0.351040D 02	0.617740D 02	0.304008D 01
0.255018D-01	0.348120D 02	0.607167D 02	0.305631D 01
0.265018D-01	0.345430D 02	0.597291D 02	0.307146D 01
0.275018D-01	0.342930D 02	0.588042D 02	0.308561D 01
0.285018D-01	0.340620D 02	0.579361D 02	0.309884D 01
0.295018D-01	0.338480D 02	0.571196D 02	0.311121D 01
0.305018D-01	0.336490D 02	0.563502D 02	0.312280D 01
0.315018D-01	0.334640D 02	0.556237D 02	0.313363D 01
0.325018D-01	0.332920D 02	0.549366D 02	0.314378D 01
0.335018D-01	0.331310D 02	0.542857D 02	0.315328D 01
0.345018D-01	0.329810D 02	0.536682D 02	0.316219D 01
0.355018D-01	0.328420D 02	0.530816D 02	0.317054D 01
0.365018D-01	0.327110D 02	0.525235D 02	0.317836D 01
0.375018D-01	0.325890D 02	0.519919D 02	0.318569D 01
0.385018D-01	0.324750D 02	0.514850D 02	0.319257D 01
0.395018D-01	0.323690D 02	0.510011D 02	0.319903D 01
0.405018D-01	0.322690D 02	0.505386D 02	0.320508D 01
0.415018D-01	0.321760D 02	0.500961D 02	0.321076D 01
0.425018D-01	0.320880D 02	0.496724D 02	0.321609D 01
0.435018D-01	0.320060D 02	0.492663D 02	0.322110D 01
0.445018D-01	0.319290D 02	0.488768D 02	0.322581D 01
0.455018D-01	0.318570D 02	0.485027D 02	0.323021D 01
0.465018D-01	0.317900D 02	0.481433D 02	0.323435D 01
0.475018D-01	0.317270D 02	0.477977D 02	0.323823D 01
0.485018D-01	0.316670D 02	0.474651D 02	0.324188D 01
0.495018D-01	0.316120D 02	0.471449D 02	0.324532D 01
0.505018D-01	0.315600D 02	0.468363D 02	0.324854D 01
0.515018D-01	0.315110D 02	0.465387D 02	0.325155D 01
0.525018D-01	0.314650D 02	0.462516D 02	0.325440D 01
0.535018D-01	0.314220D 02	0.459744D 02	0.325706D 01
0.545018D-01	0.313810D 02	0.457067D 02	0.325958D 01
0.555018D-01	0.313430D 02	0.454479D 02	0.326193D 01
0.565018D-01	0.313070D 02	0.451976D 02	0.326413D 01
0.575018D-01	0.312740D 02	0.449555D 02	0.326622D 01
0.585018D-01	0.312430D 02	0.447211D 02	0.326817D 01
0.595018D-01	0.312130D 02	0.444940D 02	0.326998D 01
0.605018D-01	0.311850D 02	0.442741D 02	0.327172D 01
0.615018D-01	0.311590D 02	0.440608D 02	0.327332D 01
0.625018D-01	0.311350D 02	0.438540D 02	0.327484D 01
0.635018D-01	0.311120D 02	0.436533D 02	0.327626D 01
0.645018D-01	0.310900D 02	0.434586D 02	0.327762D 01
0.655018D-01	0.310700D 02	0.432694D 02	0.327886D 01
0.658929D-01	0.310625D 02	0.431976D 02	0.327951D 01

$H = 0.4 \qquad M = 24$

$f_{fd,0}Re = 90.95$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-05	0.136550D 05	0.136550D 05	0.542562D-01
0.210000D-05	0.924361D 04	0.113443D 05	0.945282D-01
0.331000D-05	0.540602D 04	0.917350D 04	0.120253D 00
0.464100D-05	0.377851D 04	0.762626D 04	0.139886D 00
0.610511D-05	0.321254D 04	0.656778D 04	0.158167D 00
0.771562D-05	0.293799D 04	0.581012D 04	0.176508D 00
0.948719D-05	0.273552D 04	0.523599D 04	0.195248D 00
0.114359D-04	0.255170D 04	0.477858D 04	0.214429D 00
0.135795D-04	0.236651D 04	0.439782D 04	0.233941D 00
0.159375D-04	0.216906D 04	0.406807D 04	0.253542D 00
0.185312D-04	0.195944D 04	0.377293D 04	0.272926D 00
0.213843D-04	0.175116D 04	0.350319D 04	0.291874D 00
0.245228D-04	0.156417D 04	0.325503D 04	0.310369D 00
0.279751D-04	0.141167D 04	0.302755D 04	0.328607D 00
0.317726D-04	0.129419D 04	0.282037D 04	0.346883D 00
0.359499D-04	0.120409D 04	0.263257D 04	0.365484D 00
0.405449D-04	0.113238D 04	0.246255D 04	0.384625D 00
0.455994D-04	0.107215D 04	0.230843D 04	0.404463D 00
0.511593D-04	0.101908D 04	0.216830D 04	0.425103D 00
0.572753D-04	0.970802D 03	0.204043D 04	0.446629D 00
0.640028D-04	0.926109D 03	0.192330D 04	0.469103D 00
0.714031D-04	0.884397D 03	0.181563D 04	0.492591D 00
0.795435D-04	0.845355D 03	0.171633D 04	0.517154D 00
0.884978D-04	0.808769D 03	0.162450D 04	0.542864D 00
0.983477D-04	0.774451D 03	0.153937D 04	0.569796D 00
0.109182D-03	0.742215D 03	0.146026D 04	0.598017D 00
0.121101D-03	0.711888D 03	0.138661D 04	0.627624D 00
0.134211D-03	0.683318D 03	0.131791D 04	0.658687D 00
0.148632D-03	0.656383D 03	0.125372D 04	0.691301D 00
0.164495D-03	0.630997D 03	0.119367D 04	0.725569D 00
0.181945D-03	0.607108D 03	0.113742D 04	0.761601D 00
0.201139D-03	0.584694D 03	0.108467D 04	0.799505D 00
0.222253D-03	0.563750D 03	0.103518D 04	0.839434D 00
0.245479D-03	0.544287D 03	0.988738D 03	0.881554D 00
0.271027D-03	0.526317D 03	0.945149D 03	0.926046D 00
0.299130D-03	0.509847D 03	0.904253D 03	0.973136D 00
0.330043D-03	0.494869D 03	0.865908D 03	0.102308D 01
0.364047D-03	0.481351D 03	0.829988D 03	0.107618D 01
0.401452D-03	0.469236D 03	0.796376D 03	0.113278D 01
0.442597D-03	0.458442D 03	0.764960D 03	0.119326D 01
0.487857D-03	0.448860D 03	0.735635D 03	0.125806D 01
0.537643D-03	0.440356D 03	0.708292D 03	0.132764D 01
0.592408D-03	0.432794D 03	0.682824D 03	0.140253D 01
0.652649D-03	0.426019D 03	0.659120D 03	0.148327D 01
0.718914D-03	0.419867D 03	0.637067D 03	0.157045D 01
0.791805D-03	0.414177D 03	0.616548D 03	0.166469D 01
0.871986D-03	0.408793D 03	0.597445D 03	0.176663D 01
0.960185D-03	0.403564D 03	0.579636D 03	0.187692D 01
0.105720D-02	0.398348D 03	0.562999D 03	0.199621D 01
0.116392D-02	0.393016D 03	0.547413D 03	0.212515D 01
0.128132D-02	0.387456D 03	0.532758D 03	0.226440D 01
0.141045D-02	0.381571D 03	0.518916D 03	0.241451D 01
0.155250D-02	0.375283D 03	0.505775D 03	0.257608D 01
0.170875D-02	0.368531D 03	0.493225D 03	0.274956D 01
0.188062D-02	0.361273D 03	0.481165D 03	0.293540D 01
0.206968D-02	0.353481D 03	0.469502D 03	0.313394D 01
0.227765D-02	0.345142D 03	0.458146D 03	0.334539D 01
0.250642D-02	0.336255D 03	0.447021D 03	0.356987D 01
0.275806D-02	0.326831D 03	0.436055D 03	0.380730D 01
0.303487D-02	0.316891D 03	0.425186D 03	0.405748D 01
0.333936D-02	0.306470D 03	0.414361D 03	0.431997D 01
0.367429D-02	0.295610D 03	0.403537D 03	0.459417D 01
0.404273D-02	0.284370D 03	0.392676D 03	0.487922D 01
0.444800D-02	0.272818D 03	0.381756D 03	0.517406D 01
0.489380D-02	0.261033D 03	0.370758D 03	0.547734D 01
0.538418D-02	0.249106D 03	0.359678D 03	0.578756D 01
0.592360D-02	0.237135D 03	0.348519D 03	0.610299D 01
0.651697D-02	0.225224D 03	0.337293D 03	0.642169D 01
0.716966D-02	0.213482D 03	0.326022D 03	0.674160D 01

0.788763D-02	0.202014D 03	0.314734D 03	0.706056D 01
0.867740D-02	0.190925D 03	0.303466D 03	0.737641D 01
0.954614D-02	0.180309D 03	0.292258D 03	0.768693D 01
0.105018D-01	0.170251D 03	0.281156D 03	0.799011D 01
0.115018D-01	0.161214D 03	0.270728D 03	0.827117D 01
0.125018D-01	0.153430D 03	0.261345D 03	0.852108D 01
0.135018D-01	0.146702D 03	0.252854D 03	0.874409D 01
0.145018D-01	0.140868D 03	0.245132D 03	0.894378D 01
0.155018D-01	0.135791D 03	0.238079D 03	0.912318D 01
0.165018D-01	0.131357D 03	0.231611D 03	0.928477D 01
0.175018D-01	0.127471D 03	0.225661D 03	0.943088D 01
0.185018D-01	0.124053D 03	0.220169D 03	0.956328D 01
0.195018D-01	0.121036D 03	0.215086D 03	0.968366D 01
0.205018D-01	0.118363D 03	0.210368D 03	0.979330D 01
0.215018D-01	0.115988D 03	0.205979D 03	0.989349D 01
0.225018D-01	0.113870D 03	0.201885D 03	0.998513D 01
0.235018D-01	0.111975D 03	0.198060D 03	0.100693D 02
0.245018D-01	0.110275D 03	0.194477D 03	0.101466D 02
0.255018D-01	0.108745D 03	0.191115D 03	0.102178D 02
0.265018D-01	0.107364D 03	0.187955D 03	0.102834D 02
0.275018D-01	0.106113D 03	0.184979D 03	0.103441D 02
0.285018D-01	0.104979D 03	0.182172D 03	0.104002D 02
0.295018D-01	0.103947D 03	0.179520D 03	0.104521D 02
0.305018D-01	0.103005D 03	0.177012D 03	0.105004D 02
0.315018D-01	0.102145D 03	0.174635D 03	0.105452D 02
0.325018D-01	0.101358D 03	0.172381D 03	0.105869D 02
0.335018D-01	0.100635D 03	0.170239D 03	0.106256D 02
0.345018D-01	0.999703D 02	0.168203D 03	0.106617D 02
0.355018D-01	0.993584D 02	0.166263D 03	0.106953D 02
0.365018D-01	0.987940D 02	0.164415D 03	0.107267D 02
0.375018D-01	0.982727D 02	0.162651D 03	0.107560D 02
0.385018D-01	0.977905D 02	0.160967D 03	0.107834D 02
0.395018D-01	0.973438D 02	0.159356D 03	0.108090D 02
0.405018D-01	0.969296D 02	0.157815D 03	0.108329D 02
0.415018D-01	0.965451D 02	0.156338D 03	0.108552D 02
0.425018D-01	0.961877D 02	0.154923D 03	0.108762D 02
0.435018D-01	0.958553D 02	0.153565D 03	0.108958D 02
0.445018D-01	0.955457D 02	0.152262D 03	0.109143D 02
0.455018D-01	0.952573D 02	0.151009D 03	0.109315D 02
0.465018D-01	0.949883D 02	0.149804D 03	0.109476D 02
0.475018D-01	0.947373D 02	0.148645D 03	0.109628D 02
0.485018D-01	0.945028D 02	0.147529D 03	0.109771D 02
0.495018D-01	0.942838D 02	0.146453D 03	0.109904D 02
0.505018D-01	0.940790D 02	0.145416D 03	0.110029D 02
0.515018D-01	0.938874D 02	0.144415D 03	0.110146D 02
0.525018D-01	0.937082D 02	0.143449D 03	0.110256D 02
0.535018D-01	0.935403D 02	0.142517D 03	0.110361D 02
0.545018D-01	0.933831D 02	0.141615D 03	0.110458D 02
0.555018D-01	0.932358D 02	0.140743D 03	0.110548D 02
0.565018D-01	0.930977D 02	0.139900D 03	0.110635D 02
0.575018D-01	0.929682D 02	0.139084D 03	0.110716D 02
0.585018D-01	0.928468D 02	0.138294D 03	0.110793D 02
0.595018D-01	0.927329D 02	0.137528D 03	0.110864D 02
0.605018D-01	0.926260D 02	0.136786D 03	0.110931D 02
0.615018D-01	0.925257D 02	0.136066D 03	0.110994D 02
0.625018D-01	0.924315D 02	0.135368D 03	0.111053D 02
0.635018D-01	0.923430D 02	0.134690D 03	0.111108D 02
0.645018D-01	0.922599D 02	0.134033D 03	0.111162D 02
0.655018D-01	0.921819D 02	0.133394D 03	0.111212D 02
0.665018D-01	0.921086D 02	0.132773D 03	0.111258D 02
0.675018D-01	0.920397D 02	0.132169D 03	0.111300D 02
0.685018D-01	0.919750D 02	0.131583D 03	0.111343D 02
0.695018D-01	0.919141D 02	0.131012D 03	0.111381D 02
0.704833D-01	0.918580D 02	0.130467D 03	0.111417D 02

$H = 0.6 \qquad M = 24$

$f_{fd,0}Re = 335.90$

X	$f_x Re$	$f_{app} Re$	K
0.100000D-06	0.188250D 05	0.188250D 05	0.739563D-02
0.210000D-06	0.200819D 05	0.194834D 05	0.160839D-01
0.331000D-06	0.210900D 05	0.200707D 05	0.261288D-01
0.464100D-06	0.204150D 05	0.201694D 05	0.368189D-01
0.610511D-06	0.180807D 05	0.196685D 05	0.472110D-01
0.771562D-06	0.159623D 05	0.188949D 05	0.572776D-01
0.948718D-06	0.142627D 05	0.180299D 05	0.671464D-01
0.114359D-05	0.127968D 05	0.171382D 05	0.768597D-01
0.135795D-05	0.114722D 05	0.162438D 05	0.864084D-01
0.159375D-05	0.102513D 05	0.153572D 05	0.957607D-01
0.185312D-05	0.911489D 04	0.144835D 05	0.104869D 00
0.213843D-05	0.805222D 04	0.136254D 05	0.113674D 00
0.245228D-05	0.707593D 04	0.127872D 05	0.122136D 00
0.279751D-05	0.623972D 04	0.119792D 05	0.130289D 00
0.317726D-05	0.559813D 04	0.112165D 05	0.138282D 00
0.359499D-05	0.514700D 04	0.105113D 05	0.146322D 00
0.405449D-05	0.483441D 04	0.986790D 04	0.154589D 00
0.455994D-05	0.460369D 04	0.928438D 04	0.163218D 00
0.511593D-05	0.441538D 04	0.875522D 04	0.172290D 00
0.572753D-05	0.424776D 04	0.827391D 04	0.181860D 00
0.640028D-05	0.409062D 04	0.783419D 04	0.191964D 00
0.714031D-05	0.393979D 04	0.743057D 04	0.202632D 00
0.795435D-05	0.379359D 04	0.705837D 04	0.213891D 00
0.884978D-05	0.365112D 04	0.671362D 04	0.225765D 00
0.983476D-05	0.351135D 04	0.639290D 04	0.238276D 00
0.109182D-04	0.337287D 04	0.609320D 04	0.251437D 00
0.121101D-04	0.323380D 04	0.581179D 04	0.265253D 00
0.134211D-04	0.309201D 04	0.554612D 04	0.279706D 00
0.148632D-04	0.294549D 04	0.529379D 04	0.294759D 00
0.164495D-04	0.279304D 04	0.505263D 04	0.310350D 00
0.181945D-04	0.263514D 04	0.482077D 04	0.326398D 00
0.201139D-04	0.247456D 04	0.459688D 04	0.342818D 00
0.222253D-04	0.231634D 04	0.438023D 04	0.359544D 00
0.245479D-04	0.216651D 04	0.417078D 04	0.376551D 00
0.271027D-04	0.203011D 04	0.396899D 04	0.393864D 00
0.299130D-04	0.190971D 04	0.377553D 04	0.411556D 00
0.330043D-04	0.180514D 04	0.359097D 04	0.429723D 00
0.364047D-04	0.171433D 04	0.341568D 04	0.448471D 00
0.401452D-04	0.163450D 04	0.324972D 04	0.467900D 00
0.442597D-04	0.156302D 04	0.309292D 04	0.488096D 00
0.487857D-04	0.149785D 04	0.294494D 04	0.509131D 00
0.537643D-04	0.143751D 04	0.280535D 04	0.531069D 00
0.592408D-04	0.138112D 04	0.267369D 04	0.553965D 00
0.652649D-04	0.132814D 04	0.254949D 04	0.577874D 00
0.718914D-04	0.127825D 04	0.243232D 04	0.602853D 00
0.791805D-04	0.123128D 04	0.232175D 04	0.628956D 00
0.871986D-04	0.118713D 04	0.221742D 04	0.656257D 00
0.960185D-04	0.114572D 04	0.211898D 04	0.684827D 00
0.105720D-03	0.110695D 04	0.202611D 04	0.714748D 00
0.116392D-03	0.107074D 04	0.193851D 04	0.746115D 00
0.128132D-03	0.103699D 04	0.185591D 04	0.779037D 00
0.141045D-03	0.100558D 04	0.177806D 04	0.813627D 00
0.155250D-03	0.976411D 03	0.170471D 04	0.850019D 00
0.170875D-03	0.949362D 03	0.163564D 04	0.888359D 00
0.188062D-03	0.924333D 03	0.157064D 04	0.928816D 00
0.206968D-03	0.901221D 03	0.150949D 04	0.971566D 00
0.227765D-03	0.879928D 03	0.145200D 04	0.101682D 01
0.250642D-03	0.860357D 03	0.139800D 04	0.106481D 01
0.275806D-03	0.842406D 03	0.134731D 04	0.111579D 01
0.303487D-03	0.825965D 03	0.129976D 04	0.117005D 01
0.333936D-03	0.810912D 03	0.125518D 04	0.122790D 01
0.367429D-03	0.797105D 03	0.121343D 04	0.128969D 01
0.404272D-03	0.784391D 03	0.117433D 04	0.135578D 01
0.444800D-03	0.772598D 03	0.113772D 04	0.142656D 01
0.489380D-03	0.761551D 03	0.110346D 04	0.150248D 01
0.538418D-03	0.751078D 03	0.107136D 04	0.158390D 01
0.592360D-03	0.741023D 03	0.104128D 04	0.167131D 01
0.651696D-03	0.731259D 03	0.101305D 04	0.176513D 01
0.716966D-03	0.721696D 03	0.986529D 03	0.186586D 01

0.788763D-03	0.712287D 03	0.961567D 03	0.197395D 01
0.867740D-03	0.703024D 03	0.938036D 03	0.208992D 01
0.954614D-03	0.693931D 03	0.915821D 03	0.221433D 01
0.105018D-02	0.685045D 03	0.894821D 03	0.234779D 01
0.115529D-02	0.676422D 03	0.874950D 03	0.249094D 01
0.127092D-02	0.668109D 03	0.856131D 03	0.264459D 01
0.139812D-02	0.660126D 03	0.838300D 03	0.280955D 01
0.153803D-02	0.652488D 03	0.821397D 03	0.298671D 01
0.169193D-02	0.645189D 03	0.805368D 03	0.317709D 01
0.186123D-02	0.638203D 03	0.790163D 03	0.338180D 01
0.204745D-02	0.631479D 03	0.775730D 03	0.360196D 01
0.225230D-02	0.624959D 03	0.762018D 03	0.383880D 01
0.247763D-02	0.618574D 03	0.748972D 03	0.409356D 01
0.272549D-02	0.612252D 03	0.736538D 03	0.436752D 01
0.299814D-02	0.605914D 03	0.724659D 03	0.466198D 01
0.329805D-02	0.599485D 03	0.713276D 03	0.497816D 01
0.362796D-02	0.592900D 03	0.702330D 03	0.531728D 01
0.399086D-02	0.586097D 03	0.691761D 03	0.568045D 01
0.439005D-02	0.579030D 03	0.681510D 03	0.606863D 01
0.482915D-02	0.571668D 03	0.671522D 03	0.648269D 01
0.531217D-02	0.563990D 03	0.661745D 03	0.692335D 01
0.584349D-02	0.555990D 03	0.652129D 03	0.739106D 01
0.642794D-02	0.547674D 03	0.642632D 03	0.788611D 01
0.707084D-02	0.539054D 03	0.633214D 03	0.840848D 01
0.777802D-02	0.530153D 03	0.623844D 03	0.895792D 01
0.855593D-02	0.520998D 03	0.614493D 03	0.953381D 01
0.941162D-02	0.511624D 03	0.605140D 03	0.101352D 02
0.103529D-01	0.502068D 03	0.595769D 03	0.107608D 02
0.113529D-01	0.492678D 03	0.586688D 03	0.113878D 02
0.123529D-01	0.483969D 03	0.578373D 03	0.119800D 02
0.133529D-01	0.475877D 03	0.570697D 03	0.125398D 02
0.143529D-01	0.468343D 03	0.563566D 03	0.130695D 02
0.153529D-01	0.461316D 03	0.556906D 03	0.135711D 02
0.163529D-01	0.454751D 03	0.550659D 03	0.140464D 02
0.173529D-01	0.448607D 03	0.544778D 03	0.144972D 02
0.183529D-01	0.442851D 03	0.539224D 03	0.149249D 02
0.193529D-01	0.437449D 03	0.533965D 03	0.153310D 02
0.203529D-01	0.432374D 03	0.528974D 03	0.157168D 02
0.213529D-01	0.427601D 03	0.524226D 03	0.160835D 02
0.223529D-01	0.423107D 03	0.519703D 03	0.164323D 02
0.233529D-01	0.418870D 03	0.515385D 03	0.167641D 02
0.243529D-01	0.414874D 03	0.511258D 03	0.170800D 02
0.253529D-01	0.411100D 03	0.507307D 03	0.173806D 02
0.263529D-01	0.407533D 03	0.503521D 03	0.176671D 02
0.273529D-01	0.404160D 03	0.499888D 03	0.179400D 02
0.283529D-01	0.400967D 03	0.496399D 03	0.182002D 02
0.293529D-01	0.397943D 03	0.493045D 03	0.184483D 02
0.303529D-01	0.395078D 03	0.489818D 03	0.186850D 02
0.313529D-01	0.392360D 03	0.486709D 03	0.189107D 02
0.323529D-01	0.389781D 03	0.483713D 03	0.191261D 02
0.333529D-01	0.387333D 03	0.480823D 03	0.193318D 02
0.343529D-01	0.385008D 03	0.478034D 03	0.195281D 02
0.353529D-01	0.382799D 03	0.475340D 03	0.197156D 02
0.363529D-01	0.380698D 03	0.472737D 03	0.198948D 02
0.373529D-01	0.378700D 03	0.470220D 03	0.200660D 02
0.383529D-01	0.376799D 03	0.467784D 03	0.202295D 02
0.393529D-01	0.374989D 03	0.465426D 03	0.203858D 02
0.403529D-01	0.373266D 03	0.463142D 03	0.205351D 02
0.413529D-01	0.371625D 03	0.460929D 03	0.206780D 02
0.423529D-01	0.370061D 03	0.458783D 03	0.208144D 02
0.433529D-01	0.368570D 03	0.456702D 03	0.209450D 02
0.443529D-01	0.367149D 03	0.454683D 03	0.210699D 02
0.453529D-01	0.365793D 03	0.452723D 03	0.211894D 02
0.463529D-01	0.364500D 03	0.450820D 03	0.213038D 02
0.473529D-01	0.363266D 03	0.448971D 03	0.214132D 02
0.483529D-01	0.362088D 03	0.447174D 03	0.215178D 02
0.493529D-01	0.360964D 03	0.445427D 03	0.216180D 02
0.503529D-01	0.359891D 03	0.443729D 03	0.217140D 02
0.513529D-01	0.358866D 03	0.442076D 03	0.218057D 02
0.523529D-01	0.357886D 03	0.440468D 03	0.218936D 02
0.533529D-01	0.356950D 03	0.438903D 03	0.219778D 02
0.543529D-01	0.356056D 03	0.437378D 03	0.220582D 02
0.553529D-01	0.355202D 03	0.435894D 03	0.221354D 02
0.563529D-01	0.354385D 03	0.434447D 03	0.222091D 02
0.573529D-01	0.353604D 03	0.433038D 03	0.222800D 02
0.583529D-01	0.352857D 03	0.431664D 03	0.223478D 02
0.593529D-01	0.352143D 03	0.430324D 03	0.224126D 02
0.603529D-01	0.351460D 03	0.429017D 03	0.224747D 02
0.613529D-01	0.350806D 03	0.427742D 03	0.225342D 02

0.623529D-01	0.350181D 03	0.426499D 03	0.225915D 02
0.633529D-01	0.349583D 03	0.425284D 03	0.226459D 02
0.643529D-01	0.349011D 03	0.424099D 03	0.226983D 02
0.653529D-01	0.348463D 03	0.422942D 03	0.227486D 02
0.663529D-01	0.347939D 03	0.421811D 03	0.227965D 02
0.673529D-01	0.347437D 03	0.420707D 03	0.228426D 02
0.683529D-01	0.346956D 03	0.419628D 03	0.228868D 02
0.693529D-01	0.346496D 03	0.418574D 03	0.229292D 02
0.703529D-01	0.346056D 03	0.417543D 03	0.229697D 02
0.713529D-01	0.345634D 03	0.416535D 03	0.230085D 02
0.723529D-01	0.345230D 03	0.415550D 03	0.230459D 02
0.733529D-01	0.344844D 03	0.414586D 03	0.230815D 02
0.743529D-01	0.344473D 03	0.413643D 03	0.231157D 02
0.753529D-01	0.344118D 03	0.412720D 03	0.231484D 02
0.763529D-01	0.343778D 03	0.411817D 03	0.231798D 02
0.773529D-01	0.343453D 03	0.410933D 03	0.232099D 02
0.783529D-01	0.343141D 03	0.410068D 03	0.232389D 02
0.793529D-01	0.342842D 03	0.409221D 03	0.232666D 02
0.803529D-01	0.342556D 03	0.408391D 03	0.232930D 02
0.813529D-01	0.342281D 03	0.407579D 03	0.233187D 02
0.823529D-01	0.342018D 03	0.406783D 03	0.233431D 02
0.833529D-01	0.341766D 03	0.406003D 03	0.233665D 02
0.843529D-01	0.341525D 03	0.405238D 03	0.233887D 02
0.853529D-01	0.341294D 03	0.404489D 03	0.234103D 02
0.863529D-01	0.341072D 03	0.403755D 03	0.234310D 02
0.873529D-01	0.340859D 03	0.403035D 03	0.234508D 02
0.883529D-01	0.340656D 03	0.402329D 03	0.234697D 02
0.893529D-01	0.340460D 03	0.401636D 03	0.234877D 02
0.903529D-01	0.340273D 03	0.400957D 03	0.235052D 02
0.913529D-01	0.340094D 03	0.400291D 03	0.235219D 02
0.923529D-01	0.339922D 03	0.399637D 03	0.235378D 02
0.933529D-01	0.339757D 03	0.398996D 03	0.235533D 02
0.943529D-01	0.339599D 03	0.398366D 03	0.235679D 02
0.953529D-01	0.339448D 03	0.397748D 03	0.235819D 02
0.963529D-01	0.339302D 03	0.397142D 03	0.235957D 02
0.965214D-01	0.339279D 03	0.397041D 03	0.235980D 02

$H = 0.8$ $M = 24$

$f_{fd,0}Re = 852.70$

X	f_xRe	$f_{app}Re$	K
0.100000D-06	0.369945D 05	0.369945D 05	0.144567D-01
0.210000D-06	0.337978D 05	0.353201D 05	0.289526D-01
0.331000D-06	0.268936D 05	0.322397D 05	0.415564D-01
0.464100D-06	0.232324D 05	0.296565D 05	0.534714D-01
0.610511D-06	0.206010D 05	0.274848D 05	0.650368D-01
0.771562D-06	0.184167D 05	0.255920D 05	0.763517D-01
0.948718D-06	0.165397D 05	0.239016D 05	0.874677D-01
0.114359D-05	0.148927D 05	0.223665D 05	0.984120D-01
0.135795D-05	0.134205D 05	0.209543D 05	0.109188D 00
0.159375D-05	0.120861D 05	0.196422D 05	0.119783D 00
0.185312D-05	0.108632D 05	0.184135D 05	0.130169D 00
0.213843D-05	0.973474D 04	0.172555D 05	0.140305D 00
0.245228D-05	0.870306D 04	0.161610D 05	0.150161D 00
0.279751D-05	0.780046D 04	0.151292D 05	0.159755D 00
0.317726D-05	0.706868D 04	0.141658D 05	0.169197D 00
0.359499D-05	0.651431D 04	0.132767D 05	0.178657D 00
0.405449D-05	0.610214D 04	0.124636D 05	0.188306D 00
0.455994D-05	0.578410D 04	0.117232D 05	0.198276D 00
0.511593D-05	0.552157D 04	0.110492D 05	0.208659D 00
0.572753D-05	0.529042D 04	0.104343D 05	0.219516D 00
0.640028D-05	0.507809D 04	0.987130D 04	0.230887D 00
0.714031D-05	0.487798D 04	0.935379D 04	0.242803D 00
0.795435D-05	0.468740D 04	0.887624D 04	0.255289D 00
0.884978D-05	0.450473D 04	0.843392D 04	0.268370D 00
0.983476D-05	0.432869D 04	0.802277D 04	0.282065D 00
0.109182D-04	0.415796D 04	0.763924D 04	0.296389D 00
0.121101D-04	0.399097D 04	0.728019D 04	0.311352D 00
0.134211D-04	0.382596D 04	0.694277D 04	0.326943D 00
0.148632D-04	0.366115D 04	0.662437D 04	0.343144D 00
0.164495D-04	0.349508D 04	0.632259D 04	0.359910D 00
0.181945D-04	0.332725D 04	0.603532D 04	0.377183D 00
0.201139D-04	0.315843D 04	0.576078D 04	0.394885D 00
0.222253D-04	0.299133D 04	0.549769D 04	0.412948D 00
0.245479D-04	0.283001D 04	0.524529D 04	0.431318D 00
0.271027D-04	0.267888D 04	0.500337D 04	0.449981D 00
0.299130D-04	0.254138D 04	0.477207D 04	0.468964D 00
0.330043D-04	0.241900D 04	0.455167D 04	0.488332D 00
0.364047D-04	0.231137D 04	0.434241D 04	0.508172D 00
0.401452D-04	0.221676D 04	0.414436D 04	0.528582D 00
0.442597D-04	0.213296D 04	0.395737D 04	0.549652D 00
0.487857D-04	0.205788D 04	0.378115D 04	0.571472D 00
0.537643D-04	0.198972D 04	0.361526D 04	0.594115D 00
0.592408D-04	0.192720D 04	0.345921D 04	0.617654D 00
0.652649D-04	0.186932D 04	0.331246D 04	0.642152D 00
0.718914D-04	0.181534D 04	0.317447D 04	0.667670D 00
0.791805D-04	0.176467D 04	0.304468D 04	0.694258D 00
0.871986D-04	0.171678D 04	0.292258D 04	0.721973D 00
0.960185D-04	0.167115D 04	0.280763D 04	0.750849D 00
0.105720D-03	0.162729D 04	0.269931D 04	0.780907D 00
0.116392D-03	0.158471D 04	0.259711D 04	0.812155D 00
0.128132D-03	0.154302D 04	0.250054D 04	0.844580D 00
0.141045D-03	0.150191D 04	0.240911D 04	0.878112D 00
0.155250D-03	0.146128D 04	0.232239D 04	0.912696D 00
0.170875D-03	0.142118D 04	0.223998D 04	0.948226D 00
0.188062D-03	0.138184D 04	0.216155D 04	0.984602D 00
0.206968D-03	0.134354D 04	0.208683D 04	0.102173D 01
0.227765D-03	0.130658D 04	0.201558D 04	0.105948D 01
0.250642D-03	0.127121D 04	0.194764D 04	0.109778D 01
0.275806D-03	0.123759D 04	0.188286D 04	0.113653D 01
0.303487D-03	0.120580D 04	0.182110D 04	0.117562D 01
0.333936D-03	0.117585D 04	0.176227D 04	0.121499D 01
0.367429D-03	0.114772D 04	0.170625D 04	0.125452D 01
0.404272D-03	0.112136D 04	0.165295D 04	0.129412D 01
0.444800D-03	0.109671D 04	0.160227D 04	0.133369D 01
0.489380D-03	0.107372D 04	0.155412D 04	0.137310D 01
0.538418D-03	0.105232D 04	0.150841D 04	0.141225D 01
0.592360D-03	0.103247D 04	0.146507D 04	0.145105D 01
0.651696D-03	0.101411D 04	0.142401D 04	0.148936D 01
0.716966D-03	0.997180D 03	0.138516D 04	0.152711D 01

0.788763D-03	0.981638D 03	0.134843D 04	0.156415D 01
0.867740D-03	0.967425D 03	0.131375D 04	0.160039D 01
0.954614D-03	0.954486D 03	0.128105D 04	0.163575D 01
0.105018D-02	0.942762D 03	0.125027D 04	0.167021D 01
0.115529D-02	0.932193D 03	0.122133D 04	0.170364D 01
0.127092D-02	0.922717D 03	0.119416D 04	0.173603D 01
0.139812D-02	0.914272D 03	0.116870D 04	0.176739D 01
0.153803D-02	0.906794D 03	0.114487D 04	0.179765D 01
0.169193D-02	0.900217D 03	0.112262D 04	0.182695D 01
0.186123D-02	0.894473D 03	0.110187D 04	0.185527D 01
0.204745D-02	0.889496D 03	0.108255D 04	0.188267D 01
0.225230D-02	0.885216D 03	0.106460D 04	0.190932D 01
0.247763D-02	0.881562D 03	0.104796D 04	0.193543D 01
0.272549D-02	0.878464D 03	0.103254D 04	0.196094D 01
0.299814D-02	0.875848D 03	0.101829D 04	0.198621D 01
0.329805D-02	0.873643D 03	0.100514D 04	0.201142D 01
0.362796D-02	0.871780D 03	0.993012D 03	0.203662D 01
0.399086D-02	0.870191D 03	0.981844D 03	0.206206D 01
0.439005D-02	0.868814D 03	0.971566D 03	0.208784D 01
0.482915D-02	0.867596D 03	0.962112D 03	0.211405D 01
0.531217D-02	0.866492D 03	0.953418D 03	0.214076D 01
0.584349D-02	0.865465D 03	0.945421D 03	0.216796D 01
0.642794D-02	0.864490D 03	0.938062D 03	0.219558D 01
0.707084D-02	0.863548D 03	0.931287D 03	0.222356D 01
0.777802D-02	0.862629D 03	0.925045D 03	0.225174D 01
0.855593D-02	0.861730D 03	0.919288D 03	0.227992D 01
0.907869D-02	0.861193D 03	0.916042D 03	0.230134D 01

APPENDIX C

Computer Codes Used in the Analysis of Model I, Model II, and Model III

MODEL I

```
      DIMENSION U(50,55),T1(50,55),T(50,55),V(50,55),RM(65)
     &,G1(50,55),G2(50,55),G3(50,55),G4(50,55),G5(50,55),T2(50,55)
      DOUBLE PRECISION DTH,G5,G1,G2,G3,T,T1,T2,T3,V,FRE
     *,G4,PI,UB,U,TB1,TB,ANUS1,DR,ANUSS,A1,A2,B1,B2,RM
      REAL N
C [ H ] IS FIN HEIGHT , [ N ] IS NUMBER OF FINS , [ NHD ] IS NUMBER OF
C ANGULAR DIVISIONS. [ NVD ] IS THE NUMBER OF RADIAL DIVISIONS....
      READ (5,*) H,N,NHD,NVD
      PRINT 5,H,N,NHD,NVD
    5 FORMAT('1',10X,'FIN HEIGHT = ',F5.3,10X,'NUMBER OF FINS = '
     *,F3.0,10X,'NHD = ',I2,10X,'NVD = ',I2)
      WRITE (4,6) H,N,NHD,NVD
    6 FORMAT (/,9X,'CHF',2(9X,F5.2),2(9X,I3))
      NHD7=NHD+7
      NHD5=NHD+5
      NHD6=NHD+6
      NHD4=NHD+4
      DR=1./NVD
      IF (H.EQ.0.0) NVD=NVD-5
      NVD10=NVD+10
      NVD11=NVD+11
      NVD12=NVD+12
      NVD13=NVD+13
      NVD14=NVD+14
      NVD15=NVD+15
      NVD16=NVD+16
      PI=3.14159265358979
      DTH=PI/N/NHD
      JF=(1-H)/DR+11.5
      IF (H.EQ.0.0) JF=NVD16
      JFN1=JF-1
      JFN2=JF-2
      JFN3=JF-3
      JFN4=JF-4
      JFN5=JF-5
      JFN6=JF-6
      RM(1)=0.0
      DO 121 J=2,NVD16
      IF (J.LE.7.OR.J.GT.JFN6.AND.J.LE.JF.OR.J.GT.NVD10) RM(J)=
     &RM(J-1)+DR/6.
      IF (J.GT.7.AND.J.LE.JFN6.OR.J.GT.JF.AND.J.LE.NVD10) RM(J)=
     &RM(J-1)+DR
  121 CONTINUE
      DO 20 J=1,NVD16
      DO 20 I=2,NHD7
      U(I,J)=.25*RM(J)*(1.0-RM(J)**2.)
      V(I,J)=1.0
   20 CONTINUE
      DO 101 K=2,NHD7
      U(K,NVD16)=0.0
      U(K,1)=0.0
  101 CONTINUE
```

```
      DO 10 J=2,NVD15
      DO 10 I=2,NHD7
      IF (I.GE.2.AND.I.LE.7) GO TO 100
      GO TO 110
  100 IF (J.GE.2.AND.J.LE.6.OR.J.GE.JFN5.AND.J.LE.JFN1.OR.J.GE.NVD11.
     &AND.J.LE.NVD15) GO TO 120
      GO TO 130
  120 A1=1./6.
      A2=1./6.
      B1=1./6.
      B2=1./6.
      GO TO 30
  130 IF(J.GE.8.AND.J.LE.JFN6-1.OR.J.GE.JF+1.AND.J.LE.NVD10-1)GO TO 140
      GO TO 150
  140 A1=1.0
      A2=1.0
      B1=1./6.
      B2=1./6.
      GO TO 30
  150 IF (J.EQ.7.OR.J.EQ.JF) GO TO 160
      GO TO 170
  160 A1=1.0
      A2=1./6.
      B1=1./6.
      B2=1./6.
      IF(J.EQ.7.AND.J.EQ.JFN6.OR.J.EQ.JF.AND.J.EQ.NVD10) A1=1./6.
      GO TO 30
  170 IF (J.EQ.JFN6.OR.J.EQ.NVD10) GO TO 180
      GO TO 110
  180 A1=1./6.
      A2=1.0
      B1=1./6.
      B2=1./6.
      IF (J.EQ.JFN6.AND.J.EQ.7.OR.J.EQ.NVD10.AND.J.EQ.JF) A2=1./6.
      GO TO 30
  110 IF (I.EQ.8) GO TO 190
      GO TO 200
  190 IF (J.GE.2.AND.J.LE.6.OR.J.GE.JFN5.AND.J.LE.JFN1.OR.J.GE.NVD11.
     &AND.J.LE.NVD15) GO TO 210
      GO TO 220
  210 A1=1./6.
      A2=1./6.
      B1=1.0
      B2=1./6.
      GO TO 30
  220 IF(J.GE.8.AND.J.LE.JFN6-1.OR.J.GE.JF+1.AND.J.LE.NVD10-1)GO TO 230
      GO TO 240
  230 A1=1.0
      A2=1.0
      B1=1.0
      B2=1./6.
      GO TO 30
  240 IF (J.EQ.7.OR.J.EQ.JF) GO TO 250
      GO TO 260
```

```
250 A1=1.0
    A2=1./6.
    B1=1.0
    B2=1./6.
    IF (J.EQ.7.AND.J.EQ.JFN6.OR.J.EQ.JF.AND.J.EQ.NVD10) A1=1./6.
    GO TO 30
260 IF (J.EQ.JFN6.OR.J.EQ.NVD10) GO TO 270
    GO TO 200
270 A1=1./6.
    A2=1.0
    B1=1.0
    B2=1./6.
    IF (J.EQ.JFN6.AND.J.EQ.7.OR.J.EQ.NVD10.AND.J.EQ.JF) A2=1./6.
    GO TO 30
200 IF (I.GE.9.AND.I.LE.NHD7) GO TO 280
280 IF (J.GE.2.AND.J.LE.6.OR.J.GE.JFN5.AND.J.LE.JFN1.OR.J.GE.NVD11.
   &AND.J.LE.NVD15) GO TO 290
    GO TO 300
290 A1=1./6.
    A2=1./6.
    B1=1.0
    B2=1.0
    GO TO 30
300 IF (J.GE.8.AND.J.LE.JFN6-1.OR.J.GE.JF+1.AND.J.LE.NVD10-1)GO TO 310
    GO TO 320
310 A1=1.0
    A2=1.0
    B1=1.0
    B2=1.0
    GO TO 30
320 IF(J.EQ.7.OR.J.EQ.JF) GO TO 330
    GO TO 340
330 A1=1.0
    A2=1./6.
    B1=1.0
    B2=1.0
    IF (J.EQ.7.AND.J.EQ.JFN6.OR.J.EQ.JF.AND.J.EQ.NVD10) A1=1./6.
    GO TO 30
340 IF (J.EQ.JFN6.OR.J.EQ.NVD10) GO TO 350
350 A1=1./6.
    A2=1.0
    B1=1.0
    B2=1.0
    IF (J.EQ.JFN6.AND.J.EQ.7.OR.J.EQ.NVD10.AND.J.EQ.JF) A2=1./6.
 30 CONTINUE
    G1(I,J)=(2.*RM(J)+A1*DR)/((A2*A2+A1*A2)*DR*DR)
    G2(I,J)=(2.*RM(J)-A2*DR)/((A1*A2+A1*A1)*DR*DR)
    G3(I,J)=2./(RM(J)*(B2*B2+B1*B2)*DTH*DTH)
    G4(I,J)=2./(RM(J)*(B1*B2+B1*B1)*DTH*DTH)
    G5(I,J)=(2.*RM(J)/A1/A2/DR/DR+(A1-A2)/(A1*A2)
   &/DR-1./RM(J)+2./RM(J)/B1/B2/DTH/DTH)
 10 CONTINUE
    N1=0
    DO 12 NITER=1,60000
```

```
      DO 70 I=2,NHD7
      DO 70 J=2,NVD15
      IF (I.EQ.2.AND.J.GE.JF) GO TO 411
      GO TO 421
  411 U(I,J)=0.0
      GO TO 70
  421 IF (I.EQ.2) U(I-1,J)=U(I+1,J)
      IF (I.EQ.NHD7) U(I+1,J)=U(I-1,J)
      U(I,J)=U(I,J)+1.997*((G1(I,J)*U(I,J-1)+G2(I,J)*U(I,J+1)+
     &G3(I,J)*U(I-1,J)+G4(I,J)*U(I+1,J)+RM(J)**2)/G5(I,J)-U(I,J))
   70 CONTINUE
      N1=N1+1
      N2=N1/10
      IF (N2.EQ.1) GO TO 431
      GO TO 441
  431 N1=0
      GO TO 451
  441 GO TO 12
  451 DO 13 I=2,NHD7
      DO 13 J=2,NVD15
      IF (V(I,J).EQ.0.0) GO TO 13
      IF (DABS((V(I,J)-U(I,J))/V(I,J))*100.0.GT.0.001) GO TO 25
   13 CONTINUE
      PRINT 55 , NITER
   55 FORMAT ('1',20X,'CONVERGENCE OF THE MOMENTUM EQ N O     CCURED AFTER '
     &,I5,' ITERATIONS')
      DO 111 J=1,NVD16
      PRINT 40,(U(I,J),I=2,NHD7)
  111 CONTINUE
   40 FORMAT(/,10(1X,D12.6))
      CALL INTEG(U,DTH,PI,UB,N,DR,NHD7,NVD,NVD16,NHD,H)
      FRE=2./UB
      PRINT 60,UB,FRE
      WRITE (4,7) UB,FRE
    7 FORMAT (/,10X,'UB ',F10.7,10X,'FRE ',F10.5)
   60 FORMAT(/,20X,'AVERAGE BULK VELOCITY',F10.7,10X,'F*RE = ',F10.5)
      GO TO 65
   25 DO 45 J=1,NVD16
      DO 45 I=2,NHD7
      V(I,J)=U(I,J)
   45 CONTINUE
   12 CONTINUE
      PRINT 75,NITER
   75 FORMAT ('1',20X,'NO CONVERGENCE WITHIN ',I5,' ITERATIONS')
CC
CC       SOLUTION OF THE CONSTANT HEAT FLUX ENERGY EQUATION.
CC
   65 CALL CHFFD(ANUS1,DR,DTH,PI,N,T,U,NHD7,NVD16,H,RM,JF,V,G1,G2,G3
     &,G4,G5,FRE,UB)
      WRITE (3,9999) FRE,ANUS1,UB
      DO 999 J=1,NVD15
      DO 999 I=2,NHD7
      WRITE (3,9999) G1(I,J),G2(I,J),G3(I,J),G4(I,J),G5(I,J),U(I,J)
  999 CONTINUE
```

```
9999 FORMAT (3(1X,D23.16))
CC
CC      SOLUTION OF THE DEVELOPING ENERGY EQUATION FOR THE CONSTANT HEAT
CC      FLUX CASE.
CC
      CALL CHFER(ANUS1,DR,DTH,PI,N,T,U,NHD7,NVD16,H,RM,JF,V,G1,G2,G3,
     &G4,G5,FRE,UB)
CC
CC       SOLUTION OF THE FULLY DEVELOPED ENERGY EQUATION FOR THE CASE
CC       OF CONSTANT WALL TEMPERATURE.
CC
      ANUSS=1.0
      DO 16 J=1,NVD16
      DO 16 I=2,NHD7
      T(I,J)=U(I,J)
      T1(I,J)=10.00
      T2(I,J)=U(I,J)
      IF (J.EQ.1.OR.J.EQ.NVD16) GO TO 460
      GO TO 16
 460  T(I,J)=0.0
      T1(I,J)=0.0
      T2(I,J)=0.0
  16  CONTINUE
      N1=0
      DO 80 NITER=1,999999
      DO 50 I=2,NHD7
      DO 50 J=2,NVD15
      IF (I.EQ.2.AND.J.GE.JF) GO TO 470
      GO TO 480
 470  T(I,J)=0.0
      GO TO 50
 480  IF (I.EQ.2) T(I-1,J)=T(I+1,J)
      IF (I.EQ.NHD7) T(I+1,J)=T(I-1,J)
      T(I,J)=T(I,J)+1.993*((G1(I,J)*T(I,J-1)+G2(I,J)*T(I,J+1)+G3(I,J)*
     &T(I-1,J)+G4(I,J)*T(I+1,J)+1./UB*U(I,J)*T2(I,J)*ANUSS)/G5(I,J)
     &-T(I,J))
  50  CONTINUE
      N1=N1+1
      N2=N1/10
      IF (N2.EQ.1) GO TO 490
      GO TO 80
 490  N1=0
      DO 85 I=2,NHD7
      DO 85 J=2,NVD15
      IF (T1(I,J).EQ.0.0) GO TO 85
      IF (DABS((T1(I,J)-T(I,J))/T1(I,J))*100.0.GT.0.001) GO TO 105
  85  CONTINUE
      DO 42 I=2,NHD7
      DO 42 J=2,NVD16
      T1(I,J)=T1(I,J)*U(I,J)/RM(J)
  42  CONTINUE
      CALL INTEG(T1,DTH,PI,TB,N,DR,NHD7,NVD,NVD16,NHD,H)
      TB=TB/UB
      ANUS2=1.0/TB
```

```
      IF(DABS((ANUS2-ANUSS)/ANUS2)*100.0.GT.0.01) GO TO 95
      PRINT 90
   90 FORMAT ('1',30X,'FULLY DEVELOPED CONSTANT WALL TEMPERATURE')
      PRINT 500,NITER
  500 FORMAT('0',30X,'CONVERGENCE O     CCURED AFTER ',I6,' ITERATIONS')
      DO 1111 I=2,NHD7
      DO 1111 J=1,NVD16
      T(I,J)=T(I,J)/TB
 1111 CONTINUE
      DO 112 J=1,NVD16
      PRINT 40,(T(I,J),I=2,NHD7)
  112 CONTINUE
      PRINT 35,TB,ANUS2
      WRITE (4,35) TB,ANUS2
      GO TO 520
   95 ANUSS=ANUS2
      DO 1235 J=1,NVD16
      DO 1235 I=2,NHD7
      T2(I,J)=T(I,J)
 1235 CONTINUE
  105 DO 115 J=1,NVD16
      DO 115 I=2,NHD7
      T1(I,J)=T(I,J)
  115 CONTINUE
   80 CONTINUE
      PRINT 530,NITER
      STOP
  530 FORMAT('1',20X,'NO CONVERGENCE WITHIN',I6,'ITERATIONS')
  520 CONTINUE
      DO 1919 J=2,NVD16
      DO 1919 I=2,NHD7
      IF (U(I,J).EQ.0.0) GO TO 1919
      T1(I,J)=T1(I,J)/U(I,J)/TB
 1919 CONTINUE
      DO 2929 J=1,NVD16
      WRITE (8,2222) (T1(I,J),I=2,NHD7)
 2929 CONTINUE
 2222 FORMAT (5(1X,D12.6))
CC
CC      SOLUTION OF THE DEVELOPING ENERGY EQUATION FOR THE CASE OF
CC      CONSTANT WALL TEMPERATURE.
CC
      CALL CWTER(G1,G2,G3,G4,G5,NHD7,NVD16,RM,JF,FRE,T,U,DTH,DR,H,
     &PI,N,ANUS2,UB,V)
      STOP
      END
      SUBROUTINE INTEG (U,DTH,PI,UB,N,DR,NHD7,NVD,NVD16,NHD,H)
      DOUBLE PRECISION U(50,55),F(65),DTH,UB,PI,DR
     *,F1(65),F2(65),F3(65),UB1,UB2,UB3,SUM1,SUM2
      REAL N
      NHD6=NHD+6
      NHD5=NHD+5
      NHD4=NHD+4
      NVD10=NVD+10
```

```
      NVD11=NVD+11
      NVD12=NVD+12
      NVD13=NVD+13
      NVD14=NVD+14
      NVD15=NVD+15
      JF=(1-H)/DR+11.5
      IF (H.EQ.0.0) JF=NVD16
      JFN1=JF-1
      JFN2=JF-2
      JFN3=JF-3
      JFN4=JF-4
      JFN5=JF-5
      JFN6=JF-6
      DO 10 I=2,NHD7
      F1(I)=DR/6./3.*(U(I,NVD10)+U(I,NVD16)+4.*(U(I,NVD11)
     &+U(I,NVD13)+U(I,NVD15))+2.0*(U(I,NVD12)+U(I,NVD14)))
      F1(I)=F1(I)+DR/6./3.*(U(I,7)+U(I,1)+4.*(U(I,2)+U(I,4)+
     &U(I,6))+2.*(U(I,3)+U(I,5)))
      IF (H.EQ.0.0) GO TO 90
      F1(I)=F1(I)+DR/6./3.*(U(I,JF)+U(I,JFN6)+4.0*(U(I,JFN1)+U(I,JFN3)
     &+U(I,JFN5))+2.0*(U(I,JFN2)+U(I,JFN4)))
   90 N1=NVD10-JF
      N2=N1/2
      IF (N1.LE.0) GO TO 140
      IF (N1.EQ.1) GO TO 150
      N3=2*N2
      IF (N1.EQ.N3) GO TO 100
      GO TO 110
  100 SUM1=0.0
      SUM2=0.0
      JF1=JF+1
      NVD9=NVD+9
      DO 120 J=JF1,NVD9,2
      SUM1=SUM1+U(I,J)
      IF (J.EQ.NVD9) GO TO 120
      SUM2=SUM2+U(I,J+1)
  120 CONTINUE
      F2(I)=DR/3.*(U(I,JF)+U(I,NVD10)+4.0*SUM1+2.0*SUM2)
      GO TO 160
  110 SUM1=0.0
      SUM2=0.0
      JF1=JF+1
      NVD8=NVD+8
      DO 130 J=JF1,NVD8,2
      SUM1=SUM1+U(I,J)
      IF (J.EQ.NVD8) GO TO 130
      SUM2=SUM2+U(I,J+1)
  130 CONTINUE
      F2(I)=DR/3.0*(U(I,JF)+U(I,NVD10-1)+4.0*SUM1+2.0*SUM2)+
     &DR/2.0*(U(I,NVD10-1)+U(I,NVD10))
      GO TO 160
  140 F2(I)=0.0
      GO TO 160
  150 F2(I)=DR/2.0*(U(I,JF)+U(I,NVD10))
```

```
160 N1=JFN6-7
    N2=N1/2
    IF (N1.EQ.0) GO TO 220
    IF (N1.EQ.1) GO TO 230
    N3=2*N2
    IF (N1.EQ.N3) GO TO 170
    GO TO 180
170 SUM1=0.0
    SUM2=0.0
    JFN7=JF-7
    DO 190 J=8,JFN7,2
    SUM1=SUM1+U(I,J)
    IF (J.EQ.JFN7) GO TO 190
    SUM2=SUM2+U(I,J+1)
190 CONTINUE
    F3(I)=DR/3.*(U(I,7)+U(I,JFN6)+4.0*SUM1+2.0*SUM2)
    GO TO 210
180 SUM1=0.0
    SUM2=0.0
    JFN7=JF-7
    DO 200 J=9,JFN7,2
    SUM1=SUM1+U(I,J)
    IF (J.EQ.JFN7) GO TO 200
    SUM2=SUM2+U(I,J+1)
200 CONTINUE
    F3(I)=DR/3.0*(U(I,8)+U(I,JFN6)+4.0*SUM1+2.0*SUM2)+
   &DR/2.0*(U(I,7)+U(I,8))
    GO TO 210
220 F3(I)=0.0
    GO TO 210
230 F3(I)=DR/2.0*(U(I,7)+U(I,JFN6))
210 F(I)=F1(I)+F2(I)+F3(I)
 10 CONTINUE
    UB1=DTH/6.0/3.0*(F(2)+F(8)+4.0*(F(3)+F(5)+F(7))+2.0*(F(4)+F(6)))
    N1=NHD/2
    N2=2*N1
    IF(NHD.EQ.N2) GO TO 480
    GO TO 520
480 SUM1=0.0
    SUM2=0.0
    DO 60 J=9,NHD5,2
    SUM1=SUM1+F(J)
    IF(J.EQ.NHD5) GO TO 60
    SUM2=SUM2+F(J+1)
 60 CONTINUE
    UB2=DTH/3.0*(F(8)+F(NHD6)+4.0*SUM1+2.0*SUM2)
    UB3=DTH/2.0*(F(NHD6)+F(NHD7))
    UB=UB1+UB2+UB3
    GO TO 530
520 SUM1=0.0
    SUM2=0.0
    DO 70 J=9,NHD6,2
    SUM1=SUM1+F(J)
    IF(J.EQ.NHD6) GO TO 70
```

```
      SUM2=SUM2+F(J+1)
   70 CONTINUE
      UB2=DTH/3.0*(F(8)+F(NHD7)+4.0*SUM1+2.0*SUM2)
      UB=UB1+UB2
  530 UB=UB/PI*2.0*N
      RETURN
      END
      SUBROUTINE CHFFD(ANUS1,DR,DTH,PI,N,T,U,NHD7,NVD16,H,RM,JF,V,G1,
     &G2,G3,G4,G5,FRE,UB)
      DIMENSION U(50,55),RM(65),V(50,55),T(50,55),
     &G1(50,55),G2(50,55),G3(50,55),G4(50,55),G5(50,55)
      DOUBLE PRECISION DR,DTH,PI,U,V,G1,G2,G3,G4,G5,FRE,A1,A2,UB,TW,
     &CORR,T,TB,ANUS1,RM
      REAL N
      DO 5 I=2,NHD7
      DO 5 J=1,NVD16
      V(I,J)=1.0
      T(I,J)=RM(J)
    5 CONTINUE
      TW=0.00
      NN=0
      DO 100 ITER=1,60000
      DO 10 I=2,NHD7
      DO 10 J=1,NVD16
      IF(J.EQ.1) GO TO 80
      GO TO 90
   80 T(I,J)=0.0
      GO TO 10
   90 IF(J.EQ.NVD16) GO TO 110
      GO TO 140
  110 T(I,J)=TW
      GO TO 10
  140 IF(I.EQ.2) GO TO 150
      GO TO 160
  150 IF(J.GE.JF) GO TO 170
      GO TO 180
  170 T(I,J)=TW*RM(J)
      GO TO 190
  180 T(I-1,J)=T(I+1,J)
      T(I,J)=T(I,J)+1.997*((G1(I,J)*T(I,J-1)+G2(I,J)*T(I,J+1)+G3(I,J)*
     &T(I-1,J)+G4(I,J)*T(I+1,J)-U(I,J)*RM(J)*FRE/2.)/(+G5(I,J))-T(I,J))
  190 GO TO 10
  160 IF(I.EQ.NHD7) GO TO 200
      GO TO 210
  200 T(I+1,J)=T(I-1,J)
      T(I,J)=T(I,J)+1.997*((G1(I,J)*T(I,J-1)+G2(I,J)*T(I,J+1)+G3(I,J)*
     &T(I-1,J)+G4(I,J)*T(I+1,J)-U(I,J)*RM(J)*FRE/2.)/(+G5(I,J))-T(I,J))
      GO TO 10
  210 T(I,J)=T(I,J)+1.997*((G1(I,J)*T(I,J-1)+G2(I,J)*T(I,J+1)+G3(I,J)*
     &T(I-1,J)+G4(I,J)*T(I+1,J)-U(I,J)*RM(J)*FRE/2.)/(+G5(I,J))-T(I,J))
   10 CONTINUE
      IF (ITER.LE.55) GO TO 100
      NN=NN+1
      IF (NN.EQ.10) GO TO 500
```

```
      GO TO 100
  500 NN=0
      DO 20 I=2,NHD7
      DO 20 J=1,NVD16
      IF(V(I,J).EQ.0.0) GO TO 20
      IF(DABS((V(I,J)-T(I,J))/V(I,J))*100.0.GT.0.001) GO TO 30
   20 CONTINUE
      PRINT 15
   15 FORMAT ('1',30X,'FULLY DEVELOPED CONSTANT HEAT FLUX')
      PRINT 35,ITER
   35 FORMAT(' ',30X,'CONVERGENCE O     CCURED AFTER ',I5,' ITERATIONS')
      DO 114 J=1,NVD16
      PRINT 45,(T(I,J),I=2,NHD7)
  114 CONTINUE
      DO 25 I=2,NHD7
      DO 25 J=2,NVD16
      T(I,J)=T(I,J)*U(I,J)/RM(J)
   25 CONTINUE
      NHD=NHD7-7
      NVD=NVD16-16
      CALL INTEG(T,DTH,PI,TB,N,DR,NHD7,NVD,NVD16,NHD,H)
      TB=TB/UB
      DO 1919 J=2,NVD16
      DO 1919 I=2,NHD7
      V(I,J)=(TW-V(I,J)/RM(J))
 1919 CONTINUE
      DO 2929 J=1,NVD16
      WRITE (8,2222) (V(I,J),I=2,NHD7)
 2929 CONTINUE
 2222 FORMAT (5(1X,D12.6))
      ANUS1=1.0/(TW-TB)
      PRINT 70,TB,ANUS1
      WRITE (4,70) TB,ANUS1
      RETURN
   45 FORMAT(/,5(10(1X,D11.5),/))
   70 FORMAT(/,10X,'AVERAGE BULK TEMP= ',F10.6,10X,'NUSSELT NUMBER ='
     @,F10.6,/)
   30 DO 40 I=2,NHD7
      DO 40 J=1,NVD16
      V(I,J)=T(I,J)
   40 CONTINUE
  100 CONTINUE
      PRINT 85,ITER
   85 FORMAT('0',20X,'NO CONVEGENCE O     CCURED WITHIN ',I5,' ITERATIONS')
      RETURN
      END
      SUBROUTINE CHFER(ANUS1,DR,DTH,PI,N,T,U,NHD7,NVD16,H,RM,JF,V,G1,
     &G2,G3,G4,G5,FRE,UB)
      DIMENSION U(50,55),RM(65),V(50,55),T(50,55),
     &G1(50,55),G2(50,55),G3(50,55),G4(50,55),G5(50,55),T1(50,55)
      DOUBLE PRECISION DR,DTH,PI,U,V,G1,G2,G3,G4,G5,FRE,A1,A2,UB,TW,
     &CORR,T,TB,T1,TW1,X,DX,CORRS,CORRSS,TWS,TWSS,ANUS1,NUSS,TT,DR1,
     &ANUSLT,ANUS21,RM
      REAL N
```

```
      DO 5 I=2,NHD7
      DO 5 J=1,NVD16
      V(I,J)=1.0
      T1(I,J)=0.0
      T(I,J)=0.0
    5 CONTINUE
      TW1=0.0
      X=0.0
      NN=0
      RF=1.1
      DO 110 NST=1,700
      NCR=1
      IF(NST.GT.20) GO TO 420
      GO TO 410
  420 DX=1.05*DX
      IF (DX.GT.0.001) DX=0.001
      GO TO 2
  410 DX=1.0E-04
      IF (NST.LE.19) DX=1.0E-05
      IF (NST.LE.10) DX=1.0E-06
    2 TW=2.0*DX+TW1
      X=X+DX
      RF=0.9224+.08*NST-0.0025*NST*NST+0.00003*NST**3
      IF (NST.GE.2) RF=RF*(N*.007143+.9714)
      IF (RF.GE.1.982)RF=1.982
      IF (NST.GE.30) RF=1.983
      IF (NST.GE.40) RF=1.984
      IF (NST.GE.50) RF=1.985
      IF (NST.GE.60) RF=1.987
      IF (NST.GE.70) RF=1.990
      IF (H.EQ.0.0.AND.NST.GT.10) RF=1.5
      DO 100 ITER=1,60000
      DO 10 I=2,NHD7
      DO 10 J=1,NVD16
      IF(J.EQ.1) GO TO 160
      GO TO 170
  160 T(I,J)=0.0
      GO TO 10
  170 IF(J.EQ.NVD16) GO TO 180
      GO TO 210
  180 T(I,J)=TW
      GO TO 10
  210 IF(I.EQ.2) GO TO 220
      GO TO 230
  220 IF(J.GE.JF) GO TO 240
      GO TO 250
  240 T(I,J)=TW*RM(J)
      GO TO 260
  250 T(I-1,J)=T(I+1,J)
      T(I,J)=T(I,J)+RF*((FRE*U(I,J)/4.0/DX*T1(I,J)+G1(I,J)*T(I,J-1)+
     &G2(I,J)*T(I,J+1)+G3(I,J)*T(I-1,J)+G4(I,J)*T(I+1,J))/((FRE*U(I,J)
     &/4.0/DX)+G5(I,J))-T(I,J))
  260 GO TO 10
  230 IF(I.EQ.NHD7) GO TO 270
```

```
      GO TO 280
  270 T(I+1,J)=T(I-1,J)
      T(I,J)=T(I,J)+RF*((FRE*U(I,J)/4.0/DX*T1(I,J)+G1(I,J)*T(I,J-1)+
     &G2(I,J)*T(I,J+1)+G3(I,J)*T(I-1,J)+G4(I,J)*T(I+1,J))/((FRE*U(I,J)
     &/4.0/DX)+G5(I,J))-T(I,J))
      GO TO 10
  280 T(I,J)=T(I,J)+RF*((FRE*U(I,J)/4.0/DX*T1(I,J)+G1(I,J)*T(I,J-1)+
     &G2(I,J)*T(I,J+1)+G3(I,J)*T(I-1,J)+G4(I,J)*T(I+1,J))/((FRE*U(I,J)
     &/4.0/DX)+G5(I,J))-T(I,J))
   10 CONTINUE
      IF (NST.EQ.1.AND.ITER.LE.40) GO TO 100
      NN=NN+1
      IF (NN.EQ.10) GO TO 400
      GO TO 100
  400 NN=0
      DO 20 I=2,NHD7
      DO 20 J=1,NVD16
      IF(V(I,J).EQ.0.0) GO TO 20
      IF(DABS((V(I,J)-T(I,J))/V(I,J))*100.0.GT.0.001) GO TO 30
   20 CONTINUE
      DO 25 I=2,NHD7
      DO 25 J=2,NVD16
      V(I,J)=T(I,J)*U(I,J)/RM(J)
   25 CONTINUE
      NHD=NHD7-7
      NVD=NVD16-16
      CALL INTEG(V,DTH,PI,TB,N,DR,NHD7,NVD,NVD16,NHD,H)
      TB=TB/UB
      CORR=2.0*X/TB
      IF(CORR.LE.1.0001.AND.CORR.GE.0.9999) GO TO 310
      GO TO 320
  310 PRINT 35,ITER,NCR
   35 FORMAT('1',20X,'CONVERGENCE O     CCURED AFTER ',I5,' ITERATIONS'
     &,10X,'AND ',I2,' CORRECTIONS')
      DO 125 J=1,NVD16
      PRINT 45,(T(I,J),I=2,NHD7)
  125 CONTINUE
      ANUS21=NUSS
      NUSS=1.0/(TW-TB)
      IF (NUSS.LE.1.05*ANUS1) GO TO 290
      GO TO 300
  290 PRINT 70,X,TB,NUSS
      ANUSLT=1.05*ANUS1
      X=X-DX*(NUSS-ANUSLT)/(NUSS-ANUS21)
      PRINT 500,X,ANUSLT
      WRITE (4,71) X,ANUSLT
 500  FORMAT (/,5X,'THE ENTRY REGION = ',F10.8, ' NUSSELT NUMBER = ',
     &F11.5)
      RETURN
  300 PRINT 70,X,TB,NUSS
      WRITE (4,71) X,NUSS
   71 FORMAT (5X,F10.8,5X,F12.5)
      GO TO 120
  320 IF (NST.EQ.1) GO TO 115
```

```
      IF (NCR.LE.25) GO TO 330
      GO TO 340
  330 IF (NCR.EQ.1) GO TO 350
      GO TO 360
  350 TWS=TW
      CORRS=CORR
      TW=TW*(1.0+CORR)/2.0
      NCR=NCR+1
      GO TO 100
  360 TWSS=TW
      CORRSS=CORR
      TW=TWS+(1.0-CORRS)*(TWSS-TWS)/(CORRSS-CORRS)
      TWS=TWSS
      CORRS=CORRSS
      NCR=NCR+1
      GO TO 100
  340 GO TO 130
  115 TW=TW*CORR
      DO 56 I=2,NHD7
      DO 56 J=1,NVD16
      T(I,J)=T(I,J)*CORR
   56 CONTINUE
      NCR=NCR+1
      GO TO 100
   45 FORMAT('0',5(10(1X,D11.5),/))
   70 FORMAT('0',9X,'AT X =',F10.8,20X,'AVERAGE BULK TEMP=',F11.7,20X,
     @'NUSSELT NUMBER = ',F10.5)
   30 DO 40 I=2,NHD7
      DO 40 J=1,NVD16
      V(I,J)=T(I,J)
   40 CONTINUE
  100 CONTINUE
      PRINT 155,ITER
      RETURN
  155 FORMAT('0',10X,'NO CONVERGENCE O     CCURED WITHIN ',I5,' ITERATIONS')
  120 DO 80 I=2,NHD7
      DO 80 J=1,NVD16
      T1(I,J)=T(I,J)
   80 CONTINUE
      TW1=TW
  110 CONTINUE
      RETURN
  130 PRINT 140,NCR
  140 FORMAT('0',///,35X,'CONVERGENCE FAILED WITHIN ',I2,' ITERATIONS')
      RETURN
      END
```

MODEL II

```
      DOUBLE PRECISION U(35,35),V(35,35),W(35,35),US(35,35),
     *VS(35,35),WS(35,35),T(35,35),APR(35,35),APT(35,35),APX(35,35),
     *ANR(35,35),ANT(35,35),ANX(35,35),ASR(35,35),AST(35,35),
     *ASX(35,35),AER(35,35),AET(35,35),AEX(35,35),AWR(35,35),
     *AWT(35,35),AWX(35,35),BR(35,35),BT(35,35),CR(55),SUMV,SUMW,
     *CT(55),CX(55),A(35,35),B(35,35),C(35,35),D(35,35),E(35,35)
      DOUBLE PRECISION F(35,35),PC(35,35),P(35,35),FC(35,35),UP(35,35),
     *VP(35,35),WP(35,35),DPDX,R(55),DR,DX,DTH,PI,DPDX1,FRE,FRE1,X
     *,V2(35,35),PC1(35,35),W2(35,35),V1(35,35),W1(35,35),P1(35,35)
     *,FREFD,FRE01,FRE05,FREP,XP,L,DP,K,CU,ZE,FAPPRE,BX(35,35)
     *,DR1,DR2,DR3,BRC,BTC,BXC,CRI,REC1(35,35),REC2(35,35),U1(35,35),
     *APRC,APTC,APXC,ANRC,ANTC,ANXC,ASRC,ASTC,ASXC,AERC,AETC,AEXC
      DOUBLE PRECISION AWRC,AWTC,AWXC,KP,FAPREP,FAPREL,KL
CC
CC      ( NRD ) IS THE RADIAL DIVISIONS, ( NAD ) IS THE ANGULAR DIVISIONS.
CC      ( H )   IS THE RELATIVE FIN HEIGHT.
CC      ( M )   IS THE NUMBER OF FINS.
CC
      READ (5,*) NRD,NAD,H,M
      DR=1.0/NRD
      IFIN=(1-H)/DR+2
      IF (H.EQ.0.0) IFIN=IFIN+10
      PRINT 7,NRD,NAD,H,M
    7 FORMAT ('1',10X,'MESH SIZE (',I2,'X',I2,')',10X,'FIN HEIGHT = ',
     *F3.1,10X,I2,' FINS',100(/))
      FREP=1.0
      FRE=2.0
      ZE=0.0000000000
      SUMV=0.0
      SUMW=0.0
      FRE1=1.0
      RFP=1.0
      RF=1.0
      RFDP=1.0
      RFCO=1.0
      RFS=1.0
      RFVC=1.0
      PI=2.0*DARCOS(ZE)
      NRD1=NRD+1
      NRD2=NRD+2
      NRD3=NRD+3
      NAD1=NAD+1
      NAD2=NAD+2
      DTH=PI/M/NAD
      DX=1.0E-09
      X=0.00
      DPDX=-32.0
      R(2)=0.0
      DO 10 I=3,NRD3
      IF (I.EQ.3.OR.I.EQ.NRD3)  R(I)=R(I-1)+DR/2.0
      IF (I.NE.3.AND.I.NE.NRD3)  R(I)=R(I-1)+DR
   10 CONTINUE
```

```
CC
CC          INITIALIZING ALL VELOCITIES AND PRESSURE.
CC
      DO 20 I=1,NRD3
      DO 20 J=1,NAD2
      IF (I.NE.1.AND.J.NE.NAD2) U(I,J)=2.0*(1.0-(R(I)+DR/2.0)**2)
      UP(I,J)=1.0
      P(I,J)=0.0
      P1(I,J)=0.0
      IF (I.NE.1.AND.I.NE.NRD3.AND.J.NE.1.AND.J.NE.NAD2) P(I,J)=0.0
      PC(I,J)=0.0
      T(I,J)=0.0
      V(I,J)=0.0
      VP(I,J)=0.0
      W(I,J)=0.0
      WP(I,J)=0.0
      APR(I,J)=0.0
      ANR(I,J)=0.0
      ASR(I,J)=0.0
      AER(I,J)=0.0
      AWR(I,J)=0.0
      BR(I,J)=0.0
      APT(I,J)=0.0
      ANT(I,J)=0.0
      AST(I,J)=0.0
      AET(I,J)=0.0
      AWT(I,J)=0.0
      BT(I,J)=0.0
      APX(I,J)=0.0
      ANX(I,J)=0.0
      ASX(I,J)=0.0
      AEX(I,J)=0.0
      AWX(I,J)=0.0
      BX(I,J)=0.0
      F(I,J)=0.0
      FC(I,J)=0.0
      V2(I,J)=0.0
      PC1(I,J)=0.0
      W2(I,J)=0.0
      V1(I,J)=0.0
      W1(I,J)=0.0
      IF (I.EQ.2.OR.I.EQ.NRD3) V(I,J)=0.0
      IF (J.EQ.2.OR.J.EQ.NAD2) W(I,J)=0.0
   20 CONTINUE
CC
CC          SOLVING THE FULLY DEVELOPED MOMENTUM.
CC
      CALL FDMOM (DR,DTH,R,U,US,APX,ANX,ASX,AEX,AWX,CX,NRD,NAD1,
     *M,DPDX,PI,T,DPDX1,IFIN)
      PRINT 11
   11 FORMAT ('1',250(/))
      FREFD=-DPDX/2.0
      DP=0.0
      XP=0.0
```

```
      FRE05=1.05*FREFD
      FRE01=1.01*FREFD
      MM=0
CC
CC         STARTING THE SOLUTION FOR THE ENTRY REGION.
CC
      DO 501 I=2,NRD2
      DO 501 J=2,NAD1
      U(I,J)=1.0
      IF (J.EQ.NAD1) U(I,NAD2)=U(I,NAD1)
      IF (I.EQ.NRD2) U(NRD3,J)=-U(NRD2,J)
      IF (I.EQ.2) U(1,J)=U(2,J)
      IF (I.GE.IFIN) U(I,1)=-U(I,2)
      IF (I.LT.IFIN) U(I,1)=U(I,2)
  501 CONTINUE
      DPDX=-100.0
      IF (DX.GE.1.0E-03) DX=1.0E-03
      X=X+DX
      DO 502 I=2,NRD2
      DO 502 J=2,NAD1
      P(I,J)=P(I,J)-P(25,5)
      PC(I,J)=0.0
  502 CONTINUE
      CRI=05.0
CC
CC         ITERATING THE VELOCITIES AND THE PRESSURE USING THE "SIMPLER"
CC         SOLUTION ALGORITHM.
CC
      DO 1000 ITERAT=1,300
CC
CC         CALCULATING THE MOMENTUM EQUATIONS COEFFICIENTS.
CC
      CRITV=0.001
      CRITP=CRITV
      CRITPC=CRITV
      CRITVR=CRITV
      CRITVA=CRITV
      CRITVX=CRITV
      RFS=1.0
      RV=0.1
      DO 30 I=2,NRD2
      DO 30 J=2,NAD1
      IF (I.EQ.2) GO TO 31
      V(I,NAD2)=V(I,NAD1)
      IF (I.GE.IFIN) V(I,1)=-V(I,2)
      IF (I.LT.IFIN) V(I,1)=V(I,2)
      W(1,J)=-W(2,J)
      W(NRD3,J)=-W(NRD2,J)
      U(I,NAD2)=U(I,NAD1)
      U(NRD3,J)=-U(NRD2,J)
      U(1,J)=U(2,J)
      IF (I.GE.IFIN) U(I,1)=-U(I,2)
      IF (I.LT.IFIN) U(I,1)=U(I,2)
      DR1=DR
```

```
      DR2=DR
      DR3=DR
      IF (I.EQ.3.OR.I.EQ.NRD2) DR3=0.75*DR
      IF (I.EQ.3) DR2=0.50*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      APRC=4.*DR3*DX/DTH/R(I)**2+2.*DTH*DX*(1./DR1+1./DR2)
     *+2.*DR3*DTH*DX/R(I)**2+DTH/4.0*(DR2*U(I,J)+(2.*DR3-DR2)*U(I-1,J))
      APR(I,J)=APR(I,J)+RFCO*(APRC-APR(I,J))
      ANRC=2.*DTH*DX/DR1+DTH*DX/R(I)+DMAX1(-V(I,J)*
     *DTH*DX/2.0,ZE)
      ANR(I,J)=ANR(I,J)+RFCO*(ANRC-ANR(I,J))
      ASRC=2.0*DTH*DX/DR2-DTH*DX/R(I)+DMAX1(V(I,J)*DTH*DX/2.0,ZE)
      ASR(I,J)=ASR(I,J)+RFCO*(ASRC-ASR(I,J))
      AERC=2.*DR3*DX/DTH/R(I)**2+DMAX1(-DX/8./R(I)*
     *((2.*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1))),ZE)
      AER(I,J)=AER(I,J)+RFCO*(AERC-AER(I,J))
      AWRC=2.*DR3*DX/DTH/R(I)**2+DMAX1(DX/8./R(I)*((2.*DR3-DR2)*
     *(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1))),ZE)
      AWR(I,J)=AWR(I,J)+RFCO*(AWRC-AWR(I,J))
      BRC=DR3*DTH*DX/R(I)*(((2.*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*
     *(W(I,J)+W(I,J+1)))/4./DR3)**2+DTH*VP(I,J)*(DR2*U(I,J)+(2.*DR3-
     *DR2)*U(I-1,J))/4.-2.*DX/R(I)**2*(DR2*(W(I,J+1)-W(I,J))+(2.*DR3-
     *DR2)*(W(I-1,J+1)-W(I-1,J)))-DMAX1(DTH*DX/2.*V(I,J),ZE)*V(I+1,J)-
     *DMAX1(-DTH*DX/2.*V(I,J),ZE)*V(I-1,J)-DMAX1(DX/8./R(I)*((2.*DR3-
     *DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1))),ZE)*V(I,J+1)
      BRC=BRC-DMAX1(-DX/8./R(I)*((2.*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+
     *DR2*(W(I,J)+W(I,J+1))),ZE)*V(I,J-1)
      BR(I,J)=BR(I,J)+RFCO*(BRC-BR(I,J))
      CR(I)=-DTH*DX
   31 IF (J.EQ.2) GO TO 32
      W(1,J)=-W(2,J)
      W(NRD3,J)=-W(NRD2,J)
      V(I,NAD2)=V(I,NAD1)
      IF (I.GE.IFIN) V(I,1)=-V(I,2)
      IF (I.LT.IFIN) V(I,1)=V(I,2)
      U(I,NAD2)=U(I,NAD1)
      U(NRD3,J)=-U(NRD2,J)
      U(1,J)=U(2,J)
      IF (I.GE.IFIN) U(I,1)=-U(I,2)
      IF (I.LT.IFIN) U(I,1)=U(I,2)
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APTC=4.*DR3*DX/DTH/(R(I)+DR3/2.)**2+2.*DTH*DX*(1./DR1+1./DR2)
     *+(U(I,J)+U(I,J-1))/4.*DR3*DTH+2.*DR3*DTH*DX/(R(I)+DR3/2.)**2
     *+DMAX1((V(I+1,J-1)+V(I+1,J)+V(I,J)+V(I,J-1))/4./(R(I)+DR3/2.)*
     *DR3*DTH*DX,ZE)+DMAX1((1./DR2-1./DR1)*DR3*DTH*DX/8.*(V(I+1,J-1)+
```

```
     *V(I+1,J)+V(I,J-1)+V(I,J)),ZE)+DMAX1(DR3*DTH*DX/(R(I)+DR3/2.)*
     *(1./DR1-1./DR2),ZE)
      APT(I,J)=APT(I,J)+RFCO*(APTC-APT(I,J))
      ANTC=2.*DTH*DX/DR1+DTH*DR3*DX/(R(I)+DR3/2.)/DR1+DMAX1(-(
     *V(I+1,J-1)+V(I+1,J)+V(I,J)+V(I,J-1))/8.*DTH*DX*DR3/DR1,ZE)
      ANT(I,J)=ANT(I,J)+RFCO*(ANTC-ANT(I,J))
      ASTC=2.*DTH*DX/DR2-DTH*DR3*DX/(R(I)+DR3/2.)/DR2+DMAX1((
     *V(I+1,J-1)+V(I+1,J)+V(I,J)+V(I,J-1))/8.*DTH*DX*DR3/DR2,ZE)
      AST(I,J)=AST(I,J)+RFCO*(ASTC-AST(I,J))
      AETC=2.*DR3*DX/DTH/(R(I)+DR3/2.)**2+DMAX1(-DR3*DX/2./
     *(R(I)+DR3/2.0)*W(I,J),ZE)
      AET(I,J)=AET(I,J)+RFCO*(AETC-AET(I,J))
      AWTC=2.*DR3*DX/DTH/(R(I)+DR3/2.)**2+DMAX1(W(I,J)
     **DR3*DX/2./(R(I)+DR3/2.),ZE)
      AWT(I,J)=AWT(I,J)+RFCO*(AWTC-AWT(I,J))
      BTC=DR3*DTH/4.*WP(I,J)*(U(I,J)+U(I,J-1))+2.*DR3*DX/(R(I)+DR3/2.)
     ***2*(V(I+1,J)+V(I,J)-V(I+1,J-1)-V(I,J-1))+DMAX1(-DR3*DTH*DX/4./
     *(R(I)+DR3/2.)*(V(I+1,J-1)+V(I+1,J)+V(I,J-1)+V(I,J)),ZE)*W(I,J)+
     *DMAX1(-DR3*DTH*DX/(R(I)+DR3/2.)*(1./DR1-1./DR2),ZE)*W(I,J)-
     *DMAX1(DR3*DTH*DX/8./DR1*(V(I+1,J-1)+V(I+1,J)+V(I,J-1)+V(I,J)),
     *ZE)*W(I+1,J)
      BTC=BTC-DMAX1(DR3*DX/2./(R(I)+DR3/2.)*W(I,J),ZE)*W(I,J+1)-
     *DMAX1(-DR3*DX/2./(R(I)+DR3/2.)*W(I,J),ZE)*W(I,J-1)
     *+DMAX1(-(1./DR2-1./DR1)*
     *DR3*DTH*DX/8.*(V(I+1,J-1)+V(I+1,J)+V(I,J-1)+V(I,J)),ZE)*W(I,J)
     *-DMAX1(-DR3*DTH*DX/8./DR2*(V(I+1,J-1)+V(I+1,J)+
     *V(I,J-1)+V(I,J)),ZE)*W(I-1,J)
      BT(I,J)=BT(I,J)+RFCO*(BTC-BT(I,J))
      CT(I)=-DR3*DX/(R(I)+DR3/2.0)
   32 CONTINUE
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      U(I,NAD2)=U(I,NAD1)
      U(NRD3,J)=-U(NRD2,J)
      U(1,J)=U(2,J)
      IF (I.GE.IFIN) U(I,1)=-U(I,2)
      IF (I.LT.IFIN) U(I,1)=U(I,2)
      V(I,NAD2)=V(I,NAD1)
      IF (I.GE.IFIN) V(I,1)=-V(I,2)
      IF (I.LT.IFIN) V(I,1)=V(I,2)
      W(1,J)=-W(2,J)
      W(NRD3,J)=-W(NRD2,J)
      APXC=4.*DR3*DX/DTH/(R(I)+DR3/2.)**2+2.*DTH*DX*(1./DR1+1./DR2)
     *+DR3*DTH/2.*U(I,J)+DMAX1(DR3*DTH*DX/4.*(1./DR2-1./DR1)*(V(I+1,J)+
     *V(I,J)),ZE)+DMAX1(-DR3*DTH*DX/(R(I)+DR3/2.)*(1./DR2-1./DR1),ZE)
      APX(I,J)=APX(I,J)+RFCO*(APXC-APX(I,J))
```

```
      ANXC=2.*DTH*DX/DR1+DTH*DX/(R(I)+DR3/2.)*DR3/DR1+DMAX1(-(
     *V(I+1,J)+V(I,J))/4.*DTH*DX*DR3/DR1,ZE)
      ANX(I,J)=ANX(I,J)+RFCO*(ANXC-ANX(I,J))
      ASXC=2.*DTH*DX/DR2-DR3*DTH*DX/DR2/(R(I)+DR3/2.)+DMAX1((
     *V(I+1,J)+V(I,J))/4.*DTH*DX*DR3/DR2,ZE)
      ASX(I,J)=ASX(I,J)+RFCO*(ASXC-ASX(I,J))
      AEXC=2.*DR3*DX/DTH/(R(I)+DR3/2.)**2+DMAX1(-(
     *W(I,J+1)+W(I,J))*DR3*DX/4./(R(I)+DR3/2.),ZE)
      AEX(I,J)=AEX(I,J)+RFCO*(AEXC-AEX(I,J))
      AWXC=2.*DR3*DX/DTH/(R(I)+DR3/2.)**2+DMAX1((
     *W(I,J+1)+W(I,J))*DR3*DX/4./(R(I)+DR3/2.),ZE)
      AWX(I,J)=AWX(I,J)+RFCO*(AWXC-AWX(I,J))
      BXC=DR3*DTH/2.*UP(I,J)*U(I,J)
     *-DMAX1((V(I+1,J)+V(I,J))*DTH*DX/4.*DR3/DR1,ZE)*U(I+1,J)-
     *DMAX1(-(V(I+1,J)+V(I,J))*DTH*DX/4.*DR3/DR2,ZE)*U(I-1,J)-
     *DMAX1((W(I,J+1)+W(I,J))*DR3*DX/4./(R(I)+DR3/2.),ZE)*U(I,J+1)
     *-DMAX1(-(W(I,J+1)+W(I,J))*DR3*DX/4./(R(I)+DR3/2.),ZE)*U(I,J-1)+
     *DMAX1(-DR3*DTH*DX/4.*(1./DR2-1./DR1)*(V(I+1,J)+V(I,J)),ZE)*U(I,J)
      BXC=BXC+DMAX1(DR3*DTH*DX/(R(I)+DR3/2.)*(1./DR2-1./DR1),ZE)*U(I,J)
      BX(I,J)=BX(I,J)+RFCO*(BXC-BX(I,J))
      CX(I)=-DR3*DTH*DX/2.0
   30 CONTINUE
CC
CC      CALCULATIONS OF PSEUDO-VELOCITIES
CC
      DO 40 I=2,NRD2
      DO 40 J=2,NAD1
      U(I,NAD2)=U(I,NAD1)
      U(NRD3,J)=-U(NRD2,J)
      U(1,J)=U(2,J)
      IF (I.GE.IFIN) U(I,1)=-U(I,2)
      IF (I.LT.IFIN) U(I,1)=U(I,2)
      V(I,NAD2)=V(I,NAD1)
      IF (I.GE.IFIN) V(I,1)=-V(I,2)
      IF (I.LT.IFIN) V(I,1)=V(I,2)
      W(1,J)=-W(2,J)
      W(NRD3,J)=-W(NRD2,J)
      IF (I.NE.2) VS(I,J)=(ANR(I,J)*V(I+1,J)+ASR(I,J)*V(I-1,J)+
     1AER(I,J)*V(I,J+1)+AWR(I,J)*V(I,J-1)+BR(I,J))/APR(I,J)
      IF (J.NE.2) WS(I,J)=(ANT(I,J)*W(I+1,J)+AST(I,J)*W(I-1,J)+
     1AET(I,J)*W(I,J+1)+AWT(I,J)*W(I,J-1)+BT(I,J))/APT(I,J)
   40 CONTINUE
CC
CC      CALCULATING THE COEFFICIENTS OF THE PRESSURE EQUATIONS.
CC
      DO 50 I=2,NRD2
      DO 50 J=2,NAD1
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.NE.NRD2) B(I,J)=R(I+1)*CR(I+1)*DTH*DX/APR(I+1,J)
      B(NRD2,J)=0.0
      IF (I.NE.2) C(I,J)=R(I)*CR(I)*DTH*DX/APR(I,J)
      C(2,J)=0.0
      IF (J.NE.NAD1) D(I,J)=CT(I)*DR3*DX/APT(I,J+1)
```

```
      D(I,NAD1)=0.0
      IF (J.NE.2) E(I,J)=CT(I)*DR3*DX/APT(I,J)
      E(I,2)=0.0
      A(I,J)=B(I,J)+C(I,J)+D(I,J)+E(I,J)
      V(2,J)=0.0
      V(NRD3,J)=0.0
      W(I,2)=0.0
      W(I,NAD2)=0.0
      F(I,J)=F(I,J)+RFS*(DR3*DTH*(R(I)+DR3/2.)/2.*(U(I,J)-UP(I,J))+DTH*
     *DX*(R(I+1)*VS(I+1,J)-R(I)*VS(I,J))+DR3*DX*(WS(I,J+1)-WS(I,J))-
     *F(I,J))
   50 CONTINUE
CC
CC        SOLUTION OF THE PRESSURE EQUATION.
CC
      N=0
      DO 620 I=2,NRD2
      REC1(I,2)=A(I,2)
      DO 620 J=3,NAD1
      REC1(I,J)=A(I,J)-E(I,J)*D(I,J-1)/REC1(I,J-1)
  620 CONTINUE
      DO 610 ITERP=1,9999
      DO 621 II=2,NRD2
      I=NRD2+2-II
      DO 622 J=3,NAD1
      P(I,1)=0.0
      P(I,NAD2)=0.0
      P(1,J)=0.0
      P(NRD3,J)=0.0
      REC2(I,2)=B(I,2)*P(I+1,2)+C(I,2)*P(I-1,2)+F(I,2)
      REC2(I,J)=E(I,J)*REC2(I,J-1)/REC1(I,J-1)+B(I,J)*P(I+1,J)+
     *C(I,J)*P(I-1,J)+F(I,J)
  622 CONTINUE
      P(I,NAD1)=P(I,NAD1)+RFP*(REC2(I,NAD1)/REC1(I,NAD1)-P(I,NAD1))
      DO 623 JJ=2,NAD
      J=NAD+2-JJ
      P(I,J)=P(I,J)+RFP*((D(I,J)*P(I,J+1)+REC2(I,J))/REC1(I,J)-
     *P(I,J))
  623 CONTINUE
  621 CONTINUE
      N=N+1
      IF (N.EQ.1) GO TO 630
      GO TO 610
  630 N=0
      DO 640 I=2,NRD2
      DO 640 J=2,NAD1
      IF (P(I,J).EQ.0.0) GO TO 640
      IF (DABS((P(I,J)-T(I,J))/P(I,J))*100.0.GE.CRITP) GO TO 650
  640 CONTINUE
      GO TO 615
  650 DO 660 I=2,NRD2
      DO 660 J=2,NAD1
      T(I,J)=P(I,J)
  660 CONTINUE
```

```
  610 CONTINUE
      PRINT 625,ITERP
  625 FORMAT (//,10X,'THE PRESS.EQN. DID NOT CONVERGE WITHIN ',
     *I7,' ITERATIONS')
      STOP
CC
CC      SOLUTION OF THE RADIAL MOMENTUM.
CC
  615 N=0
      DO 130 I=3,NRD2
      IF (I.GE.IFIN) REC1(I,2)=APR(I,2)+AWR(I,2)
      IF (I.LT.IFIN) REC1(I,2)=APR(I,2)-AWR(I,2)
      DO 130 J=3,NAD1
      REC1(I,J)=APR(I,J)-AWR(I,J)*AER(I,J-1)/REC1(I,J-1)
  130 CONTINUE
      DO 120 ITERRA=1,5000
      DO 139 I=3,NRD2
      DO 139 J=2,NAD1
      IF (J.EQ.NAD1) V(I,J+1)=V(I,J)
      IF (J.EQ.2.AND.I.LT.IFIN) V(I,J-1)=V(I,J)
      IF (J.EQ.2.AND.I.GE.IFIN) V(I,J-1)=-V(I,J)
  139 CONTINUE
      DO 131 II=3,NRD2
      I=NRD2+3-II
      DO 132 J=3,NAD1
      REC2(I,2)=ANR(I,2)*V(I+1,2)+ASR(I,2)*V(I-1,2)+BR(I,2)+
     *CR(I)*(P(I,2)-P(I-1,2))
      REC2(I,J)=AWR(I,J)*REC2(I,J-1)/REC1(I,J-1)+ANR(I,J)*V(I+1,J)+
     *ASR(I,J)*V(I-1,J)+BR(I,J)+CR(I)*(P(I,J)-P(I-1,J))
  132 CONTINUE
      V(I,NAD1)=V(I,NAD1)+RF*(REC2(I,NAD1)/(REC1(I,NAD1)-AER(I,NAD1))
     *-V(I,NAD1))
      DO 133 JJ=2,NAD
      J=NAD+2-JJ
      V(I,J)=V(I,J)+RF*((AER(I,J)*V(I,J+1)+REC2(I,J))/REC1(I,J)-V(I,J))
  133 CONTINUE
  131 CONTINUE
      N=N+1
      IF (N.EQ.1) GO TO 140
      GO TO 120
  140 N=0
      DO 150 I=3,NRD2
      DO 150 J=2,NAD1
      IF (V(I,J).EQ.0.0) GO TO 150
      IF (DABS((V(I,J)-T(I,J))/V(I,J))*100.0.GE.CRITVR) GO TO 160
  150 CONTINUE
      GO TO 25
  160 DO 170 I=3,NRD2
      DO 170 J=2,NAD1
      T(I,J)=V(I,J)
  170 CONTINUE
  120 CONTINUE
      PRINT 35,ITERRA
   35 FORMAT (//,10X,'THE RADIAL MOMENTUM DID NOT CONVERGE WITHIN ',
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     *I7,' ITERATIONS')
      STOP
CC
CC      SOLUTION OF THE ANGULAR MOMENTUM
CC
   25 N=0
      DO 190 I=2,NRD2
      IF (I.NE.2.AND.I.NE.NRD2) REC1(I,3)=APT(I,3)
      IF (I.EQ.NRD2) REC1(I,3)=APT(I,3)+ANT(I,3)
      IF (I.EQ.2)    REC1(I,3)=APT(I,3)-AST(I,3)
      DO 190 J=4,NAD1
      IF (I.NE.2.AND.I.NE.NRD2) REC1(I,J)=APT(I,J)-AWT(I,J)*
     *AET(I,J-1)/REC1(I,J-1)
      IF (I.EQ.NRD2) REC1(I,J)=APT(I,J)+ANT(I,J)-AWT(I,J)*
     *AET(I,J-1)/REC1(I,J-1)
      IF (I.EQ.2) REC1(I,J)=APT(I,J)-AST(I,J)-AWT(I,J)*
     *AET(I,J-1)/REC1(I,J-1)
  190 CONTINUE
      DO 180 ITERAN=1,5000
      DO 199 I=2,NRD2
      DO 199 J=3,NAD1
      IF (I.EQ.2) W(I-1,J)=-W(I,J)
      IF (I.EQ.NRD2) W(I+1,J)=-W(I,J)
  199 CONTINUE
      DO 191 II=2,NRD2
      I=NRD2+2-II
      DO 192 J=4,NAD1
      IF (I.NE.2.AND.I.NE.NRD2) REC2(I,3)=ANT(I,3)*W(I+1,3)+
     *AST(I,3)*W(I-1,3)+BT(I,3)+CT(I)*(P(I,3)-P(I,2))
      IF (I.EQ.NRD2) REC2(I,3)=AST(I,3)*W(I-1,3)+BT(I,3)+CT(I)*
     *(P(I,3)-P(I,2))
      IF (I.EQ.2) REC2(I,3)=ANT(I,3)*W(I+1,3)+BT(I,3)+CT(I)*
     *(P(I,3)-P(I,2))
      IF (I.NE.2.AND.I.NE.NRD2) REC2(I,J)=AWT(I,J)*REC2(I,J-1)/
     *REC1(I,J-1)+ANT(I,J)*W(I+1,J)+AST(I,J)*W(I-1,J)+BT(I,J)+
     *CT(I)*(P(I,J)-P(I,J-1))
      IF (I.EQ.NRD2) REC2(I,J)=AWT(I,J)*REC2(I,J-1)/REC1(I,J-1)+
     *AST(I,J)*W(I-1,J)+BT(I,J)+CT(I)*(P(I,J)-P(I,J-1))
      IF (I.EQ.2) REC2(I,J)=AWT(I,J)*REC2(I,J-1)/REC1(I,J-1)+
     *ANT(I,J)*W(I+1,J)+BT(I,J)+CT(I)*(P(I,J)-P(I,J-1))
  192 CONTINUE
      W(I,NAD1)=W(I,NAD1)+RF*(REC2(I,NAD1)/REC1(I,NAD1)-W(I,NAD1))
      DO 193 JJ=3,NAD
      J=NAD+3-JJ
      W(I,J)=W(I,J)+RF*((AET(I,J)*W(I,J+1)+REC2(I,J))/REC1(I,J)-
     *W(I,J))
  193 CONTINUE
  191 CONTINUE
      N=N+1
      IF (N.EQ.1) GO TO 200
      GO TO 180
  200 N=0
      DO 210 I=2,NRD2
      DO 210 J=3,NAD1
```

```
      IF (W(I,J).EQ.0.0) GO TO 210
      IF (DABS((W(I,J)-T(I,J))/W(I,J))*100.0.GE.CRITVA) GO TO 220
  210 CONTINUE
      GO TO 55
  220 DO 230 I=2,NRD2
      DO 230 J=3,NAD1
      T(I,J)=W(I,J)
  230 CONTINUE
  180 CONTINUE
      PRINT 65,ITERAN
   65 FORMAT (//,10X,'THE ANG. MOM. DID NOT CONVERGE WITHIN ',
     *I7,' ITERATIONS')
      STOP
CC
CC        SOLUTION OF THE AXIAL MOMENTUM.
CC
   55 N=0
      DO 250 I=2,NRD2
      IF (I.GE.IFIN) REC1(I,2)=APX(I,2)+AWX(I,2)
      IF (I.LT.IFIN) REC1(I,2)=APX(I,2)-AWX(I,2)
      IF (I.EQ.NRD2) REC1(I,2)=REC1(I,2)+ANX(I,2)
      IF (I.EQ.2)    REC1(I,2)=REC1(I,2)-ASX(I,2)
      DO 250 J=3,NAD1
      IF (I.NE.2.AND.I.NE.NRD2) REC1(I,J)=APX(I,J)-AWX(I,J)*AEX(I,J-1)/
     *REC1(I,J-1)
      IF (I.EQ.NRD2) REC1(I,J)=APX(I,J)+ANX(I,J)-AWX(I,J)*AEX(I,J-1)/
     *REC1(I,J-1)
      IF (I.EQ.2) REC1(I,J)=APX(I,J)-ASX(I,J)-AWX(I,J)*AEX(I,J-1)/
     *REC1(I,J-1)
  250 CONTINUE
      DO 240 ITERAX=1,5000
      DO 259 I=2,NRD2
      DO 259 J=2,NAD1
      IF (I.EQ.2) U(I-1,J)=U(I,J)
      IF (I.EQ.NRD2) U(I+1,J)=-U(I,J)
      IF (J.EQ.NAD1) U(I,J+1)=U(I,J)
      IF (J.EQ.2.AND.I.LT.IFIN) U(I,J-1)=U(I,J)
      IF (J.EQ.2.AND.I.GE.IFIN) U(I,J-1)=-U(I,J)
  259 CONTINUE
      DO 251 II=2,NRD2
      I=NRD2+2-II
      DO 252 J=3,NAD1
      IF (I.NE.2.AND.I.NE.NRD2) REC2(I,2)=ANX(I,2)*U(I+1,2)+ASX(I,2)*
     *U(I-1,2)+BX(I,2)+CX(I)*DPDX
      IF (I.EQ.NRD2) REC2(I,2)=ASX(I,2)*U(I-1,2)+BX(I,2)+CX(I)*DPDX
      IF (I.EQ.2)    REC2(I,2)=ANX(I,2)*U(I+1,2)+BX(I,2)+CX(I)*DPDX
      IF (I.NE.2.AND.I.NE.NRD2) REC2(I,J)=AWX(I,J)*REC2(I,J-1)/
     *REC1(I,J-1)+ANX(I,J)*U(I+1,J)+ASX(I,J)*U(I-1,J)+BX(I,J)+
     *CX(I)*DPDX
      IF (I.EQ.NRD2) REC2(I,J)=AWX(I,J)*REC2(I,J-1)/REC1(I,J-1)+
     *ASX(I,J)*U(I-1,J)+BX(I,J)+CX(I)*DPDX
      IF (I.EQ.2)    REC2(I,J)=AWX(I,J)*REC2(I,J-1)/REC1(I,J-1)+
     *ANX(I,J)*U(I+1,J)+BX(I,J)+CX(I)*DPDX
  252 CONTINUE
```

```
      U(I,NAD1)=U(I,NAD1)+1.*(REC2(I,NAD1)/(REC1(I,NAD1)-AEX(I,NAD1))-
     *U(I,NAD1))
      DO 253 JJ=2,NAD
      J=NAD+2-JJ
      U(I,J)=U(I,J)+1.*((AEX(I,J)*U(I,J+1)+REC2(I,J))/REC1(I,J)-U(I,J))
  253 CONTINUE
  251 CONTINUE
      N=N+1
      IF (N.EQ.1) GO TO 260
      GO TO 240
  260 N=0
      DO 270 I=2,NRD2
      DO 270 J=2,NAD1
      IF (U(I,J).EQ.0.0) GO TO 270
      IF (DABS((U(I,J)-T(I,J))/U(I,J))*100.0.GE.CRITVX) GO TO 280
  270 CONTINUE
      GO TO 85
  280 DO 290 I=2,NRD2
      DO 290 J=2,NAD1
      T(I,J)=U(I,J)
  290 CONTINUE
  240 CONTINUE
      PRINT 95,ITERAX
   95 FORMAT (//,10X,'THE AXIAL MOMENTUM DID NOT CONVERGE WITHIN ',
     *I7,' ITERATIONS')
      STOP
CC
CC      EVALUATION OF THE SOURCE TERM FOR THE PRESSURE CORRECTION EQUATION.
CC
   85 DO 300 I=2,NRD2
      DO 300 J=2,NAD1
      V(2,J)=0.0
      V(NRD3,J)=0.0
      W(I,2)=0.0
      W(I,NAD2)=0.0
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      FC(I,J)=FC(I,J)+1.0*(DR3*DTH*(R(I)+DR3/2.)/2.*(U(I,J)-UP(I,J))+
     *DTH*DX*(R(I+1)*V(I+1,J)-R(I)*V(I,J))+DR3*DX*(W(I,J+1)-W(I,J))-
     *FC(I,J))
  300 CONTINUE
CC
CC      SOLUTION OF THE PRESSURE CORRECTION EQUATION.
CC
   86 N=0
      DO 320 I=2,NRD2
      REC1(I,2)=A(I,2)
      DO 320 J=3,NAD1
      REC1(I,J)=A(I,J)-E(I,J)*D(I,J-1)/REC1(I,J-1)
  320 CONTINUE
      DO 310 ITERPC=1,9999
      DO 321 II=2,NRD2
      I=NRD2+2-II
      DO 322 J=3,NAD1
```

```
      PC(I,1)=0.0
      PC(I,NAD2)=0.0
      PC(1,J)=0.0
      PC(NRD3,J)=0.0
      REC2(I,2)=B(I,2)*PC(I+1,2)+C(I,2)*PC(I-1,2)+FC(I,2)
      REC2(I,J)=E(I,J)*REC2(I,J-1)/REC1(I,J-1)+B(I,J)*PC(I+1,J)+
     *C(I,J)*PC(I-1,J)+FC(I,J)
  322 CONTINUE
      PC(I,NAD1)=PC(I,NAD1)+RFP*(REC2(I,NAD1)/REC1(I,NAD1)-PC(I,NAD1))
      DO 323 JJ=2,NAD
      J=NAD+2-JJ
      PC(I,J)=PC(I,J)+RFP*((D(I,J)*PC(I,J+1)+REC2(I,J))/REC1(I,J)-
     *PC(I,J))
  323 CONTINUE
  321 CONTINUE
      N=N+1
      IF (N.EQ.1) GO TO 330
      GO TO 310
  330 N=0
      DO 340 I=2,NRD2
      DO 340 J=2,NAD1
      IF (PC(I,J).EQ.0.0) GO TO 340
      IF (DABS((PC(I,J)-T(I,J))/PC(I,J))*100.0.GE.CRITPC) GO TO 350
  340 CONTINUE
      GO TO 115
  350 DO 360 I=2,NRD2
      DO 360 J=2,NAD1
      T(I,J)=PC(I,J)
  360 CONTINUE
  310 CONTINUE
      PRINT 125,ITERPC
  125 FORMAT (//,10X,'THE PRESS. CORR. EQN. DID NOT CONVERGE WITHIN ',
     *I7,' ITERATIONS')
      STOP
  115 CALL AXPRES (U,CX,APX,DPDX,NRD,NAD1,R,DR,PI,M
     *,DTH,RFDP,DPDX1,ITERAT)
      FRE=-DPDX/2.0
      ICOUNT=0
      IF (ITERAT.LT.50) GO TO 1100
      CRI=DABS((FRE-FRE1)/FRE)*100.0
      IF (CRI.GT.1.0E-03) GO TO 1101
      ICOUNT=ICOUNT+1
 1101 SUMW=0.0
      SUMV=0.0
      DO 888 I=3,NRD2
      DO 888 J=2,NAD1
      SUMV=SUMV+DABS((V1(I,J)-V(I,J))*100.0)
      SUMW=SUMW+DABS(V(I,J))
  888 CONTINUE
      SE=SUMV/SUMW
      WRITE (9,303) SE
  303 FORMAT (10X,'SUMV = ',D25.6)
      IF (SUMV/SUMW.GT.1.0E-02) GO TO 1102
      ICOUNT=ICOUNT+1
```

```
1102 SUMV=0.0
     SUMW=0.0
     DO 878 I=2,NRD2
     DO 878 J=3,NAD1
     SUMW=SUMW+DABS((W1(I,J)-W(I,J))*100.0)
     SUMV=SUMV+DABS(W(I,J))
 878 CONTINUE
     SS=SUMW/SUMV
     WRITE (9,202) SS
 202 FORMAT (10X,'SUMW = ',D25.6)
     IF (SUMW/SUMV.GT.1.0E-02) GO TO 1103
     ICOUNT=ICOUNT+1
1103 DO 868 I=2,NRD2
     DO 868 J=2,NAD1
     IF (DABS(FC(I,J)).GT.1.0E-06) GO TO 1104
 868 CONTINUE
     ICOUNT=ICOUNT+1
1104 IF (ICOUNT.LT.4) GO TO 1100
     PRINT 2,ITERAT
   2 FORMAT ('1',20X,'CONVERGED AFTER ',I5,' ITERATIONS')
     PRINT 987
 987 FORMAT (2(/),50X,'AXIAL VELOCITY')
     DO 380 I=2,NRD2
     PRINT 2000,(U(I,J),J=2,NAD1)
 380 CONTINUE
     PRINT 876
 876 FORMAT (2(/),50X,'RADIAL VELOCITY')
     DO 390 I=2,NRD3
     PRINT 2000,(V(I,J),J=2,NAD1)
 390 CONTINUE
     PRINT 765
 765 FORMAT (2(/),50X,'ANGULAR VELOCITY')
     DO 400 I=2,NRD2
     PRINT 2000,(W(I,J),J=2,NAD2)
 400 CONTINUE
     PRINT 654
 654 FORMAT (2(/),50X,'PRESSURE')
     DO 410 I=2,NRD2
     PRINT 2000,(P(I,J),J=2,NAD1)
 410 CONTINUE
     KP=K
     FAPREP=FAPPRE
     DP=DP-DX*DPDX
     K=2.0*(DP-FREFD*X)
     FAPPRE=DP/X/2.0
     PRINT 3,DPDX,X,FRE,FAPPRE,K,NST
   3 FORMAT (/,1X,'DPDX = ',D12.5,1X,'X+ = ',D12.5,1X,'FRE = ',D12.5,
    *1X,'FAPPRE = ',D12.5,1X,'K(X) = ',D12.5,' NST = ',I3)
     WRITE (3,123) X,FRE,FAPPRE,K
 123 FORMAT (5X,4(D16.6))
2000 FORMAT (/,10(1X,D12.5))
     IF (MM.EQ.1) GO TO 102
     IF (FRE.LE.FRE05) GO TO 101
     GO TO 102
```

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  101 L=(FRE05-FREP)/(FRE-FREP)*(X-XP)+XP
      PRINT 103,L,FRE05
  103 FORMAT (//,5X,'AT 5% L = ',D14.6,5X,'FRE = ',D14.6)
      MM=1
      GO TO 510
  102 IF (FRE.LE.FRE01) GO TO 105
      GO TO 510
  105 L=(FRE01-FREP)/(FRE-FREP)*(X-XP)+XP
      KL=(FRE01-FREP)/(FRE-FREP)*(K-KP)+KP
      FAPREL=(FRE01-FREP)/(FRE-FREP)*(FAPPRE-FAPREP)+FAPREP
      PRINT 106,L,FRE01
      WRITE (3,123) L,FRE01,FAPREL,KL
  106 FORMAT (//,5X,'AT 1% L = ',D14.6,5X,'FRE = ',D14.6)
      STOP
CC
CC      CORRECTION OF ALL VELOCITIES USING THE CORRECTION PRESSURE.
CC
 1100 DO 370 I=2,NRD2
      DO 370 J=2,NAD1
      IF (I.NE.2) V1(I,J)=V(I,J)
      IF (J.NE.2) W1(I,J)=W(I,J)
      IF (I.NE.2) V(I,J)=V(I,J)+RFVC*CR(I)*(PC(I,J)-PC(I-1,J))/APR(I,J)
      IF (J.NE.2) W(I,J)=W(I,J)+RFVC*CT(I)*(PC(I,J)-PC(I,J-1))/APT(I,J)
  370 CONTINUE
CC
CC      UNDERRELAXING THE DEPENDENT VARIABLES
CC
      DO 116 I=2,NRD2
      DO 116 J=2,NAD1
      V(I,J)=V2(I,J)+RV*(V(I,J)-V2(I,J))
      W(I,J)=W2(I,J)+RV*(W(I,J)-W2(I,J))
      V2(I,J)=V(I,J)
      W2(I,J)=W(I,J)
  116 CONTINUE
      IF(ITERAT.GE.050) WRITE (9,371) ITERAT,ITERRA,ITERAN,ITERAX,ITERP
     *,ITERPC,DPDX,DPDX1,NST,ICOUNT
      IF(ITERAT.GE.050)WRITE(9,372)U(9,12),V(9,12),W(9,12),FC(9,12),CRI
  372 FORMAT (5(D14.6))
  371 FORMAT (2X,6(1X,I4),2(D13.5),I3,1X,I2)
 1000 FRE1=FRE
      PRINT 4,ITERAT
    4 FORMAT (//,10X,'THE ALGORITHM FAILED WITHIN ',I7,
     *' ITERATIONS')
      STOP
  510 DO 520 I=2,NRD2
      DO 520 J=2,NAD1
      UP(I,J)=U(I,J)
      VP(I,J)=V(I,J)
      WP(I,J)=W(I,J)
  520 CONTINUE
      DX=1.10*DX
      XP=X
      FREP=FRE
  500 CONTINUE
```

```
      REWIND 4
      PRINT 7788
 7788 FORMAT ('1',150(/))
      WRITE(4,1111) X,DX,DP,FREP,FREFD,FRE01,FRE05,DPDX,XP,FAPPRE,K
      DO 1118 I=2,NRD2
      WRITE (4,1111) (U(I,J),J=2,NAD1)
 1118 CONTINUE
      DO 1119 I=2,NRD3
      WRITE (4,1111) (V(I,J),J=2,NAD1)
 1119 CONTINUE
      DO 1120 I=2,NRD2
      WRITE (4,1111) (W(I,J),J=2,NAD2)
 1120 CONTINUE
      DO 1122 I=2,NRD2
      WRITE (4,1111) (P(I,J),J=2,NAD1)
 1122 CONTINUE
      PRINT 1515
 1515 FORMAT ('1',150(/))
      STOP
      END
      SUBROUTINE AXPRES (US,CX,APX,DPDX,NRD,NAD1,R,DR,PI,M,DTH,RFDP,
     *DPDX1,ITERAT)
      DOUBLE PRECISION US(35,35),APX(35,35),CX(55),R(55),DPDX
     *,PI,DR,DTH,DPDX1,SUM,SUM1,DR2
      NRD2=NRD+2
      SUM=0.0
      SUM1=0.0
      DO 10 I=2,NRD2
      DO 10 J=2,NAD1
      DR2=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR2=DR/2.0
      SUM=SUM+US(I,J)*(R(I)+DR2/2.0)*DR2
      SUM1=SUM1+CX(I)/APX(I,J)*(R(I)+DR2/2.0)*DR2
   10 CONTINUE
      DPDX1=(PI/2.0/M/DTH-SUM)/SUM1
      DPDX=DPDX+RFDP*DPDX1
      RETURN
      END
CC
      SUBROUTINE FDMOM (DR,DTH,R,U,US,APX,ANX,ASX,AEX,AWX,CX,NRD,
     *NAD1,M,DPDX,PI,T,DPDX1,IFIN)
      DOUBLE PRECISION U(35,35),US(35,35),APX(35,35),ANX(35,35),
     *ASX(35,35),AEX(35,35),AWX(35,35),CX(55),DPDX,DR,DTH,T(35,35),
     *R(55),PI,DPDX1,FRE,FRE1,DR1,DR2,DR3,REC1(35,35),REC2(35,35)
      NRD1=NRD+1
      NRD2=NRD+2
      NAD=NAD1-1
      FRE=1.0
      FRE1=0.0
      RFDP=0.0005
      RFVC=1.0
CC
CC          CALCULATION OF THE VELOCITY COEFFICIENTS.
CC
```

```
      DO 10 I=2,NRD2
      DO 10 J=2,NAD1
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=DR/2.0
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=DR/2.0
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=DR/2.0
      IF (I.EQ.NRD2) DR2=0.75*DR
      APX(I,J)=2.*DR3/DTH/(R(I)+DR3/2.)+DTH*(R(I)/DR2+R(I+1)/DR1)
      ANX(I,J)=DTH*R(I+1)/DR1
      ASX(I,J)=DTH*R(I)/DR2
      AEX(I,J)=DR3/DTH/(R(I)+DR3/2.0)
      AWX(I,J)=DR3/DTH/(R(I)+DR3/2.0)
      CX(I)=-(R(I)+DR3/2.0)*DR3*DTH/4.0
   10 CONTINUE
CC
CC         CALCULATION OF THE PSEUDO-VELOCITIES.
CC
      DO 1000 ITERAT=1,9999
      IF (ITERAT.EQ.50)  RFDP=0.001
      IF (ITERAT.EQ.100) RFDP=0.005
      CRIT=0.1-0.009*ITERAT
      IF (CRIT.LT.0.001) CRIT=0.001
CC
CC         SOLVING THE MOMENTUM EQUATION.
CC
      N=0
      DO 40 I=2,NRD2
      IF (I.GE.IFIN) REC1(I,2)=APX(I,2)+AWX(I,2)
      IF (I.LT.IFIN) REC1(I,2)=APX(I,2)-AWX(I,2)
      IF (I.EQ.NRD2) REC1(I,2)=REC1(I,2)+ANX(I,2)
      IF (I.EQ.2)    REC1(I,2)=REC1(I,2)-ASX(I,2)
      DO 40 J=3,NAD1
      IF (I.NE.2.AND.I.NE.NRD2) REC1(I,J)=APX(I,J)-AWX(I,J)*AEX(I,J-1)/
     *REC1(I,J-1)
      IF (I.EQ.NRD2) REC1(I,J)=APX(I,J)+ANX(I,J)-AWX(I,J)*AEX(I,J-1)/
     *REC1(I,J-1)
      IF (I.EQ.2) REC1(I,J)=APX(I,J)-ASX(I,J)-AWX(I,J)*AEX(I,J-1)/
     *REC1(I,J-1)
   40 CONTINUE
      DO 30 ITER=1,9999
      IF (I.EQ.2) U(I-1,J)=U(I,J)
      IF (I.EQ.NRD2) U(I+1,J)=-U(I,J)
      IF (J.EQ.2.AND.I.LT.IFIN) U(I,J-1)=U(I,J)
      IF (J.EQ.2.AND.I.GE.IFIN) U(I,J-1)=-U(I,J)
      IF (J.EQ.NAD1) U(I,J+1)=U(I,J)
      DO 41 II=2,NRD2
      I=NRD2+2-II
      DO 42 J=3,NAD1
      IF (I.NE.2.AND.I.NE.NRD2) REC2(I,2)=ANX(I,2)*U(I+1,2)+ASX(I,2)*
```

```
     *U(I-1,2)+CX(I)*DPDX
      IF (I.EQ.NRD2) REC2(I,2)=ASX(I,2)*U(I-1,2)+CX(I)*DPDX
      IF (I.EQ.2)    REC2(I,2)=ANX(I,2)*U(I+1,2)+CX(I)*DPDX
      IF (I.NE.2.AND.I.NE.NRD2) REC2(I,J)=AWX(I,J)*REC2(I,J-1)/
     *REC1(I,J-1)+ANX(I,J)*U(I+1,J)+ASX(I,J)*U(I-1,J)+CX(I)*DPDX
      IF (I.EQ.NRD2) REC2(I,J)=AWX(I,J)*REC2(I,J-1)/REC1(I,J-1)+
     *ASX(I,J)*U(I-1,J)+CX(I)*DPDX
      IF (I.EQ.2)    REC2(I,J)=AWX(I,J)*REC2(I,J-1)/REC1(I,J-1)+
     *ANX(I,J)*U(I+1,J)+CX(I)*DPDX
   42 CONTINUE
      U(I,NAD1)=REC2(I,NAD1)/(REC1(I,NAD1)-AEX(I,NAD1))
      DO 43 JJ=2,NAD
      J=NAD+2-JJ
      U(I,J)=(AEX(I,J)*U(I,J+1)+REC2(I,J))/REC1(I,J)
   43 CONTINUE
   41 CONTINUE
      N=N+1
      IF (N.EQ.1) GO TO 50
      GO TO 30
   50 N=0
      DO 60 I=2,NRD2
      DO 60 J=2,NAD1
      IF (U(I,J).EQ.0.0) GO TO 60
      IF (DABS((U(I,J)-T(I,J))/U(I,J))*100.0.GE.CRIT) GO TO 70
   60 CONTINUE
      GO TO 55
   70 DO 90 I=2,NRD2
      DO 90 J=2,NAD1
      T(I,J)=U(I,J)
   90 CONTINUE
   30 CONTINUE
      PRINT 100,ITER
  100 FORMAT (/,10X,'F.D. MOM. DID NOT CONVERGE WITHIN ',I7,
     *' ITERATIONS')
      STOP
CC
CC         EVALUATING THE PRESSURE GRADIENT CORRECTING PARAMETER.
CC
   55 CALL AXPRES (U,CX,APX,DPDX,NRD,NAD1,R,DR,PI,M,DTH,RFDP,DPDX1
     *,ITERAT)
      FRE=-DPDX/2.0
      WRITE (9,85) ITERAT,ITER,DPDX,DPDX1
   85 FORMAT (2(1X,I5),2(1X,D15.5))
CC
CC         CORRECTING THE VELOCITY DISTRIBUTION.
CC
      DO 140 I=2,NRD2
      DO 140 J=2,NAD1
      U(I,J)=U(I,J)+RFVC*CX(I)*DPDX1/APX(I,J)
  140 CONTINUE
      KK=ITERAT/2
      KK1=2*KK
      IF (KK1.NE.ITERAT) GO TO 1000
      IF (DABS((FRE-FRE1)/FRE)*100.0.GE.1.0E-04) GO TO 1000
```

```
      PRINT 120,ITERAT
  120 FORMAT (/,10X,'CONVERGED AFTER ',I5,' ITERATIONS')
      DO 110 I=2,NRD2
      PRINT 2000,(U(I,J),J=2,NAD1)
  110 CONTINUE
 2000 FORMAT (/,10(1X,D12.5))
      PRINT 130,DPDX,FRE
  130 FORMAT (/,10X,'DPDX = ',D14.6,10X,'FRE = ',D12.5)
      RETURN
 1000 IF (KK1.EQ.ITERAT) FRE1=FRE
      PRINT 150,ITERAT
  150 FORMAT (//,10X,'THE ALGORITHM FAILED WITHIN ',I5,' ITERATIONS')
      STOP
      END
```

MODEL III

```
      DIMENSION JA(20),JB(20)
      DOUBLE PRECISION U(33,66),V(33,66),W(33,66),UB,TB,
     1VS(33,66),WS(33,66),T(33,66),APR(33,66),APT(33,66),APG(33,66),
     2ANR(33,66),ANT(33,66),ANG(33,66),ASR(33,66),AST(33,66),DR4,NU,
     3ASG(33,66),AER(33,66),AET(33,66),AEG(33,66),AWR(33,66),T1(33,66),
     4AWT(33,66),AWG(33,66),BR(33,66),BT(33,66),CR(55),SUMV,SUMW,
     5CT(55),CX(55),A(33,66),B(33,66),C(33,66),D(33,66),E(33,66)
      DOUBLE PRECISION F(33,66),PC(33,66),P(33,66),FC(33,66),Q(33,66),
     1DPDX,R(55),DR,DTH,PI,DPDX1,FRE,FRE1,U1(33,66),TC(33,66),THETA
     2,V2(33,66),PC1(33,66),W2(33,66),V1(33,66),W1(33,66),P1(33,66)
     3,ZE,BG(33,66),APX(33,66),ANX(33,66),ASX(33,66),AEX(33,66),
     4AWX(33,66),BX(33,66),DR1,DR2,DR3,CRI,REC1(33,66),REC2(33,66),
     5T2(33,66),VL,VR,TL,TR,UL,UR,PR,PL,PCR,PCL,PRTL
CC
CC      ( NRD ) IS THE NUMBER OF RADIAL DIVISIONS.
CC      ( NAD ) IS THE NUMBER OF ANGULAR DIVISIONS.
CC      ( H ) IS THE RELATIVE FIN HEIGHT.
CC      ( M ) IS THE NUMBER OF FINS.
CC      ( PRTL ) IS THE PRANDTL NUMBER.
CC      ( GR ) IS THE GRASHOF NUMBER.
CC
      READ (5,*) NRD,NAD,H,M,PRTL,GR
      DR=1.0/NRD
      IFIN=(1-H)/DR+2
      IFF=IFIN
      IFF1=IFIN-1
      IF (H.EQ.0.0) IFF=NRD+2
      IF (H.EQ.0.0) IFF1=NRD+2
      IF (H.EQ.0.0) IFIN=NRD+10
      IFIN1=IFIN+1
      M2=M/2
      FRE=2.0
      ZE=0.000000000000000
      SUMV=0.0
      SUMW=0.0
      FRE1=1.0
      RFDP=0.5
      RV=0.22
      RFCO=1.0
      RFS=1.0
      RFVC=1.0
      PI=2.0*DARCOS(ZE)
      NRD1=NRD+1
      NRD2=NRD+2
      NRD3=NRD+3
      NAD1=NAD+1
      NAD2=NAD+2
      DTH=PI/NAD
      DPDX=-44.0
      R(2)=0.0
      DO 10 I=3,NRD3
      IF (I.EQ.3.OR.I.EQ.NRD3)  R(I)=R(I-1)+DR/2.0
```

```
      IF (I.NE.3.AND.I.NE.NRD3)  R(I)=R(I-1)+DR
   10 CONTINUE
CC
CC          INITIALIZING ALL VELOCITIES AND PRESSURE.
CC
      DO 20 I=1,NRD3
      DO 20 J=1,NAD2
      U(I,J)=0.0
      P(I,J)=0.0
      P1(I,J)=0.0
      PC(I,J)=0.0
      T(I,J)=0.0
      TC(I,J)=0.0
      V(I,J)=0.0
      W(I,J)=0.0
      APR(I,J)=0.0
      ANR(I,J)=0.0
      ASR(I,J)=0.0
      AER(I,J)=0.0
      AWR(I,J)=0.0
      BR(I,J)=0.0
      APT(I,J)=0.0
      ANT(I,J)=0.0
      AST(I,J)=0.0
      AET(I,J)=0.0
      AWT(I,J)=0.0
      BT(I,J)=0.0
      APX(I,J)=0.0
      ANX(I,J)=0.0
      ASX(I,J)=0.0
      AEX(I,J)=0.0
      AWX(I,J)=0.0
      BX(I,J)=0.0
      APG(I,J)=0.0
      ANG(I,J)=0.0
      ASG(I,J)=0.0
      AEG(I,J)=0.0
      AWG(I,J)=0.0
      BG(I,J)=0.0
      F(I,J)=0.0
      FC(I,J)=0.0
      V1(I,J)=0.0
      W1(I,J)=0.0
      IF (I.EQ.2.OR.I.EQ.NRD3) V(I,J)=0.0
      IF (J.EQ.2.OR.J.EQ.NAD2) W(I,J)=0.0
   20 CONTINUE
CC
CC       READING VELOCITIES AND PRESSURE FROM PREVIOUS SOLUTION AT LOWER
CC       GRASHOF NUMBER AND USE THEM AS INITIAL VALUES FOR HIGHER GRASHOF.
CC
 1111 FORMAT (3(1X,D22.14))
      READ (4,1111) DPDX
      DO 1112 I=1,NRD3
      READ (4,1111) ((U(I,J),T(I,J)),J=1,NAD2)
```

```
 1112 CONTINUE
      DO 1113 I=2,NRD3
      READ (4,1111) (V(I,J),J=1,NAD2)
 1113 CONTINUE
      DO 1114 I=1,NRD3
      READ (4,1111) (W(I,J),J=2,NAD2)
 1114 CONTINUE
      DO 1121 I=1,NRD3
      READ (4,1111) ((P(I,J),PC(I,J)),J=1,NAD2)
 1121 CONTINUE
      DO 1115 I=2,NRD2
      DO 1115 J=2,NAD1
      T2(I,J)=T(I,J)
      U1(I,J)=U(I,J)
      P1(I,J)=P(I,J)
      PC1(I,J)=PC(I,J)
 1115 CONTINUE
      DO 1116 I=3,NRD2
      DO 1116 J=2,NAD1
      V2(I,J)=V(I,J)
 1116 CONTINUE
      DO 1117 I=2,NRD2
      DO 1117 J=3,NAD1
      W2(I,J)=W(I,J)
 1117 CONTINUE
      CRI=05.0
CC
CC         ITERATING THE VELOCITIES AND THE PRESSURE USING THE "SIMPLER"
CC         SOLUTION ALGORITHM.
CC
      NN=1
      JA(1)=2
      JB(1)=NAD*2/M+1
      DO 5 I=2,M2
      IF (M2.LT.2) GO TO 5
      JA(I)=JA(I-1)+2*NAD/M
      JB(I)=JB(I-1)+2*NAD/M
    5 CONTINUE
CC
CC         CALCULATING THE MOMENTUM EQUATIONS COEFFICIENTS.
CC
      DO 30 I=2,NRD2
      DO 30 J=2,NAD1
      VL=V(I,J-1)
      VR=V(I,J+1)
      TL=T(I,J-1)
      TR=T(I,J+1)
      UL=U(I,J-1)
      UR=U(I,J+1)
      DO 75 L=1,M2
      IF (I.GE.IFIN1.AND.J.EQ.JA(L)) VL=-V(I,J)
      IF (I.GE.IFIN1.AND.J.EQ.JB(L)) VR=-V(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L))  TL=-T(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JB(L))  TR=-T(I,J)
```

```
      IF (I.GE.IFIN.AND.J.EQ.JA(L))  UL=-U(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JB(L))  UR=-U(I,J)
   75 CONTINUE
      THETA=(J-2)*DTH+DTH/2.0
      IF (I.EQ.2) GO TO 31
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.3.OR.I.EQ.NRD2) DR3=0.75*DR
      IF (I.EQ.3) DR2=0.50*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      APR(I,J)=APR(I,J)+1.00*(4.0*DR3/DTH/R(I)**3+2.0*DTH/R(I)/DR2+
     12.0*DTH/R(I)/DR1-APR(I,J))
      ANR(I,J)=ANR(I,J)+1.00*(2.0*DTH/DR1/R(I)-DTH/R(I)**2+DMAX1(-
     1V(I,J)*DTH/2.0/R(I)**2,ZE)-ANR(I,J))
      ASR(I,J)=ASR(I,J)+1.00*(2.0*DTH/DR2/R(I)+DTH/R(I)**2+DMAX1(
     1V(I,J)*DTH/2.0/R(I)**2,ZE)-ASR(I,J))
      AER(I,J)=AER(I,J)+1.00*(2.0*DR3/DTH/R(I)**3+DMAX1(-
     1((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/
     28.0/R(I)**2,ZE)-AER(I,J))
      AWR(I,J)=AWR(I,J)+1.00*(2.0*DR3/DTH/R(I)**3+DMAX1(+
     1((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/
     28.0/R(I)**2,ZE)-AWR(I,J))
      BR(I,J)=BR(I,J)+1.00*(DR3*DTH/R(I)*(((2.0*DR3-DR2)*(W(I-1,J)+
     1W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/4./DR3)**2+GR*DTH*DCOS(THETA)
     2/4.*(DR2*T(I,J)+(2.*DR3-DR2)*T(I-1,J))-2./R(I)**2*(DR2*(W(I,J+1)-
     3W(I,J))+(2.0*DR3-DR2)*(W(I-1,J+1)-W(I-1,J)))-DMAX1(V(I,J)*DTH/
     42.0/R(I)**2,ZE)*V(I+1,J)-DMAX1(-V(I,J)*DTH/2.0/R(I)**2,ZE)*
     5V(I-1,J)-DMAX1(-((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(
     6W(I,J)+W(I,J+1)))/8.0/R(I)**2,ZE)*VL+DR3*DTH*V(I,J)**2/R(I)**3
     7-DMAX1(+((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(
     8W(I,J)+W(I,J+1)))/8.0/R(I)**2,ZE)*VR-BR(I,J))
      CR(I)=-DTH
   31 IF (J.EQ.2) GO TO 32
      THETA=(J-2)*DTH
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APT(I,J)=APT(I,J)+1.00*(4.0*DR3/DTH/(R(I)+DR3/2.0)**2+2.0*
     1DR3*DTH/(R(I)+DR3/2.)**2-DR3*DTH*(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.)
     2+2.0*DTH/DR2+2.0*DTH/DR1+DMAX1(+DR3*DTH/4.0/(R(I)+DR3/2.0)**2*(
     3V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)+DMAX1(+DR3*DTH/8.0*
     4(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+
     5V(I,J-1)),ZE)-APT(I,J))
      ANT(I,J)=ANT(I,J)+1.00*(DR3*DTH/DR1/(R(I)+DR3/2.0)+2.0*DTH/DR1+
     1DMAX1(-DR3*DTH/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)
     2+V(I,J-1)),ZE)-ANT(I,J))
```

```
      AST(I,J)=AST(I,J)+1.00*(-DR3*DTH/DR2/(R(I)+DR3/2.0)+2.0*DTH/DR2+
     1DMAX1(+DR3*DTH/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)
     2+V(I,J-1)),ZE)-AST(I,J))
      AET(I,J)=AET(I,J)+1.00*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-
     1DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)-AET(I,J))
      AWT(I,J)=AWT(I,J)+1.00*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(
     1DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)-AWT(I,J))
      BT(I,J)=BT(I,J)+1.00*(2.0*DR3/(R(I)+DR3/2.0)**3*(V(I,J)+
     1V(I+1,J)-V(I+1,J-1)-V(I,J-1))-DR3*DTH*GR/4.0*(T(I,J)+T(I,J-1))
     2*DSIN(THETA)+DMAX1(-DR3*DTH/4./(R(I)+DR3/2.)**2*(V(I,J)+V(I+1,J)+
     3V(I+1,J-1)+V(I,J-1)),ZE)*W(I,J)+DMAX1(-DR3*DTH*(1.0/DR2-1.0/DR1)/
     48.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)*
     5W(I,J)-DMAX1(DR3*DTH/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+
     6V(I+1,J-1)+V(I,J-1)),ZE)*W(I+1,J)-DMAX1(-DR3*DTH/8.0/DR2/
     7(R(I)+DR3/2.)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)*W(I-1,J)-
     8DMAX1(DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)*W(I,J+1)-DMAX1(-DR3*
     9W(I,J)/2.0/(R(I)+DR3/2.0),ZE)*W(I,J-1)-BT(I,J))
      CT(I)=-DR3/(R(I)+DR3/2.0)
   32 DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APX(I,J)=APX(I,J)+1.00*(4.0*DR3/DTH/(R(I)+DR3/2.0)**2-DR3*DTH*
     1(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.0)+2.0*DTH/DR2+2.0*DTH/DR1-
     2APX(I,J))
      ANX(I,J)=ANX(I,J)+1.00*(DR3*DTH/DR1/(R(I)+DR3/2.0)+2.0*DTH/DR1+
     1DMAX1(-DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)-ANX(I,J))
      ASX(I,J)=ASX(I,J)+1.00*(-DR3*DTH/DR2/(R(I)+DR3/2.0)+2.0*DTH/DR2+
     1DMAX1(DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)-ASX(I,J))
      AEX(I,J)=AEX(I,J)+1.00*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-
     1DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AEX(I,J))
      AWX(I,J)=AWX(I,J)+1.00*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(
     1DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AWX(I,J))
      BX(I,J)=BX(I,J)+1.00*(-DMAX1(DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+
     1V(I+1,J)),ZE)*U(I+1,J)-DMAX1(-DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+
     2V(I+1,J)),ZE)*U(I-1,J)-DMAX1(DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+
     3W(I,J+1)),ZE)*UR-DMAX1(-DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+
     4W(I,J+1)),ZE)*UL-BX(I,J))
      CX(I)=-DR3*DTH/2.0
      APG(I,J)=APG(I,J)+1.00*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2-DR3*DTH
     1*(1./DR2-1./DR1)/2.0/(R(I)+DR3/2.0)+DTH/DR2+DTH/DR1+DTH*DR3*
     2PRTL/8./(R(I)+DR3/2.)*DMAX1(((1./DR2-1./DR1)*(V(I,J)+V(I+1,J)))
     3,ZE)-APG(I,J))
      ANG(I,J)=ANG(I,J)+1.00*(DR3*DTH/2.0/DR1/(R(I)+DR3/2.0)+DTH/DR1
     1+DMAX1(-DTH*DR3*PRTL/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)
     2-ANG(I,J))
      ASG(I,J)=ASG(I,J)+1.00*(-DR3*DTH/2.0/DR2/(R(I)+DR3/2.0)+DTH/DR2
     1+DMAX1(DTH*DR3*PRTL/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)
```

```
     2-ASG(I,J))
      AEG(I,J)=AEG(I,J)+1.00*(DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-DR3*
     1PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AEG(I,J))
      AWG(I,J)=AWG(I,J)+1.00*(DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(DR3*PRTL/
     18.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AWG(I,J))
      BG(I,J)=BG(I,J)+1.00*(-DR3*DTH*U(I,J)+DMAX1(-DTH*DR3*PRTL*
     1(1./DR2-1.0/DR1)/8./(R(I)+DR3/2.)*(V(I,J)+V(I+1,J)),ZE)*T(I,J)-
     2DMAX1(DTH*DR3*PRTL/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)*
     3T(I+1,J)-DMAX1(-DTH*DR3*PRTL/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+
     4V(I+1,J)),ZE)*T(I-1,J)-DMAX1(DR3*PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)
     5+W(I,J+1)),ZE)*TR-DMAX1(-DR3*PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)
     6+W(I,J+1)),ZE)*TL-BG(I,J))
   30 CONTINUE
CC
CC       CORRECTION OF ALL VELOCITIES USING THE CORRECTION PRESSURE.
CC
      DO 374 I=2,NRD2
      DO 374 J=2,NAD1
      IF (I.NE.2) V(I,J)=V(I,J)+RFVC*CR(I)*(PC(I,J)-PC(I-1,J))/APR(I,J)
      DO 376 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) W(I,J)=0.0
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) GO TO 374
  376 CONTINUE
      IF (J.NE.2) W(I,J)=W(I,J)+RFVC*CT(I)*(PC(I,J)-PC(I,J-1))/APT(I,J)
  374 CONTINUE
CC
      DO 1000 ITERAT=1,9000
CC
      CALL ANGSWE (APR,ANR,ASR,AER,AWR,BR,APT,ANT,
     1AST,AET,AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,ITERAT,PRTL,
     3GR,NRD2,NRD1,NAD1,P,PC,A,B,C,D,E,F,FC,REC1,REC2,Q,IFF,IFF1,
     4WS,VS,T2,U1,V2,W2,RFS,DPDX,RV,H)
CC
CC
CC       APPLYING THE BOUNDARY CONDITIONS.
CC
      DO 11 I=2,NRD2
      DO 11 J=2,NAD1
      JJ=NAD1+2-J
      V(2,J)=0.0
      V(NRD3,J)=0.0
      V(I,1)=V(I,2)
      V(I,NAD2)=V(I,NAD1)
      IF (I.GE.IFIN1) V(I,1)=-V(I,2)
      IF (I.GE.IFIN1) V(I,NAD2)=-V(I,NAD1)
CC
      W(I,2)=0.0
      W(I,NAD2)=0.0
      W(NRD3,J)=-W(NRD2,J)
      W(1,J)=-W(2,J)
      DO 12 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JB(L)+1) W(I,J)=0.0
   12 CONTINUE
```

```
CC
      U(I,1)=U(I,2)
      U(I,NAD2)=U(I,NAD1)
      U(NRD3,J)=-U(NRD2,J)
      U(1,J)=U(2,JJ)
      IF (I.GE.IFIN) U(I,1)=-U(I,2)
      IF (I.GE.IFIN) U(I,NAD2)=-U(I,NAD1)
CC
      T(I,1)=T(I,2)
      T(I,NAD2)=T(I,NAD1)
      T(NRD3,J)=-T(NRD2,J)
      T(1,J)=T(2,JJ)
      IF (I.GE.IFIN) T(I,1)=-T(I,2)
      IF (I.GE.IFIN) T(I,NAD2)=-T(I,NAD1)
CC
   11 CONTINUE
CC
CC
      CALL AXPRES (U,CX,APX,DPDX,NRD,NAD1,R,DR,PI
     *,DTH,RFDP,DPDX1,ITERAT)
CC
CC
      FRE=-DPDX/2.0
      ICOUNT=0
      CRI=DABS((FRE-FRE1)/FRE)*100.0
      IF (CRI.GT.1.0E-03) GO TO 1101
      ICOUNT=ICOUNT+1
 1101 SUMW=0.0
      SUMV=0.0
      DO 888 I=3,NRD2
      DO 888 J=2,NAD1
      SUMV=SUMV+DABS((V1(I,J)-V(I,J))*100.0)
      SUMW=SUMW+DABS(V(I,J))
  888 CONTINUE
      IF (SUMW.EQ.0.0) GO TO 1108
      SE=SUMV/SUMW
      WRITE (8,303) SE
  303 FORMAT (10X,'SUMV = ',D25.6)
      IF (SUMV/SUMW.GT.1.0E-03) GO TO 1102
 1108 ICOUNT=ICOUNT+1
 1102 SUMV=0.0
      SUMW=0.0
      DO 878 I=2,NRD2
      DO 878 J=3,NAD1
      SUMW=SUMW+DABS((W1(I,J)-W(I,J))*100.0)
      SUMV=SUMV+DABS(W(I,J))
  878 CONTINUE
      IF (SUMV.EQ.0.0) GO TO 1109
      SS=SUMW/SUMV
      WRITE (8,202) SS
  202 FORMAT (10X,'SUMW = ',D25.6)
      IF (SUMW/SUMV.GT.1.0E-03) GO TO 1103
 1109 ICOUNT=ICOUNT+1
 1103 DO 868 I=2,NRD2
```

```
      DO 868 J=2,NAD1
      IF (DABS(FC(I,J)).GT.1.0E-03) GO TO 1104
  868 CONTINUE
      ICOUNT=ICOUNT+1
 1104 SUMV=0.0
      SUMW=0.0
      DO 898 I=2,NRD2
      DO 898 J=2,NAD1
      SUMW=SUMW+DABS((T1(I,J)-T(I,J))*100.0)
      SUMV=SUMV+DABS(T(I,J))
  898 CONTINUE
      SS=SUMW/SUMV
      WRITE (8,203) SS
  203 FORMAT (10X,'SUMT = ',D25.6)
      IF (SUMW/SUMV.GT.1.0E-03) GO TO 1105
      ICOUNT=ICOUNT+1
 1105 IF (ICOUNT.LT.5.AND.ITERAT.LT.0360) GO TO 1100
      PRINT 7,NRD,NAD,H,M,PRTL,GR
    7 FORMAT ('1',3X,'MESH SIZE (',I2,'X',I2,')',3X,'H = ',
     *F3.1,3X,' M = ',I2,3X,'PRTL= ',F4.1,3X,'GR= ',D10.4,////)
      PRINT 2,ITERAT
    2 FORMAT ('1',20X,'CONVERGED AFTER ',I5,' ITERATIONS')
      PRINT 987
  987 FORMAT (2(/),50X,'AXIAL VELOCITY')
      DO 380 I=2,NRD2
      PRINT 2000,(U(I,J),J=2,NAD1)
  380 CONTINUE
      PRINT 876
  876 FORMAT (2(/),50X,'RADIAL VELOCITY')
      DO 390 I=2,NRD3
      PRINT 2000,(V(I,J),J=2,NAD1)
  390 CONTINUE
      PRINT 765
  765 FORMAT (2(/),50X,'ANGULAR VELOCITY')
      DO 400 I=2,NRD2
      PRINT 2000,(W(I,J),J=2,NAD2)
  400 CONTINUE
      PRINT 654
  654 FORMAT (2(/),50X,'PRESSURE ')
      DO 410 I=2,NRD2
      PRINT 2000,(P(I,J),J=2,NAD1)
  410 CONTINUE
      PRINT 655
  655 FORMAT (2(/),50X,'TEMPERATURE')
      DO 420 I=2,NRD2
      PRINT 2000,(T(I,J),J=2,NAD1)
  420 CONTINUE
      SUM=0.0
      SUM1=0.0
      DO 1500 I=2,NRD2
      DR4=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR4=DR/2.0
      DO 1500 J=2,NAD1
      SUM=SUM+U(I,J)*(R(I)+DR4/2.0)*DR4*DTH
```

```
      SUM1=SUM1+U(I,J)*T(I,J)*(R(I)+DR4/2.0)*DR4*DTH
 1500 CONTINUE
      UB=SUM/PI*2.0
      TB=SUM1*2.0/PI
      NU=-1.0/TB
      PRINT 3,UB,FRE,TB,NU
    3 FORMAT (/,' UB = ',D13.5,' FRE = ',D13.5,' TB = ',D13.5,' NU = ',
     1D13.6,10(/))
      CALL FLUX (H,M,T,PI,DR,DTH,NRD,NAD,R,JA,JB,M2,IFIN)
      IF (GR.GT.0.0) CALL SECFLO (V,W,PI,NAD,NRD,R,DTH,DR)
      PRINT 2222
 2222 FORMAT (10(/))
      DO 1420 I=2,NRD2
      PRINT 2000,(FC(I,J),J=2,NAD1)
 1420 CONTINUE
  123 FORMAT (5X,4(D16.6))
 2000 FORMAT (/,10(1X,D12.5))
      GO TO 1212
CC
CC      CORRECTION OF ALL VELOCITIES USING THE CORRECTION PRESSURE.
CC
 1100 DO 370 I=2,NRD2
      DO 370 J=2,NAD1
      T1(I,J)=T(I,J)
      IF (GR.EQ.0.0) GO TO 370
      IF (I.NE.2) V1(I,J)=V(I,J)
      IF (J.NE.2) W1(I,J)=W(I,J)
      IF (I.NE.2) V(I,J)=V(I,J)+RFVC*CR(I)*(PC(I,J)-PC(I-1,J))/APR(I,J)
      DO 375 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) W(I,J)=0.0
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) GO TO 370
  375 CONTINUE
      IF (J.NE.2) W(I,J)=W(I,J)+RFVC*CT(I)*(PC(I,J)-PC(I,J-1))/APT(I,J)
  370 CONTINUE
CC
CC      UNDERRELAXING THE DEPENDENT VARIABLES
CC
      DO 116 I=2,NRD2
      DO 116 J=2,NAD1
      T2(I,J)=T(I,J)
      U1(I,J)=U(I,J)
      IF (I.NE.2) V2(I,J)=V(I,J)
      IF (J.NE.2) W2(I,J)=W(I,J)
  116 CONTINUE
      IF(ITERAT.GE.0200) WRITE (8,371) ITERAT,ICOUNT,DPDX,DPDX1,GR
      IF(ITERAT.GE.0200) WRITE (8,372)U(15,15),V(15,15),W(15,15)
     1,T(15,15),FC(15,15),CRI
  372 FORMAT (6(D11.4))
  371 FORMAT (2(I7),3(D18.7))
 1000 FRE1=FRE
      PRINT 4,ITERAT
    4 FORMAT (//,10X,'THE ALGORITHM FAILED WITHIN ',I7,
     *' ITERATIONS')
      STOP
```

```
 1212 REWIND 4
      PRINT 7788
 7788 FORMAT ('1',150(/))
      WRITE (4,1111) DPDX
      DO 1118 I=1,NRD3
      WRITE (4,1111) ((U(I,J),T(I,J)),J=1,NAD2)
 1118 CONTINUE
      DO 1119 I=2,NRD3
      WRITE (4,1111) (V(I,J),J=1,NAD2)
 1119 CONTINUE
      DO 1120 I=1,NRD3
      WRITE (4,1111) (W(I,J),J=2,NAD2)
 1120 CONTINUE
      DO 1122 I=1,NRD3
      WRITE (4,1111) ((P(I,J),PC(I,J)),J=1,NAD2)
 1122 CONTINUE
      DO 9182 I=2,NRD2
      WRITE (2,1111) (T(I,J),J=2,NAD1)
      WRITE (1,1111) (U(I,J),J=2,NAD1)
 9182 CONTINUE
      PRINT 1515
 1515 FORMAT (50(/))
      STOP
      END
      SUBROUTINE AXPRES (U,CX,APX,DPDX,NRD,NAD1,R,DR,PI,DTH,RFDP,
     *DPDX1,ITERAT)
      DOUBLE PRECISION U(33,66),APX(33,66),CX(55),R(55),DPDX
     *,PI,DR,DTH,DPDX1,SUM,SUM1,DR2
      NRD2=NRD+2
      SUM=0.0
      SUM1=0.0
      DO 10 I=2,NRD2
      DO 10 J=2,NAD1
      DR2=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR2=DR/2.0
      SUM=SUM+U(I,J)*(R(I)+DR2/2.0)*DR2
      SUM1=SUM1+CX(I)/APX(I,J)*(R(I)+DR2/2.0)*DR2
   10 CONTINUE
      DPDX1=(PI/2.0/DTH-SUM)/SUM1
      IF (DABS(DPDX1).GT.01.0) DPDX1=01.0*DPDX1/DABS(DPDX1)
      N1=ITERAT/01
      N2=N1*01
      IF (N2.EQ.ITERAT) DPDX=DPDX+RFDP*DPDX1
      RETURN
      END
CC
CC         SUBROUTINE TO UPDATE THE COEFFICIENTS.
CC
      SUBROUTINE COEFF1 (I,APR,ANR,ASR,AER,AWR,BR,APT,ANT,AST,AET,
     1AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,PRTL,
     3GR,NRD2,NRD1,NAD1)
      DIMENSION JA(20),JB(20)
      DOUBLE PRECISION APR(33,66),ANR(33,66),ASR(33,66),AER(33,66),
```

```
     1AWR(33,66),BR(33,66),CR(55),APT(33,66),ANT(33,66),AST(33,66),
     2AET(33,66),AWT(33,66),BT(33,66),CT(55),APX(33,66),ANX(33,66),
     3ASX(33,66),AEX(33,66),AWX(33,66),BX(33,66),CX(55),APG(33,66),
     4ANG(33,66),ASG(33,66),AEG(33,66),AWG(33,66),BG(33,66),R(55),
     5DR,DTH,VR,VL,UR,UL,TR,TL,THETA,ZE,DR1,DR2,DR3,U(33,66),
     6V(33,66),W(33,66),T(33,66)
CC
      DO 30 J=2,NAD1
      VL=V(I,J-1)
      VR=V(I,J+1)
      TL=T(I,J-1)
      TR=T(I,J+1)
      UL=U(I,J-1)
      UR=U(I,J+1)
      DO 75 L=1,M2
      IF (I.GE.IFIN1.AND.J.EQ.JA(L)) VL=-V(I,J)
      IF (I.GE.IFIN1.AND.J.EQ.JB(L)) VR=-V(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L))  TL=-T(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JB(L))  TR=-T(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L))  UL=-U(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JB(L))  UR=-U(I,J)
   75 CONTINUE
      THETA=(J-2)*DTH+DTH/2.0
      IF (I.EQ.2) GO TO 31
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.3.OR.I.EQ.NRD2) DR3=0.75*DR
      IF (I.EQ.3) DR2=0.50*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      APR(I,J)=APR(I,J)+RFCO*(4.0*DR3/DTH/R(I)**3+2.0*DTH/R(I)/DR2+
     12.0*DTH/R(I)/DR1-APR(I,J))
      ANR(I,J)=ANR(I,J)+RFCO*(2.0*DTH/DR1/R(I)-DTH/R(I)**2+DMAX1(-
     1V(I,J)*DTH/2.0/R(I)**2,ZE)-ANR(I,J))
      ASR(I,J)=ASR(I,J)+RFCO*(2.0*DTH/DR2/R(I)+DTH/R(I)**2+DMAX1(
     1V(I,J)*DTH/2.0/R(I)**2,ZE)-ASR(I,J))
      AER(I,J)=AER(I,J)+RFCO*(2.0*DR3/DTH/R(I)**3+DMAX1(-
     1((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/
     28.0/R(I)**2,ZE)-AER(I,J))
      AWR(I,J)=AWR(I,J)+RFCO*(2.0*DR3/DTH/R(I)**3+DMAX1(+
     1((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/
     28.0/R(I)**2,ZE)-AWR(I,J))
      BR(I,J)=BR(I,J)+RFCO*(DR3*DTH/R(I)*(((2.0*DR3-DR2)*(W(I-1,J)+
     1W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/4./DR3)**2+GR*DTH*DCOS(THETA)
     2/4.*(DR2*T(I,J)+(2.*DR3-DR2)*T(I-1,J))-2./R(I)**2*(DR2*(W(I,J+1)-
     3W(I,J))+(2.0*DR3-DR2)*(W(I-1,J+1)-W(I-1,J)))-DMAX1(V(I,J)*DTH/
     42.0/R(I)**2,ZE)*V(I+1,J)-DMAX1(-V(I,J)*DTH/2.0/R(I)**2,ZE)*
     5V(I-1,J)-DMAX1(-((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(
     6W(I,J)+W(I,J+1)))/8.0/R(I)**2,ZE)*VL+DR3*DTH*V(I,J)**2/R(I)**3
     7-DMAX1(+((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(
     8W(I,J)+W(I,J+1)))/8.0/R(I)**2,ZE)*VR-BR(I,J))
      CR(I)=-DTH
   31 IF (J.EQ.2) GO TO 32
      THETA=(J-2)*DTH
```

```
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APT(I,J)=APT(I,J)+RFCO*(4.0*DR3/DTH/(R(I)+DR3/2.0)**2+2.0*
     1DR3*DTH/(R(I)+DR3/2.)**2-DR3*DTH*(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.)
     2+2.0*DTH/DR2+2.0*DTH/DR1+DMAX1(+DR3*DTH/4.0/(R(I)+DR3/2.0)**2*(
     3V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)+DMAX1(+DR3*DTH/8.0*
     4(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+
     5V(I,J-1)),ZE)-APT(I,J))
      ANT(I,J)=ANT(I,J)+RFCO*(DR3*DTH/DR1/(R(I)+DR3/2.0)+2.0*DTH/DR1+
     1DMAX1(-DR3*DTH/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)
     2+V(I,J-1)),ZE)-ANT(I,J))
      AST(I,J)=AST(I,J)+RFCO*(-DR3*DTH/DR2/(R(I)+DR3/2.0)+2.0*DTH/DR2+
     1DMAX1(+DR3*DTH/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)
     2+V(I,J-1)),ZE)-AST(I,J))
      AET(I,J)=AET(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-
     1DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)-AET(I,J))
      AWT(I,J)=AWT(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(
     1DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)-AWT(I,J))
      BT(I,J)=BT(I,J)+RFCO*(2.0*DR3/(R(I)+DR3/2.0)**3*(V(I,J)+
     1V(I+1,J)-V(I+1,J-1)-V(I,J-1))-DR3*DTH*GR/4.0*(T(I,J)+T(I,J-1))
     2*DSIN(THETA)+DMAX1(-DR3*DTH/4./(R(I)+DR3/2.)**2*(V(I,J)+V(I+1,J)+
     3V(I+1,J-1)+V(I,J-1)),ZE)*W(I,J)+DMAX1(-DR3*DTH*(1.0/DR2-1.0/DR1)/
     48.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)*
     5W(I,J)-DMAX1(DR3*DTH/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+
     6V(I+1,J-1)+V(I,J-1)),ZE)*W(I+1,J)-DMAX1(-DR3*DTH/8.0/DR2/
     7(R(I)+DR3/2.)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)*W(I-1,J)-
     8DMAX1(DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)*W(I,J+1)-DMAX1(-DR3*
     9W(I,J)/2.0/(R(I)+DR3/2.0),ZE)*W(I,J-1)-BT(I,J))
      CT(I)=-DR3/(R(I)+DR3/2.0)
   32 CONTINUE
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APX(I,J)=APX(I,J)+RFCO*(4.0*DR3/DTH/(R(I)+DR3/2.0)**2-DR3*DTH*
     1(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.0)+2.0*DTH/DR2+2.0*DTH/DR1-
     2APX(I,J))
      ANX(I,J)=ANX(I,J)+RFCO*(DR3*DTH/DR1/(R(I)+DR3/2.0)+2.0*DTH/DR1+
     1DMAX1(-DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)-ANX(I,J))
      ASX(I,J)=ASX(I,J)+RFCO*(-DR3*DTH/DR2/(R(I)+DR3/2.0)+2.0*DTH/DR2+
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     1DMAX1(DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)-ASX(I,J))
      AEX(I,J)=AEX(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-
     1DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AEX(I,J))
      AWX(I,J)=AWX(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(
     1DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AWX(I,J))
      BX(I,J)=BX(I,J)+RFCO*(-DMAX1(DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+
     1V(I+1,J)),ZE)*U(I+1,J)-DMAX1(-DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+
     2V(I+1,J)),ZE)*U(I-1,J)-DMAX1(DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+
     3W(I,J+1)),ZE)*UR-DMAX1(-DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+
     4W(I,J+1)),ZE)*UL-BX(I,J))
      CX(I)=-DR3*DTH/2.0
      APG(I,J)=APG(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2-DR3*DTH
     1*(1./DR2-1./DR1)/2.0/(R(I)+DR3/2.0)+DTH/DR2+DTH/DR1+DTH*DR3*
     2PRTL/8./(R(I)+DR3/2.)*DMAX1(((1./DR2-1./DR1)*(V(I,J)+V(I+1,J)))
     3,ZE)-APG(I,J))
      ANG(I,J)=ANG(I,J)+RFCO*(DR3*DTH/2.0/DR1/(R(I)+DR3/2.0)+DTH/DR1
     1+DMAX1(-DTH*DR3*PRTL/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)
     2-ANG(I,J))
      ASG(I,J)=ASG(I,J)+RFCO*(-DR3*DTH/2.0/DR2/(R(I)+DR3/2.0)+DTH/DR2
     1+DMAX1(DTH*DR3*PRTL/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)
     2-ASG(I,J))
      AEG(I,J)=AEG(I,J)+RFCO*(DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-DR3*
     1PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AEG(I,J))
      AWG(I,J)=AWG(I,J)+RFCO*(DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(DR3*PRTL/
     18.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AWG(I,J))
      BG(I,J)=BG(I,J)+RFCO*(-DR3*DTH*U(I,J)+DMAX1(-DTH*DR3*PRTL*
     1(1./DR2-1./DR1)/8./(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)*T(I,J)-
     2DMAX1(DTH*DR3*PRTL/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)*
     3T(I+1,J)-DMAX1(-DTH*DR3*PRTL/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+
     4V(I+1,J)),ZE)*T(I-1,J)-DMAX1(DR3*PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)
     5+W(I,J+1)),ZE)*TR-DMAX1(-DR3*PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)
     6+W(I,J+1)),ZE)*TL-BG(I,J))
   30 CONTINUE
      RETURN
      END
      SUBROUTINE COEFF (J,APR,ANR,ASR,AER,AWR,BR,APT,ANT,AST,AET,
     1AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,PRTL,
     3GR,NRD2,NRD1,NAD1)
      DIMENSION JA(20),JB(20)
      DOUBLE PRECISION APR(33,66),ANR(33,66),ASR(33,66),AER(33,66),
     1AWR(33,66),BR(33,66),CR(55),APT(33,66),ANT(33,66),AST(33,66),
     2AET(33,66),AWT(33,66),BT(33,66),CT(55),APX(33,66),ANX(33,66),
     3ASX(33,66),AEX(33,66),AWX(33,66),BX(33,66),CX(55),APG(33,66),
     4ANG(33,66),ASG(33,66),AEG(33,66),AWG(33,66),BG(33,66),R(55),
     5DR,DTH,VR,VL,UR,UL,TR,TL,THETA,ZE,DR1,DR2,DR3,U(33,66),
     6V(33,66),W(33,66),T(33,66)
CC
      DO 30 I=2,NRD2
      VL=V(I,J-1)
      VR=V(I,J+1)
      TL=T(I,J-1)
      TR=T(I,J+1)
      UL=U(I,J-1)
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      UR=U(I,J+1)
      DO 75 L=1,M2
      IF (I.GE.IFIN1.AND.J.EQ.JA(L)) VL=-V(I,J)
      IF (I.GE.IFIN1.AND.J.EQ.JB(L)) VR=-V(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L))  TL=-T(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JB(L))  TR=-T(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L))  UL=-U(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JB(L))  UR=-U(I,J)
   75 CONTINUE
      THETA=(J-2)*DTH+DTH/2.0
      IF (I.EQ.2) GO TO 31
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.3.OR.I.EQ.NRD2) DR3=0.75*DR
      IF (I.EQ.3) DR2=0.50*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      APR(I,J)=APR(I,J)+RFCO*(4.0*DR3/DTH/R(I)**3+2.0*DTH/R(I)/DR2+
     12.0*DTH/R(I)/DR1-APR(I,J))
      ANR(I,J)=ANR(I,J)+RFCO*(2.0*DTH/DR1/R(I)-DTH/R(I)**2+DMAX1(-
     1V(I,J)*DTH/2.0/R(I)**2,ZE)-ANR(I,J))
      ASR(I,J)=ASR(I,J)+RFCO*(2.0*DTH/DR2/R(I)+DTH/R(I)**2+DMAX1(
     1V(I,J)*DTH/2.0/R(I)**2,ZE)-ASR(I,J))
      AER(I,J)=AER(I,J)+RFCO*(2.0*DR3/DTH/R(I)**3+DMAX1(-
     1((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/
     28.0/R(I)**2,ZE)-AER(I,J))
      AWR(I,J)=AWR(I,J)+RFCO*(2.0*DR3/DTH/R(I)**3+DMAX1(+
     1((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/
     28.0/R(I)**2,ZE)-AWR(I,J))
      BR(I,J)=BR(I,J)+RFCO*(DR3*DTH/R(I)*(((2.0*DR3-DR2)*(W(I-1,J)+
     1W(I-1,J+1))+DR2*(W(I,J)+W(I,J+1)))/4./DR3)**2+GR*DTH*DCOS(THETA)
     2/4.*(DR2*T(I,J)+(2.*DR3-DR2)*T(I-1,J))-2./R(I)**2*(DR2*(W(I,J+1)-
     3W(I,J))+(2.0*DR3-DR2)*(W(I-1,J+1)-W(I-1,J)))-DMAX1(V(I,J)*DTH/
     42.0/R(I)**2,ZE)*V(I+1,J)-DMAX1(-V(I,J)*DTH/2.0/R(I)**2,ZE)*
     5V(I-1,J)-DMAX1(-((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(
     6W(I,J)+W(I,J+1)))/8.0/R(I)**2,ZE)*VL+DR3*DTH*V(I,J)**2/R(I)**3
     7-DMAX1(+((2.0*DR3-DR2)*(W(I-1,J)+W(I-1,J+1))+DR2*(
     8W(I,J)+W(I,J+1)))/8.0/R(I)**2,ZE)*VR-BR(I,J))
      CR(I)=-DTH
   31 IF (J.EQ.2) GO TO 32
      THETA=(J-2)*DTH
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APT(I,J)=APT(I,J)+RFCO*(4.0*DR3/DTH/(R(I)+DR3/2.0)**2+2.0*
     1DR3*DTH/(R(I)+DR3/2.)**2-DR3*DTH*(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.)
     2+2.0*DTH/DR2+2.0*DTH/DR1+DMAX1(+DR3*DTH/4.0/(R(I)+DR3/2.0)**2*(
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     3V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)+DMAX1(+DR3*DTH/8.0*
     4(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+
     5V(I,J-1)),ZE)-APT(I,J))
      ANT(I,J)=ANT(I,J)+RFCO*(DR3*DTH/DR1/(R(I)+DR3/2.0)+2.0*DTH/DR1+
     1DMAX1(-DR3*DTH/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)
     2+V(I,J-1)),ZE)-ANT(I,J))
      AST(I,J)=AST(I,J)+RFCO*(-DR3*DTH/DR2/(R(I)+DR3/2.0)+2.0*DTH/DR2+
     1DMAX1(+DR3*DTH/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)
     2+V(I,J-1)),ZE)-AST(I,J))
      AET(I,J)=AET(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-
     1DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)-AET(I,J))
      AWT(I,J)=AWT(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(
     1DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)-AWT(I,J))
      BT(I,J)=BT(I,J)+RFCO*(2.0*DR3/(R(I)+DR3/2.0)**3*(V(I,J)+
     1V(I+1,J)-V(I+1,J-1)-V(I,J-1))-DR3*DTH*GR/4.0*(T(I,J)+T(I,J-1))
     2*DSIN(THETA)+DMAX1(-DR3*DTH/4./(R(I)+DR3/2.)**2*(V(I,J)+V(I+1,J)+
     3V(I+1,J-1)+V(I,J-1)),ZE)*W(I,J)+DMAX1(-DR3*DTH*(1.0/DR2-1.0/DR1)/
     48.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)*
     5W(I,J)-DMAX1(DR3*DTH/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)+
     6V(I+1,J-1)+V(I,J-1)),ZE)*W(I+1,J)-DMAX1(-DR3*DTH/8.0/DR2/
     7(R(I)+DR3/2.)*(V(I,J)+V(I+1,J)+V(I+1,J-1)+V(I,J-1)),ZE)*W(I-1,J)-
     8DMAX1(DR3*W(I,J)/2.0/(R(I)+DR3/2.0),ZE)*W(I,J+1)-DMAX1(-DR3*
     9W(I,J)/2.0/(R(I)+DR3/2.0),ZE)*W(I,J-1)-BT(I,J))
      CT(I)=-DR3/(R(I)+DR3/2.0)
   32 CONTINUE
      DR1=DR
      DR2=DR
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.EQ.2) DR1=0.75*DR
      IF (I.EQ.2) DR2=0.50*DR
      IF (I.EQ.3) DR2=0.75*DR
      IF (I.EQ.NRD1) DR1=0.75*DR
      IF (I.EQ.NRD2) DR1=0.50*DR
      IF (I.EQ.NRD2) DR2=0.75*DR
      APX(I,J)=APX(I,J)+RFCO*(4.0*DR3/DTH/(R(I)+DR3/2.0)**2-DR3*DTH*
     1(1.0/DR2-1.0/DR1)/(R(I)+DR3/2.0)+2.0*DTH/DR2+2.0*DTH/DR1-
     2APX(I,J))
      ANX(I,J)=ANX(I,J)+RFCO*(DR3*DTH/DR1/(R(I)+DR3/2.0)+2.0*DTH/DR1+
     1DMAX1(-DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)-ANX(I,J))
      ASX(I,J)=ASX(I,J)+RFCO*(-DR3*DTH/DR2/(R(I)+DR3/2.0)+2.0*DTH/DR2+
     1DMAX1(DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)-ASX(I,J))
      AEX(I,J)=AEX(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-
     1DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AEX(I,J))
      AWX(I,J)=AWX(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(
     1DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AWX(I,J))
      BX(I,J)=BX(I,J)+RFCO*(-DMAX1(DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+
     1V(I+1,J)),ZE)*U(I+1,J)-DMAX1(-DTH/4.0/(R(I)+DR3/2.0)*(V(I,J)+
     2V(I+1,J)),ZE)*U(I-1,J)-DMAX1(DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+
     3W(I,J+1)),ZE)*UR-DMAX1(-DR3/4.0/(R(I)+DR3/2.0)*(W(I,J)+
     4W(I,J+1)),ZE)*UL-BX(I,J))
      CX(I)=-DR3*DTH/2.0
      APG(I,J)=APG(I,J)+RFCO*(2.0*DR3/DTH/(R(I)+DR3/2.0)**2-DR3*DTH
     1*(1./DR2-1./DR1)/2.0/(R(I)+DR3/2.0)+DTH/DR2+DTH/DR1+DTH*DR3*
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     2PRTL/8./(R(I)+DR3/2.)*DMAX1(((1./DR2-1./DR1)*(V(I,J)+V(I+1,J)))
     3,ZE)-APG(I,J))
      ANG(I,J)=ANG(I,J)+RFCO*(DR3*DTH/2.0/DR1/(R(I)+DR3/2.0)+DTH/DR1
     1+DMAX1(-DTH*DR3*PRTL/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)
     2-ANG(I,J))
      ASG(I,J)=ASG(I,J)+RFCO*(-DR3*DTH/2.0/DR2/(R(I)+DR3/2.0)+DTH/DR2
     1+DMAX1(DTH*DR3*PRTL/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)
     2-ASG(I,J))
      AEG(I,J)=AEG(I,J)+RFCO*(DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(-DR3*
     1PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AEG(I,J))
      AWG(I,J)=AWG(I,J)+RFCO*(DR3/DTH/(R(I)+DR3/2.0)**2+DMAX1(DR3*PRTL/
     18.0/(R(I)+DR3/2.0)*(W(I,J)+W(I,J+1)),ZE)-AWG(I,J))
      BG(I,J)=BG(I,J)+RFCO*(-DR3*DTH*U(I,J)+DMAX1(-DTH*DR3*PRTL*
     1(1./DR2-1./DR1)/8./(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)*T(I,J)-
     2DMAX1(DTH*DR3*PRTL/8.0/DR1/(R(I)+DR3/2.0)*(V(I,J)+V(I+1,J)),ZE)*
     3T(I+1,J)-DMAX1(-DTH*DR3*PRTL/8.0/DR2/(R(I)+DR3/2.0)*(V(I,J)+
     4V(I+1,J)),ZE)*T(I-1,J)-DMAX1(DR3*PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)
     5+W(I,J+1)),ZE)*TR-DMAX1(-DR3*PRTL/8.0/(R(I)+DR3/2.0)*(W(I,J)
     6+W(I,J+1)),ZE)*TL-BG(I,J))
   30 CONTINUE
      RETURN
      END
      SUBROUTINE ANGSWE (APR,ANR,ASR,AER,AWR,BR,APT,ANT,
     1AST,AET,AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,ITERAT,PRTL,
     3GR,NRD2,NRD1,NAD1,P,PC,A,B,C,D,E,F,FC,REC1,REC2,Q,IFF,IFF1,
     4WS,VS,T2,U1,V2,W2,RFS,DPDX,RV,H)
      DIMENSION JA(20),JB(20)
      DOUBLE PRECISION APR(33,66),ANR(33,66),ASR(33,66),AER(33,66),
     1AWR(33,66),BR(33,66),CR(55),APT(33,66),ANT(33,66),AST(33,66),
     2AET(33,66),AWT(33,66),BT(33,66),CT(55),APX(33,66),ANX(33,66),
     3ASX(33,66),AEX(33,66),AWX(33,66),BX(33,66),CX(55),APG(33,66),
     4ANG(33,66),ASG(33,66),AEG(33,66),AWG(33,66),BG(33,66),R(55),
     5DR,DTH,VR,VL,UR,UL,TR,TL,THETA,ZE,DR1,DR2,DR3,U(33,66),
     6V(33,66),W(33,66),T(33,66),P(33,66),PC(33,66),A(33,66),B(33,66)
     7,C(33,66),D(33,66),E(33,66),F(33,66),FC(33,66),REC1(33,66),
     8REC2(33,66),Q(33,66),WS(33,66),VS(33,66),T2(33,66),U1(33,66),
     9V2(33,66),W2(33,66)
      NRD3=NRD2+1
      NAD2=NAD1+1
CC
CC        CALCULATIONS OF PSEUDO-VELOCITIES
CC
      DO 40 I=2,NRD2
      DO 40 J=2,NAD1
      VL=V(I,J-1)
      VR=V(I,J+1)
      DO 47 L=1,M2
      IF (I.GE.IFIN1.AND.J.EQ.JB(L)) VR=-V(I,J)
      IF (I.GE.IFIN1.AND.J.EQ.JA(L)) VL=-V(I,J)
   47 CONTINUE
      IF (I.NE.2) VS(I,J)=(ANR(I,J)*V(I+1,J)+ASR(I,J)*V(I-1,J)+
     1AER(I,J)*VR+AWR(I,J)*VL+BR(I,J))/APR(I,J)
      IF (J.NE.2) WS(I,J)=(ANT(I,J)*W(I+1,J)+AST(I,J)*W(I-1,J)+
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```
     1AET(I,J)*W(I,J+1)+AWT(I,J)*W(I,J-1)+BT(I,J))/APT(I,J)
      DO 45 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) WS(I,J)=0.0
   45 CONTINUE
      VS(2,J)=0.0
      VS(NRD3,J)=0.0
      WS(I,2)=0.0
      WS(I,NAD2)=0.0
   40 CONTINUE
CC
CC       CALCULATING THE COEFFICIENTS OF THE PRESSURE EQUATIONS.
CC
      DO 50 I=2,NRD2
      DO 50 J=2,NAD1
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      IF (I.NE.NRD2) B(I,J)=CR(I+1)*DTH/APR(I+1,J)
      IF (I.NE.2) C(I,J)=CR(I)*DTH/APR(I,J)
      IF (J.NE.NAD1) D(I,J)=CT(I)*DR3/APT(I,J+1)
      IF (J.NE.2) E(I,J)=CT(I)*DR3/APT(I,J)
      B(NRD2,J)=0.0
      C(2,J)=0.0
      D(I,NAD1)=0.0
      E(I,2)=0.0
      DO 46 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JB(L)) D(I,J)=0.0
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) E(I,J)=0.0
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) WS(I,J)=0.0
   46 CONTINUE
      A(I,J)=B(I,J)+C(I,J)+D(I,J)+E(I,J)
      F(I,J)=F(I,J)+RFS*(DTH*(VS(I+1,J)-VS(I,J))+DR3*(WS(I,J+1)
     1-WS(I,J))-F(I,J))
   50 CONTINUE
CC
CC       SOLUTION OF THE PRESSURE EQUATION.
CC
      IF (GR.EQ.0.0) GO TO 610
      DO 610 ITERP=1,5000
      DO 1620 I=2,NRD2
      DO 1620 J=2,NAD1
      P(I,1)=0.0
      P(I,NAD2)=0.0
      P(1,J)=0.0
      P(NRD3,J)=0.0
      PL=P(I,J-1)
      PR=P(I,J+1)
      DO 1625 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JB(L)) PR=0.0
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) PL=0.0
 1625 CONTINUE
      Q(I,J)=D(I,J)*PR+E(I,J)*PL+F(I,J)
      IF (I.EQ.2) REC1(I,J)=B(I,J)/A(I,J)
      IF (I.EQ.2) REC2(I,J)=Q(I,J)/A(I,J)
      IF (I.NE.2) REC1(I,J)=(B(I,J)/A(I,J))/(1.0-C(I,J)/A(I,J)*
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```
     1REC1(I-1,J))
      IF (I.NE.2) REC2(I,J)=(C(I,J)/A(I,J)*REC2(I-1,J)+Q(I,J)/A(I,J))/
     1(1.0-C(I,J)/A(I,J)*REC1(I-1,J))
 1620 CONTINUE
      DO 1621 J=2,NAD1
      DO 1621 II=2,NRD2
      I=NRD2+2-II
      P(I,J)=REC1(I,J)*P(I+1,J)+REC2(I,J)
 1621 CONTINUE
      DO 621 I=2,IFF1
      DO 621 J=2,NAD1
      Q(I,J)=B(I,J)*P(I+1,J)+C(I,J)*P(I-1,J)+F(I,J)
      IF (J.EQ.2) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/A(I,J))
      IF (J.EQ.2) REC2(I,J)=Q(I,J)/A(I,J)/(1.0-E(I,J)/A(I,J))
      IF (J.NE.2) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/A(I,J)*
     1REC1(I,J-1))
      IF (J.NE.2) REC2(I,J)=(E(I,J)/A(I,J)*REC2(I,J-1)+Q(I,J)/
     1A(I,J))/(1.0-E(I,J)/A(I,J)*REC1(I,J-1))
  621 CONTINUE
      IF (H.EQ.0.0) GO TO 626
      DO 622 I=IFIN,NRD2
      DO 622 L=1,M2
      JAC=JA(L)
      JBC=JB(L)
      DO 622 J=JAC,JBC
      Q(I,J)=B(I,J)*P(I+1,J)+C(I,J)*P(I-1,J)+F(I,J)
      IF (J.EQ.JA(L)) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/
     1A(I,J))
      IF (J.EQ.JA(L)) REC2(I,J)=Q(I,J)/A(I,J)/(1.0-E(I,J)/
     1A(I,J))
      IF (J.NE.JA(L)) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/
     1A(I,J)*REC1(I,J-1))
      IF (J.NE.JA(L)) REC2(I,J)=(E(I,J)/A(I,J)*REC2(I,J-1)+
     1Q(I,J)/A(I,J))/(1.0-E(I,J)/A(I,J)*REC1(I,J-1))
  622 CONTINUE
      DO 623 II=IFIN,NRD2
      I=NRD2+IFIN-II
      DO 623 LL=1,M2
      L=M2+1-LL
      JAC=JA(L)
      JBC=JB(L)
      DO 623 JJ=JAC,JBC
      J=JB(L)+JA(L)-JJ
      P(I,J)=REC1(I,J)*P(I,J+1)+REC2(I,J)
  623 CONTINUE
  626 DO 624 II=2,IFF1
      I=IFF1+2-II
      DO 624 JJ=2,NAD1
      J=NAD1+2-JJ
      P(I,J)=REC1(I,J)*P(I,J+1)+REC2(I,J)
  624 CONTINUE
  610 CONTINUE
      DO 35 J=2,NAD1
      DO 1252 I=2,NRD2
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```
      UR=U(I,J+1)
      UL=U(I,J-1)
      DO 1255 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JB(L)) UR=-U(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) UL=-U(I,J)
 1255 CONTINUE
      Q(I,J)=AEX(I,J)*UR+AWX(I,J)*UL+BX(I,J)+CX(I)*DPDX
      IF (I.EQ.2) REC1(I,J)=ANX(I,J)/APX(I,J)
      IF (I.EQ.2) REC2(I,J)=ASX(I,J)/APX(I,J)*U(I-1,J)+Q(I,J)/APX(I,J)
      IF (I.NE.2) REC1(I,J)=(ANX(I,J)/APX(I,J))/(1.0-ASX(I,J)/APX(I,J)*
     1REC1(I-1,J))
      IF (I.NE.2) REC2(I,J)=(ASX(I,J)/APX(I,J)*REC2(I-1,J)+Q(I,J)/
     1APX(I,J))/(1.0-ASX(I,J)/APX(I,J)*REC1(I-1,J))
 1252 CONTINUE
      U(NRD2,J)=REC2(NRD2,J)/(1.0+REC1(NRD2,J))
      DO 1253 II=2,NRD1
      I=NRD1+2-II
      U(I,J)=REC1(I,J)*U(I+1,J)+REC2(I,J)
 1253 CONTINUE
      DO 38 I=2,NRD2
      U(I,J)=U1(I,J)+RV*(U(I,J)-U1(I,J))
   38 CONTINUE
      IF (ITERAT.GT.000) CALL COEFF (J,APR,ANR,ASR,AER,AWR,BR,APT,ANT,
     1AST,AET,AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,PRTL,
     3GR,NRD2,NRD1,NAD1)
      IF (GR.EQ.0.0) GO TO 620
      DO 1130 I=3,NRD2
      VR=V(I,J+1)
      VL=V(I,J-1)
      DO 1135 L=1,M2
      IF (I.GE.IFIN1.AND.J.EQ.JB(L)) VR=-V(I,J)
      IF (I.GE.IFIN1.AND.J.EQ.JA(L)) VL=-V(I,J)
 1135 CONTINUE
      Q(I,J)=AER(I,J)*VR+AWR(I,J)*VL+BR(I,J)+CR(I)*
     1(P(I,J)-P(I-1,J))
      IF (I.EQ.3) REC1(I,J)=ANR(I,J)/APR(I,J)
      IF (I.EQ.3) REC2(I,J)=Q(I,J)/APR(I,J)
      IF (I.NE.3) REC1(I,J)=(ANR(I,J)/APR(I,J))/(1.0-ASR(I,J)/
     1APR(I,J)*REC1(I-1,J))
      IF (I.NE.3) REC2(I,J)=(ASR(I,J)/APR(I,J)*REC2(I-1,J)+
     1Q(I,J)/APR(I,J))/(1.0-ASR(I,J)/APR(I,J)*REC1(I-1,J))
 1130 CONTINUE
      DO 1131 II=3,NRD2
      I=NRD2+3-II
      V(I,J)=REC1(I,J)*V(I+1,J)+REC2(I,J)
 1131 CONTINUE
      DO 36 I=3,NRD2
      V(I,J)=V2(I,J)+RV*(V(I,J)-V2(I,J))
   36 CONTINUE
      CALL COEFF (J,APR,ANR,ASR,AER,AWR,BR,APT,ANT,
     1AST,AET,AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,PRTL,
     3GR,NRD2,NRD1,NAD1)
```

```
      IF (J.EQ.2) GO TO 620
      DO 1190 I=2,IFF1
      Q(I,J)=AET(I,J)*W(I,J+1)+AWT(I,J)*W(I,J-1)+BT(I,J)+CT(I)*
     1(P(I,J)-P(I,J-1))
      IF (I.EQ.2) REC1(I,J)=(ANT(I,J)/APT(I,J))/(1.0+AST(I,J)/APT(I,J))
      IF (I.EQ.2) REC2(I,J)=(Q(I,J)/APT(I,J))/(1.0+AST(I,J)/APT(I,J))
      IF (I.NE.2) REC1(I,J)=(ANT(I,J)/APT(I,J))/(1.0-AST(I,J)/APT(I,J)*
     1REC1(I-1,J))
      IF (I.NE.2) REC2(I,J)=(AST(I,J)/APT(I,J)*REC2(I-1,J)+Q(I,J)/
     1APT(I,J))/(1.0-AST(I,J)/APT(I,J)*REC1(I-1,J))
 1190 CONTINUE
      DO 1191 II=2,IFF1
      I=IFF1+2-II
      W(I,J)=REC1(I,J)*W(I+1,J)+REC2(I,J)
 1191 CONTINUE
      DO 37 I=2,NRD2
      W(I,J)=W2(I,J)+RV*(W(I,J)-W2(I,J))
   37 CONTINUE
      IF (ITERAT.GT.000) CALL COEFF (J,APR,ANR,ASR,AER,AWR,BR,APT,ANT,
     1AST,AET,AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,PRTL,
     3GR,NRD2,NRD1,NAD1)
  620 DO 1520 I=2,NRD2
      TR=T(I,J+1)
      TL=T(I,J-1)
      DO 1525 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JB(L)) TR=-T(I,J)
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) TL=-T(I,J)
 1525 CONTINUE
      Q(I,J)=AEG(I,J)*TR+AWG(I,J)*TL+BG(I,J)
      IF (I.EQ.2) REC1(I,J)=ANG(I,J)/APG(I,J)
      IF (I.EQ.2) REC2(I,J)=ASG(I,J)/APG(I,J)*T(I-1,J)+Q(I,J)/APG(I,J)
      IF (I.NE.2) REC1(I,J)=(ANG(I,J)/APG(I,J))/(1.0-ASG(I,J)/APG(I,J)*
     1REC1(I-1,J))
      IF (I.NE.2) REC2(I,J)=(ASG(I,J)/APG(I,J)*REC2(I-1,J)+Q(I,J)/
     1APG(I,J))/(1.0-ASG(I,J)/APG(I,J)*REC1(I-1,J))
 1520 CONTINUE
      T(NRD2,J)=REC2(NRD2,J)/(1.0+REC1(NRD2,J))
      DO 1512 II=2,NRD1
      I=NRD1+2-II
      T(I,J)=REC1(I,J)*T(I+1,J)+REC2(I,J)
 1512 CONTINUE
      DO 39 I=2,NRD2
      T(I,J)=T2(I,J)+RV*(T(I,J)-T2(I,J))
   39 CONTINUE
      CALL COEFF (J,APR,ANR,ASR,AER,AWR,BR,APT,ANT,
     1AST,AET,AWT,BT,APX,ANX,ASX,AEX,AWX,BX,APG,ANG,ASG,AEG,AWG,BG,DR,
     2DTH,M2,IFIN,IFIN1,JA,JB,RFCO,CT,CR,CX,ZE,U,V,W,T,R,PRTL,
     3GR,NRD2,NRD1,NAD1)
   35 CONTINUE
      IF (GR.EQ.0.0) RETURN
CC
CC      CALCULATING THE COEFFICIENTS OF THE PRESSURE CORR EQUATION.
CC
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      DO 300 I=2,NRD2
      DO 300 J=2,NAD1
      DR3=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR3=0.50*DR
      FC(I,J)=FC(I,J)+RFS*(DTH*(V(I+1,J)-V(I,J))+DR3*(W(I,J+1)
     1-W(I,J))-FC(I,J))
  300 CONTINUE
CC
CC      SOLUTION OF THE PRESSURE CORRECTION EQUATION.
CC
      DO 310 ITERPC=1,5000
      DO 1320 I=2,NRD2
      DO 1320 J=2,NAD1
      PC(I,1)=0.0
      PC(I,NAD2)=0.0
      PC(1,J)=0.0
      PC(NRD3,J)=0.0
      PCR=PC(I,J+1)
      PCL=PC(I,J-1)
      DO 1325 L=1,M2
      IF (I.GE.IFIN.AND.J.EQ.JB(L)) PCR=0.0
      IF (I.GE.IFIN.AND.J.EQ.JA(L)) PCL=0.0
 1325 CONTINUE
      Q(I,J)=D(I,J)*PCR+E(I,J)*PCL+FC(I,J)
      IF (I.EQ.2) REC1(I,J)=B(I,J)/A(I,J)
      IF (I.EQ.2) REC2(I,J)=Q(I,J)/A(I,J)
      IF (I.NE.2) REC1(I,J)=(B(I,J)/A(I,J))/(1.0-C(I,J)/A(I,J)*
     1REC1(I-1,J))
      IF (I.NE.2) REC2(I,J)=(C(I,J)/A(I,J)*REC2(I-1,J)+Q(I,J)/A(I,J))/
     1(1.0-C(I,J)/A(I,J)*REC1(I-1,J))
 1320 CONTINUE
      DO 1321 J=2,NAD1
      DO 1321 II=2,NRD2
      I=NRD2+2-II
      PC(I,J)=REC1(I,J)*PC(I+1,J)+REC2(I,J)
 1321 CONTINUE
      DO 321 I=2,IFF1
      DO 321 J=2,NAD1
      Q(I,J)=B(I,J)*PC(I+1,J)+C(I,J)*PC(I-1,J)+FC(I,J)
      IF (J.EQ.2) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/A(I,J))
      IF (J.EQ.2) REC2(I,J)=Q(I,J)/A(I,J)/(1.0-E(I,J)/A(I,J))
      IF (J.NE.2) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/A(I,J)*
     1REC1(I,J-1))
      IF (J.NE.2) REC2(I,J)=(E(I,J)/A(I,J)*REC2(I,J-1)+Q(I,J)/
     1A(I,J))/(1.0-E(I,J)/A(I,J)*REC1(I,J-1))
  321 CONTINUE
      IF (H.EQ.0.0) GO TO 326
      DO 322 I=IFIN,NRD2
      DO 322 L=1,M2
      JAC=JA(L)
      JBC=JB(L)
      DO 322 J=JAC,JBC
      Q(I,J)=B(I,J)*PC(I+1,J)+C(I,J)*PC(I-1,J)+FC(I,J)
      IF (J.EQ.JA(L)) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/
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     1A(I,J))
      IF (J.EQ.JA(L)) REC2(I,J)=Q(I,J)/A(I,J)/(1.0-E(I,J)/
     1A(I,J))
      IF (J.NE.JA(L)) REC1(I,J)=D(I,J)/A(I,J)/(1.0-E(I,J)/
     1A(I,J)*REC1(I,J-1))
      IF (J.NE.JA(L)) REC2(I,J)=(E(I,J)/A(I,J)*REC2(I,J-1)+
     1Q(I,J)/A(I,J))/(1.0-E(I,J)/A(I,J)*REC1(I,J-1))
  322 CONTINUE
      DO 323 II=IFIN,NRD2
      I=NRD2+IFIN-II
      DO 323 LL=1,M2
      L=M2+1-LL
      JAC=JA(L)
      JBC=JB(L)
      DO 323 JJ=JAC,JBC
      J=JB(L)+JA(L)-JJ
      PC(I,J)=REC1(I,J)*PC(I,J+1)+REC2(I,J)
  323 CONTINUE
  326 DO 324 II=2,IFF1
      I=IFF1+2-II
      DO 324 JJ=2,NAD1
      J=NAD1+2-JJ
      PC(I,J)=REC1(I,J)*PC(I,J+1)+REC2(I,J)
  324 CONTINUE
  310 CONTINUE
      RETURN
      END
      SUBROUTINE FLUX (H,M,T,PI,DR,DTH,NRD,NAD,R,JA,JB,M2,IFIN)
      DIMENSION  JA(20),JB(20)
      DOUBLE PRECISION T(33,66),PI,DR,DTH,R(55),QR,QA,DR2,SUM,SUM1
      NRD1=NRD+1
      NRD2=NRD+2
      NAD1=NAD+1
      WRITE (6,15)
      SUM=0.0
      DO 10 J=2,NAD1
      QR=-2.0*(1.0+H*M/PI)*(16.0*T(NRD2,J)-T(NRD1,J))/3.0/DR
      WRITE (6,20) J,QR
      SUM=SUM+QR*DTH
   10 CONTINUE
      SUM=SUM/(PI+H*M)
   20 FORMAT (10X,I4,10X,D13.5)
   15 FORMAT ('1',4X,'ANGULAR LOCATION',6X,'RAD FLUX')
      WRITE (6,5) SUM
    5 FORMAT (2(/),10X,'THE TOTAL WALL FLUX = ',D13.5)
      IF (H.EQ.0.0) RETURN
      WRITE (6,90)
      WRITE (6,100)
      SUM1=0.0
      DO 110 J=2,NAD1
      DO 120 L=1,M2
      IF (J.EQ.JA(L)) GO TO 130
      IF (J.EQ.JB(L)) GO TO 140
  120 CONTINUE
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      GO TO 110
  130 DO 150 I=IFIN,NRD2
      DR2=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR2=DR/2.0
      QA=-2.0*(1.0+H*M/PI)/(R(I)+DR2/2.0)*(9.0*T(I,J)-T(I,J+1))
     1/3.0/DTH
      IF (I.EQ.IFIN) DR2=DR2/2.0
      SUM1=SUM1+QA*DR2
      WRITE (6,60) I,J,QA
  150 CONTINUE
      GO TO 110
  140 DO 70 I=IFIN,NRD2
      DR2=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR2=DR/2.0
      QA=-2.0*(1.0+H*M/PI)/(R(I)+DR2/2.0)*(9.0*T(I,J)-T(I,J-1))
     1/3.0/DTH
      IF (I.EQ.IFIN) DR2=DR2/2.0
      SUM1=SUM1+QA*DR2
      WRITE (6,60) I,J,QA
   70 CONTINUE
  110 CONTINUE
      SUM1=SUM1/(PI+H*M)
   90 FORMAT (5(/),25X,'FINS FLUX')
  100 FORMAT (4X,'RADIAL LOCATION',4X,'ANGULAR LOCATION',4X,
     1'ANGULAR FLUX')
   60 FORMAT (10X,I4,14X,I4,10X,D13.5)
      WRITE (6,80) SUM1
   80 FORMAT (5(/),10X,'THE TOTAL FINS FLUX = ',D13.5)
      RETURN
      END
      SUBROUTINE SECFLO (V,W,PI,NAD,NRD,R,DTH,DR)
      DOUBLE PRECISION V(33,66),W(33,66),PI,R(55),RADCOM,ANGCOM,
     1SECF(33,66),DIR,DR,DR2,DTH,DIRECT(33,66)
      NAD1=NAD+1
      NRD1=NRD+1
      NRD2=NRD+2
      WRITE (6,15)
      DO 10 I=2,NRD2
      DR2=DR
      IF (I.EQ.2.OR.I.EQ.NRD2) DR2=DR/2.0
      DO 10 J=2,NAD1
      RADCOM=(V(I,J)+V(I+1,J))/2.0/R(I)
      ANGCOM=(W(I,J)+W(I,J+1))/2.0
      SECF(I,J)=DSQRT(RADCOM**2+ANGCOM**2)
      DIR=RADCOM/ANGCOM
      DIR=DATAN(DIR)*180.0/PI
      DIRECT(I,J)=DIR
      IF (RADCOM.GT.0.0.AND.ANGCOM.LT.0.0) DIRECT(I,J)=DABS(DIR)+90.0
      IF (RADCOM.LT.0.0.AND.ANGCOM.LT.0.0) DIRECT(I,J)=DABS(DIR)+180.0
      IF (RADCOM.LT.0.0.AND.ANGCOM.GT.0.0) DIRECT(I,J)=DABS(DIR)+270.0
   10 CONTINUE
      DO 30 I=2,NRD2
      WRITE (6,20) (SECF(I,J),J=2,NAD1)
   30 CONTINUE
```

```
      WRITE (6,16)
      DO 40 I=2,NRD2
      WRITE (6,20) (DIRECT(I,J),J=2,NAD1)
   40 CONTINUE
   16 FORMAT ('1',7X,'THE DIRECTION IN DEGREES')
   20 FORMAT (/,10(1X,D12.5))
   15 FORMAT ('1',7X,'DISTRIBUTION OF RESULTANT OF SEC. FLOW')
      RETURN
      END
```