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THE IMPACTION OF SPHERICAL PARTICLES ON CIRCULAR CYLINDERS

by

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ABSTRACT

Inertial and interceptive impaction of spherical particles on circular cylinders was investigated theoretically. The particles were considered to be suspended in a fluid moving steadily through a random array of parallel cylinders.

Fluid flowfields around the cylinders were obtained by numerically solving the Navier-Stokes Equation subject to Kuwabara's zero vorticity boundary condition. These solutions were subsequently utilized in calculating particle trajectories and impaction efficiencies. The latter are presented as functions of Reynolds number ($0.2 \leq Re_c \leq 40$), particle inertial parameter ($0 \leq P \leq 1000$), particle to cylinder size ratio ($0.001 \leq K \leq 1.$) and cylinder concentration ($10^{-4} \leq c \leq 0.111$).

The impaction efficiencies and critical inertial parameters differ significantly from earlier theoretical predictions. The discrepancies are primarily attributable to the inaccurate flowfield representations used by previous authors. The agreement between Subramanyam and Kuloor's experimental work and present theory is satisfactory.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

Figure		Page

Figure		Page

Figure		Page

Figure		Page

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Chapter 1

INTRODUCTION

The removal of particulate matter from liquids and gases has been an important operation since the inception of Chemical Engineering. Although the subject of particle separation has in the past received intensive study, present concern about air and water pollution is stimulating further research. Special efforts are being made to improve or develop techniques suitable for the removal of very fine particles.

Several methods are available for removing very small (i.e. micron-size) particles, the principle ones being electrostatic precipitation, scrubbing, centrifugal cleaning and filtration. Since the former three techniques are costly and electrostatic precipitation and scrubbing are only suitable for gases, filtration is frequently the preferred method. There are basically two different ways in which filters separate particles and they may therefore be classified as surface or deep bed filters.

Surface filters achieve particle separation by a straining or sieving action because the pores of the filter cake are smaller than the particles. The particles are retained at the surface of the cake and the cake thickness increases as the filtration proceeds. Since micron size particles form very compact cakes with concomitant high pressure drops, surface filters are only suitable for coarser particles (generally having diameters in excess of 10μ) or under circumstances where high pressure drops are inconsequential.

Deep bed filters, on the other hand, are loosely packed assemblages of granules or cylindrical fibres. Their solids fraction is generally less than 0.1 and the pressure drops are therefore significantly lower than those of surface filters. The main disadvantages of deep bed filters arise from the fact that they separate and retain the particles inside the filter medium which makes regeneration difficult. Consequently they are mainly used for cleaning dilute suspensions and the filters are discarded once they have become loaded.

Very little sieving occurs in deep bed filters and particles are removed mainly by inertial impaction and interception. Other separation mechanisms such as electrostatic, gravitational and Brownian motion effects are frequently less important.

In the present study the latter effects were omitted and the work was restricted to deep bed filters composed of randomly spaced, parallel cylinders lying at right angles to the main direction of flow. In order to gain a better understanding of the inertial and interceptive mechanisms in such a filter it is instructive to consider a very dilute bed. Under these conditions the mechanisms can be described in reference to a single cylinder situated in a very large amount of moving fluid. After providing a brief account of the fluid flowfield, inertial impaction and interception are discussed separately. Finally it will be shown that in reality the effects always occur together and should therefore be considered jointly.

The Fluid Flowfield

A typical, steady state flowfield around a stationary cylinder is shown in Figure 1-1. The velocity of the fluid far away from the cylinder is rectilinear and of magnitude U_0. In the vicinity of the cylinder the stream lines are curved and closely spaced. A wake may also be present.

It may be pointed out that the flow in deep bed filters is generally steady and laminar. The following arguments apply however equally well to turbulent flows

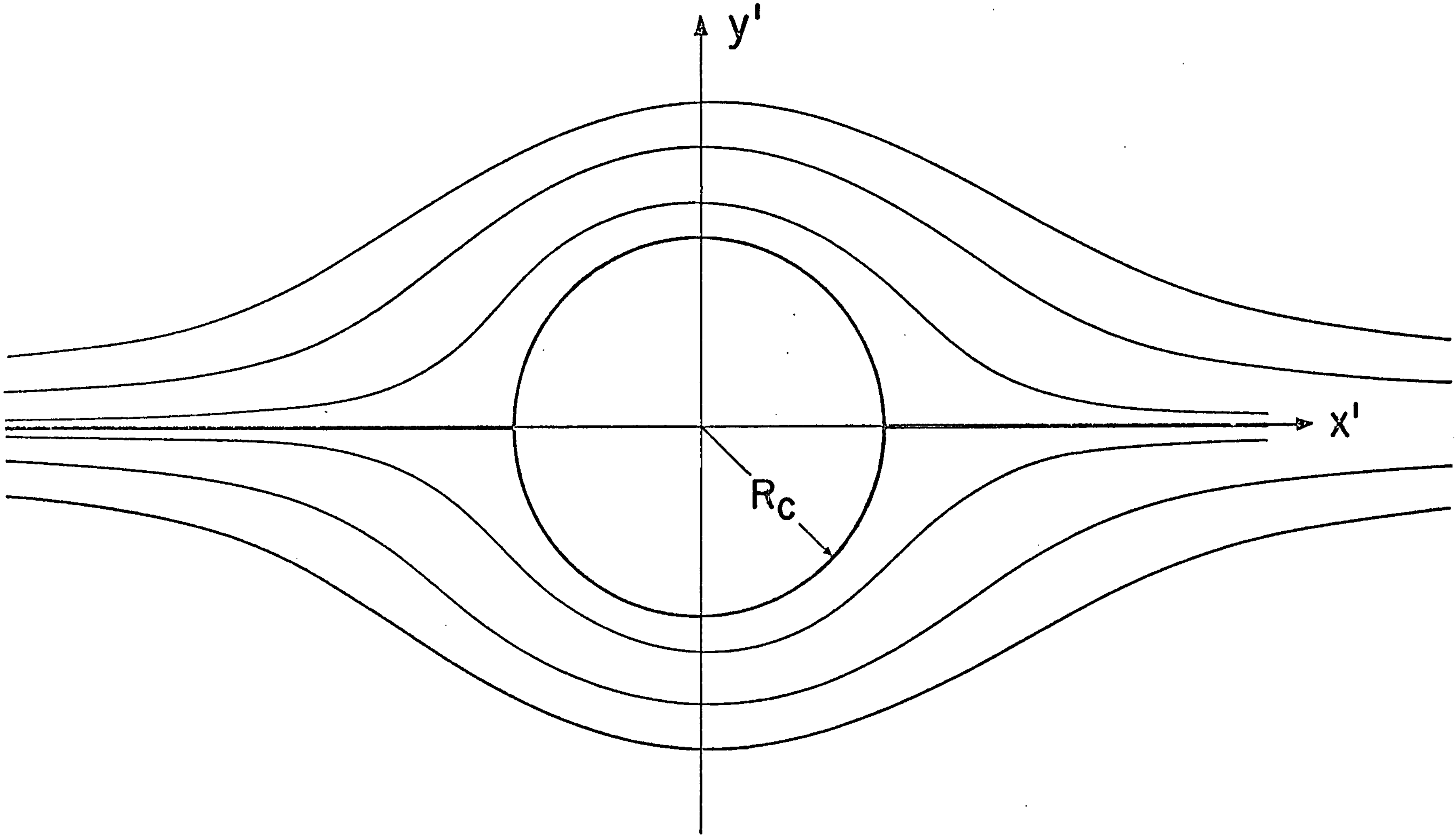

Figure 1-1. Typical flowfield around a circular cylinder.

provided the particle motion is not affected by the microstructure of the turbulence.

The Inertial Impaction Mechanism

The mechanism of inertial impaction will be illustrated by considering three identical spherical particles having radius, R_p, and density, ρ_p. The ratio of particle to cylinder radius, i.e.

$$K = \frac{R_p}{R_c} \tag{1-1}$$

is taken to be very small so that the particles may be regarded as points. The particle density is stipulated to exceed the fluid density, i.e. $\rho_p > \rho$.

When the three particles are started far upstream of the cylinder with velocity U_0 at $x_p' = -R_\infty'$ and at three different heights, y_p', above the centre line, they travel along different trajectories as shown in Figure 1-2. Since the inertia of the particles are higher than those of equivalent volumes of fluid, their trajectories deviate from the streamlines and approach the front of the cylinder. In the case of particle 1 the deviation is sufficient for the trajectory to intersect the cylinder surface.

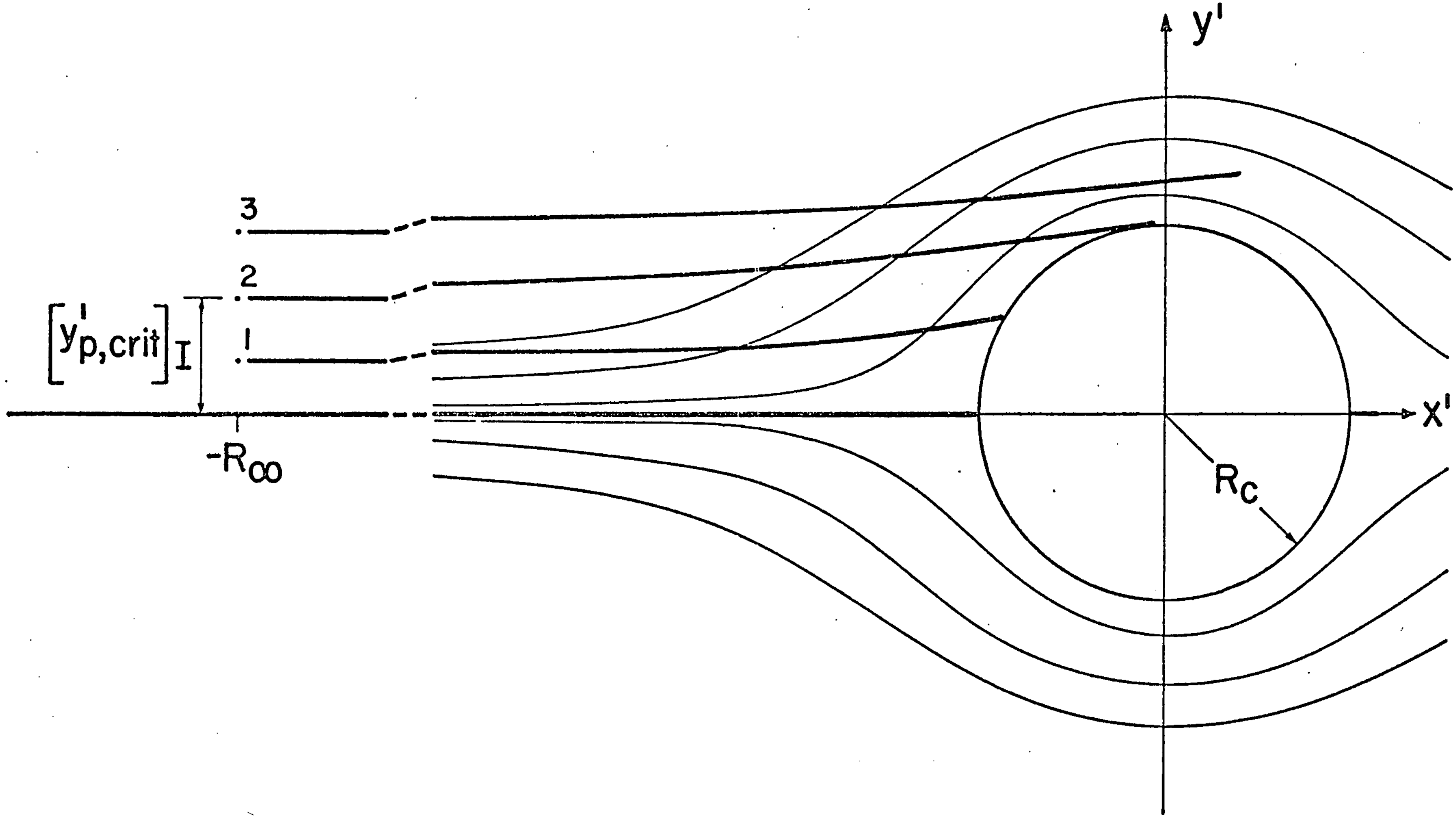

Figure 1-2. Trajectories of three very small particles ($\rho_p > \rho$).

Hence when the *centre* of a particle coincides with the cylinder surface as the result of the aforementioned cause, *inertial impaction* is said to occur. Since in reality the particle centre cannot touch the cylinder surface, this is clearly an idealized situation. However, for small radius ratios, K, the idealization does not lead to significant errors.

As may be seen from Figure 1-2 particle 3 misses the cylinder whereas the trajectory of the centre of particle 2 just grazes the surface. The latter is called the critical trajectory since particles starting at $x'_p = -R'_\infty$ with $y'_p < \left[y'_{p,crit}\right]_I$ collide with the cylinder whereas particles starting with $y'_p > \left[y'_{p,crit}\right]_I$ miss. It is therefore possible to define a dimensionless *inertial impaction coefficient*, ε_I, as follows:

$$\varepsilon_I = \frac{\left[y'_{p,crit}\right]_I}{R_c} \tag{1-2}$$

It may be noted that ε_I increases with particle inertia and ranges from 0 to 1. The upper limit is attained by particles with infinite inertia whose trajectories are therefore straight lines.

The Interceptive Mechanism

As in the previous section three identical spherical particles are considered to approach the cylinder with velocity U_0. However, in the present case the particle density equals the fluid density and the radius ratio K is significantly greater than zero.

If it is assumed that the particles do not appreciably disturb the fluid flowfield, the trajectories of their centres coincide with the stream lines. Hence, when a particle of radius R_p travels along a streamline, which approaches the cylinder within a distance R_p, it is intercepted by the cylinder. The collision is solely due to the size of the particle and is called the *interceptive* mechanism.

As seen from Figure 1-3 there is a critical starting position, $\left[y'_{p,crit}\right]_K$, which results in the particle surface just grazing the cylinder surface. A dimensionless *interception coefficient*, ε_K, may therefore be defined analogous to Equation (1-2):

$$\varepsilon_K = \frac{\left[y'_{p,crit}\right]_K}{R_c} \qquad (1\text{-}3)$$

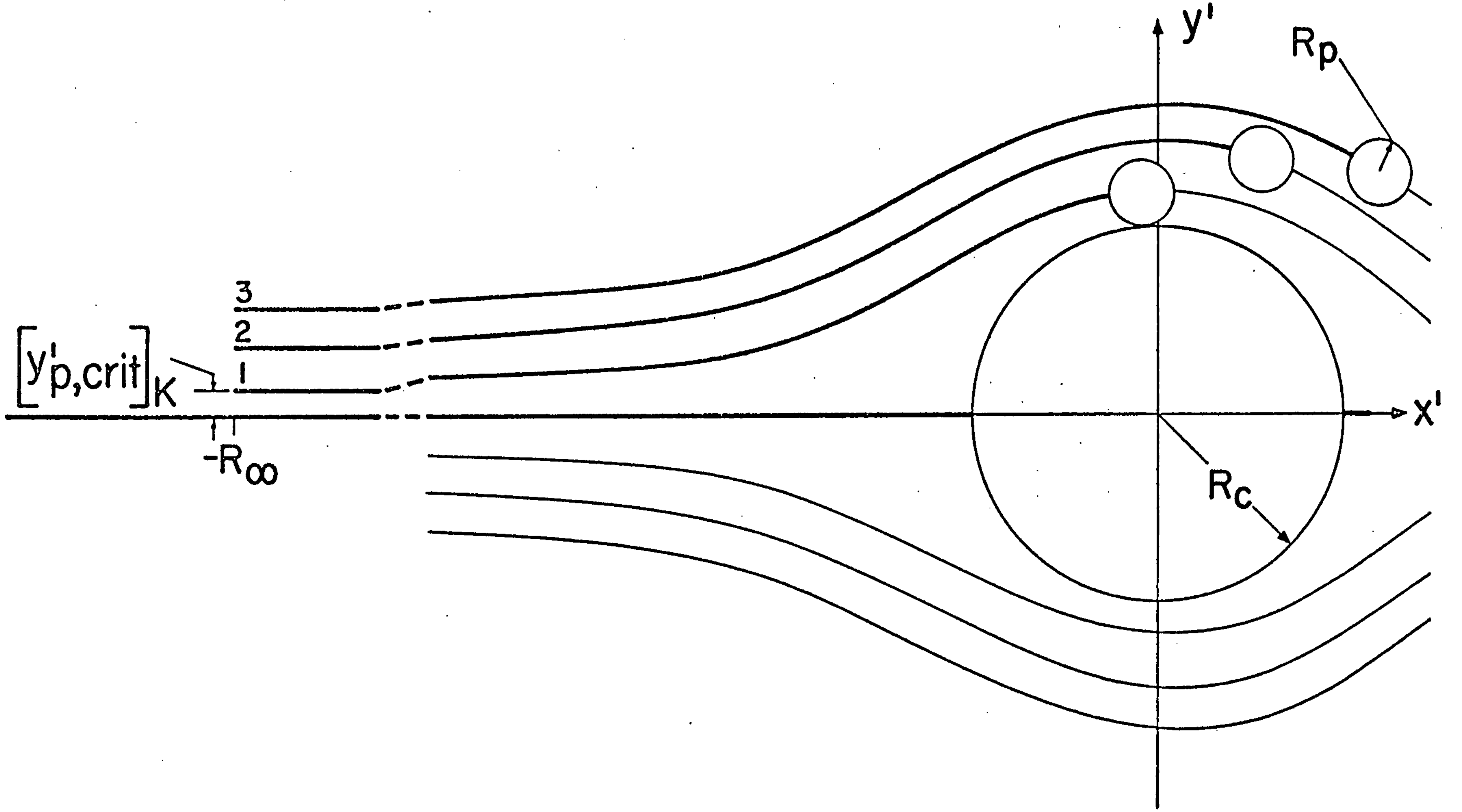

Figure 1-3. Trajectories of three particles having finite size ($\rho_p = \rho$).

This coefficient may however exceed unity for large particles, i.e. $K >> 0$, and it is therefore convenient to normalize it by introducing the *impaction efficiency*, E_K, where

$$E_K = \frac{\varepsilon_K}{1+K} \tag{1-4}$$

The impaction efficiency therefore ranges from 0 to 1.

Combined Inertial and Interceptive Mechanisms

In most practical situations $\rho_p > \rho$ and $K > 0$ so that both the inertial and interceptive mechanisms are operative. It is possible to define an overall impaction coefficient and efficiency:

$$\varepsilon = \frac{y'_{p,crit}}{R_c} \tag{1-5}$$

$$E = \frac{\varepsilon}{1 + K} \tag{1-6}$$

The critical trajectory starting at $x'_p = - R'_\infty$ and $y'_p = y'_{p,crit}$ is determined by selecting the trajectory which causes the particle surface to just touch the cylinder surface. In principle this trajectory can be determined by a trial and error procedure.

The above discussion has dealt solely with the mechanisms of particle transport to the surface of the cylinder. No mention has been made of the interaction which occurs between the particle and the cylinder at the instance of impaction.

The impaction efficiency indicates how many of the particles approaching a cylinder will actually hit under given flow conditions. Since particles colliding with a cylinder do not necessarily adhere, the actual *collection* efficiency of the fibres is less than or equal to the *impaction* efficiency.

In practice it is known that micron-size particles are permanently retained in fibre filters by virtue of van der Waals forces, surface tension and electrostatic effects. In the case where all particles contacting the cylinder are thus retained without rebound from the surface, the collection efficiency is numerically equal to the impaction efficiency.

Scope of the Present Work

The primary objective of this thesis was to calculate impaction efficiencies for spherical particles impinging on circular cylinders. The following mechanisms and range of variables were considered:

- inertial and interceptive effects
- Reynolds number based on cylinder diameter, $0.2 \leq Re_c \leq 40$
- particle inertial parameter, $0 \leq P \leq 1000$
- ratio of particle radius to cylinder radius, $0.001 \leq K \leq 1.0$
- concentration of cylinders ranging from 10^{-4} to 0.111

The fluid flowfields around the cylinder were obtained by solving the Navier-Stokes Equation numerically with a relaxation technique. Various criteria for monitoring the convergence of the solution were developed.

Chapter 2

LITERATURE REVIEW

This section is primarily restricted to a review of the literature on particle and fluid motion around cylinders in the viscous flow régime. However, a brief account of the key papers describing particle collisions with cylinders in the potential flow régime is also provided. The latter were used to verify the computer programmes calculating the particle trajectories (Appendix V).

Fuchs [1], Dorman [2], Pich [3] and Löffler [4] have written general reviews on particle deposition on cylinders and other objects.

Particle-Cylinder Collision in Viscous Flow

Landahl and Herrmann [5] were the first who theoretically calculated the impaction coefficient due to inertial and interceptive mechanisms in the viscous flow régime. Their work was restricted to a circular cylinder with $Re_c = 10$, and Thom's [6] approximate flowfield was used. The particles were assumed to obey Stokes' Law, and their motion was calculated by an iterative procedure involving piecewise linearization of the flowfield and trajectories. The particle inertial parameter was varied from $0 \leq P \leq 3$, and their predictions have been summarized [3] by the following equation:

$$\varepsilon = \frac{P^3}{P^3 + 1.54P^2 + 1.76} + K \qquad (2\text{-}1)$$

Equation (2-1) indicates that ε is an increasing function of P and K. However, since it is based on Thom's data it is somewhat inaccurate. Furthermore, the expression implies that the inertial and interceptive contributions to the impaction coefficient are additive. This is not strictly correct because the fluid streamlines are not equispaced at $Re_c = 10$.

Davies and Peetz [7] also used Thom's results at $Re_c = 10$. By means of interpolation and extrapolation polynomials they were able to obtain a finer grid, and to extend the flowfield to 5 radii from the centre of the cylinder. The authors initiated their particle trajectories on the outer boundary of their flowfield.

Stokes' Law was used to calculate the drag on the particles and numerical integration with variable step size was employed to calculate the trajectories (see Davies and Aylward [8] for a description of this technique).

Both inertial and interceptive effects were studied, plots being given for ε vs P in the ranges $0 \leq P \leq 30$, $0 \leq K \leq 1$. Contrary to Landahl and Herrmann, Davies and Peetz found that the interceptive and inertial mechanisms of impaction were not strictly additive.

Davies and Peetz also determined a so-called "critical inertial parameter," P_c of 0.417. P_c is defined such that an infinitely small particle ($K \rightarrow 0$) having inertial parameter $P < P_c$ would fail to collide with the cylinder.

These authors also studied particle collection at a Reynold's number of $Re_c = 0.2$, by utilizing a Bessel function representation of the flowfield [9]. The following equations were used:

$$
\left.\begin{aligned}
v_x &= 1 + \left\{ -\frac{1}{2r^2} + \frac{x}{r^2}\left[K_1\left(\frac{Re_c}{4}\right) - \frac{Re_c}{16}K_0\left(\frac{Re_c}{4}\right)\left(1 - \frac{5}{r^4}\right) + \frac{Re_c}{64}\left(1 - \frac{6}{r^2} + \frac{5}{r^4}\right)\right] \right. \\
&\quad + \frac{x^2}{r^4} + \frac{x^3}{r^6}\cdot\frac{Re_c}{8} - \exp\left(\frac{Re_c \cdot x}{4}\right)\cdot\left[K_0\left(\frac{Re_c \cdot r}{4}\right) \right. \\
&\quad \left.\left. + \frac{x}{r}K_1\left(\frac{Re_c \cdot r}{4}\right)\right]\right\} \Big/ \left[K_0\left(\frac{Re_c}{4}\right) + 0.5\right] \\
v_y &= \left\{ \frac{y}{r^2}\left[K_1\left(\frac{Re_c}{4}\right) - \frac{Re_c}{16}K_0\left(\frac{Re_c}{4}\right)\left(1 - \frac{1}{r^4}\right) \right.\right. \\
&\quad \left. + \frac{Re_c}{64}\left(1 - \frac{2}{r^2} + \frac{1}{r^4}\right)\right] + \frac{xy}{r^4} + \frac{x^2y}{r^6}\cdot\frac{Re_c}{8} \\
&\quad \left. - \exp\left(\frac{Re_c \cdot x}{4}\right)\frac{y}{r}K_1\left(\frac{Re_c \cdot r}{4}\right)\right\} \Big/ \left[K_0\left(\frac{Re_c}{4}\right) + 0.5\right]
\end{aligned}\right\} \quad (2\text{-}2)
$$

where K_0 and K_1 are modified Bessel functions of the second kind.

The particle trajectories were calculated as before at $Re_c = 10$, except that the starting position was 200 cylinder radii upstream from the cylinder centre.

The results were presented in graphical form by plotting ε versus P with K as a parameter. The ranges investigated were $0 \leq P \leq 80$, and $0 \leq K \leq 1$, and P_c in this instance was estimated to be 0.899.

Davies and Peetz' results are the most accurate to date in the viscous régime because they are based on good approximations of the fluid flowfields. The Bessel function expression at $Re_c = 0.2$ satisfies the Navier-Stokes Equation and the boundary condition far away from the cylinder. However, as is shown later (Chapter 4), it does not predict zero fluid velocities at the cylinder surface. This feature produces significant errors in the calculated efficiencies of small particles which closely approach the cylinder surface.

Wong, Ranz and Johnstone [10] used the equation given by Lamb [11] for viscous flow around a cylinder:

$$\left.\begin{aligned} v_x &= \gamma\left[\ln\left(x^2+ y^2\right)^{\frac{1}{2}} + \left(x^2+y^2-1\right)\left(y^2-x^2\right)/2\left(x^2+y^2\right)\right] \\ v_y &= \gamma\left(x^2+y^2-1\right) xy/\left(x^2+y^2\right)^2 \\ \gamma &= \frac{1}{2.002 - \ln Re_c} \end{aligned}\right\} \quad (2\text{-}3)$$

Assuming Stokes' Law for the particles they calculated the following theoretical expression for ε_K, i.e., the impaction coefficient due to interception alone:

$$\varepsilon_K = \gamma\left[(1+K) \ln (1+K) - K(2+K)/2(1+K)\right] \quad (2\text{-}4)$$

The authors present curves for Equation (2-4) at Re_c = 0.01, 0.1, 1.0 , the highest values of Re_c extending past the limit of applicability of Equation (2-3). Furthermore, Equation (2-3) is valid only close to the cylinder and does not satisfy the boundary conditions at infinity.

Subramanyam and Kuloor [12] used Davies and Peetz' extension of Thom's calculations at $Re_c = 10$. They calculated particle trajectories starting at 5 radii upstream, for $0 \leq P \leq 10$, and $K = 0$. Neither the method of calculating the particle trajectories nor the drag law for the particles were clearly stated. However, their drag coefficient would appear to be very close to that given by Stokes' Law.

Householder and Goldschmidt [13] used Davies' [9] analytical approximation to the flowfield at $Re_c = 0.2$. They assumed Stokes' drag law for the particles and used a second-order Runge-Kutta integration technique to determine particle trajectories. The starting position was 400 radii upstream. Impaction efficiency, E, was plotted as a function of P and K for the ranges $1 \leq P \leq 10^4$ and $0 \leq K \leq 7$. The authors also calculated values of E at $Re_c \approx 1000$ for similar ranges of P and K. Using a least-squares technique they fitted the following equation to their theoretical predictions:

$$E = 0.5 \left\{ 1 + \tanh \left[C_1 + C_2 \ln(1+P) + C_3 K + C_4 \ln(1+Re_c) + C_5 \ln(1+P)K + C_6 \ln(1+P) \ln(1+Re_c) + C_7 K \ln(1+Re_c) + C_8 \left(\ln(1+P) \right)^2 + C_9 K^2 + C_{10} \left(\ln(1+Re_c) \right)^2 \right] \right\} \tag{2-5}$$

where

$C_1 = -0.9965$	$C_6 = 0.0010$
$C_2 = 0.1921$	$C_7 = 0.0197$
$C_3 = 0.1426$	$C_8 = 0.0464$
$C_4 = 0.0066$	$C_9 = -0.0036$
$C_5 = -0.0251$	$C_{10} = 0.0287$

The above expression is intended to predict the impaction efficiency, E, by incorporating the effects of flowfield, particle inertial parameter, P, and particle size parameter, K. No mention is made of a critical inertial parameter P_c .

Equation (2-5) cannot be regarded as well-founded because it is based on results obtained at just two Reynolds numbers. Furthermore, the trajectory calculations assumed that the particles do not influence the fluid flowfield. This condition is clearly violated for diameter ratios, K, greater than unity.

Experimental work on particle collection by cylinders has been mainly concerned with potential flow situations [5,10,12-17] ($Re_c \geq 1000$). Although data are available [5,10,12,16,17] at lower values of Re_c, the variable flowrates make analysis difficult. In addition, the particles used were generally so small or so polydisperse as to make it impossible to determine the interceptive contributions to impaction efficiency.

Subramanyam and Kuloor performed impaction efficiency experiments in the ranges: $4 \leq Re_c \leq 240$, $0 \leq K \leq 0.10$ and $1 \leq P \leq 60$. Their results gave at least a quantitative indication of the effects of particle size on impaction efficiency.

<u>Particle-Cylinder Collision in Potential Flow</u>

Langmuir and Blodgett [18] presented the first comprehensive study of particle deposition on cylinders in the potential flow régime. The work was entirely theoretical and utilized Lamb's [11] equations to define the flowfield:

$$\left.\begin{aligned} v_x &= 1 + \frac{y^2 - x^2}{(x^2 + y^2)^2} \\ v_y &= \frac{-\,2xy}{(x^2 + y^2)^2} \end{aligned}\right\} \qquad (2\text{-}6)$$

The particle trajectories were initiated four cylinder diameters upstream of the cylinder and the calculations performed on a differential analyzer (analog computer). The drag experienced by the particles was expressed either by Stokes Law at low Reynolds numbers, or by an empirical equation at high values of Re_p.

Langmuir and Blodgett considered particle deposition due to inertial effects only, and presented graphs of the impaction coefficient, ε, as a function of P, with ϕ as a parameter. ϕ was defined as:

$$\phi = \frac{Re_c^{\,2} \cdot K^2}{P} = \frac{18\rho^2\, U_0\, R_c}{\mu\, \rho_p} \qquad (2\text{-}7)$$

The authors investigated the ranges $0 \leq \phi \leq 10^6$ and $0.1 \leq P \leq 100$. Using strictly theoretical arguments based on Equation (2-6) they determined a value of 0.125 for the critical inertial parameter P_c.

Davies and Peetz [7] also reported theoretical results on particle collisions with cylinders in the potential flow régime. Their work was basically similar to that of Langmuir and Blodgett, except that they also considered the interception effect. The trajectories were started 5 radii upstream of the cylinder, and the particles were assumed to obey Stokes' Law at all times. Impaction coefficients, ε, were reported for the ranges $0 \leq K \leq 1$, and $0 \leq P \leq 40$. By using a method similar to Langumuir and Blodgett's, they also calculated the critical inertial parameter, P_c, to be 0.125.

Further theoretical and experimental results in the potential flow régime may be found in references [18] to [24].

Numerical Solution of Navier-Stokes Equation

Thom [6] was one of the first to use a finite difference iterative method to solve the steady state

Navier-Stokes Equation for flow around cylinders. He calculated flowfields at $Re_c = 10$ and 20 and achieved good agreement with his experimental results.

Tomotoika and Aoi [25] obtained an exact solution to Oseen's linearized form of the Navier-Stokes Equation for Re_c up to 10. However, they erroneously predicted wake formation at $Re_c = 0.05$, and Yamada [26] (quoted by Underwood [27]) indicated serious numerical errors in their work. Proudman and Pearson [28] used matched asymptotic expansions, but the results were only valid up to $Re_c \approx 5$.

Happel [29] presented a solution to the creeping flow equation for cylinders, using the boundary condition that the fluid shear stress becomes zero at large but finite distances from the cylinder.

Kawaguti [30] solved the steady state Navier-Stokes Equation in finite difference form for a circular cylinder at $Re_c = 40$. The results of his laborious calculations agree reasonably well with experimental data [31]. The work of Allen and Southwell [32] and Dennis and Shimshoni [33] is generally regarded as imprecise [34], since they predict, for example, a decrease in wake size with increasing Reynolds number at $Re_c = 40$.

Jenson [35] used a Gauss-Seidel relaxation technique to solve the finite difference form of the Navier-Stokes Equation for spheres, under non-turbulent flow conditions. In establishing the boundary conditions for numerical solution he used Kuwabara's [36] model, which stipulates that the fluid vorticity tends to zero at large distances from the sphere. This technique of relaxation may also be applied to the solution of the Navier-Stokes Equation for circular cylinders, using either Happel's or Kuwabara's model for the numerical boundary condition far from the cylinder.

Jenson suggested criteria to ensure the convergence of the numerical solution, but these were found to lead to excessive computation times [37]. He also introduced the transformation $r = e^z$, for determining appropriate radial spacing of the numerical solution points. Hamielec *et al.* [37] discussed several of the problems associated with numerical solution of the Navier-Stokes equation for spheres. Their discussion included angular and radial spacing of grid points, as well as the effect of the size of the outer boundary.

Subsequently, Kawaguti and Jain [38] and Son and Hanratty [34] solved the unsteady state form of the Navier-Stokes equation for cylinders and extrapolated their values to infinite times. Kawaguti and Jain found that their results approached the steady state solutions of Kawaguti [30] and Thom [6]. However, the unsteady state solution predicted wakes larger than expected

Takami and Keller [39], Hamielec and Raal [40] and Dennis and Chang [41] numerically solved the steady-state Navier-Stokes Equation for cylinders, and their tabulated results afford easy comparison. Hamielec and Raal used a modified relaxation technique to study the range $1 \leq Re_c \leq 500$, and obtained reasonable agreement with previous experimental and theoretical results. They used two relaxation factors, one for stream function and one for vorticity.

Pruppacher *et al.* [42] compiled a useful summary of the best theoretical and experimental data on circular cylinders. Masliyah [43] and Masliyah and Epstein [44] solved the steady state Navier-Stokes Equation for flow around spheroids and elliptical cylinders. They introduced an additional relaxation factor for the vorticity at the surface of the solid object. The authors provide a detailed discussion of the problems involved in selecting grid spacing and outer boundary radius. Their results for elliptical cylinders with aspect ratios of 0.995 compared well with recent theoretical results for circular cylinders [39-41].

Chapter 3

THEORY

Navier-Stokes Equation for Flow Around a Cylinder

The flow of an incompressible Newtonian Fluid around a cylinder is described by the Navier-Stokes and Continuity Equations, subject to appropriate boundary conditions. When the flow is steady the equations may be written in dimensionless form as follows:

$$\underline{v} \cdot \underline{\nabla}\, \underline{v} = -\tfrac{1}{2}\underline{\nabla} p + \frac{2}{Re_c} \underline{\nabla}^2 \underline{v} \qquad (3\text{-}1)$$

$$\underline{\nabla} \cdot \underline{v} = 0 \qquad (3\text{-}2)$$

where

$$Re_c = \frac{2R_c \rho U_0}{\mu}$$

In this work the dimensionless quantities are based on the cylinder radius R_c, and the free stream velocity, U_0.

The pressure p is defined in terms of the dimensional pressure p', and a reference pressure p'_∞:

$$p = \frac{p' - p'_\infty}{\frac{1}{2}\rho U_0^{\,2}} \tag{3-3}$$

For two-dimensional flow around a cylinder, Equations (3-1) and (3-2) represent a system of three simultaneous partial differential equations. These equations may be combined by means of a *stream function*, ψ, and a *vorticity*, ζ, defined as:

$$\left.\begin{aligned} v_r &= -\frac{1}{r}\frac{\partial\psi}{\partial\theta} \\ v_\theta &= \frac{\partial\psi}{\partial r} \end{aligned}\right\} \tag{3-4}$$

$$\zeta = \nabla^2 \psi \tag{3-5}$$

By virtue of its definition, ψ automatically satisfies the Continuity Equation. The Navier-Stokes Equation thus becomes:

$$\frac{Re_c}{2r}\left(\frac{\partial\psi}{\partial r}\cdot\frac{\partial\zeta}{\partial\theta}-\frac{\partial\psi}{\partial\theta}\cdot\frac{\partial\zeta}{\partial r}\right)=\nabla^2\zeta \tag{3-6}$$

$$\zeta=\nabla^2\psi \tag{3-7}$$

Figure 3-1 illustrates the cylinder and surrounding fluid. Due to the dimensionless representation, the radius of the cylinder is unity.

In devising a numerical technique for solving Equations (3-6) and (3-7) it is necessary to consider the nature of the flowfield as a function of position. Close to the cylinder, ψ and ζ have large radial gradients, while farther away radial changes are more gradual. Hence it is desirable to have a fine grid close to the cylinder, and a coarser mesh at large values of r. Such a grid spacing is achieved by using the exponential transformation:

$$r=e^z \tag{3-8}$$

Substitution of Equation (3-8) into (3-6) and (3-7) yields:

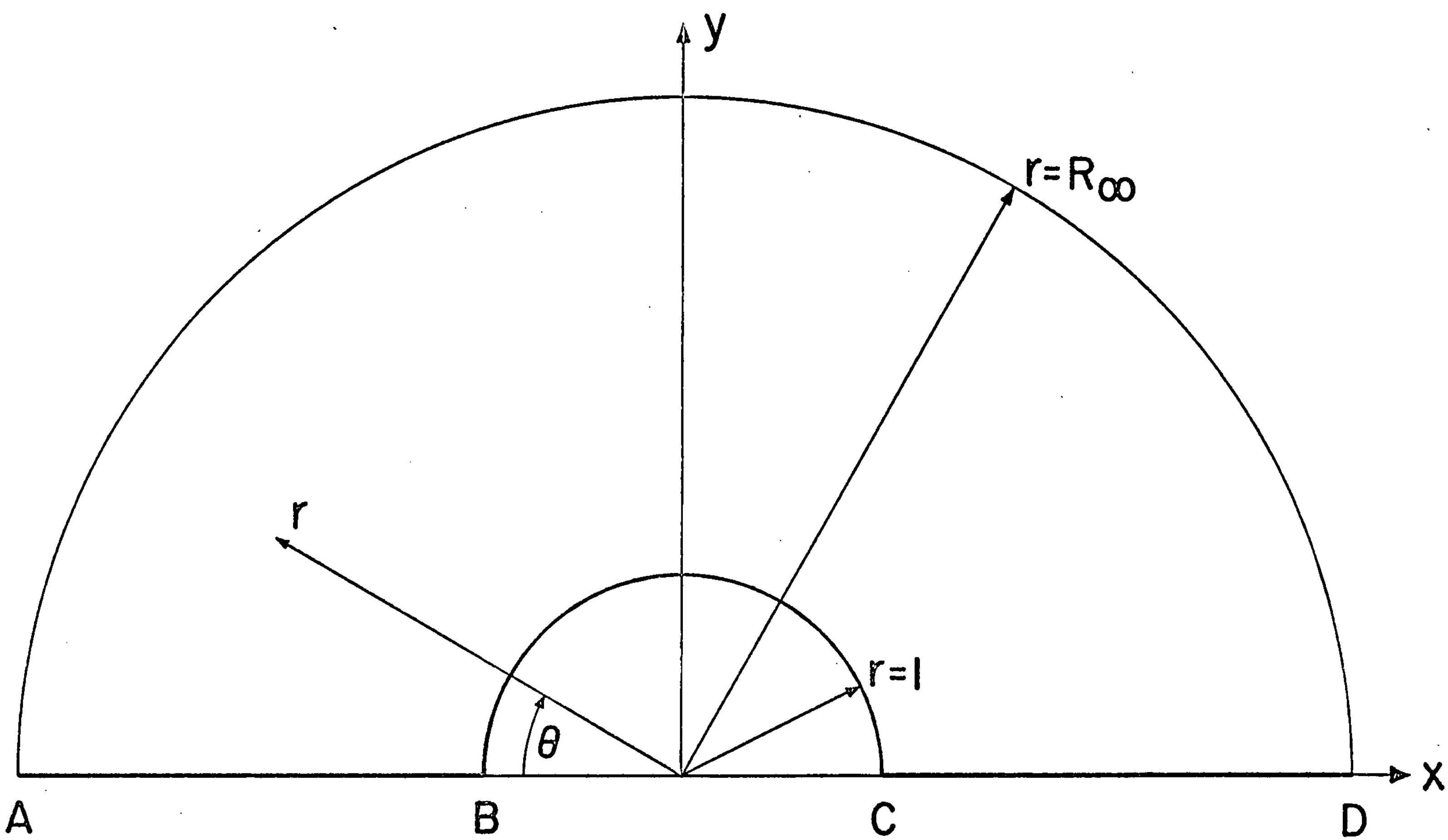

Figure 3-1. Co-ordinate system for circular cylinder and surrounding fluid.

$$\frac{Re_c}{2}\left(\frac{\partial\psi}{\partial z}\cdot\frac{\partial\zeta}{\partial\theta}-\frac{\partial\psi}{\partial\theta}\cdot\frac{\partial\zeta}{\partial z}\right)=\frac{\partial^2\zeta}{\partial z^2}+\frac{\partial^2\zeta}{\partial\theta^2} \tag{3-9}$$

$$\zeta=\frac{1}{e^{2z}}\left(\frac{\partial^2\psi}{\partial z^2}+\frac{\partial^2\psi}{\partial\theta^2}\right) \tag{3-10}$$

The above equations are second order, and four separate boundary conditions are required to define their solutions.

Boundary Conditions

The boundary conditions of the Navier-Stokes Equation may be put in two categories: those pertaining to the cylinder surface and axis of symmetry, and those which apply some distance from the cylinder surface. The first group presents no difficulties and will be discussed first. All boundary conditions are written for the case of fluid flow perpendicular to the axis of the cylinder (Figure 3-1).

On the surface of the cylinder:

$$\left.\begin{aligned}\psi &= 0\\ \zeta &= \nabla^2\psi\end{aligned}\right\}\ \text{at}\quad r=1\quad\text{or}\quad z=0 \tag{3-11}$$

Along the axis of symmetry (AD in Figure 3-1)

$$\left.\begin{array}{llll} \psi = \zeta = 0 & \text{Along AB} & , & \theta = 0 \\ \psi = \zeta = 0 & \text{Along CD} & , & \theta = \pi \end{array}\right\} \qquad (3\text{-}12)$$

Kuwabara [36] and Happel [29] have respectively proposed the *zero vorticity* and *free-surface models* which define ζ on the outer boundary. These models assume identical parallel cylinders in a randomly spaced assemblage. Each cylinder is associated with a concentric fluid "envelope" of radius R_∞, and the *solids concentration*, c, is given by:

$$c = \left(\frac{R_c}{R_\infty}\right)^2 \qquad (3\text{-}13)$$

Hence, by changing the numerical value of R_∞ in the boundary conditions it is possible to obtain flowfields around cylinders in assemblages of various concentrations. In this work, two main values of R_∞ were studied, $R_\infty = 3.0$, 100. These correspond, respectively, to solids concentration of 0.111 and 10^{-4}. It may be noted that at $R_\infty = 100$ the system is a good approximation to a cylinder in an infinitely dilute array, that is, a single cylinder in an infinite medium.

The values of ψ and ζ must be defined on the outer circular boundary. Since Kirsch and Fuchs' [45] experimental data agreed better with the predictions of Kuwabara than with those of Happel, the zero vorticity model was adopted in this work. However, for comparison purposes some computations were also made with Happel's model.

The assumption of streaming parallel flow on the outer boundary gives:

$$\psi = R_\infty \sin\theta = e^{Z_\infty} \sin\theta \qquad \text{at} \qquad r = R_\infty \text{ or } z = Z_\infty \qquad (3\text{-}14)$$

Since Kuwabara postulates zero values of vorticity on the outer boundary:

$$\zeta = 0 \qquad \text{at} \qquad r = R_\infty \text{ or } z = Z_\infty \qquad (3\text{-}15)$$

Numerical Solution of Navier-Stokes Equation

For the purpose of numerical solution, the flow-field was divided into a grid with angular spacing $\Delta\theta$ and radial spacing Δz. Figure 3-2 represents such a grid in the θ-z plane. The number of angular lines is N_a, and the number of radial lines is N_r, giving a total of $N_a \times N_r$

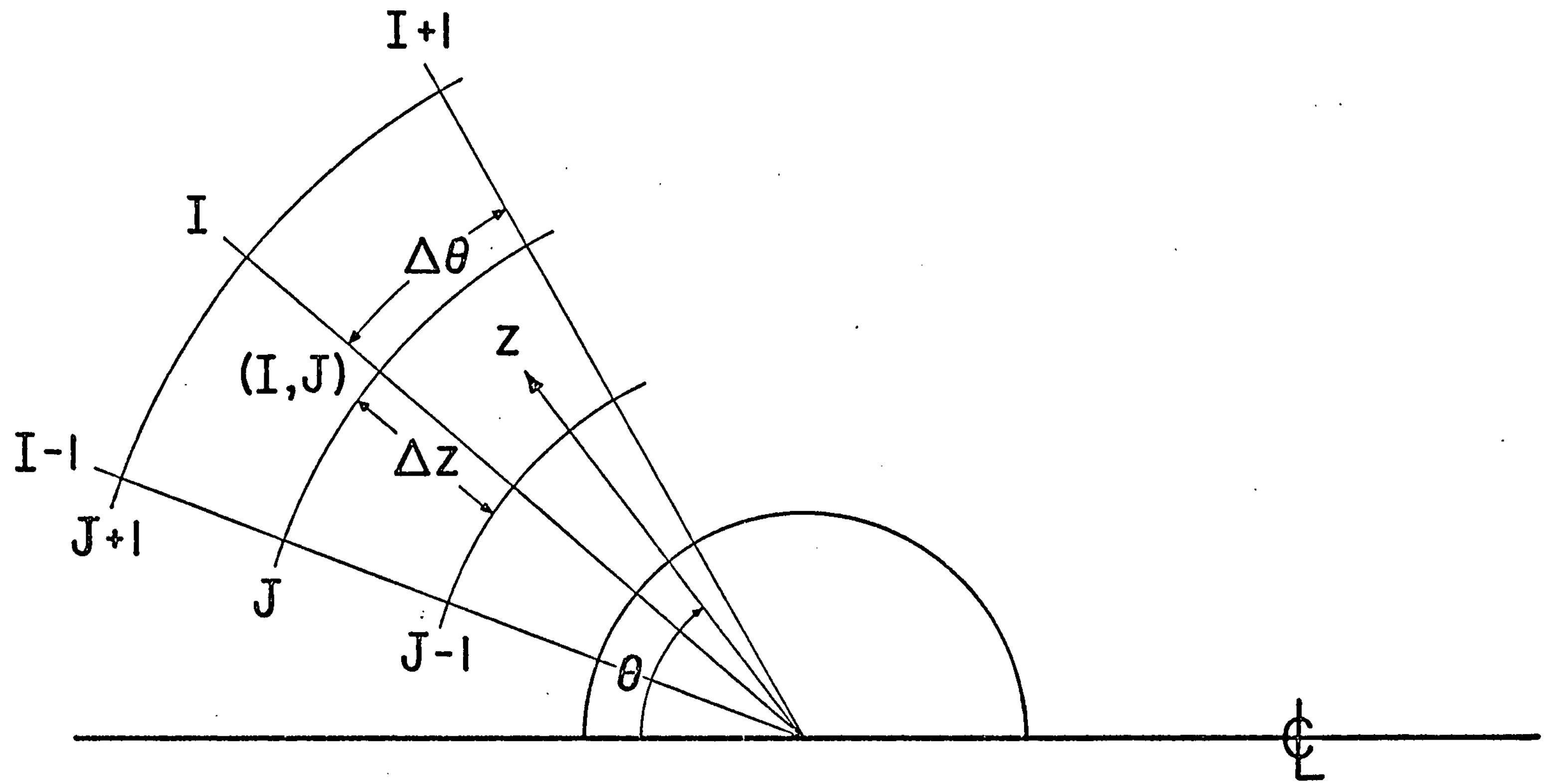

Figure 3-2. Grid system in the θ-z plane.

grid points. The increments $\Delta\theta$ and Δz are related to N_a and N_r as follows:

$$\Delta\theta = \frac{\pi}{(N_a - 1)} \tag{3-16}$$

$$\Delta z = \frac{Z_\infty}{(N_r - 1)} \tag{3-17}$$

Let the letters I and J refer to the subscripts of a general grid point (I,J). The point (I,J) therefore lies at the intersection of the I^{th} angular line and the J^{th} radial line. It follows that $1 \leq I \leq N_a$ and $1 \leq J \leq N_r$. Using this nomenclature, the θ-z co-ordinates of the point (I,J) are:

$$\theta(I) = (I-1)\,\Delta\theta \tag{3-18}$$

$$z(I) = (J-1)\,\Delta z \tag{3-19}$$

The values of the stream function and vorticity at (I,J) are similarly designated as $\psi(I,J)$ and $\zeta(I,J)$.

The partial derivatives at (I,J) can be approximated by second order central difference expressions. For example:

$$\left.\frac{\partial\psi}{\partial z}\right|_{(I,J)} \approx \frac{\psi(I,J+1) - \psi(I,J-1)}{2\Delta z} \qquad (3\text{-}20)$$

$$\left.\frac{\partial^2\psi}{\partial z^2}\right|_{(I,J)} \approx \frac{\psi(I,J+1) - 2\psi(I,J) + \psi(I,J-1)}{\Delta z^2} \qquad (3\text{-}21)$$

Jenson [35] found that fourth order approximations gave results nearly identical to those obtained with second order formulations. Hence the use of fourth order approximations is not warranted.

Finite Difference Formulation of the Navier-Stokes Equation

The Navier-Stokes Equation may be expanded in finite difference form by substitution of second order central difference expressions into Equations (3-9) and (3-10). These equations yield, on rearrangement:

$$\zeta(I,J) = \frac{\Delta\theta^2 \cdot \Delta z^2}{2(\Delta\theta^2+\Delta z^2)} \Bigg\{ \frac{1}{\Delta z^2}\Big[\zeta(I,J+1) + \zeta(I,J-1)\Big]$$

$$+ \frac{1}{\Delta\theta^2}\Big[\zeta(I+1,J) + \zeta(I-1,J)\Big] + \frac{Re_c}{8\Delta\theta\Delta z}\Bigg[\Big[\psi(I+1,J) - \psi(I-1,J)\Big] \cdot$$

$$\Big[\zeta(I,J+1) - \zeta(I,J-1)\Big] - \Big[\psi(I,J+1) - \psi(I,J-1)\Big] \cdot$$

$$\Big[\zeta(I+1,J) - \zeta(I-1,J)\Big]\Bigg]\Bigg\} \tag{3-22}$$

and

$$\psi(I,J) = \frac{\Delta\theta^2 \cdot \Delta z^2}{2(\Delta\theta^2+\Delta z^2)} \Bigg\{- e^{2z}\zeta(I,J)$$

$$+ \frac{1}{\Delta z}\Big[\psi(I,J+1) + \psi(I,J-1)\Big] + \frac{1}{\Delta\theta^2}\Big[\psi(I+1,J) + \psi(I-1,J)\Big]\Bigg\} \tag{3-23}$$

Finite Difference Formulation of Boundary Conditions

The boundary condition (of Equation (3-11)):

$$\zeta = \nabla^2 \psi \quad \text{at} \quad r = 1 \text{ or } z = 0$$

must also be written in finite difference form. Utilizing the boundary condition for ψ on the cylinder surface, namely,

$$\psi = \frac{\partial \psi}{\partial \theta} = \frac{\partial^2 \psi}{\partial \theta^2} = 0 \quad \text{at} \quad r = 1 \text{ or } z = 0 , \tag{3-24}$$

Equation (3-11) becomes:

$$\zeta \bigg|_{z=0} = \frac{\partial^2 \psi}{\partial z^2}\bigg|_{z=0} \tag{3-25}$$

The stream function near the surface may be expanded in a Taylor series:

$$\psi \bigg|_{z=\Delta z} = \psi \bigg|_{z=0} + \Delta z \frac{\partial \psi}{\partial z}\bigg|_{z=0} + \frac{\Delta z^2}{2} \frac{\partial^2 \psi}{\partial z^2}\bigg|_{z=0} + \frac{\Delta z^3}{6} \frac{\partial^3 \psi}{\partial z^3}\bigg|_{z=0} + \cdots \tag{3-26}$$

$$\psi \bigg|_{z=2\Delta z} = \psi \bigg|_{z=0} + 2\Delta z \frac{\partial \psi}{\partial z}\bigg|_{z=0} + 2\Delta z^2 \frac{\partial^2 \psi}{\partial z^2}\bigg|_{z=0} + \frac{8\Delta z^3}{6} \frac{\partial^3 \psi}{\partial z^3}\bigg|_{z=0} + \cdots \tag{3-27}$$

Since $v_r = v_\theta = 0$ on the surface:

$$\left.\frac{\partial\psi}{\partial z}\right|_{z=0} = 0 \tag{3-28}$$

Neglecting terms of order greater than 3, Equations (3-25) to (3-28) yield:

$$\left.\zeta\right|_{z=0} = \left.\frac{\partial^2\psi}{\partial z^2}\right|_{z=0} \approx \frac{1}{2\Delta z^2}\left(8\psi\Big|_{\Delta z} - \psi\Big|_{2\Delta z}\right) \tag{3-29}$$

or in terms of I and J:

$$\zeta(I,1) \approx \frac{1}{2\Delta z^2}\left[8\psi(I,2) - \psi(I,3)\right] \tag{3-30}$$

<u>Relaxation Method</u>

Equation (3-21) is nonlinear and particularly unstable at $Re_c \gtrsim 0.10$. Previous authors [40,43] have successfully solved similar equations using the iterative Relaxation Method, which was also adopted for this study.

If $\psi_n^*(I,J)$ and $\zeta_n^*(I,J)$ denote the results obtained from Equations (3-21) and (3-22) after the n^{th} iteration, the process of relaxation modifies these results as follows:

$$\psi_n(I,J) = \psi_{n-1}(I,J) + \alpha_\psi\left[\psi_n^*(I,J) - \psi_{n-1}(I,J)\right] \qquad (3\text{-}31)$$

$$\zeta_n(I,J) = \zeta_{n-1}(I,J) + \alpha_\zeta\left[\zeta_n^*(I,J) - \zeta_{n-1}(I,J)\right] \qquad (3\text{-}32)$$

where:

α_ψ = relaxation factor for stream function

α_ζ = relaxation factor for vorticity

As soon as the new values $\psi_n(I,J)$ and $\zeta_n(I,J)$ are available, they replace the old values $\psi_{n-1}(I,J)$ and $\zeta_{n-1}(I,J)$. The method for obtaining the starting values ψ_0 and ζ_0 is described in the next section.

The relaxation factors determine the amount by which the grid values are modified between successive iterations. If $\alpha_\psi = \alpha_\zeta = 1$, Equations (3-31) and (3-32) represent the Gauss-Seidel Method, which involves no relaxation. α_ψ was generally selected in the range 1.7-1.8, but for small values of R_∞ it was necessary to reduce α_ψ to 1.

The solution of the vorticity Equation (3-21) for the cylinder surface is even less stable than that for the bulk of the fluid. For this reason Masliyah [43] introduced an additional relaxation factor, $\alpha_{\zeta s}$, for obtaining vorticities on the cylinder surface. The values of α_ζ and $\alpha_{\zeta s}$ suggested by Masliyah were used as a basis for this work*(see Figure 3-3).

Initial Values for Relaxation Method

The solution procedure for Equations (3-21) and (3-22) requires a set of *initial values,* ψ_0 and ζ_0. If inertial terms are omitted, the Navier-Stokes Equation for a cylinder may be written:

$$\nabla^4\psi = 0 \qquad (3\text{-}33)$$

Both Kuwabara [36] and Happel [29] have presented particular solutions to Equation (3-33).

Kuwabara's solution which satisfies the boundary condition $\zeta = 0$ at $r = R_\infty$, is:

$$\psi = \sin\theta \left[A_1 r^2 + A_2 r + A_3\, r\ln r + \frac{A_4}{r}\right] \qquad (3\text{-}34)$$

where

*The relaxation factors used in this work are listed in Appendix IV.

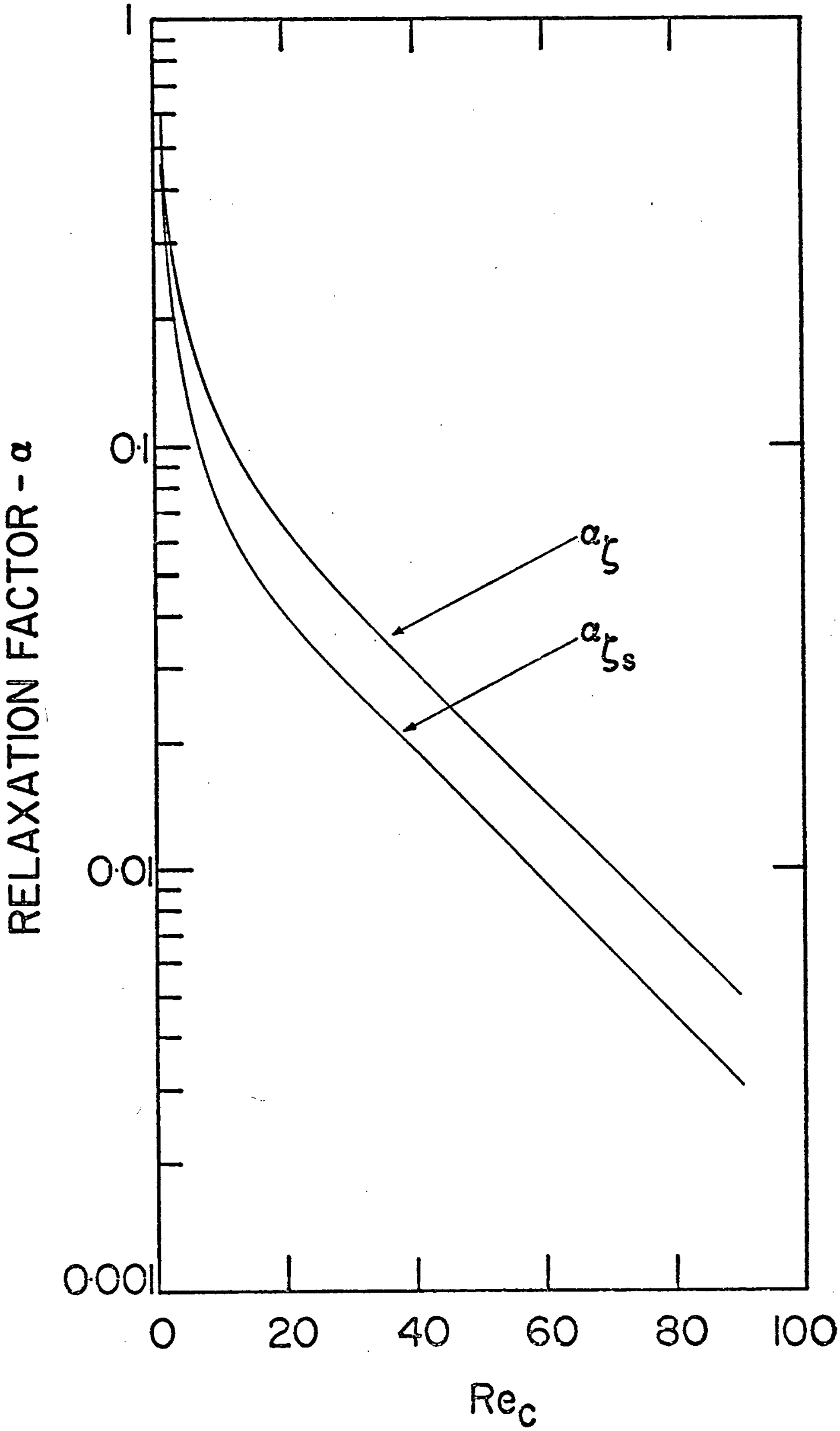

Figure 3-3. Masliyah's [43] relaxation factors for vorticity.

$$A_1 = \frac{-U_0}{4A_5 R_\infty^2}$$

$$A_2 = - U_0 \frac{(1 - R_\infty^{-2})}{2A_5}$$

$$A_3 = \frac{U_0}{A_5}$$

$$A_4 = U_0 \frac{(1 - \frac{1}{2}R_\infty^{-2})}{2A_5}$$

$$A_5 = A_6 + R_\infty^{-2} - \frac{1}{4}R_\infty^{-4}$$

$$A_6 = \ln R_\infty - \frac{3}{4}$$

Happel's particular solution to Equation (3-33) is:

$$\psi = \sin\theta \left[\frac{1}{8} H_1 r^3 + \frac{1}{2} H_2 r \left(\ln r - \frac{1}{2}\right) + H_3 r + \frac{H_4}{r}\right] \tag{3-35}$$

The coefficients H_1 to H_4 can be evaluated from the boundary conditionsfor ψ stated previously (Equations (3-11), (3-12) and (3-14)), along with Kuwabara's zero vorticity condition (Equation (3-15)). Substitution of these equations into Equation (3-35) yields the following simultaneous equations:

$$\frac{1}{8} H_1 + \frac{1}{2} H_2 \left(-\frac{1}{2}\right) + H_3 + H_4 = 0 \qquad (3\text{-}36)$$

$$\frac{3}{8} H_1 + H_2 \left(\frac{1}{2}\right) + H_3 + H_4 = 0 \qquad (3\text{-}37)$$

$$\frac{1}{8} H_1 R^3_\infty + \frac{1}{2} H_2 R_\infty \left(\ln R_\infty - \frac{1}{2}\right) + H_3 R_\infty + \frac{H_4}{R_\infty} = U_0 R_\infty \qquad (3\text{-}38)$$

$$H_4 = - H_1 R^2_\infty \qquad (3\text{-}39)$$

Equations (3-36) to (3-39) were solved for the coefficients H_1 to H_4:

$$H_1 = \frac{8\ U_0\ R_\infty^2}{G}$$

$$H_2 = \frac{-\ 8\ U_0\ R_\infty^4}{G}$$

$$H_3 = \frac{-\ 2\ U_0 R_\infty^2}{G}$$

$$H_4 = \frac{U_0 R_\infty^4 (1/R_\infty^2\ -\ 1)}{G}$$

$$G = 4\ R_\infty^4\ \ln\frac{1}{R_\infty} - R_\infty^4 + \left(1\ -\ 2\ R_\infty^2\right)^2$$

Utilizing the fact that $\zeta = \nabla^2 \psi$, Equation (3-35) gives the following expression for vorticity:

$$\zeta = \frac{1}{G} \cdot \frac{8 \sin \theta}{r} \left[\frac{r^2}{R_\infty^2} - 1\right] \tag{3-40}$$

In this work, Equations (3-35) and (3-40) were used to estimate ψ_0 and ζ_0 at $Re_c = 0.5$. Once this grid was sufficiently converged, the new values of ψ and ζ in the grid were used as starting conditions for a higher value of Re_c. Similarly, when the values in the second grid had been iterated to convergence, they were used as starting values for larger Reynolds numbers. This process was continued until a converged grid had been obtained at $Re_c = 40.0$.

Convergence Criteria

As mentioned in the previous section the numerical procedure starts from an initial guess of ψ and ζ, and converges to a final solution after a certain number of iterations. It is very difficult to estimate, *a priori*, the number of iterations which are needed to converge a given grid of values. Consequently, the computations must be continuously monitored and terminated once certain convergence criteria are satisfied.

In this work, the most relevant criteria are the particle impaction efficiencies. For a given grid, representative efficiencies were calculated every 100 iterations. When these efficiencies varied by less than a specified amount over a given "cycle" of 100 iterations, the calculations were terminated. Efficiencies calculated for grids having $R_\infty = 100$ were constrained to show no variation in the 5^{th} significant digit, and at $R_\infty = 3$, constancy in the 4^{th} significant digit was required.

Numerous other convergence criteria may be suggested. Before presenting them it is convenient to define some additional variables. The changes in stream function and vorticity values per iteration may be denoted by:

$$\Delta_n \psi (I,J) = \left| \psi_n^*(I,J) - \psi_{n-1}(I,J) \right| \qquad (3\text{-}41)$$

$$\Delta_n \zeta (I,J) = \left| \zeta_n^*(I,J) - \zeta_{n-1}(I,J) \right| \qquad (3\text{-}42)$$

$$\Delta_n \zeta_b(I,J) = \left| \zeta_n^*(I,J) - \zeta_{n-1}(I,J) \right| \quad J \neq 1 \qquad (3\text{-}43)$$

$$\Delta_n \zeta_s(I,1) = \left| \zeta_n^*(I,1) - \zeta_{n-1}(I,1) \right| \qquad (3\text{-}44)$$

The convergence criteria which were monitored in this study are the following:

<u>Maximum changes in stream function and vorticity</u>:

$$M_n \psi = \max_{\substack{1 \leq I \leq N_a \\ 1 \leq J \leq N_r}} \left[\Delta_n \psi(I,J)\right] \qquad (3\text{-}45)$$

$$M_n \zeta_b = \max_{\substack{1 \leq I \leq N_a \\ 2 \leq J \leq N_r}} \left[\Delta_n \zeta_b(I,J)\right] \qquad (3\text{-}46)$$

$$M_n \zeta_s = \max_{1 \leq I \leq N_a} \left[\Delta_n \zeta_s(I,1)\right] \qquad (3\text{-}47)$$

These criteria are similar to those of Hamielec and Raal [40], who considered their grids to be converged when:

$$M_n^{\alpha} \psi < 10^{-4}$$

$$M_n^{\alpha} \zeta < 10^{-4}$$

where

$$M_n^{\alpha}\,\psi = \max_{\substack{1 \le I \le N_a \\ 1 \le J \le N_r}} \left[\Delta_n^{\alpha}\,\psi(I,J)\right] \tag{3-48}$$

and

$$\Delta_n^{\alpha} \quad \left|\, \psi_n(I,J) - \psi_{n-1}(I,J) \,\right| \tag{3-49}$$

That is, these authors compared changes in the *relaxed* values of ψ and ζ. Hence, for values of $\alpha < 1.0$, their criteria are less stringent than those employed in this work.

Sum of all stream function and vorticity values:

$$S_n\,\psi = \sum_{I=1}^{N_a} \sum_{J=1}^{N_r} \psi_{n-1}(I,J) \tag{3-50}$$

$$S_n\,\zeta_b = \sum_{I=1}^{N_a} \sum_{J=2}^{N_r} \zeta_{n-1}(I,J) \tag{3-51}$$

$$S_n \zeta_s = \sum_{I=1}^{N_a} \zeta_{n-1}(I,1) \tag{3-52}$$

Sum of all changes in stream function and vorticity values per iteration:

$$D_n \psi = \sum_{I=1}^{N_a} \sum_{J=1}^{N_r} \Delta_n \psi(I,J) \tag{3-53}$$

$$D_n \zeta_b = \sum_{I=1}^{N_a} \sum_{J=2}^{N_r} \Delta_n \zeta(I,J) \tag{3-54}$$

$$D_n \zeta_s = \sum_{I=1}^{N_a} \Delta_n \zeta(I,1) \tag{3-55}$$

Fractional changes in the sum of stream function and vorticity changes per iteration:

$$Q_n \psi = \frac{D_n \psi}{S_n \psi} \tag{3-56}$$

$$Q_n \zeta_b = \frac{D_n \zeta_b}{S_n \zeta_b} \tag{3-57}$$

$$Q_n \zeta_s = \frac{D_n \zeta_s}{S_n \zeta_s} \tag{3-58}$$

<u>Sum of fractional changes over 100 iterations</u>:

$$Q_n^{100} \psi = \sum_{n=N}^{N+99} Q_n \psi \tag{3-59}$$

$$Q_n^{100} \zeta_b = \sum_{n=N}^{N+99} Q_n \zeta_b \tag{3-60}$$

$$Q_n^{100} \zeta_s = \sum_{n=N}^{N+99} Q_n \zeta_s \tag{3-61}$$

Several authors [31,39-41] have reported theoretical and experimental values for stagnation pressures and drag coefficients for flow around cylinders. Their results can be compared with values calculated in this study* as further tests of convergence. In addition, the pressures and drag coefficients calculated during relaxation tend to stabilize near convergence.

Frontal stagnation pressure:

$$p_0 = 1 + \frac{4}{Re_c} \int_0^{Z_\infty} \left. \frac{\partial \zeta}{\partial \theta} \right|_{\theta=0} dz \tag{3-62}$$

Rear stagnation pressure:

$$p_\pi = p_0 + \int_0^{\pi} \frac{\partial \zeta_s}{\partial z} d\theta \tag{3-63}$$

Skin drag coefficient:

---

*The equations for the stagnation pressures and drag coefficients are derived in Appendix II.

$$C_{DS} = \frac{\int_0^{\pi} - \tau'_{r\theta}\Big|_s R_c \sin\theta \, d\theta}{R_c(\frac{1}{2}\rho U_0^2)}$$

$$= \frac{4}{Re_c} \int_0^{\pi} \zeta_s \sin\theta \, d\theta \qquad (3\text{-}64)$$

<u>Form drag coefficient</u>:

$$C_{DF} = \frac{\int_0^{\pi} p_\theta' \cos\theta \, R_c \, d\theta}{R_c(\frac{1}{2}\rho U_0^2)}$$

$$= \int_0^{\pi} \left[p_0 + \frac{4}{Re_c} \int_0^{\theta} \frac{\partial \zeta_s}{\partial z} \, d\theta \right] \cos\theta \, d\theta \qquad (3\text{-}65)$$

Ratio of drag coefficients:

It was useful to combine the drag coefficients in the form of a ratio

$$\text{DRAG RATIO} = \frac{C_{DS}}{C_{DF}} \tag{3-66}$$

Integration of Equations (3-62) to (3-65) was performed by a Simpson's three-point method.

Calculation of Particle Trajectories

Equation of Particle Motion

The motion of a spherical particle subjected to a drag force $\underline{F}_D$, is governed by Newton's second law of motion which may be written as:

$$m_p \frac{d\underline{v}'_p}{dt'} = \underline{F}_D \tag{3-67}$$

or

$$m_p \frac{d\underline{v}_p'}{dt'} = C_D \, \pi \, R_p^2 \, \tfrac{1}{2} \rho \, |\underline{v}' - \underline{v}_p'| (\underline{v}' - \underline{v}_p') \tag{3-68}$$

The drag coefficient, C_D, is defined for a spherical particle as follows:

$$C_D = \frac{|F_D|}{\left(\pi \; R_p^{\,2}\right) \frac{1}{2} \rho \; |\underline{v}' - \underline{v}_p'|^2} \tag{3-69}$$

Equation (3-68) takes the following dimensionless form:

$$\frac{d\underline{v}_p}{dt} = \frac{Re_p}{24} \cdot \frac{C_D}{P} \left(\underline{v} - \underline{v}_p\right) \tag{3-70}$$

where:

$$P = \frac{m_p \; U_0}{6 \pi \mu \; R_p \; R_c} = \frac{2 \; (\rho_p - \rho) \; R_p^{\,2} \, U_0}{9 \; \mu \; R_c}$$

$$Re_p = \frac{2 \, \rho \, R_p \; |\underline{v}' - \underline{v}_p'|}{\mu}$$

The dimensionless group P is variously referred to as the *particle inertial parameter,* inertial parameter, or simply, the "Stokes Number." When defined in terms of diameters instead of radii, as is sometimes the case, P differs by a factor of ½ from the definition used in this work.

P reflects the magnitude of the inertial and viscous forces present, and is particularly significant in the Stokes' régime (where $C_D = 24/Re_p$). In this case it is the sole dimensionless group characterizing the particle trajectories. P can also be written as:

$$P = \frac{1}{9}\left(\frac{\rho_p - \rho}{\rho}\right) Re_c K^2 \tag{3-71}$$

to illustrate its dependence on the density ratio, $(\rho_p - \rho)/\rho$, and on the size parameter, K.

Drag Coefficients

For small values of the particle Reynolds number, $Re_p \ll 1$, Stokes' Law for spheres may be applied:

$$C_D = \frac{24}{Re_p} \tag{3-72}$$

At larger values of Re_p the drag coefficient may be expressed by any of a number of empirical and theoretical formulae. A simple expression which gives good agreement with experimental data in the range $0 \leq Re_p \leq 300$ was suggested by Klyachko [46]

$$C_D = \frac{24}{Re_p} + \frac{4}{Re_p^{1/3}} \tag{3-73}$$

This equation is continuous in its range of applicability and deviates only marginally from Stokes' Law at low Re_p.

Integration of Particle Equations

In order to obtain the particle trajectories, Equation (3-70) must be integrated twice, subject to the initial conditions:

$$\left.\begin{array}{lll} t = 0 & v_{px} = 1 & v_{py} = 0 \\ & x_p = -\sqrt{R_\infty^2 + y_p^2} & y_p = y \end{array}\right\} \tag{3-74}$$

i.e. the particles are started at the outer boundary of the fluid flowfield with the free stream velocity.

The integration is performed in a stepwise manner by dividing the particle motion into intervals of duration Δt. Equation (3-70) is integrated analytically over each interval by assigning appropriate constant values to the fluid velocity $\underline{v}$, and to $C_D \, Re_p / 24 \, P$.

If the subscript "0" denotes the conditions at the beginning of an interval, integration of Equation (3-70) over Δt yields:

$$v_{px} = \bar{v}_x - \left(\bar{v}_x - v_{px_0}\right) e^{-\beta \Delta t} \tag{3-75}$$

$$v_{py} = \bar{v}_y - \left(\bar{v}_y - v_{py_0}\right) e^{-\beta \Delta t} \tag{3-76}$$

$$x_p = x_{p_0} + \bar{v}_x \Delta t + \frac{1}{\beta}\left(\bar{v}_x - v_{px_0}\right)\left(e^{-\beta \Delta t} - 1\right) \tag{3-77}$$

$$y_p = y_{p_0} + \bar{v}_y \Delta t + \frac{1}{\beta}\left(\bar{v}_y - v_{py_0}\right)\left(e^{-\beta \Delta t} - 1\right) \tag{3-78}$$

where

$$\beta = \frac{C_D \ Re_p}{24 \ P} \tag{3-79}$$

The values of the fluid velocity, $\underline{v}$, at the start and end of the previous time interval were linearly extrapolated by $\Delta t/2$ into the next interval. This gave $\overline{v}$, the constant value of fluid velocity used in the analytical integration of the trajectory segment (see Appendix I). The summation of these trajectory segments produced the full trajectory of the particle.

Selection of the variable time step Δt was performed so as to reflect the varying nature of the flow-field. When a particle entered a grid cell of radial dimension Δr (Figure I-1) with a velocity $|\underline{v}_p|$, Δt was determined from:

$$\Delta t = \frac{\Delta r}{3 \cdot |\underline{v}_p|} \tag{3-80}$$

Hence, up to three trajectory segments were calculated for each grid cell, depending on the direction of the particle motion. Equation (3-80) has the advantageous property that it produces small time steps near the cylinder surface, where velocity gradients are steepest and high accuracy is required.

Test calculations were performed using five integration steps per grid cell, to detect any changes in accuracy due to the use of shorter trajectory intervals.

Fibonacci Search for Critical Trajectory

As mentioned in the Introduction, the efficiency, E, for a particular set of conditions was determined from $y_{p,crit}$, the initial critical position of the particle above the centre line. It was possible to estimate an accurate value of E with a minimum number of trajectory calculations by using the Fibonacci sequential search scheme [47].

Optimum search techniques like the Fibonacci method locate maxima, minima or discontinuities in unimodel functions with considerable precision. For the purposes of efficiency calculations it was necessary to describe the process of "hitting" or "missing" the cylinder in terms of a simple function. Arbitrarily assigning a functional value of 1 to every y_p giving a miss, and a value of 0 to every y_p giving a hit, the collision process may be described by a step function (Figure 3-4).

Figure 1-3 illustrates three particle trajectories, each starting at a different value of y_p. These same points are plotted in Figure 3-4. Because the search procedure requires an independent variable scaled from 0. to 1., values of y_p were scaled with division by $1 + K$. The transformed value of y_p for the N^{th} iteration, y_{pN}, is denoted λ_N, where $\lambda_N = y_{pN}/1+K$. Consequently, the critical value λ_{crit} is identical to the desired value of the efficiency, E.

The accuracy of the estimate of E was expressed in terms of L_N, the "interval of uncertainty" remaining after N separate trajectory calculations. L_N is defined such that the estimated value of E differs from the true value of the efficiency by less than L_N. If δ represents the smallest separation of two values of y_p giving two distinct trajectories, L_N is given by the following formula:

$$L_N = \frac{1}{F_N} + \frac{F_{N-2}}{F_N} \cdot \delta \qquad (3\text{-}81)$$

Where F_N represents the N^{th} Fibonacci number

and

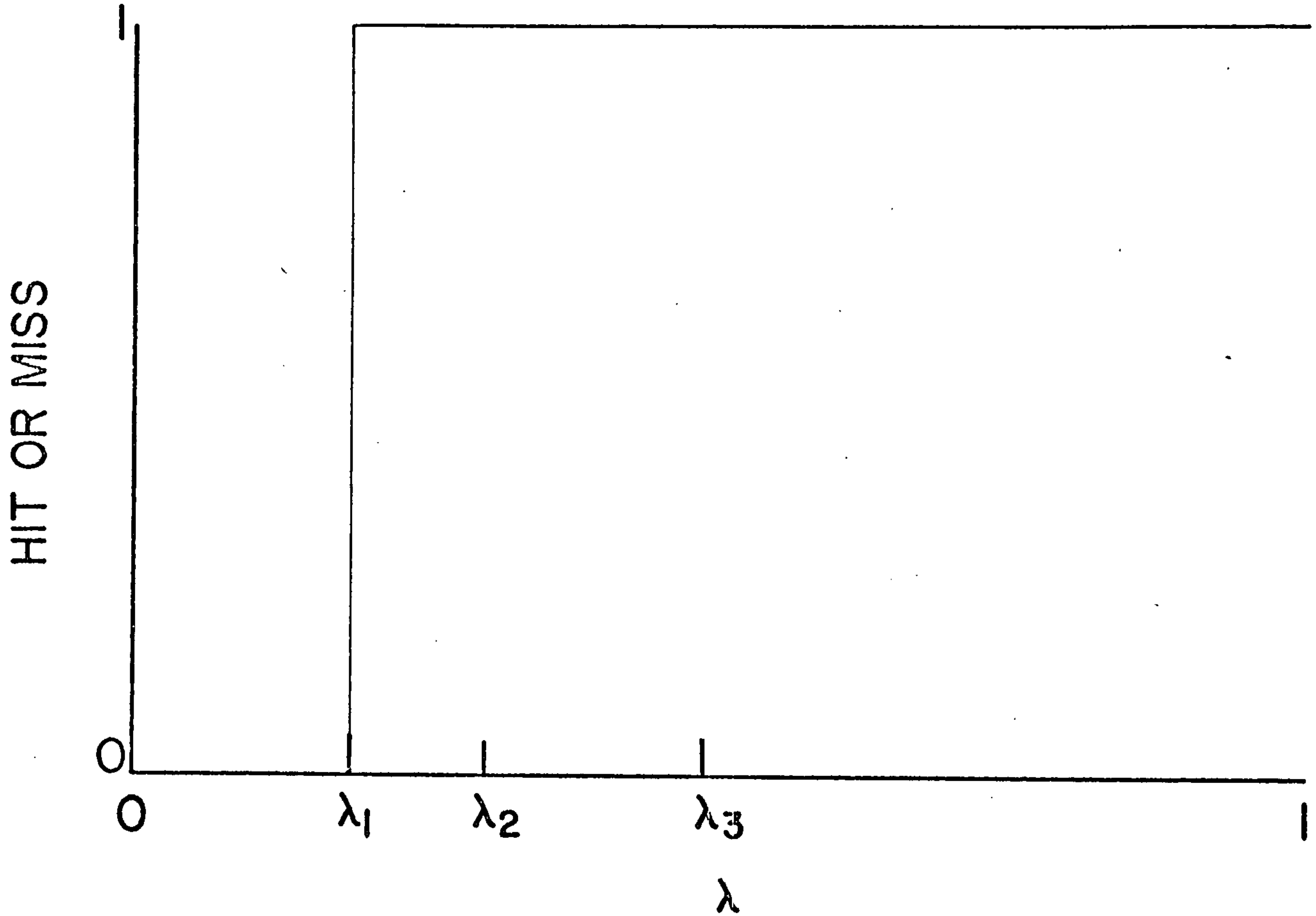

Figure 3-4. Collision function for Fibonacci search.

$$\left.\begin{aligned} F_0 &= F_1 = 1 \\ F_N &= F_{N-1} + F_{N-2} \qquad N = 2,3,\cdots N \end{aligned}\right\} \tag{3-82}$$

Assuming that $\delta = 0$ for the numerical calculations involved, Equation (3-81) becomes:

$$L_N = \frac{1}{F_N} \tag{3-83}$$

Since the efficiencies were expected to be lowest at low values of P, the highest accuracy was required in that range. Consequently, for $P \leq 1$, N was set equal to 31, while for $P > 1$, $N = 21$. The corresponding intervals of uncertainty, or the errors in the efficiencies were:

$$\left.\begin{aligned} L_{21} &= \frac{1}{F_{21}} = \frac{1}{17711.} = 5.64 \times 10^{-5} \\ L_{31} &= \frac{1}{F_{31}} = \frac{1}{2178309.} = 4.59 \times 10^{-7} \end{aligned}\right\} \tag{3-84}$$

These estimates of error do not include contributions resulting from inaccuracies on the flowfields, or cumulative machine error.

Chapter 4

RESULTS AND DISCUSSION

The main results of this work are presented and discussed in the present chapter. For the sake of convenience the chapter is divided into three major sections.

The first section contains all findings pertaining to particle behaviour. In particular, it comprises the important results on particle impaction efficiencies as functions of: Reynolds number, Re_c, particle inertial parameter, P, and particle size parameter, K. The results are compared with those of other workers whenever possible.

Fluid flowfields, as predicted by the numerical solution of the Navier-Stokes Equation, Davies' Bessel function expression, and by Thom are presented in the second section. The differences evident between these flowfields help to explain the discrepancies between particle efficiencies calculated in this work and those found by other authors.

The third and final section is devoted to the convergence criteria which were monitored during the relaxation solution of the Navier-Stokes Equation. The criteria are compared with one another, and the criterion best suited for determining the convergence of the numerical solution is indicated.

Typical Particle Trajectories

Trajectories obtained by means of Equations (3-75) to (3-78) are depicted in Figures 4-1 and 4-2, for $Re_c = 0.2$ and $Re_c = 40$, respectively.* In both cases the particles started at the same points in the flowfield and with the local fluid velocity. At the smaller Reynolds number the particles possessed less momentum than at $Re_c = 40$, and consequently diverged less from the stream lines. When wakes were present behind the cylinder, particles were never observed to enter them. This observation is only valid provided particle transport occurs solely due to an inertial mechanism. In the presence of other forces, such as gravity and electrostatic attraction, particles can conceivably enter the wake region.

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*All figures and tables are located at the end of the chapter, starting on pages 93 and 153, respectively.

The curves in Figure 4-3 show how the particle Reynolds number, Re_p, varies with position for the case of $Re_c = 40$. Clearly Stokes Law is not suitable for calculating the drag coefficient for the particles in question. This fact demonstrates the necessity of using Equation (3-73) to calculate C_D for the particles, since it gives valid predictions both in Stokes régime, as well as at higher values of Re_p. It is also interesting to note the twin maxima which occur for trajectory 2.

The values of Re_p for the trajectories shown in Figure 4-1 for $Re_c = 0.2$ have not been plotted, but in this case they were very small ($Re_p << 0.1$) and well within the range of Stokes Law.

Since C_D must be calculated in both Stokes régime and at higher particle Reynolds numbers, Equation (3-73) is quite suitable since it gives continuous predictions for the desired range. At no time during the trajectory calculations did Re_p exceed 30, so that the upper limit of applicability of Equation (3-73) was never reached.

PARTICLE IMPACTION EFFICIENCIES

The results are summarized in Tables 4-1 to 4-2. Figures 4-4 to 4-15 show the variation of efficiency with particle inertial parameter for most of the numerical flowfields. Graphs have not been prepared for all values of Re_c since most of the curves are fairly similar.

Before proceeding with the discussion of the results it is expedient to comment on the size parameter K.

One basic assumption inherent in the determination of particle trajectories is that the presence of the particle does not influence the fluid flowfield itself. It is very difficult, however, to estimate the value of K for which this assumption becomes invalid and when significan error is thereby introduced.

Because the predicted efficiences showed uniform increase with K, curves have been presented to a maximum particle size of K = 1.0. Although the possibility exists that these particles are too large to be handled properly by the present solution procedure, they have been included to illustrate the effect of particle size on impaction efficiency. The problems that would accompany an attempt to solve both the fluid and particle motion equations simultaneously are beyond the scope of this work.

Apart from the small uncertainty regarding efficiency prediction at K = 1.0, those values calculated at $K \leq 0.5$ are felt to be quite accurate.

The curves of efficiency given for K = 0.001 deserve special mention, since they are actually curves of E_I, the impaction efficiency due to inertial effects alone. They were obtained by slight modifications of the trajectory calculations: K was considered to have the finite value 0.001 for the purpose of calculating C_D, but collision with the cylinder was taken to occur only when the *centre* of the small particle coincided with the surface of the cylinder. Alternately expressed, the interceptive effect was entirely neglected for particles having K = 0.001.

Effect of Inertial Parameter on E

$R_\infty = 100$.

The following general observations can be made on the appearance of the curves at $R_\infty = 100$:

a) All of the curves are similar and have an S-type shape.

b) For large values of P the impaction efficiences tend to unity as expected from physical considerations.

c) For small P, the values of E approach E_K.

d) There is an interval of the inertial parameter, generally one order of magnitude wide, in which the efficiencies rise rapidly from approximately E_K to unity.

<u>$R_\infty = 3$.</u>

The curves of efficiency versus P for $R_\infty = 3$ have a very similar shape to those obtained at $R_\infty = 100$. However, for a given Reynolds number the efficiences are considerably higher than those calculated from flowfields having $R_\infty = 100$. Two further differences are evident:

a) The effect of Reynolds number on E is much less pronounced at $R_\infty = 3$ than at $R_\infty = 100$. This is not unexpected when it is realized that the flowfields at $R_\infty = 3$ are not strongly dependent on the Reynolds number, Re_c.

b) The interceptive efficiences, E_K, are significantly higher at $R_\infty = 3$ than at $R_\infty = 100$. Once again this is a consequence of the more closely spaced stream lines at $R_\infty = 3$.

Comparison with Davies

$Re_c = 0.2$.

Table 4-3 contains the efficiencies calculated for $Re_c = 0.2$ on the basis of the numerical flowfield obtained at $R_\infty = 200$. Figure 4-16 compares these efficiences with those presented graphically by Davies and Peetz [7]. It should be noted that K = 0.001 corresponds to their condition of an infinitely small particle.

The agreement is generally quite good, although Davies and Peetz' predictions are somewhat higher, especially in the range $1 \leq P \leq 40$. This discrepancy is attributable to the inaccurate expression used by these authors in discribing their flowfield in the vicinity of the cylinder (cf. Equation (2-2)). A more detailed examination of their flowfield is made in the second section of this chapter.

$\underline{Re_c = 10}$.

Figure 4-17 provides a comparison of the efficiencies calculated in this work at $Re_c = 10$ and $R_\infty = 100$ with those obtained by Davies and Peetz using Thom's data.

Their results are considerably higher, except for the case of K = 0.001, and Thom's approximate representation of the flowfield accounts in part for these differences. A further reason which explains their higher efficiences is the fact that these workers started their particles close to the cylinder, i.e., at $x_p = -5.0$, in contrast with $x_p \approx -100$ in this study.

Particles whose trajectories begin close to the cylinder experience the upward fluid forces for a much shorter time than those started far away from the cylinder. Consequently, even with identical flowfields the efficiency calculated for a particle starting at $x_p = -5.0$ would be higher than for one starting at $x_p \approx -100$. This effect decreases as P increases since heavy particles undergo less deflection.

This argument is supported by the fact that the efficiency curves do approach each other as P increases (cf. Figure 4-17). Thom's flowfield is described in more detail in the second section of this chapter.

Experimental Impaction Efficiencies

Subramanyam and Kuloor [12] reported experimental values of the impaction coefficient, ε, for $4 \leq Re_c \leq 240$. These results have been replotted as efficiences, E, in Figure 4-18 . Since the size parameter of their particles ranged from K = 0 to K = 0.1, the efficiencies were calculated on the basis of both these values.

As a qualitative indication of how their data compare with the predictions in this work, the curve of E vs. P calculated at K = 0.1, $Re_c = 40$ and $R_\infty = 100$ has been given as a solid line in Figure 4-18 . The reason that the impaction efficiences for $Re_c = 40$ were shown is that they correspond to the highest Reynolds number for which a numerical grid was calculated.

It is seen that the curves are of very similar shape. The good agreement suggests that the experimental flowfield may have been close to that obtained by solution of the Navier-Stokes Equation at $Re_c = 40$.

The above observations therefore give qualitative support to the predictive technique used in this study.

Potential Efficiencies

The computer programme used to calculate the efficiencies for the numerical flowfields was modified to duplicate the assumptions used by Davies and Peetz [7], Householder and Goldschmidt [13], and Subramanyam and Kuloor [12].

Efficiences were then calculated for potential flow on the basis of Equation (2-6). Since the authors mentioned above used the same equations in their predictions of impaction efficiencies, comparison of their results with the "duplicates" calculated in this work gave an indication of the programme accuracy.

These comparisons are shown in Table 4-4 . The values ascribed to Davies and Peetz and Householder and Goldschmidt were read from curves presented by these authors. A dash ("-") has been inserted where the efficiences were not available. The last column in the table contains efficiencies calculated in the normal manner for this study, i.e., x_p = -100 and Klyachko's formula. The full set of potential efficiencies is contained in Table 4- 5 , and plotted in Figure 4-19.

It is clear that the agreement is fairly good in all cases, with Davies and Peetz' results showing the largest differences. These authors did not have the benefit of modern computers to aid their calculations, and may have used excessive step sizes in their work. The predicted efficiencies in the other two cases differ by less than 2%, the numbers being virtually identical for the predictions of Householder and Goldschmidt.

Therefore, it is felt that this test substantially confirms the validity of the solution techniques which were employed in this work for calculating the particle trajectories and impaction efficiencies.

The effect of initial starting position, x_p, is also demonstrated in Table 4-4 . For particles having the same P and K, the efficiency increases as the particles are started closer to the cylinder. This observation has been made in connection with Davies' efficiencies at $Re_c = 10$.

Critical Particle Inertial Parameter

As mentioned previously, the efficiencies at K = 0.001 are actually the efficiences due to interception alone, E_K. In order to estimate the *critical* particle inertial parameters, P_c, the curves of E vs. P at K = 0.001 were extrapolated to E = 0, in the range $0.2 \leq Re_c \leq 40$. The results, shown in Figure 4-20, can only be regarded as approximate, due to the uncertainties involved in the extrapolation.

Davies and Peetz' predictions of P_c for $Re_c = 0.2$ and $Re_c = 10$ were also included for comparison purposes. Their critical values are seen to be significantly lower than those predicted in this work.

Effect of Reynolds Number on E

Figures 4-21, to 4-26 show how the impaction efficiencies change with increasing Reynolds number, Re_c. The effect of Reynolds number was studied for both $R_\infty = 100$ and $R_\infty = 3$.

$R_\infty = 100$.

Figures 4-21 to 4-23 indicate the relationship between efficiency and Reynolds number for $0.2 \leq Re_c \leq 40$. The increase of E with Re_c is fairly gradual, being most pronounced at lower values of P. Although the curves are plotted to a maximum Reynolds number of $Re_c = 40$, the efficiencies ultimately approach the values obtained under potential flow conditions(Figure 4-19 and Tables 4-4 and 4-5). The intermediate values were, however, not found because the flowfield becomes unsteady for $Re_c > 40$ and consequently Equation (3-1) fails.

$R_\infty = 3$.

The effect of Re_c on efficiency at $R_\infty = 3$ is illustrated by Figures 4-24 to 4-26. The increase of efficiency with Reynolds number for any given values of P is very small. Furthermore the efficiencies at $R_\infty = 3$ are higher than at $R_\infty = 100$ for a given P and K.

Comparison with Householder and Goldschmidt

Figures 4-27 and 4-28 compare efficiencies given by Householder and Goldschmidt's expression (Equation (2-5)) with those calculated in this work.

In general their efficiency curves are significantly lower than those of this work, except in the case of P = 1.and K = 0.1, where their curve is higher. Since the agreement is shown to be poor for both K = 0.1 and K = 1.0 (cf. Figures 4-27 and 4-28) it is clear that Equation (2-5) is unsuitable for efficiency prediction.

Contour Plots of Efficiency

The dependence of impaction efficiency on Reynolds number and particle inertial parameter may be compactly presented by contour diagrams such as those in Figure 4-29 to 4-34. The lines of constant efficiency, E, are plotted with Reynolds number, Re_c, as the abscissa, and $\sqrt{p}$ as the ordinate.

These curves are redrawn from original contour plots obtained from the UBC "Calcomp" ink plotter. The UBC contouring subroutine was used to contour both these efficiency diagrams, as well as the stream lines and equi-vorticity lines shown in the next section.

Each figure is drawn for a particular value of K and outer boundary radius. The contour diagrams for $K = 0.10$ and $R_\infty = 100$ and $R_\infty = 3$ are not given because they were almost identical to the ones shown at $K = 0.001$. This similarity is to be expected from the close spacing of the efficiency curves at lower values of K in the E versus P plots.

The distinct rise of the E contours at low values of Re_c is due to the fact that the impaction efficiencies increase more rapidly with Reynolds number at lower values of Re_c.

The dependence of E on K is seen to be greatest for the lower contour lines, which move closer to the horizontal axis as K increases. This too was evident from the plots of E vs. Re_p at different values of K.

Effect of Solids Concentration

In order to determine the effect of solids fraction on impaction efficiency, additional flowfields were calculated at $Re_c = 0.2$ and $Re_c = 40$. The outer boundary radii for these grids were: $R_\infty = 50$, $R_\infty = 25$ and $R_\infty = 10$. Together with the basic grids at $R_\infty = 100$ and $R_\infty = 3$, flowfields for the following solids fractions were therefore available: $c = 10^{-4}$, 4×10^{-3}, 1.6×10^{-3}, 10^{-2} and 0.111. When $c = 10^{-4}$ the conditions correspond very closely to a cylinder in a fluid of infinite extent.

It is seen from Figures 4-35 to 4-40,* which show E vs. $\sqrt{c}$, that E increases with increasing solids concentration, but that the rate of increase is not particularly rapid. The greatest rate of increase is apparent at lower values of P, as was previously found for the curves of E versus Re_c.

As $c \to 0$ the efficiencies approach constant values corresponding to an infinitely dilute array. At the other extreme, c increases to a maximum value imposed by the physical arrangement of the cylinders. The maximum solids concentration for cylinders in a triangular array may be shown to be $c = \pi\sqrt{3}/6 \approx 0.907$.

Kuwabara's and Happel's models implicitly assume that there exists a finite distance between the surfaces of

*See also Tables 4-6 and 4-7.

the randomly spaced cylinders in the array. This assumption is not violated for real arrays of cylinders, so long as they are not in contact with one another.

Sieving

As the solids concentration is increased the average distance between the cylinders is reduced. Hence there is a concentration, denoted by c_m, for which the distance exactly equals the particle diameter. Under these conditions the particles are retained by sieving and the collection efficiency is unity. Neither the inertial impaction nor the interception effects are significant when sieving occurs. Raising the solids concentration above c_m does not result in any further increases of the efficiency.

The sieving mechanism is illustrated in Figure 4-41 and it is easy to show that

$$c_m = \left[\frac{1}{K + 1}\right]^2 \qquad (4\text{-}1)$$

The concentration, c_m, is indicated in Figures 4-35 to 4-40 by an asterisk. As a first approximation the efficiency curves may be extrapolated to the asterisks if it is desired to obtain values for $c > 0.111$.

Inertial and Interceptive Mechanisms

In the Introduction, particle impaction was discussed in reference to the inertial and interceptive mechanisms. Although these effects generally occur simultaneously, it was pointed out that they could be considered independently.

The efficiencies due to interception, E_K, were calculated by modifying Equations (3-75) to (3-78) so that they calculated the paths of fluid streamlines. These streamlines represent the trajectories of finite-sized particles having $P = 0$, which impact on the cylinder by virtue of their size alone. Table 4-8 contains E_K results for both $R_\infty = 100$ and $R_\infty = 3$.

The additivity of the inertial and interceptive effects is tested in Figures 4-42 and 4-43, where efficiencies are plotted versus Reynolds number for the following cases: inertial impaction efficiency, E_I; interceptive efficiency, E_K; the arithmetic sum, $E_I + E_K$, and the impaction efficiency for the combined effects of inertial impaction and interception, E.

It is clear that the effects are not linearly additive, since the dashed lines representing the sums $E_I + E_K$ lie above the curves for E. Both E_I and E_K increase with increasing Re_c, although this behaviour is more evident at $R_\infty = 100$ than at $R_\infty = 3$. For both $R_\infty = 100$ and $R_\infty = 3$ the efficiency due to inertial effects, E_I, is seen to exceed the efficiency due to interception, E_K.

The calculation of E_K for the case of K = 0.001 afforded another opportunity to determine the accuracy of the computer programme used in this work. It is clear that for a particle having P = 0 and experiencing no interceptive effect the predicted efficiency should be zero.

The largest value of E_K under these conditions is 0.0014 and occurs at $Re_c = 40$ and $R_\infty = 100$ (cf. Table 4-8 This amounts to an error of 0.0014. In view of the good agreement with the known theoretical limit of $E_K = 0.0$ for K = 0.001, the validity of the programme is considered to have been demonstrated.

Comparison with Wong *et al.*

Figure 4-44 compares values of E_K predicted by Equation (2-4), as given by Wong, Ranz and Johnstone [10], with the interceptive efficiencies calculated in this work.

The agreement is fairly good up to $Re_c \approx 1.0$, at which point the predictions of Equation (2-4) increase rapidly. The failure of Equation (2- 4) at higher values of $Re_c \geq 1$ is expected, since it is based on Equation (2-3) which is valid only for creeping flow.

Selection of Numerical Grid

Angular and Radial Divisions

In order to determine the optimum grid spacing for efficiency calculations, the Navier-Stokes Equation was solved for two additional grids at $Re_c = 40$, one being finer than the "standard" grid ($N_a = 49$, $N_r = 93$), and the other, coarser ($N_a = 33$, $N_r = 79$). This comparison was performed at $Re_c = 40$, since finite difference representation of the fluid flowfield was most difficult at this maximum Reynolds number.

The results of this comparison are shown in Table 4- 9 , from which it is seen that the test grids yielded slightly higher values of E than the standard grid. Since these differences were quite small, the spacing afforded by the standard grid ($N_a = 33$, $N_r = 93$) was felt to be adequate for this work. Hence, for $R_\infty = 100$, $\Delta z \approx 0.05$ and $\Delta\theta \approx 0.0982$ rad. or 5.6°.

Steps Per Cell

As described in the Theory Chapter, the particle trajectories were integrated on the basis of three steps per grid "cell." To ascertain the effect of decreasing the step size, the efficiencies at $Re_c = 40$ were recalculated using five steps per grid cell.

It is clear from Table 4-9 that the results for three steps and five steps per cell are virtually identical. On the basis of this finding, all the efficiency calculations were performed with three steps per cell.

Happel's Model

Table 4-9 also contains the efficiencies calculated from a flowfield which was obtained by solving the Navier-Stokes Equation subject to Happel's boundary condition. The Reynolds number and outer boundary radius were 40 and 100, respectively.

Happel's model is seen to predict somewhat higher efficiencies than given by Kuwabara's zero vorticity condition. Kuwabara's model therefore provides more conservative estimates of impaction efficiencies. Since the latter model also predicts drag coefficients for cylinders which are in better agreement with experimental data (Kirsch and Fuchs

[45]) than Happel's model, Kuwabara's zero vorticity boundary condition was used throughout this work.

FLOWFIELDS

$R_\infty = 100.$

Figures 4-45 to 4-47 show representative streamlines and equi-vorticity lines for some flowfields used for efficiency calculations. The symmetry of the stream function and vorticity values is apparent at low values of Re_c.

As the Reynolds number increases, the flowfields become progressively more asymmetric, and a wake appears behind the cylinder between $Re_c = 5$ and $Re_c = 10$. With a further increase in Re_c the wake grows and the angle of separation is seen to advance.

$R_\infty = 3.$

Due to the drastically decreased radius of the outer boundary, the streamlines and equi-vorticity lines lie much closer to the cylinder (cf. Figure 4-48 to 4-50). Furthermore, at high Reynolds numbers the streamlines are more symmetric for $R_\infty = 3$ than for $R_\infty = 100$. It may also be noted that the wakes are considerably smaller, and appear only when $Re_c > 10$.

The values of vorticity are much higher at $R_\infty = 3$ than at $R_\infty = 100$ numbers. This is expected since the gradient of stream function is much steeper for $R_\infty = 3$ than for $R_\infty = 100$.

Effect of R_∞

Figures 4-51 to 4-54 show how the shapes of the flowfields at $Re_c = 50$, 25 and 10 change from those shown for $R_\infty = 100$ to those at $R_\infty = 3$. The vorticity increases with decreasing R_∞, whereas the streamlines become more symmetric and move closer to the cylinder. There is little discernible change in the flowfields between $R_\infty = 50$ and $R_\infty = 25$, but it is quite marked between $R_\infty = 25$ and $R_\infty = 10$.

Characteristic Parameters

Table 4-10 summarizes the stagnation pressures and drag coefficients calculated for the various Reynolds numbers and outer boundary radii.

Figure 4-55 shows the excellent agreement between the values of C_{DT} calculated in this study and those obtained experimentally and numerically by other authors.

The other calculated parameters in Table 4-10 also agree quite well with those determined by others [39-41]. However, the values of p_π at $Re_c = 20$ and $Re_c = 30$ are larger than expected. The explanation for this behaviour is that these two flowfields were not fully converged with respect to the rear stagnation pressures. In certain cases p_π was found to approach a constant value only long after the efficiencies had stabilized. Since the present work was primarily concerned with efficiency calculations it was not considered necessary to execute the additional lengthy iterations to converge the stagnation pressures.

Davies' Flowfield at $Re_c = 0.2$

As mentioned earlier, Davies' Bessel representation of the fluid flowfield at $Re_c = 0.2$ (Equation (2-2)) was somewhat inaccurate. The errors were particularly apparent close to the surface of the cylinder.

Figure 4-56 shows the same streamlines for: (a) the numerical flowfield at $Re_c = 0.2$ and $R_\infty = 200$ and (b) the flowfield predicted by Equation (2-2). Davies [9] recognized that Equation (2-2) was incorrect in the area behind the cylinder, though he felt it was adequate on the upstream side. It is clear from Figure 4-56 that Equation (2-2) is invalid on the downstream side of the cylinder, but a closer examination of the flowfield shows discrepancies on the upstream side as well.

Figure 4-57 depicts some stream lines corresponding to low values of ψ, which actually terminate on the surface of the cylinder, a condition which is physically impossible. Furthermore, the stream lines which do not contact the cylinder surface approach it more closely than those calculated numerically.

Since the integration of the particle trajectories involved the rectangular components of the fluid velocity, v_x and v_y, these quantities have been plotted for constant values of the y-co-ordinate (cf. Figure 4-58 and 4-59) at $Re_c = 0.2$. Davies' predictions of v_x are higher than those derived from the numerical flowfield, while those for v_y are lower. Such differences explain the higher efficiencies generally predicted by Davies. Tables 4-11 to 4-14 contain the calculated values of v_x and v_y for: a) Davies' equation and (b) the numerical flowfield in the region near the upstream half of the cylinder.

Davies' Flowfield at $Re_c = 10$

Table 4-15 contains the values of the rectangular fluid velocity components given by Davies [7] on the basis of Thom's [6] data. These, together with the velocities interpolated from the numerical flowfield at $Re_c = 10$, are plotted in Figures 4-60 and 4-61 for $y = 1.0$, and $y = 0.6$. Tables 4-16 and 4-17 displays v_x and v_y calculated from the numerical flowfield at $Re_c = 10$.

Thom's predictions of v_x and v_y are considerably higher than the velocities calculated from the numerical flowfield. The errors in his velocities are not surprising when one considers the approximate method he used to integrate the equations of motion of the fluid.

CONVERGENCE CRITERIA

As mentioned in the Theory Chapter, several criteria were monitored during the convergence of the numerical solutions of the Navier-Stokes Equation. The result for five typical cases ($Re_c = 0.2$, 0.5 and 40, $R_\infty = 3$ and 100) are summarized in Tables 4-18 to 4-22.

It must be stressed that the specific behaviour of the convergence criteria is strongly dependent on the starting grid values, ψ_0 and ζ_0.

In order to afford a standard basis of comparison for one solution, the initial values of ψ and ζ for

$Re_c = 0.5$ and $R_\infty = 100$ were calculated from Equations (3-35) and (3-40).

The following discussion outlines some general properties of the convergence criteria illustrated by the five cases cited above.

a) Maximum changes in stream function and vorticity, $M_n\ \psi$, $M_n\ \zeta_b$, $M_n\ \zeta_s$:

In most cases these values decreased appreciably over the first few hundred iterations and then decreased slowly while displaying an oscillatory behaviour. $M_n\ \zeta_b$ and $M_n\ \zeta_s$ were larger than $M_n\ \psi$ in most cases.

b) Sum of all stream function and vorticity values, $S_n\ \psi$, $S_n\ \zeta_b$, $S_n\ \zeta_s$:

These sums did not change appreciably over the course of several thousand iterations, although slight increases or decreases were noted in some cases.

c) Fractional changes in the sum of stream function and vorticity changes per iteration, $Q_n \psi$, $Q_n \zeta_b$, $Q_n \zeta_s$:

All of these parameters decreased during the relaxation of each grid. This is to be expected as the stream function and vorticity approach their final constant values throughout the grid.

d) Sum of fractional changes over 100 iterations, $Q_n^{100} \psi$, $Q_n^{100} \zeta_b$, $Q_n^{100} \zeta_s$:

The sums related to the vorticity changes decreased with increasing number of iterations. The same was true in most cases for the sums of stream function changes.

e) Frontal stagnation pressure, p_0:

This parameter changed very slowly, generally decreasing slightly during the relaxation.

f) Rear stagnation pressure, p_π:

The magnitude of p_π changed more noticeably than p_0, and it sometimes converged very slowly to its final value.

g) Skin drag coefficient, C_{DS}:

The skin drag coefficient showed very little change with the number of iterations performed on a given grid.

h) Form drag coefficient, C_{DF}:

This drag coefficient was somewhat more sensitive to the number of iterations than C_{DS}. This resulted mainly from the fact that it was based on the vorticity values in the vicinity of the cylinder surface, which converged more slowly than the stream function in the same area.

i) Ratio of drag coefficients, C_{DS}/C_{DF}:

In most cases this ratio showed a steady decrease with increasing number of iterations, but the change was quite gradual.

Since the stream lines moved closer to the cylinder with increasing Reynolds number, one would anticipate a similar increase in $S_n\ \psi$, $S_n\ \zeta_b$ and $S_n\ \zeta_s$. Examination of Tables 4-18 to 4-22 clearly demonstrates this effect.

In addition, $S_n \psi$ decreased with decreasing R_∞ at a given Reynolds number, whereas $S_n \zeta_b$ and $S_n \zeta_s$ increased under the same conditions.

Selection of Standard Criterion

Q_n^{100} is the best of the mentioned criteria for monitoring a numerical relaxation solution of the Navier-Stokes Equation. The primary advantage of Q_n^{100} is that it was a direct measure of the amount of change occurring at *all* points in the grid.

Because the sums $S_n \psi$, $S_n \zeta_b$ and $S_n \zeta_s$ did not change appreciably with the number of iterations performed, Q_n^{100} essentially represented a normalized measure of the changes in ψ, ζ_b and ζ_s. Since Q_n^{100} was based on the changes over 100 iterations it was preferable to Q_n, which merely gave the normalized change during one iteration.

Q_n^{100} almost invariably decreased as the values in the numerical flowfield approached near their final values. In some instances Q_n^{100} decreased by two orders of magnitude, as in the case of $Re_c = 40$ and $R_\infty = 3$.

M_n^α was used by Hamielec and Raal [40] to decide when their numerical solutions of the Navier-Stokes Equation were converged. However, this criterion was much less reliable than ${Q_n}^{100}$, since it decreased very slowly during most of the iterations, and displayed considerable oscillatory behaviour. As a consequence of these variations, it is conceivable that M_n^{α} drops below some pre-set minimum value before the final, converged solution is attained.

RECOMMENDATIONS FOR FUTURE WORK

The techniques developed in the present work can readily be extended to include gravitational, electrostatic, Brownian and radiometric effects, in addition to the inertial and interceptive mechanisms. It would also be useful to investigate the nature of the particle cylinder interaction at the instant of contact, since it determines the *collection* efficiency.

A similar study of particle impaction on spheres at intermediate Reynolds numbers is also of practical interest. This could be effected by utilizing the same approach adopted for cylinders.

Experimental research should be performed in order to test the various assumptions made in the present theoretical study. In particular this could provide information on the extent to which particles of finite size disturb the fluid flowfield.

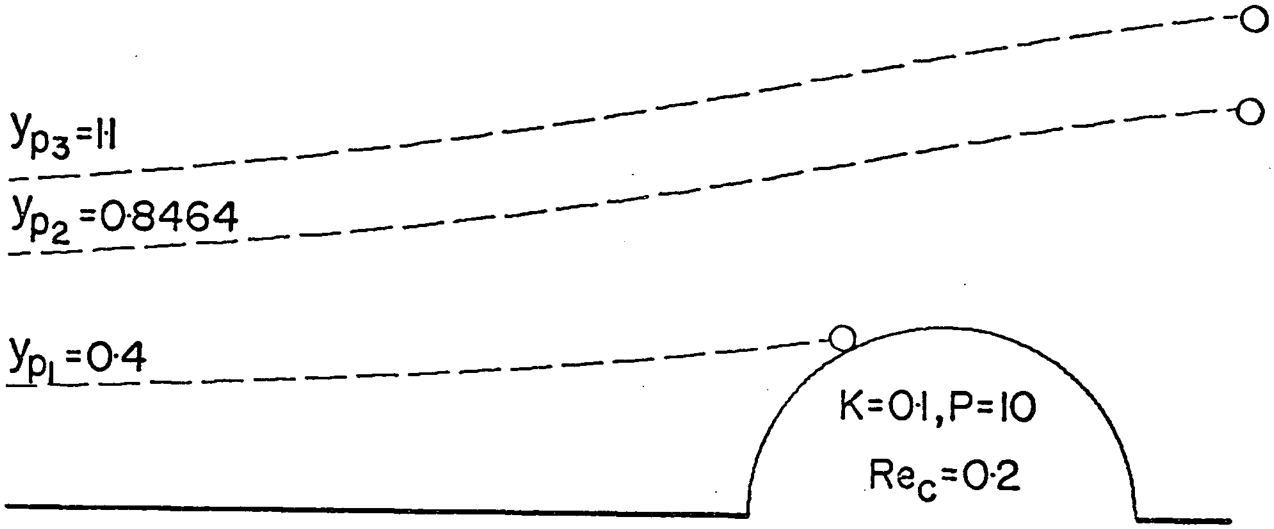


Figure 4-1. Particle trajectories for R_∞ = 100.

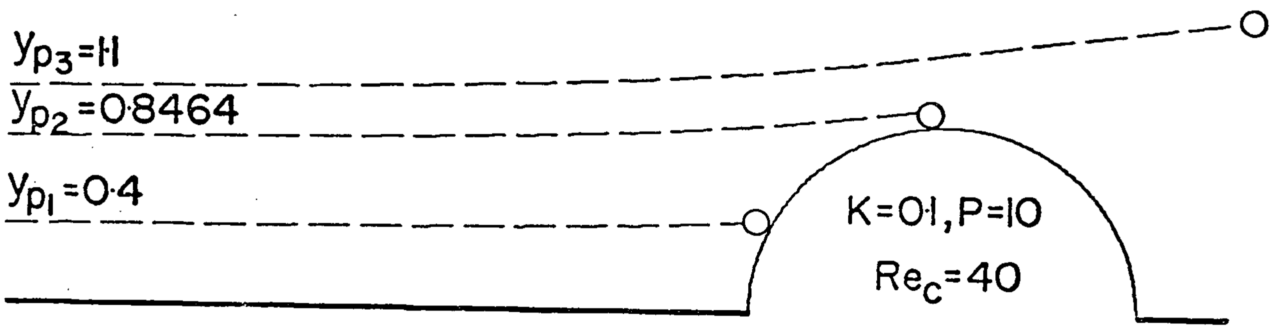


Figure 4-2. Particle trajectories for R_∞ = 100.

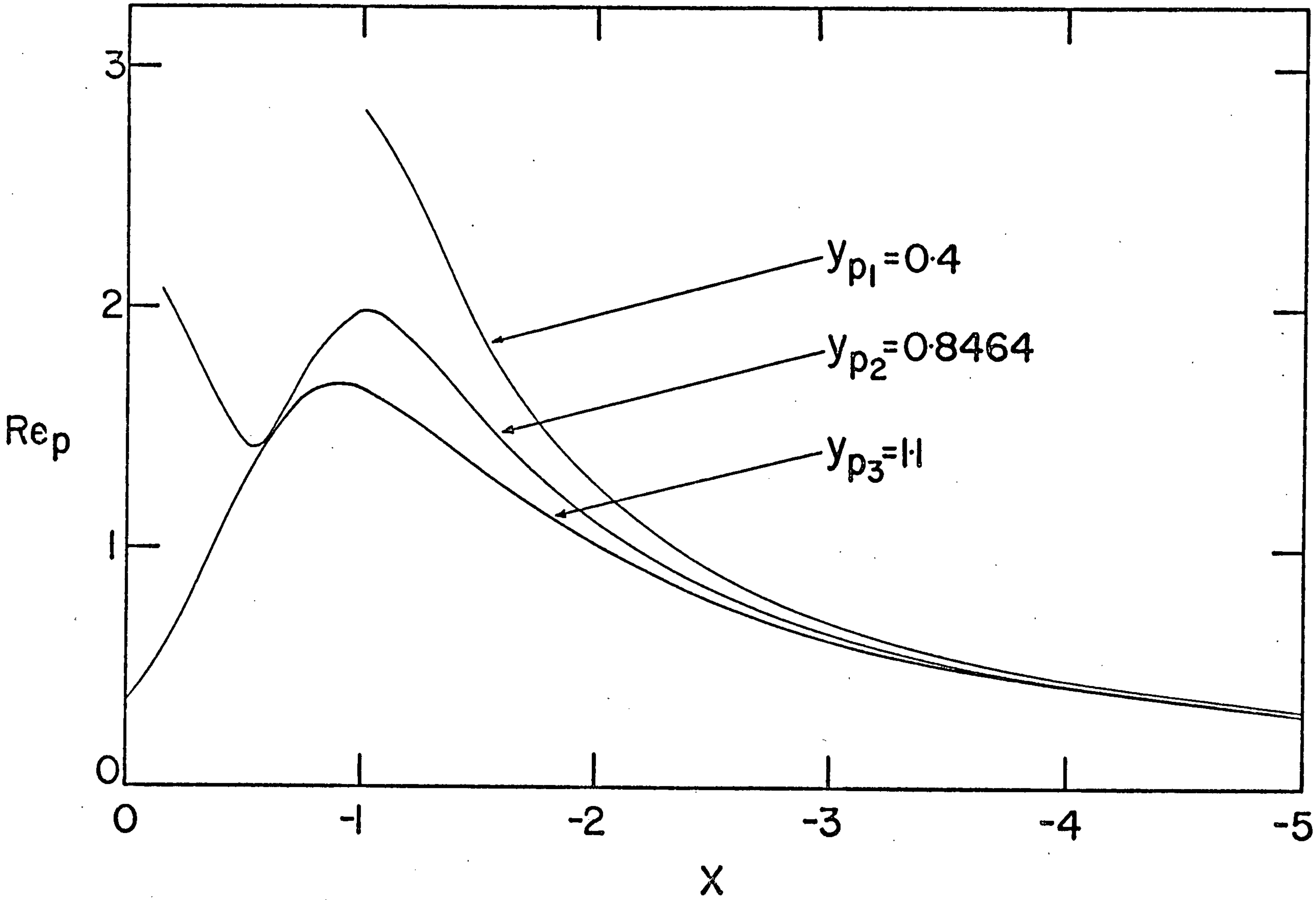


Figure 4-3. Particle Reynolds number as a function of x and starting position, y_p (K = 0.1, P = 10, Re_c = 40, R_∞ = 100.

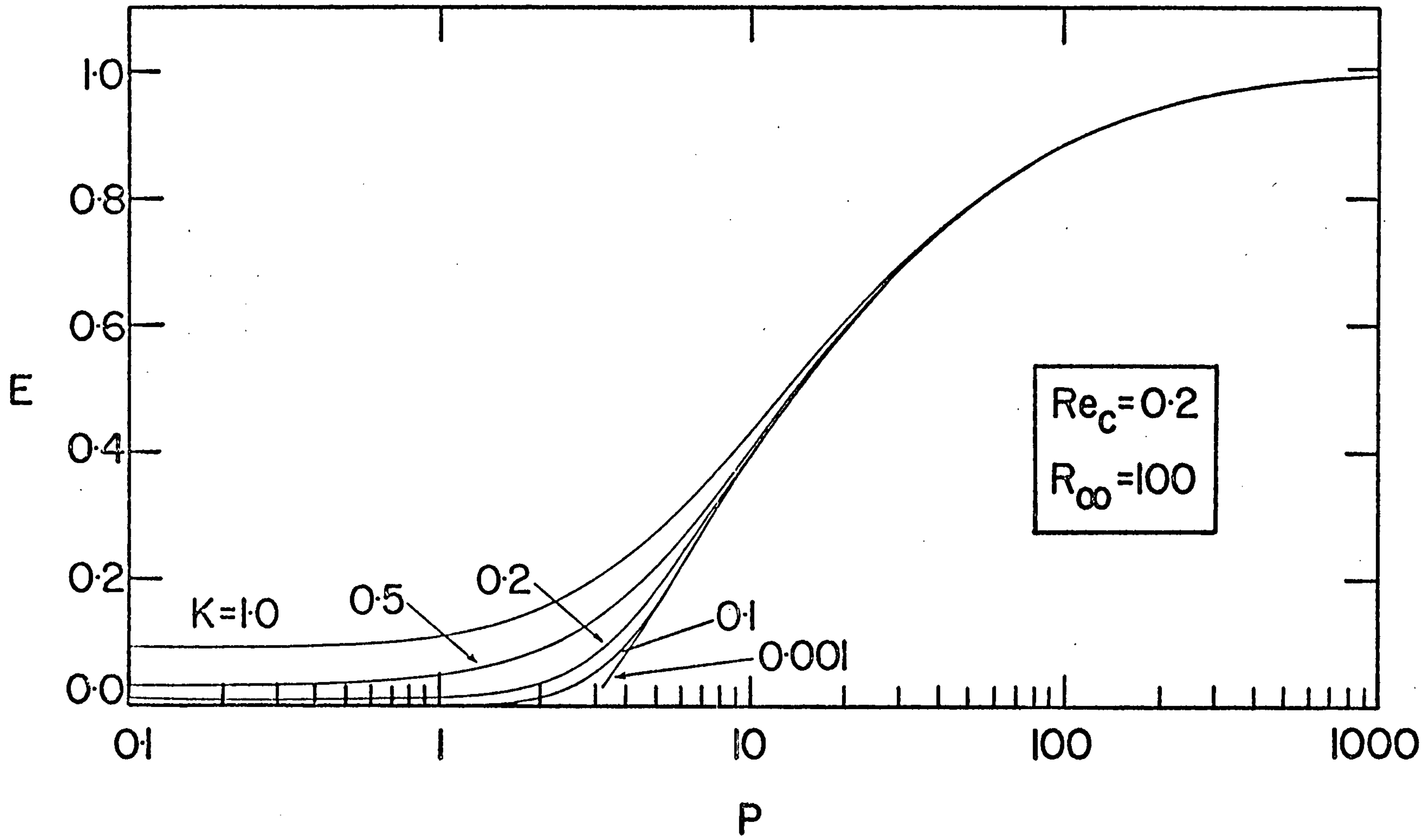


Figure 4-4. Impaction efficiency as a function of inertial parameter.

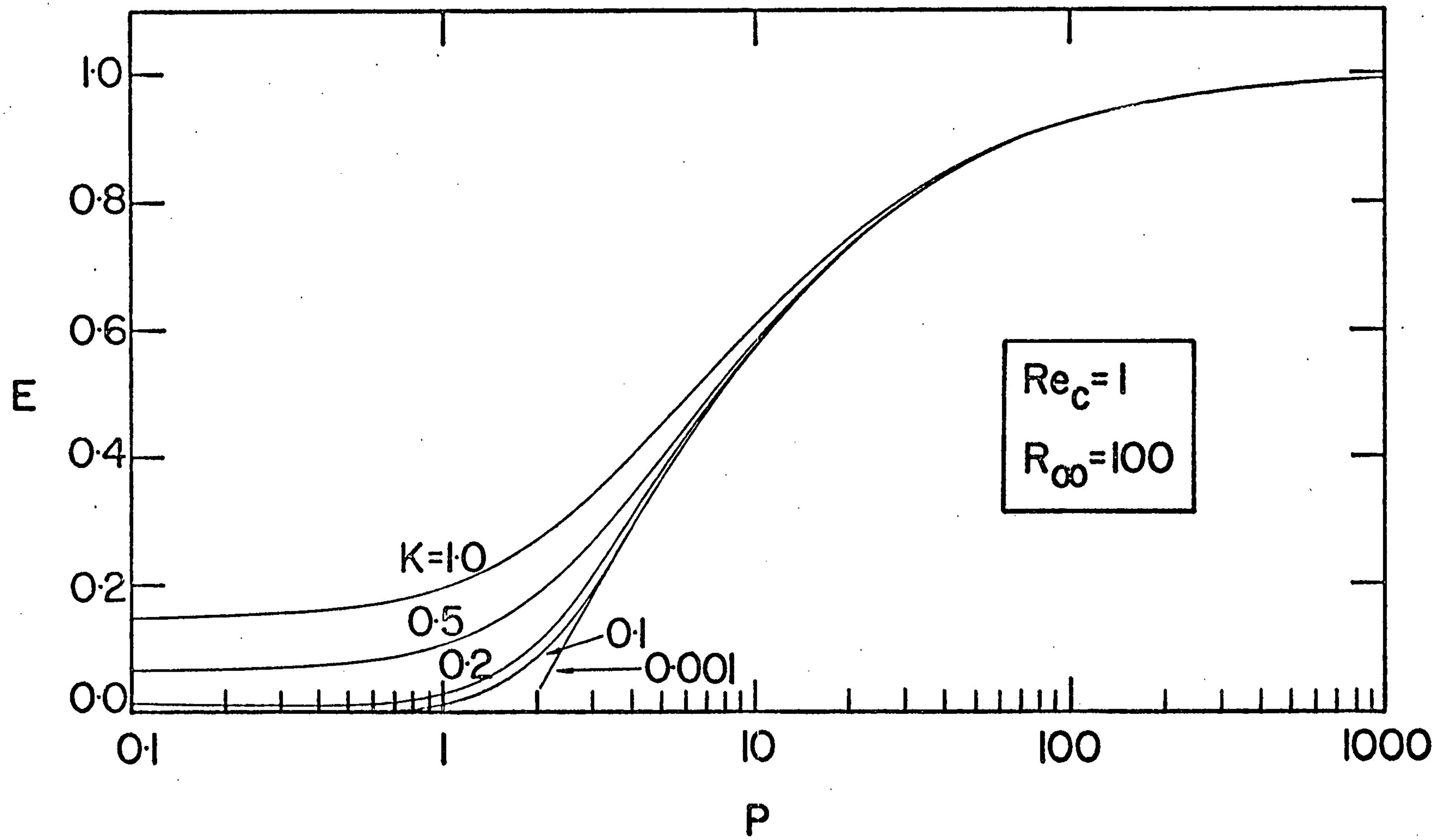


Figure 4-5. Impaction efficiency as a function of inertial parameter.

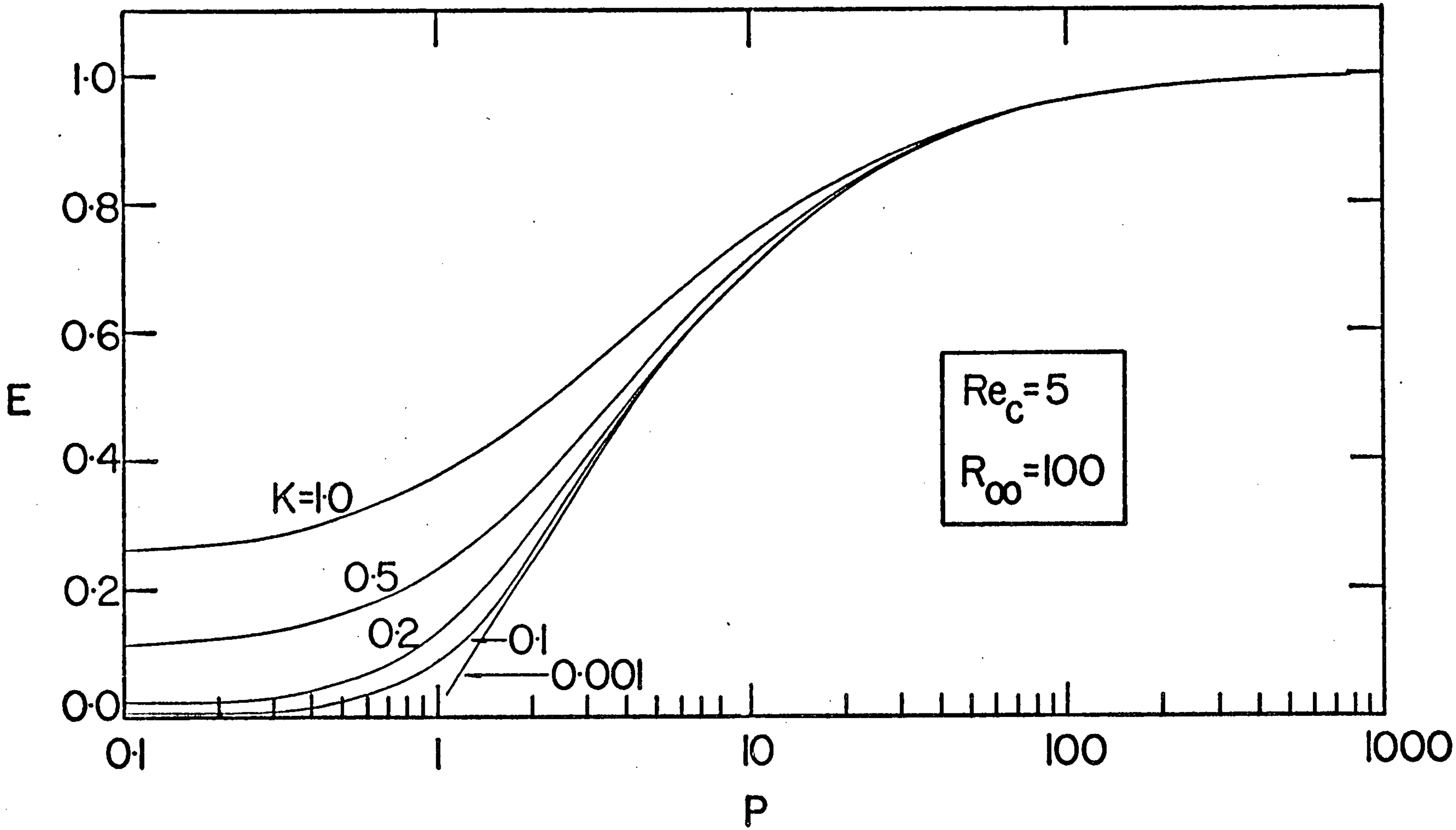


Figure 4-6. Impaction efficiency as a function of inertial parameter.

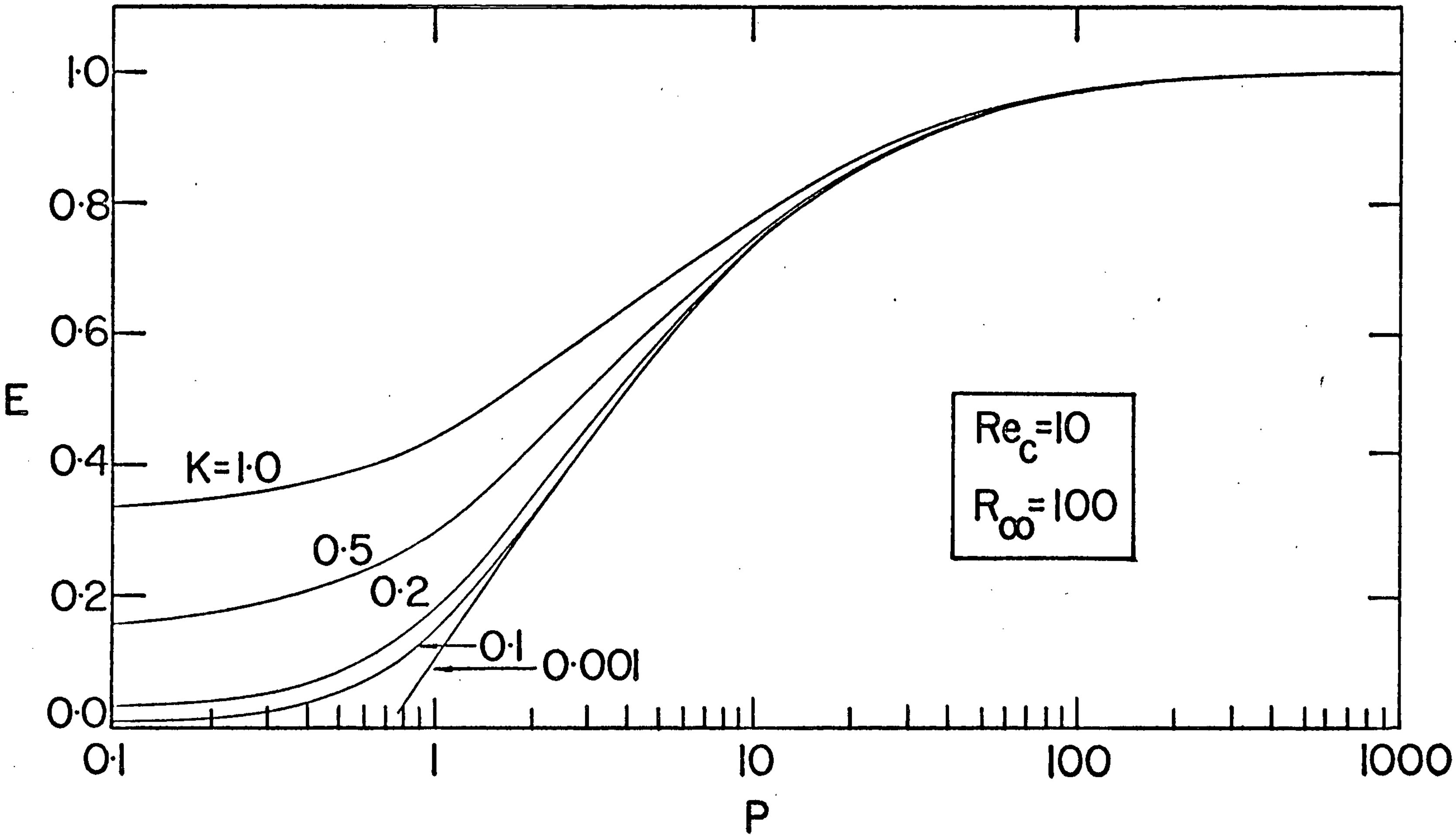


Figure 4-7. Impaction efficiency as a function of inertial parameter.

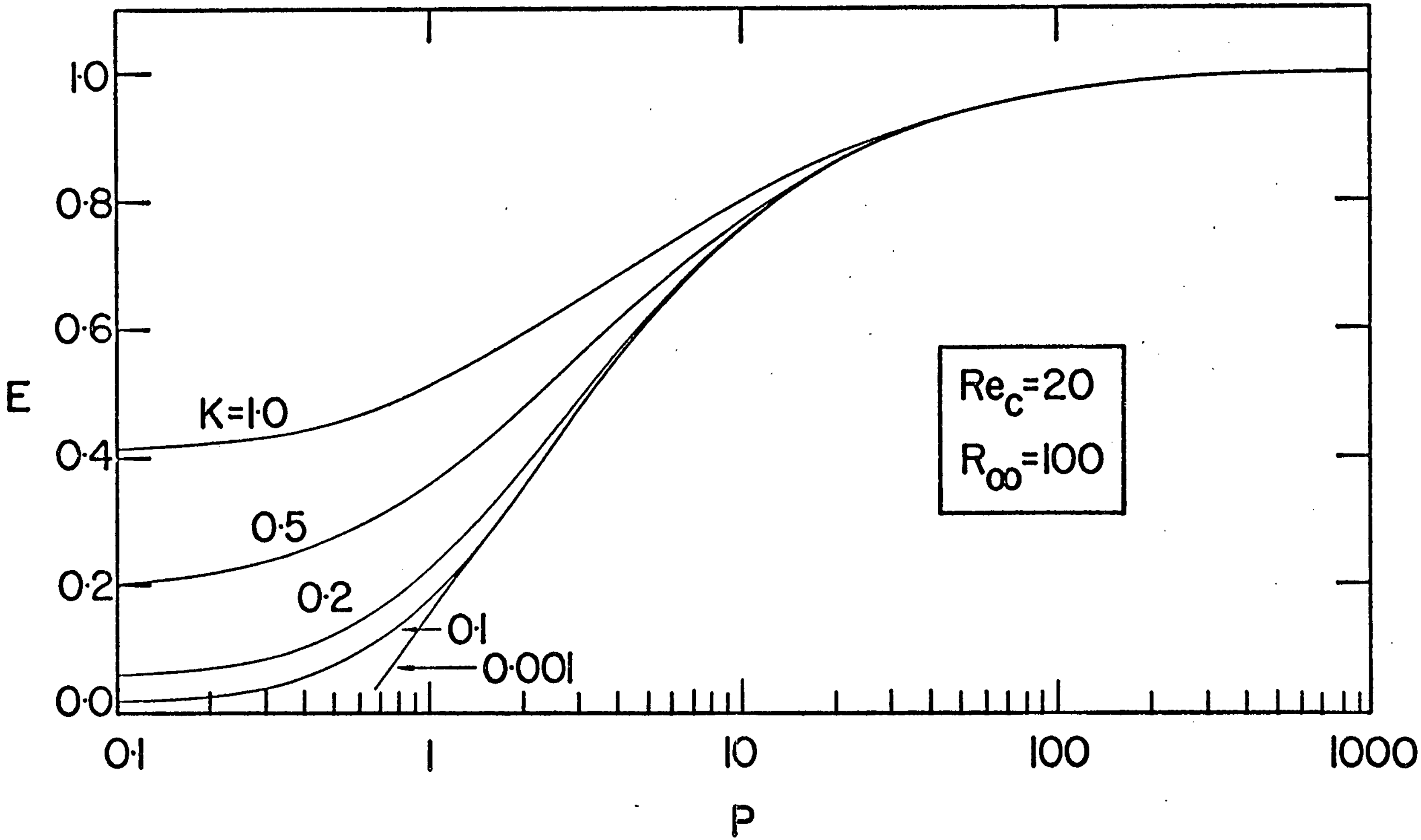


Figure 4-8. Impaction efficiency as a function of inertial parameter.

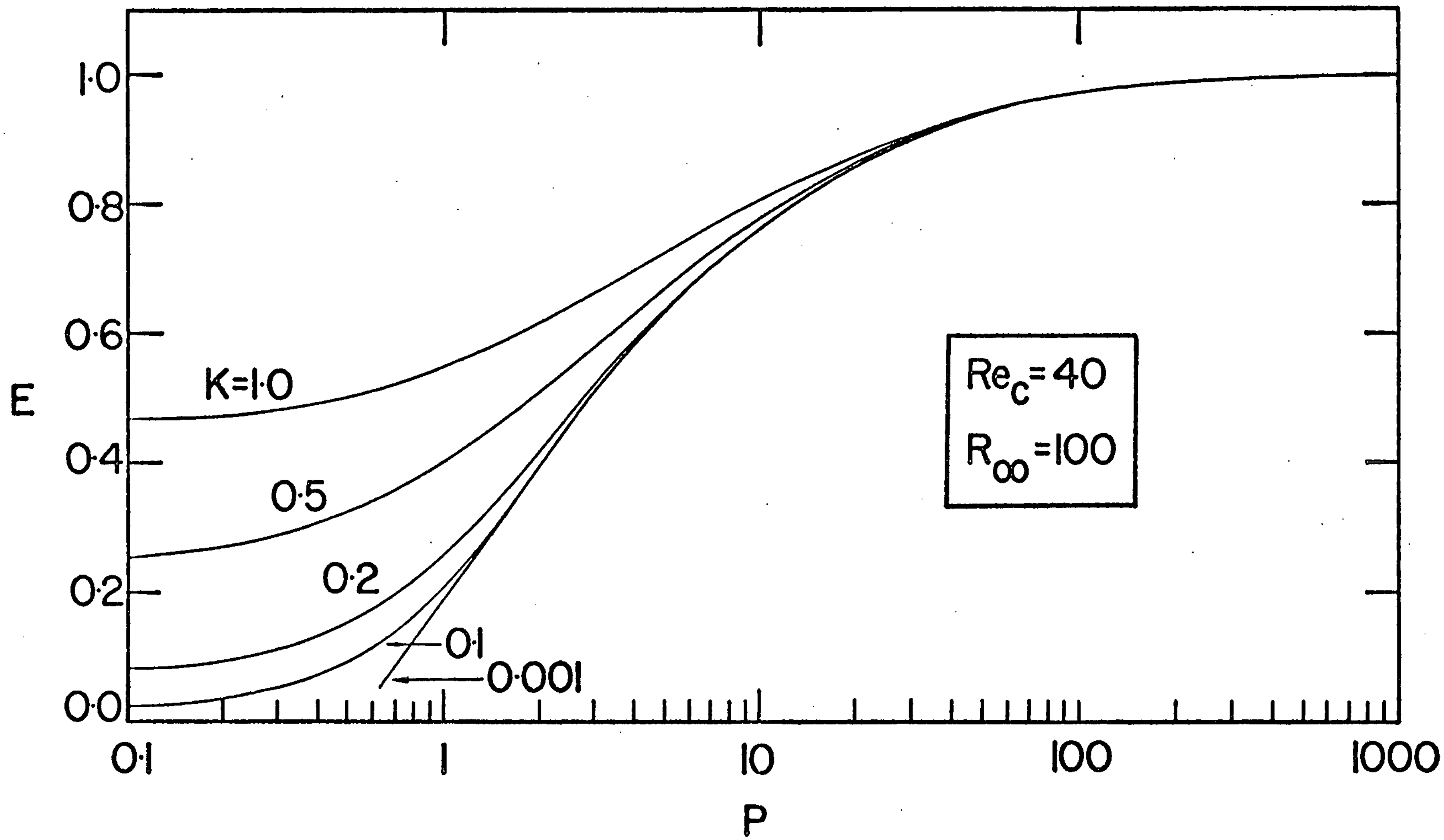


Figure 4-9. Impaction efficiency as a function of inertial parameter.

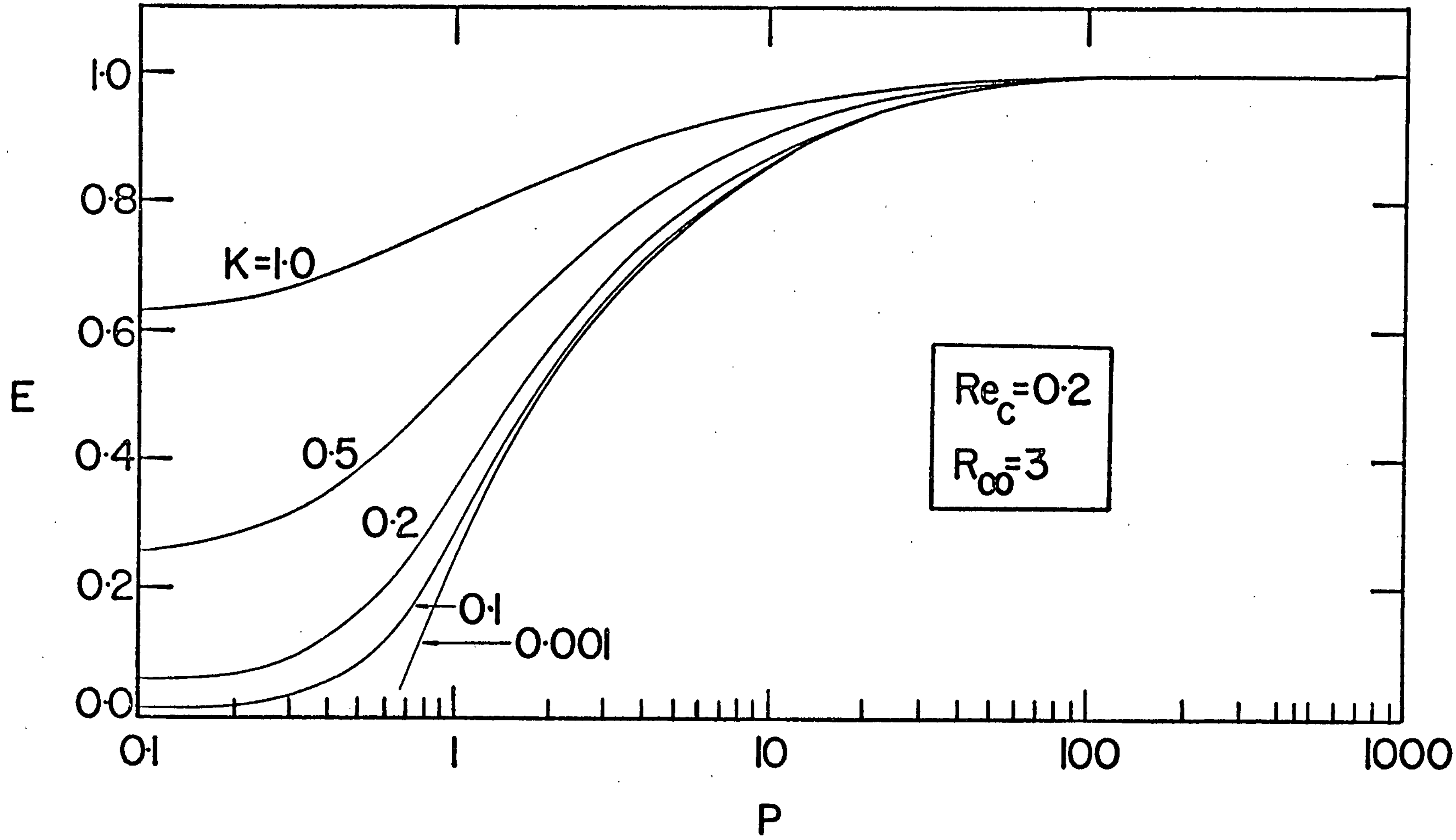


Figure 4-10. Impaction efficiency as a function of inertial parameter.

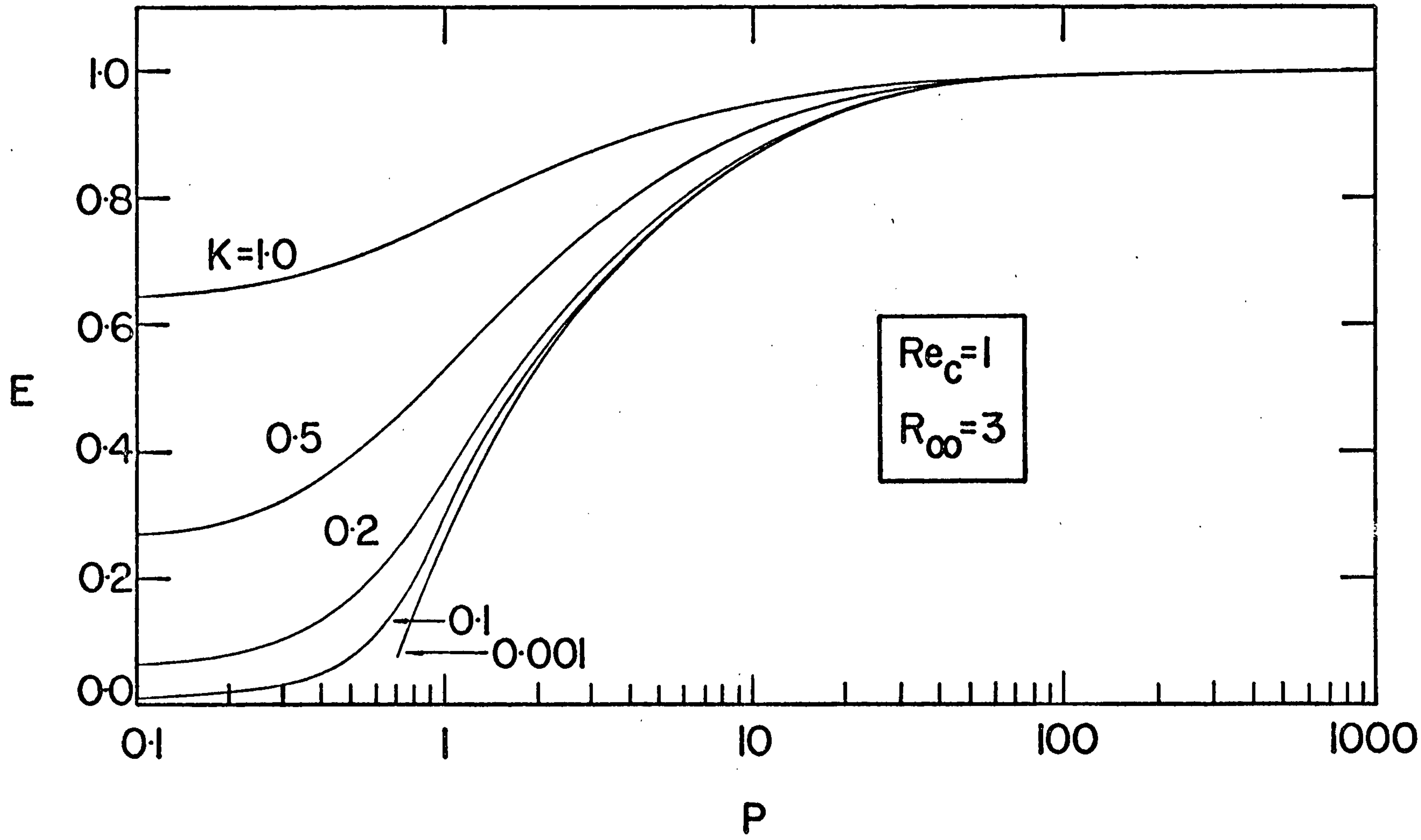


Figure 4-11. Impaction efficiency as a function of inertial parameter.

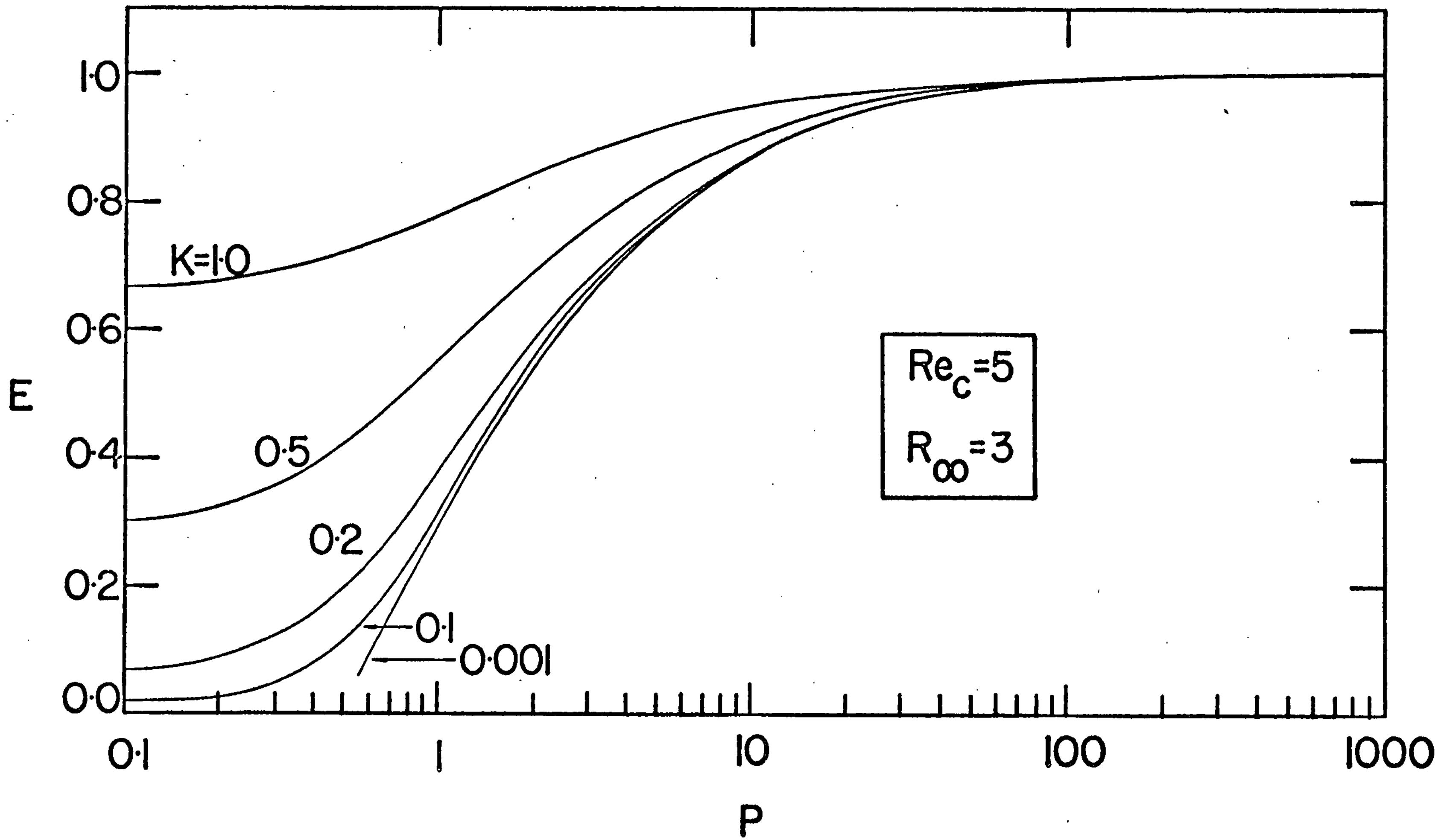


Figure 4-12. Impaction efficiency as a function of inertial parameter.

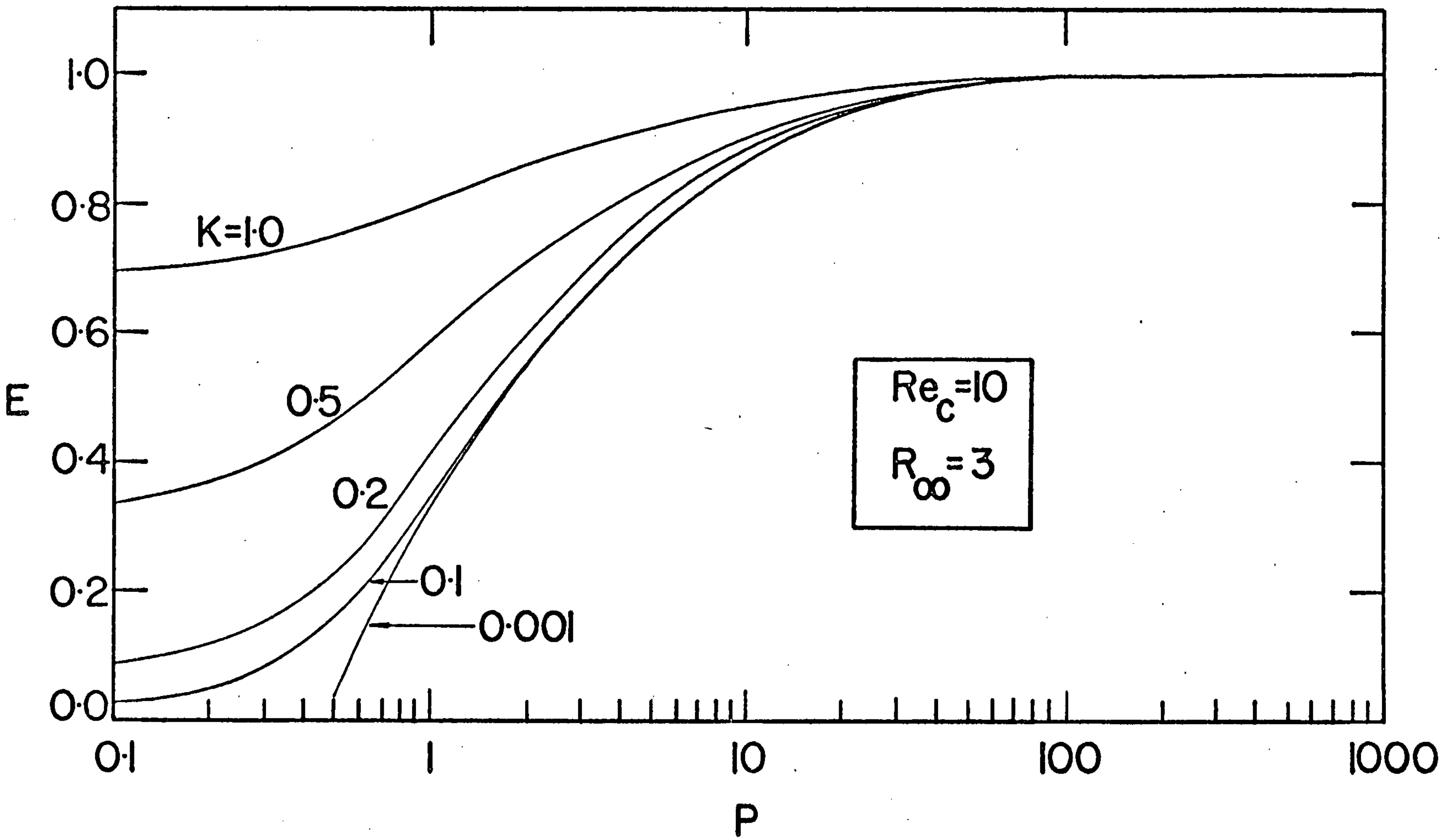


Figure 4-13. Impaction efficiency as a function of inertial parameter.

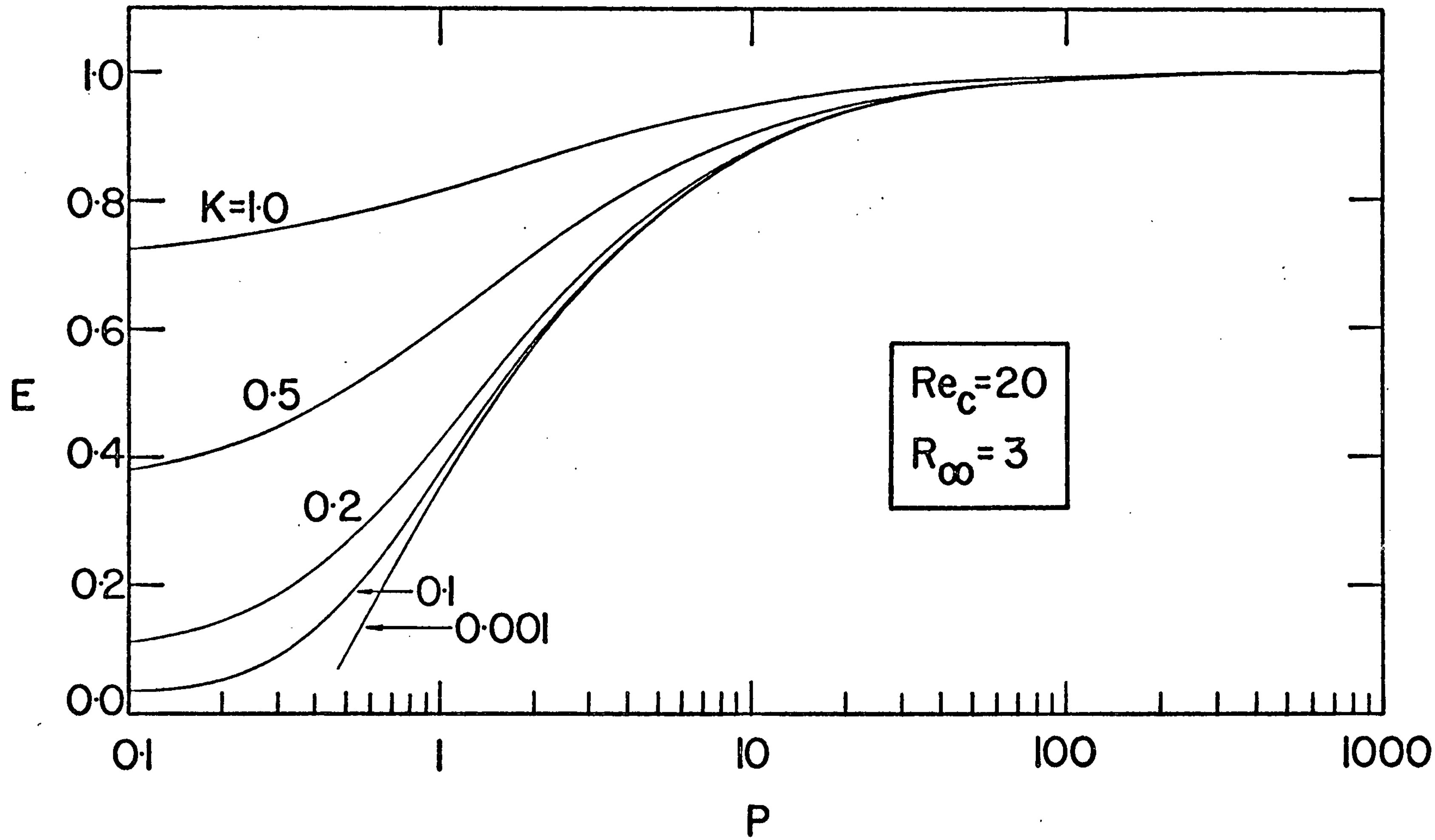


Figure 4-14. Impaction efficiency as a function of inertial parameter.

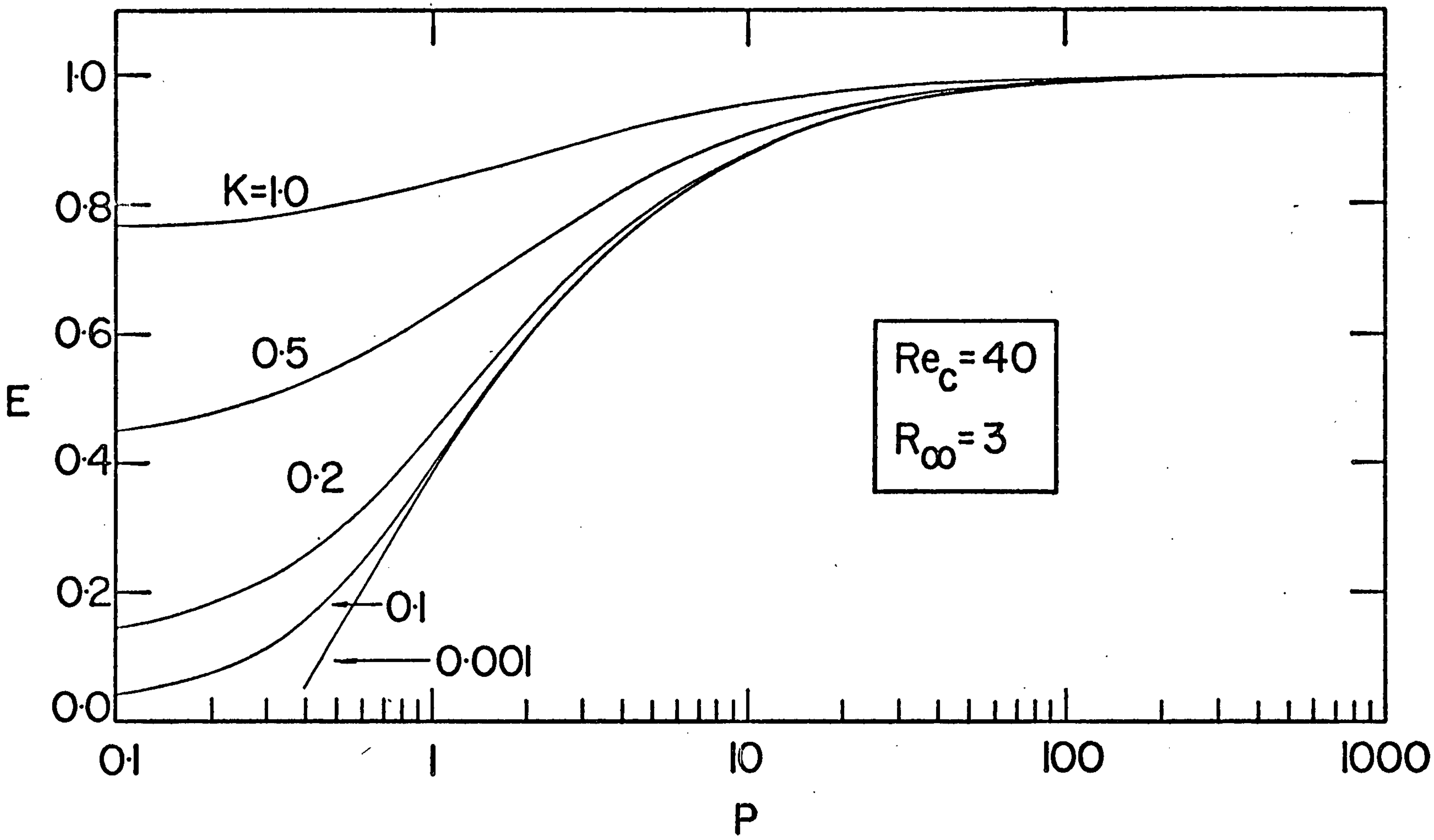


Figure 4-15. Impaction efficiency as a function of inertial parameter.

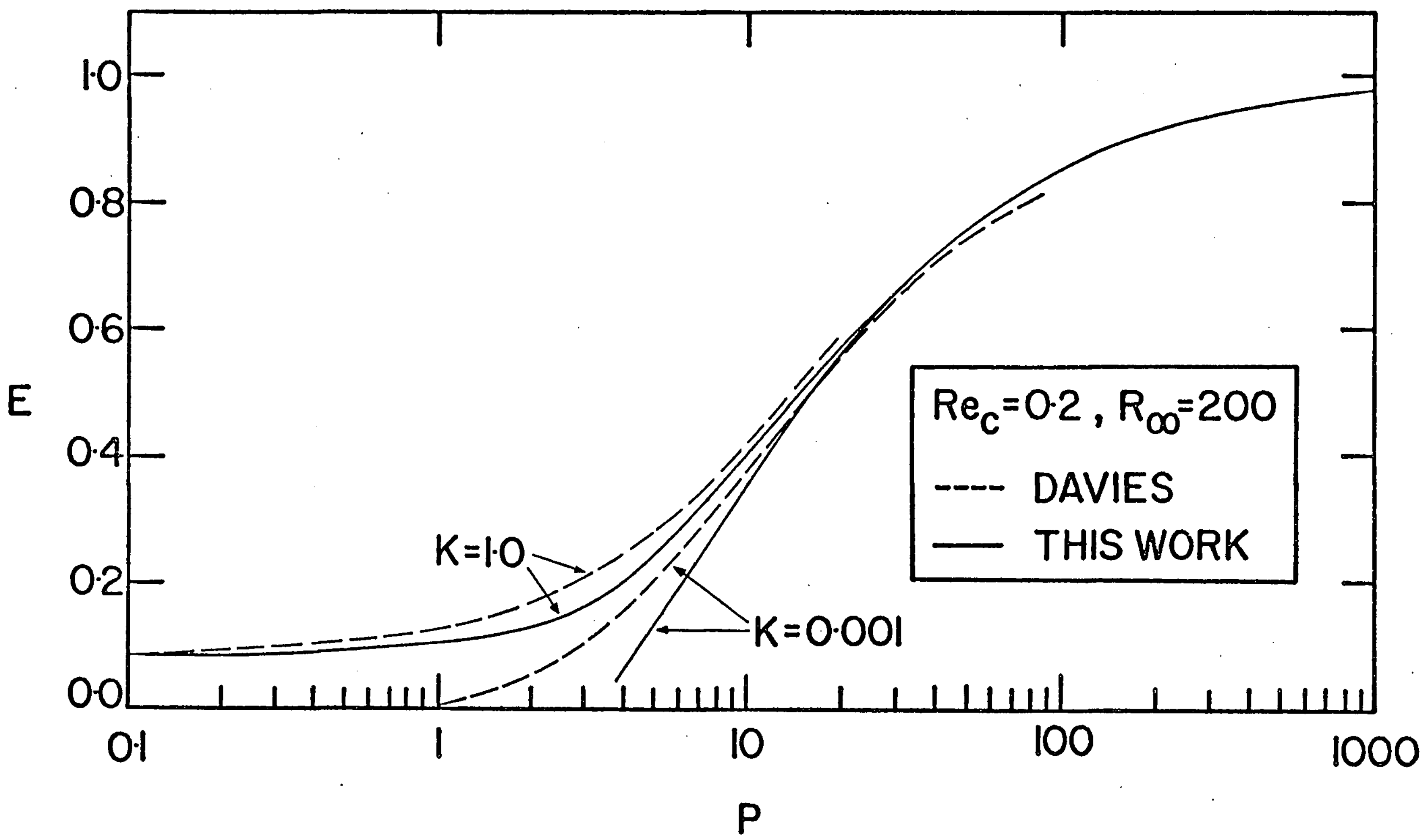


Figure 4-16. Comparison of impaction efficiencies as predicted by: (i) Davies and Peetz [7], (ii) this work.

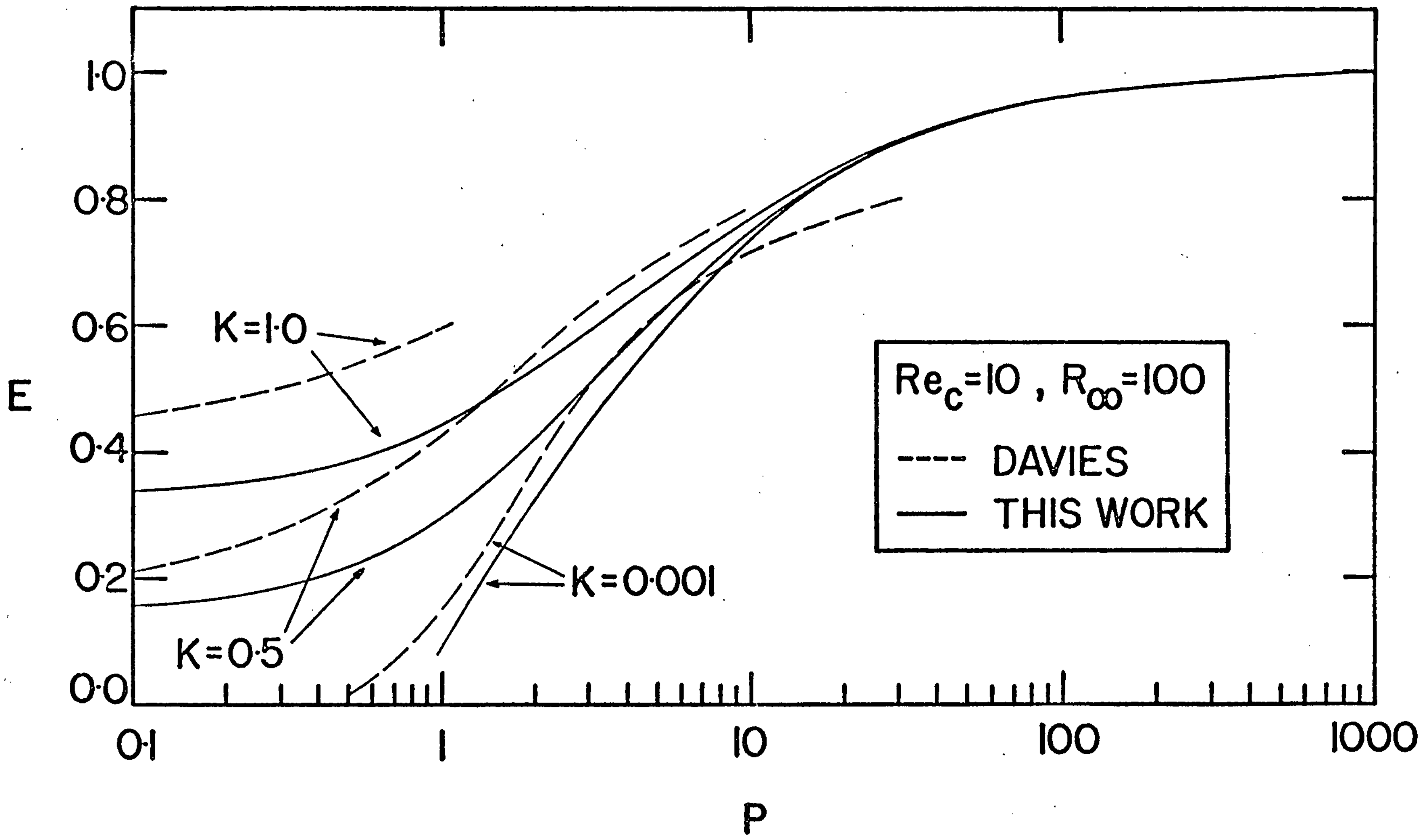


Figure 4-17. Comparison if impaction efficiencies as predicted by: (i) Davies and Peetz [7], (ii) this work.

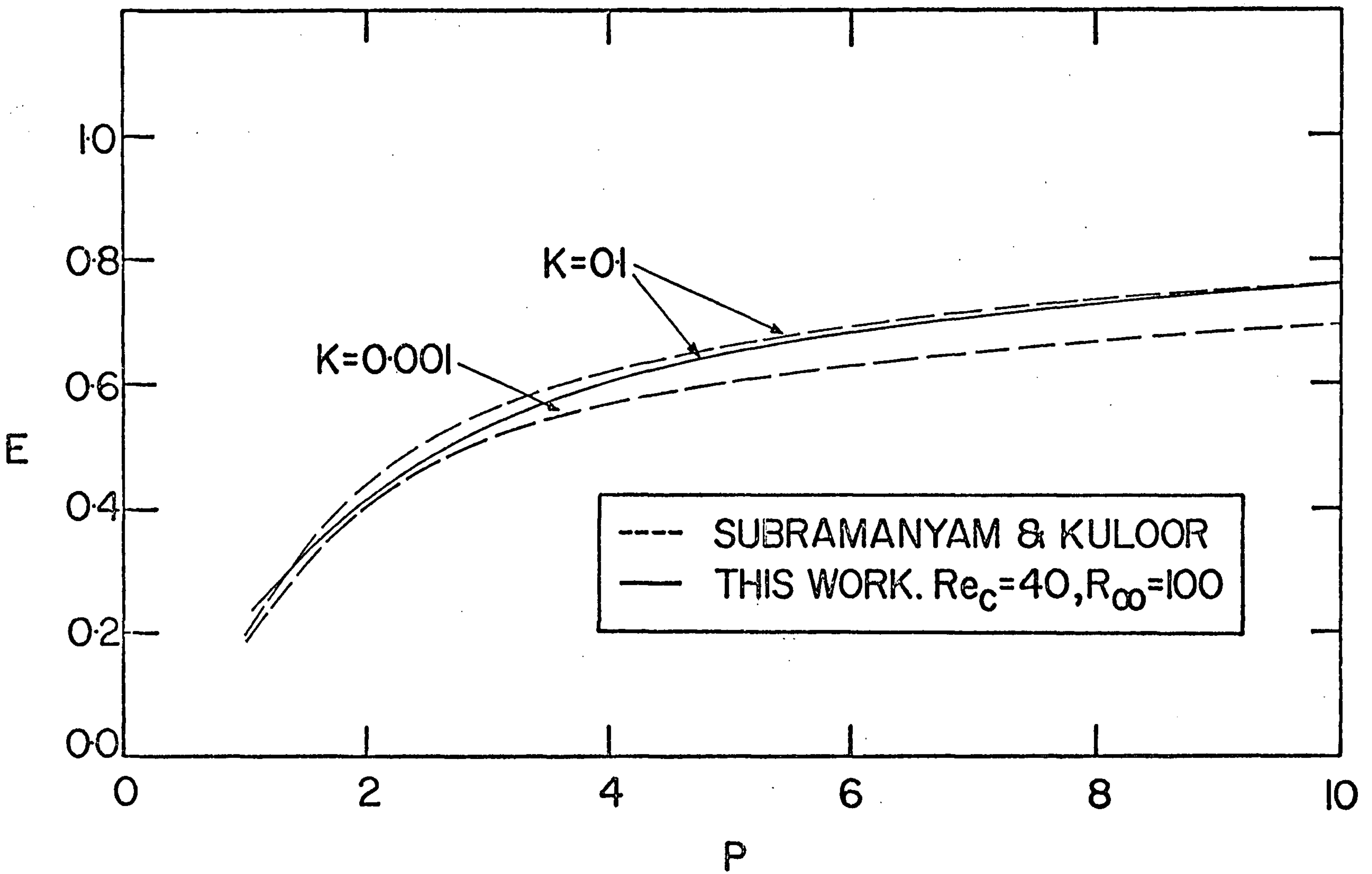


Figure 4-18. Comparison of impaction efficiencies as given by:
(i) Subramanyam and Kuloor [12] (experimental),
(ii) this work.

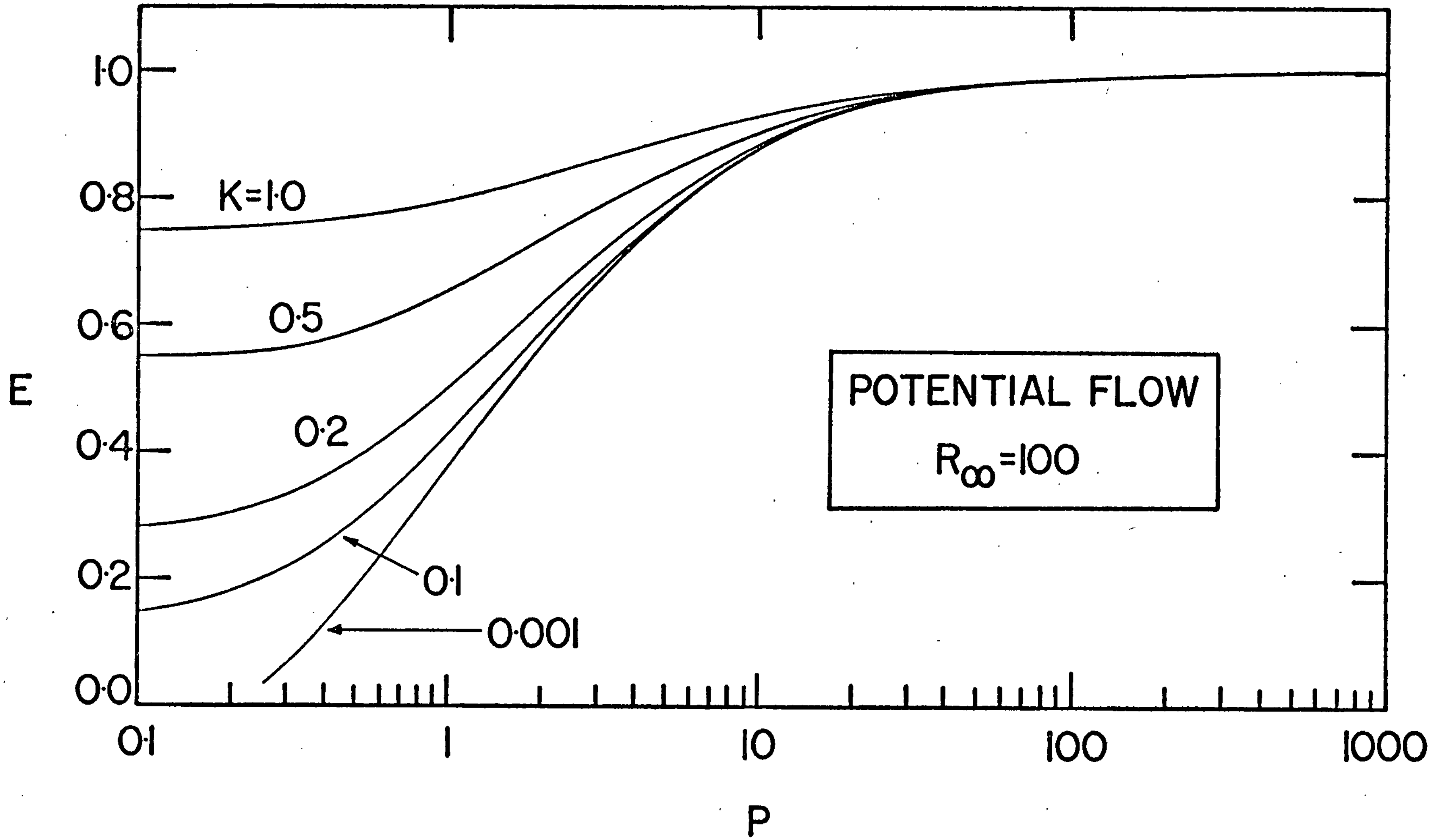


Figure 4-19. Impaction efficiency as a function of inertial parameter for potential flow.

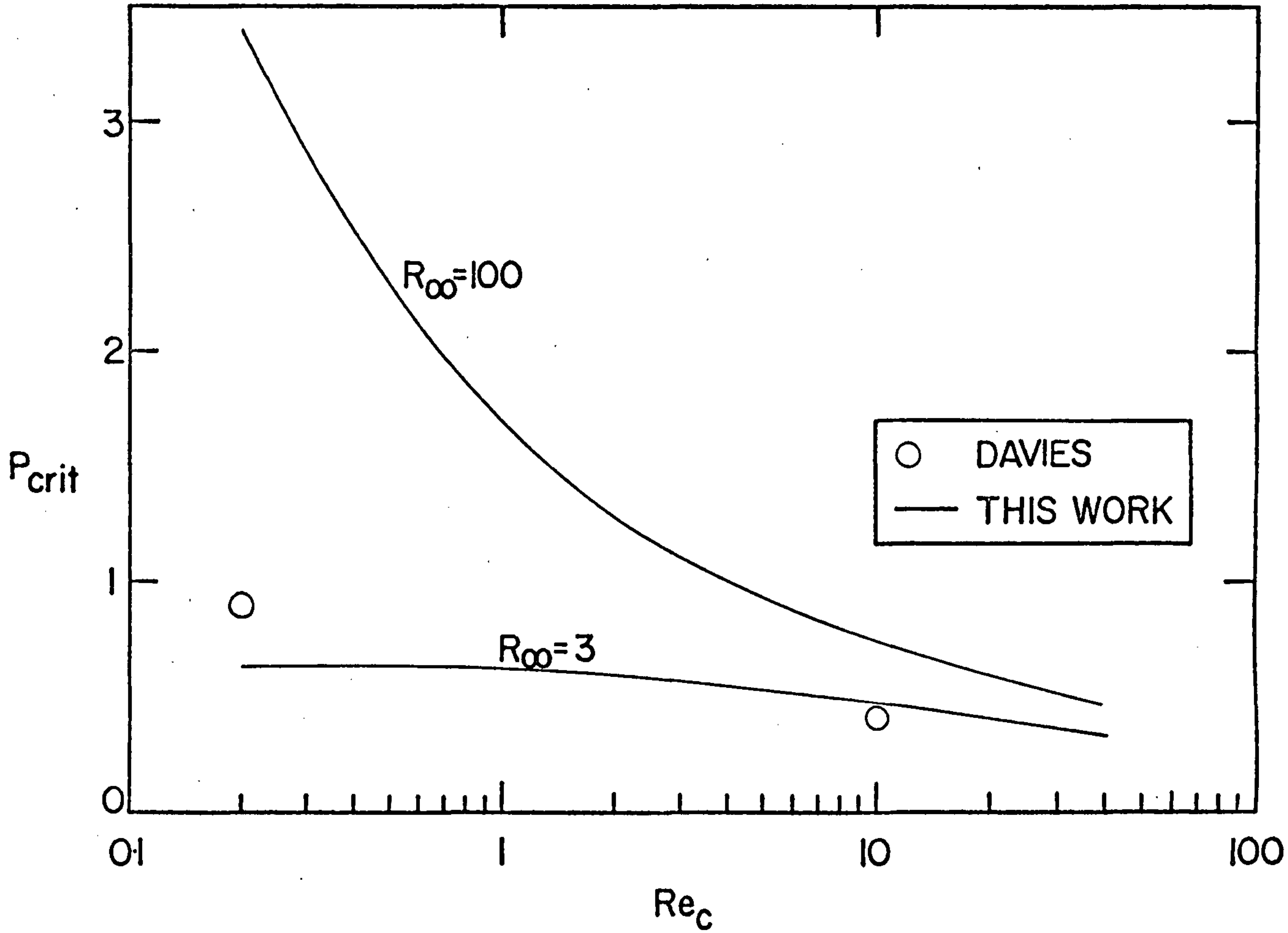


Figure 4-20. Critical inertial parameter as a function of Reynolds number.

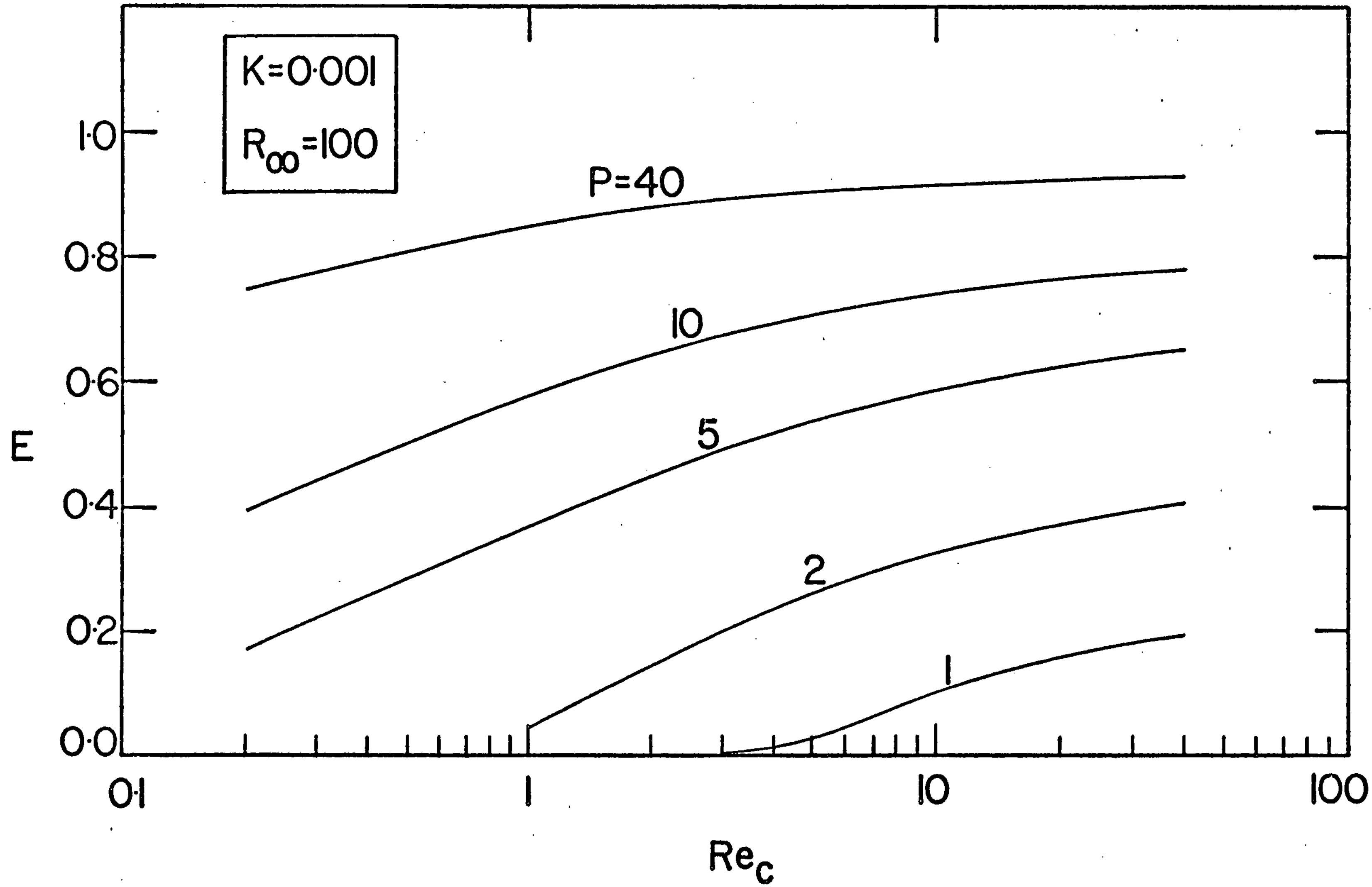


Figure 4-21. Impaction efficiency as a function of Reynolds number.

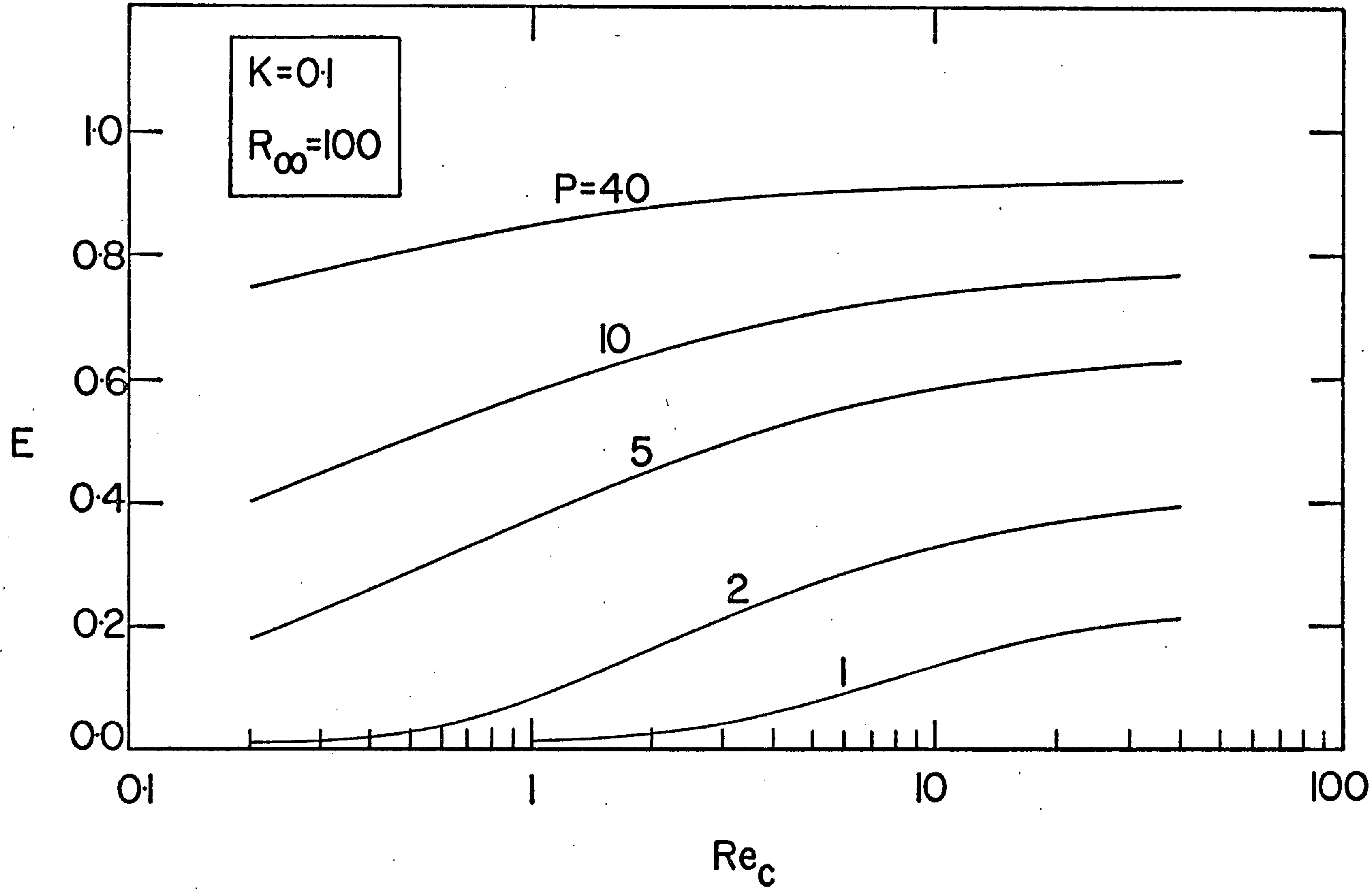


Figure 4-22. Impaction efficiency as a function of Reynolds number.

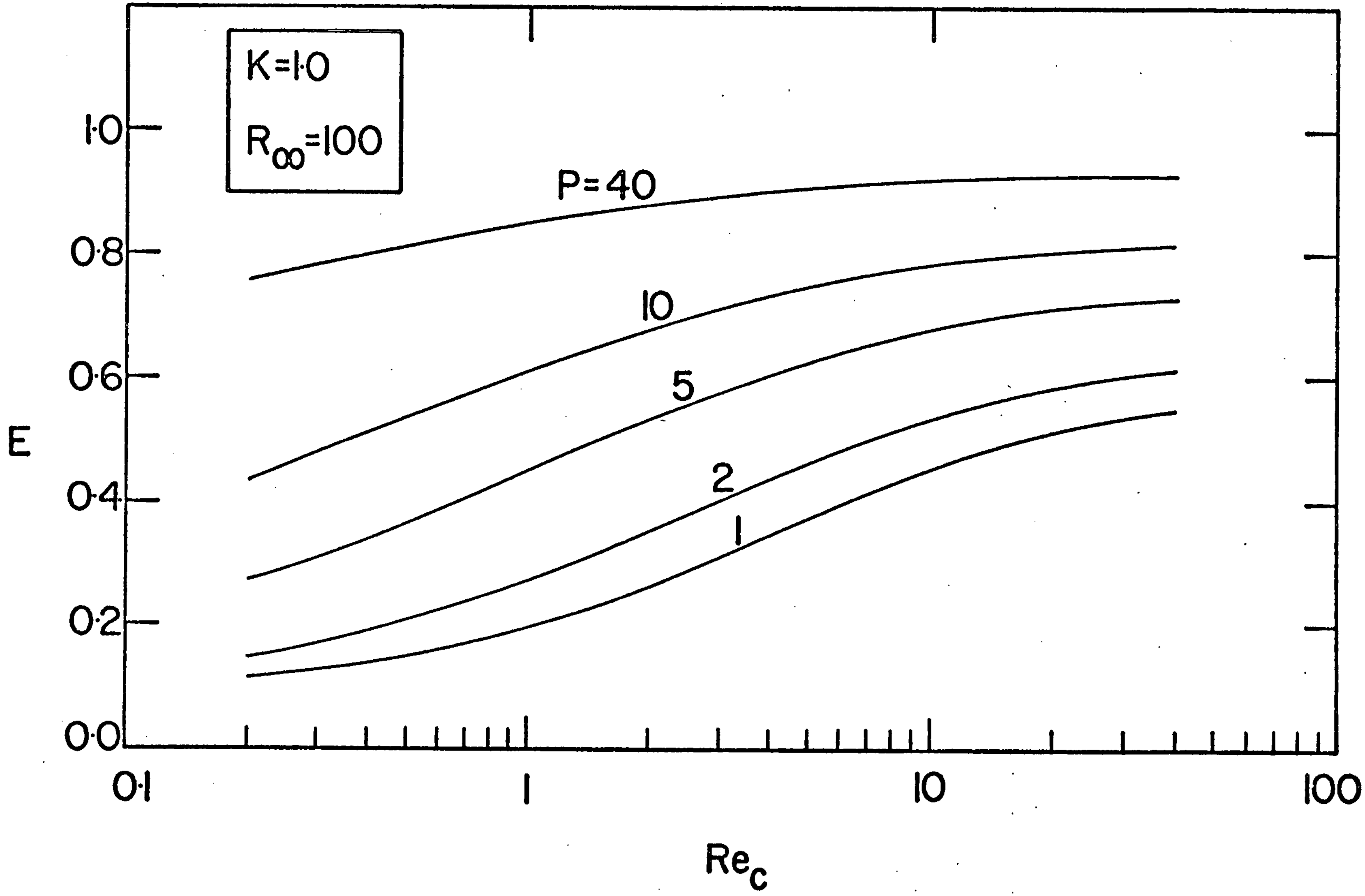


Figure 4-23. Impaction efficiency as a function of Reynolds number.

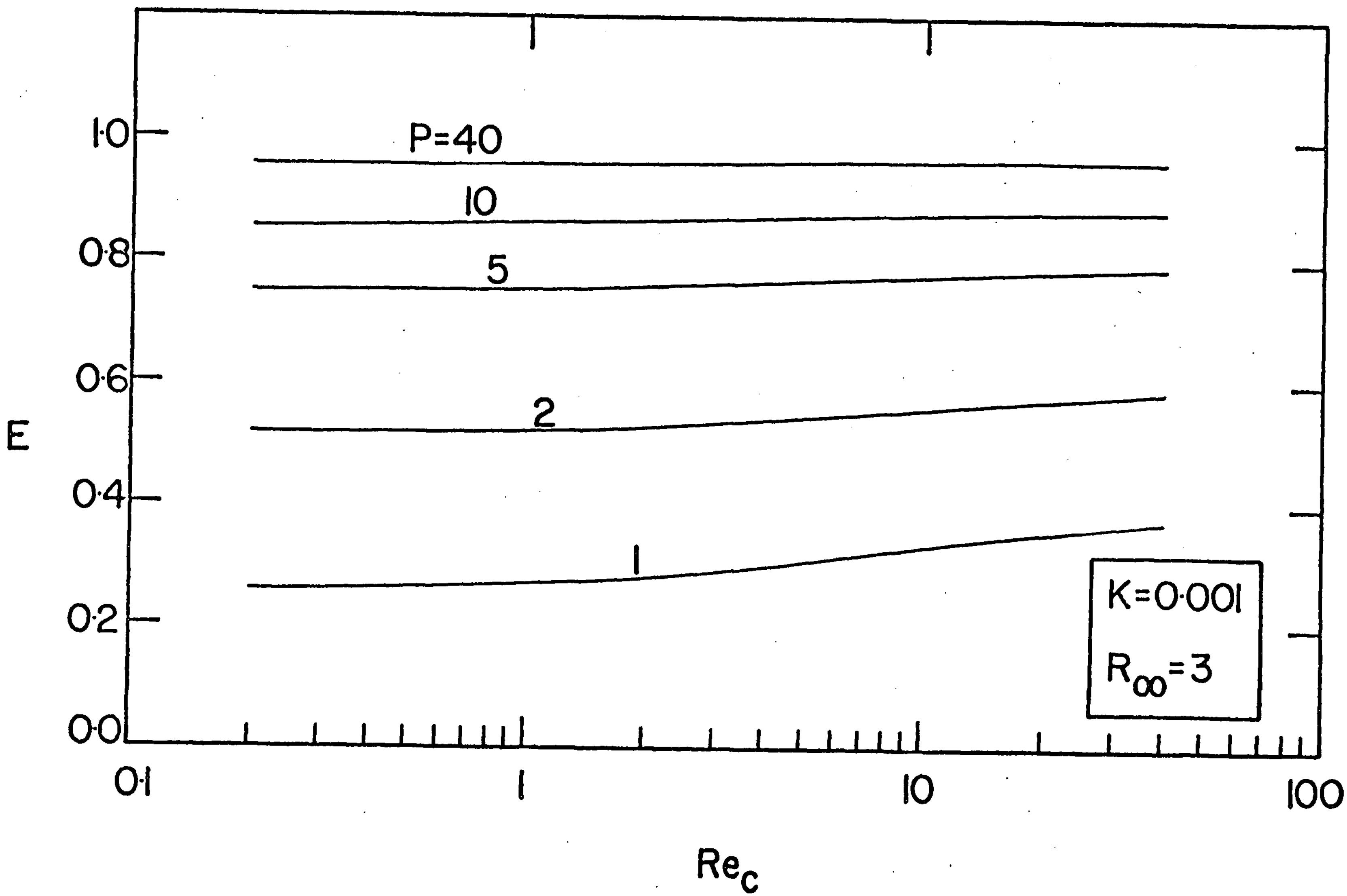


Figure 4-24. Impaction efficiency as a function of Reynolds number.

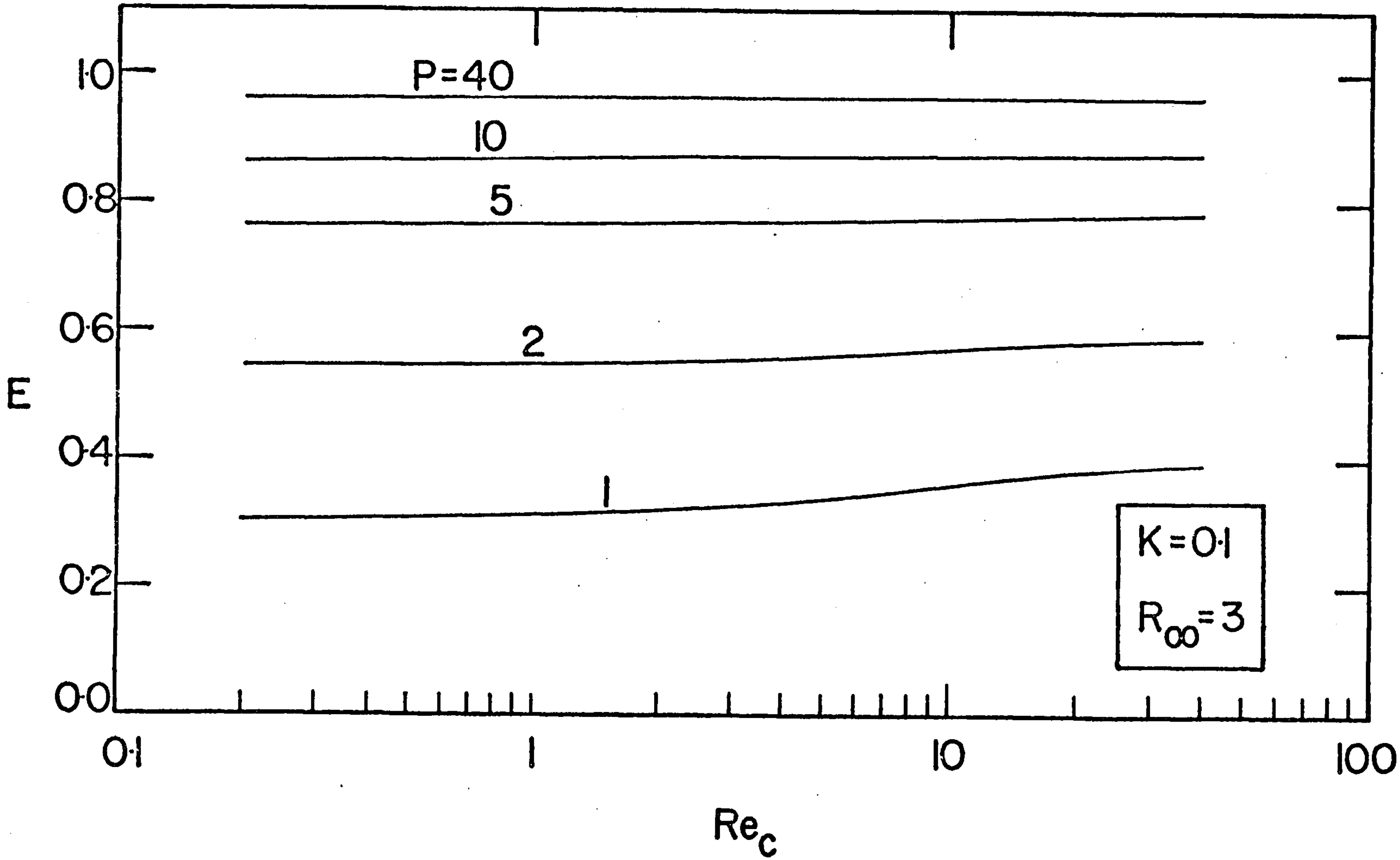


Figure 4-25. Impaction efficiency as a function of Reynolds number.

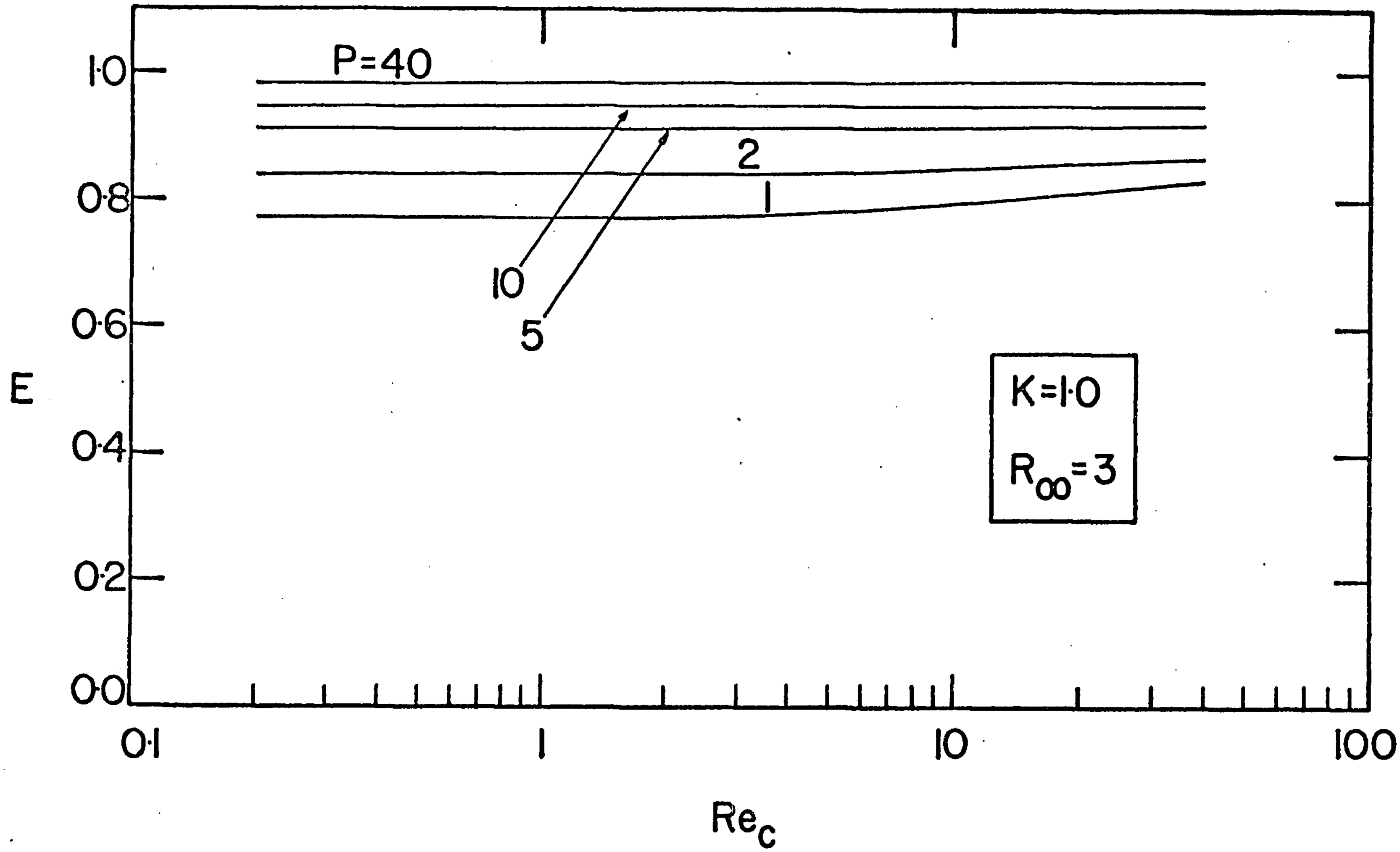


Figure 4-26. Impaction efficiency as a function of Reynolds number.

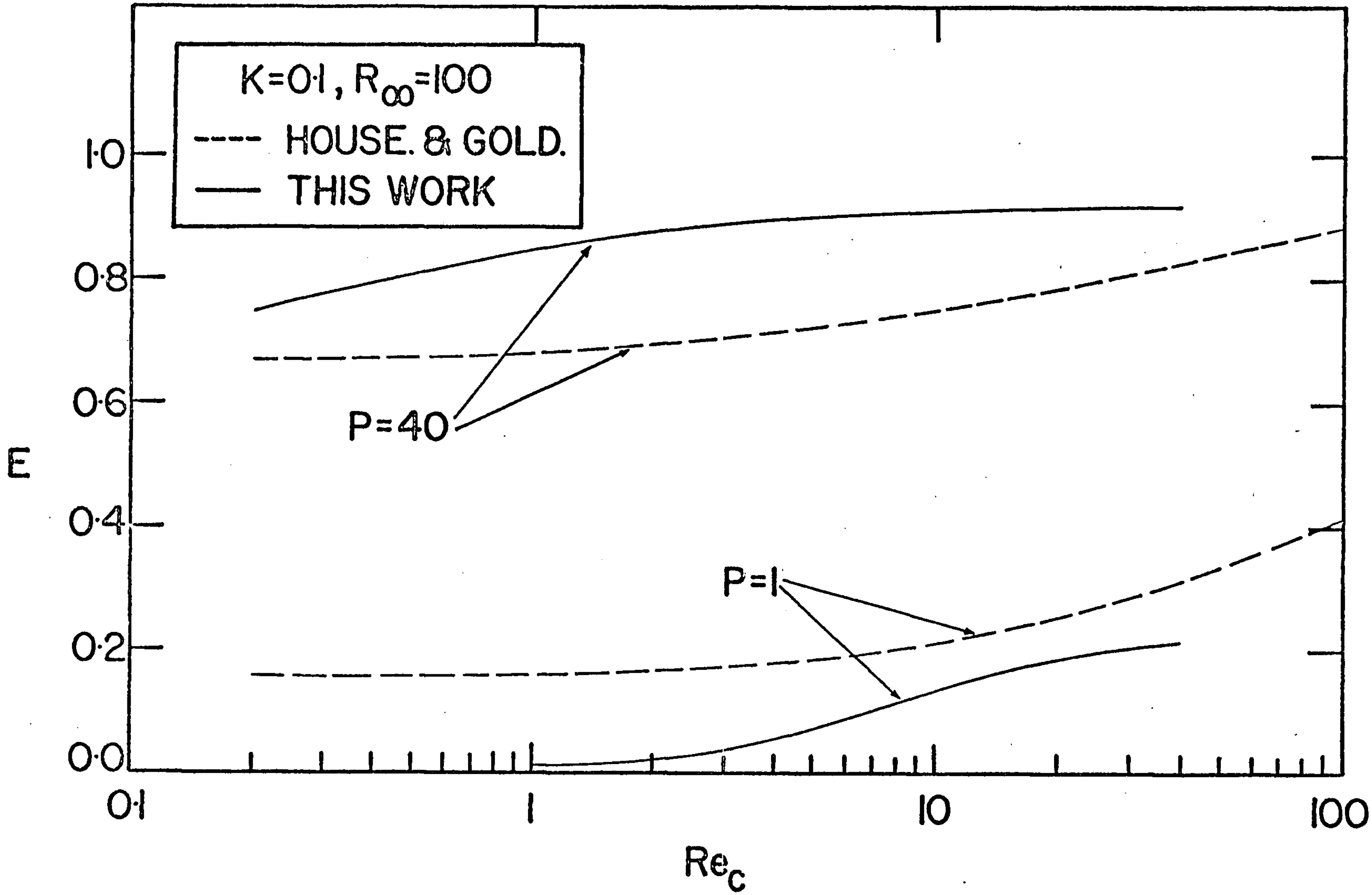


Figure 4-27. Comparison of impaction efficiencies predicted by: (i) Householder and Goldschmidt [13], (ii) this work.

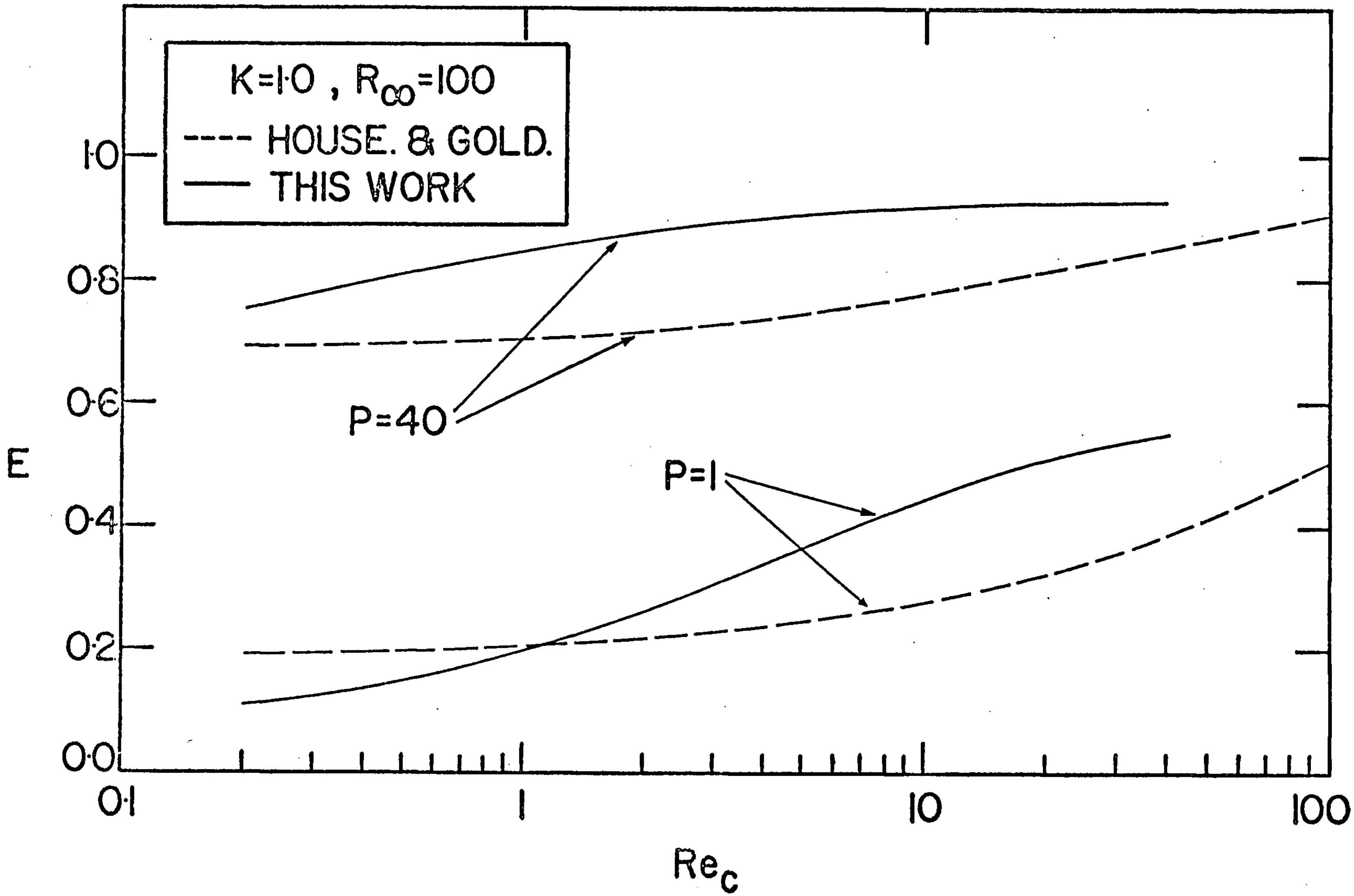


Figure 4-28. Comparison of impaction efficiencies predicted by: (i) Householder and Goldschmidt [13], (ii) this work.

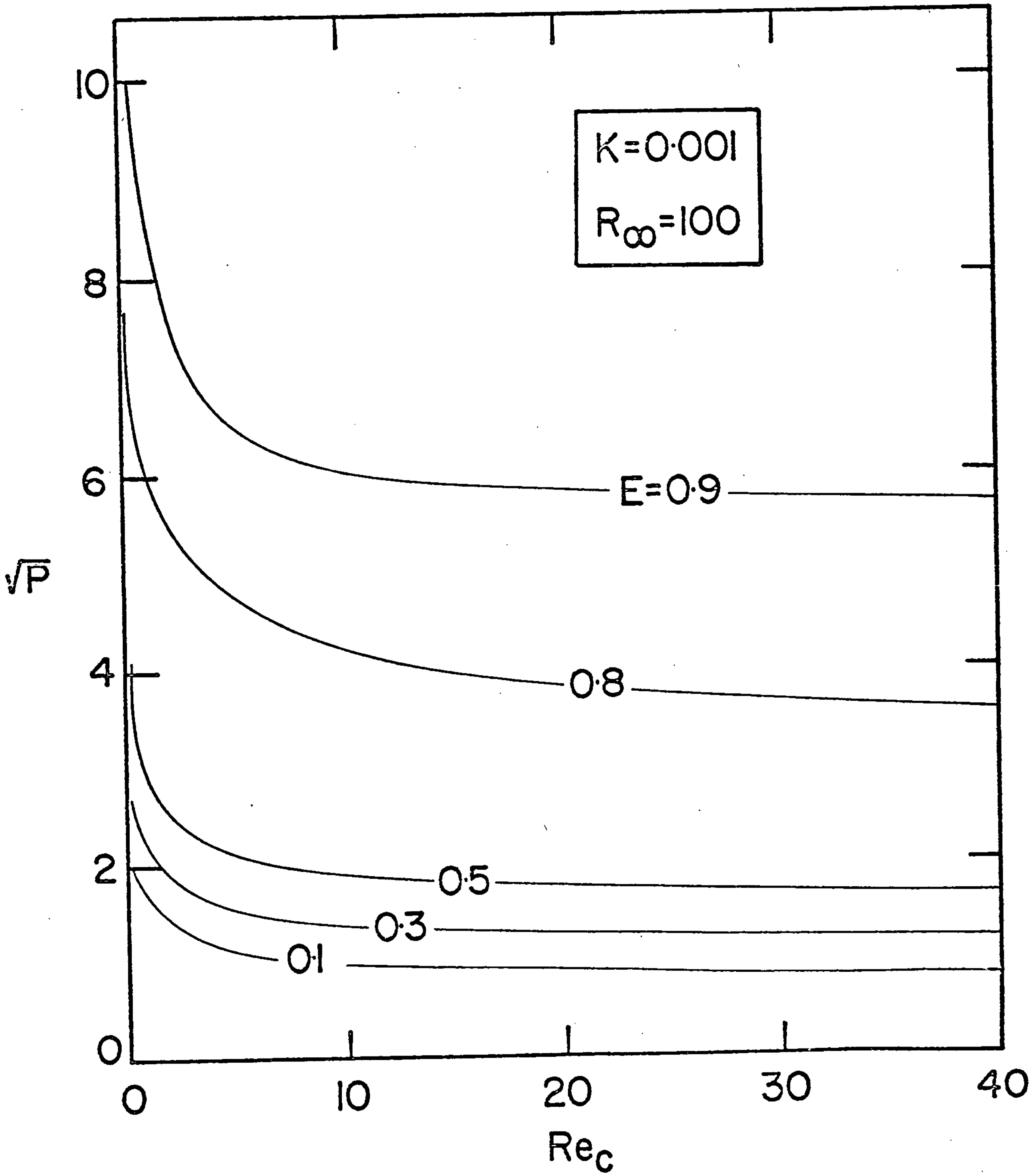


Figure 4-29. Impaction efficiency as a function of Reynolds number and inertial parameter.

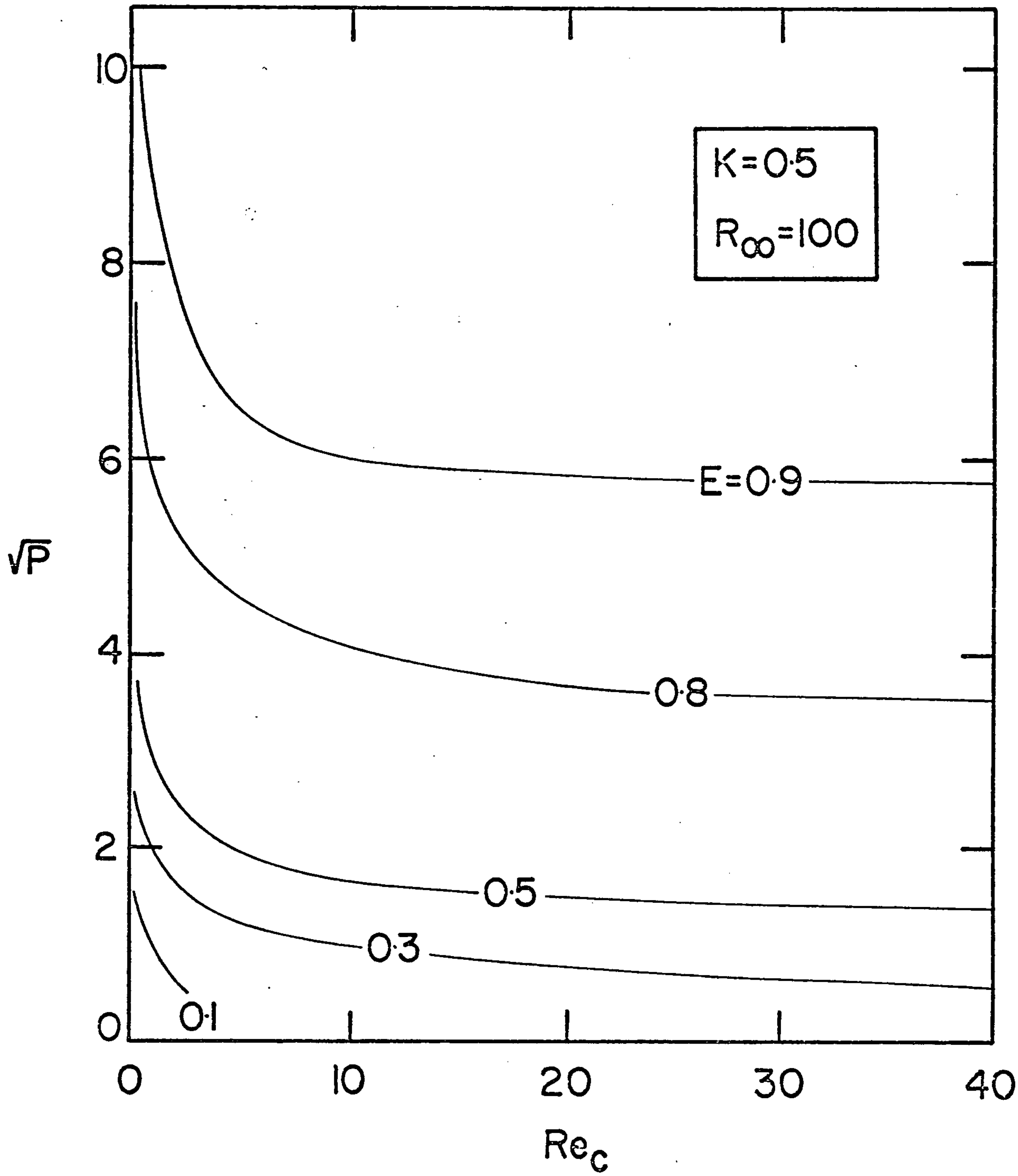


Figure 4-30. Impaction efficiency as a function of Reynolds number and inertial parameter.

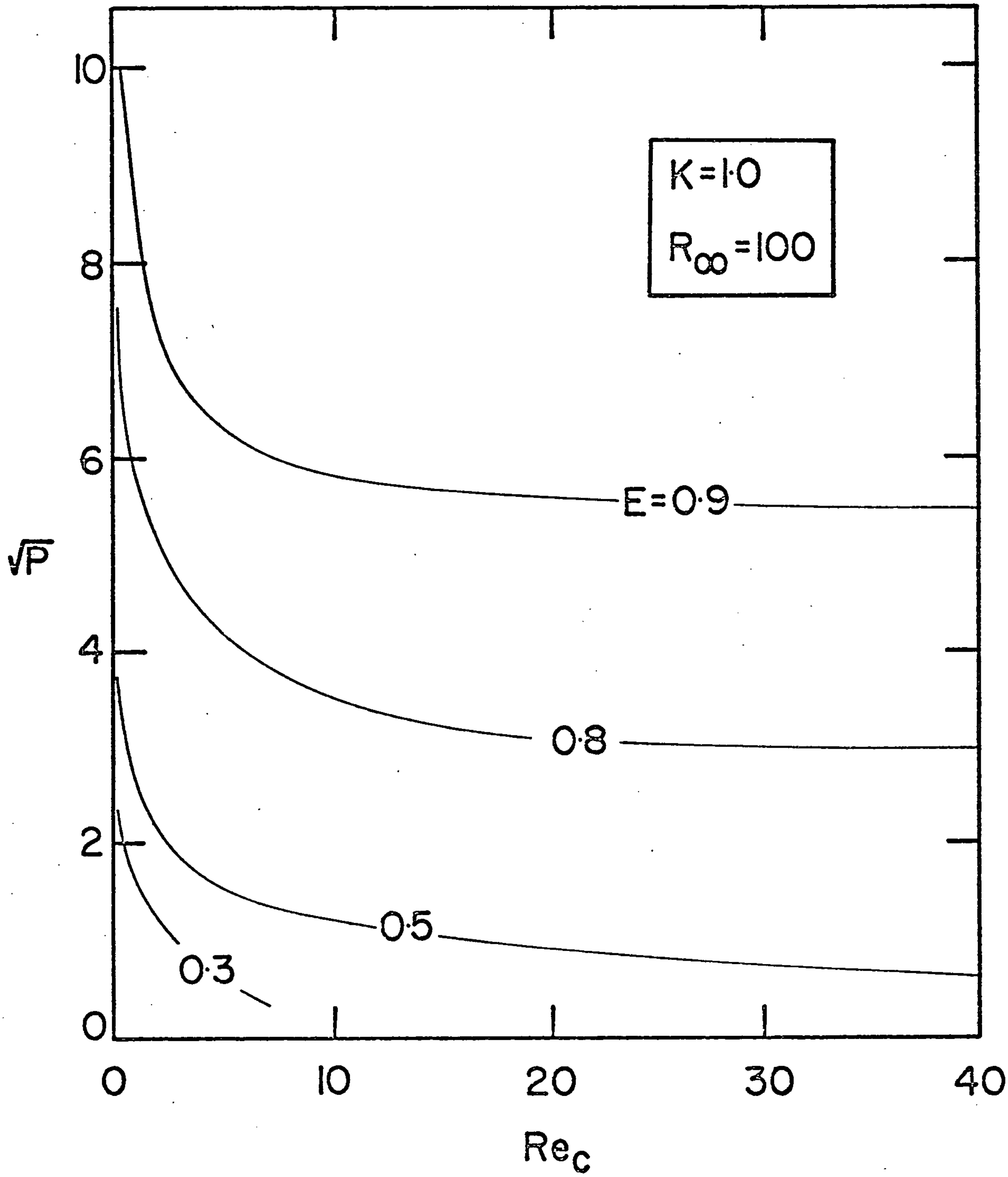


Figure 4-31. Impaction efficiency as a function of Reynolds number and inertial parameter.

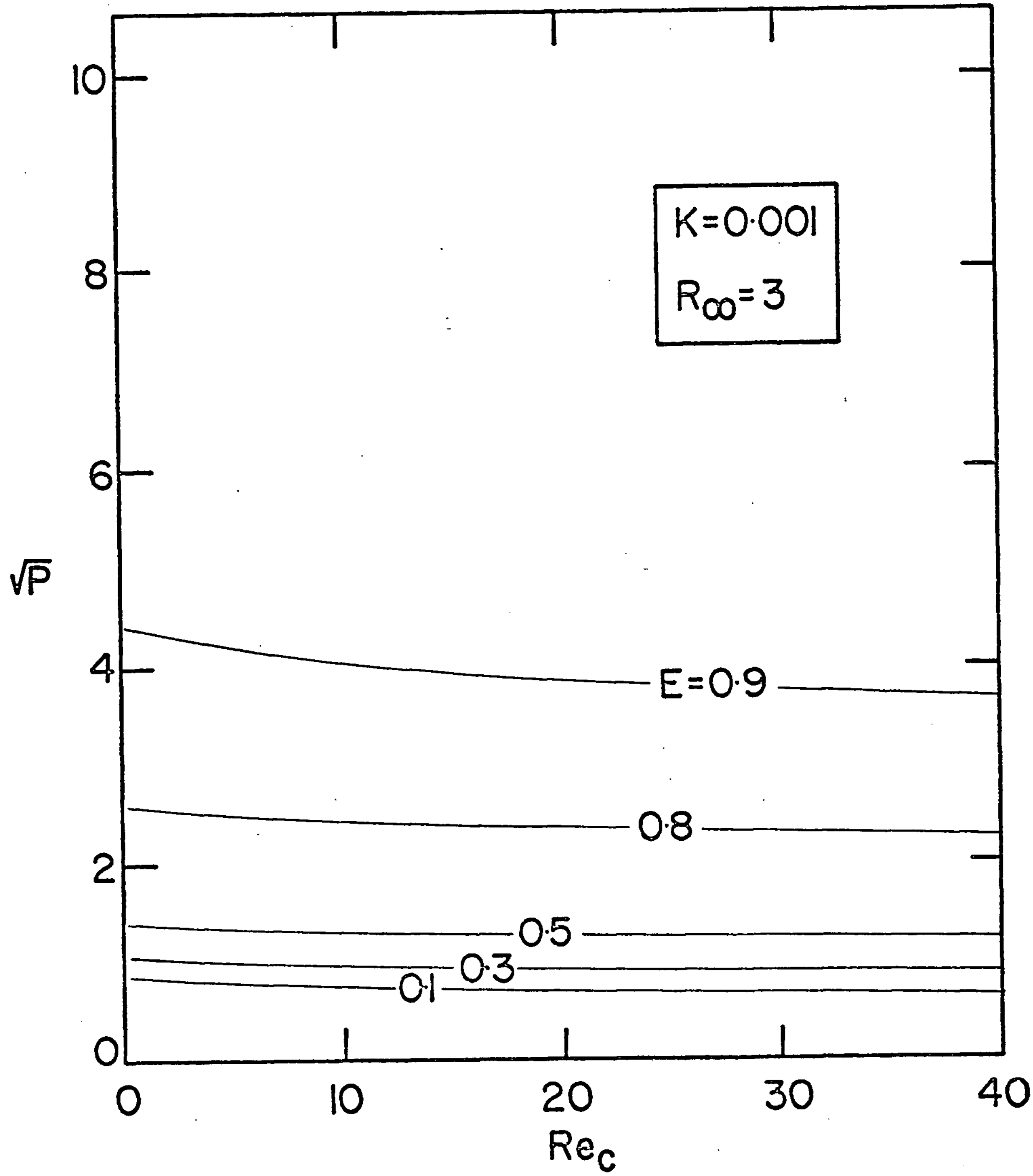


Figure 4-32. Impaction efficiency as a function of Reynolds number and inertial parameter.

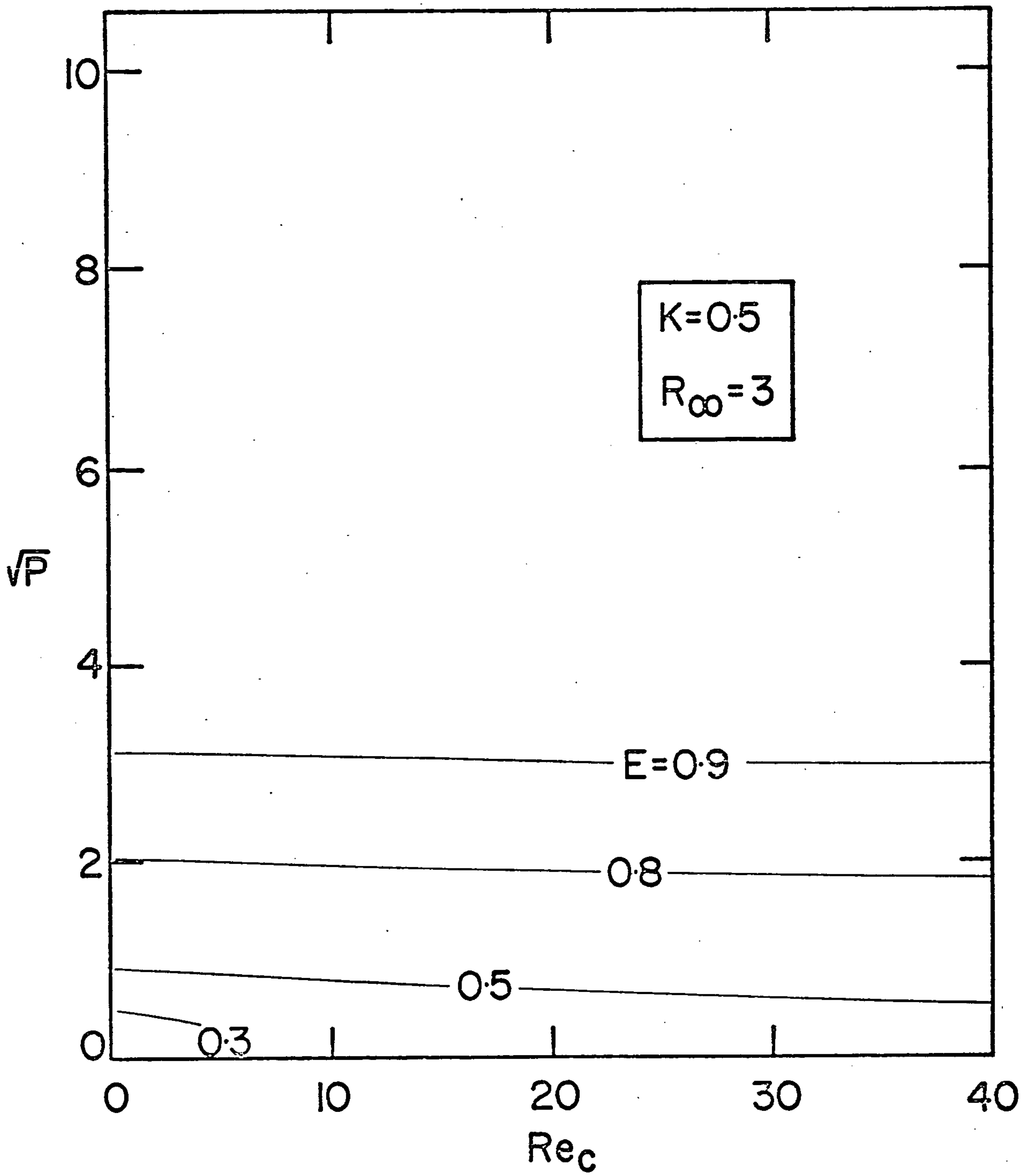


Figure 4-33. Impaction efficiency as a function of Reynolds number and inertial parameter.

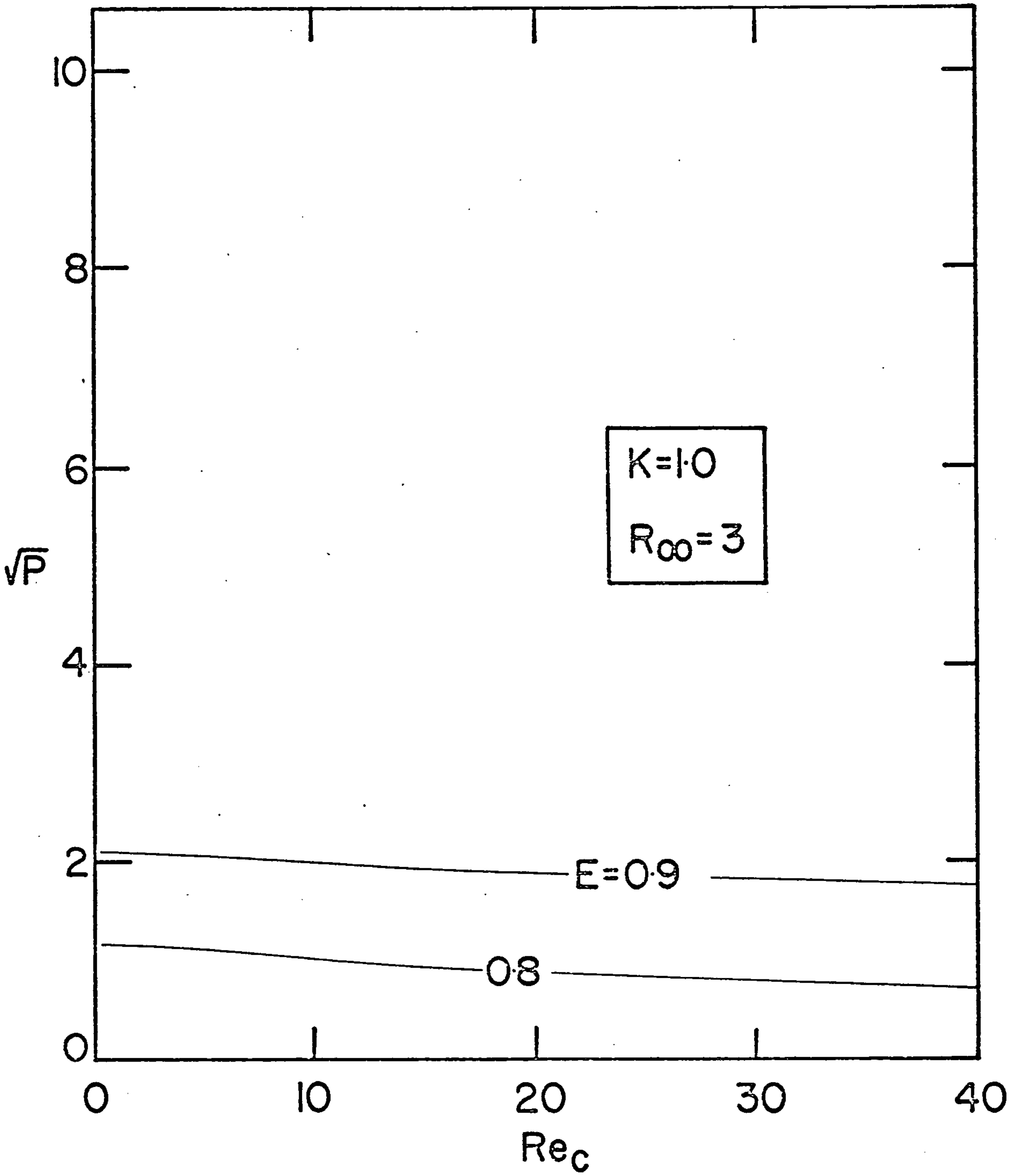


Figure 4-34. Impaction efficiency as a function of Reynolds number and inertial parameter.

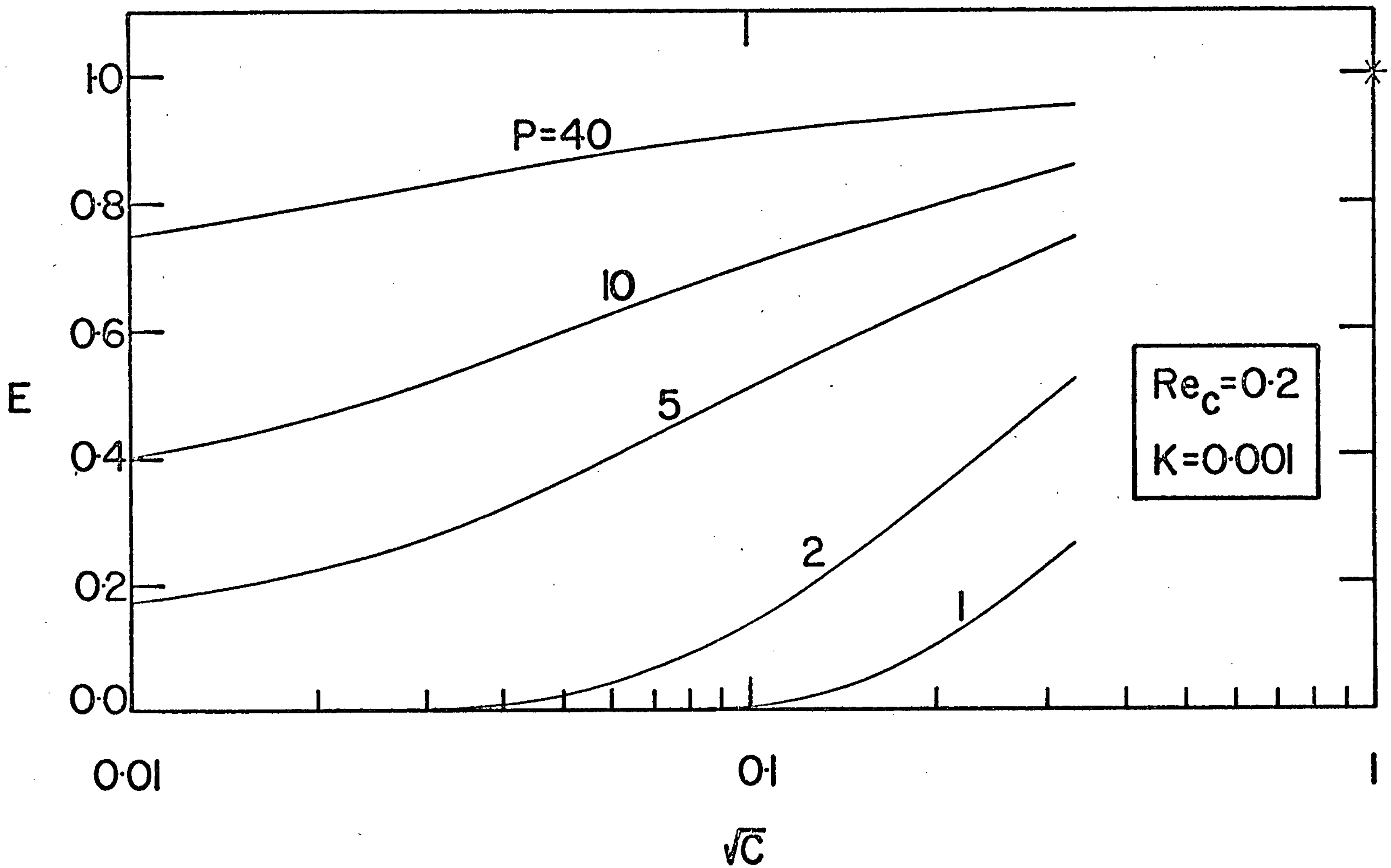


Figure 4-35. Impaction efficiency as a function of solids concentration.

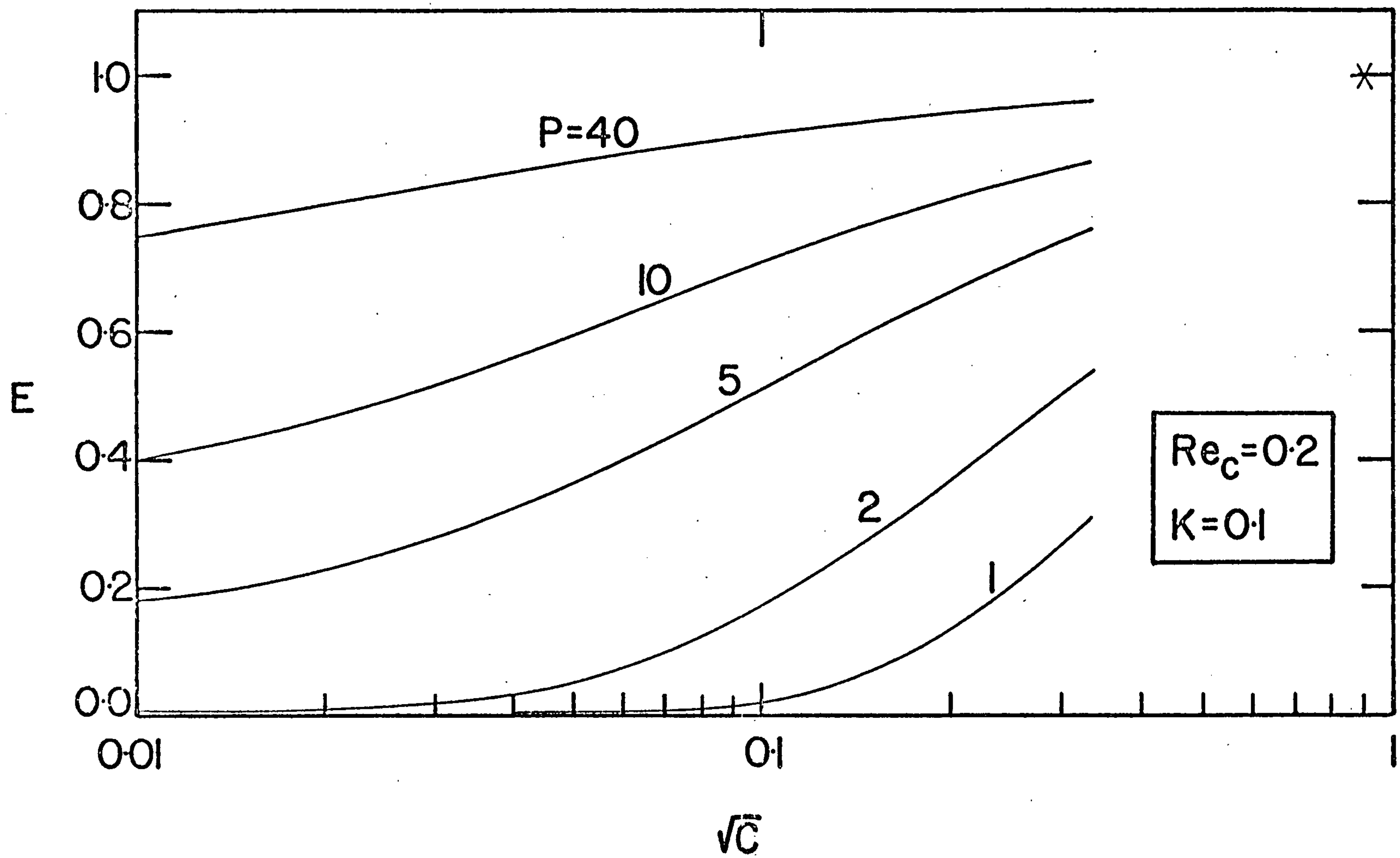


Figure 4-36. Impaction efficiency as a function of solids concentration.

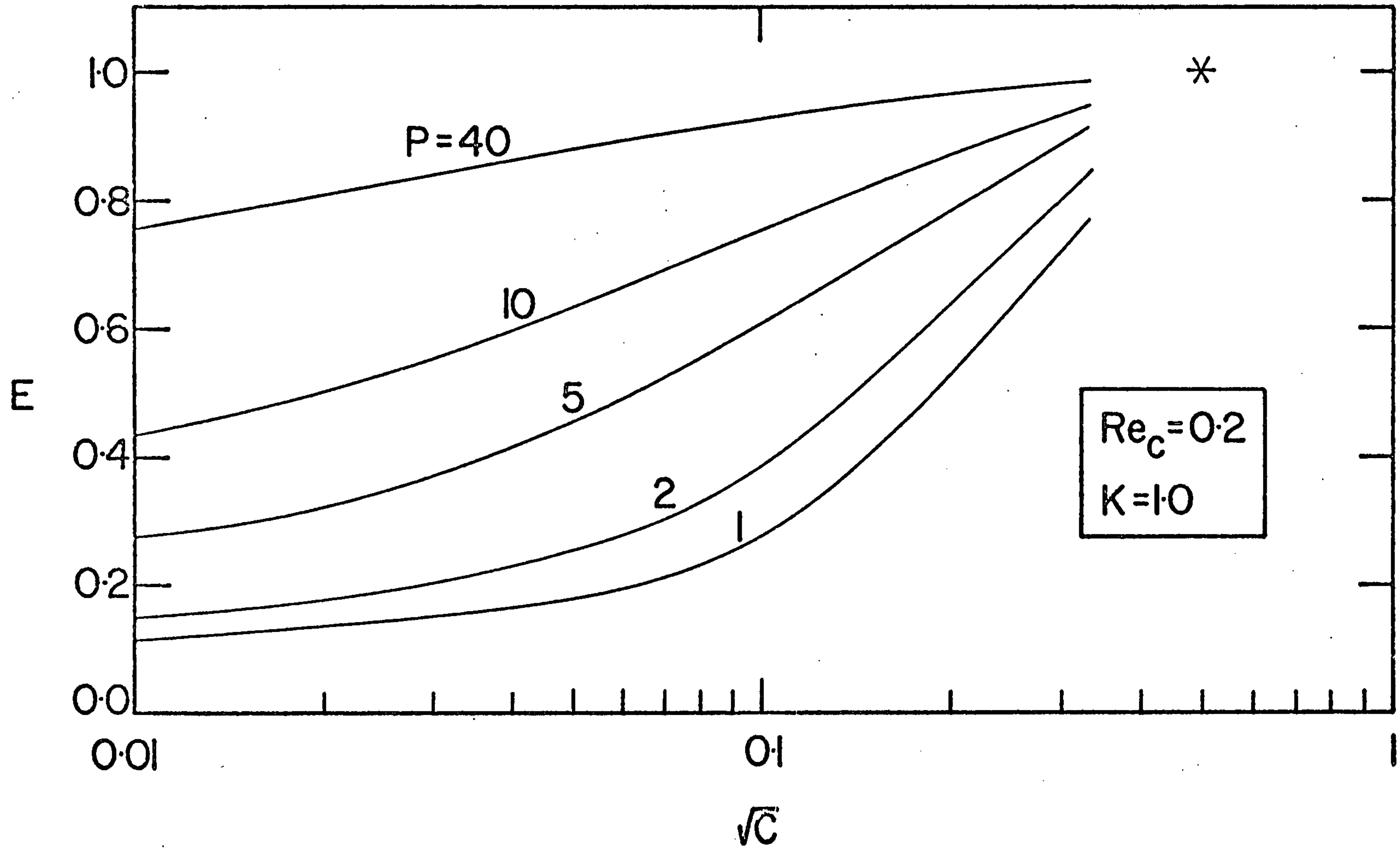


Figure 4-37. Impaction efficiency as a function of solids concentration.

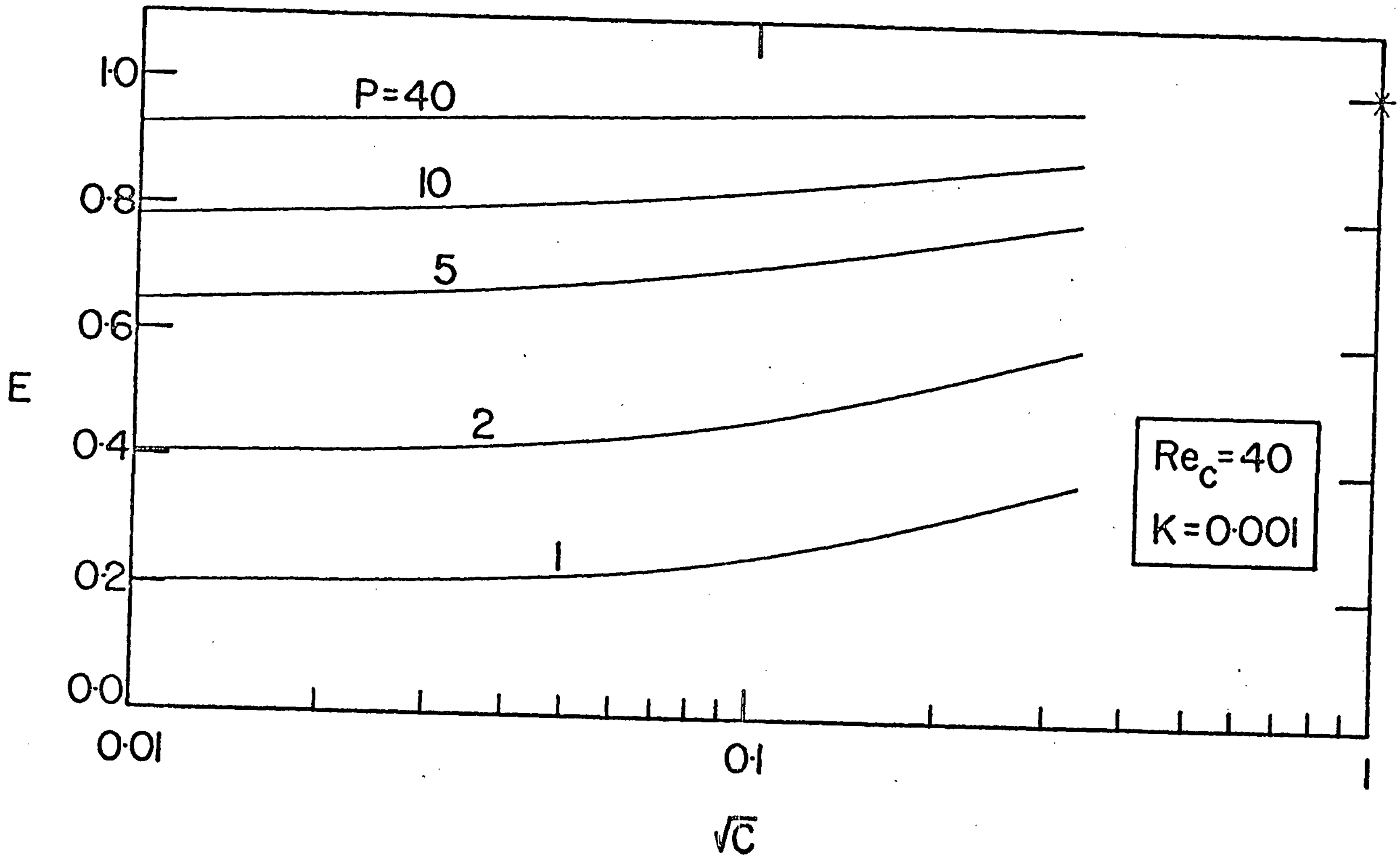


Figure 4-38. Impaction efficiency as a function of solids concentration.

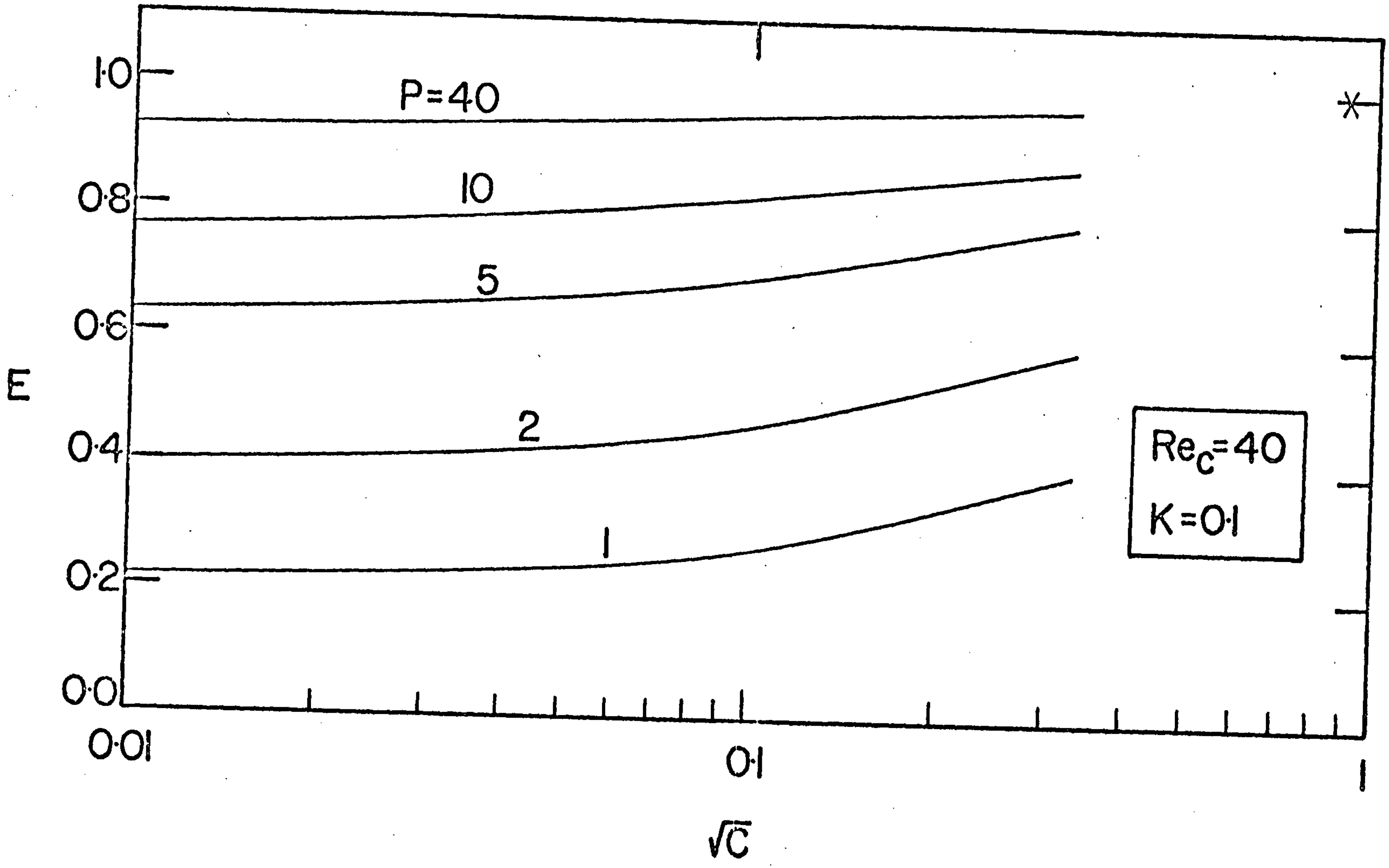


Figure 4-39. Impaction efficiency as a function of solids concentration.

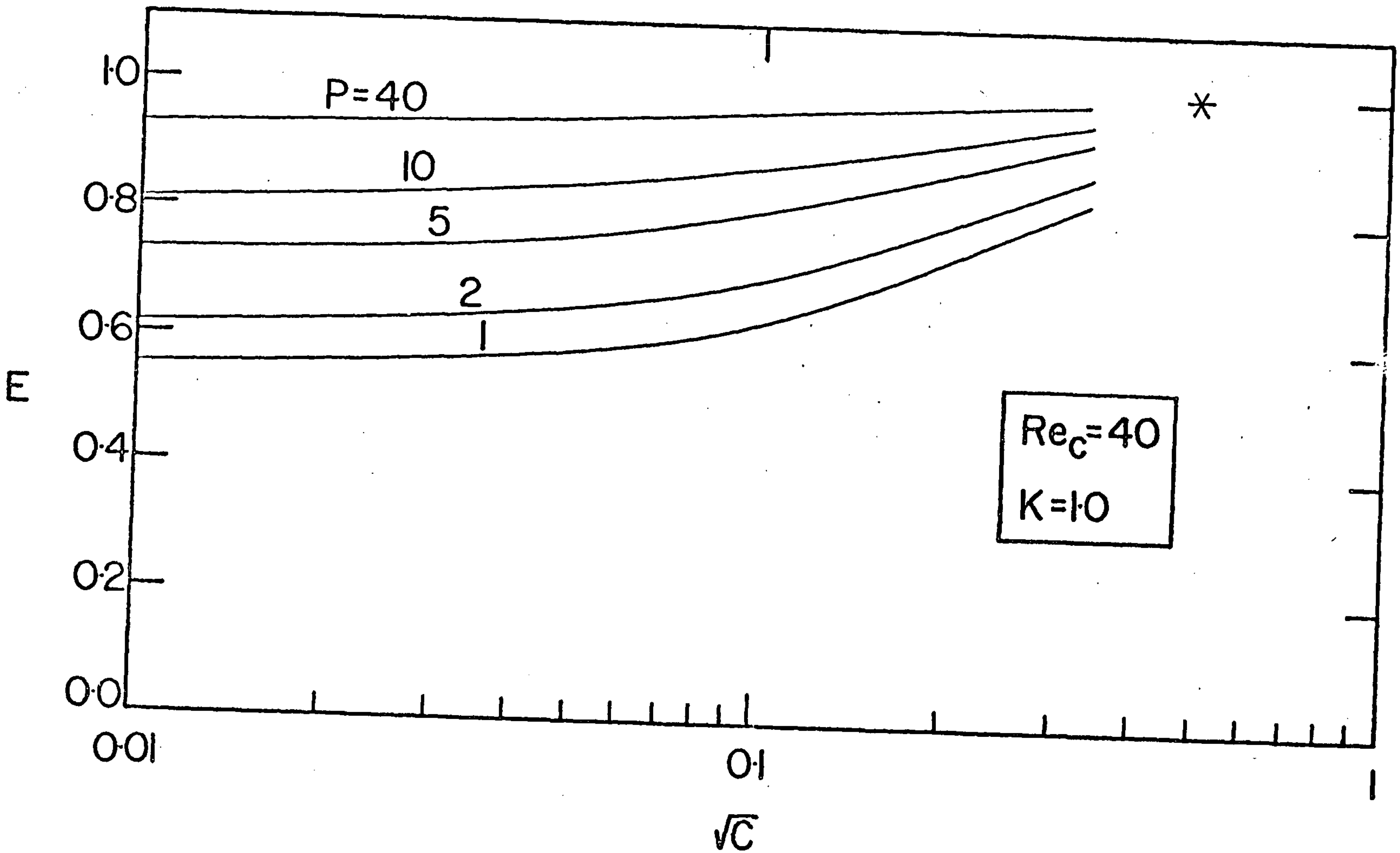


Figure 4-40. Impaction efficiency as a function of solids concentration.

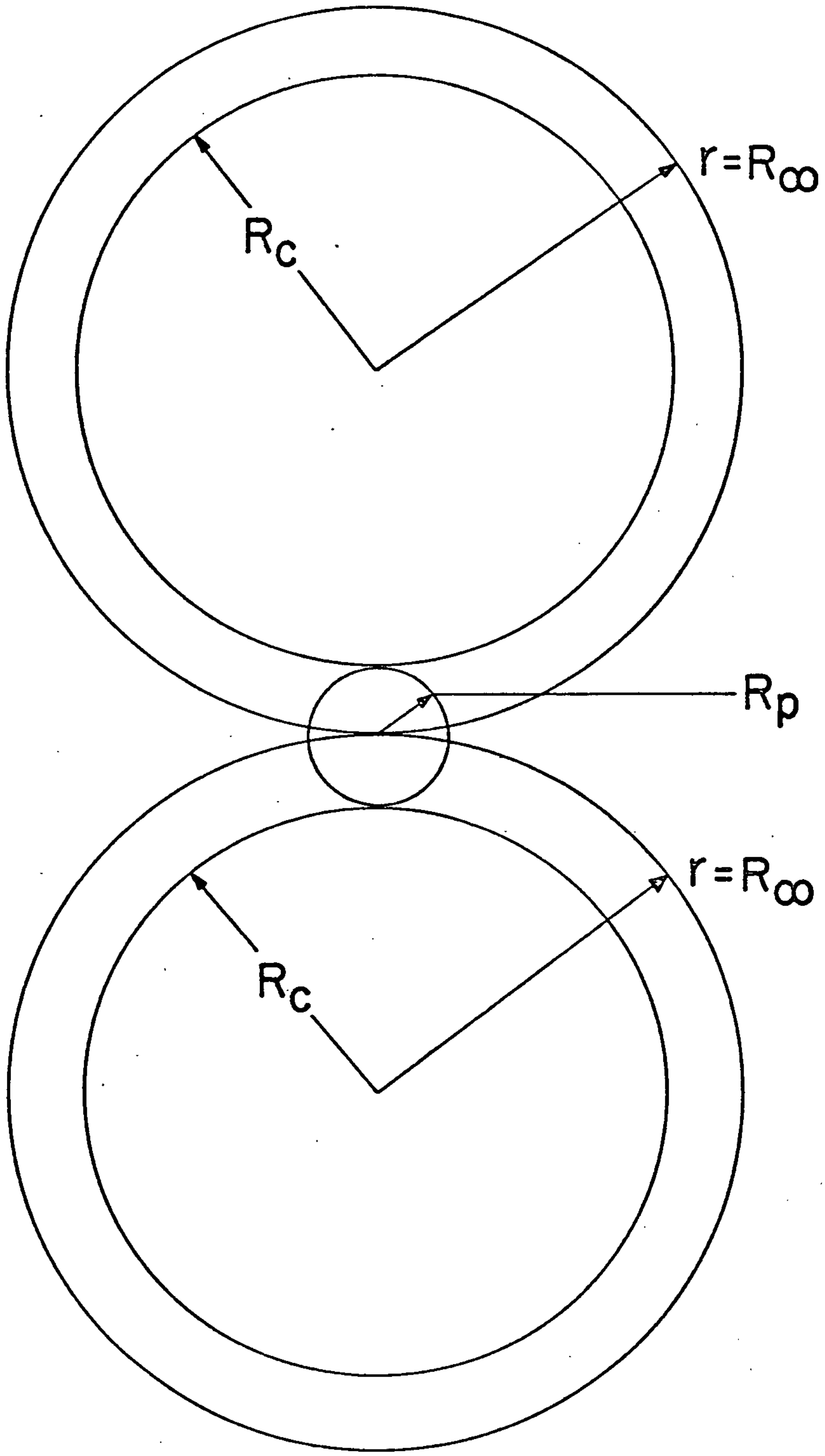


Figure 4-41. Sieving mechanism at high solids concentration.

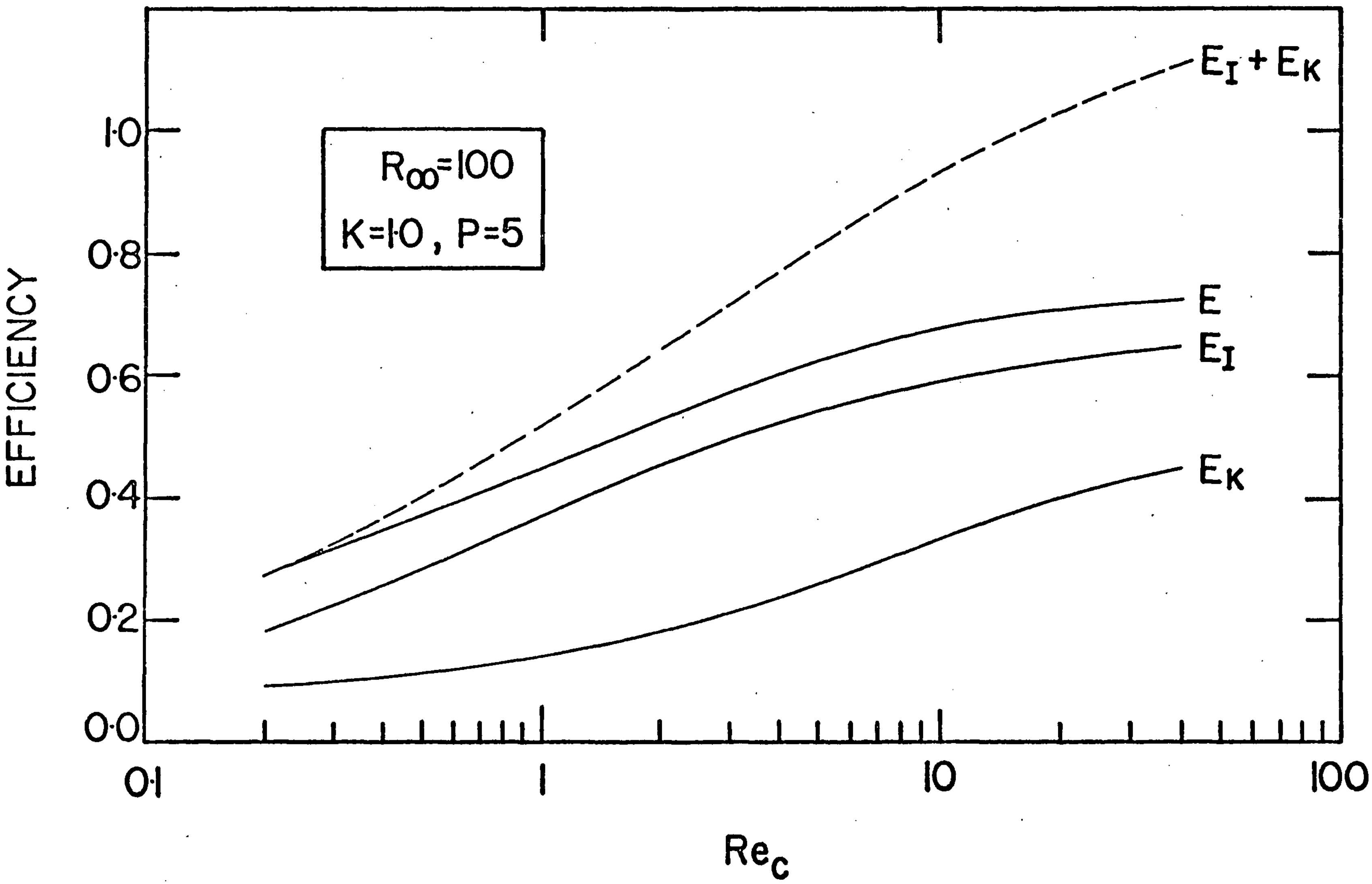


Figure 4-42. Impaction efficiencies (E_I, E_K, $E_I + E_K$, E) as a function of Reynolds number.

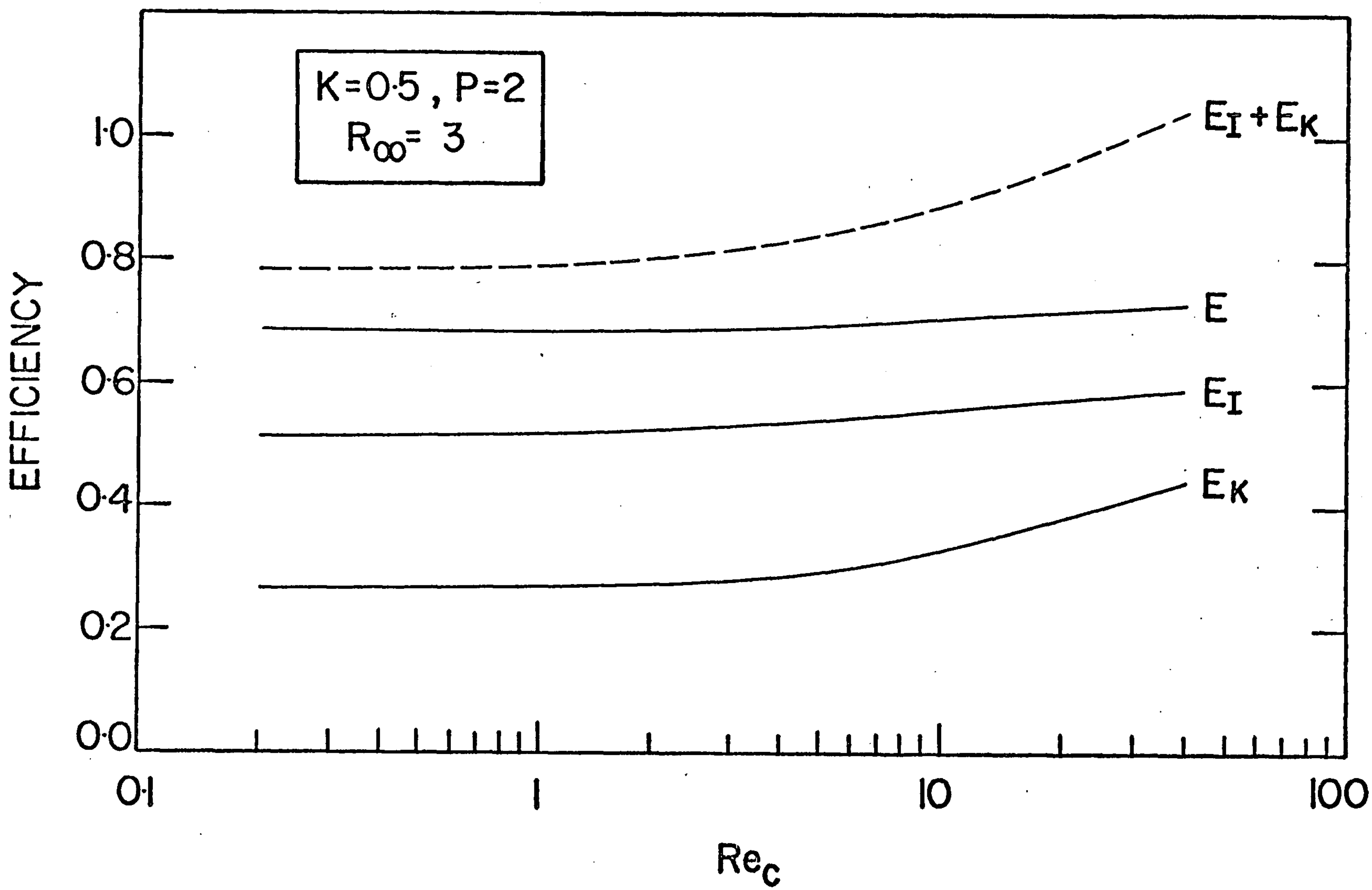


Figure 4-43. Impaction efficiencies (E_I, E_K, $E_I + E_K$, E) as a function of Reynolds number.

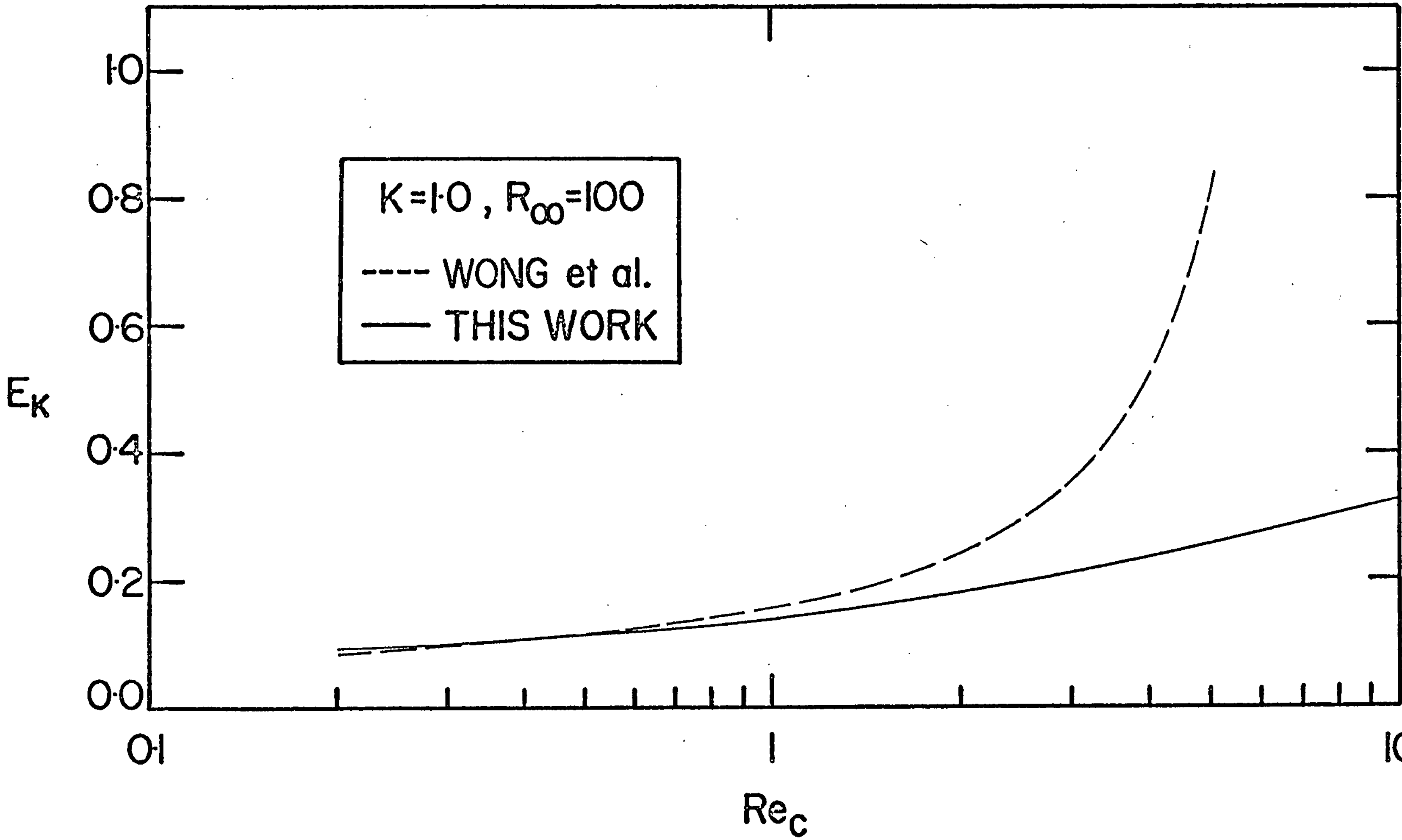


Figure 4-44. Comparison of impaction efficiencies due to interception as predicted by: (i) Wong *et al.* [10], (ii) this work.

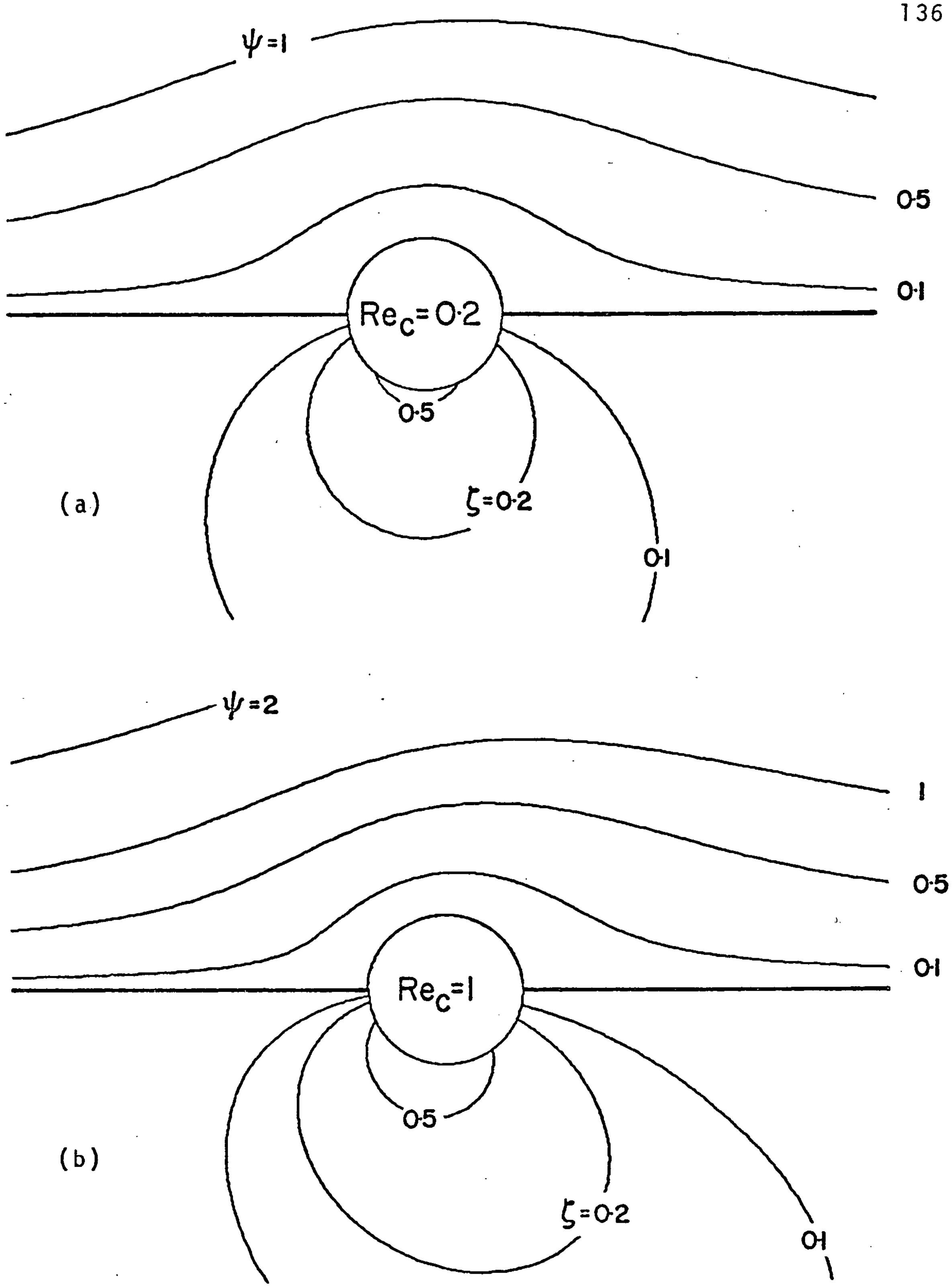
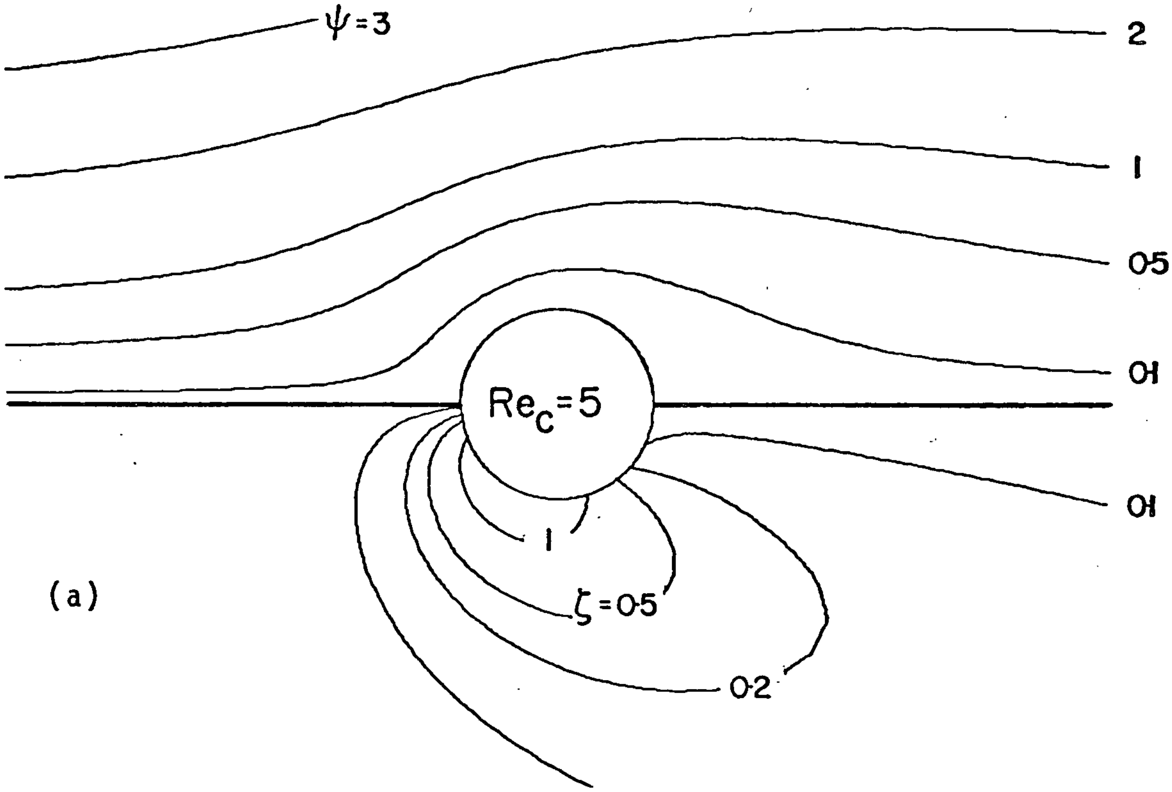


Figure 4-45. Streamlines and equi-vorticity lines at $R_\infty = 100$.



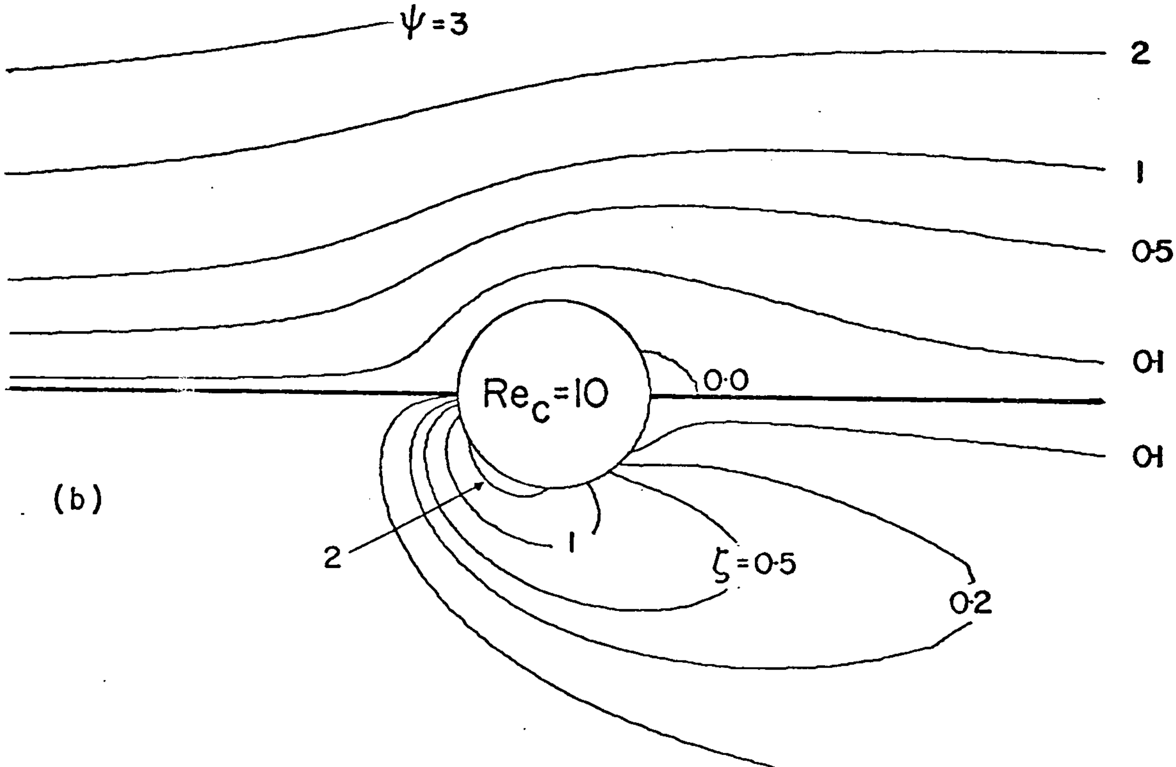


Figure 4-46. Streamlines and equi-vorticity lines at R_∞ = 100.

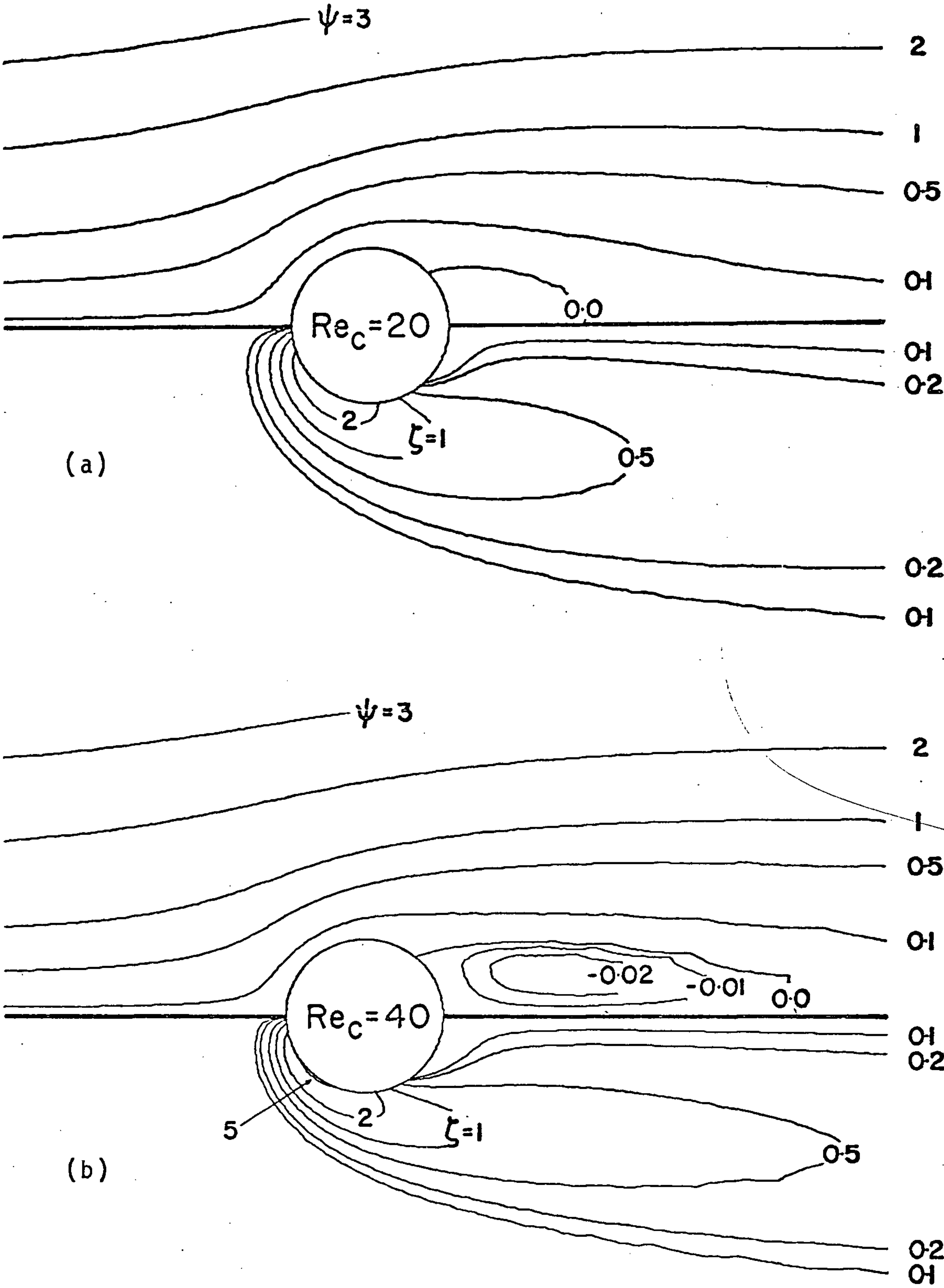
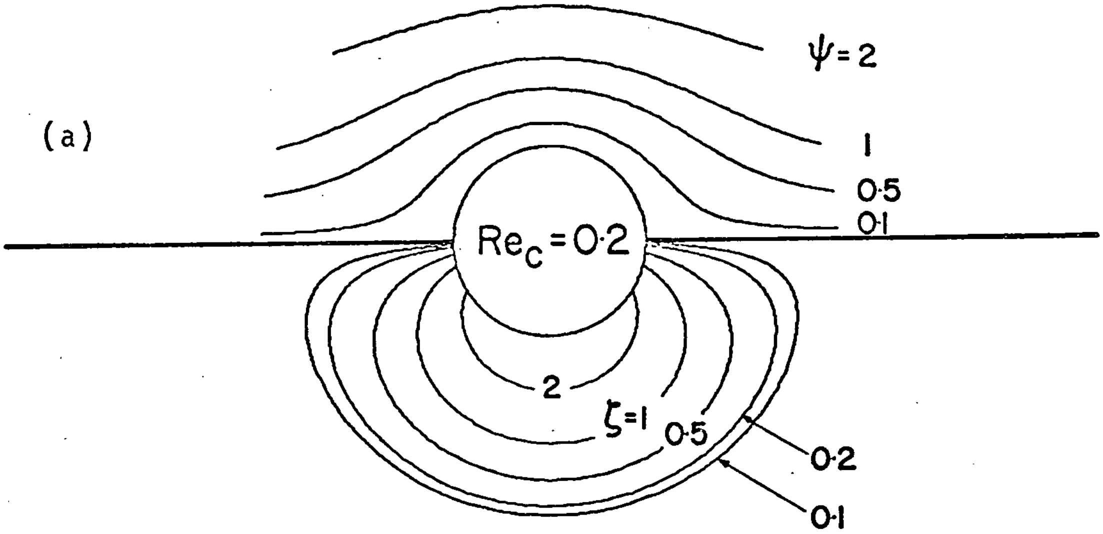


Figure 4-47. Streamlines and equi-vorticity lines at R_∞ = 100.

(a)



(b)

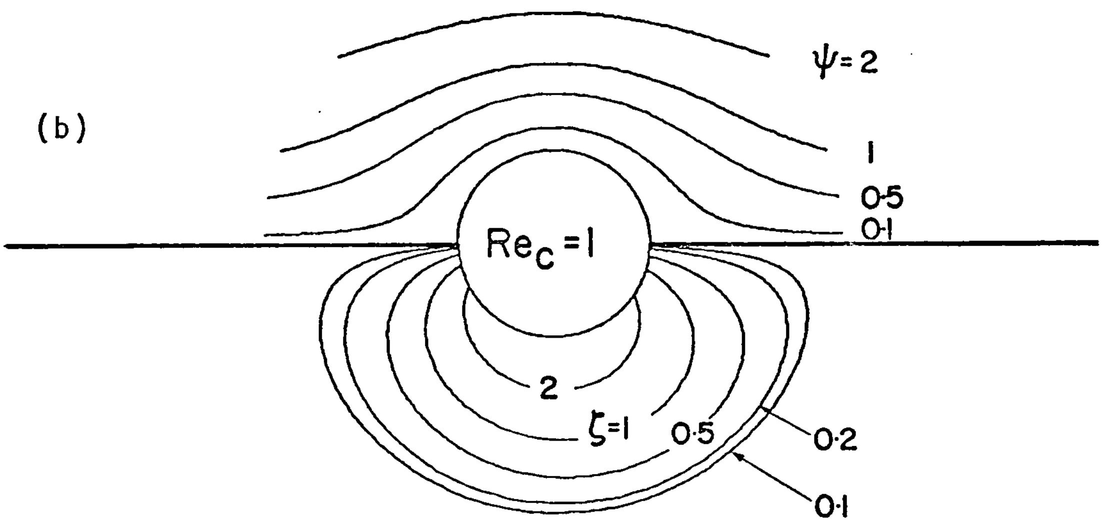
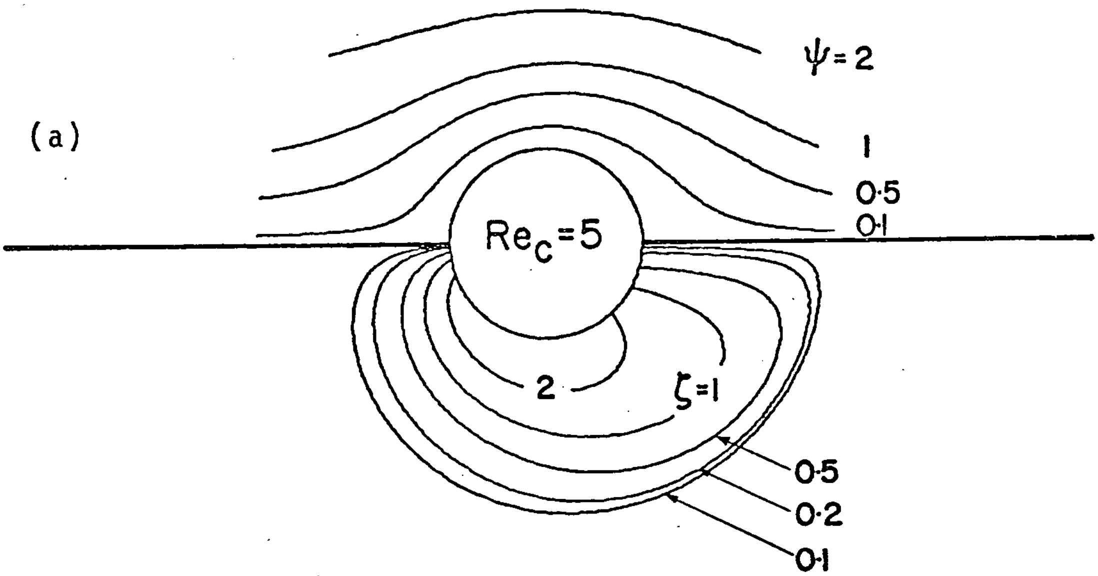


Figure 4-48. Streamlines and equi-vorticity lines at $R_\infty = 3$.



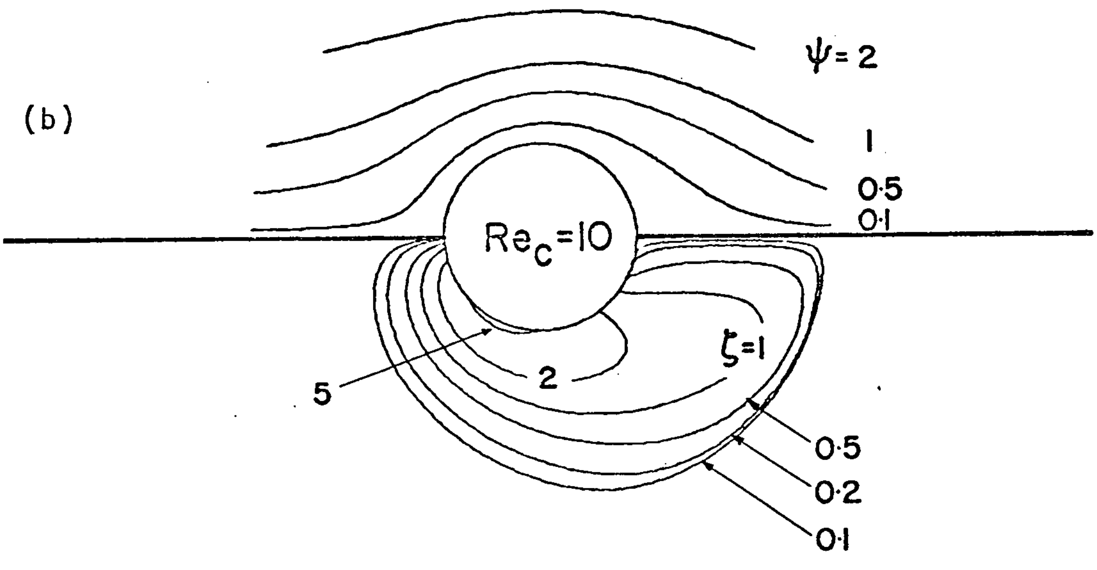


Figure 4-49. Streamlines and equi-vorticity lines at $R_{\infty} = 3$.

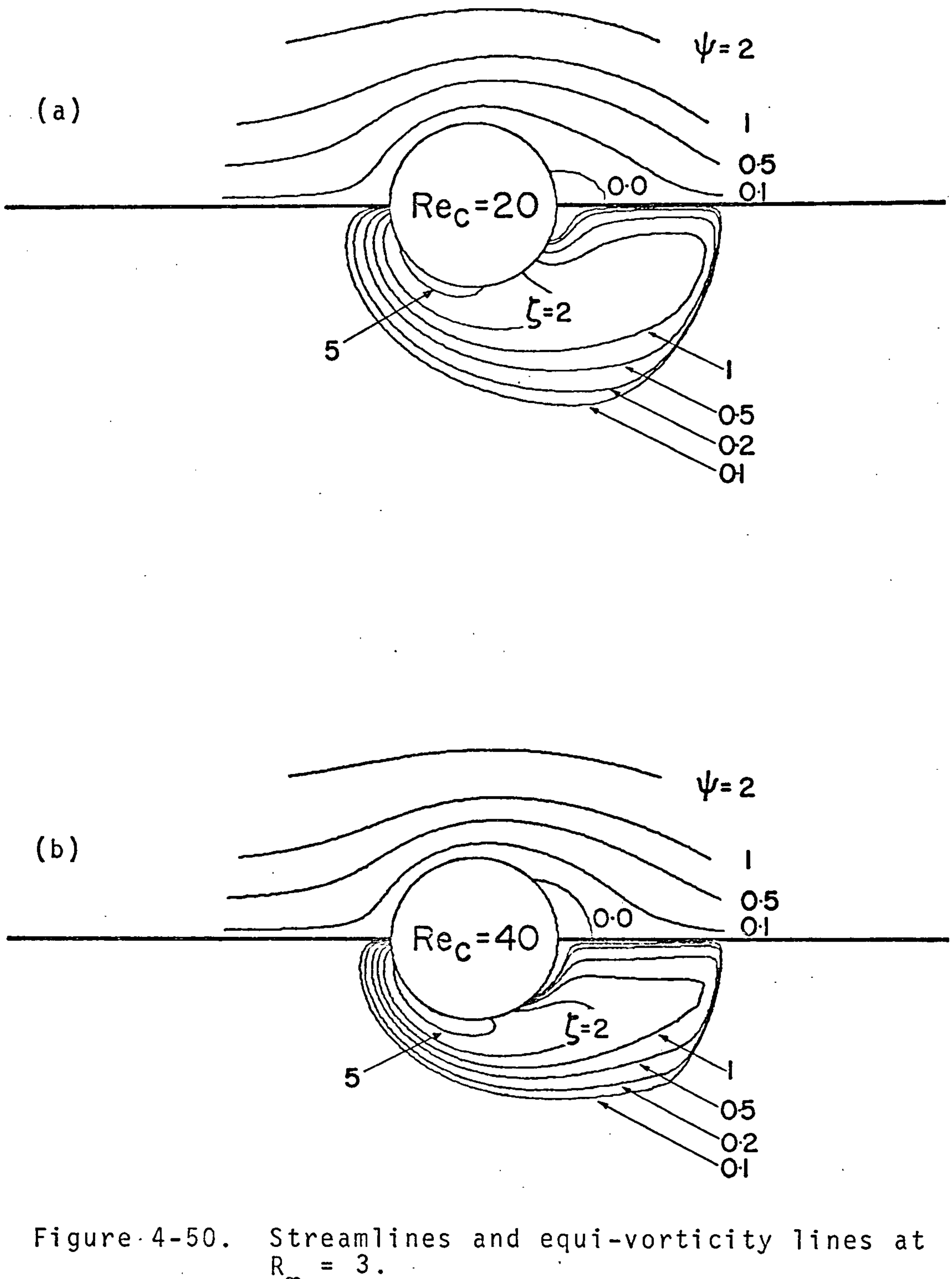


Figure 4-50. Streamlines and equi-vorticity lines at $R_\infty = 3$.

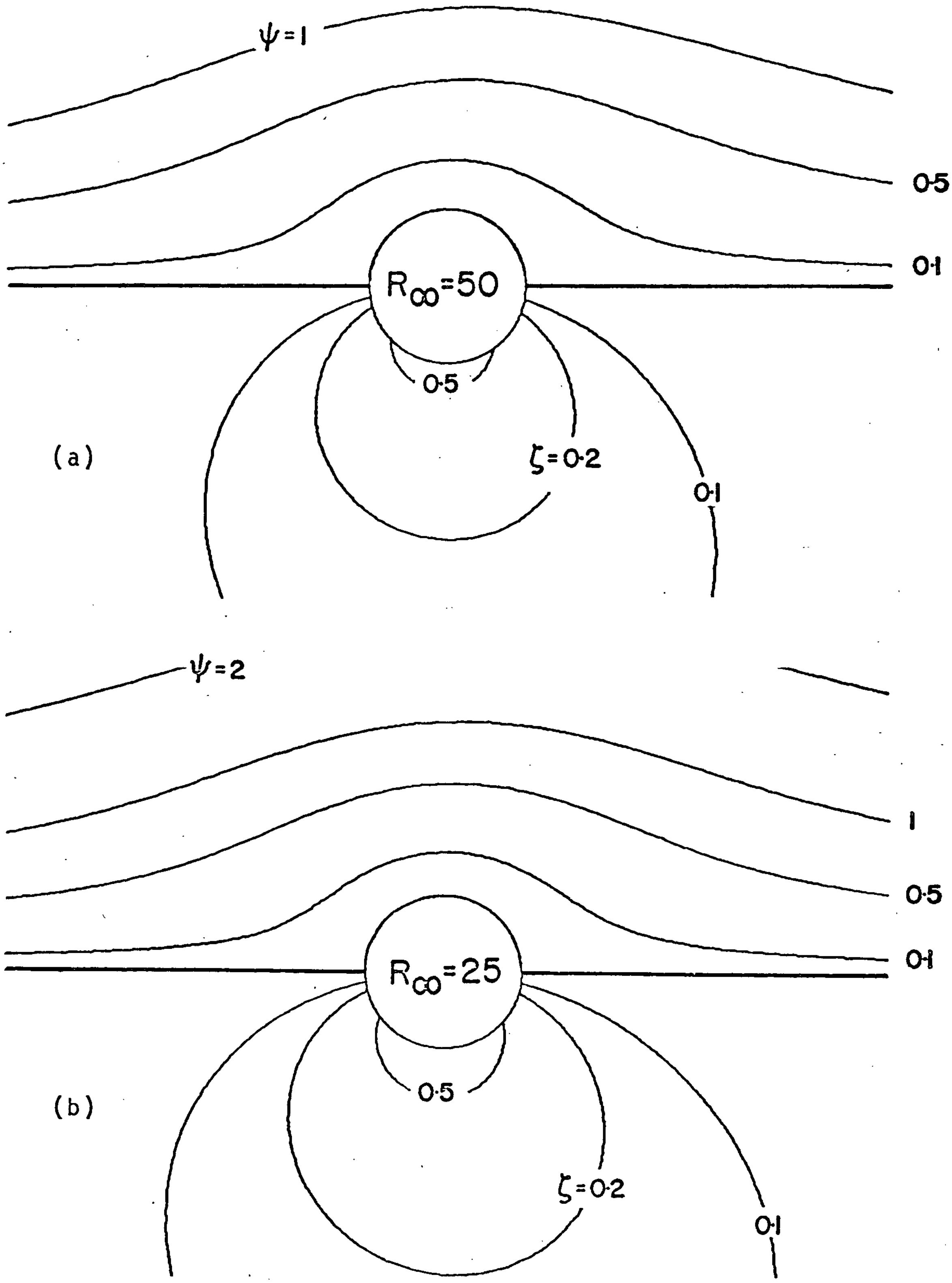


Figure 4-51. Streamlines and equi-vorticity lines at Re_c = 0.2.

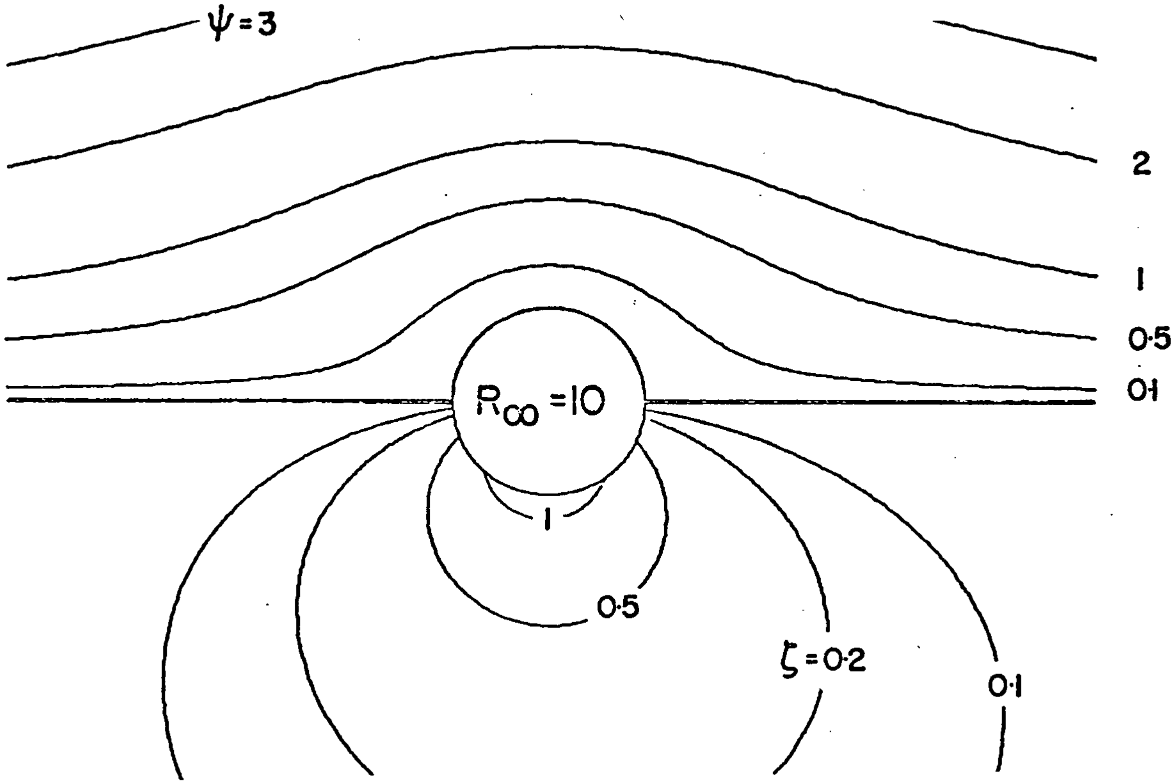
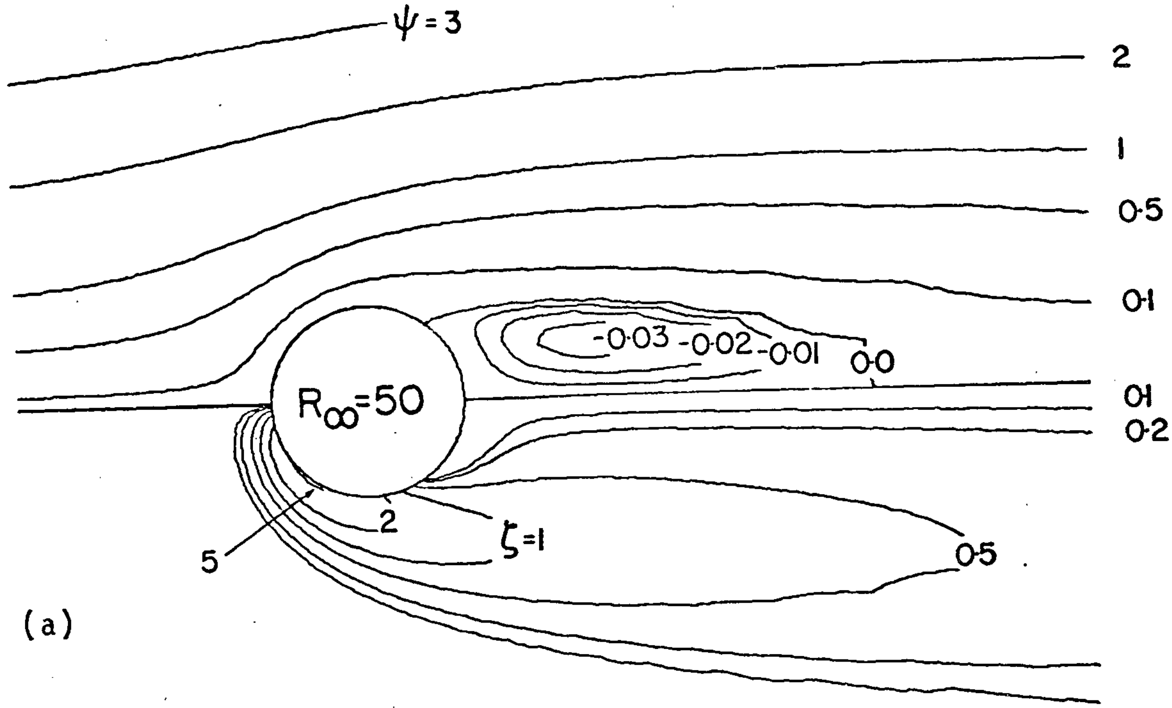


Figure 4-52. Streamlines and equi-vorticity lines at $Re_c = 0.2$.



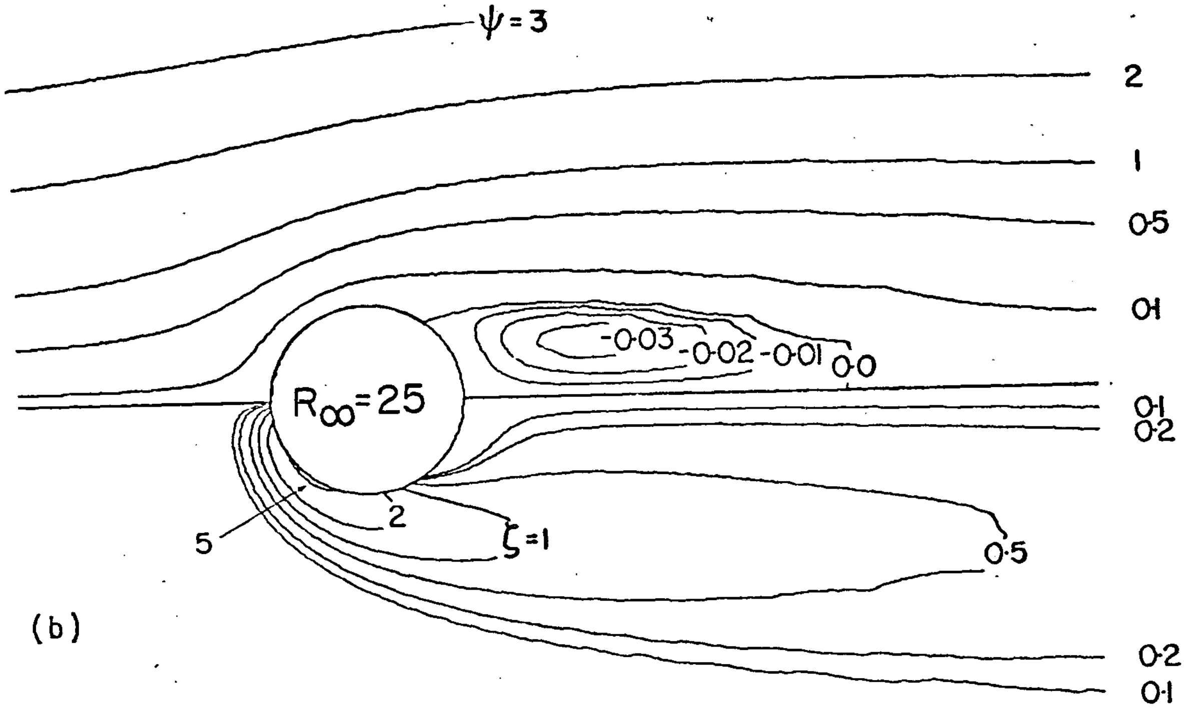


Figure 4-53. Streamlines and equi-vorticity lines at $Re_c = 40$.

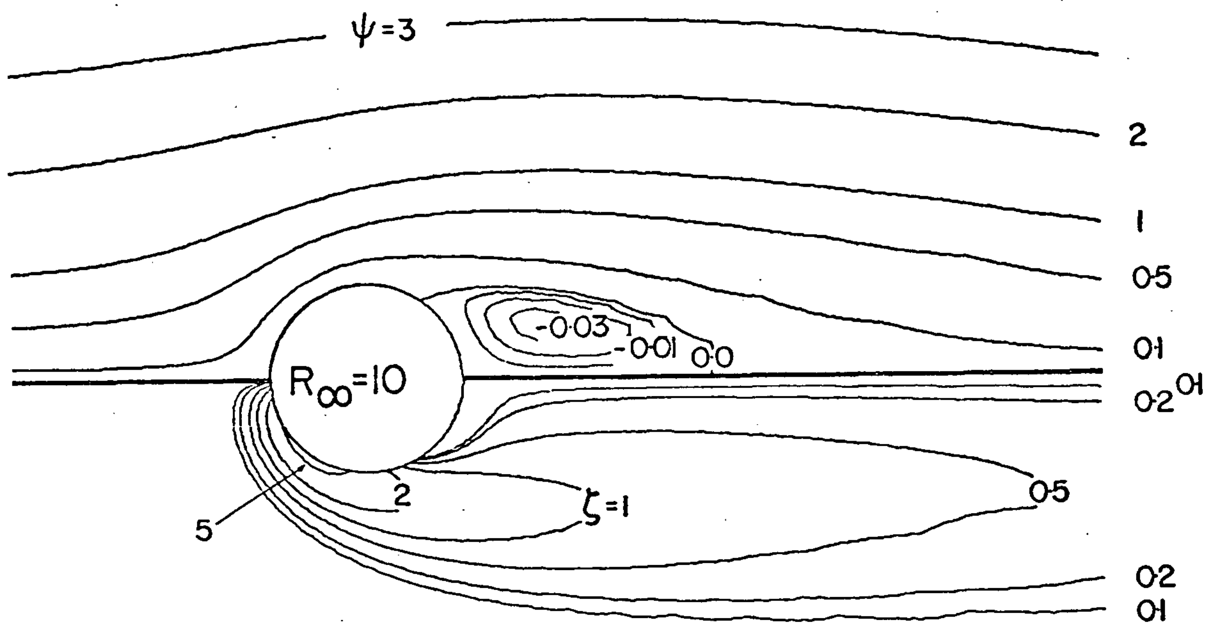


Figure 4-54. Streamlines and equi-vorticity lines at Re_c = 40.

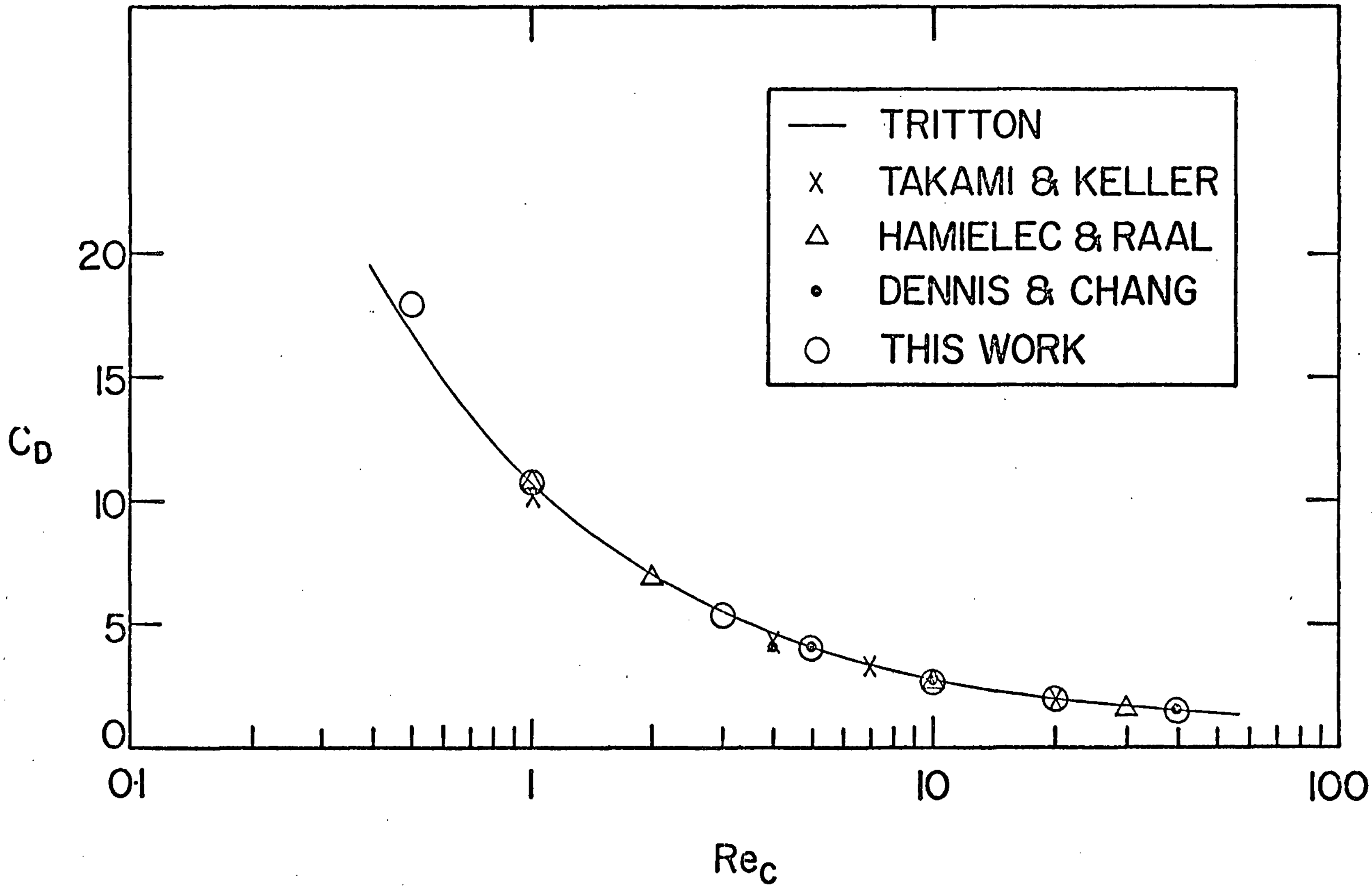


Figure 4-55. Comparison of drag coefficients as given by Tritton [31], Takami and Keller [39], Hamielec and Raal [40], Dennis and Chang [41], and this work.

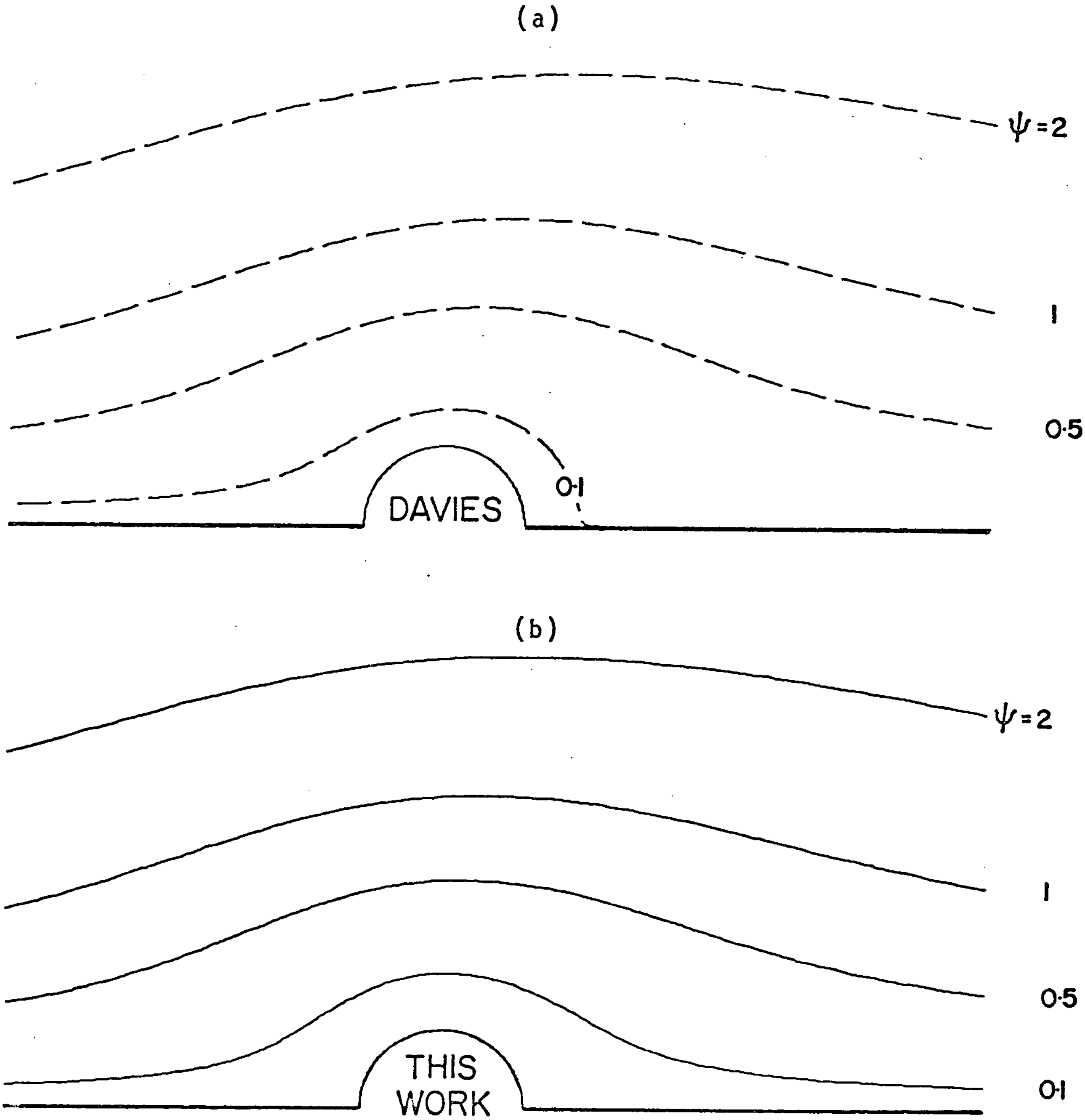


Figure 4-56. Streamlines at for: (a) Davies and Peetz [7], (b) this work.

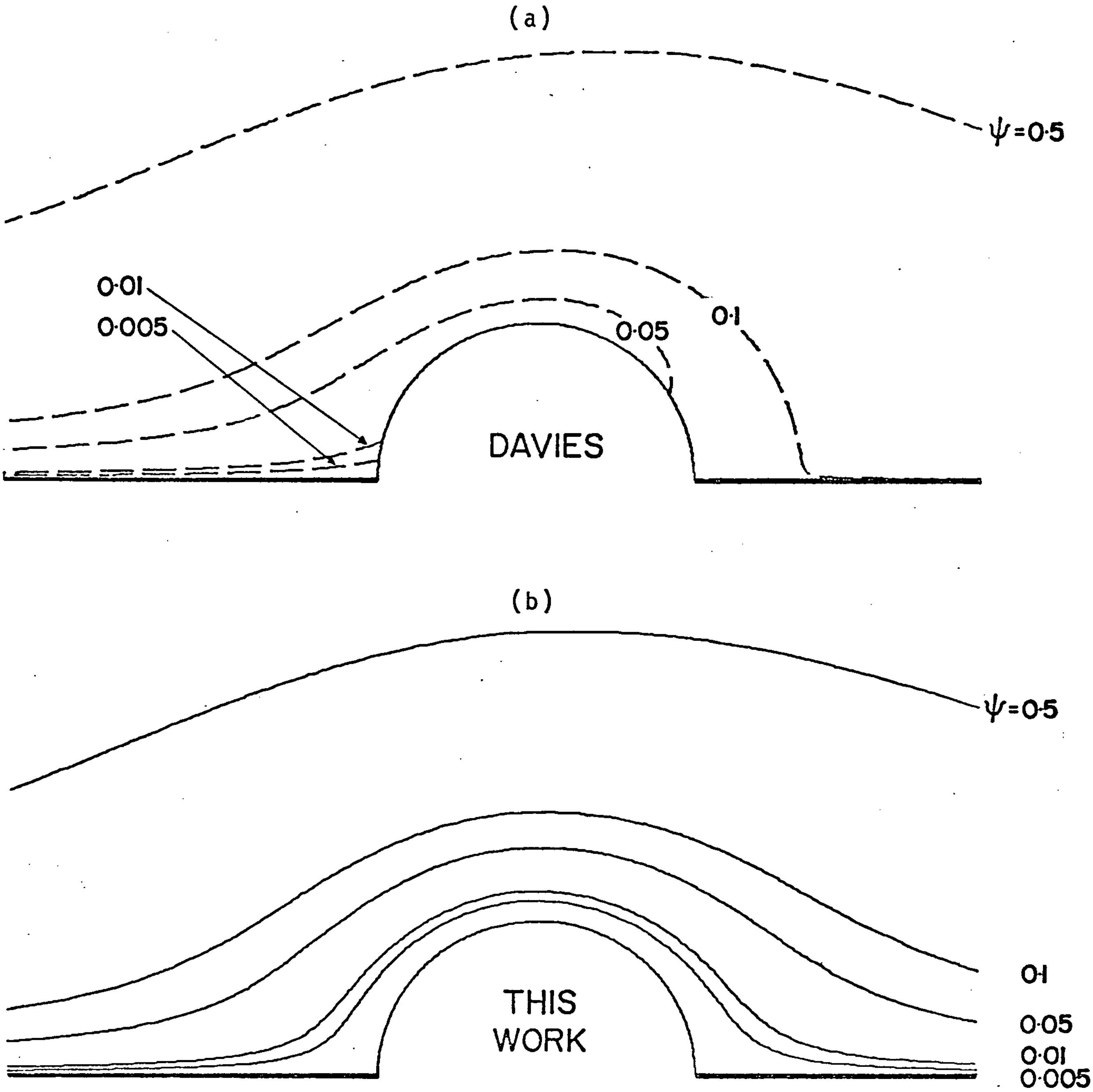


Figure 4-57. Streamlines in the vicinity of the cylinder for: (a) Davies and Peetz [7], (b) this work.

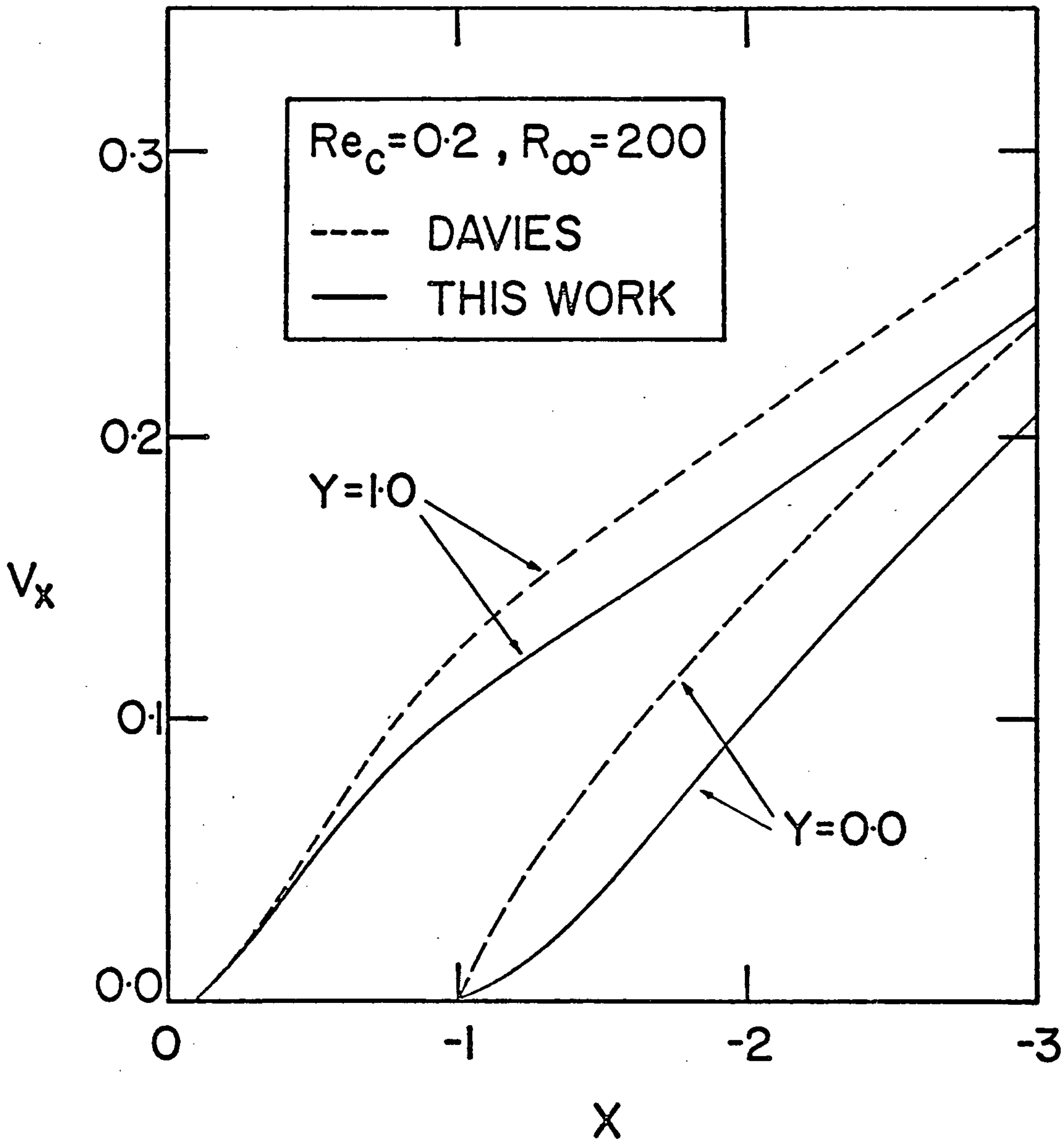


Figure 4-58. Fluid velocity, v_x, as a function of x for: (i) Davies and Peetz [7], (ii) this work.

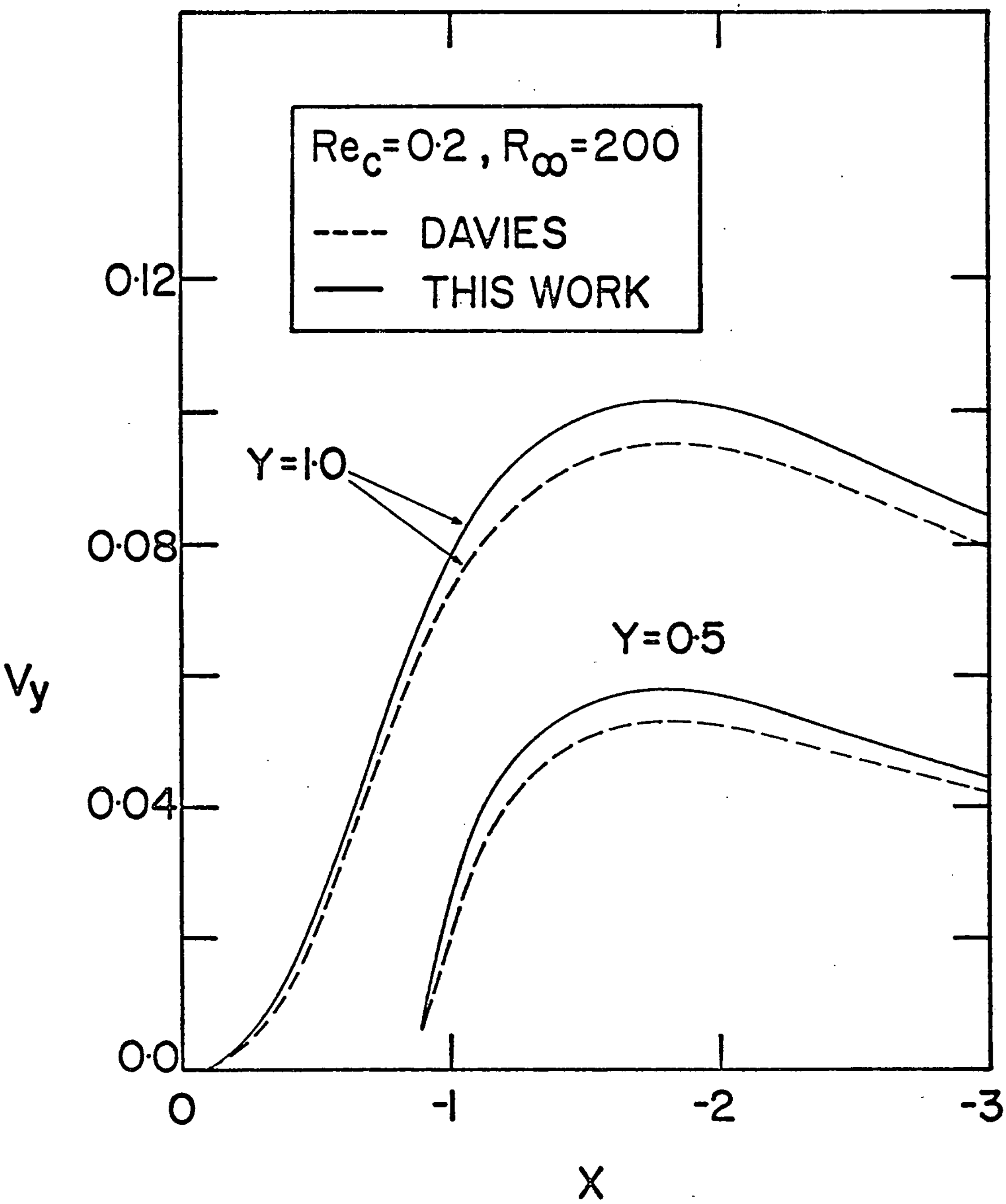


Figure 4-59. Fluid velocity, v_y, as a function of x for: (i) Davies and Peetz [7], (ii) this work.

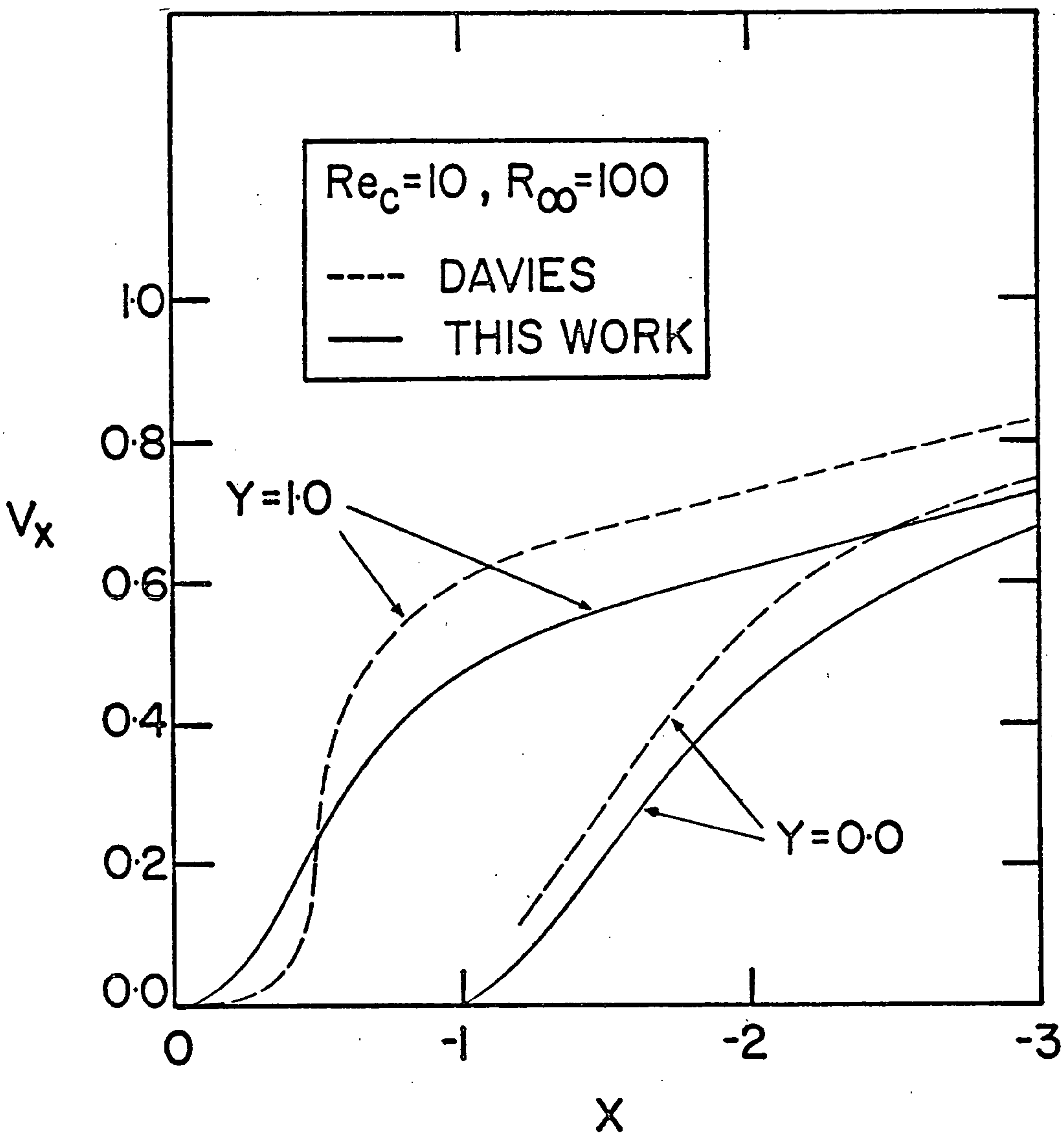


Figure 4-60. Fluid velocity, v_x, as a function of x for: (i) Davies and Peetz [7], (ii) this work.

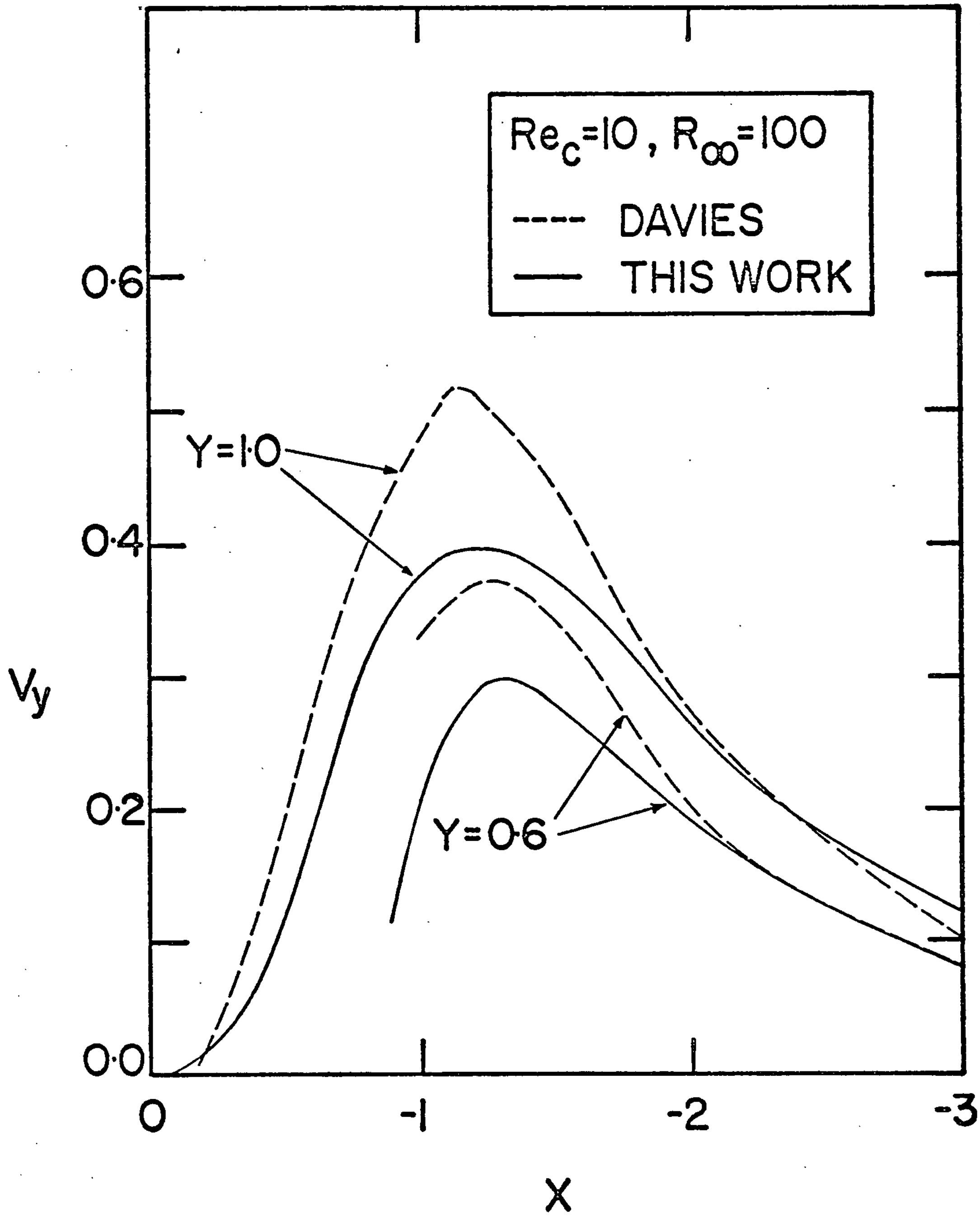


Figure 4-61. Fluid velocity, v_y, as a function of x for: (i) Davies and Peetz [7], (ii) this work.

Table 4-1

Impaction Efficiencies at $R_\infty = 100$

P	K	RE= 0.2		RE= 0.5		RE= 1.0		RE= 3.0		RE= 5.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0005	0.0005
0.10	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0004	0.0006	0.0006
0.15	0.001	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0005	0.0005	0.0007	0.0007
0.25	0.001	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0006	0.0006	0.0009	0.0009
0.50	0.001	0.0002	0.0002	0.0003	0.0003	0.0005	0.0005	0.0011	0.0011	0.0018	0.0018
0.75	0.001	0.0003	0.0003	0.0004	0.0004	0.0007	0.0007	0.0020	0.0020	0.0041	0.0041
1.00	0.001	0.0004	0.0004	0.0006	0.0006	0.0010	0.0010	0.0047	0.0047	0.0234	0.0234
2.00	0.001	0.0010	0.0010	0.0029	0.0029	0.0414	0.0413	0.2008	0.2006	0.2601	0.2598
3.00	0.001	0.0082	0.0082	0.1023	0.1022	0.1962	0.1960	0.3373	0.3369	0.3909	0.3905
5.00	0.001	0.1740	0.1738	0.2805	0.2802	0.3707	0.3703	0.4963	0.4958	0.5421	0.5416
7.50	0.001	0.3069	0.3066	0.4141	0.4136	0.4971	0.4967	0.6069	0.6063	0.6458	0.6452
10.00	0.001	0.3990	0.3986	0.5018	0.5013	0.5779	0.5773	0.6753	0.6747	0.7091	0.7084
40.00	0.001	0.7522	0.7515	0.8096	0.8088	0.8465	0.8456	0.8887	0.8878	0.9022	0.9013
100.00	0.001	0.8827	0.8818	0.9125	0.9116	0.9307	0.9297	0.9506	0.9497	0.9569	0.9559
1000.00	0.001	0.9867	0.9857	0.9903	0.9893	0.9924	0.9914	0.9947	0.9937	0.9953	0.9943
0.01	0.010	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0005	0.0005	0.0006	0.0006
0.10	0.010	0.0002	0.0002	0.0003	0.0003	0.0004	0.0003	0.0006	0.0006	0.0008	0.0008
0.15	0.010	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0007	0.0007	0.0009	0.0009
0.25	0.010	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0008	0.0008	0.0012	0.0012
0.50	0.010	0.0003	0.0003	0.0004	0.0004	0.0006	0.0006	0.0014	0.0014	0.0022	0.0022
0.75	0.010	0.0004	0.0004	0.0005	0.0005	0.0009	0.0009	0.0024	0.0024	0.0049	0.0048
1.00	0.010	0.0004	0.0004	0.0007	0.0007	0.0013	0.0012	0.0055	0.0055	0.0256	0.0253
2.00	0.010	0.0012	0.0012	0.0034	0.0034	0.0436	0.0432	0.2030	0.2010	0.2623	0.2597
3.00	0.010	0.0093	0.0092	0.1038	0.1027	0.1985	0.1966	0.3403	0.3369	0.3940	0.3901
5.00	0.010	0.1762	0.1744	0.2835	0.2807	0.3743	0.3706	0.5006	0.4956	0.5465	0.5411
7.50	0.010	0.3103	0.3072	0.4182	0.4141	0.5019	0.4969	0.6124	0.6063	0.6513	0.6448
10.00	0.010	0.4031	0.3991	0.5067	0.5017	0.5833	0.5775	0.6814	0.6747	0.7154	0.7083
40.00	0.010	0.7597	0.7521	0.8176	0.8095	0.8548	0.8463	0.8972	0.8884	0.9108	0.9018
100.00	0.010	0.8915	0.8826	0.9215	0.9124	0.9399	0.9306	0.9601	0.9506	0.9663	0.9567
1000.00	0.010	0.9965	0.9866	1.0002	0.9903	1.0023	0.9924	1.0045	0.9946	1.0053	0.9954

Table 4-1 (Continued)

P	K	RE= 0.2		RE= 0.5		RE= 1.0		RE= 3.0		RE= 5.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0031	0.0028	0.0038	0.0034	0.0047	0.0043	0.0075	0.0068	0.0095	0.0087
0.10	0.100	0.0031	0.0028	0.0039	0.0036	0.0050	0.0045	0.0082	0.0074	0.0106	0.0096
0.15	0.100	0.0032	0.0029	0.0040	0.0037	0.0052	0.0047	0.0087	0.0079	0.0114	0.0103
0.25	0.100	0.0033	0.0030	0.0042	0.0039	0.0056	0.0051	0.0099	0.0090	0.0134	0.0121
0.50	0.100	0.0037	0.0033	0.0050	0.0046	0.0071	0.0064	0.0145	0.0132	0.0217	0.0197
0.75	0.100	0.0042	0.0038	0.0062	0.0056	0.0093	0.0085	0.0234	0.0213	0.0407	0.0370
1.00	0.100	0.0050	0.0045	0.0077	0.0070	0.0128	0.0116	0.0438	0.0398	0.0862	0.0783
2.00	0.100	0.0112	0.0102	0.0288	0.0262	0.0890	0.0809	0.2364	0.2149	0.2977	0.2706
3.00	0.100	0.0457	0.0415	0.1323	0.1203	0.2277	0.2070	0.3770	0.3428	0.4339	0.3945
5.00	0.100	0.2002	0.1820	0.3143	0.2858	0.4116	0.3742	0.5468	0.4971	0.5956	0.5415
7.50	0.100	0.3417	0.3106	0.4579	0.4162	0.5480	0.4982	0.6667	0.6061	0.7081	0.6437
10.00	0.100	0.4413	0.4012	0.5531	0.5028	0.6359	0.5781	0.7413	0.6739	0.7773	0.7067
40.00	0.100	0.8273	0.7521	0.8901	0.8092	0.9305	0.8459	0.9763	0.8875	0.9907	0.9007
100.00	0.100	0.9707	0.8825	1.0035	0.9122	1.0234	0.9303	1.0451	0.9501	1.0518	0.9562
1000.00	0.100	1.0853	0.9866	1.0893	0.9902	1.0916	0.9924	1.0941	0.9946	1.0948	0.9953
0.01	0.200	0.0110	0.0092	0.0135	0.0113	0.0168	0.0140	0.0264	0.0220	0.0335	0.0279
0.10	0.200	0.0112	0.0094	0.0140	0.0117	0.0177	0.0147	0.0285	0.0238	0.0366	0.0305
0.15	0.200	0.0114	0.0095	0.0143	0.0119	0.0182	0.0152	0.0299	0.0250	0.0388	0.0323
0.25	0.200	0.0117	0.0098	0.0150	0.0125	0.0196	0.0163	0.0334	0.0278	0.0442	0.0369
0.50	0.200	0.0129	0.0108	0.0174	0.0145	0.0240	0.0200	0.0461	0.0384	0.0648	0.0540
0.75	0.200	0.0146	0.0122	0.0208	0.0173	0.0304	0.0253	0.0668	0.0557	0.0996	0.0830
1.00	0.200	0.0169	0.0140	0.0253	0.0211	0.0396	0.0330	0.1002	0.0835	0.1494	0.1245
2.00	0.200	0.0337	0.0281	0.0687	0.0572	0.1348	0.1123	0.2846	0.2372	0.3499	0.2915
3.00	0.200	0.0819	0.0683	0.1689	0.1408	0.2673	0.2227	0.4264	0.3553	0.4881	0.4068
5.00	0.200	0.2313	0.1927	0.3527	0.2939	0.4572	0.3810	0.6036	0.5030	0.6568	0.5473
7.50	0.200	0.3791	0.3159	0.5045	0.4204	0.6022	0.5018	0.7310	0.6092	0.7760	0.6467
10.00	0.200	0.4854	0.4045	0.6065	0.5054	0.6962	0.5802	0.8110	0.6758	0.8501	0.7084
40.00	0.200	0.9029	0.7524	0.9712	0.8094	1.0151	0.8459	1.0650	0.8875	1.0806	0.9005
100.00	0.200	1.0591	0.8826	1.0947	0.9122	1.1163	0.9303	1.1400	0.9500	1.1473	0.9561
1000.00	0.200	1.1839	0.9866	1.1883	0.9903	1.1909	0.9924	1.1935	0.9946	1.1943	0.9953

Table 4-1 (Continued)

P	K	RE= 0.2		RE= 0.5		RE= 1.0		RE= 3.0		RE= 5.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.0578	0.0386	0.0708	0.0472	0.0877	0.0584	0.1348	0.0899	0.1682	0.1122
0.10	0.500	0.0587	0.0391	0.0726	0.0484	0.0908	0.0606	0.1418	0.0946	0.1779	0.1186
0.15	0.500	0.0593	0.0395	0.0737	0.0491	0.0928	0.0619	0.1464	0.0976	0.1843	0.1228
0.25	0.500	0.0606	0.0404	0.0764	0.0509	0.0974	0.0649	0.1568	0.1045	0.1988	0.1325
0.50	0.500	0.0651	0.0434	0.0848	0.0565	0.1118	0.0745	0.1895	0.1263	0.2432	0.1621
0.75	0.500	0.0710	0.0473	0.0956	0.0638	0.1302	0.0868	0.2299	0.1533	0.2952	0.1968
1.00	0.500	0.0781	0.0521	0.1089	0.0726	0.1527	0.1018	0.2757	0.1838	0.3497	0.2331
2.00	0.500	0.1206	0.0804	0.1870	0.1247	0.2757	0.1838	0.4592	0.3061	0.5429	0.3620
3.00	0.500	0.1856	0.1237	0.2915	0.1943	0.4075	0.2717	0.6031	0.4021	0.6828	0.4552
5.00	0.500	0.3393	0.2262	0.4838	0.3225	0.6109	0.4072	0.7945	0.5297	0.8632	0.5754
7.50	0.500	0.5025	0.3350	0.6552	0.4368	0.7759	0.5173	0.9385	0.6256	0.9963	0.6642
10.00	0.500	0.6255	0.4170	0.7745	0.5163	0.8862	0.5908	1.0307	0.6872	1.0809	0.7206
40.00	0.500	1.1310	0.7540	1.2163	0.8109	1.2712	0.8475	1.3340	0.8894	1.3538	0.9025
100.00	0.500	1.3245	0.8830	1.3689	0.9126	1.3961	0.9307	1.4259	0.9506	1.4349	0.9566
1000.00	0.500	1.4799	0.9866	1.4854	0.9902	1.4886	0.9924	1.4919	0.9946	1.4929	0.9953
0.01	1.000	0.1903	0.0952	0.2321	0.1160	0.2858	0.1429	0.4278	0.2139	0.5205	0.2602
0.10	1.000	0.1924	0.0962	0.2361	0.1181	0.2924	0.1462	0.4407	0.2204	0.5366	0.2683
0.15	1.000	0.1937	0.0968	0.2387	0.1193	0.2966	0.1483	0.4486	0.2243	0.5465	0.2733
0.25	1.000	0.1966	0.0983	0.2442	0.1221	0.3056	0.1528	0.4658	0.2329	0.5677	0.2838
0.50	1.000	0.2059	0.1029	0.2608	0.1304	0.3319	0.1660	0.5141	0.2571	0.6250	0.3125
0.75	1.000	0.2173	0.1087	0.2808	0.1404	0.3626	0.1813	0.5660	0.2830	0.6834	0.3417
1.00	1.000	0.2306	0.1153	0.3033	0.1516	0.3964	0.1982	0.6184	0.3092	0.7396	0.3698
2.00	1.000	0.2978	0.1489	0.4106	0.2053	0.5439	0.2720	0.8074	0.4037	0.9288	0.4644
3.00	1.000	0.3792	0.1896	0.5277	0.2639	0.6843	0.3422	0.9542	0.4771	1.0678	0.5339
5.00	1.000	0.5499	0.2749	0.7374	0.3687	0.9056	0.4528	1.1577	0.5789	1.2548	0.6274
7.50	1.000	0.7344	0.3672	0.9335	0.4667	1.0946	0.5473	1.3178	0.6589	1.3994	0.6997
10.00	1.000	0.8797	0.4398	1.0756	0.5378	1.2254	0.6127	1.4239	0.7120	1.4942	0.7471
40.00	1.000	1.5156	0.7578	1.6296	0.8148	1.7036	0.8518	1.7891	0.8945	1.8166	0.9083
100.00	1.000	1.7684	0.8842	1.8278	0.9139	1.8642	0.9321	1.9050	0.9525	1.9176	0.9588
1000.00	1.000	1.9735	0.9868	1.9807	0.9904	1.9851	0.9925	1.9895	0.9948	1.9910	0.9955

Table 4-1 (Continued)

P	K	RE=10.0		RE=15.0		RE=20.0		RE=30.0		RE=40.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0007	0.0007	0.0008	0.0008	0.0010	0.0010	0.0013	0.0013	0.0015	0.0015
0.10	0.001	0.0009	0.0009	0.0012	0.0012	0.0015	0.0015	0.0019	0.0019	0.0023	0.0023
0.15	0.001	0.0011	0.0011	0.0014	0.0014	0.0018	0.0018	0.0024	0.0024	0.0029	0.0029
0.25	0.001	0.0015	0.0015	0.0021	0.0021	0.0026	0.0026	0.0037	0.0037	0.0046	0.0046
0.50	0.001	0.0038	0.0038	0.0063	0.0063	0.0096	0.0096	0.0181	0.0181	0.0270	0.0270
0.75	0.001	0.0201	0.0201	0.0517	0.0517	0.0769	0.0768	0.1052	0.1051	0.1200	0.1199
1.00	0.001	0.1036	0.1035	0.1406	0.1404	0.1625	0.1623	0.1872	0.1870	0.2001	0.1999
2.00	0.001	0.3250	0.3247	0.3548	0.3544	0.3733	0.3730	0.3938	0.3934	0.4040	0.4036
3.00	0.001	0.4494	0.4490	0.4759	0.4755	0.4925	0.4920	0.5103	0.5098	0.5189	0.5184
5.00	0.001	0.5911	0.5905	0.6129	0.6123	0.6264	0.6258	0.6408	0.6402	0.6474	0.6467
7.50	0.001	0.6867	0.6860	0.7046	0.7039	0.7155	0.7148	0.7271	0.7264	0.7323	0.7316
10.00	0.001	0.7442	0.7435	0.7594	0.7586	0.7687	0.7679	0.7784	0.7777	0.7828	0.7820
40.00	0.001	0.9156	0.9147	0.9212	0.9203	0.9246	0.9237	0.9282	0.9273	0.9299	0.9290
100.00	0.001	0.9630	0.9621	0.9656	0.9646	0.9671	0.9662	0.9687	0.9678	0.9695	0.9686
1000.00	0.001	0.9961	0.9951	0.9963	0.9953	0.9965	0.9955	0.9966	0.9957	0.9968	0.9958
0.01	0.010	0.0009	0.0009	0.0012	0.0012	0.0014	0.0014	0.0018	0.0018	0.0021	0.0021
0.10	0.010	0.0012	0.0012	0.0016	0.0016	0.0019	0.0019	0.0025	0.0025	0.0030	0.0029
0.15	0.010	0.0014	0.0014	0.0019	0.0019	0.0023	0.0023	0.0030	0.0030	0.0036	0.0036
0.25	0.010	0.0019	0.0019	0.0026	0.0026	0.0033	0.0033	0.0045	0.0044	0.0055	0.0054
0.50	0.010	0.0045	0.0045	0.0073	0.0073	0.0109	0.0108	0.0196	0.0195	0.0282	0.0279
0.75	0.010	0.0220	0.0218	0.0530	0.0524	0.0772	0.0765	0.1048	0.1038	0.1191	0.1179
1.00	0.010	0.1045	0.1034	0.1412	0.1398	0.1631	0.1615	0.1869	0.1850	0.1990	0.1971
2.00	0.010	0.3270	0.3237	0.3563	0.3527	0.3743	0.3706	0.3938	0.3899	0.4030	0.3990
3.00	0.010	0.4522	0.4477	0.4783	0.4736	0.4943	0.4894	0.5113	0.5062	0.5189	0.5137
5.00	0.010	0.5953	0.5894	0.6168	0.6107	0.6298	0.6236	0.6434	0.6370	0.6492	0.6428
7.50	0.010	0.6920	0.6851	0.7095	0.7025	0.7202	0.7131	0.7311	0.7239	0.7357	0.7284
10.00	0.010	0.7503	0.7429	0.7652	0.7576	0.7742	0.7666	0.7834	0.7756	0.7872	0.7795
40.00	0.010	0.9243	0.9151	0.9297	0.9205	0.9331	0.9239	0.9365	0.9272	0.9380	0.9287
100.00	0.010	0.9725	0.9628	0.9750	0.9653	0.9765	0.9668	0.9780	0.9683	0.9787	0.9690
1000.00	0.010	1.0060	0.9960	1.0062	0.9963	1.0064	0.9964	1.0066	0.9966	1.0067	0.9967

Table 4-1 (Continued)

P	K	RE=10.0		RE=15.0		RE=20.0		RE=30.0		RE=40.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0135	0.0123	0.0166	0.0151	0.0192	0.0175	0.0234	0.0213	0.0267	0.0243
0.10	0.100	0.0153	0.0139	0.0190	0.0173	0.0221	0.0201	0.0270	0.0246	0.0308	0.0280
0.15	0.100	0.0168	0.0152	0.0210	0.0191	0.0245	0.0223	0.0302	0.0275	0.0346	0.0314
0.25	0.100	0.0205	0.0187	0.0263	0.0239	0.0313	0.0285	0.0393	0.0357	0.0453	0.0412
0.50	0.100	0.0388	0.0352	0.0541	0.0492	0.0673	0.0612	0.0860	0.0782	0.0978	0.0889
0.75	0.100	0.0856	0.0778	0.1158	0.1053	0.1360	0.1236	0.1593	0.1448	0.1717	0.1561
1.00	0.100	0.1532	0.1393	0.1864	0.1695	0.2072	0.1884	0.2299	0.2090	0.2410	0.2191
2.00	0.100	0.3650	0.3318	0.3948	0.3589	0.4127	0.3752	0.4307	0.3916	0.4379	0.3981
3.00	0.100	0.4948	0.4498	0.5210	0.4737	0.5366	0.4878	0.5516	0.5015	0.5568	0.5062
5.00	0.100	0.6465	0.5877	0.6678	0.6071	0.6802	0.6184	0.6917	0.6288	0.6950	0.6319
7.50	0.100	0.7504	0.6822	0.7677	0.6979	0.7779	0.7072	0.7869	0.7154	0.7893	0.7176
10.00	0.100	0.8137	0.7397	0.8284	0.7531	0.8370	0.7609	0.8445	0.7677	0.8464	0.7695
40.00	0.100	1.0049	0.9135	1.0102	0.9184	1.0134	0.9213	1.0162	0.9238	1.0169	0.9245
100.00	0.100	1.0582	0.9620	1.0607	0.9643	1.0621	0.9656	1.0634	0.9667	1.0638	0.9671
1000.00	0.100	1.0955	0.9959	1.0958	0.9962	1.0959	0.9963	1.0960	0.9964	1.0961	0.9965
0.01	0.200	0.0468	0.0390	0.0569	0.0474	0.0653	0.0544	0.0782	0.0651	0.0879	0.0733
0.10	0.200	0.0519	0.0432	0.0632	0.0527	0.0726	0.0605	0.0869	0.0724	0.0975	0.0812
0.15	0.200	0.0556	0.0463	0.0681	0.0567	0.0784	0.0653	0.0939	0.0782	0.1052	0.0877
0.25	0.200	0.0650	0.0542	0.0805	0.0671	0.0931	0.0776	0.1115	0.0929	0.1244	0.1037
0.50	0.200	0.1016	0.0847	0.1275	0.1062	0.1467	0.1223	0.1718	0.1432	0.1871	0.1559
0.75	0.200	0.1573	0.1311	0.1909	0.1591	0.2136	0.1780	0.2403	0.2003	0.2549	0.2124
1.00	0.200	0.2197	0.1831	0.2558	0.2131	0.2789	0.2324	0.3047	0.2539	0.3177	0.2648
2.00	0.200	0.4232	0.3527	0.4561	0.3801	0.4760	0.3967	0.4959	0.4132	0.5037	0.4198
3.00	0.200	0.5546	0.4621	0.5833	0.4861	0.6002	0.5002	0.6162	0.5135	0.6214	0.5178
5.00	0.200	0.7122	0.5935	0.7349	0.6124	0.7481	0.6234	0.7598	0.6332	0.7626	0.6355
7.50	0.200	0.8218	0.6849	0.8403	0.7002	0.8508	0.7090	0.8597	0.7164	0.8613	0.7178
10.00	0.200	0.8892	0.7410	0.9048	0.7540	0.9136	0.7613	0.9209	0.7674	0.9221	0.7684
40.00	0.200	1.0958	0.9131	1.1014	0.9178	1.1046	0.9205	1.1072	0.9226	1.1076	0.9230
100.00	0.200	1.1541	0.9618	1.1567	0.9639	1.1582	0.9652	1.1594	0.9661	1.1596	0.9664
1000.00	0.200	1.1951	0.9959	1.1953	0.9961	1.1955	0.9963	1.1957	0.9964	1.1957	0.9964

Table 4-1 (Continued)

P	K	RE=10.0		RE=15.0		RE=20.0		RE=30.0		RE=40.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.2272	0.1515	0.2676	0.1784	0.2988	0.1992	0.3415	0.2277	0.3695	0.2463
0.10	0.500	0.2408	0.1606	0.2833	0.1889	0.3159	0.2106	0.3599	0.2399	0.3882	0.2588
0.15	0.500	0.2499	0.1666	0.2938	0.1958	0.3271	0.2180	0.3717	0.2478	0.4000	0.2667
0.25	0.500	0.2703	0.1802	0.3169	0.2113	0.3516	0.2344	0.3970	0.2647	0.4250	0.2833
0.50	0.500	0.3292	0.2195	0.3808	0.2538	0.4171	0.2781	0.4621	0.3080	0.4881	0.3254
0.75	0.500	0.3912	0.2608	0.4445	0.2964	0.4806	0.3204	0.5232	0.3488	0.5465	0.3643
1.00	0.500	0.4507	0.3005	0.5036	0.3358	0.5385	0.3590	0.5783	0.3855	0.5991	0.3994
2.00	0.500	0.6414	0.4276	0.6875	0.4583	0.7161	0.4774	0.7460	0.4973	0.7591	0.5061
3.00	0.500	0.7716	0.5144	0.8113	0.5408	0.8351	0.5567	0.8584	0.5723	0.8673	0.5782
5.00	0.500	0.9360	0.6240	0.9667	0.6445	0.9848	0.6565	1.0010	0.6673	1.0056	0.6704
7.50	0.500	1.0559	0.7039	1.0801	0.7201	1.0941	0.7294	1.1057	0.7372	1.1080	0.7387
10.00	0.500	1.1315	0.7544	1.1517	0.7678	1.1631	0.7754	1.1723	0.7815	1.1736	0.7824
40.00	0.500	1.3727	0.9151	1.3796	0.9197	1.3836	0.9224	1.3865	0.9243	1.3866	0.9244
100.00	0.500	1.4436	0.9624	1.4467	0.9644	1.4485	0.9657	1.4497	0.9665	1.4498	0.9666
1000.00	0.500	1.4939	0.9959	1.4942	0.9961	1.4944	0.9963	1.4945	0.9963	1.4946	0.9964
0.01	1.000	0.6651	0.3325	0.7495	0.3747	0.8073	0.4036	0.8744	0.4372	0.9103	0.4551
0.10	1.000	0.6846	0.3423	0.7699	0.3849	0.8277	0.4139	0.8944	0.4472	0.9296	0.4648
0.15	1.000	0.6963	0.3481	0.7819	0.3909	0.8396	0.4198	0.9057	0.4529	0.9405	0.4702
0.25	1.000	0.7207	0.3604	0.8065	0.4033	0.8637	0.4319	0.9285	0.4643	0.9622	0.4811
0.50	1.000	0.7832	0.3916	0.8677	0.4339	0.9227	0.4614	0.9835	0.4917	1.0139	0.5069
0.75	1.000	0.8429	0.4214	0.9248	0.4624	0.9771	0.4885	1.0337	0.5168	1.0610	0.5305
1.00	1.000	0.8978	0.4489	0.9766	0.4883	1.0261	0.5131	1.0788	0.5394	1.1036	0.5518
2.00	1.000	1.0725	0.5363	1.1391	0.5696	1.1797	0.5898	1.2201	0.6101	1.2371	0.6186
3.00	1.000	1.1959	0.5980	1.2529	0.6265	1.2871	0.6436	1.3199	0.6599	1.3323	0.6662
5.00	1.000	1.3592	0.6796	1.4035	0.7017	1.4296	0.7148	1.4532	0.7266	1.4604	0.7302
7.50	1.000	1.4843	0.7422	1.5192	0.7596	1.5394	0.7697	1.5566	0.7783	1.5609	0.7805
10.00	1.000	1.5661	0.7830	1.5950	0.7975	1.6115	0.8058	1.6252	0.8126	1.6279	0.8139
40.00	1.000	1.8433	0.9217	1.8529	0.9265	1.8584	0.9292	1.8623	0.9311	1.8627	0.9313
100.00	1.000	1.9295	0.9647	1.9339	0.9669	1.9363	0.9681	1.9378	0.9689	1.9379	0.9690
1000.00	1.000	1.9922	0.9961	1.9928	0.9964	1.9930	0.9965	1.9931	0.9966	1.9931	0.9966

Table 4-2

Impaction Efficiencies at $R_\infty = 3$

P	K	RE= 0.2		RE= 0.5		RE= 1.0		RE= 3.0		RE= 5.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
0.10	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
0.15	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003
0.25	0.001	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005
0.50	0.001	0.0010	0.0010	0.0011	0.0011	0.0013	0.0013	0.0022	0.0022	0.0042	0.0042
0.75	0.001	0.1054	0.1053	0.1142	0.1141	0.1295	0.1294	0.1650	0.1648	0.1884	0.1882
1.00	0.001	0.2603	0.2600	0.2639	0.2636	0.2709	0.2706	0.2904	0.2901	0.3057	0.3054
2.00	0.001	0.5182	0.5176	0.5199	0.5194	0.5235	0.5229	0.5342	0.5337	0.5435	0.5429
3.00	0.001	0.6352	0.6346	0.6366	0.6359	0.6394	0.6388	0.6479	0.6472	0.6553	0.6546
5.00	0.001	0.7515	0.7507	0.7525	0.7517	0.7546	0.7539	0.7610	0.7602	0.7664	0.7657
7.50	0.001	0.8213	0.8205	0.8221	0.8213	0.8238	0.8229	0.8287	0.8279	0.8328	0.8320
10.00	0.001	0.8602	0.8594	0.8609	0.8601	0.8623	0.8614	0.8663	0.8654	0.8697	0.8688
40.00	0.001	0.9612	0.9602	0.9614	0.9605	0.9618	0.9609	0.9631	0.9621	0.9641	0.9631
100.00	0.001	0.9841	0.9831	0.9842	0.9832	0.9844	0.9834	0.9849	0.9840	0.9854	0.9844
1000.00	0.001	0.9984	0.9974	0.9984	0.9974	0.9984	0.9974	0.9984	0.9974	0.9986	0.9976
0.01	0.010	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005
0.10	0.010	0.0004	0.0004	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006
0.15	0.010	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0007	0.0007
0.25	0.010	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0009	0.0009	0.0011	0.0011
0.50	0.010	0.0021	0.0021	0.0023	0.0023	0.0027	0.0026	0.0045	0.0044	0.0084	0.0083
0.75	0.010	0.1142	0.1131	0.1221	0.1209	0.1362	0.1349	0.1693	0.1676	0.1918	0.1899
1.00	0.010	0.2661	0.2634	0.2693	0.2667	0.2760	0.2733	0.2947	0.2917	0.3095	0.3064
2.00	0.010	0.5253	0.5201	0.5268	0.5216	0.5301	0.5248	0.5399	0.5346	0.5486	0.5432
3.00	0.010	0.6431	0.6367	0.6442	0.6378	0.6468	0.6404	0.6545	0.6480	0.6614	0.6548
5.00	0.010	0.7600	0.7525	0.7608	0.7533	0.7628	0.7552	0.7685	0.7609	0.7736	0.7659
7.50	0.010	0.8302	0.8220	0.8309	0.8226	0.8324	0.8242	0.8368	0.8286	0.8407	0.8324
10.00	0.010	0.8694	0.8608	0.8699	0.8613	0.8712	0.8625	0.8748	0.8661	0.8779	0.8693
40.00	0.010	0.9709	0.9613	0.9711	0.9615	0.9715	0.9619	0.9726	0.9630	0.9736	0.9639
100.00	0.010	0.9940	0.9842	0.9941	0.9843	0.9943	0.9844	0.9947	0.9848	0.9952	0.9853
1000.00	0.010	1.0084	0.9985	1.0084	0.9985	1.0084	0.9985	1.0084	0.9985	1.0084	0.9985

Table 4-2 (Continued)

P	K	RE= 0.2		RE= 0.5		RE= 1.0		RE= 3.0		RE= 5.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0204	0.0186	0.0204	0.0186	0.0208	0.0190	0.0219	0.0199	0.0239	0.0217
0.10	0.100	0.0210	0.0191	0.0213	0.0193	0.0220	0.0200	0.0243	0.0220	0.0270	0.0245
0.15	0.100	0.0229	0.0208	0.0233	0.0212	0.0243	0.0220	0.0272	0.0248	0.0306	0.0279
0.25	0.100	0.0293	0.0266	0.0300	0.0272	0.0315	0.0287	0.0366	0.0333	0.0422	0.0384
0.50	0.100	0.0747	0.0679	0.0777	0.0706	0.0845	0.0768	0.1061	0.0964	0.1262	0.1147
0.75	0.100	0.2139	0.1945	0.2173	0.1976	0.2252	0.2047	0.2468	0.2244	0.2647	0.2406
1.00	0.100	0.3385	0.3077	0.3403	0.3094	0.3455	0.3140	0.3604	0.3276	0.3738	0.3398
2.00	0.100	0.5983	0.5439	0.5988	0.5443	0.6010	0.5463	0.6083	0.5530	0.6154	0.5595
3.00	0.100	0.7196	0.6542	0.7198	0.6543	0.7214	0.6558	0.7266	0.6605	0.7320	0.6654
5.00	0.100	0.8406	0.7642	0.8407	0.7642	0.8418	0.7653	0.8454	0.7685	0.8492	0.7720
7.50	0.100	0.9133	0.8303	0.9133	0.8303	0.9142	0.8311	0.9169	0.8336	0.9197	0.8361
10.00	0.100	0.9538	0.8671	0.9539	0.8672	0.9546	0.8678	0.9567	0.8697	0.9590	0.8718
40.00	0.100	1.0593	0.9630	1.0593	0.9630	1.0594	0.9631	1.0601	0.9637	1.0607	0.9643
100.00	0.100	1.0833	0.9848	1.0833	0.9848	1.0834	0.9849	1.0837	0.9852	1.0840	0.9855
1000.00	0.100	1.0983	0.9985	1.0983	0.9985	1.0983	0.9985	1.0983	0.9985	1.0984	0.9985
0.01	0.200	0.0748	0.0623	0.0748	0.0623	0.0761	0.0634	0.0795	0.0662	0.0857	0.0715
0.10	0.200	0.0757	0.0631	0.0764	0.0637	0.0787	0.0656	0.0853	0.0711	0.0935	0.0779
0.15	0.200	0.0810	0.0675	0.0820	0.0683	0.0848	0.0707	0.0931	0.0776	0.1028	0.0856
0.25	0.200	0.0982	0.0819	0.0999	0.0832	0.1039	0.0866	0.1163	0.0969	0.1295	0.1079
0.50	0.200	0.1876	0.1563	0.1909	0.1591	0.1988	0.1657	0.2214	0.1845	0.2423	0.2019
0.75	0.200	0.3231	0.2693	0.3254	0.2712	0.3321	0.2767	0.3511	0.2926	0.3688	0.3074
1.00	0.200	0.4369	0.3641	0.4381	0.3650	0.4427	0.3689	0.4566	0.3805	0.4706	0.3922
2.00	0.200	0.6916	0.5763	0.6915	0.5762	0.6932	0.5777	0.6993	0.5827	0.7066	0.5889
3.00	0.200	0.8136	0.6780	0.8131	0.6776	0.8143	0.6786	0.8181	0.6818	0.8233	0.6861
5.00	0.200	0.9359	0.7799	0.9355	0.7796	0.9361	0.7801	0.9385	0.7821	0.9418	0.7848
7.50	0.200	1.0096	0.8413	1.0092	0.8410	1.0096	0.8414	1.0112	0.8427	1.0136	0.8446
10.00	0.200	1.0508	0.8757	1.0504	0.8753	1.0508	0.8757	1.0520	0.8767	1.0538	0.8782
40.00	0.200	1.1582	0.9652	1.1582	0.9652	1.1582	0.9652	1.1586	0.9655	1.1591	0.9659
100.00	0.200	1.1829	0.9857	1.1829	0.9857	1.1829	0.9857	1.1831	0.9859	1.1832	0.9860
1000.00	0.200	1.1983	0.9986	1.1983	0.9986	1.1983	0.9986	1.1983	0.9986	1.1983	0.9986

Table 4-2 (Continued).

P	K	RE= 0.2		RE= 0.5		RE= 1.0		RE= 3.0		RE= 5.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.4057	0.2705	0.4050	0.2700	0.4089	0.2726	0.4182	0.2788	0.4392	0.2928
0.10	0.500	0.4002	0.2668	0.4018	0.2679	0.4086	0.2724	0.4275	0.2850	0.4532	0.3021
0.15	0.500	0.4113	0.2742	0.4135	0.2757	0.4213	0.2809	0.4434	0.2956	0.4707	0.3138
0.25	0.500	0.4489	0.2993	0.4519	0.3012	0.4609	0.3073	0.4866	0.3244	0.5156	0.3438
0.50	0.500	0.5801	0.3867	0.5824	0.3882	0.5908	0.3938	0.6149	0.4100	0.6413	0.4275
0.75	0.500	0.7039	0.4693	0.7047	0.4698	0.7107	0.4738	0.7286	0.4858	0.7497	0.4998
1.00	0.500	0.8014	0.5343	0.8012	0.5341	0.8053	0.5369	0.8183	0.5455	0.8350	0.5567
2.00	0.500	1.0254	0.6836	1.0237	0.6825	1.0248	0.6832	1.0291	0.6861	1.0377	0.6918
3.00	0.500	1.1363	0.7575	1.1345	0.7563	1.1347	0.7565	1.1363	0.7575	1.1418	0.7612
5.00	0.500	1.2492	0.8328	1.2475	0.8316	1.2472	0.8314	1.2471	0.8314	1.2501	0.8334
7.50	0.500	1.3181	0.8787	1.3166	0.8778	1.3162	0.8775	1.3156	0.8771	1.3175	0.8783
10.00	0.500	1.3569	0.9046	1.3558	0.9038	1.3553	0.9036	1.3546	0.9031	1.3560	0.9040
40.00	0.500	1.4596	0.9730	1.4591	0.9728	1.4589	0.9726	1.4585	0.9724	1.4587	0.9725
100.00	0.500	1.4834	0.9890	1.4832	0.9888	1.4831	0.9888	1.4829	0.9886	1.4830	0.9887
1000.00	0.500	1.4983	0.9989	1.4983	0.9989	1.4983	0.9989	1.4983	0.9989	1.4983	0.9989
0.01	1.000	1.3002	0.6501	1.2973	0.6486	1.2984	0.6492	1.3011	0.6506	1.3208	0.6604
0.10	1.000	1.2798	0.6399	1.2793	0.6397	1.2842	0.6421	1.2987	0.6493	1.3243	0.6621
0.15	1.000	1.2846	0.6423	1.2848	0.6424	1.2907	0.6453	1.3081	0.6540	1.3348	0.6674
0.25	1.000	1.3131	0.6565	1.3133	0.6567	1.3193	0.6597	1.3379	0.6689	1.3639	0.6820
0.50	1.000	1.4081	0.7041	1.4069	0.7034	1.4104	0.7052	1.4236	0.7118	1.4440	0.7220
0.75	1.000	1.4860	0.7430	1.4838	0.7419	1.4854	0.7427	1.4938	0.7469	1.5097	0.7548
1.00	1.000	1.5451	0.7726	1.5422	0.7711	1.5428	0.7714	1.5480	0.7740	1.5607	0.7803
2.00	1.000	1.6826	0.8413	1.6791	0.8396	1.6782	0.8391	1.6778	0.8389	1.6847	0.8424
3.00	1.000	1.7533	0.8767	1.7500	0.8750	1.7483	0.8741	1.7465	0.8732	1.7511	0.8755
5.00	1.000	1.8274	0.9137	1.8248	0.9124	1.8232	0.9116	1.8201	0.9100	1.8224	0.9112
7.50	1.000	1.8736	0.9368	1.8712	0.9356	1.8696	0.9348	1.8673	0.9337	1.8689	0.9344
10.00	1.000	1.9002	0.9501	1.8982	0.9491	1.8969	0.9485	1.8946	0.9473	1.8954	0.9477
40.00	1.000	1.9715	0.9857	1.9708	0.9854	1.9703	0.9852	1.9693	0.9846	1.9694	0.9847
100.00	1.000	1.9883	0.9942	1.9880	0.9940	1.9877	0.9939	1.9873	0.9937	1.9873	0.9937
1000.00	1.000	1.9988	0.9994	1.9987	0.9993	1.9987	0.9993	1.9987	0.9993	1.9987	0.9993

Table 4-2 (Continued)

P	K	RE=10.0		RE=15.0		RE=20.0		RE=30.0		RE=40.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003
0.10	0.001	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0006	0.0006
0.15	0.001	0.0004	0.0004	0.0005	0.0005	0.0005	0.0005	0.0007	0.0007	0.0008	0.0008
0.25	0.001	0.0007	0.0007	0.0009	0.0009	0.0011	0.0011	0.0016	0.0016	0.0020	0.0020
0.50	0.001	0.0380	0.0380	0.0807	0.0806	0.1006	0.1005	0.1272	0.1271	0.1415	0.1414
0.75	0.001	0.2236	0.2234	0.2438	0.2435	0.2545	0.2542	0.2717	0.2714	0.2820	0.2817
1.00	0.001	0.3321	0.3317	0.3482	0.3479	0.3570	0.3566	0.3715	0.3712	0.3804	0.3800
2.00	0.001	0.5606	0.5600	0.5715	0.5710	0.5776	0.5770	0.5880	0.5874	0.5941	0.5935
3.00	0.001	0.6689	0.6682	0.6777	0.6770	0.6825	0.6818	0.6908	0.6901	0.6958	0.6951
5.00	0.001	0.7765	0.7757	0.7830	0.7822	0.7864	0.7856	0.7923	0.7916	0.7959	0.7951
7.50	0.001	0.8404	0.8396	0.8453	0.8445	0.8479	0.8470	0.8523	0.8515	0.8549	0.8541
10.00	0.001	0.8757	0.8749	0.8796	0.8788	0.8817	0.8808	0.8853	0.8844	0.8874	0.8865
40.00	0.001	0.9660	0.9650	0.9671	0.9661	0.9677	0.9667	0.9687	0.9678	0.9693	0.9684
100.00	0.001	0.9861	0.9852	0.9866	0.9856	0.9869	0.9859	0.9873	0.9863	0.9875	0.9865
1000.00	0.001	0.9986	0.9976	0.9987	0.9977	0.9987	0.9977	0.9987	0.9977	0.9987	0.9977
0.01	0.010	0.0006	0.0006	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010
0.10	0.010	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010	0.0012	0.0012	0.0014	0.0014
0.15	0.010	0.0009	0.0009	0.0011	0.0011	0.0013	0.0013	0.0016	0.0016	0.0019	0.0019
0.25	0.010	0.0015	0.0015	0.0020	0.0020	0.0024	0.0024	0.0033	0.0033	0.0041	0.0041
0.50	0.010	0.0467	0.0462	0.0860	0.0852	0.1040	0.1030	0.1284	0.1271	0.1415	0.1401
0.75	0.010	0.2262	0.2239	0.2456	0.2431	0.2555	0.2530	0.2715	0.2688	0.2806	0.2779
1.00	0.010	0.3349	0.3316	0.3502	0.3468	0.3582	0.3546	0.3714	0.3677	0.3790	0.3752
2.00	0.010	0.5647	0.5591	0.5750	0.5693	0.5802	0.5745	0.5892	0.5834	0.5943	0.5885
3.00	0.010	0.6742	0.6675	0.6823	0.6755	0.6863	0.6796	0.6934	0.6865	0.6972	0.6903
5.00	0.010	0.7830	0.7752	0.7888	0.7810	0.7917	0.7838	0.7967	0.7888	0.7994	0.7915
7.50	0.010	0.8478	0.8394	0.8521	0.8437	0.8543	0.8458	0.8580	0.8495	0.8600	0.8515
10.00	0.010	0.8836	0.8749	0.8871	0.8783	0.8888	0.8800	0.8917	0.8829	0.8933	0.8844
40.00	0.010	0.9753	0.9656	0.9763	0.9666	0.9768	0.9671	0.9777	0.9680	0.9781	0.9684
100.00	0.010	0.9959	0.9860	0.9963	0.9864	0.9965	0.9866	0.9968	0.9869	0.9970	0.9871
1000.00	0.010	1.0086	0.9986	1.0086	0.9986	1.0086	0.9986	1.0087	0.9987	1.0087	0.9987

Table 4-2 (Continued)

P	K	RE=10.0		RE=15.0		RE=20.0		RE=30.0		RE=40.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0287	0.0261	0.0330	0.0300	0.0362	0.0329	0.0427	0.0388	0.0481	0.0437
0.10	0.100	0.0332	0.0302	0.0385	0.0350	0.0424	0.0386	0.0499	0.0453	0.0558	0.0507
0.15	0.100	0.0384	0.0349	0.0450	0.0409	0.0499	0.0453	0.0590	0.0536	0.0661	0.0601
0.25	0.100	0.0551	0.0501	0.0661	0.0600	0.0739	0.0672	0.0882	0.0802	0.0985	0.0896
0.50	0.100	0.1622	0.1475	0.1845	0.1677	0.1964	0.1786	0.2156	0.1960	0.2266	0.2060
0.75	0.100	0.2952	0.2684	0.3134	0.2849	0.3223	0.2930	0.3371	0.3065	0.3450	0.3136
1.00	0.100	0.3978	0.3617	0.4125	0.3750	0.4191	0.3810	0.4307	0.3915	0.4363	0.3966
2.00	0.100	0.6295	0.5723	0.6381	0.5801	0.6411	0.5828	0.6469	0.5881	0.6488	0.5898
3.00	0.100	0.7424	0.6749	0.7487	0.6806	0.7505	0.6823	0.7542	0.6857	0.7550	0.6864
5.00	0.100	0.8563	0.7785	0.8604	0.7822	0.8614	0.7831	0.8635	0.7850	0.8635	0.7850
7.50	0.100	0.9250	0.8409	0.9278	0.8435	0.9284	0.8440	0.9296	0.8451	0.9293	0.8449
10.00	0.100	0.9631	0.8755	0.9654	0.8776	0.9657	0.8779	0.9666	0.8787	0.9663	0.8784
40.00	0.100	1.0620	0.9655	1.0626	0.9660	1.0626	0.9660	1.0628	0.9662	1.0626	0.9660
100.00	0.100	1.0845	0.9859	1.0846	0.9860	1.0847	0.9861	1.0848	0.9862	1.0846	0.9860
1000.00	0.100	1.0985	0.9986	1.0985	0.9986	1.0985	0.9986	1.0985	0.9986	1.0985	0.9986
0.01	0.200	0.1015	0.0846	0.1155	0.0962	0.1253	0.1044	0.1454	0.1211	0.1616	0.1347
0.10	0.200	0.1122	0.0935	0.1280	0.1066	0.1391	0.1159	0.1602	0.1335	0.1765	0.1471
0.15	0.200	0.1243	0.1035	0.1419	0.1182	0.1541	0.1284	0.1768	0.1474	0.1938	0.1615
0.25	0.200	0.1579	0.1316	0.1798	0.1499	0.1941	0.1617	0.2195	0.1829	0.2372	0.1977
0.50	0.200	0.2806	0.2338	0.3057	0.2547	0.3194	0.2662	0.3432	0.2860	0.3579	0.2983
0.75	0.200	0.4015	0.3346	0.4224	0.3520	0.4326	0.3605	0.4512	0.3760	0.4619	0.3849
1.00	0.200	0.4973	0.4144	0.5144	0.4286	0.5220	0.4350	0.5365	0.4471	0.5442	0.4535
2.00	0.200	0.7217	0.6014	0.7310	0.6092	0.7339	0.6116	0.7404	0.6170	0.7428	0.6190
3.00	0.200	0.8339	0.6949	0.8403	0.7003	0.8416	0.7013	0.8452	0.7044	0.8458	0.7049
5.00	0.200	0.9485	0.7905	0.9524	0.7937	0.9526	0.7938	0.9541	0.7951	0.9535	0.7946
7.50	0.200	1.0183	0.8486	1.0208	0.8507	1.0206	0.8505	1.0212	0.8510	1.0204	0.8503
10.00	0.200	1.0575	0.8812	1.0594	0.8828	1.0591	0.8826	1.0593	0.8827	1.0584	0.8820
40.00	0.200	1.1600	0.9667	1.1604	0.9670	1.1603	0.9669	1.1601	0.9668	1.1597	0.9664
100.00	0.200	1.1836	0.9863	1.1838	0.9865	1.1838	0.9865	1.1836	0.9863	1.1834	0.9862
1000.00	0.200	1.1983	0.9986	1.1983	0.9986	1.1983	0.9986	1.1983	0.9986	1.1983	0.9986

Table 4-2 (Continued)

P	K	RE=10.0		RE=15.0		RE=20.0		RE=30.0		RE=40.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.4940	0.3293	0.5401	0.3601	0.5662	0.3775	0.6230	0.4153	0.6623	0.4415
0.10	0.500	0.5128	0.3419	0.5603	0.3735	0.5878	0.3918	0.6431	0.4287	0.6801	0.4534
0.15	0.500	0.5320	0.3547	0.5796	0.3864	0.6068	0.4045	0.6606	0.4404	0.6961	0.4641
0.25	0.500	0.5777	0.3851	0.6239	0.4160	0.6497	0.4331	0.6997	0.4665	0.7318	0.4879
0.50	0.500	0.6959	0.4639	0.7348	0.4899	0.7548	0.5032	0.7947	0.5298	0.8190	0.5460
0.75	0.500	0.7944	0.5296	0.8262	0.5508	0.8413	0.5609	0.8729	0.5819	0.8916	0.5944
1.00	0.500	0.8718	0.5812	0.8981	0.5987	0.9096	0.6064	0.9354	0.6236	0.9500	0.6333
2.00	0.500	1.0585	0.7056	1.0733	0.7155	1.0782	0.7188	1.0921	0.7281	1.0990	0.7327
3.00	0.500	1.1559	0.7706	1.1661	0.7774	1.1684	0.7790	1.1775	0.7850	1.1813	0.7875
5.00	0.500	1.2586	0.8391	1.2647	0.8432	1.2652	0.8435	1.2700	0.8467	1.2716	0.8477
7.50	0.500	1.3231	0.8821	1.3271	0.8847	1.3268	0.8845	1.3296	0.8864	1.3301	0.8867
10.00	0.500	1.3600	0.9067	1.3629	0.9086	1.3624	0.9083	1.3642	0.9095	1.3644	0.9096
40.00	0.500	1.4597	0.9731	1.4603	0.9735	1.4599	0.9732	1.4601	0.9734	1.4599	0.9732
100.00	0.500	1.4834	0.9889	1.4836	0.9891	1.4834	0.9889	1.4834	0.9890	1.4833	0.9889
1000.00	0.500	1.4983	0.9989	1.4983	0.9989	1.4983	0.9989	1.4983	0.9989	1.4983	0.9989
0.01	1.000	1.3819	0.6910	1.4308	0.7154	1.4514	0.7257	1.5027	0.7514	1.5336	0.7668
0.10	1.000	1.3903	0.6952	1.4395	0.7198	1.4606	0.7303	1.5093	0.7546	1.5380	0.7690
0.15	1.000	1.4007	0.7003	1.4488	0.7244	1.4694	0.7347	1.5162	0.7581	1.5436	0.7718
0.25	1.000	1.4266	0.7133	1.4713	0.7356	1.4902	0.7451	1.5329	0.7665	1.5575	0.7787
0.50	1.000	1.4943	0.7472	1.5302	0.7651	1.5444	0.7722	1.5777	0.7888	1.5964	0.7982
0.75	1.000	1.5507	0.7753	1.5801	0.7900	1.5906	0.7953	1.6175	0.8087	1.6320	0.8160
1.00	1.000	1.5953	0.7976	1.6201	0.8101	1.6283	0.8141	1.6506	0.8253	1.6623	0.8311
2.00	1.000	1.7062	0.8531	1.7217	0.8608	1.7252	0.8626	1.7385	0.8693	1.7443	0.8722
3.00	1.000	1.7666	0.8833	1.7781	0.8891	1.7797	0.8899	1.7891	0.8945	1.7926	0.8963
5.00	1.000	1.8329	0.9164	1.8402	0.9201	1.8406	0.9203	1.8463	0.9231	1.8479	0.9240
7.50	1.000	1.8759	0.9380	1.8812	0.9406	1.8805	0.9402	1.8844	0.9422	1.8851	0.9426
10.00	1.000	1.9008	0.9504	1.9047	0.9523	1.9044	0.9522	1.9071	0.9536	1.9075	0.9537
40.00	1.000	1.9706	0.9853	1.9718	0.9859	1.9715	0.9857	1.9721	0.9860	1.9718	0.9859
100.00	1.000	1.9877	0.9939	1.9883	0.9942	1.9880	0.9940	1.9883	0.9942	1.9883	0.9942
1000.00	1.000	1.9987	0.9993	1.9987	0.9993	1.9987	0.9993	1.9987	0.9993	1.9987	0.9993

Table 4-3

Impaction Efficiencies at $Re_c = 0.2$, $R_\infty = 200$

P	K=0.001		K=0.010		K=0.100		K=0.200		K=0.500		K=1.000	
	ε	E	ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.0002	0.0002	0.0002	0.0002	0.0029	0.0026	0.0103	0.0086	0.0540	0.0360	0.1777	0.0889
0.10	0.0002	0.0002	0.0002	0.0002	0.0029	0.0027	0.0105	0.0087	0.0548	0.0365	0.1796	0.0898
0.15	0.0002	0.0002	0.0003	0.0002	0.0030	0.0027	0.0106	0.0088	0.0553	0.0369	0.1808	0.0904
0.25	0.0002	0.0002	0.0003	0.0003	0.0031	0.0028	0.0109	0.0091	0.0565	0.0376	0.1834	0.0917
0.50	0.0003	0.0003	0.0003	0.0003	0.0034	0.0031	0.0120	0.0100	0.0603	0.0402	0.1915	0.0957
0.75	0.0003	0.0003	0.0004	0.0004	0.0039	0.0035	0.0134	0.0112	0.0654	0.0436	0.2014	0.1007
1.00	0.0004	0.0004	0.0005	0.0005	0.0045	0.0041	0.0153	0.0127	0.0715	0.0477	0.2130	0.1065
2.00	0.0010	0.0010	0.0012	0.0012	0.0095	0.0086	0.0288	0.0240	0.1073	0.0715	0.2714	0.1357
3.00	0.0047	0.0047	0.0053	0.0052	0.0321	0.0292	0.0661	0.0551	0.1627	0.1085	0.3429	0.1715
5.00	0.1462	0.1460	0.1482	0.1467	0.1703	0.1548	0.1994	0.1662	0.3005	0.2003	0.4973	0.2486
7.50	0.2738	0.2735	0.2768	0.2740	0.3054	0.2777	0.3398	0.2832	0.4540	0.3027	0.6702	0.3351
10.00	0.3634	0.3630	0.3671	0.3635	0.4022	0.3656	0.4428	0.3690	0.5727	0.3818	0.8097	0.4048
40.00	0.7183	0.7176	0.7254	0.7183	0.7900	0.7182	0.8622	0.7185	1.0800	0.7200	1.4473	0.7237
100.00	0.8594	0.8585	0.8679	0.8593	0.9451	0.8592	1.0310	0.8592	1.2892	0.8595	1.7214	0.8607
1000.00	0.9830	0.9820	0.9928	0.9830	1.0813	0.9830	1.1794	0.9829	1.4744	0.9829	1.9660	0.9830

Table 4-4

Comparison of Impaction Efficiencies for Potential Flow

P	K	$x_p = -5$		$x_p = -8$		$x_p = -40$		$x_p = -100$
		Davies & Peetz [7]	this work	Subr. & Kuloor [12]	this work	House. & Gold. [13]	this work	this work
1	0.001	0.38	0.4000	0.38	0.3875	—	0.3839	0.3801
5	0.001	0.77	0.8020	0.77	0.7856	—	0.7757	0.7729
10	0.001	0.84	0.8923	0.88	0.8812	—	0.8724	0.8700
40	0.001	0.91	0.9712	—	0.9677	—	0.9639	0.9622
1	0.10	0.47	0.4884	0.46	0.4453	—	0.4689	0.4384
5	0.10	0.79	0.8269	0.80	0.7900	—	0.8003	0.7786
10	0.10	0.85	0.9055	0.89	0.8814	—	0.8855	0.8714
40	0.10	0.93	0.9746	—	0.9672	—	0.9673	0.9627
1	1.0	—	0.8299	—	0.8017	0.80	0.8003	0.7899
5	1.0	—	0.9337	—	0.9030	0.91	0.9077	0.8913
10	1.0	—	0.9628	—	0.9412	0.94	0.9439	0.9313
40	1.0	—	0.9898	—	0.9825	0.98	0.9830	0.9782

Table 4-5

Impaction Efficiencies for Potential Flow

P	K=0.001		K=0.010		K=0.100		K=0.200		K=0.500		K=1.000	
	ε	E	ε	E	ε	E	ε	F	ε	E	ε	E
0.01	0.0001	0.0001	0.0100	0.0099	0.1782	0.1620	0.3586	0.2988	0.8307	0.5538	1.4993	0.7497
0.10	0.0004	0.0004	0.0122	0.0121	0.1642	0.1493	0.3419	0.2849	0.8230	0.5486	1.4976	0.7488
0.15	0.0007	0.0007	0.0202	0.0200	0.1783	0.1621	0.3516	0.2930	0.8263	0.5509	1.4991	0.7496
0.25	0.0376	0.0375	0.0589	0.0583	0.2171	0.1974	0.3823	0.3186	0.8405	0.5603	1.5051	0.7526
0.50	0.1840	0.1839	0.1953	0.1933	0.3228	0.2934	0.4685	0.3905	0.8894	0.5929	1.5286	0.7643
0.75	0.2968	0.2965	0.3042	0.3012	0.4115	0.3741	0.5434	0.4528	0.9376	0.6251	1.5547	0.7774
1.00	0.3805	0.3801	0.3864	0.3826	0.4822	0.4384	0.6047	0.5039	0.9797	0.6532	1.5799	0.7899
2.00	0.5744	0.5738	0.5788	0.5731	0.6587	0.5988	0.7643	0.6369	1.1001	0.7334	1.6598	0.8299
3.00	0.6724	0.6718	0.6773	0.6706	0.7541	0.6855	0.8542	0.7118	1.1740	0.7827	1.7143	0.8571
5.00	0.7737	0.7729	0.7796	0.7718	0.8565	0.7786	0.9534	0.7945	1.2606	0.8404	1.7826	0.8913
7.50	0.8359	0.8350	0.8425	0.8342	0.9214	0.8376	1.0176	0.8480	1.3193	0.8795	1.8320	0.9160
10.00	0.8709	0.8700	0.8781	0.8694	0.9586	0.8714	1.0549	0.8791	1.3545	0.9030	1.8627	0.9313
40.00	0.9632	0.9622	0.9723	0.9627	1.0589	0.9627	1.1573	0.9644	1.4558	0.9705	1.9563	0.9782
100.00	0.9848	0.9838	0.9944	0.9846	1.0830	0.9846	1.1822	0.9852	1.4814	0.9876	1.9814	0.9907
1000.00	0.9984	0.9974	1.0084	0.9985	1.0983	0.9985	1.1981	0.9985	1.4981	0.9987	1.9981	0.9990

Table 4-6

Impaction Efficiencies at Re_c = 0.2

P	K	RINF=100.0		RINF= 50.0		RINF= 25.0		RINF= 10.0		RINF= 3.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
0.10	0.001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002
0.15	0.001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002
0.25	0.001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0003	0.0003
0.50	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0010	0.0010
0.75	0.001	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.1054	0.1053
1.00	0.001	0.0004	0.0004	0.0003	0.0003	0.0004	0.0004	0.0006	0.0006	0.2603	0.2600
2.00	0.001	0.0010	0.0010	0.0011	0.0011	0.0022	0.0022	0.1394	0.1393	0.5182	0.5176
3.00	0.001	0.0082	0.0082	0.0407	0.0407	0.1260	0.1259	0.3181	0.3178	0.6352	0.6346
5.00	0.001	0.1740	0.1738	0.2270	0.2268	0.3225	0.3222	0.5085	0.5080	0.7515	0.7507
7.50	0.001	0.3069	0.3066	0.3673	0.3669	0.4670	0.4665	0.6322	0.6316	0.8213	0.8205
10.00	0.001	0.3990	0.3986	0.4619	0.4614	0.5590	0.5584	0.7054	0.7046	0.8602	0.8594
40.00	0.001	0.7522	0.7515	0.7994	0.7986	0.8527	0.8518	0.9121	0.9112	0.9612	0.9602
100.00	0.001	0.8827	0.8818	0.9098	0.9089	0.9365	0.9356	0.9633	0.9623	0.9841	0.9831
1000.00	0.001	0.9867	0.9857	0.9902	0.9892	0.9933	0.9923	0.9962	0.9952	0.9984	0.9974
0.01	0.010	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0004
0.10	0.010	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0004
0.15	0.010	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005
0.25	0.010	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0007	0.0007
0.50	0.010	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.0021	0.0021
0.75	0.010	0.0004	0.0004	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.1142	0.1131
1.00	0.010	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0009	0.0009	0.2661	0.2634
2.00	0.010	0.0012	0.0012	0.0014	0.0014	0.0027	0.0027	0.1421	0.1407	0.5253	0.5201
3.00	0.010	0.0093	0.0092	0.0427	0.0422	0.1279	0.1266	0.3221	0.3189	0.6431	0.6367
5.00	0.010	0.1762	0.1744	0.2298	0.2275	0.3261	0.3228	0.5140	0.5089	0.7600	0.7525
7.50	0.010	0.3103	0.3072	0.3712	0.3675	0.4718	0.4671	0.6388	0.6325	0.8302	0.8220
10.00	0.010	0.4031	0.3991	0.4666	0.4619	0.5647	0.5591	0.7126	0.7055	0.8694	0.8608
40.00	0.010	0.7597	0.7521	0.8073	0.7993	0.8612	0.8527	0.9211	0.9120	0.9709	0.9613
100.00	0.010	0.8915	0.8826	0.9189	0.9098	0.9458	0.9364	0.9729	0.9633	0.9940	0.9842
1000.00	0.010	0.9965	0.9866	1.0001	0.9902	1.0032	0.9933	1.0062	0.9963	1.0084	0.9985

Table 4-6 (Continued)

P	K	RINF=100.0		RINF= 50.0		RINF= 25.0		RINF= 10.0		RINF= 3.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0031	0.0028	0.0035	0.0032	0.0042	0.0039	0.0065	0.0059	0.0204	0.0186
0.10	0.100	0.0031	0.0028	0.0036	0.0032	0.0043	0.0039	0.0066	0.0060	0.0210	0.0191
0.15	0.100	0.0032	0.0029	0.0036	0.0033	0.0044	0.0040	0.0068	0.0062	0.0229	0.0208
0.25	0.100	0.0033	0.0030	0.0038	0.0034	0.0046	0.0042	0.0073	0.0067	0.0293	0.0266
0.50	0.100	0.0037	0.0033	0.0043	0.0039	0.0054	0.0049	0.0095	0.0087	0.0747	0.0679
0.75	0.100	0.0042	0.0038	0.0050	0.0046	0.0067	0.0061	0.0133	0.0121	0.2139	0.1945
1.00	0.100	0.0050	0.0045	0.0061	0.0055	0.0084	0.0077	0.0200	0.0182	0.3385	0.3077
2.00	0.100	0.0112	0.0102	0.0162	0.0147	0.0349	0.0317	0.1844	0.1676	0.5983	0.5439
3.00	0.100	0.0457	0.0415	0.0804	0.0731	0.1586	0.1441	0.3630	0.3300	0.7196	0.6542
5.00	0.100	0.2002	0.1820	0.2576	0.2342	0.3615	0.3287	0.5658	0.5144	0.8406	0.7642
7.50	0.100	0.3417	0.3106	0.4078	0.3707	0.5171	0.4701	0.6996	0.6360	0.9133	0.8303
10.00	0.100	0.4413	0.4012	0.5102	0.4638	0.6172	0.5611	0.7789	0.7081	0.9538	0.8671
40.00	0.100	0.8273	0.7521	0.8794	0.7994	0.9382	0.8529	1.0040	0.9128	1.0593	0.9630
100.00	0.100	0.9707	0.8825	1.0006	0.9096	1.0300	0.9364	1.0599	0.9636	1.0833	0.9848
1000.00	0.100	1.0853	0.9866	1.0892	0.9902	1.0926	0.9933	1.0959	0.9963	1.0983	0.9985
0.01	0.200	0.0110	0.0092	0.0125	0.0104	0.0153	0.0128	0.0235	0.0196	0.0748	0.0623
0.10	0.200	0.0112	0.0094	0.0127	0.0106	0.0156	0.0130	0.0240	0.0200	0.0757	0.0631
0.15	0.200	0.0114	0.0095	0.0129	0.0107	0.0159	0.0132	0.0245	0.0204	0.0810	0.0675
0.25	0.200	0.0117	0.0098	0.0133	0.0111	0.0165	0.0138	0.0261	0.0217	0.0982	0.0819
0.50	0.200	0.0129	0.0108	0.0149	0.0125	0.0190	0.0159	0.0327	0.0272	0.1876	0.1563
0.75	0.200	0.0146	0.0122	0.0172	0.0144	0.0227	0.0189	0.0434	0.0362	0.3231	0.2693
1.00	0.200	0.0169	0.0140	0.0202	0.0169	0.0279	0.0232	0.0607	0.0506	0.4369	0.3641
2.00	0.200	0.0337	0.0281	0.0457	0.0381	0.0801	0.0667	0.2380	0.1983	0.6916	0.5763
3.00	0.200	0.0819	0.0683	0.1180	0.0983	0.1984	0.1653	0.4150	0.3459	0.8136	0.6780
5.00	0.200	0.2313	0.1927	0.2928	0.2440	0.4049	0.3374	0.6274	0.5228	0.9359	0.7799
7.50	0.200	0.3791	0.3159	0.4509	0.3757	0.5699	0.4749	0.7698	0.6415	1.0096	0.8413
10.00	0.200	0.4854	0.4045	0.5604	0.4670	0.6769	0.5641	0.8546	0.7122	1.0508	0.8757
40.00	0.200	0.9029	0.7524	0.9597	0.7998	1.0241	0.8534	1.0964	0.9137	1.1582	0.9652
100.00	0.200	1.0591	0.8826	1.0917	0.9098	1.1240	0.9366	1.1568	0.9640	1.1829	0.9857
1000.00	0.200	1.1839	0.9866	1.1882	0.9902	1.1920	0.9933	1.1956	0.9963	1.1983	0.9986

Table 4-6 (Continued)

P	K	RINF=100.0		RINF= 50.0		RINF= 25.0		RINF= 10.0		RINF= 3.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.0578	0.0386	0.0655	0.0436	0.0804	0.0536	0.1234	0.0823	0.4C57	0.2705
0.10	0.500	0.0587	0.0391	0.0665	0.0443	0.0817	0.0545	0.1251	0.0834	0.4002	0.2668
0.15	0.500	0.0593	0.0395	0.0672	0.0448	0.0827	0.0551	0.1269	0.0846	0.4113	0.2742
0.25	0.500	0.0606	0.0404	0.0689	0.0459	0.0851	0.0567	0.1321	0.0881	0.4489	0.2993
0.50	0.500	0.0651	0.0434	0.0746	0.0497	0.0937	0.0625	0.1527	0.1018	0.5801	0.3867
0.75	0.500	0.0710	0.0473	0.0823	0.0548	0.1056	0.0704	0.1821	0.1214	0.7039	0.4693
1.00	0.500	0.0781	0.0521	0.0917	0.0611	0.1205	0.0803	0.2197	0.1465	0.8014	0.5343
2.00	0.500	0.1206	0.0804	0.1487	0.0991	0.2115	0.1410	0.4184	0.2790	1.0254	0.6836
3.00	0.500	0.1856	0.1237	0.2334	0.1556	0.3333	0.2222	0.5976	0.3984	1.1363	0.7575
5.00	0.500	0.3393	0.2262	0.4143	0.2762	0.5516	0.3677	0.8295	0.5530	1.2492	0.8328
7.50	0.500	0.5025	0.3350	0.5911	0.3940	0.7390	0.4927	0.9922	0.6615	1.3181	0.8787
10.00	0.500	0.6255	0.4170	0.7189	0.4793	0.8645	0.5763	1.0910	0.7273	1.3569	0.9046
40.00	0.500	1.1310	0.7540	1.2025	0.8017	1.2839	0.8560	1.3764	0.9176	1.4596	0.9730
100.00	0.500	1.3245	0.8830	1.3657	0.9104	1.4063	0.9376	1.4482	0.9655	1.4834	0.9890
1000.00	0.500	1.4799	0.9866	1.4854	0.9903	1.4902	0.9934	1.4947	0.9964	1.4983	0.9989
0.01	1.000	0.1903	0.0952	0.2153	0.1076	0.2645	0.1323	0.4052	0.2026	1.3C02	0.6501
0.10	1.000	0.1924	0.0962	0.2177	0.1088	0.2673	0.1337	0.4082	0.2041	1.2798	0.6399
0.15	1.000	0.1937	0.0968	0.2192	0.1096	0.2693	0.1347	0.4113	0.2057	1.2846	0.6423
0.25	1.000	0.1966	0.0983	0.2228	0.1114	0.2742	0.1371	0.4203	0.2101	1.3131	0.6565
0.50	1.000	0.2059	0.1029	0.2344	0.1172	0.2907	0.1453	0.4547	0.2273	1.4081	0.7041
0.75	1.000	0.2173	0.1087	0.2489	0.1245	0.3120	0.1560	0.4999	0.2499	1.4860	0.7430
1.00	1.000	0.2306	0.1153	0.2659	0.1329	0.3370	0.1685	0.5515	0.2758	1.5451	0.7726
2.00	1.000	0.2978	0.1489	0.3510	0.1755	0.4598	0.2299	0.7720	0.3860	1.6826	0.8413
3.00	1.000	0.3792	0.1896	0.4517	0.2259	0.5952	0.2976	0.9590	0.4795	1.7533	0.8767
5.00	1.000	0.5499	0.2749	0.6504	0.3252	0.8338	0.4169	1.2117	0.6059	1.8274	0.9137
7.50	1.000	0.7344	0.3672	0.8520	0.4260	1.0494	0.5247	1.3965	0.6982	1.8736	0.9368
10.00	1.000	0.8797	0.4398	1.0039	0.5019	1.1992	0.5996	1.5108	0.7554	1.9002	0.9501
40.00	1.000	1.5156	0.7578	1.6118	0.8059	1.7222	0.8611	1.8504	0.9252	1.9715	0.9857
100.00	1.000	1.7684	0.8842	1.8240	0.9120	1.8793	0.9396	1.9372	0.9686	1.9883	0.9942
1000.C0	1.000	1.9735	0.9868	1.9808	0.9904	1.9872	0.9936	1.9935	0.9968	1.9988	0.9994

Table 4-7

Impaction Efficiencies at $Re_c = 40$

P	K	RINF=100.0		RINF= 50.0		RINF= 25.0		RINF= 10.0		RINF= 3.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0015	0.0015	0.0011	0.0011	0.0008	0.0008	0.0005	0.0005	0.0003	0.0003
0.10	0.001	0.0023	0.0023	0.0018	0.0018	0.0013	0.0013	0.0009	0.0009	0.0006	0.0006
0.15	0.001	0.0029	0.0029	0.0022	0.0022	0.0017	0.0017	0.0012	0.0012	0.0008	0.0008
0.25	0.001	0.0046	0.0046	0.0036	0.0036	0.0028	0.0028	0.0022	0.0021	0.0020	0.0020
0.50	0.001	0.0270	0.0270	0.0260	0.0260	0.0260	0.0260	0.0406	0.0405	0.1415	0.1414
0.75	0.001	0.1200	0.1199	0.1249	0.1247	0.1321	0.1320	0.1615	0.1613	0.2820	0.2817
1.00	0.001	0.2001	0.1999	0.2066	0.2064	0.2159	0.2156	0.2501	0.2498	0.3804	0.3800
2.00	0.001	0.4040	0.4036	0.4130	0.4126	0.4256	0.4252	0.4670	0.4666	0.5941	0.5935
3.00	0.001	0.5189	0.5184	0.5287	0.5282	0.5424	0.5419	0.5843	0.5837	0.6958	0.6951
5.00	0.001	0.6474	0.6467	0.6574	0.6568	0.6716	0.6709	0.7102	0.7095	0.7959	0.7951
7.50	0.001	0.7323	0.7316	0.7420	0.7413	0.7556	0.7549	0.7894	0.7886	0.8549	0.8541
10.00	0.001	0.7828	0.7820	0.7921	0.7913	0.8050	0.8041	0.8344	0.8336	0.8874	0.8865
40.00	0.001	0.9299	0.9290	0.9358	0.9348	0.9423	0.9414	0.9535	0.9525	0.9693	0.9684
100.00	0.001	0.9695	0.9686	0.9727	0.9717	0.9760	0.9750	0.9809	0.9799	0.9875	0.9865
1000.00	0.001	0.9968	0.9958	0.9972	0.9962	0.9975	0.9966	0.9981	0.9971	0.9987	0.9977
0.01	0.010	0.0021	0.0021	0.0017	0.0017	0.0014	0.0013	0.0011	0.0011	0.0010	0.0010
0.10	0.010	0.0030	0.0029	0.0024	0.0024	0.0019	0.0019	0.0015	0.0015	0.0014	0.0014
0.15	0.010	0.0036	0.0036	0.0030	0.0029	0.0024	0.0024	0.0019	0.0019	0.0019	0.0019
0.25	0.010	0.0055	0.0054	0.0045	0.0045	0.0037	0.0037	0.0031	0.0031	0.0041	0.0041
0.50	0.010	0.0282	0.0279	0.0274	0.0271	0.0277	0.0275	0.0425	0.0420	0.1415	0.1401
0.75	0.010	0.1191	0.1179	0.1241	0.1229	0.1315	0.1302	0.1608	0.1592	0.2806	0.2779
1.00	0.010	0.1990	0.1971	0.2055	0.2035	0.2147	0.2126	0.2488	0.2463	0.3790	0.3752
2.00	0.010	0.4030	0.3990	0.4120	0.4080	0.4247	0.4205	0.4662	0.4616	0.5943	0.5885
3.00	0.010	0.5189	0.5137	0.5288	0.5236	0.5425	0.5371	0.5848	0.5790	0.6972	0.6903
5.00	0.010	0.6492	0.6428	0.6592	0.6527	0.6735	0.6668	0.7126	0.7056	0.7994	0.7915
7.50	0.010	0.7357	0.7284	0.7454	0.7381	0.7592	0.7517	0.7934	0.7856	0.8600	0.8515
10.00	0.010	0.7872	0.7795	0.7966	0.7887	0.8096	0.8016	0.8396	0.8312	0.8933	0.8844
40.00	0.010	0.9380	0.9287	0.9438	0.9344	0.9506	0.9412	0.9620	0.9524	0.9781	0.9684
100.00	0.010	0.9787	0.9690	0.9819	0.9722	0.9853	0.9755	0.9902	0.9804	0.9970	0.9871
1000.00	0.010	1.0067	0.9967	1.0071	0.9971	1.0074	0.9974	1.0080	0.9980	1.0087	0.9987

Table 4-7 (Continued)

P	K	RINF=100.0		RINF= 50.0		RINF= 25.0		RINF= 10.0		RINF= 3.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0267	0.0243	0.0272	0.0247	0.0276	0.0251	0.0309	0.0281	0.0481	0.0437
0.10	0.100	0.0308	0.0280	0.0315	0.0286	0.0320	0.0291	0.0359	0.0326	0.0558	0.0507
0.15	0.100	0.0346	0.0314	0.0354	0.0322	0.0361	0.0328	0.0409	0.0372	0.0661	0.0601
0.25	0.100	0.0453	0.0412	0.0466	0.0423	0.0480	0.0436	0.0558	0.0507	0.0985	0.0896
0.50	0.100	0.0978	0.0889	0.1014	0.0922	0.1062	0.0966	0.1274	0.1158	0.2266	0.2060
0.75	0.100	0.1717	0.1561	0.1773	0.1612	0.1851	0.1683	0.2158	0.1962	0.3450	0.3136
1.00	0.100	0.2410	0.2191	0.2481	0.2255	0.2578	0.2343	0.2941	0.2674	0.4363	0.3966
2.00	0.100	0.4379	0.3981	0.4475	0.4068	0.4609	0.4190	0.5060	0.4600	0.6488	0.5898
3.00	0.100	0.5568	0.5062	0.5673	0.5158	0.5820	0.5291	0.6283	0.5712	0.7550	0.6864
5.00	0.100	0.6950	0.6319	0.7059	0.6418	0.7213	0.6557	0.7648	0.6953	0.8635	0.7850
7.50	0.100	0.7893	0.7176	0.7999	0.7272	0.8150	0.7409	0.8534	0.7758	0.9293	0.8449
10.00	0.100	0.8464	0.7695	0.8567	0.7788	0.8709	0.7917	0.9048	0.8225	0.9663	0.8784
40.00	0.100	1.0169	0.9245	1.0234	0.9304	1.0310	0.9373	1.0441	0.9492	1.0626	0.9660
100.00	0.100	1.0638	0.9671	1.0674	0.9704	1.0712	0.9738	1.0770	0.9791	1.0846	0.9860
1000.00	0.100	1.0961	0.9965	1.0966	0.9969	1.0970	0.9973	1.0976	0.9979	1.0985	0.9986
0.01	0.200	0.0879	0.0733	0.0896	0.0747	0.0918	0.0765	0.1035	0.0862	0.1616	0.1347
0.10	0.200	0.0975	0.0812	0.0995	0.0829	0.1021	0.0851	0.1149	0.0958	0.1765	0.1471
0.15	0.200	0.1052	0.0877	0.1075	0.0896	0.1106	0.0921	0.1248	0.1040	0.1938	0.1615
0.25	0.200	0.1244	0.1037	0.1275	0.1062	0.1316	0.1096	0.1497	0.1248	0.2372	0.1977
0.50	0.200	0.1871	0.1559	0.1922	0.1602	0.1992	0.1660	0.2280	0.1900	0.3579	0.2983
0.75	0.200	0.2549	0.2124	0.2618	0.2182	0.2711	0.2260	0.3078	0.2565	0.4619	0.3849
1.00	0.200	0.3177	0.2648	0.3258	0.2715	0.3369	0.2808	0.3788	0.3157	0.5442	0.4535
2.00	0.200	0.5037	0.4198	0.5145	0.4287	0.5291	0.4409	0.5796	0.4830	0.7428	0.6190
3.00	0.200	0.6214	0.5178	0.6330	0.5275	0.6490	0.5408	0.7009	0.5840	0.8458	0.7049
5.00	0.200	0.7626	0.6355	0.7746	0.6455	0.7914	0.6595	0.8402	0.7002	0.9535	0.7946
7.50	0.200	0.8613	0.7178	0.8730	0.7275	0.8895	0.7412	0.9328	0.7773	1.0204	0.8503
10.00	0.200	0.9221	0.7684	0.9334	0.7778	0.9491	0.7909	0.9874	0.8229	1.0584	0.8820
40.00	0.200	1.1076	0.9230	1.1148	0.9290	1.1232	0.9360	1.1382	0.9485	1.1597	0.9664
100.00	0.200	1.1596	0.9664	1.1636	0.9697	1.1678	0.9732	1.1745	0.9788	1.1834	0.9862
1000.00	0.200	1.1957	0.9964	1.1962	0.9968	1.1967	0.9973	1.1974	0.9979	1.1983	0.9986

Table 4-7 (Continued)

P	K	RINF=100.0		RINF= 50.0		RINF= 25.0		RINF= 10.0		RINF= 3.0	
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.3695	0.2463	0.3771	0.2514	0.3866	0.2577	0.4326	0.2884	0.6623	0.4415
0.10	0.500	0.3882	0.2588	0.3964	0.2642	0.4066	0.2711	0.4538	0.3025	0.6801	0.4534
0.15	0.500	0.4000	0.2667	0.4085	0.2723	0.4192	0.2795	0.4675	0.3117	0.6961	0.4641
0.25	0.500	0.4250	0.2833	0.4341	0.2894	0.4458	0.2972	0.4966	0.3311	0.7318	0.4879
0.50	0.500	0.4881	0.3254	0.4986	0.3324	0.5124	0.3416	0.5694	0.3796	0.8190	0.5460
0.75	0.500	0.5465	0.3643	0.5583	0.3722	0.5737	0.3825	0.6354	0.4236	0.8916	0.5944
1.00	0.500	0.5991	0.3994	0.6117	0.4078	0.6284	0.4189	0.6934	0.4622	0.9500	0.6333
2.00	0.500	0.7591	0.5061	0.7737	0.5158	0.7933	0.5289	0.8641	0.5761	1.0990	0.7327
3.00	0.500	0.8673	0.5782	0.8827	0.5885	0.9034	0.6023	0.9743	0.6495	1.1813	0.7875
5.00	0.500	1.0056	0.6704	1.0210	0.6806	1.0424	0.6949	1.1088	0.7392	1.2716	0.8477
7.50	0.500	1.1080	0.7387	1.1229	0.7486	1.1442	0.7628	1.2032	0.8021	1.3301	0.8867
10.00	0.500	1.1736	0.7824	1.1880	0.7920	1.2083	0.8055	1.2608	0.8405	1.3644	0.9096
40.00	0.500	1.3866	0.9244	1.3958	0.9305	1.4069	0.9380	1.4278	0.9519	1.4599	0.9732
100.00	0.500	1.4498	0.9666	1.4550	0.9700	1.4605	0.9737	1.4699	0.9799	1.4833	0.9889
1000.00	0.500	1.4946	0.9964	1.4953	0.9968	1.4959	0.9973	1.4970	0.9980	1.4983	0.9989
0.01	1.000	0.9103	0.4551	0.9274	0.4637	0.9491	0.4746	1.0503	0.5252	1.5336	0.7668
0.10	1.000	0.9296	0.4648	0.9470	0.4735	0.9694	0.4847	1.0702	0.5351	1.5380	0.7690
0.15	1.000	0.9405	0.4702	0.9580	0.4790	0.9807	0.4904	1.0816	0.5408	1.5436	0.7718
0.25	1.000	0.9622	0.4811	0.9800	0.4900	1.0034	0.5017	1.1048	0.5524	1.5575	0.7787
0.50	1.000	1.0139	0.5069	1.0326	0.5163	1.0573	0.5287	1.1604	0.5802	1.5964	0.7982
0.75	1.000	1.0610	0.5305	1.0803	0.5402	1.1062	0.5531	1.2106	0.6053	1.6320	0.8160
1.00	1.000	1.1036	0.5518	1.1233	0.5616	1.1500	0.5750	1.2554	0.6277	1.6623	0.8311
2.00	1.000	1.2371	0.6186	1.2579	0.6289	1.2868	0.6434	1.3925	0.6963	1.7443	0.8722
3.00	1.000	1.3323	0.6662	1.3531	0.6765	1.3829	0.6914	1.4860	0.7430	1.7926	0.8963
5.00	1.000	1.4604	0.7302	1.4808	0.7404	1.5109	0.7554	1.6062	0.8031	1.8479	0.9240
7.50	1.000	1.5609	0.7805	1.5806	0.7903	1.6099	0.8049	1.6947	0.8474	1.8851	0.9426
10.00	1.000	1.6279	0.8139	1.6468	0.8234	1.6749	0.8375	1.7506	0.8753	1.9075	0.9537
40.00	1.000	1.8627	0.9313	1.8748	0.9374	1.8905	0.9452	1.9216	0.9608	1.9718	0.9859
100.00	1.000	1.9379	0.9690	1.9449	0.9725	1.9529	0.9764	1.9669	0.9835	1.9883	0.9942
1000.00	1.000	1.9931	0.9966	1.9942	0.9971	1.9951	0.9976	1.9966	0.9983	1.9987	0.9993

Table 4-8

Interception Efficiencies

RE	RINF	K=0.001		K=0.010		K=0.100		K=0.200		K=0.500		K=1.000	
		ε	E	ε	E	ε	E	ε	E	ε	E	ε	E
0.2	100.0	0.0001	0.0001	0.0002	0.0002	0.0031	0.0028	0.0110	0.0092	0.0578	0.0385	0.1901	0.0950
0.5	100.0	0.0002	0.0002	0.0002	0.0002	0.0038	0.0034	0.0135	0.0112	0.0706	0.0470	C.2317	0.1158
1.0	100.0	0.0002	0.0002	0.0003	0.0003	0.0047	0.0043	0.0168	0.0140	0.0874	0.0582	0.2851	0.1425
3.0	100.0	0.0003	0.0003	0.0005	0.0005	0.0074	0.0067	0.0262	0.0218	0.1341	0.0894	C.4264	0.2132
5.0	100.0	0.0004	0.0004	0.0006	0.0006	0.0094	0.0086	0.0332	0.0277	0.1673	0.1115	0.5188	0.2594
10.0	100.0	0.0006	0.0006	0.0009	0.0009	0.0134	0.0121	0.0464	0.0387	0.2259	0.1506	C.6631	0.3315
15.0	100.0	0.0008	0.0008	0.0012	0.0011	0.0164	0.0149	0.0564	0.0470	0.2661	0.1774	0.7473	0.3737
20.0	100.0	0.0010	0.0010	0.0014	0.0013	0.0190	0.0173	0.0647	0.0539	0.2972	0.1981	C.8051	0.4025
30.0	100.0	0.0012	0.0012	0.0017	0.0017	0.0232	0.0211	0.0776	0.0646	0.3398	0.2266	0.8723	0.4361
40.0	100.0	0.0014	0.0014	0.0020	0.0020	0.0265	0.0241	0.0873	0.0728	0.3677	0.2451	C.9082	0.4541
0.2	3.0	0.0001	0.0001	0.0004	0.0004	0.0207	0.0188	0.0757	0.0631	0.4093	0.2729	1.3054	0.6527
0.5	3.0	0.0001	0.0001	0.0004	0.0004	0.0207	0.0188	0.0756	0.0630	0.4083	0.2722	1.3022	0.6511
1.0	3.0	0.0001	0.0001	0.0004	0.0004	0.0210	0.0191	0.0768	0.0640	0.4117	0.2744	1.3028	0.6514
3.0	3.0	0.0001	0.0001	0.0004	0.0004	0.0220	0.0200	0.0797	0.0664	0.4196	0.2797	1.3038	0.6519
5.0	3.0	0.0001	0.0001	0.0005	0.0005	0.0239	0.0217	0.0859	0.0716	0.4399	0.2933	1.3224	0.6612
10.0	3.0	0.0002	0.0002	0.0006	0.0006	0.0287	0.0261	0.1015	0.0846	0.4941	0.3294	1.3825	0.6913
15.0	3.0	0.0002	0.0002	0.0007	0.0007	0.0331	0.0301	0.1156	0.0964	0.5401	0.3601	1.4310	0.7155
20.0	3.0	0.0002	0.0002	0.0008	0.0007	0.0364	0.0331	0.1255	0.1045	0.5658	0.3772	1.4515	0.7257
40.0	3.0	0.0003	0.0003	0.0010	0.0010	0.0486	0.0442	0.1625	0.1354	0.6623	0.4415	1.5342	0.7671
30.0	3.0	0.0002	0.0002	0.0009	0.0009	0.0430	0.0391	0.1459	0.1215	0.6228	0.4152	1.5030	0.7515

Table 4-9

Impaction Efficiencies Calculated at Re_c = 40, R_∞ = 100 under Various Conditions

P	K	KUWABARA'S MODEL								HAPPEL'S MODEL	
		STEPS/CELL= 3		STEPS/CELL= 3		STEPS/CELL= 3		STEPS/CELL= 5		STEPS/CELL= 3	
		NA=33	NR=93	NA=49	NR=93	NA=33	NR=79	NA=33	NR=93	NA=33	NR=93
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.001	0.0015	0.0015	0.0014	0.0014	0.0021	0.0021	0.0016	0.0016	0.0016	0.0016
0.10	0.001	0.0023	0.0023	0.0021	0.0021	0.0031	0.0031	0.0024	0.0024	0.0025	0.0025
0.15	0.001	0.0029	0.0029	0.0026	0.0026	0.0039	0.0039	0.0030	0.0030	0.0031	0.0031
0.25	0.001	0.0046	0.0046	0.0042	0.0042	0.0061	0.0061	0.0048	0.0048	0.0051	0.0051
0.50	0.001	0.0270	0.0270	0.0265	0.0265	0.0324	0.0324	0.0274	0.0273	0.0348	0.0347
0.75	0.001	0.1200	0.1199	0.1224	0.1223	0.1243	0.1242	0.1198	0.1197	0.1361	0.1359
1.00	0.001	0.2001	0.1999	0.2036	0.2034	0.2044	0.2042	0.2000	0.1998	0.2195	0.2193
2.00	0.001	0.4040	0.4036	0.4090	0.4086	0.4085	0.4081	0.4039	0.4035	0.4301	0.4297
3.00	0.001	0.5189	0.5184	0.5243	0.5238	0.5235	0.5229	0.5188	0.5183	0.5479	0.5474
5.00	0.001	0.6474	0.6467	0.6525	0.6519	0.6516	0.6510	0.6473	0.6467	0.6788	0.6781
7.50	0.001	0.7323	0.7316	0.7369	0.7362	0.7361	0.7354	0.7323	0.7315	0.7646	0.7639
10.00	0.001	0.7828	0.7820	0.7869	0.7861	0.7862	0.7855	0.7827	0.7819	0.8152	0.8144
40.00	0.001	0.9299	0.9290	0.9317	0.9308	0.9316	0.9306	0.9299	0.9290	0.9554	0.9544
100.00	0.001	0.9695	0.9686	0.9704	0.9695	0.9704	0.9694	0.9695	0.9686	0.9848	0.9838
1000.00	0.001	0.9968	0.9958	0.9969	0.9959	0.9968	0.9958	0.9968	0.9958	0.9989	0.9979
0.01	0.010	0.0021	0.0021	0.0019	0.0019	0.0027	0.0027	0.0022	0.0021	0.0022	0.0022
0.10	0.010	0.0030	0.0029	0.0027	0.0027	0.0039	0.0038	0.0031	0.0031	0.0032	0.0032
0.15	0.010	0.0036	0.0036	0.0033	0.0033	0.0047	0.0046	0.0038	0.0037	0.0039	0.0039
0.25	0.010	0.0055	0.0054	0.0051	0.0050	0.0071	0.0070	0.0057	0.0057	0.0061	0.0060
0.50	0.010	0.0282	0.0279	0.0278	0.0275	0.0332	0.0329	0.0288	0.0285	0.0357	0.0353
0.75	0.010	0.1191	0.1179	0.1215	0.1203	0.1232	0.1220	0.1192	0.1180	0.1351	0.1338
1.00	0.010	0.1990	0.1971	0.2026	0.2006	0.2032	0.2012	0.1990	0.1971	0.2182	0.2160
2.00	0.010	0.4030	0.3990	0.4081	0.4041	0.4076	0.4036	0.4030	0.3990	0.4291	0.4248
3.00	0.010	0.5189	0.5137	0.5243	0.5191	0.5234	0.5183	0.5189	0.5137	0.5480	0.5425
5.00	0.010	0.6492	0.6428	0.6544	0.6480	0.6535	0.6470	0.6491	0.6427	0.6807	0.6739
7.50	0.010	0.7357	0.7284	0.7404	0.7330	0.7395	0.7322	0.7357	0.7284	0.7681	0.7605
10.00	0.010	0.7872	0.7795	0.7913	0.7835	0.7907	0.7829	0.7872	0.7795	0.8199	0.8117
40.00	0.010	0.9380	0.9287	0.9399	0.9306	0.9397	0.9304	0.9380	0.9287	0.9638	0.9542
100.00	0.010	0.9787	0.9690	0.9796	0.9699	0.9796	0.9699	0.9787	0.9690	0.9941	0.9843
1000.00	0.010	1.0067	0.9967	1.0068	0.9968	1.0068	0.9968	1.0067	0.9967	1.0087	0.9987

Table 4-9 (Continued)

P	K	KUWABARA'S MODEL								HAPPEL'S MODEL	
		STEPS/CELL= 3		STEPS/CELL= 3		STEPS/CELL= 3		STEPS/CELL= 5		STEPS/CELL= 3	
		NA=33	NR=93	NA=49	NR=93	NA=33	NR=79	NA=33	NR=93	NA=33	NR=93
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.100	0.0267	0.0243	0.0265	0.0241	0.0276	0.0251	0.0268	0.0244	0.0281	0.0256
0.10	0.100	0.0308	0.0280	0.0306	0.0278	0.0320	0.0291	0.0309	0.0281	0.0327	0.0297
0.15	0.100	0.0346	0.0314	0.0344	0.0313	0.0358	0.0326	0.0347	0.0316	0.0369	0.0335
0.25	0.100	0.0453	0.0412	0.0453	0.0412	0.0468	0.0425	0.0455	0.0414	0.0490	0.0446
0.50	0.100	0.0978	0.0889	0.0993	0.0902	0.1004	0.0913	0.0982	0.0892	0.1082	0.0984
0.75	0.100	0.1717	0.1561	0.1747	0.1588	0.1752	0.1593	0.1720	0.1563	0.1876	0.1706
1.00	0.100	0.2410	0.2191	0.2449	0.2227	0.2450	0.2228	0.2412	0.2193	0.2606	0.2369
2.00	0.100	0.4379	0.3981	0.4435	0.4031	0.4426	0.4024	0.4379	0.3981	0.4651	0.4228
3.00	0.100	0.5568	0.5062	0.5627	0.5115	0.5617	0.5107	0.5568	0.5062	0.5873	0.5339
5.00	0.100	0.6950	0.6319	0.7009	0.6372	0.6997	0.6361	0.6950	0.6319	0.7285	0.6623
7.50	0.100	0.7893	0.7176	0.7946	0.7223	0.7936	0.7214	0.7893	0.7175	0.8241	0.7492
10.00	0.100	0.8464	0.7695	0.8511	0.7738	0.8502	0.7729	0.8464	0.7694	0.8815	0.8014
40.00	0.100	1.0169	0.9245	1.0191	0.9265	1.0188	0.9262	1.0169	0.9245	1.0453	0.9503
100.00	0.100	1.0638	0.9671	1.0649	0.9681	1.0648	0.9680	1.0638	0.9671	1.0809	0.9826
1000.00	0.100	1.0961	0.9965	1.0962	0.9966	1.0962	0.9966	1.0961	0.9965	1.0985	0.9986
0.01	0.200	0.0879	0.0733	0.0888	0.0740	0.0892	0.0744	0.0880	0.0733	0.0924	0.0770
0.10	0.200	0.0975	0.0812	0.0984	0.0820	0.0990	0.0825	0.0976	0.0813	0.1029	0.0858
0.15	0.200	0.1052	0.0877	0.1063	0.0886	0.1069	0.0891	0.1053	0.0878	0.1114	0.0929
0.25	0.200	0.1244	0.1037	0.1260	0.1050	0.1265	0.1054	0.1246	0.1038	0.1326	0.1105
0.50	0.200	0.1871	0.1559	0.1899	0.1583	0.1901	0.1584	0.1873	0.1561	0.2008	0.1673
0.75	0.200	0.2549	0.2124	0.2589	0.2158	0.2587	0.2156	0.2552	0.2126	0.2732	0.2277
1.00	0.200	0.3177	0.2648	0.3226	0.2688	0.3220	0.2683	0.3179	0.2649	0.3394	0.2828
2.00	0.200	0.5037	0.4198	0.5101	0.4251	0.5089	0.4241	0.5038	0.4199	0.5330	0.4442
3.00	0.200	0.6214	0.5178	0.6281	0.5234	0.6267	0.5223	0.6215	0.5179	0.6542	0.5452
5.00	0.200	0.7626	0.6355	0.7691	0.6409	0.7676	0.6397	0.7626	0.6355	0.7987	0.6656
7.50	0.200	0.8613	0.7178	0.8673	0.7228	0.8661	0.7217	0.8613	0.7178	0.8990	0.7491
10.00	0.200	0.9221	0.7684	0.9275	0.7729	0.9264	0.7720	0.9221	0.7684	0.9603	0.8002
40.00	0.200	1.1076	0.9230	1.1101	0.9251	1.1098	0.9248	1.1076	0.9230	1.1386	0.9489
100.00	0.200	1.1596	0.9664	1.1608	0.9673	1.1607	0.9672	1.1596	0.9664	1.1784	0.9820
1000.00	0.200	1.1957	0.9964	1.1959	0.9966	1.1958	0.9965	1.1957	0.9964	1.1982	0.9985

Table 4-9 (Continued)

P	K	KUWABARA'S MODEL								HAPPEL'S MODEL	
		STEPS/CELL= 3		STEPS/CELL= 3		STEPS/CELL= 3		STEPS/CELL= 5		STEPS/CELL= 3	
		NA=33	NR=93	NA=49	NR=93	NA=33	NR=79	NA=33	NR=93	NA=33	NR=93
		ε	E	ε	E	ε	E	ε	E	ε	E
0.01	0.500	0.3695	0.2463	0.3750	0.2500	0.3734	0.2489	0.3694	0.2463	0.3864	0.2576
0.10	0.500	0.3882	0.2588	0.3940	0.2627	0.3923	0.2615	0.3883	0.2589	0.4066	0.2711
0.15	0.500	0.4000	0.2667	0.4060	0.2707	0.4043	0.2695	0.4002	0.2668	0.4194	0.2796
0.25	0.500	0.4250	0.2833	0.4313	0.2875	0.4295	0.2863	0.4252	0.2835	0.4462	0.2974
0.50	0.500	0.4881	0.3254	0.4952	0.3301	0.4932	0.3288	0.4883	0.3255	0.5133	0.3422
0.75	0.500	0.5465	0.3643	0.5543	0.3696	0.5522	0.3682	0.5468	0.3645	0.5751	0.3834
1.00	0.500	0.5991	0.3994	0.6074	0.4049	0.6050	0.4034	0.5993	0.3995	0.6303	0.4202
2.00	0.500	0.7591	0.5061	0.7683	0.5122	0.7658	0.5105	0.7593	0.5062	0.7969	0.5313
3.00	0.500	0.8673	0.5782	0.8765	0.5844	0.8741	0.5827	0.8674	0.5783	0.9088	0.6059
5.00	0.500	1.0056	0.6704	1.0143	0.6762	1.0121	0.6747	1.0056	0.6704	1.0506	0.7004
7.50	0.500	1.1080	0.7387	1.1159	0.7439	1.1141	0.7427	1.1080	0.7387	1.1549	0.7699
10.00	0.500	1.1736	0.7824	1.1808	0.7872	1.1793	0.7862	1.1736	0.7824	1.2212	0.8141
40.00	0.500	1.3866	0.9244	1.3899	0.9266	1.3896	0.9264	1.3866	0.9244	1.4259	0.9506
100.00	0.500	1.4498	0.9666	1.4513	0.9675	1.4513	0.9675	1.4498	0.9666	1.4740	0.9827
1000.00	0.500	1.4946	0.9964	1.4947	0.9965	1.4948	0.9966	1.4946	0.9964	1.4979	0.9986
0.01	1.000	0.9103	0.4551	0.9231	0.4616	0.9188	0.4594	0.9102	0.4551	0.9475	0.4737
0.10	1.000	0.9296	0.4648	0.9424	0.4712	0.9381	0.4690	0.9296	0.4648	0.9680	0.4840
0.15	1.000	0.9405	0.4702	0.9534	0.4767	0.9490	0.4745	0.9405	0.4703	0.9797	0.4899
0.25	1.000	0.9622	0.4811	0.9750	0.4875	0.9708	0.4854	0.9622	0.4811	1.0026	0.5013
0.50	1.000	1.0139	0.5069	1.0270	0.5135	1.0229	0.5115	1.0141	0.5070	1.0575	0.5287
0.75	1.000	1.0610	0.5305	1.0743	0.5371	1.0703	0.5351	1.0613	0.5306	1.1071	0.5535
1.00	1.000	1.1036	0.5518	1.1169	0.5584	1.1129	0.5565	1.1038	0.5519	1.1517	0.5759
2.00	1.000	1.2371	0.6186	1.2504	0.6252	1.2469	0.6234	1.2374	0.6187	1.2911	0.6456
3.00	1.000	1.3323	0.6662	1.3450	0.6725	1.3418	0.6709	1.3323	0.6662	1.3894	0.6947
5.00	1.000	1.4604	0.7302	1.4720	0.7360	1.4696	0.7348	1.4604	0.7302	1.5211	0.7606
7.50	1.000	1.5609	0.7805	1.5713	0.7856	1.5693	0.7846	1.5609	0.7805	1.6237	0.8119
10.00	1.000	1.6279	0.8139	1.6372	0.8186	1.6358	0.8179	1.6279	0.8139	1.6916	0.8458
40.00	1.000	1.8627	0.9313	1.8666	0.9333	1.8666	0.9333	1.8627	0.9313	1.9159	0.9579
100.00	1.000	1.9379	0.9690	1.9400	0.9700	1.9401	0.9700	1.9379	0.9690	1.9712	0.9856
1000.00	1.000	1.9931	0.9966	1.9934	0.9967	1.9934	0.9967	1.9932	0.9966	1.9978	0.9989

Table 4-10

Stagnation Pressures and Drag Coefficients

RE	RINF	P-ZERO	P-REAR	CDSKIN	CDFORM	CDS/CDF	CDTOTAL
0.2	100.0	12.4746	-11.2923	18.6320	18.6693	0.9980	37.3013
0.5	100.0	6.3393	-5.1553	8.9444	9.0223	0.9914	17.9667
1.0	100.0	4.0705	-2.9527	5.3813	5.5002	0.9784	10.8815
3.0	100.0	2.2916	-1.3310	2.5783	2.7917	0.9236	5.3699
5.0	100.0	1.8575	-0.9727	1.8703	2.1354	0.8759	4.0057
10.0	100.0	1.4842	-0.6910	1.2234	1.5592	0.7846	2.7827
15.0	100.0	1.3427	-0.6133	0.9553	1.3427	0.7115	2.2981
20.0	100.0	1.2672	-0.5513	0.8022	1.2022	0.6673	2.0045
30.0	100.0	1.1851	-0.5113	0.6221	1.0574	0.5883	1.6795
40.0	100.0	1.1390	-0.5735	0.5255	1.0362	0.5071	1.5616
0.2	3.0	39.8528	-155.9388	122.3114	153.7286	0.7956	276.0398
0.5	3.0	16.4796	-61.8939	48.9497	61.5427	0.7954	110.4924
1.0	3.0	8.7176	-31.0064	24.9073	31.1941	0.7985	56.1013
3.0	3.0	3.5405	-10.2030	8.4207	10.7682	0.7820	19.1890
5.0	3.0	2.5177	-6.9304	5.3155	7.3744	0.7208	12.6899
10.0	3.0	1.7673	-4.5321	3.0185	4.7874	0.6305	7.8059
15.0	3.0	1.5193	-3.8959	2.2486	3.9771	0.5654	6.2258
20.0	3.0	1.3930	-3.6887	1.8324	3.6603	0.5006	5.4927
30.0	3.0	1.2668	-2.9315	1.3576	2.9204	0.4649	4.2780
40.0	3.0	1.2027	-1.7336	1.1125	2.0441	0.5443	3.1566
0.2	200.0	11.8113	-10.4274	17.4483	17.4655	0.9990	34.9138
0.2	100.0	12.4746	-11.2923	18.6320	18.6693	0.9980	37.3013
0.2	50.0	13.7751	-13.1261	21.0467	21.1307	0.9960	42.1774
0.2	25.0	16.1542	-16.9694	25.8824	26.0080	0.9952	51.8904
0.2	10.0	21.7583	-30.2886	39.9402	40.9005	0.9765	80.8407
0.2	3.0	39.8528	-155.9388	122.3114	153.7286	0.7956	276.0398
40.0	100.0	1.1390	-0.5735	0.5255	1.0362	0.5071	1.5616
40.0	50.0	1.1447	-0.5238	0.5253	0.9993	0.5257	1.5246
40.0	25.0	1.1483	-0.5818	0.5474	1.0386	0.5271	1.5860
40.0	10.0	1.1586	-0.8610	0.6278	1.2358	0.5080	1.8636
40.0	3.0	1.2027	-1.7336	1.1125	2.0441	0.5443	3.1566

Table 4-11

Fluid Velocity, v_x, According to Davies and Peetz [7] at $Re_c = 0.2$

Y \ X	-3.0	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3	-2.2	-2.1
0.0	0.24128	0.23247	0.22344	0.21419	0.20470	0.19496	0.18498	0.17475	0.16426	0.15350
0.1	0.24164	0.23286	0.22385	0.21462	0.20516	0.19546	0.18551	0.17531	0.16486	0.15415
0.2	0.24272	0.23400	0.22507	0.21592	0.20654	0.19693	0.18709	0.17700	0.16667	0.15609
0.3	0.24451	0.23590	0.22709	0.21806	0.20883	0.19937	0.18969	0.17979	0.16965	0.15928
0.4	0.24698	0.23853	0.22988	0.22104	0.21199	0.20275	0.19329	0.18363	0.17376	0.16368
0.5	0.25013	0.24186	0.23342	0.22480	0.21600	0.20701	0.19784	0.18849	0.17895	0.16922
0.6	0.25391	0.24587	0.23767	0.22932	0.22080	0.21212	0.20328	0.19429	0.18513	0.17582
0.7	0.25830	0.25052	0.24259	0.23454	0.22634	0.21801	0.20955	0.20096	0.19224	0.18339
0.8	0.26325	0.25576	0.24814	0.24041	0.23257	0.22462	0.21657	0.20841	0.20017	0.19183
0.9	0.26874	0.26155	0.25426	0.24688	0.23942	0.23188	0.22426	0.21658	0.20883	0.20103
1.0	0.27471	0.26784	0.26090	0.25390	0.24683	0.23972	0.23255	0.22535	0.21813	0.21088
1.1	0.28111	0.27459	0.26801	0.26139	0.25474	0.24806	0.24136	0.23466	0.22796	0.22127
1.2	0.28791	0.28173	0.27553	0.26930	0.26307	0.25683	0.25061	0.24440	0.23823	0.23210
1.3	0.29506	0.28924	0.28341	0.27758	0.27176	0.26597	0.26021	0.25450	0.24885	0.24327
1.4	0.30251	0.29704	0.29159	0.28616	0.28076	0.27540	0.27011	0.26488	0.25973	0.25468
1.5	0.31023	0.30511	0.30002	0.29498	0.28999	0.28507	0.28022	0.27546	0.27080	0.26626
1.6	0.31815	0.31339	0.30867	0.30401	0.29941	0.29490	0.29049	0.28618	0.28199	0.27793
1.7	0.32626	0.32183	0.31747	0.31318	0.30897	0.30486	0.30086	0.29698	0.29323	0.28962
1.8	0.33450	0.33041	0.32639	0.32246	0.31862	0.31489	0.31128	0.30780	0.30446	0.30128
1.9	0.34285	0.33908	0.33539	0.33180	0.32831	0.32494	0.32170	0.31860	0.31565	0.31285
2.0	0.35128	0.34781	0.34444	0.34117	0.33801	0.33498	0.33209	0.32934	0.32674	0.32430
2.1	0.35974	0.35657	0.35349	0.35053	0.34769	0.34498	0.34241	0.33998	0.33771	0.33560
2.2	0.36822	0.36533	0.36254	0.35986	0.35732	0.35490	0.35262	0.35050	0.34853	0.34672
2.3	0.37670	0.37407	0.37154	0.36914	0.36686	0.36472	0.36272	0.36087	0.35917	0.35762
2.4	0.38514	0.38276	0.38049	0.37833	0.37631	0.37442	0.37267	0.37107	0.36962	0.36831
2.5	0.39354	0.39139	0.38935	0.38743	0.38564	0.38399	0.38247	0.38109	0.37986	0.37877
2.6	0.40188	0.39994	0.39812	0.39642	0.39484	0.39340	0.39209	0.39092	0.38989	0.38900
2.7	0.41013	0.40840	0.40678	0.40528	0.40390	0.40265	0.40154	0.40055	0.39970	0.39897
2.8	0.41830	0.41675	0.41532	0.41400	0.41280	0.41173	0.41079	0.40997	0.40928	0.40871
2.9	0.42636	0.42499	0.42373	0.42258	0.42155	0.42064	0.41985	0.41918	0.41863	0.41819
3.0	0.43432	0.43311	0.43200	0.43101	0.43013	0.42936	0.42871	0.42818	0.42775	0.42744

Table 4-11 (Continued)

Y \ X	-2.0	-1.9	-1.8	-1.7	-1.6	-1.5	-1.4	-1.3	-1.2	-1.1
0.0	0.14249	0.13120	0.11964	0.10780	0.09565	0.08313	0.07012	0.05633	0.04119	0.02339
0.1	0.14318	0.13195	0.12044	0.10866	0.09656	0.08410	0.07114	0.05740	0.04230	0.02459
0.2	0.14526	0.13417	0.12282	0.11120	0.09927	0.08697	0.07417	0.06059	0.04566	0.02819
0.3	0.14867	0.13783	0.12674	0.11538	0.10373	0.09171	0.07919	0.06590	0.05127	0.03426
0.4	0.15338	0.14287	0.13213	0.12114	0.10988	0.09825	0.08614	0.07327	0.05913	0.04279
0.5	0.15931	0.14920	0.13890	0.12838	0.11760	0.10648	0.09491	0.08260	0.06914	0.05372
0.6	0.16636	0.15673	0.14694	0.13697	0.12676	0.11626	0.10533	0.09375	0.08115	0.06687
0.7	0.17443	0.16534	0.15613	0.14676	0.13721	0.12740	0.11724	0.10650	0.09490	0.08193
0.8	0.18341	0.17490	0.16631	0.15760	0.14876	0.13972	0.13039	0.12059	0.11010	0.09854
0.9	0.19318	0.18528	0.17734	0.16933	0.16123	0.15300	0.14454	0.13574	0.12641	0.11628
1.0	0.20361	0.19635	0.18907	0.18177	0.17444	0.16702	0.15947	0.15167	0.14350	0.13475
1.1	0.21460	0.20796	0.20135	0.19477	0.18819	0.18159	0.17492	0.16811	0.16105	0.15361
1.2	0.22602	0.22000	0.21405	0.20816	0.20232	0.19651	0.19069	0.18481	0.17880	0.17255
1.3	0.23777	0.23236	0.22704	0.22182	0.21668	0.21162	0.20660	0.20158	0.19652	0.19133
1.4	0.24974	0.24490	0.24019	0.23560	0.23113	0.22676	0.22248	0.21824	0.21403	0.20977
1.5	0.26185	0.25756	0.25342	0.24942	0.24556	0.24183	0.23821	0.23468	0.23120	0.22775
1.6	0.27401	0.27024	0.26663	0.26317	0.25987	0.25671	0.25368	0.25077	0.24795	0.24517
1.7	0.28617	0.28287	0.27974	0.27678	0.27398	0.27134	0.26884	0.26647	0.26420	0.26199
1.8	0.29825	0.29540	0.29271	0.29019	0.28785	0.28566	0.28362	0.28171	0.27991	0.27818
1.9	0.31022	0.30776	0.30548	0.30336	0.30141	0.29963	0.29798	0.29647	0.29506	0.29374
2.0	0.32203	0.31993	0.31800	0.31625	0.31465	0.31321	0.31191	0.31074	0.30966	0.30866
2.1	0.33366	0.33188	0.33027	0.32883	0.32754	0.32640	0.32539	0.32450	0.32370	0.32296
2.2	0.34506	0.34358	0.34225	0.34108	0.34006	0.33918	0.33842	0.33777	0.33719	0.33667
2.3	0.35624	0.35501	0.35393	0.35300	0.35222	0.35155	0.35101	0.35055	0.35016	0.34982
2.4	0.36716	0.36616	0.36530	0.36459	0.36400	0.36352	0.36315	0.36286	0.36262	0.36242
2.5	0.37783	0.37703	0.37637	0.37583	0.37541	0.37509	0.37487	0.37471	0.37460	0.37450
2.6	0.38824	0.38761	0.38711	0.38673	0.38646	0.38628	0.38617	0.38612	0.38611	0.38611
2.7	0.39838	0.39791	0.39755	0.39731	0.39715	0.39708	0.39708	0.39712	0.39718	0.39725
2.8	0.40825	0.40792	0.40769	0.40755	0.40751	0.40753	0.40760	0.40772	0.40784	0.40796
2.9	0.41787	0.41765	0.41752	0.41749	0.41753	0.41762	0.41777	0.41793	0.41811	0.41827
3.0	0.42722	0.42710	0.42707	0.42711	0.42722	0.42738	0.42758	0.42779	0.42800	0.42819

Table 4-11 (Continued)

Y \ X	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1
0.0	0.00006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00144	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00564	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.01265	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.02246	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.03496	0.01041	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.04987	0.02848	0.00006	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.06683	0.04847	0.02529	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	0.08536	0.06984	0.05107	0.02806	0.00005	0.0	0.0	0.0	0.0	0.0
0.9	0.10496	0.09203	0.07693	0.05921	0.03865	0.01558	0.0	0.0	0.0	0.0
1.0	0.12519	0.11453	0.10247	0.08881	0.07353	0.05699	0.04008	0.02422	0.01124	0.00284
1.1	0.14563	0.13693	0.12736	0.11682	0.10537	0.09330	0.08119	0.06988	0.06039	0.05366
1.2	0.16597	0.15894	0.15138	0.14324	0.13461	0.12567	0.11680	0.10851	0.10136	0.09590
1.3	0.18596	0.18032	0.17438	0.16810	0.16155	0.15485	0.14823	0.14200	0.13647	0.13196
1.4	0.20543	0.20095	0.19630	0.19145	0.18645	0.18137	0.17635	0.17155	0.16717	0.16338
1.5	0.22427	0.22074	0.21710	0.21337	0.20953	0.20564	0.20176	0.19799	0.19443	0.19118
1.6	0.24242	0.23964	0.23683	0.23394	0.23098	0.22796	0.22492	0.22190	0.21894	0.21611
1.7	0.25983	0.25768	0.25550	0.25327	0.25098	0.24861	0.24618	0.24371	0.24120	0.23870
1.8	0.27651	0.27485	0.27317	0.27145	0.26966	0.26779	0.26582	0.26375	0.26159	0.25934
1.9	0.29246	0.29119	0.28991	0.28858	0.28718	0.28567	0.28404	0.28228	0.28038	0.27834
2.0	0.30770	0.30675	0.30578	0.30476	0.30364	0.30241	0.30105	0.29952	0.29782	0.29594
2.1	0.32226	0.32156	0.32084	0.32004	0.31915	0.31814	0.31697	0.31562	0.31408	0.31234
2.2	0.33618	0.33568	0.33514	0.33453	0.33381	0.33295	0.33193	0.33073	0.32932	0.32769
2.3	0.34949	0.34914	0.34875	0.34827	0.34768	0.34695	0.34605	0.34496	0.34365	0.34212
2.4	0.36222	0.36199	0.36171	0.36134	0.36085	0.36022	0.35940	0.35840	0.35717	0.35572
2.5	0.37441	0.37428	0.37408	0.37379	0.37338	0.37281	0.37207	0.37113	0.36998	0.36860
2.6	0.38609	0.38603	0.38590	0.38567	0.38531	0.38480	0.38412	0.38323	0.38214	0.38082
2.7	0.39729	0.39729	0.39720	0.39702	0.39671	0.39624	0.39560	0.39476	0.39372	0.39245
2.8	0.40805	0.40809	0.40804	0.40789	0.40760	0.40717	0.40656	0.40576	0.40476	0.40354
2.9	0.41839	0.41845	0.41843	0.41830	0.41804	0.41763	0.41705	0.41629	0.41532	0.41414
3.0	0.42834	0.42842	0.42842	0.42830	0.42806	0.42767	0.42711	0.42637	0.42543	0.42430

Table 4-12

Fluid Velocity, v_y, According to Davies and Peetz [7] at Re_c = 0.2

Y \ X	-3.0	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3	-2.2	-2.1
0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
0.1	0.00865	0.00886	0.00908	0.00929	0.00951	0.00973	0.00995	0.01016	0.01036	0.01054
0.2	0.01727	0.01768	0.01810	0.01853	0.01896	0.01940	0.01983	0.02025	0.02065	0.02101
0.3	0.02579	0.02640	0.02703	0.02766	0.02830	0.02894	0.02957	0.03019	0.03077	0.03130
0.4	0.03419	0.03499	0.03581	0.03663	0.03747	0.03830	0.03912	0.03992	0.04067	0.04135
0.5	0.04243	0.04340	0.04439	0.04540	0.04641	0.04741	0.04841	0.04937	0.05027	0.05109
0.6	0.05047	0.05160	0.05275	0.05391	0.05508	0.05624	0.05738	0.05848	0.05951	0.06045
0.7	0.05828	0.05955	0.06084	0.06214	0.06344	0.06473	0.06599	0.06721	0.06835	0.06937
0.8	0.06583	0.06722	0.06863	0.07005	0.07146	0.07285	0.07421	0.07551	0.07673	0.07782
0.9	0.07309	0.07459	0.07609	0.07760	0.07910	0.08057	0.08200	0.08336	0.08462	0.08574
1.0	0.08005	0.08163	0.08321	0.08479	0.08635	0.08787	0.08934	0.09073	0.09200	0.09313
1.1	0.08669	0.08833	0.08996	0.09158	0.09318	0.09473	0.09621	0.09760	0.09886	0.09996
1.2	0.09300	0.09468	0.09634	0.09798	0.09959	0.10114	0.10261	0.10397	0.10519	0.10624
1.3	0.09897	0.10066	0.10234	0.10398	0.10557	0.10709	0.10853	0.10984	0.11100	0.11196
1.4	0.10460	0.10629	0.10795	0.10957	0.11113	0.11260	0.11398	0.11522	0.11629	0.11715
1.5	0.10988	0.11155	0.11318	0.11476	0.11626	0.11768	0.11897	0.12011	0.12108	0.12182
1.6	0.11483	0.11646	0.11804	0.11956	0.12099	0.12232	0.12352	0.12455	0.12539	0.12600
1.7	0.11943	0.12101	0.12253	0.12398	0.12532	0.12655	0.12764	0.12855	0.12925	0.12971
1.8	0.12371	0.12523	0.12667	0.12803	0.12928	0.13039	0.13135	0.13213	0.13268	0.13298
1.9	0.12767	0.12911	0.13047	0.13172	0.13286	0.13386	0.13469	0.13532	0.13572	0.13586
2.0	0.13132	0.13268	0.13394	0.13509	0.13611	0.13698	0.13766	0.13815	0.13839	0.13836
2.1	0.13468	0.13594	0.13710	0.13813	0.13903	0.13976	0.14031	0.14064	0.14072	0.14053
2.2	0.13776	0.13891	0.13996	0.14088	0.14165	0.14224	0.14264	0.14282	0.14274	0.14239
2.3	0.14056	0.14162	0.14255	0.14335	0.14398	0.14444	0.14469	0.14472	0.14449	0.14397
2.4	0.14312	0.14406	0.14488	0.14555	0.14606	0.14637	0.14648	0.14636	0.14597	0.14530
2.5	0.14544	0.14627	0.14697	0.14751	0.14789	0.14807	0.14804	0.14776	0.14723	0.14641
2.6	0.14754	0.14826	0.14883	0.14925	0.14950	0.14954	0.14937	0.14896	0.14828	0.14732
2.7	0.14943	0.15003	0.15049	0.15079	0.15090	0.15081	0.15051	0.14996	0.14915	0.14805
2.8	0.15112	0.15161	0.15195	0.15213	0.15212	0.15190	0.15147	0.15079	0.14985	0.14863
2.9	0.15263	0.15301	0.15324	0.15330	0.15316	0.15283	0.15227	0.15147	0.15041	0.14907
3.0	0.15397	0.15425	0.15436	0.15431	0.15406	0.15360	0.15293	0.15201	0.15083	0.14938

Table 4-12 (Continued)

Y \ X	-2.0	-1.9	-1.8	-1.7	-1.6	-1.5	-1.4	-1.3	-1.2	-1.1
0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
0.1	0.01070	0.01081	0.01086	0.01082	0.01065	0.01028	0.00963	0.00857	0.00689	0.00425
0.2	0.02131	0.02153	0.02164	0.02156	0.02123	0.02054	0.01931	0.01730	0.01414	0.00925
0.3	0.03175	0.03208	0.03224	0.03214	0.03169	0.03073	0.02904	0.02630	0.02203	0.01552
0.4	0.04194	0.04236	0.04258	0.04248	0.04194	0.04080	0.03878	0.03556	0.03060	0.02320
0.5	0.05179	0.05231	0.05257	0.05248	0.05190	0.05065	0.04845	0.04498	0.03974	0.03209
0.6	0.06124	0.06184	0.06215	0.06208	0.06148	0.06018	0.05792	0.05439	0.04918	0.04174
0.7	0.07024	0.07089	0.07123	0.07118	0.07058	0.06927	0.06703	0.06359	0.05858	0.05162
0.8	0.07873	0.07941	0.07977	0.07972	0.07913	0.07784	0.07566	0.07235	0.06765	0.06126
0.9	0.08668	0.08736	0.08772	0.08766	0.08706	0.08578	0.08367	0.08052	0.07613	0.07029
1.0	0.09405	0.09471	0.09504	0.09495	0.09432	0.09305	0.09098	0.08796	0.08384	0.07846
1.1	0.10085	0.10146	0.10173	0.10157	0.10090	0.09959	0.09754	0.09461	0.09069	0.08565
1.2	0.10706	0.10759	0.10777	0.10753	0.10678	0.10542	0.10335	0.10046	0.09666	0.09185
1.3	0.11269	0.11312	0.11320	0.11284	0.11199	0.11054	0.10841	0.10551	0.10176	0.09709
1.4	0.11776	0.11807	0.11801	0.11753	0.11654	0.11498	0.11277	0.10982	0.10607	0.10145
1.5	0.12230	0.12247	0.12226	0.12163	0.12050	0.11880	0.11647	0.11344	0.10964	0.10504
1.6	0.12633	0.12634	0.12597	0.12517	0.12388	0.12204	0.11958	0.11644	0.11257	0.10793
1.7	0.12988	0.12972	0.12919	0.12822	0.12676	0.12476	0.12216	0.11890	0.11494	0.11025
1.8	0.13299	0.13266	0.13195	0.13080	0.12918	0.12701	0.12426	0.12088	0.11683	0.11208
1.9	0.13570	0.13519	0.13430	0.13298	0.13118	0.12886	0.12597	0.12246	0.11831	0.11349
2.0	0.13803	0.13735	0.13628	0.13479	0.13282	0.13035	0.12731	0.12370	0.11946	0.11457
2.1	0.14002	0.13917	0.13793	0.13627	0.13415	0.13152	0.12836	0.12463	0.12031	0.11537
2.2	0.14172	0.14070	0.13929	0.13747	0.13520	0.13244	0.12916	0.12533	0.12093	0.11594
2.3	0.14314	0.14196	0.14040	0.13842	0.13601	0.13312	0.12973	0.12582	0.12136	0.11634
2.4	0.14431	0.14298	0.14127	0.13916	0.13662	0.13361	0.13013	0.12614	0.12162	0.11658
2.5	0.14527	0.14380	0.14195	0.13971	0.13705	0.13394	0.13037	0.12632	0.12177	0.11671
2.6	0.14604	0.14443	0.14246	0.14010	0.13733	0.13413	0.13049	0.12638	0.12180	0.11675
2.7	0.14664	0.14491	0.14282	0.14035	0.13749	0.13421	0.13050	0.12636	0.12176	0.11671
2.8	0.14710	0.14525	0.14305	0.14048	0.13754	0.13419	0.13044	0.12626	0.12166	0.11662
2.9	0.14742	0.14547	0.14317	0.14052	0.13750	0.13410	0.13030	0.12611	0.12150	0.11649
3.0	0.14764	0.14558	0.14320	0.14047	0.13739	0.13394	0.13012	0.12591	0.12131	0.11632

Table 4-12 (Continued)

Y \ X	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1
0.0	-0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00173	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.00572	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.01233	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.02117	0.00590	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.03144	0.01755	-0.00055	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.04226	0.03007	0.01482	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	0.05290	0.04234	0.02956	0.01492	-0.00057	0.0	0.0	0.0	0.0	0.0
0.9	0.06282	0.05361	0.04277	0.03063	0.01797	0.00603	0.0	0.0	0.0	0.0
1.0	0.07170	0.06355	0.05410	0.04365	0.03274	0.02221	0.01299	0.00603	0.00182	0.00014
1.1	0.07943	0.07203	0.06352	0.05415	0.04430	0.03450	0.02530	0.01725	0.01066	0.00537
1.2	0.08600	0.07909	0.07121	0.06252	0.05328	0.04384	0.03454	0.02572	0.01757	0.01009
1.3	0.09147	0.08488	0.07739	0.06912	0.06023	0.05095	0.04154	0.03220	0.02308	0.01424
1.4	0.09596	0.08956	0.08231	0.07428	0.06559	0.05642	0.04691	0.03724	0.02755	0.01790
1.5	0.09959	0.09330	0.08619	0.07831	0.06975	0.06064	0.05110	0.04126	0.03124	0.02115
1.6	0.10250	0.09626	0.08923	0.08145	0.07299	0.06394	0.05441	0.04452	0.03435	0.02405
1.7	0.10480	0.09858	0.09160	0.08390	0.07552	0.06656	0.05709	0.04721	0.03703	0.02666
1.8	0.10659	0.10038	0.09344	0.08580	0.07752	0.06865	0.05927	0.04948	0.03937	0.02905
1.9	0.10798	0.10176	0.09486	0.08729	0.07910	0.07035	0.06109	0.05143	0.04144	0.03124
2.0	0.10902	0.10282	0.09595	0.08846	0.08037	0.07174	0.06264	0.05313	0.04331	0.03328
2.1	0.10980	0.10361	0.09679	0.08938	0.08140	0.07291	0.06397	0.05464	0.04502	0.03519
2.2	0.11036	0.10419	0.09742	0.09010	0.08225	0.07391	0.06514	0.05601	0.04660	0.03698
2.3	0.11075	0.10461	0.09791	0.09068	0.08295	0.07477	0.06618	0.05726	0.04806	0.03867
2.4	0.11100	0.10489	0.09827	0.09114	0.08355	0.07553	0.06713	0.05841	0.04944	0.04028
2.5	0.11115	0.10508	0.09853	0.09152	0.08406	0.07620	0.06799	0.05948	0.05073	0.04181
2.6	0.11121	0.10520	0.09873	0.09183	0.08451	0.07682	0.06880	0.06050	0.05197	0.04327
2.7	0.11121	0.10526	0.09888	0.09209	0.08491	0.07739	0.06955	0.06146	0.05315	0.04468
2.8	0.11116	0.10527	0.09899	0.09231	0.08528	0.07792	0.07027	0.06237	0.05428	0.04603
2.9	0.11107	0.10526	0.09907	0.09251	0.08562	0.07842	0.07095	0.06325	0.05537	0.04734
3.0	0.11096	0.10522	0.09913	0.09269	0.08594	0.07890	0.07161	0.06410	0.05642	0.04860

Table 4-13

Fluid Velocity, v_x, as Interpolated from the Numerical

Flowfield at $Re_c = 0.2$, $R_\infty = 200$

Y \ X	-3.0	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3	-2.2	-2.1
0.0	0.20665	0.19716	0.18753	0.17759	0.16740	0.15701	0.14630	0.13532	0.12411	0.11267
0.1	0.20715	0.19770	0.18812	0.17821	0.16807	0.15774	0.14707	0.13615	0.12501	0.11363
0.2	0.20794	0.19856	0.18905	0.17920	0.16914	0.15889	0.14829	0.13746	0.12642	0.11514
0.3	0.20912	0.20003	0.19083	0.18126	0.17154	0.16162	0.15137	0.14092	0.13027	0.11938
0.4	0.21250	0.20356	0.19448	0.18507	0.17552	0.16574	0.15568	0.14544	0.13500	0.12426
0.5	0.21615	0.20738	0.19843	0.18921	0.17987	0.17027	0.16077	0.15112	0.14125	0.13115
0.6	0.22011	0.21183	0.20331	0.19463	0.18584	0.17675	0.16754	0.15819	0.14857	0.13881
0.7	0.22568	0.21766	0.20932	0.20092	0.19233	0.18354	0.17467	0.16558	0.15677	0.14787
0.8	0.23149	0.22365	0.21558	0.20749	0.19924	0.19122	0.18307	0.17474	0.16635	0.15786
0.9	0.23751	0.23010	0.22272	0.21525	0.20761	0.19997	0.19209	0.18418	0.17623	0.16843
1.0	0.24481	0.23772	0.23069	0.22345	0.21620	0.20883	0.20142	0.19444	0.18728	0.18014
1.1	0.25227	0.24552	0.23877	0.23184	0.22522	0.21857	0.21201	0.20535	0.19868	0.19208
1.2	0.25988	0.25348	0.24733	0.24123	0.23505	0.22886	0.22268	0.21642	0.21047	0.20466
1.3	0.26815	0.26247	0.25663	0.25090	0.24501	0.23929	0.23352	0.22820	0.22283	0.21756
1.4	0.27693	0.27146	0.26603	0.26053	0.25517	0.25011	0.24511	0.24017	0.23526	0.23052
1.5	0.28579	0.28054	0.27549	0.27066	0.26601	0.26127	0.25673	0.25211	0.24791	0.24379
1.6	0.29455	0.29003	0.28554	0.28115	0.27673	0.27248	0.26819	0.26441	0.26064	0.25711
1.7	0.30399	0.29987	0.29563	0.29157	0.28750	0.28370	0.28012	0.27669	0.27339	0.27024
1.8	0.31349	0.30956	0.30575	0.30189	0.29856	0.29513	0.29201	0.28888	0.28602	0.28336
1.9	0.32302	0.31927	0.31586	0.31263	0.30951	0.30657	0.30366	0.30107	0.29857	0.29644
2.0	0.33233	0.32923	0.32615	0.32333	0.32045	0.31781	0.31532	0.31307	0.31109	0.30915
2.1	0.34200	0.33921	0.33643	0.33378	0.33136	0.32897	0.32695	0.32500	0.32327	0.32182
2.2	0.35167	0.34904	0.34665	0.34421	0.34209	0.34018	0.33832	0.33679	0.33532	0.33404
2.3	0.36125	0.35885	0.35660	0.35472	0.35278	0.35112	0.34964	0.34825	0.34714	0.34610
2.4	0.37062	0.36864	0.36667	0.36494	0.36342	0.36190	0.36069	0.35959	0.35860	0.35796
2.5	0.38001	0.37824	0.37669	0.37508	0.37375	0.37262	0.37147	0.37062	0.36999	0.36946
2.6	0.38945	0.38780	0.38639	0.38517	0.38395	0.38295	0.38219	0.38144	0.38102	0.38078
2.7	0.39863	0.39731	0.39601	0.39495	0.39404	0.39315	0.39253	0.39219	0.39182	0.39152
2.8	0.40770	0.40657	0.40557	0.40456	0.40380	0.40327	0.40275	0.40251	0.40230	0.40213
2.9	0.41672	0.41568	0.41482	0.41411	0.41343	0.41302	0.41287	0.41251	0.41237	0.41252
3.0	0.42560	0.42469	0.42391	0.42337	0.42300	0.42266	0.42242	0.42236	0.42237	0.42257

Table 4-13 (Continued)

Y \ X	-2.0	-1.9	-1.8	-1.7	-1.6	-1.5	-1.4	-1.3	-1.2	-1.1
0.0	0.10097	0.08905	0.07699	0.06485	0.05273	0.04080	0.02936	0.01879	0.00959	0.00294
0.1	0.10199	0.09014	0.07815	0.06607	0.05400	0.04211	0.03065	0.02003	0.01068	0.00364
0.2	0.10366	0.09216	0.08052	0.06878	0.05705	0.04543	0.03411	0.02348	0.01388	0.00587
0.3	0.10823	0.09691	0.08543	0.07384	0.06222	0.05069	0.03972	0.02911	0.01925	0.01033
0.4	0.11338	0.10266	0.09180	0.08082	0.06977	0.05871	0.04773	0.03703	0.02696	0.01727
0.5	0.12090	0.11049	0.09993	0.08923	0.07867	0.06833	0.05795	0.04756	0.03717	0.02704
0.6	0.12890	0.11924	0.10951	0.09966	0.08972	0.07968	0.06981	0.06007	0.05007	0.03969
0.7	0.13885	0.12964	0.12033	0.11092	0.10192	0.09287	0.08366	0.07429	0.06501	0.05511
0.8	0.14919	0.14061	0.13235	0.12402	0.11556	0.10699	0.09880	0.09040	0.08165	0.07267
0.9	0.16077	0.15310	0.14532	0.13747	0.13002	0.12260	0.11508	0.10757	0.09994	0.09183
1.0	0.17302	0.16576	0.15887	0.15216	0.14546	0.13863	0.13215	0.12560	0.11891	0.11204
1.1	0.18560	0.17940	0.17330	0.16711	0.16115	0.15549	0.14986	0.14415	0.13850	0.13274
1.2	0.19895	0.19335	0.18769	0.18253	0.17752	0.17246	0.16764	0.16302	0.15835	0.15351
1.3	0.21240	0.20737	0.20275	0.19819	0.19373	0.18965	0.18563	0.18176	0.17800	0.17425
1.4	0.22606	0.22188	0.21771	0.21376	0.21019	0.20667	0.20349	0.20031	0.19734	0.19454
1.5	0.23997	0.23617	0.23267	0.22944	0.22639	0.22368	0.22092	0.21861	0.21628	0.21404
1.6	0.25365	0.25051	0.24759	0.24490	0.24248	0.24015	0.23821	0.23636	0.23467	0.23308
1.7	0.26737	0.26474	0.26232	0.26016	0.25814	0.25643	0.25499	0.25353	0.25236	0.25134
1.8	0.28099	0.27877	0.27683	0.27503	0.27352	0.27233	0.27111	0.27022	0.26959	0.26880
1.9	0.29435	0.29262	0.29097	0.28963	0.28858	0.28758	0.28687	0.28635	0.28592	0.28546
2.0	0.30762	0.30605	0.30487	0.30391	0.30309	0.30247	0.30203	0.30189	0.30151	0.30163
2.1	0.32038	0.31934	0.31841	0.31777	0.31717	0.31680	0.31693	0.31656	0.31666	0.31710
2.2	0.33307	0.33219	0.33171	0.33110	0.33079	0.33096	0.33075	0.33084	0.33141	0.33140
2.3	0.34535	0.34496	0.34434	0.34409	0.34417	0.34420	0.34429	0.34472	0.34513	0.34535
2.4	0.35746	0.35699	0.35680	0.35675	0.35701	0.35711	0.35736	0.35801	0.35833	0.35880
2.5	0.36913	0.36887	0.36879	0.36909	0.36926	0.36944	0.37004	0.37074	0.37096	0.37164
2.6	0.38040	0.38036	0.38069	0.38085	0.38103	0.38160	0.38236	0.38263	0.38322	0.38424
2.7	0.39154	0.39163	0.39201	0.39220	0.39260	0.39322	0.39386	0.39438	0.39508	0.39591
2.8	0.40223	0.40265	0.40289	0.40314	0.40374	0.40469	0.40499	0.40555	0.40648	0.40712
2.9	0.41283	0.41310	0.41337	0.41395	0.41465	0.41522	0.41572	0.41657	0.41760	0.41780
3.0	0.42305	0.42333	0.42364	0.42426	0.42518	0.42564	0.42619	0.42705	0.42779	0.42825

Table 4-13 (Continued)

Y \ X	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1
0.0	0.00000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00012	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00079	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.00291	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.00786	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.01637	0.00459	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.02868	0.01590	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.04432	0.03190	0.01670	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	0.06274	0.05142	0.03790	0.02116	0.0	0.0	0.0	0.0	0.0	0.0
0.9	0.08311	0.07331	0.06184	0.04823	0.03203	0.01297	0.0	0.0	0.0	0.0
1.0	0.10471	0.09643	0.08715	0.07645	0.06424	0.05088	0.03638	0.02241	0.01041	0.00266
1.1	0.12665	0.12015	0.11266	0.10452	0.09574	0.08579	0.07579	0.06635	0.05862	0.05290
1.2	0.14873	0.14354	0.13796	0.13170	0.12524	0.11830	0.11136	0.10456	0.09898	0.09512
1.3	0.17032	0.16655	0.16210	0.15784	0.15287	0.14795	0.14316	0.13857	0.13430	0.13125
1.4	0.19147	0.18861	0.18543	0.18218	0.17886	0.17526	0.17175	0.16851	0.16555	0.16309
1.5	0.21211	0.20970	0.20780	0.20519	0.20293	0.20049	0.19775	0.19563	0.19310	0.19121
1.6	0.23161	0.23003	0.22857	0.22696	0.22519	0.22383	0.22157	0.21996	0.21805	0.21635
1.7	0.25024	0.24948	0.24834	0.24749	0.24607	0.24522	0.24352	0.24219	0.24080	0.23921
1.8	0.26822	0.26764	0.26704	0.26637	0.26572	0.26488	0.26385	0.26266	0.26168	0.26014
1.9	0.28541	0.28497	0.28490	0.28429	0.28422	0.28327	0.28278	0.28164	0.28099	0.27946
2.0	0.30158	0.30143	0.30156	0.30134	0.30140	0.30056	0.30050	0.29934	0.29896	0.29741
2.1	0.31688	0.31729	0.31734	0.31733	0.31730	0.31688	0.31684	0.31595	0.31558	0.31404
2.2	0.33170	0.33243	0.33221	0.33257	0.33243	0.33238	0.33223	0.33141	0.33096	0.32956
2.3	0.34605	0.34629	0.34646	0.34718	0.34690	0.34696	0.34654	0.34596	0.34549	0.34422
2.4	0.35960	0.35969	0.36021	0.36070	0.36044	0.36073	0.36020	0.35981	0.35930	0.35813
2.5	0.37235	0.37268	0.37324	0.37341	0.37344	0.37395	0.37329	0.37307	0.37245	0.37133
2.6	0.38450	0.38491	0.38575	0.38574	0.38601	0.38631	0.38564	0.38544	0.38472	0.38368
2.7	0.39618	0.39686	0.39765	0.39751	0.39779	0.39790	0.39741	0.39734	0.39655	0.39559
2.8	0.40757	0.40826	0.40867	0.40875	0.40922	0.40918	0.40884	0.40885	0.40792	0.40699
2.9	0.41836	0.41928	0.41948	0.41974	0.42021	0.41988	0.41956	0.41960	0.41860	0.41774
3.0	0.42902	0.42981	0.42976	0.43005	0.43067	0.43019	0.42998	0.43011	0.42905	0.42824

Table 4-14

Fluid Velocity, v_y, as Interpolated from the Numerical

Flowfield at $Re_c = 0.2$, $R_\infty = 200$

Y \ X	-3.0	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3	-2.2	-2.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00925	0.00948	0.00973	0.00997	0.01023	0.01049	0.01075	0.01100	0.01126	0.01150
0.2	0.01849	0.01895	0.01944	0.01993	0.02044	0.02096	0.02148	0.02200	0.02251	0.02300
0.3	0.02769	0.02835	0.02904	0.02974	0.03046	0.03120	0.03192	0.03266	0.03338	0.03408
0.4	0.03653	0.03741	0.03833	0.03926	0.04022	0.04120	0.04218	0.04317	0.04416	0.04508
0.5	0.04532	0.04642	0.04756	0.04872	0.04994	0.05113	0.05221	0.05331	0.05437	0.05536
0.6	0.05402	0.05522	0.05643	0.05768	0.05898	0.06027	0.06159	0.06293	0.06421	0.06546
0.7	0.06205	0.06344	0.06485	0.06632	0.06782	0.06933	0.07090	0.07242	0.07361	0.07478
0.8	0.07000	0.07158	0.07318	0.07487	0.07645	0.07789	0.07935	0.08077	0.08220	0.08361
0.9	0.07787	0.07944	0.08096	0.08253	0.08411	0.08576	0.08738	0.08904	0.09072	0.09189
1.0	0.08486	0.08648	0.08819	0.08991	0.09169	0.09351	0.09526	0.09662	0.09789	0.09914
1.1	0.09166	0.09344	0.09531	0.09719	0.09890	0.10035	0.10187	0.10336	0.10484	0.10635
1.2	0.09836	0.10032	0.10186	0.10345	0.10505	0.10669	0.10836	0.11002	0.11138	0.11220
1.3	0.10437	0.10602	0.10767	0.10940	0.11113	0.11295	0.11449	0.11560	0.11665	0.11768
1.4	0.10986	0.11160	0.11340	0.11523	0.11699	0.11820	0.11943	0.12066	0.12186	0.12310
1.5	0.11527	0.11710	0.11899	0.12026	0.12160	0.12291	0.12429	0.12561	0.12659	0.12689
1.6	0.12055	0.12193	0.12329	0.12470	0.12610	0.12757	0.12901	0.12963	0.13012	0.13063
1.7	0.12466	0.12611	0.12754	0.12904	0.13054	0.13171	0.13237	0.13302	0.13365	0.13426
1.8	0.12868	0.13018	0.13173	0.13328	0.13413	0.13486	0.13564	0.13636	0.13712	0.13676
1.9	0.13265	0.13419	0.13547	0.13629	0.13713	0.13798	0.13880	0.13951	0.13921	0.13893
2.0	0.13649	0.13743	0.13830	0.13922	0.14009	0.14102	0.14155	0.14140	0.14125	0.14100
2.1	0.13922	0.14017	0.14110	0.14204	0.14304	0.14340	0.14338	0.14330	0.14320	0.14309
2.2	0.14187	0.14284	0.14386	0.14484	0.14510	0.14516	0.14516	0.14519	0.14514	0.14389
2.3	0.14447	0.14548	0.14650	0.14666	0.14675	0.14686	0.14695	0.14700	0.14591	0.14472
2.4	0.14700	0.14788	0.14805	0.14823	0.14842	0.14854	0.14869	0.14771	0.14665	0.14557
2.5	0.14910	0.14935	0.14960	0.14980	0.15001	0.15023	0.14932	0.14840	0.14743	0.14638
2.6	0.15056	0.15082	0.15109	0.15137	0.15160	0.15081	0.15000	0.14910	0.14818	0.14684
2.7	0.15197	0.15229	0.15258	0.15288	0.15219	0.15142	0.15064	0.14984	0.14876	0.14669
2.8	0.15337	0.15372	0.15407	0.15341	0.15275	0.15206	0.15130	0.15052	0.14863	0.14661
2.9	0.15477	0.15513	0.15457	0.15398	0.15333	0.15266	0.15199	0.15037	0.14849	0.14656
3.0	0.15614	0.15563	0.15508	0.15452	0.15394	0.15329	0.15198	0.15024	0.14841	0.14652

Table 4-14 (Continued)

Y \ X	-2.0	-1.9	-1.8	-1.7	-1.6	-1.5	-1.4	-1.3	-1.2	-1.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.01172	0.01190	0.01203	0.01206	0.01197	0.01168	0.01107	0.00998	0.00818	0.00519
0.2	0.02343	0.02375	0.02396	0.02401	0.02380	0.02323	0.02210	0.02005	0.01667	0.01127
0.3	0.03469	0.03521	0.03557	0.03571	0.03551	0.03477	0.03312	0.03038	0.02576	0.01858
0.4	0.04591	0.04648	0.04686	0.04697	0.04666	0.04575	0.04396	0.04082	0.03558	0.02739
0.5	0.05629	0.05709	0.05770	0.05802	0.05770	0.05654	0.05446	0.05106	0.04574	0.03735
0.6	0.06665	0.06743	0.06788	0.06801	0.06771	0.06680	0.06471	0.06109	0.05585	0.04808
0.7	0.07586	0.07675	0.07746	0.07789	0.07733	0.07613	0.07414	0.07097	0.06556	0.05829
0.8	0.08488	0.08587	0.08626	0.08641	0.08611	0.08529	0.08288	0.07955	0.07507	0.06805
0.9	0.09284	0.09371	0.09436	0.09474	0.09405	0.09278	0.09095	0.08784	0.08315	0.07735
1.0	0.10037	0.10142	0.10172	0.10158	0.10118	0.10028	0.09778	0.09467	0.09064	0.08470
1.1	0.10724	0.10771	0.10810	0.10820	0.10754	0.10597	0.10407	0.10097	0.09652	0.09155
1.2	0.11300	0.11374	0.11428	0.11364	0.11278	0.11153	0.10914	0.10593	0.10222	0.09645
1.3	0.11870	0.11909	0.11885	0.11841	0.11778	0.11586	0.11336	0.11058	0.10599	0.10097
1.4	0.12324	0.12333	0.12324	0.12299	0.12137	0.11945	0.11743	0.11353	0.10938	0.10430
1.5	0.12722	0.12741	0.12722	0.12597	0.12455	0.12306	0.11973	0.11632	0.11209	0.10658
1.6	0.13106	0.13085	0.12991	0.12887	0.12773	0.12492	0.12201	0.11863	0.11379	0.10863
1.7	0.13400	0.13332	0.13255	0.13171	0.12931	0.12678	0.12410	0.11978	0.11520	0.10991
1.8	0.13630	0.13574	0.13514	0.13306	0.13087	0.12856	0.12492	0.12081	0.11647	0.11054
1.9	0.13853	0.13814	0.13631	0.13440	0.13238	0.12936	0.12565	0.12172	0.11669	0.11095
2.0	0.14078	0.13915	0.13748	0.13570	0.13324	0.12984	0.12626	0.12209	0.11676	0.11134
2.1	0.14165	0.14020	0.13861	0.13665	0.13353	0.13025	0.12688	0.12190	0.11683	0.11138
2.2	0.14260	0.14118	0.13968	0.13678	0.13378	0.13073	0.12649	0.12175	0.11692	0.11086
2.3	0.14349	0.14223	0.13969	0.13693	0.13409	0.13060	0.12617	0.12161	0.11652	0.11039
2.4	0.14441	0.14230	0.13977	0.13710	0.13431	0.13016	0.12585	0.12145	0.11588	0.10994
2.5	0.14468	0.14231	0.13982	0.13729	0.13376	0.12969	0.12556	0.12089	0.11522	0.10948
2.6	0.14459	0.14230	0.13996	0.13701	0.13320	0.12932	0.12531	0.12008	0.11463	0.10910
2.7	0.14458	0.14234	0.14000	0.13643	0.13274	0.12894	0.12455	0.11938	0.11408	0.10848
2.8	0.14453	0.14241	0.13937	0.13586	0.13228	0.12864	0.12373	0.11867	0.11355	0.10770
2.9	0.14456	0.14205	0.13875	0.13538	0.13189	0.12775	0.12295	0.11807	0.11307	0.10693
3.0	0.14454	0.14143	0.13819	0.13489	0.13149	0.12693	0.12224	0.11747	0.11219	0.10624

Table 4-14 (Continued)

Y \ X	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00029	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00227	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.00719	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.01505	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.02532	0.00734	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.03652	0.02097	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.04818	0.03479	0.01779	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	0.05930	0.04775	0.03393	0.01758	0.0	0.0	0.0	0.0	0.0	0.0
0.9	0.06904	0.05943	0.04739	0.03415	0.02029	0.00699	0.0	0.0	0.0	0.0
1.0	0.07793	0.06873	0.05862	0.04718	0.03533	0.02412	0.01410	0.00662	0.00207	0.00027
1.1	0.08450	0.07684	0.06721	0.05712	0.04666	0.03587	0.02602	0.01748	0.01055	0.00499
1.2	0.09038	0.08264	0.07425	0.06448	0.05457	0.04438	0.03436	0.02488	0.01631	0.00853
1.3	0.09454	0.08749	0.07901	0.07020	0.06025	0.05023	0.04016	0.03016	0.02050	0.01131
1.4	0.09793	0.09097	0.08278	0.07395	0.06450	0.05442	0.04420	0.03388	0.02365	0.01361
1.5	0.10085	0.09334	0.08578	0.07669	0.06744	0.05745	0.04708	0.03669	0.02603	0.01556
1.6	0.10234	0.09526	0.08741	0.07875	0.06937	0.05968	0.04920	0.03872	0.02796	0.01726
1.7	0.10344	0.09672	0.08859	0.08026	0.07076	0.06118	0.05078	0.04029	0.02956	0.01879
1.8	0.10436	0.09724	0.08941	0.08093	0.07178	0.06214	0.05198	0.04154	0.03093	0.02019
1.9	0.10493	0.09755	0.09003	0.08137	0.07253	0.06282	0.05293	0.04257	0.03213	0.02150
2.0	0.10484	0.09769	0.09015	0.08165	0.07297	0.06332	0.05371	0.04344	0.03321	0.02273
2.1	0.10461	0.09779	0.09002	0.08175	0.07305	0.06371	0.05424	0.04421	0.03418	0.02389
2.2	0.10439	0.09771	0.08978	0.08178	0.07308	0.06402	0.05467	0.04488	0.03506	0.02500
2.3	0.10418	0.09716	0.08951	0.08180	0.07307	0.06425	0.05501	0.04548	0.03589	0.02608
2.4	0.10390	0.09665	0.08927	0.08152	0.07299	0.06443	0.05533	0.04606	0.03669	0.02712
2.5	0.10325	0.09618	0.08898	0.08117	0.07292	0.06462	0.05564	0.04663	0.03747	0.02814
2.6	0.10256	0.09567	0.08872	0.08088	0.07287	0.06469	0.05592	0.04715	0.03820	0.02912
2.7	0.10189	0.09524	0.08833	0.08058	0.07278	0.06471	0.05620	0.04767	0.03893	0.03008
2.8	0.10130	0.09481	0.08781	0.08030	0.07274	0.06477	0.05649	0.04820	0.03965	0.03103
2.9	0.10071	0.09443	0.08737	0.08007	0.07271	0.06482	0.05676	0.04870	0.04034	0.03195
3.0	0.10021	0.09400	0.08694	0.07983	0.07268	0.06489	0.05706	0.04921	0.04104	0.03287

Table 4-15

Fluid Velocities According to Davies and Peetz [7] at $Re_c = 10$

y \ x	0	-0.2	-0.4	-0.6	-0.8	-1.0	-1.2	-1.4	-1.6	-1.8	-2.0	-2.2	-2.4	-2.6	-2.8	-3.0
v_x																
0	.	.	.	.	.	.	0.12	0.24	0.35	0.46	0.54	0.61	0.66	0.695	0.725	0.75
0.2	.	.	.	.	0.	0.015	0.13	0.26	0.38	0.48	0.56	0.63	0.675	0.71	0.74	0.76
0.4	.	.	.	.	0	0.04	0.20	0.33	0.44	0.52	0.59	0.65	0.69	0.73	0.755	0.78
0.6	.	.	.	.	0	0.23	0.35	0.43	0.51	0.57	0.63	0.68	0.72	0.75	0.775	0.795
0.8	.	.	.	0	0.30	0.43	0.50	0.55	0.60	0.64	0.68	0.71	0.74	0.77	0.79	0.81
1.0	0	0.01	0.05	0.45	0.55	0.60	0.64	0.67	0.69	0.71	0.73	0.75	0.775	0.80	0.82	0.835
1.2	0.40	0.47	0.60	0.72	0.76	0.77	0.78	0.78	0.78	0.785	0.79	0.80	0.82	0.845	0.865	0.88
1.4	0.71	0.80	0.86	0.91	0.92	0.915	0.90	0.88	0.86	0.85	0.845	0.85	0.87	0.89	0.91	0.92
1.6	0.95	1.04	1.05	1.04	1.02	1.00	0.98	0.955	0.93	0.90	0.89	0.90	0.92	0.935	0.95	0.96
1.8	1.10	1.18	1.17	1.12	1.06	1.03	1.00	0.97	0.95	0.925	0.915	0.925	0.915	0.96	0.975	0.99
2.0	1.17	1.25	1.21	1.13	1.07	1.00	.	.	.	.	.	.	.	.	.	.
v_y																
0	.	.	.	.	.	0	0	0	0	0	0	0	0	0	0	0
0.2	.	.	.	.	.	0.11	0.14	0.14	0.125	0.095	0.075	0.06	0.05	0.04	0.035	0.030
0.4	.	.	.	.	.	0.22	0.26	0.26	0.23	0.18	0.14	0.12	0.10	0.08	0.065	0.055
0.6	.	.	.	.	0	0.33	0.37	0.36	0.32	0.25	0.20	0.165	0.14	0.115	0.095	0.08
0.8	.	.	.	0	0.28	0.41	0.46	0.43	0.38	0.30	0.25	0.205	0.17	0.14	0.115	0.095
1.0	0	0.01	0.13	0.27	0.40	0.475	0.51	0.47	0.41	0.33	0.275	0.22	0.19	0.16	0.13	0.105
1.2	0.06	0.12	0.28	0.39	0.465	0.51	0.52	0.485	0.42	0.345	0.28	0.23	0.19	.	.	.
1.4	0.12	0.21	0.35	0.45	0.49	0.51	0.51	0.47	0.41	0.34	0.28	0.23	.	.	.	.
1.6	0.18	0.28	0.38	0.46	0.495	0.50	0.49	0.44	0.39	0.33	0.28	0.23	.	.	.	.
1.8	0.23	0.32	0.39	0.44	0.47	0.48	0.46	0.41	0.37	0.315	0.265	0.23	.	.	.	.
2.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 4-16

Fluid Velocity, v_x, as Interpolated from the Numerical Flowfield at $Re_c = 10$, $R_\infty = 100$

Y \ X	-3.0	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3	-2.2	-2.1
0.0	0.67960	0.66454	0.64832	0.63092	0.61184	0.59068	0.56762	0.54238	0.51461	0.48397
0.1	0.67931	0.66430	0.64819	0.63090	0.61192	0.59092	0.56805	0.54304	0.51554	0.48522
0.2	0.67952	0.66458	0.64865	0.63158	0.61272	0.59200	0.56947	0.54484	0.51781	0.48802
0.3	0.68025	0.66589	0.65063	0.63434	0.61616	0.59644	0.57507	0.55179	0.52630	0.49823
0.4	0.68463	0.67077	0.65608	0.64027	0.62270	0.60381	0.58338	0.56117	0.53666	0.50971
0.5	0.68938	0.67607	0.66202	0.64660	0.62982	0.61191	0.59312	0.57252	0.54998	0.52557
0.6	0.69452	0.68220	0.66924	0.65479	0.63950	0.62322	0.60553	0.58617	0.56535	0.54289
0.7	0.70163	0.69010	0.67764	0.66417	0.64997	0.63479	0.61808	0.60034	0.58225	0.56294
0.8	0.70898	0.69826	0.68629	0.67382	0.66100	0.64723	0.63276	0.61756	0.60151	0.58396
0.9	0.71652	0.70654	0.69603	0.68523	0.67353	0.66115	0.64828	0.63470	0.61998	0.60540
1.0	0.72554	0.71622	0.70674	0.69679	0.68608	0.67510	0.66370	0.65220	0.64046	0.62847
1.1	0.73434	0.72593	0.71747	0.70811	0.69901	0.69001	0.68034	0.67063	0.66088	0.65044
1.2	0.74315	0.73565	0.72824	0.72062	0.71306	0.70484	0.69671	0.68860	0.68039	0.67296
1.3	0.75263	0.74640	0.73973	0.73324	0.72630	0.71940	0.71286	0.70653	0.70060	0.69501
1.4	0.76252	0.75673	0.75104	0.74521	0.73940	0.73443	0.72916	0.72436	0.71979	0.71537
1.5	0.77197	0.76690	0.76203	0.75743	0.75327	0.74888	0.74493	0.74121	0.73804	0.73608
1.6	0.78111	0.77735	0.77342	0.76982	0.76621	0.76288	0.75985	0.75766	0.75632	0.75509
1.7	0.79093	0.78769	0.78450	0.78155	0.77866	0.77648	0.77475	0.77380	0.77297	0.77305
1.8	0.80052	0.79763	0.79522	0.79267	0.79121	0.78976	0.78905	0.78853	0.78880	0.79009
1.9	0.80946	0.80729	0.80539	0.80414	0.80305	0.80249	0.80220	0.80263	0.80399	0.80613
2.0	0.81815	0.81685	0.81570	0.81492	0.81442	0.81432	0.81485	0.81622	0.81821	0.82088
2.1	0.82715	0.82613	0.82560	0.82510	0.82517	0.82572	0.82708	0.82888	0.83136	0.83448
2.2	0.83560	0.83507	0.83475	0.83487	0.83548	0.83682	0.83840	0.84072	0.84349	0.84740
2.3	0.84367	0.84353	0.84355	0.84431	0.84549	0.84698	0.84914	0.85158	0.85515	0.85925
2.4	0.85146	0.85155	0.85236	0.85333	0.85478	0.85664	0.85890	0.86217	0.86580	0.87021
2.5	0.85890	0.85959	0.86052	0.86192	0.86350	0.86560	0.86847	0.87178	0.87578	0.88020
2.6	0.86619	0.86715	0.86832	0.86982	0.87178	0.87427	0.87731	0.88084	0.88482	0.88954
2.7	0.87320	0.87424	0.87567	0.87734	0.87965	0.88245	0.88553	0.88915	0.89334	0.89812
2.8	0.87975	0.88103	0.88252	0.88468	0.88713	0.88994	0.89325	0.89689	0.90123	0.90614
2.9	0.88594	0.88738	0.88931	0.89150	0.89411	0.89703	0.90031	0.90423	0.90859	0.91340
3.0	0.89188	0.89359	0.89565	0.89799	0.90060	0.90361	0.90710	0.91100	0.91537	0.92018

Table 4-16 (Continued)

Y \ X	-2.0	-1.9	-1.8	-1.7	-1.6	-1.5	-1.4	-1.3	-1.2	-1.1
0.0	0.45008	0.41262	0.37131	0.32603	0.27686	0.22422	0.16881	0.11293	0.06071	0.01868
0.1	0.45172	0.41470	0.37392	0.32923	0.28073	0.22880	0.17412	0.11876	0.06640	0.02281
0.2	0.45536	0.41984	0.38078	0.33805	0.29172	0.24210	0.18980	0.13612	0.08373	0.03746
0.3	0.46724	0.43330	0.39616	0.35537	0.31102	0.26352	0.21473	0.16396	0.11272	0.06332
0.4	0.48036	0.44918	0.41523	0.37837	0.33851	0.29520	0.24913	0.20108	0.15248	0.10190
0.5	0.49908	0.47027	0.43897	0.40502	0.36915	0.33160	0.29133	0.24797	0.20186	0.15326
0.6	0.51861	0.49330	0.46630	0.43721	0.40592	0.37232	0.33726	0.30064	0.26036	0.21491
0.7	0.54229	0.51984	0.49588	0.47030	0.44458	0.41741	0.38820	0.35645	0.32286	0.28435
0.8	0.56540	0.54616	0.52682	0.50645	0.48494	0.46215	0.43944	0.41489	0.38764	0.35690
0.9	0.59057	0.57516	0.55913	0.54219	0.52576	0.50892	0.49123	0.47273	0.45269	0.42949
1.0	0.61599	0.60287	0.59042	0.57822	0.56588	0.55332	0.54141	0.52877	0.51480	0.49831
1.1	0.64058	0.63132	0.62228	0.61315	0.60449	0.59663	0.58888	0.58108	0.57269	0.56302
1.2	0.66588	0.65872	0.65179	0.64640	0.64170	0.63751	0.63355	0.62999	0.62642	0.62121
1.3	0.68932	0.68468	0.68133	0.67825	0.67586	0.67489	0.67490	0.67503	0.67462	0.67425
1.4	0.71248	0.71013	0.70830	0.70754	0.70837	0.70962	0.71201	0.71526	0.71839	0.72084
1.5	0.73438	0.73350	0.73391	0.73516	0.73766	0.74151	0.74570	0.75108	0.75719	0.76183
1.6	0.75482	0.75561	0.75748	0.76067	0.76450	0.76975	0.77631	0.78319	0.79057	0.79820
1.7	0.77413	0.77627	0.77949	0.78344	0.78915	0.79549	0.80322	0.81139	0.82015	0.82941
1.8	0.79230	0.79535	0.79928	0.80477	0.81102	0.81884	0.82690	0.83643	0.84629	0.85593
1.9	0.80900	0.81274	0.81782	0.82383	0.83102	0.83904	0.84824	0.85817	0.86850	0.87889
2.0	0.82433	0.82901	0.83462	0.84118	0.84880	0.85736	0.86702	0.87720	0.88796	0.89900
2.1	0.83876	0.84388	0.84985	0.85686	0.86475	0.87382	0.88354	0.89394	0.90473	0.91618
2.2	0.85201	0.85740	0.86373	0.87093	0.87927	0.88820	0.89803	0.90837	0.91955	0.93071
2.3	0.86413	0.86978	0.87629	0.88384	0.89197	0.90109	0.91075	0.92117	0.93229	0.94292
2.4	0.87522	0.88108	0.88785	0.89522	0.90355	0.91242	0.92203	0.93257	0.94288	0.95370
2.5	0.88546	0.89149	0.89815	0.90567	0.91374	0.92255	0.93219	0.94209	0.95229	0.96319
2.6	0.89489	0.90090	0.90767	0.91493	0.92295	0.93170	0.94095	0.95051	0.96067	0.97113
2.7	0.90355	0.90956	0.91612	0.92340	0.93126	0.93970	0.94868	0.95801	0.96774	0.97789
2.8	0.91146	0.91739	0.92397	0.93101	0.93868	0.94698	0.95549	0.96450	0.97406	0.98367
2.9	0.91875	0.92460	0.93098	0.93794	0.94542	0.95328	0.96156	0.97036	0.97955	0.98850
3.0	0.92539	0.93119	0.93749	0.94419	0.95142	0.95901	0.96703	0.97545	0.98411	0.99284

Table 4-16 (Continued)

Y \ X	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1
0.0	0.00000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.00497	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.01836	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.04872	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.09738	0.02823	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.16235	0.09380	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.23824	0.17747	0.09545	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	0.31927	0.26941	0.20381	0.11502	0.0	0.0	0.0	0.0	0.0	0.0
0.9	0.40011	0.36279	0.31204	0.24631	0.16356	0.06503	0.0	0.0	0.0	0.0
1.0	0.47822	0.45053	0.41502	0.36799	0.30852	0.23926	0.16586	0.09811	0.04243	0.00997
1.1	0.54940	0.53227	0.50608	0.47285	0.43145	0.38202	0.32897	0.27587	0.23019	0.19554
1.2	0.61487	0.60323	0.58773	0.56400	0.53564	0.50097	0.45984	0.41833	0.37939	0.34412
1.3	0.67194	0.66702	0.65669	0.64386	0.62276	0.59707	0.56859	0.53413	0.49985	0.46788
1.4	0.72256	0.72196	0.71727	0.70978	0.69654	0.67830	0.65568	0.63005	0.60108	0.57168
1.5	0.76720	0.76903	0.76982	0.76558	0.75795	0.74561	0.72858	0.70929	0.68439	0.65927
1.6	0.80439	0.81015	0.81248	0.81316	0.80866	0.80204	0.78983	0.77447	0.75447	0.73259
1.7	0.83701	0.84544	0.84921	0.85352	0.85153	0.84838	0.83996	0.82892	0.81362	0.79494
1.8	0.86544	0.87418	0.88065	0.88581	0.88760	0.88624	0.88203	0.87420	0.86325	0.84761
1.9	0.88966	0.89863	0.90743	0.91325	0.91779	0.91788	0.91717	0.91148	0.90461	0.89178
2.0	0.90978	0.91965	0.92909	0.93650	0.94261	0.94424	0.94637	0.94250	0.93883	0.92857
2.1	0.92687	0.93769	0.94711	0.95557	0.96213	0.96612	0.96945	0.96822	0.96649	0.95899
2.2	0.94151	0.95284	0.96247	0.97156	0.97842	0.98425	0.98838	0.98910	0.98888	0.98399
2.3	0.95423	0.96516	0.97492	0.98496	0.99202	0.99922	1.00368	1.00596	1.00709	1.00443
2.4	0.96525	0.97532	0.98553	0.99536	1.00335	1.01124	1.01582	1.01966	1.02187	1.02108
2.5	0.97387	0.98400	0.99455	1.00406	1.01235	1.02070	1.02571	1.03075	1.03382	1.03460
2.6	0.98124	0.99151	1.00218	1.01089	1.01956	1.02789	1.03375	1.03970	1.04345	1.04552
2.7	0.98773	0.99783	1.00778	1.01658	1.02556	1.03371	1.04026	1.04677	1.05082	1.05377
2.8	0.99315	1.00299	1.01245	1.02139	1.03050	1.03821	1.04495	1.05177	1.05623	1.05999
2.9	0.99782	1.00749	1.01647	1.02518	1.03406	1.04154	1.04862	1.05575	1.06050	1.06489
3.0	1.00193	1.01108	1.01955	1.02819	1.03700	1.04427	1.05154	1.05885	1.06381	1.06860

Table 4-17

Fluid Velocity, v_y, as Interpolated from the Numerical

Flowfield at $Re_c = 10$, $R_\infty = 100$

Y \ X	-3.0	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3	-2.2	-2.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.01426	0.01546	0.01679	0.01827	0.01995	0.02185	0.02397	0.02636	0.02904	0.03202
0.2	0.02842	0.03080	0.03345	0.03639	0.03973	0.04349	0.04770	0.05243	0.05774	0.06367
0.3	0.04239	0.04589	0.04976	0.05407	0.05897	0.06446	0.07060	0.07748	0.08519	0.09379
0.4	0.05580	0.06037	0.06542	0.07106	0.07747	0.08461	0.09261	0.10156	0.11162	0.12281
0.5	0.06887	0.07444	0.08059	0.08753	0.09533	0.10399	0.11349	0.12415	0.13605	0.14920
0.6	0.08148	0.08786	0.09490	0.10288	0.11173	0.12156	0.13258	0.14493	0.15863	0.17380
0.7	0.09308	0.10025	0.10826	0.11722	0.12713	0.13817	0.15061	0.16437	0.17912	0.19537
0.8	0.10412	0.11199	0.12092	0.13073	0.14143	0.15330	0.16639	0.18084	0.19681	0.21449
0.9	0.11457	0.12304	0.13236	0.14255	0.15397	0.16661	0.18053	0.19594	0.21307	0.23114
1.0	0.12371	0.13275	0.14257	0.15341	0.16551	0.17876	0.19333	0.20891	0.22590	0.24441
1.1	0.13233	0.14176	0.15196	0.16347	0.17572	0.18891	0.20358	0.21955	0.23696	0.25615
1.2	0.14032	0.15002	0.16038	0.17171	0.18398	0.19772	0.21261	0.22884	0.24633	0.26452
1.3	0.14716	0.15675	0.16741	0.17885	0.19159	0.20542	0.22018	0.23591	0.25278	0.27098
1.4	0.15301	0.16296	0.17366	0.18539	0.19810	0.21120	0.22572	0.24126	0.25811	0.27638
1.5	0.15842	0.16847	0.17919	0.19054	0.20258	0.21594	0.23020	0.24568	0.26195	0.27848
1.6	0.16333	0.17283	0.18330	0.19444	0.20663	0.21974	0.23389	0.24831	0.26344	0.27992
1.7	0.16683	0.17639	0.18674	0.19783	0.20992	0.22242	0.23561	0.24942	0.26455	0.28039
1.8	0.16978	0.17945	0.18954	0.20073	0.21172	0.22385	0.23647	0.25028	0.26473	0.27905
1.9	0.17255	0.18193	0.19186	0.20199	0.21298	0.22456	0.23710	0.25015	0.26317	0.27678
2.0	0.17481	0.18354	0.19297	0.20293	0.21361	0.22497	0.23673	0.24859	0.26107	0.27422
2.1	0.17586	0.18460	0.19360	0.20353	0.21380	0.22447	0.23522	0.24669	0.25868	0.27131
2.2	0.17678	0.18519	0.19420	0.20359	0.21323	0.22296	0.23356	0.24444	0.25607	0.26692
2.3	0.17739	0.18554	0.19432	0.20291	0.21190	0.22154	0.23139	0.24214	0.25205	0.26251
2.4	0.17761	0.18561	0.19336	0.20179	0.21051	0.21967	0.22941	0.23841	0.24815	0.25797
2.5	0.17750	0.18476	0.19247	0.20034	0.20893	0.21774	0.22615	0.23501	0.24395	0.25353
2.6	0.17684	0.18381	0.19123	0.19903	0.20699	0.21492	0.22295	0.23128	0.24006	0.24856
2.7	0.17589	0.18281	0.18986	0.19739	0.20458	0.21185	0.21971	0.22769	0.23571	0.24339
2.8	0.17494	0.18152	0.18851	0.19501	0.20190	0.20907	0.21630	0.22403	0.23107	0.23806
2.9	0.17390	0.18022	0.18631	0.19272	0.19921	0.20603	0.21314	0.21969	0.22635	0.23321
3.0	0.17261	0.17835	0.18416	0.19021	0.19660	0.20306	0.20929	0.21556	0.22182	0.22816

Table 4-17 (Continued)

Y \ X	-2.0	-1.9	-1.8	-1.7	-1.6	-1.5	-1.4	-1.3	-1.2	-1.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.03533	0.03893	0.04275	0.04667	0.05043	0.05362	0.05533	0.05427	0.04815	0.03331
0.2	0.07020	0.07723	0.08469	0.09231	0.09961	0.10580	0.10949	0.10769	0.09735	0.07027
0.3	0.10328	0.11360	0.12463	0.13594	0.14686	0.15627	0.16174	0.16023	0.14708	0.11358
0.4	0.13511	0.14813	0.16196	0.17621	0.19016	0.20210	0.21024	0.21128	0.19735	0.16330
0.5	0.16365	0.17934	0.19607	0.21342	0.22995	0.24413	0.25431	0.25659	0.24704	0.21475
0.6	0.19048	0.20798	0.22637	0.24532	0.26401	0.28118	0.29355	0.29795	0.29100	0.26529
0.7	0.21317	0.23244	0.25295	0.27430	0.29395	0.31195	0.32659	0.33455	0.32916	0.31007
0.8	0.23379	0.25427	0.27506	0.29653	0.31801	0.33844	0.35289	0.36192	0.36312	0.34792
0.9	0.25048	0.27128	0.29342	0.31645	0.33759	0.35718	0.37437	0.38528	0.38702	0.37978
1.0	0.26457	0.28628	0.30799	0.32984	0.35182	0.37320	0.38902	0.40095	0.40646	0.39973
1.1	0.27606	0.29668	0.31845	0.34106	0.36259	0.38175	0.39914	0.41175	0.41683	0.41597
1.2	0.28404	0.30496	0.32704	0.34767	0.36834	0.38861	0.40480	0.41671	0.42499	0.42268
1.3	0.29070	0.31080	0.33083	0.35151	0.37239	0.39020	0.40628	0.42003	0.42551	0.42691
1.4	0.29439	0.31341	0.33332	0.35374	0.37190	0.38943	0.40602	0.41689	0.42457	0.42611
1.5	0.29629	0.31499	0.33395	0.35189	0.36983	0.38766	0.40088	0.41249	0.42073	0.42196
1.6	0.29720	0.31461	0.33176	0.34925	0.36700	0.38149	0.39521	0.40685	0.41317	0.41670
1.7	0.29623	0.31227	0.32886	0.34598	0.36070	0.37506	0.38876	0.39799	0.40512	0.40885
1.8	0.29387	0.30938	0.32548	0.33981	0.35416	0.36827	0.37944	0.38890	0.39664	0.39897
1.9	0.29113	0.30606	0.31970	0.33353	0.34739	0.35956	0.37004	0.37956	0.38561	0.38878
2.0	0.28797	0.30075	0.31379	0.32709	0.33950	0.35035	0.36064	0.36915	0.37465	0.37861
2.1	0.28314	0.29530	0.30783	0.32003	0.33083	0.34124	0.35128	0.35807	0.36380	0.36774
2.2	0.27820	0.28985	0.30161	0.31205	0.32221	0.33240	0.34051	0.34728	0.35324	0.35611
2.3	0.27324	0.28427	0.29434	0.30405	0.31400	0.32289	0.33015	0.33687	0.34215	0.34471
2.4	0.26823	0.27786	0.28704	0.29654	0.30576	0.31317	0.32023	0.32674	0.33087	0.33377
2.5	0.26261	0.27129	0.28021	0.28898	0.29680	0.30389	0.31056	0.31628	0.32010	0.32320
2.6	0.25676	0.26505	0.27324	0.28130	0.28821	0.29484	0.30143	0.30596	0.30972	0.31300
2.7	0.25103	0.25881	0.26677	0.27336	0.27991	0.28639	0.29186	0.29605	0.29990	0.30285
2.8	0.24550	0.25291	0.25943	0.26586	0.27209	0.27807	0.28261	0.28675	0.29044	0.29266
2.9	0.24002	0.24664	0.25271	0.25860	0.26441	0.26963	0.27387	0.27774	0.28137	0.28310
3.0	0.23479	0.24044	0.24595	0.25169	0.25724	0.26143	0.26542	0.26929	0.27222	0.27392

Table 4-17 (Continued)

Y \ X	-1.0	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.00196	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.01499	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.04710	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.09441	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.15295	0.04642	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.21368	0.12666	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.27010	0.20072	0.10373	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	0.31764	0.26366	0.19041	0.09819	0.0	0.0	0.0	0.0	0.0	0.0
0.9	0.35422	0.31502	0.25618	0.18550	0.10867	0.03647	0.0	0.0	0.0	0.0
1.0	0.38384	0.35081	0.30663	0.24983	0.18620	0.12343	0.06959	0.03107	0.00936	0.00125
1.1	0.40138	0.37849	0.34031	0.29383	0.24050	0.18477	0.13247	0.08756	0.05277	0.02746
1.2	0.41456	0.39380	0.36496	0.32466	0.27941	0.22979	0.17951	0.13319	0.09272	0.05882
1.3	0.41964	0.40434	0.37881	0.34713	0.30649	0.26208	0.21622	0.17051	0.12833	0.09074
1.4	0.42098	0.40883	0.38767	0.36041	0.32566	0.28629	0.24395	0.20115	0.15978	0.12119
1.5	0.41996	0.40853	0.39255	0.36802	0.33835	0.30352	0.26544	0.22590	0.18642	0.14888
1.6	0.41376	0.40612	0.39155	0.37181	0.34564	0.31568	0.28178	0.24570	0.20882	0.17307
1.7	0.40657	0.40160	0.38839	0.37262	0.34939	0.32341	0.29318	0.26111	0.22733	0.19385
1.8	0.39866	0.39366	0.38359	0.36954	0.35035	0.32733	0.30110	0.27256	0.24215	0.21120
1.9	0.38956	0.38480	0.37756	0.36486	0.34907	0.32861	0.30609	0.28048	0.25358	0.22522
2.0	0.37874	0.37554	0.36949	0.35900	0.34579	0.32776	0.30860	0.28565	0.26194	0.23612
2.1	0.36776	0.36604	0.36042	0.35192	0.34032	0.32524	0.30853	0.28849	0.26746	0.24422
2.2	0.35687	0.35606	0.35107	0.34424	0.33394	0.32140	0.30672	0.28919	0.27059	0.24985
2.3	0.34623	0.34518	0.34130	0.33616	0.32692	0.31654	0.30344	0.28817	0.27177	0.25337
2.4	0.33582	0.33434	0.33160	0.32705	0.31946	0.31076	0.29896	0.28586	0.27139	0.25512
2.5	0.32472	0.32382	0.32202	0.31783	0.31150	0.30425	0.29375	0.28254	0.26976	0.25540
2.6	0.31396	0.31364	0.31256	0.30850	0.30333	0.29701	0.28802	0.27843	0.26712	0.25449
2.7	0.30363	0.30375	0.30277	0.29933	0.29518	0.28955	0.28190	0.27367	0.26353	0.25235
2.8	0.29374	0.29420	0.29310	0.29039	0.28706	0.28191	0.27530	0.26819	0.25916	0.24933
2.9	0.28430	0.28498	0.28376	0.28161	0.27890	0.27421	0.26856	0.26248	0.25441	0.24577
3.0	0.27518	0.27595	0.27478	0.27310	0.27092	0.26662	0.26181	0.25659	0.24936	0.24173

Table 4-18

Convergence Criteria for $Re_c = 0.2$, $R_\infty = 100$

n	$M_n\ \psi$	$M_n\ \zeta_b$	$M_n\ \zeta_s$	$S_n\ \psi$	$S_n\ \zeta_b$	$S_n\ \zeta_s$	$Q_n\ \psi$	$Q_n\ \zeta_b$	$Q_n\ \zeta_s$
	$\times 10^3$	$\times 10^4$	$\times 10^3$				$\times 10^6$	$\times 10^5$	$\times 10^3$
100	0.3662109	0.6133318	0.1939535	32424.47	223.3393	11.88349	7.150173	4.935801	0.1898850
200	0.2593994	0.6181002	0.3061295	32391.41	222.8590	11.88748	3.972983	3.583687	0.2537882
300	0.1831055	0.7987022	0.2726912	32377.59	222.8292	11.95545	1.595299	3.997266	0.2987888
400	0.1678467	0.7551908	0.3543496	32378.21	223.1770	12.02909	1.291838	4.018430	0.2217368
500	0.2136230	0.6848574	0.2304316	32386.64	223.6526	12.08207	2.006573	3.606286	0.2223956
600	0.1525879	0.4804134	0.2557039	32397.70	224.0821	12.10978	2.104382	2.627323	0.2312208
700	0.1678467	0.7200241	0.2989173	32408.15	224.3869	12.11779	1.786049	1.861549	0.2352977
800	0.1373291	0.4565716	0.2302527	32415.90	224.5573	12.11320	1.231336	1.225793	0.2362006
900	0.1678467	0.5465746	0.2422333	32420.19	224.6109	12.10024	0.7276921	1.025761	0.2059342
1000	0.1525879	0.4553795	0.2218485	32421.61	224.5710	12.08541	0.4844510	0.9798929	0.2050424
1100	0.1831055	0.4017353	0.2691746	32421.28	224.4960	12.07522	0.4265002	0.8423536	0.2810527
1200	0.1373291	0.6759167	0.2540946	32419.88	224.4247	12.06913	0.5417496	0.7821969	0.2007642
1300	0.2288818	0.5650520	0.2390742	32417.80	224.3533	12.06310	0.5757742	0.6369250	0.2144844
1400	0.1220703	0.9381771	0.2876520	32416.00	224.3000	12.06217	0.4796247	0.6948230	0.2852161
1500	0.1525879	0.4756451	0.1652241	32414.73	224.2751	12.06344	0.4365410	0.3656165	0.1687109
1600	0.1678467	0.3957748	0.2100468	32414.04	224.2698	12.06556	0.3567274	0.3559429	0.1580623
1700	0.1220703	0.3451109	0.1873374	32413.76	224.2748	12.06791	0.3003355	0.3094173	0.1306260
1800	0.1220703	0.3689528	0.2254248	32413.82	224.2839	12.06886	0.3126982	0.2457092	0.1201635
1900	0.1220703	0.4374981	0.2340674	32414.03	224.2961	12.07075	0.2898445	0.3256616	0.1373836
2000	0.1373291	0.3033876	0.2139807	32414.30	224.3054	12.07086	0.3109455	0.2737409	0.1552640
2100	0.1525879	0.3212690	0.1379251	32414.56	224.3123	12.07135	0.3120705	0.2546480	0.1173576
2200	0.1678467	0.5418062	0.3687143	32414.80	224.3187	12.07148	0.3070587	0.2364612	0.1578440
2300	0.1525879	0.3743172	0.2601147	32414.87	224.3233	12.07162	0.3418558	0.2197179	0.1453026
2400	0.1525879	0.4512072	0.3088713	32414.90	224.3243	12.07140	0.3265565	0.2537884	0.1826439
2500	0.1678467	0.1829863	0.1275539	32414.91	224.3243	12.07180	0.3420255	0.1811919	0.1084351
2600	0.2441406	0.4172325	0.1881719	32414.94	224.3252	12.07182	0.3508134	0.2339178	0.1409571
2700	0.1678467	0.3790855	0.1763701	32414.96	224.3252	12.07171	0.3017497	0.2079946	0.1376554
2800	0.1220703	0.3379583	0.1655817	32414.98	224.3256	12.07195	0.2806894	0.2379599	0.1353326
2900	0.1525879	0.3951788	0.1761913	32414.98	224.3258	12.07171	0.3272932	0.2240903	0.1456900
3000	0.1220703	0.4810095	0.1909733	32414.99	224.3264	12.07202	0.3035752	0.2377925	0.1246146
3100	0.1678467	0.2974272	0.1407266	32414.98	224.3267	12.07178	0.2820640	0.2298317	0.1340814
3200	0.1373291	0.3820658	0.2023578	32415.00	224.3258	12.07147	0.3344360	0.2571139	0.1714804
3300	0.1373291	0.4303455	0.2081394	32414.99	224.3265	12.07161	0.3218735	0.2336772	0.1622145
3400	0.1220703	0.2563000	0.0621842	32415.00	224.3264	12.07185	0.3179489	0.1556114	0.1018527
3500	0.1678467	0.3182888	0.2275109	32414.99	224.3267	12.07186	0.3451950	0.2527984	0.1557258
3600	0.1373291	0.2658367	0.2171397	32415.01	224.3264	12.07168	0.3050212	0.2068497	0.1332243
3700	0.1220703	0.3492832	0.1794696	32415.04	224.3278	12.07179	0.2826210	0.2592765	0.1598873
3800	0.1373291	0.5745888	0.2851486	32415.02	224.3272	12.07166	0.2844763	0.2651960	0.1727926
3900	0.1220703	0.3701448	0.1338720	32415.04	224.3277	12.07162	0.3015327	0.1805770	0.1025956
4000	0.1525879	0.3558397	0.1871162	32415.01	224.3274	12.07203	0.2884764	0.2658353	0.1645718

Table 4-18 (Continued)

n	Q_n^{100} ψ	Q_n^{100} ζ_b	Q_n^{100} ζ_s	p_o	p_π	C_{DS}	C_{DF}	C_{DS}/C_{DF}	C_D TOTAL
	x 10^4	x 10^2	x 10^1						
100	7.732573	8.026108	0.2888260	12.42114	-10.88319	18.34061	18.29985	1.002227	36.64046
200	5.615565	3.867237	0.2382388	12.39877	-10.97000	18.34688	18.34366	1.000175	36.69054
300	2.604036	3.789320	0.2537769	12.39844	-11.40244	18.45369	18.69798	0.986935	37.15167
400	1.236813	4.133679	0.2434398	12.41647	-11.62570	18.56787	18.89192	0.982847	37.45979
500	1.660638	3.906574	0.2416733	12.44124	-11.65694	18.64868	18.92371	0.985467	37.57239
600	2.105945	3.174808	0.2257891	12.46280	-11.58049	18.69147	18.87633	0.990207	37.56779
700	1.971503	2.281506	0.2252967	12.47843	-11.50123	18.70422	18.84224	0.992675	37.54646
800	1.517206	1.473901	0.2051357	12.48667	-11.35229	18.69496	18.72481	0.998406	37.41977
900	0.954553	1.068371	0.2130742	12.48917	-11.32813	18.67744	18.69952	0.998819	37.37697
1000	0.585362	1.039642	0.2374525	12.48693	-11.26943	18.65321	18.65115	1.000110	37.30437
1100	0.439911	0.952705	0.2241366	12.48299	-11.24377	18.63721	18.63858	0.999926	37.27579
1200	0.478394	0.813143	0.2196897	12.47928	-11.26189	18.62828	18.65472	0.998582	37.28300
1300	0.560640	0.740319	0.2192370	12.47559	-11.23158	18.61845	18.61946	0.999946	37.23792
1400	0.518971	0.666703	0.2393850	12.47287	-11.26669	18.61732	18.65097	0.998196	37.26830
1500	0.453138	0.467445	0.1920039	12.47189	-11.25685	18.61839	18.63422	0.999151	37.25261
1600	0.369607	0.334040	0.1485944	12.47161	-11.29150	18.62247	18.66212	0.997875	37.28459
1700	0.346567	0.313880	0.1505162	12.47176	-11.29163	18.62576	18.66394	0.997954	37.28970
1800	0.314561	0.287733	0.1417457	12.47232	-11.31389	18.62825	18.68796	0.996805	37.31621
1900	0.306497	0.303364	0.1504800	12.47293	-11.30577	18.63020	18.67574	0.997562	37.30594
2000	0.312265	0.275238	0.1406657	12.47334	-11.31006	18.63098	18.68289	0.997221	37.31387
2100	0.304181	0.251536	0.1355204	12.47371	-11.29468	18.63121	18.66769	0.998046	37.29890
2200	0.307096	0.249181	0.1375719	12.47401	-11.32909	18.63261	18.70255	0.996261	37.33516
2300	0.320471	0.246286	0.1380551	12.47426	-11.30711	18.63203	18.67764	0.997558	37.30968
2400	0.320482	0.228877	0.1365416	12.47448	-11.30654	18.63193	18.68332	0.997249	37.31525
2500	0.327679	0.240385	0.1480852	12.47449	-11.30057	18.63191	18.67282	0.997809	37.30473
2600	0.338027	0.216020	0.1299474	12.47453	-11.29313	18.63196	18.67061	0.997930	37.30257
2700	0.300572	0.230483	0.1411159	12.47433	-11.30625	18.63205	18.67685	0.997601	37.30890
2800	0.296888	0.241187	0.1482385	12.47445	-11.29723	18.63196	18.66417	0.998274	37.29613
2900	0.319610	0.244308	0.1489319	12.47443	-11.29459	18.63181	18.66756	0.998085	37.29936
3000	0.307807	0.228157	0.1396955	12.47435	-11.30437	18.63246	18.67850	0.997535	37.31096
3100	0.309469	0.234688	0.1438734	12.47436	-11.28905	18.63184	18.66170	0.998400	37.29353
3200	0.317932	0.236364	0.1470463	12.47443	-11.32988	18.63242	18.69502	0.996651	37.32744
3300	0.311189	0.225638	0.1368260	12.47446	-11.29414	18.63173	18.66534	0.998199	37.29707
3400	0.325372	0.233173	0.1424393	12.47449	-11.30502	18.63216	18.67316	0.997804	37.30531
3500	0.319297	0.218356	0.1339688	12.47436	-11.29507	18.63202	18.66586	0.998187	37.29788
3600	0.315672	0.225532	0.1373813	12.47450	-11.28871	18.63168	18.66212	0.998369	37.29381
3700	0.289290	0.230780	0.1404415	12.47423	-11.30902	18.63237	18.67828	0.997542	37.31065
3800	0.296593	0.250369	0.1520862	12.47448	-11.31734	18.63228	18.68742	0.997049	37.31970
3900	0.310010	0.229651	0.1417075	12.47447	-11.30644	18.63219	18.67889	0.997499	37.31108
4000	0.314439	0.232862	0.1463900	12.47462	-11.29218	18.63202	18.66928	0.998004	37.30130

Table 4-19

Convergence Criteria for $Re_c = 0.2$, $R_\infty = 3$

n	$M_n\ \psi$	$M_n\ \zeta_b$	$M_n\ \zeta_s$	$S_n\ \psi$	$S_n\ \zeta_b$	$S_n\ \zeta_s$	$Q_n\ \psi$	$Q_n\ \zeta_b$	$Q_n\ \zeta_s$
	$\times 10^6$	$\times 10^4$	$\times 10^4$				$\times 10^4$	$\times 10^3$	$\times 10^3$
100	7.688999	1.696348	2.508163	1771.311	3282.504	80.56285	3.665644	6.043103	4.237801
200	12.39777	2.307892	3.385544	1770.941	3283.510	80.43411	5.622692	5.585801	6.273467
300	15.25879	2.794266	4.053116	1770.505	3284.180	80.29771	7.066622	5.300507	8.070458
400	16.74891	3.175735	4.653931	1770.045	3284.537	80.16118	8.031356	5.103365	9.384096
500	17.58337	3.356934	4.796982	1769.548	3284.607	80.03004	8.614443	4.934125	10.94751
600	18.11981	3.356934	4.796982	1769.048	3284.444	79.90666	8.877232	4.754219	10.15857
700	18.11981	3.309250	4.682541	1766.548	3284.094	79.79274	8.889337	4.544154	9.955030
800	17.28535	3.118515	4.348755	1768.052	3283.589	79.68860	8.678266	4.298594	9.293891
900	17.28535	2.861023	3.881454	1767.577	3282.964	79.59460	8.315190	4.022188	8.588515
1000	16.21246	2.574921	3.576279	1767.125	3282.263	79.51059	7.895411	3.722415	7.799447
1100	15.25879	2.279282	3.261566	1766.689	3281.483	79.43639	7.375022	3.413866	6.850116
1200	14.54353	1.993179	2.737045	1766.302	3280.684	79.37161	6.776687	3.101599	5.963568
1300	13.35144	1.707077	2.241135	1765.932	3279.865	79.31569	6.145390	2.792990	5.033828
1400	12.09974	1.468658	2.031326	1765.605	3279.049	79.26810	5.549570	2.495288	4.293259
1500	10.72884	1.220703	1.468658	1765.304	3278.238	79.22929	4.927446	2.210183	3.496339
1600	9.596348	1.039505	1.392365	1765.045	3277.465	79.19786	4.344992	1.944807	2.957584
1700	8.583069	0.877380	1.125336	1764.809	3276.728	79.17294	3.785610	1.699361	2.220203
1800	7.450581	0.743866	0.848770	1764.611	3276.035	79.15366	3.262402	1.473492	1.813659
1900	6.675720	0.619888	0.619888	1764.438	3275.395	79.13992	2.795525	1.268199	1.332181
2000	5.722046	0.524521	0.514984	1764.292	3274.800	79.13092	2.361546	1.083920	1.028249
2100	4.768372	0.438690	0.391007	1764.177	3274.260	79.12613	1.978497	0.918955	0.777392
2200	3.814697	0.371933	0.381470	1764.080	3273.783	79.12431	1.600771	0.774262	0.500194
2300	3.039837	0.314713	0.257492	1764.011	3273.358	79.12560	1.302906	0.645247	0.356382
2400	2.980232	0.267029	0.457764	1763.952	3272.982	79.12926	0.979475	0.537941	0.353353
2500	2.205372	0.219345	0.305176	1763.926	3272.671	79.13528	0.780561	0.449259	0.294953
2600	1.907349	0.190735	0.352860	1763.902	3272.401	79.14275	0.557911	0.376650	0.441258
2700	1.907349	0.162125	0.333786	1763.892	3272.180	79.15096	0.403196	0.322402	0.427356
2800	1.907349	0.143051	0.295639	1763.891	3271.991	79.15974	0.206111	0.282809	0.433784
2900	0.953674	0.190735	0.314713	1763.909	3271.843	79.16890	0.085670	0.250734	0.387055
3000	0.953674	0.162125	0.333786	1763.922	3271.729	79.17813	0.057209	0.226068	0.412003
3100	0.953674	0.238419	0.333786	1763.932	3271.632	79.18567	0.071355	0.207723	0.412716
3200	0.834465	0.181198	0.305176	1763.947	3271.551	79.19330	0.093325	0.193708	0.405075
3300	0.953674	0.171661	0.314713	1763.961	3271.507	79.20090	0.110211	0.178787	0.371105
3400	0.953674	0.152588	0.276566	1763.980	3271.478	79.20828	0.135777	0.169710	0.342841
3500	1.072884	0.162125	0.238419	1764.000	3271.460	79.21455	0.157709	0.155822	0.309255
3600	1.132488	0.114441	0.305176	1764.018	3271.458	79.22069	0.140339	0.141678	0.354224
3700	1.907349	0.123978	0.286102	1764.037	3271.467	79.22652	0.150980	0.132230	0.344342
3800	1.907349	0.143051	0.381470	1764.058	3271.474	79.23099	0.153984	0.119577	0.289707
3900	1.907349	0.104904	0.257492	1764.081	3271.499	79.23566	0.176497	0.112916	0.303380
4000	1.072884	0.114441	0.333786	1764.106	3271.521	79.23984	0.148587	0.102654	0.269666
4100	1.132488	0.095367	0.276566	1764.126	3271.557	79.24324	0.140848	0.092805	0.276273
4200	0.953674	0.114409	0.219345	1764.147	3271.586	79.24649	0.116996	0.086500	0.230156
4300	0.953674	0.104904	0.276566	1764.162	3271.621	79.24994	0.102239	0.082807	0.227814
4400	0.953674	0.667572	0.190735	1764.175	3271.666	79.25195	0.073288	0.070994	0.185390
4500	0.953674	0.667572	0.247955	1764.187	3271.706	79.25290	0.068793	0.060974	0.115294

Table 4-19 (Continued)

n	$Q_n^{100}\ \psi$	$Q_n^{100a}\ \zeta_b$	$Q_n^{100a}\ \zeta_s$	p_a	p_π	C_{DS}	C_{DF}	C_{DS}/C_{DF}	C_D TOTAL
	$\times 10^4$	$\times 10^3$	$\times 10^3$						
100	2.583549	6.444227	3.193853	39.85486	-158.7242	124.3777	156.0578	0.7969976	280.4353
200	4.698345	5.792599	5.342774	40.06970	-157.1782	124.1856	155.0768	0.8008001	279.2622
300	6.396144	5.432308	7.184137	40.23824	-155.7266	123.9795	154.0817	0.8046347	278.0610
400	7.589322	5.196106	8.652471	40.36414	-154.4993	123.7698	153.1913	0.8079424	276.9609
500	8.352662	5.016956	9.659093	40.45186	-153.5629	123.5652	152.4798	0.8103712	276.0449
600	8.764211	4.845861	10.13161	40.50615	-152.8267	123.3702	151.8947	0.8122089	275.2646
700	8.889313	4.651256	10.10136	40.53261	-152.2967	123.1886	151.4564	0.8133605	274.6448
800	8.791771	4.422847	9.688854	40.53636	-151.9308	123.0218	151.1395	0.8139619	274.1611
900	2.515895	4.160725	9.009130	40.52269	-151.7114	122.8709	150.9311	0.8140863	273.8020
1000	8.114893	3.872286	8.165877	40.49586	-151.5990	122.7357	150.8038	0.8138767	273.5393
1100	7.616449	3.567281	7.267587	40.45953	-151.5893	122.6162	150.7545	0.8133500	273.3706
1200	7.055230	3.255383	6.352384	40.41701	-151.6490	122.5121	150.7645	0.8126054	273.2764
1300	6.460268	2.944244	5.469970	40.37074	-151.7663	122.4220	150.8139	0.8117424	273.2358
1400	5.844426	2.640916	4.644755	40.32275	-151.9428	122.3456	150.9136	0.8106995	273.2590
1500	5.235441	2.350033	3.878897	40.27455	-152.1974	122.2834	151.0839	0.8093740	273.3672
1600	4.633926	2.074864	3.198716	40.22731	-152.4465	122.2330	151.2432	0.8081884	273.4761
1700	4.061419	1.819421	2.591989	40.18199	-152.7222	122.1929	151.4261	0.8069476	273.6189
1800	3.524381	1.582745	2.053485	40.13930	-152.9903	122.1621	151.6074	0.8057794	273.7693
1900	3.020708	1.367905	1.598944	40.09952	-153.2954	122.1400	151.8227	0.8044911	273.9626
2000	2.566229	1.173433	1.207811	40.06300	-153.5595	122.1255	152.0043	0.8034342	274.1296
2100	2.150231	0.998216	0.875003	40.02977	-153.8629	122.1178	152.2230	0.8022295	274.3406
2200	1.768756	0.844695	0.613017	40.00000	-154.1187	122.1146	152.4035	0.8012586	274.5181
2300	1.438465	0.708735	0.415187	39.97359	-154.3553	122.1163	152.5716	0.8003870	274.6877
2400	1.139820	0.590515	0.297954	39.95039	-154.5942	122.1220	152.7442	0.7995196	274.8660
2500	0.880219	0.490525	0.282180	39.93025	-154.8362	122.1313	152.9243	0.7986385	275.0554
2600	0.657482	0.411033	0.320917	39.91295	-155.0470	122.1431	153.0802	0.7979029	275.2231
2700	0.464176	0.347852	0.353551	39.89830	-155.2213	122.1558	153.2054	0.7973334	275.3611
2800	0.287206	0.300964	0.392682	39.88612	-155.3615	122.1694	153.3089	0.7968841	275.4783
2900	0.140709	0.264753	0.420449	39.87617	-155.5067	122.1835	153.4131	0.7964340	275.5964
3000	0.069986	0.238843	0.448121	39.86809	-155.6129	122.1979	153.4876	0.7961414	275.6853
3100	0.068452	0.218061	0.456232	39.86177	-155.6595	122.2090	153.5168	0.7960630	275.7256
3200	0.092637	0.201865	0.475389	39.85718	-155.7427	122.2208	153.5824	0.7957994	275.8030
3300	0.103976	0.186498	0.436316	39.85368	-155.8118	122.2324	153.6346	0.7956041	275.8669
3400	0.119918	0.174016	0.419280	39.85155	-155.8751	122.2439	153.6873	0.7954066	275.9312
3500	0.132400	0.160776	0.378339	39.84978	-155.8913	122.2534	153.6932	0.7954380	275.9465
3600	0.149762	0.147814	0.356970	39.84892	-155.9336	122.2630	153.7300	0.7953101	275.9929
3700	0.139312	0.138158	0.337809	39.84851	-155.9559	122.2720	153.7457	0.7952873	276.0176
3800	0.152425	0.126041	0.290798	39.84851	-155.9583	122.2787	153.7460	0.7953297	276.0247
3900	0.161051	0.117114	0.294745	39.84872	-155.9595	122.2860	153.7448	0.7953831	276.0308
4000	0.155760	0.107053	0.269724	39.84946	-156.0029	122.2926	153.7840	0.7952229	276.0764
4100	0.140247	0.097784	0.243714	39.85031	-155.9814	122.2976	153.7692	0.7953321	276.0667
4200	0.133075	0.091302	0.249651	39.85126	-155.9710	122.3025	153.7591	0.7954160	276.0615
4300	0.113824	0.083672	0.227649	39.85213	-156.0180	122.3079	153.8000	0.7952398	276.1077
4400	0.094787	0.076321	0.183333	39.85310	-155.9713	122.3105	153.7562	0.7954832	276.0667
4500	0.075530	0.065425	0.120520	39.85422	-155.9299	122.3115	153.7231	0.7956607	276.0344

Table 4-20

Convergence Criteria for $Re_c = 0.5$, $R_\infty = 100$

n	$M_n\ \psi$	$M_n\ \zeta_b$	$M_n\ \zeta_s$	$S_n\ \psi$	$S_n\ \zeta_b$	$S_n\ \zeta_s$	$Q_n\ \psi$	$Q_n\ \zeta_b$	$Q_n\ \zeta_s$
	$\times 10^3$	$\times 10^4$	$\times 10^3$				$\times 10^6$	$\times 10^5$	$\times 10^3$
100	9.521484	308.9738	69.45044	32152.98	269.6206	12.48976	192.2936	598.1970	78.60362
200	5.813599	72.93880	11.64007	32897.04	217.3437	11.56137	135.9953	378.1964	20.20574
300	3.005981	15.23376	1.390696	33521.07	248.5018	16.95943	73.88487	158.3455	1.337505
400	1.464844	5.143881	0.960767	33836.05	263.7090	16.82074	34.05107	61.77011	0.956267
500	0.747681	5.266070	0.942051	33974.82	267.5125	15.95480	14.89648	41.41983	1.089754
600	0.366211	3.955364	0.911474	34024.83	266.6531	15.23694	6.696414	32.34337	0.917320
700	0.196457	3.103614	0.573337	34023.62	264.2664	14.74446	4.349235	26.18395	0.495385
800	0.320435	2.298355	0.394404	33988.12	261.5579	14.41931	7.746299	21.33438	0.358446
900	0.389099	1.533628	0.418961	33935.96	259.0725	14.22863	8.805154	16.11329	0.299834
1000	0.342369	0.569820	0.345707	33885.04	257.1851	14.16297	7.489736	10.49571	0.199975
1100	0.274658	0.652075	0.409603	33846.32	256.0806	14.19449	4.979044	6.285653	0.218003
1200	0.167847	1.133084	0.356316	33823.99	255.7011	14.27831	2.504750	5.082808	0.290933
1300	0.167847	1.282692	0.422418	33816.34	255.8445	14.37438	1.081979	4.848797	0.337939
1400	0.106812	0.735521	0.413001	33819.36	256.2695	14.45832	1.197126	4.547894	0.187760
1500	0.122070	0.736713	0.300169	33827.48	256.7605	14.51092	1.808348	3.623804	0.259597
1600	0.183106	0.713468	0.413179	33837.37	257.1919	14.53942	1.768719	2.749849	0.197124
1700	0.183106	0.494719	0.365496	33846.16	257.4912	14.54451	1.426763	1.841213	0.214781
1800	0.183106	0.478625	0.422001	33852.08	257.6426	14.53440	0.995388	1.156043	0.212080
1900	0.122070	0.505447	0.275791	33855.00	257.6755	14.51743	0.581042	1.062523	0.198199
2000	0.228882	0.723004	0.222564	33855.89	257.6230	14.49941	0.417295	1.044971	0.182862
2100	0.122070	0.582337	0.360787	33855.43	257.5464	14.48388	0.428892	0.928156	0.267273
2200	0.213623	0.404716	0.309050	33853.83	257.4719	14.48084	0.516841	0.786435	0.180125
2300	0.122070	0.604987	0.259578	33851.95	257.3989	14.47639	0.459557	0.774381	0.201942
2400	0.137329	0.600219	0.341415	33850.60	257.3545	14.47627	0.416522	0.543386	0.221883
2500	0.167847	0.324249	0.259042	33849.67	257.3345	14.47839	0.395265	0.357152	0.113529
2600	0.152588	0.309348	0.209153	33849.21	257.3303	14.48089	0.313978	0.305742	0.176529
2700	0.183106	0.318885	0.192285	33849.12	257.3359	14.48322	0.337376	0.230977	0.153277
2800	0.137329	0.585318	0.340045	33849.25	257.3494	14.48550	0.311518	0.254344	0.143917
2900	0.152588	0.320077	0.249744	33849.43	257.3604	14.48582	0.319694	0.254052	0.145055
3000	0.137329	0.510812	0.220895	33849.63	257.3696	14.48641	0.313066	0.229429	0.154955
3100	0.137329	0.313520	0.188053	33849.81	257.3748	14.48655	0.271504	0.199335	0.132320
3200	0.198364	0.417233	0.190496	33849.93	257.3779	14.48654	0.299809	0.158379	0.093568
3300	0.167847	0.287890	0.198245	33850.00	257.3818	14.48684	0.264300	0.185080	0.105418
3400	0.152588	0.439882	0.142992	33850.05	257.3826	14.48667	0.271885	0.214491	0.125815
3500	0.137329	0.409484	0.155151	33850.06	257.3848	14.48735	0.315248	0.199007	0.108058
3600	0.183106	0.367761	0.225425	33850.07	257.3845	14.48654	0.300786	0.202527	0.170830
3700	0.167847	0.281334	0.121892	33850.07	257.3845	14.48670	0.280235	0.147138	0.102530
3800	0.152588	0.486970	0.206471	33850.09	257.3843	14.48687	0.307100	0.185090	0.124333
3900	0.167847	0.277758	0.137448	33850.08	257.3848	14.48711	0.262374	0.174157	0.108831
4000	0.183106	0.392199	0.303388	33850.09	257.3848	14.48661	0.286841	0.191796	0.132210

Table 4-20 (Continued)

n	$Q_n^{100}\ \psi$	$Q_n^{100}\ \zeta_b$	$Q_n^{100}\ \zeta_s$	p_0	p_π	C_{DS}	C_{DF}	C_{DS}/C_{DF}	C_{D} TOTAL
	x 10^4	x 10^3	x 10^1						
100	777.9241	2594.948	604.9518	6.399675	36.34631	7.469881	-23.85773	-0.313101	-16.38783
200	155.8785	562.1548	45.24591	5.401373	-17.31380	7.211985	17.85170	0.403994	25.06367
300	103.8590	263.4616	7.496189	6.116107	-14.23011	10.47842	15.97412	0.655963	26.45255
400	51.71347	98.06842	6.254554	6.454000	-8.026783	10.38021	11.36821	0.913091	21.74841
500	23.07153	49.45197	1.060185	6.538251	-5.374091	9.845118	9.352885	1.052629	19.19800
600	10.25873	36.62514	0.922711	6.521586	-4.425424	9.402945	8.589066	1.094757	17.99200
700	5.033973	29.15219	0.658928	6.473050	-4.177400	9.101320	8.360942	1.088552	17.46225
800	6.010483	23.67815	0.467425	6.418550	-4.151567	8.901600	8.301298	1.072313	17.20290
900	8.527758	18.77093	0.323148	6.369474	-4.292788	8.784275	8.373407	1.049067	17.15767
1000	8.320517	13.30759	0.233420	6.332848	-4.573229	8.744663	8.562129	1.021318	17.30678
1100	6.293631	8.077320	0.218993	6.011744	-4.869937	8.764620	8.782026	0.998018	17.54665
1200	3.713081	5.580425	0.243026	6.305036	-5.121823	8.816704	8.969275	0.982990	17.78596
1300	1.688944	5.011052	0.248738	6.308683	-5.282665	8.876005	9.096009	0.975813	17.97200
1400	1.029053	4.753985	0.229748	6.317655	-5.339795	8.927345	9.149370	0.975733	18.07671
1500	1.566322	4.138451	0.213067	6.327747	-5.329376	8.959652	9.151669	0.979018	18.11131
1600	1.827121	3.254870	0.206023	6.336169	-5.285035	8.976837	9.121782	0.984110	18.09862
1700	1.625662	2.260068	0.198879	6.341838	-5.232705	8.979706	9.081871	0.988751	18.06157
1800	1.180066	1.429558	0.186788	6.344737	-5.174661	8.973278	9.039791	0.992642	18.01306
1900	0.741426	1.074603	0.184246	6.345247	-5.143297	8.963215	9.017463	0.993984	17.98067
2000	0.497338	1.064901	0.218978	6.344159	-5.108975	8.951845	8.987653	0.996016	17.93948
2100	0.408959	0.936774	0.205980	6.342561	-5.122100	8.945486	8.998137	0.994149	17.94362
2200	0.482327	0.797232	0.201985	6.341143	-5.141502	8.941284	9.015608	0.991756	17.95688
2300	0.505006	0.727014	0.206333	6.339540	-5.140205	8.938021	9.009363	0.992081	17.94737
2400	0.454986	0.569552	0.210985	6.338715	-5.141205	8.937981	9.012220	0.991762	17.95020
2500	0.409966	0.396451	0.170176	6.338330	-5.141486	8.939159	9.011545	0.991967	17.95070
2600	0.358159	0.293308	0.137626	6.338263	-5.145746	8.940617	9.014179	0.991839	17.95479
2700	0.332902	0.273993	0.134507	6.338476	-5.169041	8.942518	9.032464	0.990042	17.97498
2800	0.300416	0.276702	0.136252	6.338636	-5.152096	8.943373	9.017553	0.991774	17.96092
2900	0.289496	0.254124	0.129680	6.338923	-5.160241	8.944004	9.027002	0.990806	17.97099
3000	0.308181	0.226922	0.124626	6.339016	-5.151320	8.944212	9.023125	0.991254	17.96733
3100	0.293890	0.203207	0.123117	6.339200	-5.151319	8.944172	9.019409	0.991658	17.96358
3200	0.295796	0.199876	0.127157	6.339210	-5.157525	8.944424	9.025557	0.991011	17.96997
3300	0.286259	0.195110	0.123262	6.339327	-5.148466	8.944311	9.016989	0.991940	17.96129
3400	0.284780	0.194784	0.128825	6.339316	-5.154813	8.944427	9.023410	0.991247	17.96783
3500	0.313081	0.188242	0.123294	6.339327	-5.149818	8.944548	9.018152	0.991838	17.96269
3600	0.316996	0.196212	0.132730	6.339297	-5.155107	8.944427	9.022446	0.991353	17.96687
3700	0.287831	0.186650	0.129220	6.339365	-5.146738	8.944244	9.016602	0.991975	17.96085
3800	0.295443	0.185980	0.128660	6.339423	-5.151116	8.944328	9.018015	0.991829	17.96234
3900	0.297497	0.185464	0.125916	6.339297	-5.153989	8.944567	9.022766	0.991333	17.96733
4000	0.279591	0.183802	0.129112	6.339336	-5.155262	8.944403	9.022274	0.991369	17.96667

Table 4-21

Convergence Criteria for $Re_c = 40$, $R_\infty = 100$

n	$M_n\ \psi$	$M_n\ \zeta_b$	$M_n\ \zeta_s$	$S_n\ \psi$	$S_n\ \zeta_b$	$S_n\ \zeta_s$	$Q_n\ \psi$	$Q_n\ \zeta_b$	$Q_n\ \zeta_s$
	$\times 10^3$	$\times 10^2$	$\times 10^2$				$\times 10^6$	$\times 10^3$	$\times 10^2$
100	0.1983643	0.6668091	1.230431				1.291594	2.102468	0.295458
200	0.1831055	0.6532669	1.170254				1.273185	2.059035	0.280922
300	0.1525879	0.6475449	1.201344				1.298084	2.016782	0.267310
400	0.2441406	0.6332397	1.192570				1.375002	1.974082	0.249072
500	0.1678467	0.6280899	1.128387				1.414542	1.937151	0.230943
600	0.1678467	0.6093025	1.089191				1.519139	1.900999	0.222784
700	0.2136230	0.5880356	1.047039				1.580679	1.868643	0.221859
800	0.2136230	0.5641937	0.977135				1.736079	1.845623	0.215696
900	0.1831055	0.5435944	0.952911				1.690156	1.838715	0.215468
1000	0.1983643	0.5089760	0.908279				1.798760	1.828332	0.214261
1100	0.2746582	0.4788399	0.877857				1.859271	1.819822	0.214214
1200	0.2288818	0.4512787	0.806522				1.807392	1.809245	0.207264
1300	0.2441406	0.4092216	0.722885				1.815648	1.788809	0.196578
1400	0.1831055	0.3764153	0.682396				1.888188	1.763372	0.191568
1500	0.2441406	0.3447533	0.714564				1.850942	1.732493	0.185764
1600	0.2593994	0.3204346	0.689363				1.850673	1.693715	0.170193
1700	0.2136230	0.3405273	0.717467				1.826818	1.646181	0.170102
1800	0.2288818	0.3511012	0.735372				1.776798	1.592637	0.166536
1900	0.1831055	0.3569067	0.724924				1.758803	1.532072	0.156058
2000	0.1678467	0.3628850	0.721192				1.680284	1.467823	0.152744
2100	0.2593994	0.3615916	0.697426	37416.02	503.9138	68.02225	1.682060	1.397989	0.136730
2200	0.1831055	0.3630996	0.665063	37407.52	503.4678	68.15862	1.525117	1.327950	0.134371
2300	0.1983643	0.3550708	0.659019	37399.82	503.0869	68.30487	1.442062	1.257850	0.132097
2400	0.1983643	0.3481805	0.637931	37392.81	502.7581	68.46954	1.363077	1.191895	0.142101
2500	0.2441406	0.3369629	0.584668	37386.56	502.5051	68.65569	1.276649	1.132730	0.138086
2600	0.1831055	0.3193557	0.552690	37381.16	502.3169	68.83795	1.153235	1.080699	0.133840
2700	0.3204346	0.3057718	0.540924	37376.59	502.1904	69.03424	1.060163	1.046091	0.143475
2800	0.1525879	0.2868772	0.490093	37372.97	502.1233	69.24002	0.966125	1.021395	0.139120
2900	0.1983643	0.2861023	0.535011	37370.29	502.1255	69.44005	0.907823	0.998151	0.149511
3000	0.1831055	0.2952576	0.603390	37368.54	502.1819	69.64682	0.868960	0.983150	0.159216
3100	0.1983643	0.2941132	0.573158	37367.81	502.2966	69.85341	0.843627	0.967126	0.142822
3200	0.2288818	0.3055573	0.584316	37367.91	502.4685	70.06000	0.848838	0.955567	0.149561
3300	0.2136230	0.2968788	0.538063	37368.79	502.6877	70.24905	0.855010	0.933772	0.127209
3400	0.1678467	0.3043175	0.534439	37370.46	502.9517	70.43877	0.813602	0.920256	0.124725
3500	0.2441406	0.2981186	0.555897	37373.07	503.2502	70.61066	0.814779	0.902206	0.119377
3600	0.1678467	0.2924919	0.569439	37376.25	503.5850	70.77069	0.868425	0.887805	0.105677
3700	0.1831055	0.2859116	0.552463	37379.97	503.9451	70.91615	0.959947	0.875755	0.104559
3800	0.1831055	0.2788544	0.511455	37384.14	504.3279	71.05078	1.005581	0.867068	0.100364
3900	0.1831055	0.2731323	0.493813	37388.98	504.7217	71.17053	1.065001	0.863128	0.100258
4000	0.1678467	0.2575874	0.515842	37393.91	505.1252	71.27045	1.084593	0.863945	0.101495

Table 4-21 (Continued)

n	$Q_n^{100}\ \psi$	$Q_n^{100}\ \zeta_b$	$Q_n^{100}\ \zeta_s$	p_0	p_π	C_{DS}	C_{DF}	C_{DS}/C_{DF}	C_D TOTAL
	$\times 10^4$	$\times 10^1$							
100	1.314693	2.124828	0.2982533	1.142896	-0.3307629	0.5247070	0.853658	0.6146572	1.378365
200	1.290960	2.080667	0.2847220	1.142811	-0.3233471	0.5215412	0.846943	0.6157926	1.368484
300	1.305476	2.037089	0.2692951	1.142702	-0.3174810	0.5185379	0.841432	0.6162565	1.359969
400	1.342586	1.996216	0.2527016	1.142573	-0.3141441	0.5157066	0.837885	0.6154861	1.353591
500	1.403603	1.955230	0.2372945	1.142424	-0.3115425	0.5130401	0.834948	0.6144574	1.347988
600	1.474733	1.917639	0.2242634	1.142255	-0.3117952	0.5106079	0.834286	0.6120300	1.344893
700	1.546225	1.883624	0.2210818	1.142069	-0.3138885	0.5084000	0.835112	0.6087808	1.343512
800	1.617093	1.855219	0.2188038	1.141873	-0.3178988	0.5064278	0.837432	0.6047392	1.343859
900	1.690562	1.842204	0.2216495	1.141663	-0.3215256	0.5046062	0.839540	0.6010505	1.344147
1000	1.739688	1.831412	0.2124700	1.141444	-0.3292017	0.5031425	0.844843	0.5955452	1.347985
1100	1.786033	1.824294	0.2100453	1.141221	-0.3369503	0.5018768	0.850240	0.5902766	1.352117
1200	1.828202	1.815712	0.2081533	1.140992	-0.3445349	0.5007747	0.855563	0.5853161	1.356338
1300	1.851610	1.798664	0.1987789	1.140762	-0.3556004	0.5000126	0.863672	0.5789383	1.363684
1400	1.867506	1.777012	0.1936976	1.140533	-0.3658161	0.4994217	0.871187	0.5732656	1.370608
1500	1.878604	1.748096	0.1868154	1.140306	-0.3758278	0.4990127	0.878553	0.5679936	1.377565
1600	1.871609	1.713039	0.1800582	1.140082	-0.3864622	0.4988132	0.886515	0.5626674	1.385328
1700	1.854698	1.670104	0.1709459	1.139865	-0.3995905	0.4988720	0.896459	0.5564917	1.395330
1800	1.820566	1.619601	0.1640437	1.139657	-0.4113731	0.4990906	0.905404	0.5512353	1.404494
1900	1.780522	1.561838	0.1557587	1.139458	-0.4234428	0.4994922	0.914654	0.5460994	1.414146
2000	1.734900	1.500093	0.1489416	1.139272	-0.4365158	0.5000812	0.924733	0.5407842	1.424814
2100	1.669077	1.433321	0.1423976	1.139099	-0.4487238	0.5008118	0.934195	0.5360893	1.435006
2200	1.588970	1.362929	0.1396648	1.138941	-0.4620934	0.5017353	0.944640	0.5311388	1.446375
2300	1.504886	1.292013	0.1336139	1.138798	-0.4739456	0.5027458	0.953946	0.5270172	1.456691
2400	1.405464	1.223427	0.1338050	1.138672	-0.4866219	0.5039123	0.963922	0.5227726	1.467834
2500	1.316716	1.161875	0.1394890	1.138570	-0.4996014	0.5052547	0.974183	0.5186447	1.479437
2600	1.217745	1.105760	0.1348662	1.138484	-0.5094404	0.5065799	0.982006	0.5158623	1.488585
2700	1.108542	1.061581	0.1433614	1.138416	-0.5208387	0.5080276	0.991100	0.5125898	1.499126
2800	1.033478	1.033845	0.1494408	1.138371	-0.5312948	0.5095615	0.999505	0.5098140	1.509066
2900	0.961960	1.007423	0.1449962	1.138343	-0.5399694	0.5110664	1.006564	0.5077336	1.517631
3000	0.897825	0.988713	0.1493978	1.138332	-0.5490694	0.5126358	1.013971	0.5055722	1.526607
3100	0.859266	0.975847	0.1485261	1.138344	-0.5563145	0.5142117	1.019884	0.5041863	1.534096
3200	0.836836	0.960633	0.1483834	1.138371	-0.5640001	0.5158043	1.026215	0.5026281	1.542019
3300	0.816519	0.944523	0.1350858	1.138417	-0.5675640	0.5172687	1.029318	0.5025354	1.546586
3400	0.814615	0.926681	0.1354721	1.138474	-0.5728397	0.5187511	1.033759	0.5018104	1.552510
3500	0.830727	0.910580	0.1224833	1.138546	-0.5750561	0.5201069	1.035835	0.5021135	1.555942
3600	0.873907	0.894979	0.1136836	1.138629	-0.5764227	0.5213783	1.037218	0.5026698	1.558596
3700	0.923325	0.881451	0.1043551	1.138721	-0.5769472	0.5225483	1.037971	0.5034322	1.560519
3800	0.978368	0.871982	0.1027506	1.138822	-0.5768309	0.5236400	1.038189	0.5043783	1.561829
3900	1.029360	0.863619	0.1005135	1.138928	-0.5762291	0.5246254	1.038030	0.5054049	1.562654
4000	1.079816	0.863020	0.0980801	1.139042	-0.5734720	0.5254627	1.036172	0.5071192	1.561634

Table 4-22

Convergence Criteria for $Re_c = 40$, $R_\infty = 3$

n	$M_n\ \psi$	$M_n\ \zeta_b$	$M_n\ \zeta_s$	$S_n\ \psi$	$S_n\ \zeta_b$	$S_n\ \zeta_s$	$Q_n\ \psi$	$Q_n\ \zeta_b$	$Q_n\ \zeta_s$
	$\times 10^4$	$\times 10^2$	$\times 10^1$				$\times 10^5$	$\times 10^3$	$\times 10^3$
100	0.1400709	0.9293556	1.392788	2040.857	3426.031	154.8513	0.3467933	0.7865638	1.165503
200	0.1394749	0.9123392	1.365238	2040.145	3426.019	154.4943	0.3493675	0.7778001	1.132417
300	0.1400709	0.8975208	1.341963	2039.431	3426.029	154.1448	0.3515810	0.7692611	1.118940
400	0.1400709	0.8826971	1.321894	2038.713	3426.031	153.7998	0.3529487	0.7610434	1.102858
500	0.1406670	0.8669615	1.300365	2037.987	3426.052	153.4611	0.3549284	0.7530260	1.083823
600	0.1406670	0.8669615	1.280403	2037.257	3426.070	153.1312	0.3595524	0.7449502	1.078818
700	0.1418591	0.8384902	1.258981	2036.529	3426.085	152.8044	0.3616924	0.7373017	1.044338
800	0.1424551	0.8255858	1.235676	2035.797	3426.110	152.4860	0.3626496	0.7296449	1.029811
900	0.1424551	0.8124582	1.216811	2035.059	3426.144	152.1719	0.3625278	0.7223630	1.024658
1000	0.1430511	0.7998999	1.197195	2034.316	3426.178	151.8632	0.3664021	0.7151753	1.013332
1100	0.1430511	0.7885221	1.179689	2033.561	3426.216	151.5589	0.3666522	0.7081628	0.981842
1200	0.1436472	0.7760465	1.159352	2032.815	3426.267	151.2624	0.3686047	0.7011962	0.973452
1300	0.1448393	0.7640958	1.138419	2032.063	3426.321	150.9705	0.3726473	0.6944281	0.942498
1400	0.1448393	0.7509828	1.120031	2031.302	3426.383	150.6871	0.3750059	0.6875819	0.936943
1500	0.1448393	0.7395923	1.100761	2030.536	3426.448	150.4056	0.3745891	0.6812334	0.914581
1600	0.1454353	0.7262230	1.071843	2029.783	3426.521	150.1301	0.3776234	0.6748337	0.890650
1700	0.1454354	0.7143248	1.058370	2029.011	3426.599	149.8630	0.3746976	0.6683898	0.897934
1800	0.1460314	0.7034846	1.041663	2028.240	3426.688	149.5962	0.3769961	0.6623900	0.881124
1900	0.1460314	0.6921146	1.018399	2027.465	3426.780	149.3348	0.3826011	0.6564409	0.854759
2000	0.1484156	0.6808143	0.9990752	2026.694	3426.872	149.0795	0.3836500	0.6506258	0.846232
2100	0.1478195	0.6697774	0.9827614	2025.922	3426.979	148.8289	0.3838099	0.6448960	0.835069
2200	0.1484156	0.6586611	0.9587288	2025.138	3427.090	148.5855	0.3855191	0.6389081	0.793672
2300	0.1484156	0.6472766	0.9402931	2024.356	3427.205	148.3485	0.3847217	0.6330991	0.791462
2400	0.1484156	0.6363988	0.9288490	2023.568	3427.333	148.1121	0.3868251	0.6277746	0.796393
2500	0.1496077	0.6263573	0.9104490	2022.790	3427.469	147.8802	0.3892183	0.6224406	0.771538
2600	0.1496077	0.6163176	0.8923113	2022.005	3427.607	147.6547	0.3879888	0.6171118	0.753766
2700	0.1496077	0.6061472	0.8769631	2021.220	3427.751	147.4351	0.3903583	0.6117045	0.728441
2800	0.1496077	0.5960863	0.8579016	2020.429	3427.906	147.2200	0.3890465	0.6064554	0.720968
2900	0.1507998	0.5857356	0.8382022	2019.644	3428.062	147.0084	0.3881885	0.6013145	0.704585
3000	0.1502037	0.5752977	0.8244157	2018.850	3428.228	146.7994	0.3884565	0.5964944	0.703523
3100	0.1513958	0.5658090	0.8070946	2018.065	3428.400	146.5969	0.3924572	0.5914154	0.669455
3200	0.1513958	0.5566299	0.7899165	2017.279	3428.583	146.4000	0.3907015	0.5864485	0.664696
3300	0.1513958	0.5473375	0.7716715	2016.486	3428.762	146.2082	0.3911441	0.5814182	0.646135
3400	0.1513958	0.5380452	0.7716715	2016.486	3428.762	146.0177	0.3933860	0.5768305	0.638486
3500	0.1537800	0.5288124	0.7384479	2014.912	3429.154	145.8339	0.3907124	0.5719939	0.616114
3600	0.1531839	0.5195856	0.7202625	2014.121	3429.365	145.6534	0.3905066	0.5673298	0.610083
3700	0.1519918	0.5109549	0.7053137	2013.325	3429.576	145.4767	0.3907352	0.5627447	0.600209
3800	0.1537800	0.5026698	0.6855965	2012.548	3429.786	145.3031	0.3906973	0.5582620	0.585128
3900	0.1519918	0.4943788	0.6685972	2011.760	3430.009	145.1341	0.3870730	0.5537209	0.572760
4000	0.1537800	0.4860520	0.6492674	2010.975	3430.240	144.9709	0.3889631	0.5491019	0.553076
4100	0.1519918	0.4776955	0.6299496	2010.192	3430.471	144.8118	0.3883103	0.5445829	0.544365
4200	0.1561642	0.4692614	0.6130517	2009.419	3430.706	144.6548	0.3864181	0.5402178	0.522291
4300	0.1537800	0.4616737	0.5951881	2008.634	3430.953	144.5063	0.3855380	0.5354874	0.521162
4400	0.1513958	0.4541039	0.5829394	2007.868	3431.203	144.3585	0.3827075	0.5311212	0.488553
4500	0.1537800	0.4464865	0.5692184	2007.094	3431.455	144.2177	0.3843792	0.5265840	0.468675
4600	0.1525879	0.4388988	0.5516112	2006.316	3431.720	144.0838	0.3822995	0.5217327	0.460922
4700	0.1537800	0.4313171	0.5395174	2005.554	3431.997	143.9499	0.3833231	0.5174421	0.459459
4800	0.1507998	0.4240811	0.5245328	2004.795	3432.265	143.8179	0.3796685	0.5132814	0.457138
4900	0.1496077	0.4173398	0.5093336	2004.030	3432.538	143.6884	0.3790741	0.5090935	0.441493
5000	0.1507998	0.4105270	0.4954338	2003.276	3432.814	143.5669	0.3749216	0.5044720	0.417942

Table 4-22 (Continued)

n	$Q_n^{100}\ \psi$	$Q_n^{100}\ \zeta_b$	$Q_n^{100}\ \zeta_s$	p_0	p_π	C_{DS}	C_{DF}	C_{DS}/C_{DF}	C_D TOTAL
	$\times 10^3$	$\times 10^1$	$\times 10^1$						
100	0.3459174	0.7909715	1.171311	1.203033	-1.470630	1.187882	1.839385	0.6458041	3.027267
200	0.3474574	0.7821536	1.150740	1.203024	-1.472588	1.185440	1.841661	0.6436797	3.027102
300	0.3503470	0.7734537	1.129601	1.203015	-1.474226	1.183050	1.843480	0.6417482	3.026530
400	0.3525801	0.7651204	1.117106	1.203006	-1.474968	1.180696	1.844854	0.6399944	3.025551
500	0.3546397	0.7569861	1.099405	1.202996	-1.476142	1.178387	1.846170	0.6382870	3.024557
600	0.3567713	0.7488716	1.072800	1.202987	-1.479044	1.176142	1.848893	0.6361328	3.025035
700	0.3592726	0.7411158	1.065190	1.202979	-1.480267	1.173922	1.850559	0.6343604	3.024481
800	0.3611837	0.7333755	1.039666	1.202971	-1.483285	1.171763	1.853428	0.6322142	3.025191
900	0.3638344	0.7259107	1.028283	1.202963	-1.484738	1.169633	1.855029	0.6305199	3.024662
1000	0.3652479	0.7187068	1.012322	1.202954	-1.486856	1.167543	1.857241	0.6286441	3.024784
1100	0.3672899	0.7116920	0.999432	1.202947	-1.488900	1.165491	1.859522	0.6267692	3.025013
1200	0.3696666	0.7045990	0.975957	1.202938	-1.492130	1.163490	1.862404	0.6247250	3.025894
1300	0.3715025	0.6978190	0.962797	1.202929	-1.495221	1.161521	1.865046	0.6227842	3.026567
1400	0.3727691	0.6909060	0.936202	1.202922	-1.499798	1.159620	1.869287	0.6203541	3.028908
1500	0.3749619	0.6844074	0.931938	1.202914	-1.502001	1.157726	1.871197	0.6187090	3.028923
1600	0.3760953	0.6780112	0.913237	1.202905	-1.505687	1.155876	1.874476	0.6166394	3.030353
1700	0.3779838	0.6714076	0.887514	1.202896	-1.510370	1.154095	1.878699	0.6143051	3.032794
1800	0.3792436	0.6653720	0.887965	1.202888	-1.512737	1.152308	1.880807	0.6126665	3.033114
1900	0.3801719	0.6594253	0.871216	1.202880	-1.516445	1.150562	1.884013	0.6106976	3.034575
2000	0.3821435	0.6534636	0.852447	1.202870	-1.520418	1.148858	1.887334	0.6087201	3.036192
2100	0.3833349	0.6477034	0.838156	1.202862	-1.524734	1.147188	1.890985	0.6066618	3.038173
2200	0.3847270	0.6419486	0.814781	1.202855	-1.531334	1.145571	1.896338	0.6040964	3.041908
2300	0.3852774	0.6359029	0.795271	1.202847	-1.536999	1.144000	1.900887	0.6018245	3.044887
2400	0.3873182	0.6303358	0.794700	1.202839	-1.539875	1.142426	1.902994	0.6003310	3.045421
2500	0.3875643	0.6251007	0.780285	1.202830	-1.544664	1.140887	1.907125	0.5982237	3.048012
2600	0.3884404	0.6197350	0.759862	1.202822	-1.550507	1.139396	1.911698	0.5960122	3.051094
2700	0.3887198	0.6143835	0.740936	1.202814	-1.557132	1.137940	1.916630	0.5937194	3.054570
2800	0.3905422	0.6090367	0.726883	1.202806	-1.563076	1.136518	1.921207	0.5915647	3.057726
2900	0.3899820	0.6038438	0.716597	1.202799	-1.568626	1.135119	1.925514	0.5895149	3.060634
3000	0.3906379	0.5988347	0.708319	1.202792	-1.573074	1.133738	1.928747	0.5878103	3.062485
3100	0.3912360	0.5939701	0.687023	1.202785	-1.580461	1.132405	1.934664	0.5853240	3.067069
3200	0.3913143	0.5888813	0.669330	1.202778	-1.587403	1.131107	1.939739	0.5831234	3.070847
3300	0.3912130	0.5839220	0.653036	1.202771	-1.595273	1.129843	1.945395	0.5807779	3.075238
3400	0.3916807	0.5790719	0.649034	1.202765	-1.600250	1.128590	1.949194	0.5790032	3.077784
3500	0.3911767	0.5743853	0.626237	1.202757	-1.608343	1.127385	1.955301	0.5765787	3.082686
3600	0.3918051	0.5696237	0.616994	1.202750	-1.614834	1.126195	1.959771	0.5746563	3.085966
3700	0.3908647	0.5650340	0.603678	1.202744	-1.622046	1.125038	1.965497	0.5723937	3.090535
3800	0.3905019	0.5604819	0.594000	1.202737	-1.628523	1.123899	1.969889	0.5705391	3.093787
3900	0.3902896	0.5559565	0.578748	1.202730	-1.635825	1.122789	1.975150	0.5684577	3.097939
4000	0.3896339	0.5514128	0.560217	1.202724	-1.644518	1.121723	1.981738	0.5660300	3.103461
4100	0.3890502	0.5468003	0.547165	1.202720	-1.652637	1.120681	1.987164	0.5639597	3.107845
4200	0.3876998	0.5423978	0.539008	1.202713	-1.659718	1.119649	1.992172	0.5620241	3.111821
4300	0.3866141	0.5377869	0.513983	1.202709	-1.670073	1.118675	1.999290	0.5595361	3.117966
4400	0.3849147	0.5333875	0.508523	1.202703	-1.678151	1.117708	2.005282	0.5573819	3.122991
4500	0.3856095	0.5288066	0.489750	1.202701	-1.687804	1.116781	2.011660	0.5551541	3.128441
4600	0.3836032	0.5241019	0.463138	1.202696	-1.699182	1.115908	2.019847	0.5524714	3.135755
4700	0.3816742	0.5195352	0.461945	1.202688	-1.706842	1.115040	2.025583	0.5504783	3.140623
4800	0.3804944	0.5153077	0.456155	1.202682	-1.714274	1.114181	2.030828	0.5486335	3.145009
4900	0.3788571	0.5111936	0.448261	1.202676	-1.722136	1.113326	2.035708	0.5468985	3.149035
5000	0.3779216	0.5067693	0.419957	1.202672	-1.733464	1.112537	2.043962	0.5443042	3.156500

NOMENCLATURE

Roman Letters

a	fraction of angular increment
A_1 to A_6	coefficients for Equation (3-34)
c	solids concentration defined by Equation (3-13)
c_m	minimum solids concentration defined by Equation (4-1)
C_D	total drag coefficient
C_{DF}	form drag coefficient defined by Equation (3-65)
C_{DS}	skin drag coefficient defined by Equation (3-64)
C_1 to C_{10}	coefficients for Equation (2-5)
$D_n\psi, D_n\zeta_b, D_n\zeta_s$	sum of changes in stream function and vorticity values for the nth iteration as defined by Equations (3-53) to (3-55)
E	impaction efficiency

E_I	impaction efficiency due to particle inertia
E_K	impaction efficiency due to interception
F_D	drag force on particle
F_N	Fibonacci number defined by Equation (3-82)
G	coefficient in Equation (3-40)
H_1 to H_4	coefficients for Equation (3-35)
i_r, i_θ, i_ξ	unit vectors in r, θ and ξ directions
I	angular subscript of a grid point
J	radial subscript of a grid point
K	size parameter defined by Equation (1-1)
K_0, K_1	modified Bessel functions
l	fraction of radial increment
L	interval of uncertainty
m_p	virtual mass of spherical particle defined by $(\rho_p - \rho)4/3\pi R_p^3$

$M_n\ \psi$, $M_n\ \zeta_b$, $M_n\ \zeta_s$	maximum changes in stream function and vorticity values for the nth iteration as defined by Equations(3-45) to (3-47)
$M_n^{\alpha}\ \psi$, $M_n^{\alpha}\ \zeta$	maximum changes in relaxed values of stream function and vorticity
N_a	number of angular grid divisions
N_r	number of radial grid divisions
p	dimensionless pressure defined by Equation (3-3)
p_0	frontal stagnation pressure defined by Equation (3-62)
p'_∞	dimensional reference pressure
p_θ	dimensionless pressure on the cylinder surface at angle θ
p_π	rear stagnation pressure defined by Equation (3-63)
P	particle inertial parameter defined on page 54
P_c	critical inertial parameter
Q	point within fluid flowfield
$Q_n\ \psi$, $Q_n\ \zeta_b$, $Q_n\ \zeta_s$	fractional changes in the sum of stream function and vorticity values for the nth iteration as defined by Equations (3-56) to (3-58)

$Q_n^{100}\psi$, $Q_n^{100}\zeta_b$, $Q_n^{100}\zeta_n$ sum of fractional changes in stream function and vorticity values over 100 iterations as defined by Equations (3-59) to (3-61)

r dimensionless radius

R_c cylinder radius

R_p radius of spherical particle

R_∞ dimensionless radius of fluid envelope

Re_c cylinder Reynolds number defined on page 27

Re_p particle Reynolds number defined on page 54

$S_n\psi$, $S_n\zeta_b$, $S_n\zeta_s$ sums of stream function and vorticity values for the nth iteration as defined by Equations (3-50) to (3-52)

t dimensionless time

Δt time increment defined by Equation (3-80)

U_0 free stream velocity

$\underline{v}$ dimensionless fluid velocity vector

$\underline{v}_p$ dimensionless particle velocity

v_r	dimensionless radial component of fluid velocity
v_θ	dimensionless angular component of fluid velocity
v_x	dimensionless x-component of fluid velocity
v_y	dimensionless y-component of fluid velocity
x	dimensionless x co-ordinate
y	dimensionless y co-ordinate
y'_p	dimensional y co-ordinate of particle
$y'_{p,crit}$	dimensional starting position of critical trajectory
Z_∞	transformed radius of fluid envelope
Δz	transformed radial spacing of grid lines defined by Equation (3-17)
z	transformed radial co-ordinate defined in Equation (3-8)

Greek Letters

α_ψ	relaxation factor for stream function
α_ζ	relaxation factor for vorticity

$\alpha_{\zeta s}$	relaxation factor for vorticity on the surface of the cylinder
β	parameter defined by Equation (3-79)
γ	factor defined by Equation (2-3)
δ	minimum separation of starting co-ordinates
$\underline{\nabla}$	"del" operator
ε	impaction coefficient
ε_I	inertial impaction coefficient
ε_K	interception coefficient
ζ	dimensionless vorticity defined by Equation (3-5)
ζ_n^*	value of vorticity without relaxation after n iterations
ζ_0	initial values of vorticity
ζ_r , ζ_θ , ζ_ξ	components of vorticity in r, θ and ξ directions
ζ_s	vorticity at the surface of the cylinder
θ	angle
$\Delta\theta$	angular spacing of grid lines defined by Equation (3-16)

λ	transformed starting position of particle defined on page 60
μ	fluid viscosity
ξ	co-ordinate in ξ-direction
ρ	fluid density
ρ_p	particle density
$\tau_{r\theta}$	dimensionless shear stress
ϕ	parameter defined by Equation (2-7)
ψ	dimensionless stream function defined by Equation (3-4)
ψ_n^*	value of stream function without relaxation after n iterations
ψ_0	initial values of stream function

Superscript

'	prime denotes dimensional quantity

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APPENDIX I

RECTANGULAR CO-ORDINATES

In polar co-ordinates, v_r refers to the radial component of fluid velocity, and v_θ to the angular component. If a rectangular co-ordinate system is located at the centre of the cylinder (Figure 3-1), the fluid velocity at a point may also be expressed in terms of v_x and v_y, i.e. the x and y components of the fluid velocity; as follows:

$$\left.\begin{aligned} v_x &= v_\theta \sin\theta - v_r \cos\theta \\ v_y &= v_\theta \cos\theta + v_r \sin\theta \end{aligned}\right\} \qquad \text{(I-1)}$$

Here r and θ are the radial and angular co-ordinates of the point. Substitution of Equation (3-4) into (I-1) gives:

$$\left.\begin{aligned} v_x &= \frac{\partial\psi}{\partial r} \cdot \sin\theta + \frac{1}{r}\frac{\partial\psi}{\partial\theta}\cos\theta \\ v_y &= \frac{\partial\psi}{\partial r} \cdot \cos\theta - \frac{1}{r}\frac{\partial\psi}{\partial\theta}\sin\theta \end{aligned}\right\} \qquad \text{(I-2)}$$

Equation (I-2), when written in finite difference form for a general point (I,J) becomes:

$$\left.\begin{aligned} v_x(I,J) &= \frac{\psi(I,J+1)-\psi(I,J-1)}{2\Delta z}\sin\theta(I) \\ &+ \frac{1}{z(J)}\frac{\psi(I+1,J)-\psi(I-1,J)}{2\Delta\theta}\cos\theta(I) \\ v_y(I,J) &= \frac{\psi(I,J+1)-\psi(I,J-1)}{2\Delta z}\cos\theta(I) \\ &- \frac{1}{z(J)}\frac{\psi(I+1,J)-\psi(I-1,J)}{2\Delta\theta}\sin\theta(I) \end{aligned}\right\} \qquad \text{(I-3)}$$

At the boundaries the rectangular velocity components are determined by physical considerations:

$$\left.\begin{array}{ll} v_x(I,1) = 0 & \\ & r=1 \text{ or } z=0 \\ v_y(I,1) = 0 & \end{array}\right\}$$ Cylinder Surface (Zero Slip Conditions)

$$\left.\begin{array}{ll} v_y(1,J) = 0 & \theta=0 \\ v_y(1,N_r) = 0 & \theta=\pi \end{array}\right\}$$ Axis of Symmetry (No flow across axis of symmetry)

$$\left.\begin{array}{ll} v_x(I,N_r) = 1.0 & \\ & r=R_\infty \text{ or } z=Z_\infty \\ v_y(I,N_r) = 0 & \end{array}\right\}$$ Parallel Streaming Flow on outer envelope

Solution of Equations (3-6) and (3-7) will yield values of ψ and ζ at all interior grid points. The rectangular fluid velocity components at these points can be estimated with the aid of Equation (I-3). However, determination of v_x and v_y at a position other than a grid point will require interpolation.

Figure (I-1) illustrates a typical grid cell delimited by angular and radial lines. Consider a point Q inside the cell, whose position is defined by the fractional quantities a and l, as shown in Figure (I-1).

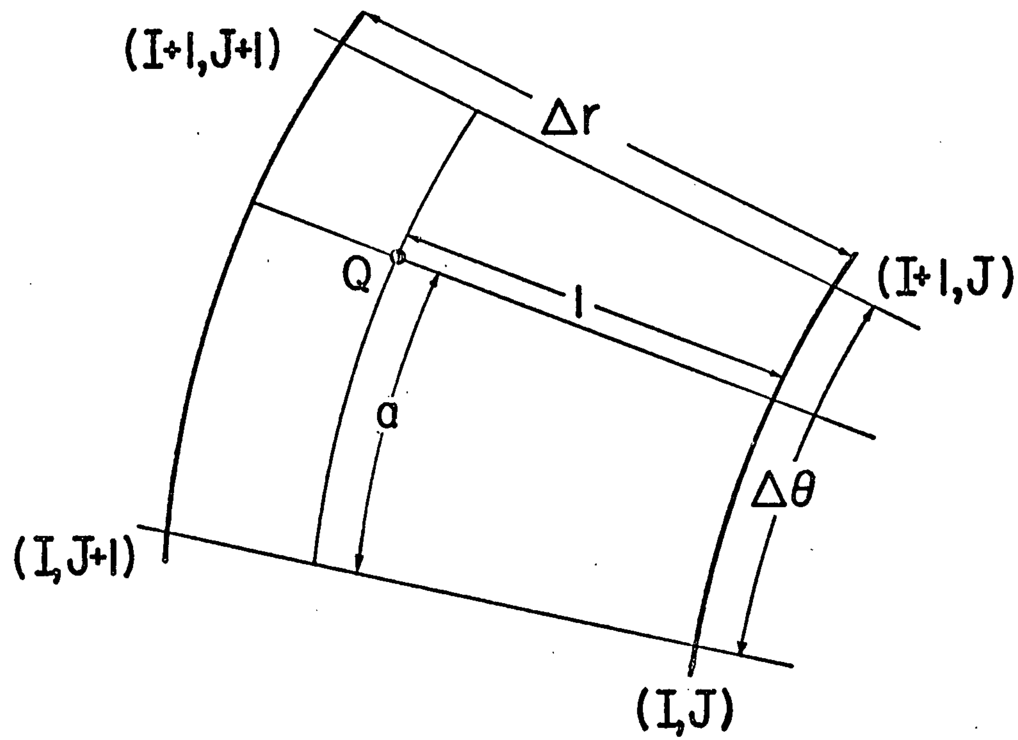

Figure I-1. Typical grid cell.

Interpolating with respect to angular and radial position yields the following formulae for the fluid velocity components at point Q:

$$\left.\begin{aligned} v_x\Big|_Q &= (1-a)\left[v_x(I,J)\cdot(1-l) + v_x(I,J+1)\cdot l\right] \\ &\quad + a\left[v_x(I+1,J)\cdot a + v_x(I+1,J+1)\cdot a\cdot l\right] \\ v_y\Big|_Q &= (1-a)\left[v_y(I,J)\cdot(1-l) + v_y(I,J+1)\cdot l\right] \\ &\quad + a\left[v_y(I+1,J)\cdot a + v_y(I+1,J+1)\cdot a\cdot l\right] \end{aligned}\right\} \qquad (I\text{-}4)$$

APPENDIX II

STAGNATION PRESSURES AND DRAG COEFFICIENTS

In order to derive the stagnation pressures and drag coefficients it is useful to write Equation (3-1) in an alternate form. To accomplish this, the following identities were used:

$$\underline{\zeta} = \underline{\nabla} \times \underline{v} \tag{II-1}$$

$$\underline{\nabla} \times \underline{\zeta} = \underline{\nabla} \times \underline{\nabla} \times \underline{v} \tag{II-2}$$

$$\underline{\nabla}^2 \underline{v} = \underline{\nabla}(\underline{\nabla} \cdot \underline{v}) - \underline{\nabla} \times (\underline{\nabla} \times \underline{v}) \tag{II-3}$$

$$(\underline{v} \cdot \underline{\nabla}) \underline{v} = \tfrac{1}{2} \underline{\nabla}(\underline{v} \cdot \underline{v}) - (\underline{v} \times \underline{\nabla} \times \underline{v}) \tag{II-4}$$

Equation (II-1) may be expanded in determinant form, giving:

$$\underline{\zeta} = \underline{\nabla} \times \underline{v} = \begin{vmatrix} i_r & i_\theta & i_\xi \\ \frac{\partial}{\partial r} & \frac{1}{r}\frac{\partial}{\partial \theta} & \frac{\partial}{\partial \xi} \\ v_r & v_\theta & v_\xi \end{vmatrix} \tag{II-5}$$

Since $v_\xi = 0$ and $\partial/\partial_\xi = 0$, Equation (II-5) becomes:

$$\zeta = i_\xi \, \zeta_\xi = i_\xi \left(\frac{\partial v_\theta}{\partial r} - \frac{1}{r} \frac{\partial v_r}{\partial \theta} \right) \tag{II-6}$$

The vorticity vector $\underline{\zeta}$ has in general three components, ζ_r, ζ_θ and ζ_ξ. In the present case of axisymmetric flow around a cylinder, ζ_r and ζ_θ are zero. For the sake of brevity the term ζ_ξ was abbreviated as simply ζ.

Substitution of Equations (II-1) to (II-4) into Equation (3-1) yields:

$$\underline{v} \times \underline{\zeta} = \tfrac{1}{2} \underline{\nabla} p + \tfrac{1}{2} \underline{\nabla} \underline{v}^2 + \frac{2}{Re_c} \underline{\nabla} \times \underline{\zeta} \tag{II-7}$$

Writing Equation (II-7) in slightly expanded form:

$$\begin{vmatrix} i_r & i_\theta & i_\xi \\ v_r & v_\theta & v_\xi \\ 0 & 0 & \zeta \end{vmatrix} = \frac{1}{2}\left(i_r \frac{\partial}{\partial r} + i_\theta \frac{1}{r}\frac{\partial}{\partial \theta} + i_\xi \frac{\partial}{\partial \xi}\right) p$$

$$+ \frac{1}{2}\left(i_r \frac{\partial}{\partial r} + i_\theta \frac{1}{r}\frac{\partial}{\partial \theta} + i_\xi \frac{\partial}{\partial \xi}\right)\left(v_r^2 + v_\theta^2 + v_\xi^2\right)$$

$$+ \frac{2}{Re_c}\begin{vmatrix} i_r & i_\theta & i_\xi \\ \frac{\partial}{\partial r} & \frac{1}{r}\frac{\partial}{\partial \theta} & \frac{\partial}{\partial \xi} \\ 0 & 0 & \zeta \end{vmatrix} \qquad \text{(II-8)}$$

Frontal Stagnation Pressure

The frontal stagnation pressure, p_0, is the pressure on the cylinder surface at $\theta = 0$, $r = 1$ as shown in Figure (3-1).

The r-component of Equation (II-8) is:

$$2\, v_\theta\, \zeta = \frac{\partial p}{\partial r} + \frac{4}{Re_c} \cdot \frac{1}{r}\frac{\partial \zeta}{\partial \theta} + \frac{\partial}{\partial r}\left(v_r^{\,2}\right)$$

Along the centreline (c.f. Figure (3-1)), $\theta = 0$ and $v_\theta = v_\xi = 0$, hence

$$\frac{\partial p}{\partial r} = - \frac{4}{Re_c}\,\frac{1}{r}\,\frac{\partial \zeta}{\partial \theta}\bigg|_{\theta=0} - \frac{\partial}{\partial r}\left(v_r^{\,2}\right) \qquad \text{(II-10)}$$

Equation (II-10) may be integrated with the following boundary conditions:

$$\left.\begin{aligned} p &= 0 & r &= R_\infty \\ p &= p_0 & r &= 1 \\ v_r &= 1 & r &= R_\infty \\ v_r &= 0 & r &= 1 \end{aligned}\right\} \qquad \text{(II-11)}$$

The following expression for p_0 is obtained:

$$p_0 = 1 + \frac{4}{Re_c} \int_1^{R_\infty} \left.\frac{\partial \zeta}{\partial \theta}\right|_{\theta=0} dr \qquad \text{(II-12)}$$

Introducing the transformation $r = e^z$ gives

$$p_0 = 1 + \frac{4}{Re_c} \int_0^{Z_\infty} \left.\frac{\partial \zeta}{\partial \theta}\right|_{\theta=0} dz \qquad \text{(II-13)}$$

Rear Stagnation Pressure

The rear stagnation pressure, p_π, is the surface pressure at $\theta = \pi$ (Figure (3-1)).

The θ-component of Equation (II-8) is:

$$- 2 v_r \zeta = \frac{1}{r}\frac{\partial p}{\partial \theta} + \frac{4}{Re_c}\frac{\partial \zeta}{\partial r} + \frac{1}{r}\frac{\partial}{\partial \theta}\left(v_r^2 + v_\theta^2 + v_\xi^2\right) \qquad \text{(II-14)}$$

On the surface of the cylinder, $v_r = v_\theta = 0$, and $r = 1$, giving:

$$\frac{\partial p_\theta}{\partial \theta} = \frac{4}{Re_c} \frac{\partial \zeta_s}{\partial r} \tag{II-15}$$

where p_θ is the pressure on the cylinder surface at $\theta = \theta$.

Integrating Equation (II-15) from p_0 to p_θ, and from $\theta = 0$ to $\theta = \theta$:

$$p_\theta - p_0 = \frac{4}{Re_c} \int_0^\theta \frac{\partial \zeta_s}{\partial r} \, d\theta \tag{II-16}$$

or

$$p_\theta = p_0 + \frac{4}{Re_c} \int_0^\theta \frac{\partial \zeta_s}{\partial z} \, d\theta \tag{II-17}$$

Hence the rear stagnation pressure is:

$$p_\pi = p_0 + \frac{4}{Re_c} \int_0^\pi \frac{\partial \zeta_s}{\partial z} \, d\theta \tag{II-18}$$

Skin Drag Coefficient

The skin drag coefficient, C_{DS}, is defined:

$$C_{DS} = \frac{\int_0^{\pi} - \tau'_{r\theta}\Big|_{r=1} R_c \sin\theta \; d\theta}{R_c\left(\frac{1}{2}\rho\, U_0{}^2\right)} \tag{II-19}$$

In terms of dimensionless shearstress, $\tau_{r\theta}$, Equation (II-19) becomes:

$$C_{DS} = - \int_0^{\pi} \tau'_{r\theta}\Big|_{r=1} \sin\theta \; d\theta \tag{II-20}$$

By definition:

$$\tau'_{r\theta} = - \mu\left[r' \frac{\partial}{\partial r'}\left(\frac{v_\theta{}'}{r'}\right) + \frac{1}{r'}\frac{\partial v_r{}'}{\partial\theta}\right] \tag{II-21}$$

and

$$\tau_{r\theta} = - \frac{4}{Re_c}\left[r \frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right] \qquad \text{(II-22)}$$

On the surface of the cylinder, $v_\theta = \frac{\partial v_r}{\partial \theta} = 0$, and $r = 1$, giving:

$$\tau_{r\theta} = - \frac{4}{Re_c}\frac{\partial v_\theta}{\partial r} \qquad \text{(II-23)}$$

Similarly, on the surface of the cylinder, Equation (II-6) becomes:

$$\zeta\Big|_{r=1} = \zeta_s = \frac{\partial v_\theta}{\partial r} \qquad \text{(II-24)}$$

Substituting Equations (II-23) and (II-24) into Equation (II-20) yields:

$$C_{DS} = \frac{4}{Re_c}\int_0^\pi \zeta_s \sin\theta \, d\theta \qquad \text{(II-25)}$$

Form Drag Coefficient

The form drag coefficient, C_{DF}, is defined:

$$C_{DF} = \frac{\int_0^{\pi} p_\theta' \cos\theta \;\; R_c \; d\theta}{\frac{1}{2}\,\rho\, U_0^{\,2}} \qquad \text{(II-26)}$$

or, in dimensionless form:

$$C_{DF} = \int_0^{\pi} p_\theta \cos\theta \;\; d\theta \qquad \text{(II-27)}$$

This is easily evaluated by substituting Equations (II-13) and (II-17) for p_θ:

$$C_{DF} = \int_0^{\pi} \left\{ \left[1 + \frac{4}{Re_c} \int_0^{Z_\infty} \left. \frac{\partial \zeta}{\partial \theta} \right|_{\theta=0} dz \right] \right.$$

(II-28)

$$\left. + \frac{4}{Re_c} \int_0^{\theta} \frac{\partial \zeta_s}{\partial z} \, d\theta \right\} \cos \theta \; d\theta$$

APPENDIX III

HAPPEL'S MODEL

Equation (II-22) may be expanded in terms of the stream function, ψ:

$$\tau_{r\theta} = -\frac{4}{Re_c}\left[\frac{\partial^2\psi}{\partial r^2} - \frac{1}{r}\frac{\partial\psi}{\partial r} - \frac{1}{r^2}\frac{\partial^2\psi}{\partial\theta^2}\right] \qquad \text{(III-1)}$$

Happel's model specifies that $\tau_{r\theta} = 0$ on the outer boundary, where $r = R_\infty$, Equation (III-1) then becomes:

$$\left.\frac{\partial^2\psi}{\partial r^2}\right|_{r=R_\infty} = \frac{1}{R_\infty}\left.\frac{\partial\psi}{\partial r}\right|_{r=R_\infty} + \frac{1}{R_\infty^{\,2}}\left.\frac{\partial^2\psi}{\partial\theta^2}\right|_{r=R_\infty} \qquad \text{(III-2)}$$

In addition, at $r = R_\infty$, $\psi = R_\infty \sin\theta$. Hence:

$$\left.\begin{aligned} \frac{\partial\psi}{\partial\theta} &= R_\infty \cos\theta \\ \frac{\partial^2\psi}{\partial\theta^2} &= -R_\infty \sin\theta \end{aligned}\right\} \tag{III-3}$$

Equation (3-7) may be expanded in terms of r and θ:

$$\zeta = \nabla^2 \psi = \frac{\partial^2\psi}{\partial r^2} + \frac{1}{r}\frac{\partial\psi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\psi}{\partial\theta^2} \tag{III-4}$$

Substituting Equations (III-2) and (III-3) into (III-4) gives:

$$\zeta\Bigg|_{r=R_\infty} = 2\left[\frac{1}{R_\infty}\frac{\partial\psi}{\partial r}\Bigg|_{r=R_\infty} - \frac{1}{R_\infty}\sin\theta\right] \tag{III-5}$$

By introducing the exponential transformation, $r = e^z$, Equation (III-5) becomes:

$$\zeta\Big|_{z=Z_\infty} = \frac{2}{e^{2Z_\infty}}\left[\frac{\partial\psi}{\partial z}\Big|_{z=Z_\infty} - e^{Z_\infty}\sin\theta\right] \qquad \text{(III-6)}$$

Equation (III-6) may be written in finite difference form as:

$$\zeta\left(N_a,J\right) = \frac{2}{e^{2Z_\infty}}\left[-\frac{\psi\left(I,N_a\right) + 4\psi\left(I,N_{a-1}\right) - 3\psi\left(I,N_{a-2}\right)}{2\,\Delta z} - e^{Z_\infty}\sin\theta\right] \qquad \text{(III-7)}$$

which is the desired equation for the vorticity on the outer boundary.

APPENDIX IV

Table IV-1

Relaxation Factors Used in this Work

Re_c	R_∞	α_ψ	α_ζ	$\alpha_{\zeta s}$
0.2	200	1.8	0.75	0.50
0.2	100	1.8	0.8	0.55
0.2	50	1.8	0.8	0.55
0.2	25	1.8	0.8	0.55
0.2	10	1.8	0.8	0.55
0.2	3	1.0	0.6	0.45
0.5	100	1.8	0.7	0.5
0.5	3	1.0	0.6	0.45
1	100	1.8	0.5	0.4
1	3	1.0	0.5	0.4
3	100	1.8	0.35	0.25
3	3	1.0	0.35	0.25
5	100	1.8	0.3	0.25
5	3	1.0	0.25	0.2
10	100	1.8	0.2	0.10
10	3	1.0	0.20	0.10
15	100	1.8	0.08	0.05
15	3	1.0	0.08	0.05
20	100	1.8	0.07	0.04
20	3	1.0	0.07	0.08
30	100	1.8	0.07	0.04
30	3	1.0	0.07	0.04
40	100	1.8	0.03	0.02
40	50	1.8	0.03	0.02
40	25	1.8	0.03	0.02
40	10	1.8	0.03	0.02
40	3	1.0	0.03	0.02

APPENDIX V

Computer Programmes and Sample Output

Computer Programme used to Solve the Navier-Stokes Equation for Flow Normal to a Circular Cylinder

```
      REAL S(33,93),V(33,93),FSIN(33),FCOS(33),RG(93),THETAG(33)
      REAL VGX(33,93),VGY(33,93),P(20),X(20)
      COMMON S,V,FSIN,FCOS,RG,THETAG,VGX,VGY,P,X
      COMMON RINF,RE,A,B,GNUM,XPST
      COMMON NR,NA,NUMBA,JSUB
      READ(4,2900) RINF,RE,RLXS,RLXV,RLXVS,A,B
      READ(4,3000) NR,NA,ITER,NCYCL,NUMBA
C
C     **************************************************************
C
C          THIS PROGRAMME CALCULATES THE FLOW FIELD ABOUT A CIRCULAR
C     CYLINDER. THE EQUATIONS ARE ALL DIMENSIONLESS, AND ARISE FROM THE
C     NAVIER STOKES EQUATION. THEY ARE EXPRESSED IN FINITE DIFFERENCE
C     FORM AND SOLVED BY A GAUSS-SEIDEL ITERATION METHOD.
C
C          THESE EQUATIONS, TWO IN NUMBER, INVOLVE VORTICITY (V)
C     AND STREAM FUNCTION (S).
C
C          IT SHOULD BE NOTED THAT RELAXATION FACTORS ARE INTRODUCED
C     TO EXPEDITE THE CONVERGENCE, AND TO GUARD AGAINST DIVERGENCE. IN
C     ALL, THREE SUCH FACTORS WERE USED: "RLXS", RELAXATION FACTOR
C     FOR THE STREAM FUNCTION, "RLXV", RELAXATION FACTOR FOR THE BULK
C     VORTICITY, AND "RLXVS", RELAXATION FACTOR FOR THE VORTICITY AT THE
C     CYLINDER SURFACE.
C
C
C     ******************************************************************
C
C
C          A GRID OF POINTS IS ESTABLISHED ABOUT THE UPPER HALF OF
C     THE CYLINDER, WITH NA POINTS IN THE ANGULAR DIRECTION, AND NR
C     IN THE RADIAL DIRECTION. TO OBTAIN FINE SPACING NEAR THE SURFACE,
C     THE TRANSFORMATION R=EXP(Z) WAS USED, WHERE Z WAS INCREASED BY
C     EVEN INCREMENTS. THE ANGULAR STEP SIZE IS CALLED B, AND THE RADIAL
C     Z-STEP SIZE IS "A".
C
C
C     ******************************************************************
C
      WRITE(6,3500)
      READ(8,3600) NCYCL,RE,RLXV,RLXVS
      ITER=100
      WRITE(6,1100) RINF,RE,NR,NA
      WRITE(6,1900) RLXS,RLXV
      WRITE(6,2400) RLXVS
      WRITE(6,1200) ITER,NCYCL
C
C     *****************************************************************
C
C
C                    A SUMMARY OF NOTATION
C                    ---------------------
C
C     A=       RADIAL INCREMENT IN Z
C     B=       ANGULAR INCREMENT (RADIANS)
C     ER=      CURRENT CHANGE IN POINT VALUES
C     NA=      NUMBER OF ANGULAR GRID DIVISIONS
C     NR=      NUMBER OF RADIAL GRID DIVISIONS
```

```
C       NUMBA=  CURRENT NUMBER OF ITERATIONS OVER GRID
C       RE=     REYNOLD'S NUMBER
C       RINF=   OUTER BOUNDARY RADIUS
C       RLXS=   RELAXATION FACTOR FOR STREAM FUNCTION
C       RLXV=   RELAXATION FACTOR FOR BULK VORTICITY
C       RLXVS=  RELAXATION FACTOR FOR SURFACE VORTICITY
C
C
C       ****************************************************************
C
C
C       ****************************************************************
C
C
C            HERE THE VALUES OF "A" AND "B" ARE CALCULATED, BASED ON
C       INPUT RINF,NR, AND NA.
C
C
C       ****************************************************************
C
        ZINF=ALOG(RINF)
        A=ZINF/(NR-1)
        PI=3.141592653589793
        B=PI/(NA-1.0)
        WRITE(6,1800) A,B
        DO 230 I=1,NA
        ANGLE=PI/(NA-1.0)*(I-1.0)
        FSIN(I)=SIN(ANGLE)
        FCOS(I)=COS(ANGLE)
        THETAG(I)=ANGLE
    230 CONTINUE
        DO 240 J=1,NR
        RG(J)=EXP(ZINF/(NR-1.0)*(J-1.0))
    240 CONTINUE
        ISPACE=4
        JSPACE=4
C
C       *****************************************************************
C
C
C            THE INITIAL MATRICES OF V(NA,NR) AND S(NA,NR) ARE READ FROM
C       UNIT 4.
C
C
C       ****************************************************************
C
        DO 20 J=1,NR
        READ(4,2910)  (V(I,J),I=1,NA)
     20 CONTINUE
        DO 30 J=1,NR
        READ(4,2910)  (S(I,J),I=1,NA)
     30 CONTINUE
        DO 210 I=1,NA
        S(I,1)=0.0
        S(I,NR)=RINF*FSIN(I)
        V(I,NR)=0.0
    210 CONTINUE
        DO 220 J=1,NR
```

```
      S(1,J)=0.0
      S(NA,J)=0.0
      V(1,J)=0.0
      V(NA,J)=0.0
  220 CONTINUE
      WRITE(6,2200)
      DO 90 J=1,NR,JSPACE
      WRITE(6,1400) (V(I,J),I=1,NA,ISPACE)
   90 CONTINUE
      WRITE(6,2300)
      DO 100 J=1,NR,JSPACE
      WRITE(6,1400) (S(I,J),I=1,NA,ISPACE)
  100 CONTINUE
      C1=(A*A*B*B)/2./(A*A+B*B)
      C2=1./A/A
      C3=1./B/B
      NA1=NA-1
      NR1=NR-1
      DO 60 KK=1,NCYCL
      SERV=0.0
      SERVS=0.0
      SERS=0.0
      SUMAX=0.0
      DO 50 KL=1,ITER
      ERS=0.0
      ERV=0.0
      ERVS=0.0
      VTL=0.0
      VSTL=0.0
      STL=0.0
      ERTS=0.0
      ERTV=0.0
      ERTVS=0.0
      IERS=0
      IERV=0
      IERVS=0
      JERS=0
      JERV=0
      JERVS=0
C
C     ******************************************************************
C
C
C          WITHIN THE NEXT TWO LOOPS, THE ACTUAL GAUSS-SEIDEL RELAXATION
C     TECHNIQUE IS EMPLOYED. A TEST FOR CONVERGENCE IS ALSO INCLUDED
C     HERE. IN EFFECT, IT COMPARES THE CHANGES IN VALUES AT GRID POINTS,
C     FROM ONE CYCLE TO THE NEXT. WHEN THIS CHANGE IS LESS THAN THE CON-
C     VERGENCE CRITERION, THE OPERATION IS CONSIDERED TO HAVE CONVERGED.
C
C
C     ******************************************************************
C
      DO 110 I=2,NA1
      Z=0.0
      DO 40 J=2,NR1
      Z=Z+A
      VTEMP=C1*(C2*(V(I,J-1)+V(I,J+1))+C3*(V(I-1,J)+V(I+1,J))
     1 +RE/8./A/B*((S(I+1,J)-S(I-1,J))*(V(I,J+1)-V(I,J-1))
```

```
     2 -(S(I,J+1)-S(I,J-1))*(V(I+1,J)-V(I-1,J))))
      VPREV=V(I,J)
      V(I,J)=RLXV*(VTEMP-V(I,J))+V(I,J)
      DIFF=ABS(VPREV-VTEMP)
      ERTV=ERTV+DIFF
      VTL=VTL+VPREV
      IF(DIFF.LT.ERV) GO TO 400
      ERV=DIFF
      IERV=I
      JERV=J
  400 CONTINUE
      STEMP=C1*(-EXP(2.*Z)*V(I,J)+C2*(S(I,J+1)+S(I,J-1))+
     1 C3*(S(I+1,J)+S(I-1,J)))
      SPREV=S(I,J)
      S(I,J)=RLXS*(STEMP-S(I,J))+S(I,J)
      DIFF=ABS(SPREV-STEMP)
      ERTS=ERTS+DIFF
      STL=STL+SPREV
      IF(DIFF.LT.ERS) GO TO 410
      ERS=DIFF
      IERS=I
      JERS=J
  410 CONTINUE
   40 CONTINUE
      VTEMP=(C2/2.0)*(8.0*S(I,2)-S(I,3))
      VPREV=V(I,1)
      DIFF=ABS(VPREV-VTEMP)
      ERTVS=ERTVS+DIFF
      IF(DIFF.LT.ERVS) GO TO 420
      ERVS=DIFF
      IERVS=I
      JERVS=1
  420 CONTINUE
      VSTL=VSTL+VPREV
      V(I,1)=RLXVS*(VTEMP-V(I,1))+V(I,1)
  110 CONTINUE
      ERTS=ERTS/STL
      ERTV=ERTV/VTL
      ERTVS=ERTVS/VSTL
      SERS=SERS+ERTS
      SERV=SERV+ERTV
      SERVS=SERVS+ERTVS
      ERTS=ERTS*100.0
      ERTV=ERTV*100.0
      ERTVS=ERTVS*100.0
      NEVEN=NUMBA
      NUMBA=NUMBA+1
      NWRITE=NEVEN/25*25
      IF(NWRITE.EQ.NEVEN) GO TO 300
      GO TO 310
  300 WRITE(6,4600)
  310 CONTINUE
      WRITE(6,4500) NUMBA,ERS,ERV,ERVS,ERTS,ERTV,ERTVS
      WRITE(6,4700) IERS,JERS,IERV,JERV,IERVS,JERVS,STL,VTL,VSTL
      ERS=ERS*RLXS
      ERV=ERV*RLXV
      ERVS=ERVS*RLXVS
      ERTS=ERTS*RLXS
```

```
      ERTV=ERTV*RLXV
      ERTVS=ERTVS*RLXVS
C
C     ****************************************************************
C
C
C          HERE THE CONVERGENCE IS TESTED, AND IF "ER" IS LESS THAN
C     THE CRITERION (HERE 0.0001), THE PROGRAMME EXITS TO DISPLAY AND
C     RECORD THE RESULTS. AS A PRECAUTION AGAINST NON-CONVERGENCE
C     WITHIN A GIVEN TIME LIMIT, VALUES OF THE VORTICITY AND STREAM
C     FUNCTION MATRICES ARE STORED EVERY 50 ITERATIONS.
C
C
C     ****************************************************************
C

   50 CONTINUE
      CERS=0.0
      CERV=0.0
      CERVS=0.0
      CSTL=0.0
      CVTL=0.0
      CVSTL=0.0
      CERTS=0.0
      CERTV=0.0
      CERTVS=0.0
      DO 190 I=2,NA1
      Z=0.0
      DO 200 J=2,NR1
      Z=Z+A
      VTEMP=C1*(C2*(V(I,J-1)+V(I,J+1))+C3*(V(I-1,J)+V(I+1,J))
     1 +RE/8./A/B*((S(I+1,J)-S(I-1,J))*(V(I,J+1)-V(I,J-1))
     2 -(S(I,J+1)-S(I,J-1))*(V(I+1,J)-V(I-1,J))))
      VPREV=V(I,J)
      DIFFV=ABS(VPREV-VTEMP)
      IF(DIFFV.GT.CERV) CERV=DIFFV
      CERTV=CERTV+DIFFV
      CVTL=CVTL+VPREV
      STEMP=C1*(-EXP(2.*Z)*V(I,J)+C2*(S(I,J+1)+S(I,J-1))+
     1 C3*(S(I+1,J)+S(I-1,J)))
      SPREV=S(I,J)
      DIFFS=ABS(SPREV-STEMP)
      IF(DIFFS.GT.CERS) CERS=DIFFS
      CERTS=CERTS+DIFFS
      CSTL=CSTL+SPREV
  200 CONTINUE
      VTEMP=(C2/2.0)*(8.0*S(I,2)-S(I,3))
      VPREV=V(I,1)
      DIFFV=ABS(VPREV-VTEMP)
      CERTVS=CERTVS+DIFFV
      IF(DIFFV.GT.CERVS) CERVS=DIFFV
      CVSTL=CVSTL+VPREV
  190 CONTINUE
      CERTS=CERTS/CSTL*100.0
      CERTV=CERTV/CVTL*100.0
      CERTVS=CERTVS/CVSTL*100.0
      WRITE(6,4200) NUMBA
      WRITE(6,3900) CERS,CERV,CERVS,CERTS,CERTV,CERTVS
```

```
      CERS=CERS*RLXS
      CERV=CERV*RLXV
      CERVS=CERVS*RLXVS
      CERTS=CERTS*RLXS
      CERTV=CERTV*RLXV
      CERTVS=CERTVS*RLXVS
      WRITE(6,4000)
      WRITE(6,3900) CERS,CERV,CERVS,CERTS,CERTV,CERTVS
      WRITE(6,4300)
      WRITE(6,4400) SERS,SERV,SERVS
      SERS=SERS*RLXS
      SERV=SERV*RLXV
      SERVS=SERVS*RLXVS
      WRITE(6,4000)
      WRITE(6,4400) SERS,SERV,SERVS
      REWIND 1
      WRITE(1,2900) RINF,RE,RLXS,RLXV,RLXVS,A,B
      WRITE(1,3000) NR,NA,ITER,NCYCL,NUMBA
      DO 170 J=1,NR
      WRITE(1,2910) (V(I,J),I=1,NA)
  170 CONTINUE
      DO 180 J=1,NR
      WRITE(1,2910) (S(I,J),I=1,NA)
  180 CONTINUE
      REWIND 1
      CALL DRAG
      CALL EFFSUB
   60 CONTINUE
C
C     ****************************************************************
C
C
C          THIS SECTION OF THE PROGRAMME IS OUTSIDE THE GAUSS-SEIDEL LOOPS,
C     AND FINAL RESULTS ARE BOTH DISPLAYED, AND RECORDED IN A FILE VIA
C     UNIT 1.
C
C
C     ****************************************************************
C
  120 WRITE(6,2500) NUMBA
      WRITE(6,2600)
      DO 70 J=1,NR,JSPACE
      WRITE(6,1400) (V(I,J),I=1,NA,ISPACE)
   70 CONTINUE
      WRITE(6,2700)
      DO 80 J=1,NR,JSPACE
      WRITE(6,1400) (S(I,J),I=1,NA,ISPACE)
   80 CONTINUE
 1000 FORMAT(5F12.5)
 1100 FORMAT('1','BOUNDARY RADIUS=',F10.5,5X,'REYNOLDS NO.=',F10.5,
     1 5X,'RADIAL DIVISIONS=',I3,5X,'ANGULAR DIVISIONS=',I3//)
 1200 FORMAT(10X,'NO. OF ITERATIONS PER CYCLE=',1X,I3,19X,
     1 'NO. OF CYCLES=',1X,I3/)
 1300 FORMAT(6I5)
 1400 FORMAT(8G14.7)
 1500 FORMAT('1',20X,'*** VALUES OF THE STREAM FUNCTION FOR CYCLE '
     1 ,I2,' ***'//)
 1600 FORMAT('1',20X,'*** VALUES OF THE VORTICITY FOR CYCLE '
```

```
      1 ,I2,' ***'//)
 1700 FORMAT(10X,'ANGULAR VALUES ARE PRINTED BY ',I2,'''S'/)
 1800 FORMAT(10X,'Z-INCREMENT=',F8.4,31X,'ANGULAR INCREMENT=',F8.4/)
 1900 FORMAT(10X,'RELAXATION FACTOR FOR STREAM FUNCTION=',F10.5,3X,
      1 'RELAXATION FACTOR FOR BULK VORTICITY=',F10.5/)
 2000 FORMAT(10X,'RADIAL VALUES ARE PRINTED BY ',I2,'''S'/)
 2100 FORMAT('1')
 2200 FORMAT('1',20X,'*** INITIAL VALUES OF VORTICITY ***'//)
 2300 FORMAT('1',20X,'*** INITIAL VALUES OF STREAM FUNCTION ***'//)
 2400 FORMAT(61X,'RELAXATION FACTOR FOR SURFACE VORTICITY=',F10.5/)
 2500 FORMAT('1',20X,'AFTER ',I4,1X,'ITERATIONS: '//)
 2600 FORMAT(20X,'*** FINAL VALUES OF VORTICITY ***'//)
 2700 FORMAT('1',20X,'*** FINAL VALUES OF STREAM FUNCTION ***'//)
 2800 FORMAT('1'/////20X'CURRENT ERROR='F10.6,3X'AFTER 'I4,1X,
      1 'ITERATIONS'/)
 2900 FORMAT(8F10.6)
 2910 FORMAT(17G14.7)
 3000 FORMAT(5I5)
 3100 FORMAT(//10X,'AFTER ',I4,' ITERATIONS,(NO RELAXATION):'//)
 3500 FORMAT(//,'ENTER THE VALUES OF NCYCL,RE,RLXV, AND RLXVS'/
      1 ,'THE FORMAT IS I2/G14.7/G14.7/G14.7 ; SO THAT MEANS FOUR'/
      2 ,'COUNT THEM, FOUR LINES OF INPUT!!'//)
 3600 FORMAT(I2/G14.7/G14.7/G14.7)
 3900 FORMAT(30X,'MAXIMUM CHANGES OVER GRID:',//,
      1 'STREAM FUNCTION=',G14.7,5X,'BULK VORTICITY=',G14.7,5X,
      2 'SURFACE VORTICITY=',G14.7//30X,'AVERAGE % CHANGE OVER GRID:'
      3 ,//,'STREAM FUNCTION=',G14.7,5X,'BULK VORTICITY=',G14.7,5X,
      4 'SURFACE VORTICITY=',G14.7)
 4000 FORMAT(///,'WITH RELAXATION:'//)
 4200 FORMAT('1',10X,'CONVERGENCE TEST ON GRID AFTER ',I4,' ITERATIONS:'
      1 //)
 4300 FORMAT(/////10X,'AVERAGING THE STEP TO STEP CHANGES OVER THE LAST
      1 100 ITERATIONS:'//)
 4400 FORMAT(10X,'OVERALL % CHANGES,(NO RELAXATION):'//,
      1 'STREAM FUNCTION=',G14.7,5X,'BULK VORTICITY=',G14.7,5X,
      2 'SURFACE VORTICITY=',G14.7//)
 4500 FORMAT(3X,I5,2X,6(4X,G14.7))
 4600 FORMAT('1',3X,'ITER',8X,'MAX STREAM',8X,'MAX VORT/B',
      1 8X,'MAX VORT/S',8X,'%AVG STREAM',7X,'%AVG VORT/B',
      2 7X,'%AVG VORT/S'//)
 4700 FORMAT(7X,3(11X,'(',I2,',',I2,')'),2X,3(4X,G14.7))
      STOP
      END
```

```
BOUNDARY RADIUS= 100.00000     REYNOLDS NO.=  10.00000     RADIAL DIVISIONS= 93     ANGULAR DIVISIONS= 33

        RELAXATION FACTOR FOR STREAM FUNCTION=   1.79999   RELAXATION FACTOR FOR BULK VORTICITY=   0.20000

                                                           RELAXATION FACTOR FOR SURFACE VORTICITY=   0.10000

        NO. OF ITERATIONS PER CYCLE= 100                   NO. OF CYCLES=   5

        Z-INCREMENT=  0.0501                               ANGULAR INCREMENT=  0.0982
```

Sample Output from Programme used to Solve Navier-Stokes Equation

*** INITIAL VALUES OF VORTICITY ***

0.0 0.0	1.641181	2.612472	2.617158	1.879713	0.9360839	0.2373648	-0.4435175E-01
0.0 0.0	0.9136698	1.580676	1.805051	1.540478	0.9731405	0.4254811	0.1111084
0.0 0.0	0.4193978	0.8165477	1.114193	1.175012	0.9293177	0.5307799	0.2084678
0.0 0.0	0.1487743	0.3364342	0.5750294	0.7892032	0.8056422	0.5725939	0.2690349
0.0 0.0	0.3761801E-01	0.1024861	0.2318138	0.4426041	0.6204315	0.5614614	0.3049777
0.0 0.0	0.6144904E-02	0.2116124E-01	0.6786603E-01	0.1958640	0.4114614	0.5049757	0.3226894
0.0 0.0	0.5735876E-03	0.2667336E-02	0.1326627E-01	0.6412619E-01	0.2256491	0.4131519	0.3252767
0.0 0.0	0.2612795E-04	0.1797718E-03	0.1560273E-02	0.1435940E-01	0.9715402E-01	0.3016922	0.3142931
0.0 0.0	0.6218472E-06	0.5632639E-05	0.9622355E-04	0.1981226E-02	0.3063117E-01	0.1910409	0.2909260
0.0 0.0	0.2368508E-06	0.2326914E-06	0.2307764E-05	0.1447208E-03	0.6374869E-02	0.1006050	0.2568098
0.0 0.0	0.3438184E-06	-0.1474846E-06	-0.7578716E-06	0.3773765E-05	0.7355977E-03	0.4121631E-01	0.2145086
0.0 0.0	0.5134202E-06	-0.8683928E-06	-0.1015634E-05	-0.5717391E-06	0.3420134E-04	0.1152652E-01	0.1676220
0.0 0.0	0.7030807E-06	-0.1602248E-05	0.8675499E-07	0.6671777E-06	0.4513903E-06	0.1501042E-02	0.1204754
0.0 0.0	0.6224574E-06	-0.7964317E-06	0.2315471E-05	0.2015129E-05	0.1314354E-05	-0.4099819E-04	0.7744730E-01
0.0 0.0	-0.5551227E-06	0.2673111E-05	0.1758114E-05	0.6315162E-07	0.3806330E-06	0.8625514E-04	0.4213854E-01
0.0 0.0	-0.4003862E-05	0.4168615E-05	-0.3432428E-05	-0.3107848E-05	0.1688709E-05	-0.4840085E-04	0.1667000E-01
0.0 0.0	-0.9616047E-05	-0.3165225E-05	-0.3081106E-05	0.4421519E-06	-0.5279333E-05	-0.1135795E-03	0.1357372E-02
0.0 0.0	-0.1395037E-04	-0.5205065E-05	0.4974175E-05	0.2437980E-06	-0.1386298E-04	0.1275432E-03	-0.5141661E-02
0.0 0.0	-0.1241508E-04	0.1545092E-04	0.2091801E-05	-0.4443281E-05	0.1775085E-04	0.2848003E-03	-0.5278055E-02
0.0 0.0	-0.6006546E-05	-0.2343501E-05	0.1390449E-04	0.3036218E-04	0.7739467E-04	-0.3196628E-04	-0.1862880E-02
0.0 0.0	-0.1124643E-05	-0.9330099E-04	0.1002831E-04	0.3088356E-04	0.6097239E-05	-0.7052913E-03	0.2562603E-02
0.0 0.0	-0.4969337E-08	-0.8370115E-04	-0.9549792E-04	-0.8000841E-04	-0.3143293E-03	-0.1275842E-02	0.5819675E-02
0.0 0.0	0.3001203E-08	-0.3962306E-05	-0.2083230E-03	-0.2677846E-03	-0.5686770E-03	-0.1273526E-02	0.5641617E-02
0.0 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*** INITIAL VALUES OF STREAM FUNCTION ***

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0							
0.0	0.3166351E-01	0.5157673E-01	0.5363615E-01	0.4057910E-01	0.2188935E-01	0.7007126E-02	0.2483537E-03
0.0							
0.0	0.1210178	0.2022458	0.2190959	0.1748646	0.1011599	0.3737145E-01	0.5312692E-02
0.0							
0.0	0.2585750	0.4429818	0.5000356	0.4215859	0.2605929	0.1065531	0.2157733E-01
0.0							
0.0	0.4361131	0.7630147	0.8940217	0.7952866	0.5248731	0.2328839	0.5598926E-01
0.0							
0.0	0.6505539	1.156322	1.396379	1.303639	0.9176478	0.4382018	0.1158362
0.0							
0.0	0.9053867	1.626942	2.008596	1.950569	1.458294	0.7475468	0.2144729
0.0							
0.0	1.209157	2.188885	2.744002	2.744241	2.161308	1.187739	0.3619673
0.0							
0.0	1.573606	2.863231	3.627474	3.704163	3.040434	1.785275	0.5756388
0.0							
0.0	2.013128	3.676451	4.692855	4.862879	4.116013	2.564778	0.8754433
0.0							
0.0	2.545129	4.660694	5.982016	6.264517	5.420938	3.549870	1.285150
0.0							
0.0	3.190701	5.854926	7.545331	7.964046	7.002493	4.767262	1.832363
0.0							
0.0	3.975480	7.306573	9.446457	10.02845	8.921789	6.252950	2.548450
0.0							
0.0	4.930648	9.073275	11.75910	12.53952	11.25446	8.057789	3.468511
0.0							
0.0	6.094239	11.22533	14.57577	15.59700	14.09279	10.25026	4.631682
0.0							
0.0	7.512609	13.84847	18.00858	19.32245	17.54967	12.91730	5.082113
0.0							
0.0	9.242293	17.04715	22.19426	23.86438	21.76305	16.16533	7.870827
0.0							
0.0	11.35221	20.94890	27.29950	29.40381	26.90120	20.12450	10.05904
0.0							
0.0	13.92657	25.70908	33.52794	36.16150	33.16959	24.95505	12.72339
0.0							
0.0	17.06801	31.51790	41.12737	44.40619	40.81833	30.85486	15.96349
0.0							
0.0	20.90201	38.60753	50.40073	54.46637	50.15288	38.06493	19.91289
0.0							
0.0	25.58179	47.25945	61.71883	66.74300	61.54584	46.87323	24.75475
0.0							
0.0	31.29436	57.81926	75.53226	81.72527	75.44626	57.61794	30.73932
0.0							
0.0	38.26833	70.71066	92.38792	100.0000	92.38800	70.71074	38.26840
0.0							

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5001	0.1525879E-03	0.4673004E-04	0.4377365E-03	0.3832535E-04	0.1139359E-02	0.1223442E-01
	(16,90)	(20, 2)	(10, 1)	36965.03	439.2815	40.03783
5002	0.1373291E-03	0.4863739E-04	0.5331039E-03	0.3367694E-04	0.1120930E-02	0.1085493E-01
	(21,90)	(22, 2)	(10, 1)	36965.02	439.2808	40.03783
5003	0.1220703E-03	0.4321337E-04	0.4538894E-03	0.3273266E-04	0.1121744E-02	0.1306074E-01
	(21,89)	(24, 2)	(24, 1)	36965.03	439.2798	40.03767
5004	0.1983643E-03	0.3165007E-04	0.4521608E-03	0.3162512E-04	0.1071175E-02	0.1465393E-01
	(15,88)	(22, 3)	(21, 1)	36965.02	439.2798	40.03798
5005	0.1831055E-03	0.4088879E-04	0.3767014E-03	0.3024828E-04	0.1093273E-02	0.9954730E-02
	(15,87)	(21, 2)	(19, 1)	36965.03	439.2795	40.03764
5006	0.1373291E-03	0.4577637E-04	0.3805161E-03	0.2815023E-04	0.1097479E-02	0.7656839E-02
	(15,86)	(19, 2)	(19, 1)	36965.03	439.2791	40.03741
5007	0.1373291E-03	0.3540516E-04	0.5769730E-03	0.2850003E-04	0.1078370E-02	0.1152435E-01
	(18,90)	(21, 2)	(11, 1)	36965.02	439.2786	40.03754
5008	0.1678467E-03	0.4291534E-04	0.4196167E-03	0.2887346E-04	0.1067379E-02	0.1127428E-01
	(20,92)	(17, 2)	(11, 1)	36965.02	439.2783	40.03748
5009	0.1373291E-03	0.4005432E-04	0.4491806E-03	0.2698971E-04	0.1069725E-02	0.1231391E-01
	(20,92)	(16, 2)	(16, 1)	36965.02	439.2776	40.03729
5010	0.1525879E-03	0.4005432E-04	0.4758835E-03	0.2723194E-04	0.1075392E-02	0.9995043E-02
	(20,89)	(19, 2)	(18, 1)	36965.01	439.2776	40.03712
5011	0.1220703E-03	0.4386902E-04	0.8459091E-03	0.2825118E-04	0.1068865E-02	0.1140550E-01
	(20,90)	(18, 2)	(15, 1)	36965.02	439.2769	40.03706
5012	0.1525879E-03	0.4959106E-04	0.4615784E-03	0.3000229E-04	0.1080786E-02	0.1211420E-01
	(19,89)	(16, 2)	(14, 1)	36965.01	439.2764	40.03688
5013	0.1831055E-03	0.4863739E-04	0.4978180E-03	0.3119644E-04	0.1067272E-02	0.1058179E-01
	(17,92)	(18, 2)	(11, 1)	36965.01	439.2764	40.03694
5014	0.1525879E-03	0.4196167E-04	0.3032684E-03	0.3127920E-04	0.1058124E-02	0.9296678E-02
	(18,92)	(16, 2)	(12, 1)	36965.02	439.2756	40.03685
5015	0.1831055E-03	0.3719330E-04	0.3881454E-03	0.3000027E-04	0.1063480E-02	0.9300850E-02
	(18,91)	(12, 2)	(20, 1)	36965.00	439.2754	40.03671
5016	0.1678467E-03	0.3337860E-04	0.3967285E-03	0.3043893E-04	0.1035866E-02	0.9530634E-02
	(21,92)	(14, 2)	(7, 1)	36965.01	439.2751	40.03685
5017	0.1373291E-03	0.2777576E-04	0.2908707E-03	0.3040301E-04	0.1016366E-02	0.8450326E-02
	(18,89)	(21, 3)	(6, 1)	36964.99	439.2747	40.03690
5018	0.1220703E-03	0.2652407E-04	0.2765656E-03	0.2874501E-04	0.1009549E-02	0.9481814E-02
	(18,89)	(21, 3)	(11, 1)	36965.01	439.2744	40.03680
5019	0.1525879E-03	0.2634525E-04	0.5540848E-03	0.3009409E-04	0.1020818E-02	0.1137315E-01
	(17,88)	(21, 3)	(14, 1)	36965.01	439.2744	40.03656
5020	0.1525879E-03	0.3242493E-04	0.5598068E-03	0.2859565E-04	0.1008032E-02	0.1104027E-01
	(15,86)	(14, 2)	(11, 1)	36965.00	439.2742	40.03648
5021	0.1831055E-03	0.3147125E-04	0.5416870E-03	0.3125262E-04	0.1011196E-02	0.1250598E-01
	(16,85)	(11, 2)	(10, 1)	36965.00	439.2739	40.03638
5022	0.1525879E-03	0.3337860E-04	0.4863739E-03	0.2982428E-04	0.1046254E-02	0.1104442E-01
	(21,90)	(10, 2)	(9, 1)	36965.01	439.2734	40.03592
5023	0.1678467E-03	0.3433228E-04	0.4062653E-03	0.3103838E-04	0.1008796E-02	0.1039615E-01
	(18,91)	(9, 2)	(14, 1)	36965.01	439.2734	40.03618
5024	0.1220703E-03	0.2956390E-04	0.3795624E-03	0.2994195E-04	0.1014166E-02	0.8963879E-02
	(21,90)	(14, 2)	(8, 1)	36964.99	439.2734	40.03596
5025	0.1068115E-03	0.2479553E-04	0.4873276E-03	0.3046263E-04	0.1003248E-02	0.1157916E-01
	(19,87)	(13, 2)	(10, 1)	36964.98	439.2732	40.03593

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5026	0.1831055E-03	0.3242493E-04	0.5989075E-03	0.3166974E-04	0.1018980E-02	0.1068764E-01
	(14,92)	(10, 2)	(10, 1)	36964.99	439.2727	40.03569
5027	0.1983643E-03	0.2312660E-04	0.4920959E-03	0.2983308E-04	0.9963840E-03	0.9222530E-02
	(14,92)	(22, 4)	(9, 1)	36964.98	439.2722	40.03587
5028	0.1373291E-03	0.2861023E-04	0.3719330E-03	0.3153236E-04	0.9795744E-03	0.9636290E-02
	(14,91)	(21, 2)	(14, 1)	36964.97	439.2725	40.03587
5029	0.1525879E-03	0.3099442E-04	0.4851222E-03	0.3109127E-04	0.9687142E-03	0.1368631E-01
	(16,92)	(25, 2)	(21, 1)	36964.96	439.2720	40.03595
5030	0.1678467E-03	0.3242493E-04	0.4043579E-03	0.3102815E-04	0.9707389E-03	0.1262989E-01
	(14,92)	(21, 2)	(15, 1)	36964.96	439.2715	40.03581
5031	0.1678467E-03	0.3147125E-04	0.5331039E-03	0.3010007E-04	0.9907670E-03	0.8505680E-02
	(17,92)	(19, 2)	(12, 1)	36964.98	439.2710	40.03558
5032	0.1678467E-03	0.2574921E-04	0.8764267E-03	0.3032872E-04	0.9785036E-03	0.1052475E-01
	(14,92)	(16, 2)	(11, 1)	36964.98	439.2708	40.03551
5033	0.1373291E-03	0.3433228E-04	0.5846024E-03	0.2829218E-04	0.9823872E-03	0.1101617E-01
	(14,92)	(13, 2)	(10, 1)	36964.97	439.2703	40.03539
5034	0.1831055E-03	0.2861023E-04	0.4148483E-03	0.2905959E-04	0.9650185E-03	0.1140799E-01
	(18,92)	(10, 2)	(10, 1)	36964.96	439.2708	40.03543
5035	0.1678467E-03	0.2574921E-04	0.5006790E-03	0.2939766E-04	0.9609357E-03	0.1186327E-01
	(14,90)	(19, 2)	(11, 1)	36964.96	439.2708	40.03523
5036	0.1068115E-03	0.2229214E-04	0.4167557E-03	0.2917735E-04	0.9284827E-03	0.9536171E-02
	(20,90)	(24, 4)	(19, 1)	36964.96	439.2705	40.03554
5037	0.1220703E-03	0.2384186E-04	0.4281998E-03	0.2815462E-04	0.9341282E-03	0.1115249E-01
	(18,92)	(20, 2)	(18, 1)	36964.96	439.2698	40.03546
5038	0.1220703E-03	0.3051758E-04	0.4061460E-03	0.2893005E-04	0.9482957E-03	0.1094829E-01
	(21,88)	(18, 2)	(23, 1)	36964.96	439.2695	40.03531
5039	0.1220703E-03	0.2777576E-04	0.3671646E-03	0.3031868E-04	0.9412940E-03	0.1009926E-01
	(17,86)	(23, 2)	(20, 1)	36964.97	439.2688	40.03525
5040	0.1220703E-03	0.2908707E-04	0.3871918E-03	0.2897454E-04	0.9498510E-03	0.9962410E-02
	(22,92)	(21, 2)	(10, 1)	36964.96	439.2695	40.03513
5041	0.1525879E-03	0.2670288E-04	0.4081726E-03	0.2929135E-04	0.9427743E-03	0.8619651E-02
	(14,92)	(19, 2)	(19, 1)	36964.96	439.2698	40.03517
5042	0.1525879E-03	0.2145767E-04	0.3166199E-03	0.3010957E-04	0.9269328E-03	0.9415470E-02
	(20,89)	(22, 4)	(18, 1)	36964.96	439.2700	40.03519
5043	0.1220703E-03	0.2133846E-04	0.2899170E-03	0.2872938E-04	0.9210431E-03	0.6712113E-02
	(20,92)	(27, 2)	(9, 1)	36964.96	439.2700	40.03514
5044	0.1373291E-03	0.2115965E-04	0.3919601E-03	0.2998793E-04	0.9218976E-03	0.1064675E-01
	(18,90)	(24, 4)	(8, 1)	36964.95	439.2698	40.03516
5045	0.1373291E-03	0.2378225E-04	0.5779266E-03	0.3023274E-04	0.9300443E-03	0.1185300E-01
	(13,92)	(24, 2)	(18, 1)	36964.96	439.2700	40.03493
5046	0.1220703E-03	0.3051758E-04	0.4100800E-03	0.3037481E-04	0.9435380E-03	0.9828378E-02
	(21,92)	(18, 2)	(12, 1)	36964.95	439.2695	40.03464
5047	0.1678467E-03	0.2318621E-04	0.5865097E-03	0.3054940E-04	0.9215283E-03	0.1138471E-01
	(17,91)	(21, 2)	(16, 1)	36964.95	439.2695	40.03482
5048	0.1678467E-03	0.3147125E-04	0.4577637E-03	0.3020710E-04	0.9069096E-03	0.8428153E-02
	(14,92)	(16, 2)	(14, 1)	36964.95	439.2686	40.03482
5049	0.1678467E-03	0.2765656E-04	0.3919601E-03	0.2907751E-04	0.8932597E-03	0.1018804E-01
	(14,89)	(18, 2)	(18, 1)	36964.94	439.2683	40.03491
5050	0.1220703E-03	0.2098083E-04	0.3814697E-03	0.2811967E-04	0.9011102E-03	0.1032757E-01
	(18,88)	(17, 2)	(19, 1)	36964.95	439.2683	40.03467

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5051	0.1220703E-03	0.2384186E-04	0.5960464E-03	0.2891931E-04	0.8888422E-03	0.1275934E-01
	(17,85)	(19, 2)	(12, 1)	36964.94	439.2686	40.03477
5052	0.1068115E-03	0.2574921E-04	0.3021955E-03	0.2752632E-04	0.8868647E-03	0.9844007E-02
	(19,92)	(14, 2)	(22, 1)	36954.95	439.2636	40.03465
5053	0.1373291E-03	0.2765656E-04	0.3633499E-03	0.2805340E-04	0.9011310E-03	0.8235261E-02
	(19,92)	(13, 2)	(5, 1)	36964.93	439.2636	40.03444
5054	0.1373291E-03	0.2765656E-04	0.3271103E-03	0.2882739E-04	0.9080332E-03	0.9187549E-02
	(17,91)	(14, 2)	(14, 1)	36964.93	439.2678	40.03432
5055	0.1525879E-03	0.2574921E-04	0.4196167E-03	0.2811955E-04	0.8969586E-03	0.1063487E-01
	(17,92)	(13, 2)	(15, 1)	36964.93	439.2676	40.03429
5056	0.1220703E-03	0.2861023E-04	0.2851486E-03	0.2729899E-04	0.9123427E-03	0.7036187E-02
	(13,89)	(15, 2)	(14, 1)	36964.93	439.2676	40.03409
5057	0.1831055E-03	0.3528595E-04	0.3385544E-03	0.2846391E-04	0.9110451E-03	0.1242282E-01
	(18,88)	(14, 2)	(17, 1)	36964.93	439.2676	40.03401
5058	0.1831055E-03	0.3242493E-04	0.3633499E-03	0.2941256E-04	0.9181297E-03	0.8130733E-02
	(15,90)	(13, 2)	(10, 1)	36964.93	439.2673	40.03381
5059	0.1678467E-03	0.3147125E-04	0.3757477E-03	0.2735080E-04	0.9183413E-03	0.9719305E-02
	(15,92)	(10, 2)	(8, 1)	36964.93	439.2671	40.03371
5060	0.1373291E-03	0.2986193E-04	0.3728867E-03	0.2634990E-04	0.9291554E-03	0.1243641E-01
	(15,92)	(21, 2)	(12, 1)	36964.93	439.2661	40.03349
5061	0.1220703E-03	0.3433228E-04	0.5598068E-03	0.2697967E-04	0.9465518E-03	0.1106507E-01
	(15,91)	(20, 2)	(11, 1)	36964.92	439.2661	40.03319
5062	0.1678467E-03	0.3814697E-04	0.7324219E-03	0.2730533E-04	0.9499732E-03	0.1410455E-01
	(14,92)	(18, 2)	(11, 1)	36964.91	439.2656	40.03305
5063	0.1373291E-03	0.3814697E-04	0.5435944E-03	0.2778311E-04	0.9832731E-03	0.1309839E-01
	(19,92)	(18, 2)	(11, 1)	36964.91	439.2654	40.03258
5064	0.1373291E-03	0.5054474E-04	0.6141663E-03	0.2713141E-04	0.9938807E-03	0.1312166E-01
	(17,87)	(17, 2)	(11, 1)	36964.91	439.2651	40.03230
5065	0.1525879E-03	0.4959106E-04	0.4272461E-03	0.2835759E-04	0.1006987E-02	0.1176592E-01
	(21,92)	(14, 2)	(17, 1)	36964.89	439.2651	40.03198
5066	0.1831055E-03	0.4577637E-04	0.6275177E-03	0.2799286E-04	0.1017252E-02	0.1312425E-01
	(15,89)	(17, 2)	(12, 1)	36964.90	439.2654	40.03175
5067	0.1831055E-03	0.5054474E-04	0.8449554E-03	0.2819599E-04	0.1029234E-02	0.1742905E-01
	(15,91)	(12, 2)	(11, 1)	36964.89	439.2644	40.03146
5068	0.1678467E-03	0.5817413E-04	0.6465912E-03	0.2829370E-04	0.1070256E-02	0.1426445E-01
	(17,87)	(17, 2)	(9, 1)	36964.90	439.2646	40.03091
5069	0.1525879E-03	0.5435944E-04	0.5664825E-03	0.2602144E-04	0.1075076E-02	0.1471501E-01
	(18,86)	(14, 2)	(11, 1)	36964.89	439.2639	40.03067
5070	0.1220703E-03	0.5054474E-04	0.4911423E-03	0.2796727E-04	0.1070946E-02	0.1074620E-01
	(18,92)	(11, 2)	(16, 1)	36964.89	439.2634	40.03046
5071	0.1373291E-03	0.4673004E-04	0.4062653E-03	0.2796174E-04	0.1074077E-02	0.9953976E-02
	(16,86)	(20, 2)	(15, 1)	36964.87	439.2629	40.03023
5072	0.1220703E-03	0.4386902E-04	0.4940033E-03	0.2786473E-04	0.1065191E-02	0.1082572E-01
	(19,89)	(16, 2)	(8, 1)	36964.88	439.2634	40.03009
5073	0.1525879E-03	0.4196167E-04	0.4825592E-03	0.2706640E-04	0.1063399E-02	0.1262376E-01
	(19,85)	(14, 2)	(14, 1)	36964.88	439.2632	40.03001
5074	0.1220703E-03	0.4005432E-04	0.3929138E-03	0.2998076E-04	0.1052680E-02	0.9496745E-02
	(19,87)	(20, 2)	(12, 1)	36964.87	439.2634	40.02991
5075	0.1525879E-03	0.3206730E-04	0.5283356E-03	0.2822118E-04	0.1021912E-02	0.9889007E-02
	(17,92)	(23, 2)	(15, 1)	36964.87	439.2634	40.02998

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5076	0.1831055E-03	0.2682209E-04	0.3986359E-03	0.2863357E-04	0.9778189E-03	0.1227741E-01
	(18,92)	(21, 3)	(14, 1)	36964.88	439.2637	40.03029
5077	0.1831055E-03	0.2533197E-04	0.4739761E-03	0.2942355E-04	0.9268131E-03	0.8885320E-02
	(18,91)	(21, 3)	(15, 1)	36964.87	439.2632	40.03069
5078	0.1373291E-03	0.2390146E-04	0.3166199E-03	0.3046120E-04	0.9164561E-03	0.1194461E-01
	(21,90)	(21, 3)	(11, 1)	36964.87	439.2629	40.03087
5079	0.1373291E-03	0.2211332E-04	0.4281998E-03	0.3045188E-04	0.9110232E-03	0.1047597E-01
	(16,90)	(21, 4)	(14, 1)	36964.87	439.2622	40.03096
5080	0.1831055E-03	0.2175570E-04	0.4949570E-03	0.3180439E-04	0.8977368E-03	0.9036683E-02
	(18,92)	(21, 4)	(12, 1)	36964.86	439.2625	40.03102
5081	0.1983643E-03	0.2157688E-04	0.3547668E-03	0.3095421E-04	0.8923549E-03	0.7672854E-02
	(18,92)	(21, 4)	(12, 1)	36964.87	439.2620	40.03110
5082	0.1678467E-03	0.2098083E-04	0.6151199E-03	0.3205962E-04	0.8892734E-03	0.1501231E-01
	(18,91)	(23, 4)	(12, 1)	36964.87	439.2617	40.03104
5083	0.1373291E-03	0.2866983E-04	0.3728867E-03	0.3191562E-04	0.9179772E-03	0.9298921E-02
	(18,91)	(21, 2)	(10, 1)	36964.87	439.2615	40.03055
5084	0.1220703E-03	0.3051758E-04	0.3871918E-03	0.3186331E-04	0.9254173E-03	0.1234569E-01
	(14,91)	(20, 2)	(14, 1)	36964.87	439.2612	40.03041
5085	0.1525879E-03	0.3051758E-04	0.4034042E-03	0.3217648E-04	0.9469597E-03	0.9582575E-02
	(14,91)	(14, 2)	(16, 1)	36964.87	439.2610	40.03011
5086	0.1373291E-03	0.3463030E-04	0.5140305E-03	0.2997756E-04	0.9604630E-03	0.1100983E-01
	(18,90)	(21, 2)	(7, 1)	36964.86	439.2603	40.02988
5087	0.1525879E-03	0.3528595E-04	0.5130768E-03	0.2962687E-04	0.9581458E-03	0.1445206E-01
	(14,90)	(17, 2)	(6, 1)	36964.86	439.2603	40.02979
5088	0.1373291E-03	0.3337860E-04	0.4177094E-03	0.3247282E-04	0.9611794E-03	0.1126930E-01
	(21,87)	(15, 2)	(10, 1)	36964.86	439.2603	40.02953
5089	0.1525879E-03	0.2801418E-04	0.3566742E-03	0.3396573E-04	0.9554601E-03	0.7710226E-02
	(20,92)	(21, 2)	(16, 1)	36964.85	439.2598	40.02945
5090	0.1525879E-03	0.2861023E-04	0.3662109E-03	0.3339014E-04	0.9572885E-03	0.8443099E-02
	(18,92)	(18, 2)	(10, 1)	36964.84	439.2603	40.02930
5091	0.1983643E-03	0.2759695E-04	0.4196167E-03	0.3341166E-04	0.9497858E-03	0.9349599E-02
	(14,90)	(21, 2)	(10, 1)	36964.84	439.2605	40.02921
5092	0.1525879E-03	0.3010035E-04	0.4043579E-03	0.3312877E-04	0.9273470E-03	0.8817099E-02
	(21,90)	(23, 2)	(21, 1)	36964.84	439.2603	40.02936
5093	0.1831055E-03	0.3004074E-04	0.4358292E-03	0.3395125E-04	0.9170268E-03	0.1101996E-01
	(21,92)	(22, 2)	(19, 1)	36964.84	439.2598	40.02936
5094	0.1525879E-03	0.3194809E-04	0.6790161E-03	0.3410418E-04	0.9110149E-03	0.1248249E-01
	(18,92)	(21, 2)	(16, 1)	36964.84	439.2593	40.02934
5095	0.1525879E-03	0.3242493E-04	0.5054474E-03	0.3173055E-04	0.9230716E-03	0.9678282E-02
	(18,91)	(16, 2)	(15, 1)	36964.82	439.2588	40.02907
5096	0.1678467E-03	0.3910065E-04	0.4281998E-03	0.3235207E-04	0.9269109E-03	0.1215373E-01
	(16,91)	(15, 2)	(10, 1)	36964.82	439.2583	40.02902
5097	0.1831055E-03	0.3528595E-04	0.4491806E-03	0.3327538E-04	0.9322299E-03	0.1016013E-01
	(20,87)	(14, 2)	(9, 1)	36964.81	439.2576	40.02887
5098	0.1983643E-03	0.3242493E-04	0.3414154E-03	0.3382019E-04	0.9353196E-03	0.1011027E-01
	(14,91)	(15, 2)	(18, 1)	36964.81	439.2571	40.02876
5099	0.1983643E-03	0.2670288E-04	0.4348755E-03	0.3356951E-04	0.9172244E-03	0.9897716E-02
	(20,92)	(19, 2)	(11, 1)	36964.81	439.2573	40.02885
5100	0.1525879E-03	0.3051758E-04	0.4081726E-03	0.3307901E-04	0.9241563E-03	0.1136728E-01
	(20,92)	(17, 2)	(15, 1)	36964.80	439.2571	40.02861

CONVERGENCE TEST ON GRID AFTER 5100 ITERATIONS:

MAXIMUM CHANGES OVER GRID:

STREAM FUNCTION= 0.2136230E-03 BULK VORTICITY= 0.2765656E-04 SURFACE VORTICITY= 0.3671646E-03

AVERAGE % CHANGE OVER GRID:

STREAM FUNCTION= 0.3553228E-04 BULK VORTICITY= 0.8203802E-03 SURFACE VORTICITY= 0.1023141E-01

WITH RELAXATION:

MAXIMUM CHANGES OVER GRID:

STREAM FUNCTION= 0.3845200E-03 BULK VORTICITY= 0.5531310E-05 SURFACE VORTICITY= 0.3671645E-04

AVERAGE % CHANGE OVER GRID:

STREAM FUNCTION= 0.6395788E-04 BULK VORTICITY= 0.1640760E-03 SURFACE VORTICITY= 0.1023140E-02

AVERAGING THE STEP TO STEP CHANGES OVER THE LAST 100 ITERATIONS:

OVERALL % CHANGES,(NO RELAXATION):

STREAM FUNCTION= 0.3002149E-04 BULK VORTICITY= 0.9792482E-03 SURFACE VORTICITY= 0.1076943E-01

WITH RELAXATION:

OVERALL % CHANGES,(NO RELAXATION):

STREAM FUNCTION= 0.5403848E-04 BULK VORTICITY= 0.1958496E-03 SURFACE VORTICITY= 0.1076942E-02

RINF= 100.000000 RE= 10.000000

SIZE OF GRID= 33 X 93

NUMBER OF ITERATIONS= 5100

SURFACE VORTICITY DISTRIBUTION

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THETAG( 1)= 0.0               VORTICITY( 1,1)= 0.0
THETAG( 2)= 0.9817475E-01     VORTICITY( 2,1)= 0.4397055
THETAG( 3)= 0.1963495         VORTICITY( 3,1)= 0.8673537
THETAG( 4)= 0.2945243         VORTICITY( 4,1)=  1.271414
THETAG( 5)= 0.3926990         VORTICITY( 5,1)=  1.641084
THETAG( 6)= 0.4908738         VORTICITY( 6,1)=  1.966905
THETAG( 7)= 0.5890485         VORTICITY( 7,1)=  2.241029
THETAG( 8)= 0.6872233         VORTICITY( 8,1)=  2.457419
THETAG( 9)= 0.7853980         VORTICITY( 9,1)=  2.612244
THETAG(10)= 0.8835728         VORTICITY(10,1)=  2.703779
THETAG(11)= 0.9817475         VORTICITY(11,1)=  2.732823
THETAG(12)=  1.079922         VORTICITY(12,1)=  2.702162
THETAG(13)=  1.178097         VORTICITY(13,1)=  2.616772
THETAG(14)=  1.276271         VORTICITY(14,1)=  2.483301
THETAG(15)=  1.374446         VORTICITY(15,1)=  2.309817
THETAG(16)=  1.472621         VORTICITY(16,1)=  2.105314
THETAG(17)=  1.570796         VORTICITY(17,1)=  1.879213
THETAG(18)=  1.668970         VORTICITY(18,1)=  1.640827
THETAG(19)=  1.767145         VORTICITY(19,1)=  1.398988
THETAG(20)=  1.865320         VORTICITY(20,1)=  1.161667
THETAG(21)=  1.963494         VORTICITY(21,1)= 0.9356664
THETAG(22)=  2.061669         VORTICITY(22,1)= 0.7265244
THETAG(23)=  2.159844         VORTICITY(23,1)= 0.5384942
THETAG(24)=  2.258018         VORTICITY(24,1)= 0.3746592
THETAG(25)=  2.356194         VORTICITY(25,1)= 0.2370090
THETAG(26)=  2.454369         VORTICITY(26,1)= 0.1265936
THETAG(27)=  2.552543         VORTICITY(27,1)= 0.4355459E-01
THETAG(28)=  2.650718         VORTICITY(28,1)=-0.1290640E-01
THETAG(29)=  2.748893         VORTICITY(29,1)=-0.4462809E-01
THETAG(30)=  2.847067         VORTICITY(30,1)=-0.5456545E-01
THETAG(31)=  2.945242         VORTICITY(31,1)=-0.4684433E-01
THETAG(32)=  3.043417         VORTICITY(32,1)=-0.2665148E-01
THETAG(33)=  3.141592         VORTICITY(33,1)= 0.0
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SURFACE PRESSURE DISTRIBUTION

THETAG(3)= 0.1963495	SURFACE PRESSURE(3)= 1.393917
THETAG(5)= 0.3926990	SURFACE PRESSURE(5)= 1.138027
THETAG(7)= 0.5890485	SURFACE PRESSURE(7)= 0.7583042
THETAG(9)= 0.7853980	SURFACE PRESSURE(9)= 0.3139000
THETAG(11)= 0.9817475	SURFACE PRESSURE(11)=-0.1310129
THETAG(13)= 1.178097	SURFACE PRESSURE(13)=-0.5205097
THETAG(15)= 1.374446	SURFACE PRESSURE(15)=-0.8168278
THETAG(17)= 1.570796	SURFACE PRESSURE(17)= -1.004923
THETAG(19)= 1.767145	SURFACE PRESSURE(19)= -1.090684
THETAG(21)= 1.963494	SURFACE PRESSURE(21)= -1.094018
THETAG(23)= 2.159844	SURFACE PRESSURE(23)= -1.040699
THETAG(25)= 2.356194	SURFACE PRESSURE(25)=-0.9556675
THETAG(27)= 2.552543	SURFACE PRESSURE(27)=-0.8605127
THETAG(29)= 2.748893	SURFACE PRESSURE(29)=-0.7741785
THETAG(31)= 2.945242	SURFACE PRESSURE(31)=-0.7136545
THETAG(33)= 3.141592	SURFACE PRESSURE(33)=-0.6918373

DRAG PARAMETERS

AFTER 5100 ITERATIONS:

R-INFINITY= 100.0000 REYNOLDS NO.= 10.00000

SIZE OF GRID= 33X93

FRONTAL STAGNATION PRESSURE= 1.484224

REAR STAGNATION PRESSURE=-0.6918373

THE SKIN DRAG COEFFICIENT= 1.223155

THE FORM DRAG COEFFICIENT= 1.559752

CDSKIN/CDFORM= 0.7841986

THE TOTAL DRAG COEFFICIENT = 2.782907

STOKES(1)= 0.5000000

STOKES(2)= 1.000000

XKAP(1)= 0.9999999E-03

XKAP(2)= 0.2000000

INITIAL VARIABLES

RINF= 100.000 REYNOLD'S NO.= 10.000

XP(1)= -100.0000

SIZE OF GRID= 33 X 93

NUMBER OF STEPS PER GRID CELL= 3.000000

***** NUMERICALLY CALCULATED FLOWFIELD USED *******

****** EFFICIENCY WITH INTERCEPTION *******

STOKES' NO.= 0.500	EFFICIENCY= 0.37953890860E-02	DP/DF= 0.001000	I= 0.37915995345E-02
STOKES' NO.= 1.000	EFFICIENCY= 0.10445642471	DP/DF= 0.001000	I= 0.10435211658

****** EFFICIENCY WITH INTERCEPTION *******

STOKES' NO.= 0.500	EFFICIENCY= 0.10357707739	DP/DF= 0.200000	I= 0.86314201355E-01
STOKES' NO.= 1.000	EFFICIENCY= 0.22413486242	DP/DF= 0.200000	I= 0.18677902222

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5101	0.1525879E-03	0.2861023E-04	0.4472733E-03	0.3293085E-04	0.9202289E-03	0.1017817E-01
	(21,90)	(15, 2)	(9, 1)	36964.80	439.2566	40.02858
5102	0.1831055E-03	0.2038479E-04	0.3614426E-03	0.3154232E-04	0.9017966E-03	0.9537667E-02
	(21,89)	(22, 4)	(20, 1)	36964.79	439.2566	40.02858
5103	0.1983643E-03	0.2098083E-04	0.4014969E-03	0.3243212E-04	0.8837758E-03	0.9403102E-02
	(18,89)	(20, 2)	(11, 1)	36964.80	439.2561	40.02873
5104	0.1525879E-03	0.2002716E-04	0.5340576E-03	0.3314609E-04	0.8581837E-03	0.8910235E-02
	(19,87)	(11, 2)	(11, 1)	36964.79	439.2561	40.02895
5105	0.1525879E-03	0.1966953E-04	0.2737045E-03	0.3295981E-04	0.8415550E-03	0.7976297E-02
	(15,89)	(22, 4)	(19, 1)	36964.79	439.2561	40.02907
5106	0.1373291E-03	0.1931190E-04	0.5102158E-03	0.3377380E-04	0.8385049E-03	0.9439100E-02
	(16,90)	(23, 4)	(12, 1)	36964.78	439.2563	40.02902
5107	0.1068115E-03	0.1919270E-04	0.6866455E-03	0.3379780E-04	0.8372634E-03	0.1452914E-01
	(19,90)	(22, 4)	(10, 1)	36964.79	439.2559	40.02899
5108	0.1068115E-03	0.2384186E-04	0.7324219E-03	0.3457602E-04	0.8458628E-03	0.1805339E-01
	(17,92)	(10, 2)	(20, 1)	36964.78	439.2556	40.02885
5109	0.1373291E-03	0.2574921E-04	0.5865097E-03	0.3403919E-04	0.8927474E-03	0.1715757E-01
	(16,86)	(20, 2)	(7, 1)	36964.76	439.2554	40.02831
5110	0.1373291E-03	0.3147125E-04	0.6628036E-03	0.3397473E-04	0.9334281E-03	0.1254840E-01
	(17,87)	(16, 2)	(6, 1)	36964.76	439.2549	40.02777
5111	0.1678467E-03	0.3802776E-04	0.7190704E-03	0.3242098E-04	0.9566867E-03	0.1513172E-01
	(21,92)	(21, 2)	(12, 1)	36964.75	439.2546	40.02744
5112	0.1525879E-03	0.4577637E-04	0.5559458E-03	0.3375584E-04	0.9703676E-03	0.1376224E-01
	(21,91)	(12, 2)	(10, 1)	36964.75	439.2542	40.02715
5113	0.1373291E-03	0.4673004E-04	0.7534027E-03	0.3390828E-04	0.9906034E-03	0.1222955E-01
	(21,92)	(17, 2)	(9, 1)	36964.74	439.2537	40.02679
5114	0.1831055E-03	0.4673004E-04	0.6437302E-03	0.3484829E-04	0.1002122E-02	0.1176801E-01
	(18,91)	(12, 2)	(8, 1)	36964.75	439.2520	40.02649
5115	0.1831055E-03	0.4291534E-04	0.5426407E-03	0.3190218E-04	0.9949040E-03	0.9765130E-02
	(18,90)	(13, 2)	(12, 1)	36964.75	439.2529	40.02637
5116	0.1220703E-03	0.4386902E-04	0.4053116E-03	0.3239006E-04	0.9976812E-03	0.1078199E-01
	(20,88)	(12, 2)	(7, 1)	36964.73	439.2527	40.02620
5117	0.1678467E-03	0.3719330E-04	0.4005432E-03	0.3327448E-04	0.9951408E-03	0.1058685E-01
	(17,91)	(19, 2)	(19, 1)	36964.73	439.2517	40.02609
5118	0.2136230E-03	0.3337860E-04	0.6093979E-03	0.3332338E-04	0.9718870E-03	0.1331570E-01
	(19,92)	(13, 2)	(12, 1)	36964.73	439.2512	40.02612
5119	0.1678467E-03	0.3623962E-04	0.5102158E-03	0.3220805E-04	0.9638444E-03	0.1501269E-01
	(19,92)	(16, 2)	(11, 1)	36964.73	439.2512	40.02615
5120	0.1525879E-03	0.3623962E-04	0.3881454E-03	0.3394697E-04	0.9498487E-03	0.9322476E-02
	(14,92)	(18, 2)	(16, 1)	36964.74	439.2510	40.02611
5121	0.1678467E-03	0.3433228E-04	0.3700256E-03	0.3390742E-04	0.9405264E-03	0.8800782E-02
	(14,92)	(16, 2)	(18, 1)	36964.72	439.2502	40.02608
5122	0.1373291E-03	0.3242493E-04	0.4644394E-03	0.3352184E-04	0.9290185E-03	0.1153548E-01
	(14,91)	(18, 2)	(10, 1)	36964.73	439.2502	40.02605
5123	0.1525879E-03	0.3147125E-04	0.4329681E-03	0.3282570E-04	0.9228615E-03	0.8993808E-02
	(18,90)	(16, 2)	(14, 1)	36964.73	439.2498	40.02605
5124	0.1373291E-03	0.2765656E-04	0.4205704E-03	0.3422948E-04	0.9117709E-03	0.1224850E-01
	(17,90)	(14, 2)	(11, 1)	36964.72	439.2493	40.02602
5125	0.1525879E-03	0.3147125E-04	0.6465912E-03	0.3203607E-04	0.9240999E-03	0.1271359E-01
	(18,92)	(18, 2)	(18, 1)	36964.73	439.2488	40.02580

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5126	0.1525879E-03	0.2765656E-04	0.4472733E-03	0.3309744E-04	0.8955309E-03	0.1145375E-01
	(14,92)	(16, 2)	(17, 1)	36964.71	439.2483	40.02600
5127	0.1831055E-03	0.2098083E-04	0.5178452E-03	0.3297126E-04	0.8802901E-03	0.9564206E-02
	(18,91)	(14, 2)	(10, 1)	36964.72	439.2476	40.02609
5128	0.1678467E-03	0.2479553E-04	0.3204346E-03	0.3182217E-04	0.8966681E-03	0.1160000E-01
	(18,90)	(13, 2)	(19, 1)	36964.72	439.2471	40.02585
5129	0.1220703E-03	0.1919270E-04	0.5064011E-03	0.3380323E-04	0.8545844E-03	0.9834450E-02
	(20,91)	(21, 4)	(17, 1)	36964.71	439.2466	40.02617
5130	0.1220703E-03	0.1913309E-04	0.2622504E-03	0.3253327E-04	0.8509515E-03	0.9271096E-02
	(15,86)	(22, 4)	(14, 1)	36964.70	439.2463	40.02621
5131	0.1678467E-03	0.1907349E-04	0.2727509E-03	0.3274276E-04	0.8401666E-03	0.9040929E-02
	(11,92)	(21, 4)	(14, 1)	36964.70	439.2454	40.02638
5132	0.1373291E-03	0.1841784E-04	0.4854202E-03	0.3180435E-04	0.8188938E-03	0.9410653E-02
	(18,91)	(21, 4)	(11, 1)	36964.70	439.2456	40.02643
5133	0.1220703E-03	0.1907349E-04	0.4853739E-03	0.3036794E-04	0.8227886E-03	0.9809572E-02
	(18,91)	(11, 2)	(11, 1)	36964.69	439.2458	40.02650
5134	0.1068115E-03	0.2002716E-04	0.5054474E-03	0.3135735E-04	0.8237415E-03	0.1150986E-01
	(19,86)	(10, 2)	(18, 1)	36964.69	439.2456	40.02643
5135	0.1220703E-03	0.2098083E-04	0.4110336E-03	0.3361104E-04	0.8388909E-03	0.8612312E-02
	(21,92)	(8, 2)	(8, 1)	36964.70	439.2451	40.02615
5136	0.1525879E-03	0.1907349E-04	0.4100800E-03	0.3262611E-04	0.8300620E-03	0.9977695E-02
	(18,92)	(17, 2)	(16, 1)	36964.69	439.2449	40.02620
5137	0.1373291E-03	0.2002716E-04	0.6542206E-03	0.3228027E-04	0.8315756E-03	0.1308735E-01
	(17,91)	(16, 2)	(16, 1)	36964.69	439.2449	40.02625
5138	0.1678467E-03	0.2056360E-04	0.4053116E-03	0.3141037E-04	0.8158921E-03	0.9517547E-02
	(16,90)	(22, 2)	(8, 1)	36964.69	439.2449	40.02646
5139	0.1678467E-03	0.2050400E-04	0.4362454E-03	0.3130041E-04	0.8100693E-03	0.1192757E-01
	(14,91)	(21, 2)	(24, 1)	36964.69	439.2444	40.02658
5140	0.1220703E-03	0.1907349E-04	0.4615784E-03	0.3314498E-04	0.7935110E-03	0.9460393E-02
	(17,92)	(12, 2)	(12, 1)	36964.70	439.2444	40.02681
5141	0.1220703E-03	0.1680851E-04	0.3414154E-03	0.3221093E-04	0.7851452E-03	0.9391584E-02
	(16,91)	(21, 5)	(11, 1)	36964.68	439.2446	40.02673
5142	0.1220703E-03	0.1716614E-04	0.3175735E-03	0.3296748E-04	0.7952419E-03	0.1008053E-01
	(15,90)	(9, 2)	(5, 1)	36964.69	439.2439	40.02660
5143	0.2136230E-03	0.1651049E-04	0.4989505E-03	0.3324146E-04	0.7861641E-03	0.1258286E-01
	(21,92)	(23, 5)	(23, 1)	36964.68	439.2434	40.02658
5144	0.1220703E-03	0.2479553E-04	0.6188154E-03	0.3296672E-04	0.8125771E-03	0.1267414E-01
	(21,88)	(15, 2)	(21, 1)	36964.68	439.2434	40.02625
5145	0.1678467E-03	0.3099442E-04	0.5998611E-03	0.3262643E-04	0.8123573E-03	0.1048648E-01
	(18,90)	(21, 2)	(18, 1)	36964.66	439.2432	40.02605
5146	0.1220703E-03	0.3337860E-04	0.6322861E-03	0.3021062E-04	0.8279241E-03	0.1208891E-01
	(21,92)	(18, 2)	(16, 1)	36964.68	439.2429	40.02580
5147	0.1525879E-03	0.4005432E-04	0.4768372E-03	0.3066452E-04	0.8388185E-03	0.1028015E-01
	(16,86)	(16, 2)	(17, 1)	36964.67	439.2419	40.02562
5148	0.1373291E-03	0.3147125E-04	0.6237030E-03	0.2904626E-04	0.8367079E-03	0.1160427E-01
	(20,87)	(15, 2)	(17, 1)	36964.67	439.2417	40.02545
5149	0.1373291E-03	0.3623962E-04	0.5369186E-03	0.3011247E-04	0.8565048E-03	0.1274844E-01
	(17,92)	(17, 2)	(10, 1)	36964.68	439.2417	40.02516
5150	0.1525879E-03	0.4673004E-04	0.4959106E-03	0.3185870E-04	0.8573621E-03	0.1159762E-01
	(14,89)	(14, 2)	(9, 1)	36964.67	439.2415	40.02505

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5151	0.1220703E-03	0.3337860E-04	0.3166199E-03	0.3117410E-04	0.8400362E-03	0.8597154E-02
	(19,92)	(9, 2)	(16, 1)	36964.68	439.2412	40.02510
5152	0.1220703E-03	0.2956390E-04	0.3590584E-03	0.3163521E-04	0.8208160E-03	0.1066765E-01
	(19,91)	(11, 2)	(23, 1)	36964.66	439.2410	40.02519
5153	0.1373291E-03	0.3337860E-04	0.3267527E-03	0.3193585E-04	0.8239138E-03	0.1052067E-01
	(18,88)	(10, 2)	(23, 1)	36964.66	439.2410	40.02515
5154	0.1525879E-03	0.3337860E-04	0.4062553E-03	0.3045026E-04	0.8288133E-03	0.9871166E-02
	(21,91)	(9, 2)	(18, 1)	36964.66	439.2402	40.02496
5155	0.1525879E-03	0.2956390E-04	0.5526543E-03	0.3021384E-04	0.8236628E-03	0.1544328E-01
	(14,90)	(8, 2)	(21, 1)	36964.66	439.2405	40.02498
5156	0.1373291E-03	0.2574921E-04	0.3919601E-03	0.2868772E-04	0.8406718E-03	0.1031034E-01
	(19,88)	(10, 2)	(18, 1)	36964.64	439.2405	40.02469
5157	0.1220703E-03	0.2765656E-04	0.4901886E-03	0.2942474E-04	0.8470046E-03	0.9652134E-02
	(19,88)	(9, 2)	(11, 1)	36964.64	439.2397	40.02454
5158	0.1373291E-03	0.2193451E-04	0.2689362E-03	0.3025726E-04	0.8215629E-03	0.8372549E-02
	(20,87)	(20, 2)	(13, 1)	36964.63	439.2390	40.02466
5159	0.1525879E-03	0.2098083E-04	0.4587173E-03	0.3070058E-04	0.8000308E-03	0.1258453E-01
	(17,87)	(18, 2)	(16, 1)	36964.64	439.2383	40.02480
5160	0.1373291E-03	0.2670288E-04	0.4615784E-03	0.3041844E-04	0.8260032E-03	0.7676132E-02
	(21,90)	(16, 2)	(14, 1)	36964.63	439.2383	40.02452
5161	0.1373291E-03	0.2861023E-04	0.3099442E-03	0.3052149E-04	0.8318427E-03	0.7864319E-02
	(21,91)	(15, 2)	(11, 1)	36964.64	439.2383	40.02435
5162	0.1373291E-03	0.2574921E-04	0.4062553E-03	0.2993536E-04	0.8396704E-03	0.1113588E-01
	(16,88)	(18, 2)	(9, 1)	36964.64	439.2380	40.02432
5163	0.1678467E-03	0.2670288E-04	0.3871918E-03	0.2990059E-04	0.8322184E-03	0.9258516E-02
	(18,92)	(12, 2)	(12, 1)	36964.64	439.2378	40.02423
5164	0.1373291E-03	0.2104044E-04	0.5187988E-03	0.3129007E-04	0.8188190E-03	0.1081047E-01
	(18,92)	(23, 2)	(20, 1)	36964.63	439.2378	40.02426
5165	0.1373291E-03	0.2866983E-04	0.4281998E-03	0.3045906E-04	0.8239201E-03	0.1116202E-01
	(20,89)	(21, 2)	(18, 1)	36964.63	439.2375	40.02405
5166	0.1525879E-03	0.3147125E-04	0.4310012E-03	0.3006024E-04	0.8124067E-03	0.9532835E-02
	(18,88)	(19, 2)	(24, 1)	36964.63	439.2375	40.02415
5167	0.1373291E-03	0.2539158E-04	0.3433228E-03	0.3093020E-04	0.8274384E-03	0.9098556E-02
	(18,89)	(25, 2)	(16, 1)	36964.62	439.2371	40.02386
5168	0.1525879E-03	0.2825260E-04	0.4024506E-03	0.3118849E-04	0.8238051E-03	0.8500364E-02
	(18,90)	(22, 2)	(20, 1)	36964.63	439.2368	40.02376
5169	0.1525879E-03	0.3433228E-04	0.3395081E-03	0.3217961E-04	0.8246000E-03	0.8604340E-02
	(18,89)	(21, 2)	(11, 1)	36964.62	439.2373	40.02376
5170	0.1525879E-03	0.2676249E-04	0.5264282E-03	0.3193643E-04	0.8219311E-03	0.1173250E-01
	(18,88)	(22, 2)	(9, 1)	36964.61	439.2371	40.02373
5171	0.1983643E-03	0.3337860E-04	0.3519058E-03	0.3282427E-04	0.8351966E-03	0.9790957E-02
	(13,90)	(19, 2)	(8, 1)	36964.61	439.2368	40.02354
5172	0.1373291E-03	0.3337860E-04	0.4730225E-03	0.3253714E-04	0.8391931E-03	0.1058556E-01
	(22,91)	(18, 2)	(18, 1)	36964.61	439.2363	40.02344
5173	0.1220703E-03	0.1907349E-04	0.3433228E-03	0.3281455E-04	0.8056690E-03	0.1114503E-01
	(22,92)	(8, 2)	(14, 1)	36964.62	439.2358	40.02373
5174	0.1220703E-03	0.1752377E-04	0.4644394E-03	0.3187274E-04	0.7870398E-03	0.1074778E-01
	(19,89)	(21, 3)	(15, 1)	36964.61	439.2361	40.02393
5175	0.1373291E-03	0.2098083E-04	0.4558563E-03	0.3170675E-04	0.7804993E-03	0.7639598E-02
	(19,91)	(16, 2)	(7, 1)	36964.61	439.2358	40.02390

ITER	MAX STREAM	MAX VORT/B	MAX VORT/S	%AVG STREAM	%AVG VORT/B	%AVG VORT/S
5176	0.1373291E-03	0.1651049E-04	0.4501343E-03	0.3292257E-04	0.7735160E-03	0.1258557E-01
	(22,92)	(21, 3)	(14, 1)	36964.61	439.2351	40.02388
5177	0.1678467E-03	0.2765656E-04	0.5002618E-03	0.3394348E-04	0.7854973E-03	0.1109088E-01
	(13,92)	(14, 2)	(22, 1)	36964.60	439.2344	40.02374
5178	0.1373291E-03	0.2384186E-04	0.6132126E-03	0.3475121E-04	0.7721498E-03	0.1043851E-01
	(22,91)	(16, 2)	(14, 1)	36964.60	439.2349	40.02376
5179	0.1525879E-03	0.3814697E-04	0.3948212E-03	0.3355832E-04	0.7785165E-03	0.9449814E-02
	(14,90)	(14, 2)	(13, 1)	36964.60	439.2336	40.02348
5180	0.1373291E-03	0.3528595E-04	0.4291534E-03	0.3457109E-04	0.7793258E-03	0.1092031E-01
	(18,89)	(13, 2)	(11, 1)	36964.59	439.2334	40.02351
5181	0.1678467E-03	0.3147125E-04	0.7314682E-03	0.3381944E-04	0.7695551E-03	0.1138190E-01
	(18,90)	(12, 2)	(10, 1)	36964.58	439.2334	40.02353
5182	0.1831055E-03	0.3433228E-04	0.4186630E-03	0.3441382E-04	0.7814635E-03	0.9880714E-02
	(16,87)	(10, 2)	(9, 1)	36964.59	439.2327	40.02330
5183	0.1831055E-03	0.3337860E-04	0.3871918E-03	0.3489738E-04	0.7724750E-03	0.1114659E-01
	(16,86)	(11, 2)	(20, 1)	36964.59	439.2327	40.02341
5184	0.1525879E-03	0.2002716E-04	0.5054474E-03	0.3421077E-04	0.7729153E-03	0.1099887E-01
	(18,89)	(10, 2)	(19, 1)	36964.59	439.2324	40.02322
5185	0.1373291E-03	0.2479553E-04	0.8211136E-03	0.3657078E-04	0.7799545E-03	0.1230837E-01
	(17,88)	(20, 2)	(16, 1)	36964.57	439.2319	40.02315
5186	0.1831055E-03	0.3528595E-04	0.3690720E-03	0.3681889E-04	0.8071980E-03	0.7777546E-02
	(17,88)	(16, 2)	(14, 1)	36964.57	439.2317	40.02277
5187	0.1678467E-03	0.3147125E-04	0.3554225E-03	0.3747032E-04	0.8012035E-03	0.1205339E-01
	(15,91)	(14, 2)	(23, 1)	36964.56	439.2314	40.02267
5188	0.1678467E-03	0.2765656E-04	0.5693436E-03	0.3539181E-04	0.7612389E-03	0.1044398E-01
	(14,90)	(13, 2)	(18, 1)	36964.57	439.2312	40.02298
5189	0.1831055E-03	0.2670288E-04	0.4920959E-03	0.3493614E-04	0.7554095E-03	0.1104842E-01
	(16,86)	(14, 2)	(15, 1)	36964.56	439.2314	40.02312
5190	0.1831055E-03	0.2670288E-04	0.3585815E-03	0.3434271E-04	0.7469167E-03	0.8223616E-02
	(19,91)	(13, 2)	(13, 1)	36964.55	439.2314	40.02318
5191	0.1831055E-03	0.2002716E-04	0.4806519E-03	0.3720382E-04	0.7301252E-03	0.7496517E-02
	(21,91)	(9, 2)	(11, 1)	36964.55	439.2314	40.02327
5192	0.1373291E-03	0.3147125E-04	0.4587173E-03	0.3480699E-04	0.7357909E-03	0.9944715E-02
	(21,92)	(11, 2)	(11, 1)	36964.54	439.2312	40.02312
5193	0.1678467E-03	0.2574921E-04	0.3633499E-03	0.3404399E-04	0.7466075E-03	0.3647043E-02
	(14,91)	(10, 2)	(11, 1)	36964.54	439.2305	40.02295
5194	0.1373291E-03	0.2384186E-04	0.4034042E-03	0.3560616E-04	0.7480343E-03	0.1068610E-01
	(19,92)	(11, 2)	(11, 1)	36964.53	439.2302	40.02287
5195	0.1373291E-03	0.1811981E-04	0.4472733E-03	0.3242130E-04	0.7462255E-03	0.1234925E-01
	(18,92)	(19, 2)	(16, 1)	36964.53	439.2297	40.02281
5196	0.1220703E-03	0.2098083E-04	0.5025864E-03	0.3121325E-04	0.7637648E-03	0.1366163E-01
	(21,91)	(14, 2)	(10, 1)	36964.53	439.2297	40.02257
5197	0.1220703E-03	0.2574921E-04	0.3242493E-03	0.3084702E-04	0.7946694E-03	0.9771109E-02
	(18,90)	(11, 2)	(13, 1)	36964.53	439.2295	40.02223
5198	0.1525879E-03	0.2741814E-04	0.2840757E-03	0.3122889E-04	0.7987283E-03	0.7034298E-02
	(20,91)	(23, 2)	(21, 1)	36964.53	439.2292	40.02208
5199	0.1525879E-03	0.2956390E-04	0.2794266E-03	0.3108681E-04	0.8029361E-03	0.9586308E-02
	(20,92)	(21, 2)	(9, 1)	36964.51	439.2290	40.02191
5200	0.1525879E-03	0.3242493E-04	0.5722046E-03	0.3081716E-04	0.8205713E-03	0.1440017E-01
	(22,89)	(20, 2)	(11, 1)	36964.52	439.2285	40.02161

CONVERGENCE TEST ON GRID AFTER 5200 ITERATIONS:

MAXIMUM CHANGES OVER GRID:

STREAM FUNCTION= 0.1525879E-03 BULK VORTICITY= 0.3719330E-04 SURFACE VORTICITY= 0.5149841E-03

AVERAGE % CHANGE OVER GRID:

STREAM FUNCTION= 0.3176701E-04 BULK VORTICITY= 0.7528174E-03 SURFACE VORTICITY= 0.1294620E-01

WITH RELAXATION:

MAXIMUM CHANGES OVER GRID:

STREAM FUNCTION= 0.2746570E-03 BULK VORTICITY= 0.7438659E-05 SURFACE VORTICITY= 0.5149838E-04

AVERAGE % CHANGE OVER GRID:

STREAM FUNCTION= 0.5718040E-04 BULK VORTICITY= 0.1505635E-03 SURFACE VORTICITY= 0.1294619E-02

AVERAGING THE STEP TO STEP CHANGES OVER THE LAST 100 ITERATIONS:

OVERALL % CHANGES,(NO RELAXATION):

STREAM FUNCTION= 0.3259513E-04 BULK VORTICITY= 0.8388790E-03 SURFACE VORTICITY= 0.1075931E-01

WITH RELAXATION:

OVERALL % CHANGES,(NO RELAXATION):

STREAM FUNCTION= 0.5867101E-04 BULK VORTICITY= 0.1677758E-03 SURFACE VORTICITY= 0.1075931E-02

RINF= 100.000000 RE= 10.000000

SIZE OF GRID= 33 X 93

NUMBER OF ITERATIONS= 5200

SURFACE VORTICITY DISTRIBUTION

THETAG(1)=	0.0	VORTICITY(1,1)=	0.0
THETAG(2)=	0.9817475E-01	VORTICITY(2,1)=	0.4396651
THETAG(3)=	0.1963495	VORTICITY(3,1)=	0.8672954
THETAG(4)=	0.2945243	VORTICITY(4,1)=	1.271282
THETAG(5)=	0.3926990	VORTICITY(5,1)=	1.640920
THETAG(6)=	0.4908738	VORTICITY(6,1)=	1.966743
THETAG(7)=	0.5890485	VORTICITY(7,1)=	2.240809
THETAG(8)=	0.6872233	VORTICITY(8,1)=	2.457161
THETAG(9)=	0.7853980	VORTICITY(9,1)=	2.611959
THETAG(10)=	0.8835728	VORTICITY(10,1)=	2.703513
THETAG(11)=	0.9817475	VORTICITY(11,1)=	2.732471
THETAG(12)=	1.079922	VORTICITY(12,1)=	2.701795
THETAG(13)=	1.178097	VORTICITY(13,1)=	2.616419
THETAG(14)=	1.276271	VORTICITY(14,1)=	2.482941
THETAG(15)=	1.374446	VORTICITY(15,1)=	2.309456
THETAG(16)=	1.472621	VORTICITY(16,1)=	2.104969
THETAG(17)=	1.570796	VORTICITY(17,1)=	1.878827
THETAG(18)=	1.668970	VORTICITY(18,1)=	1.640441
THETAG(19)=	1.767145	VORTICITY(19,1)=	1.398632
THETAG(20)=	1.865320	VORTICITY(20,1)=	1.161340
THETAG(21)=	1.963494	VORTICITY(21,1)=	0.9353606
THETAG(22)=	2.061669	VORTICITY(22,1)=	0.7262393
THETAG(23)=	2.159844	VORTICITY(23,1)=	0.5382329
THETAG(24)=	2.258018	VORTICITY(24,1)=	0.3744163
THETAG(25)=	2.356194	VORTICITY(25,1)=	0.2367879
THETAG(26)=	2.454369	VORTICITY(26,1)=	0.1263933
THETAG(27)=	2.552543	VORTICITY(27,1)=	0.4337758E-01
THETAG(28)=	2.650718	VORTICITY(28,1)=	-0.1306023E-01
THETAG(29)=	2.748893	VORTICITY(29,1)=	-0.4475339E-01
THETAG(30)=	2.847067	VORTICITY(30,1)=	-0.5466870E-01
THETAG(31)=	2.945242	VORTICITY(31,1)=	-0.4692010E-01
THETAG(32)=	3.043417	VORTICITY(32,1)=	-0.2669584E-01
THETAG(33)=	3.141592	VORTICITY(33,1)=	0.0

SURFACE PRESSURE DISTRIBUTION

THETAG(3)= 0.1963495	SURFACE PRESSURE(3)= 1.393908
THETAG(5)= 0.3926990	SURFACE PRESSURE(5)= 1.138104
THETAG(7)= 0.5890485	SURFACE PRESSURE(7)= 0.7584244
THETAG(9)= 0.7853980	SURFACE PRESSURE(9)= 0.3141203
THETAG(11)= 0.9817475	SURFACE PRESSURE(11)=-0.1307583
THETAG(13)= 1.178097	SURFACE PRESSURE(13)=-0.5201273
THETAG(15)= 1.374446	SURFACE PRESSURE(15)=-0.8163815
THETAG(17)= 1.570796	SURFACE PRESSURE(17)= -1.004440
THETAG(19)= 1.767145	SURFACE PRESSURE(19)= -1.090083
THETAG(21)= 1.963494	SURFACE PRESSURE(21)= -1.093371
THETAG(23)= 2.159844	SURFACE PRESSURE(23)= -1.040020
THETAG(25)= 2.356194	SURFACE PRESSURE(25)=-0.9549694
THETAG(27)= 2.552543	SURFACE PRESSURE(27)=-0.8598185
THETAG(29)= 2.748893	SURFACE PRESSURE(29)=-0.7735138
THETAG(31)= 2.945242	SURFACE PRESSURE(31)=-0.7130127
THETAG(33)= 3.141592	SURFACE PRESSURE(33)=-0.6911907

DRAG PARAMETERS

AFTER 5200 ITERATIONS:

R-INFINITY= 100.0000 REYNOLDS NO.= 10.00000

SIZE OF GRID= 33X93

FRONTAL STAGNATION PRESSURE= 1.484200

REAR STAGNATION PRESSURE=-0.6911907

THE SKIN DRAG COEFFICIENT= 1.222929

THE FORM DRAG COEFFICIENT= 1.559216

CDSKIN/CDFORM= 0.7843232

THE TOTAL DRAG COEFFICIENT = 2.782145

STOKES(1)= 0.5000000

STOKES(2)= 1.000000

XKAP(1)= 0.9999999E-03

XKAP(2)= 0.2000000

INITIAL VARIABLES

RINF= 100.000 REYNOLD'S NO.= 10.000

XP(1)= -100.0000

SIZE OF GRID= 33 X 93

NUMBER OF STEPS PER GRID CELL= 3.000000

***** NUMERICALLY CALCULATED FLOWFIELD USED *******

****** EFFICIENCY WITH INTERCEPTION *******

STOKES' NO.= 0.500	EFFICIENCY= 0.37953890860E-02	DP/DF= 0.001000	I= 0.37915995345E-02
STOKES' NO.= 1.000	EFFICIENCY= 0.10445642471	DP/DF= 0.001000	I= 0.10435211658

****** EFFICIENCY WITH INTERCEPTION *******

STOKES' NO.= 0.500	EFFICIENCY= 0.10357707739	DP/DF= 0.200000	I= 0.86314201355E-01
STOKES' NO.= 1.000	EFFICIENCY= 0.22409653664	DP/DF= 0.200000	I= 0.18674713373

Computer Programme used to Calculate Stagnation Pressures and Drag Coefficients

```
      REAL S(33,93),V(33,93),FSIN(33),FCOS(33)
      REAL P(33),PT(33)
      REAL RG(93),THETAG(33)
      READ(4,2900) RINF,RE,RLXS,RLXV,RLXVS,A,B
      READ(4,3000) NR,NA,ITER,NCYCL,NUMBA
      WRITE(6,3100) RINF,RE,NA,NR,NUMBA
      DO 10 J=1,NR
      READ(4,2910) (V(I,J),I=1,NA)
   10 CONTINUE
      DO 20 J=1,NR
      READ(4,2910) (S(I,J),I=1,NA)
   20 CONTINUE
      PI=3.141592653589793
      B=PI/(NA-1.0)
      DO 40 I=1,NA
      ANGLE=PI/(NA-1.0)*(I-1.0)
      FSIN(I)=SIN(ANGLE)
      FCOS(I)=COS(ANGLE)
      THETAG(I)=ANGLE
   40 CONTINUE
      DO 80 I=1,NA
   80 CONTINUE
      NA2=NA-2
      NB2=NB-2
      CDSKIN=0.0
      DO 30 I=1,NA2,2
      CDSKIN=FSIN(I)*V(I,1)+4.*FSIN(I+1)*V(I+1,1)
     1 +FSIN(I+2)*V(I+2,1)+CDSKIN
   30 CONTINUE
      CDSKIN=CDSKIN*4.0*B/3.0/RE
      PO=0.0
      DO 50 J=1,NB2,2
      PO=PO+(-3.0*V(1,J)+4.*V(2,J)-V(3,J))
     1 +4.*(-3.*V(1,J+1)+4.*V(2,J+1)-V(3,J+1))
     2 +(-3.*V(1,J+2)+4.*V(2,J+2)-V(3,J+2))
   50 CONTINUE
      PO=PO*4.*A/3./RE/B/2.+1.0
      PZERO=PO
      P(1)=0.0
      DO 60 I=1,NA2,2
      KK=I+2
      P(KK)=((-3.*V(I,1)+4.*V(I,2)-V(I,3))
     1 +4.*(-3.*V(I+1,1)+4.*V(I+1,2)-V(I+1,3))
     2 +(-3.*V(I+2,1)+4.*V(I+2,2)-V(I+2,3)))/2./A+P(I)
      PT(KK)=PO+P(KK)*4.*B/3./RE
   60 CONTINUE
      PT(1)=PO
      PREAR=PT(NA)
      CDFORM=0.0
      DO 70 I=1,NA2,4
      CDFORM=CDFORM+PT(I)*FCOS(I)+4.0*PT(I+2)*FCOS(I+2)
     1 +PT(I+4)*FCOS(I+4)
   70 CONTINUE
      THSEP=0.0
      D1=1./(NA-1.0)
      DO 100 I=1,NA
      IF(I.EQ.1) GO TO 100
      IF(I.EQ.NA) GO TO 100
```

```
          IF(V(I,1).GT.0.0) GO TO 100
          THSEP=180.*(1.0-D1*(I-2.-V(I-1,J)/(V(I,1)-V(I-1,1))))
          GO TO 90
  100 CONTINUE
   90 CONTINUE
          CDFORM=CDFORM*B/1.5
          CDTOT=CDSKIN+CDFORM
          CRAT=CDSKIN/CDFORM
          WRITE(6,4200)
          WRITE(6,4000)  RE,RINF,NA,NR
          WRITE(6,4100)  PZERO,PREAR,THSEP,CDSKIN,CDFORM,CRAT,CDTOT
          WRITE(1,4300)  RINF,RE,NR,NA,NUMBA,PZERO,PREAR,THSEP,CDSKIN,CDFORM,
         1 CRAT,CDTOT
          WRITE(6,4200)
          WRITE(6,4200)
 1000 FORMAT(10X,'THE SKIN DRAG COEFFICIENT=',G14.7/)
 1100 FORMAT(5F12.5)
 1200 FORMAT(10X,'THE FORM DRAG COEFFICIENT =',G14.7/)
 1300 FORMAT(6I5)
 1400 FORMAT(10X,'THE TOTAL DRAG COEFFICIENT =',G14.7//)
 1500 FORMAT(10X,'FRONTAL STAGNATION PRESSURE=',G14.7/)
 1600 FORMAT(10X,'THETAG(',I2,')=',G14.7,5X,'SURFACE PRESSURE(',
        1 I2,')=',G14.7//)
 1700 FORMAT(10X,'THETAG(',I2,')=',G14.7,5X,'VORTICITY(',I2,',1)=',
        1 G14.7//)
 1800 FORMAT(10X,'CDSKIN/CDFORM=',G14.7/)
 2900 FORMAT(8F10.6)
 2910 FORMAT(17G14.7)
 3000 FORMAT(5I5)
 3100 FORMAT('1',10X,'RINF=',F12.6,5X,'RE=',F12.6//10X,'SIZE OF GRID=',
        1 1X,I2,' X ',I2//10X,'NUMBER OF ITERATIONS=',I5/)
 3200 FORMAT('1',15X,'SURFACE VORTICITY DISTRIBUTION'//)
 3300 FORMAT('1',15X,'SURFACE PRESSURE DISTRIBUTION'//)
 3400 FORMAT('1',15X,'         DRAG PARAMETERS'//)
 3500 FORMAT(10X,'REAR STAGNATION PRESSURE=',G14.7/)
 3600 FORMAT('1',10X)
 3700 FORMAT(10X,'AFTER',1X,I4,1X,'ITERATIONS:'///)
 3800 FORMAT(10X,'R-INFINITY=',G14.7,5X,'REYNOLDS NO.=',G14.7/
        1 10X,'SIZE OF GRID=',1X,I2,'X',I2/)
 3900 FORMAT(10X,'ANGLE OF WAKE SEPARATION=',F8.3,' DEGREES'//)
 4000 FORMAT(13X,'REYNOLD''S NO.=',F5.2,18X,'OUTER BOUNDARY RADIUS=',
        1 F5.1//50X,'GRID DIMENSIONS: ',I2,' X ',I2///24X,
        2 'CALCULATED VALUES'//)
 4100 FORMAT(13X,'FRONTAL STAGNATION PRESSURE=',1X,F10.6//
        1 13X,'REAR STAGNATION PRESSURE=',3X,F11.6//13X
        2 'ANGLE OF WAKE SEPARATION=',4X,F10.6//13X,
        3 'SKIN DRAG COEFFICIENT=',7X,F10.6//13X,'FORM DRAG COEFFICIENT=',
        4 7X,F10.6//13X,'RATIO: CDSKIN/CDFORM=',8X,F10.6//13X,
        5 'TOTAL DRAG COEFFICIENT=',6X,F10.6)
 4200 FORMAT('1')
 4300 FORMAT(12G14.7)
          STOP
          END
```

```
REYNOLD'S NO.= 0.20                 OUTER BOUNDARY RADIUS=100.0
                                    GRID DIMENSIONS: 33 X 93

           CALCULATED VALUES

FRONTAL STAGNATION PRESSURE=  12.474579
REAR STAGNATION PRESSURE=    -11.292297
ANGLE OF WAKE SEPARATION=      0.0
SKIN DRAG COEFFICIENT=        18.632019
FORM DRAG COEFFICIENT=        18.669342
RATIO: CDSKIN/CDFORM=          0.998001
TOTAL DRAG COEFFICIENT=       37.301361
```

Sample Output from Programme Calculating Stagnation Pressures and Drag Coefficients

REYNOLD'S NO.=10.00 OUTER BOUNDARY RADIUS=100.0

GRID DIMENSIONS: 33 X 93

CALCULATED VALUES

FRONTAL STAGNATION PRESSURE=	1.484242
REAR STAGNATION PRESSURE=	-0.691041
ANGLE OF WAKE SEPARATION=	33.753769
SKIN DRAG COEFFICIENT=	1.223443
FORM DRAG COEFFICIENT=	1.559248
RATIO: CDSKIN/CDFORM=	0.784637
TOTAL DRAG COEFFICIENT=	2.782691

REYNOLD'S NO.=40.00

OUTER BOUNDARY RADIUS=100.0

GRID DIMENSIONS: 33 X 93

CALCULATED VALUES

FRONTAL STAGNATION PRESSURE=	1.139041
REAR STAGNATION PRESSURE=	-0.573483
ANGLE OF WAKE SEPARATION=	55.672012
SKIN DRAG COEFFICIENT=	0.525463
FORM DRAG COEFFICIENT=	1.036178
RATIO: CDSKIN/CDFORM=	0.507116
TOTAL DRAG COEFFICIENT=	1.561641

Computer Programme used to Calculate Impaction Efficiencies

```
      REAL PSIN(51),PCOS(51),RG(93),THETAG(51),XP(2000),YP(2000)
C
C
C*****************************************************************************
C
C
C      THIS IS THE MAIN PROGRAMME FOR CALCULATING THE PARTICLE COLLECTION
C      EFFICIENCIES, FOR ALL CASES, EXCEPT THAT WHERE STOKES' NUMBER IS
C      EQUAL TO ZERO. BY PROPER SELECTION OF THE VARIABLE "JSUB"
C      ANY OF THE FOLLOWING THREE FLOWFIELDS CAN BE USED: POTENTIAL,
C      DAVIES' BESSEL EQUATION ONE AT RE=0.2, OR THE GRID OF NUMERICAL
C      VALUES FOR THE GIVEN REYNOLD'S NUMBER.
C
C
C      IT SHOULD BE NOTED THAT THE CO-ORDINATES FOR THE PARTICLE TRAJECTORY
C      HAVE BEEN MOVED TO THE CENTRE OF THE CYLINDER. THIS HAS HAD EFFECT
C      ON CERTAIN EQUATIONS IN THE M/P AND S/R 'LOCATE'.
C
C
C*****************************************************************************
C
C
      REAL VGX(51,93),VGY(51,93),VPX(2000),VPY(2000)
      REAL S(51,93),V(51,93)
      REAL EPSIL(20),P(20),KSIZE(20),EFF(20)
      REAL XPST,RE,RINF,A,B,GNUM
      INTEGER NR,NA,JSUB,JINT
      COMMON XPST,RE,RINF,A,B,NR,NA
      COMMON RG,THETAG,VGX,VGY,P,KSIZE
      COMMON GNUM,JSUB,JINT
      IPA=0
      READ(8,2900) START,GNUM
      WRITE(6,9910)
      READ(7,9110) JSUB,JBOUND,JINT
      READ(5,2300) MSTK1,MSTK2,MKAP1,MKAP2,MANY
      DO 220 I=1,MANY
      READ(5,2100) KSIZE(I),P(I)
  220 CONTINUE
      REWIND 5
      READ(4,2900) RINF,RE,RLXS,RLXV,RLXVS
      READ(4,3000) NR,NA,ITER,NCYCL,NUMBA
      XPST=-RINF*START
      DO 350 I=MSTK1,MSTK2
      WRITE(6,9730) I,P(I)
  350 CONTINUE
      DO 360 I=MKAP1,MKAP2
      WRITE(6,9740) I,KSIZE(I)
  360 CONTINUE
      IF(JSUB.NE.1) GO TO 630
      DO 20 J=1,NR
      READ(4,2910) (V(I,J),I=1,NA)
   20 CONTINUE
      DO 30 J=1,NR
      READ(4,2910) (S(I,J),I=1,NA)
   30 CONTINUE
  630 CONTINUE
      REWIND 4
      WRITE(6,3300)
```

```
      IF (JSUB.EQ.3) GO TO 640
  660 WRITE(6,1100) RINF,RE
      GO TO 650
  640 WRITE(6,1110) RE
  650 CONTINUE
      WRITE(6,2500) XPST
      WRITE(6,1800) NA,NR
      WRITE(6,3600) GNUM
      IF(JBOUND.EQ.1) GO TO 500
      IF(JBOUND.EQ.2) GO TO 510
      WRITE(6,5201)
      GO TO 251
  500 WRITE(6,5200)
      GO TO 520
  510 WRITE(6,5300)
  520 CONTINUE
      IF(JINT.EQ.1) GO TO 550
      IF(JINT.EQ.2) GO TO 560
      WRITE(6,6201)
      GO TO 251
  550 WRITE(6,6200)
      GO TO 570
  560 WRITE(6,6300)
  570 CONTINUE
      ZINF=ALOG(RINF)
      A=ZINF/(NR-1)
      PI=3.141592653589793
      B=PI/(NA-1)
      DO 10 I=1,NA
      ANGLE=PI/(NA-1.)*(I-1.)
      FSIN(I)=SIN(ANGLE)
      FCOS(I)=COS(ANGLE)
      THETAG(I)=ANGLE
   10 CONTINUE
      DO 11 J=1,NR
      RG(J)=EXP(ZINF/(NR-1.)*(J-1.))
   11 CONTINUE
      IF(JSUB.EQ.1) GO TO 400
      IF(JSUB.EQ.2) GO TO 260
      IF(JSUB.EQ.3) GO TO 270
      WRITE(6,9201)
      GO TO 251
  400 WRITE(6,9200)
      NA1=NA-1
      NR1=NR-1
      DO 40 I=2,NA1
      DO 40 J=2,NR1
      VTH=(S(I,J+1)-S(I,J-1))/2./A/RG(J)
      VR=(S(I-1,J)-S(I+1,J))/2./B/RG(J)
      VGX(I,J)=VTH*FSIN(I)-VR*FCOS(I)
      VGY(I,J)=VTH*FCOS(I)+VR*FSIN(I)
   40 CONTINUE
      DO 50 I=1,NA
      VGX(I,1)=0.0
      VGY(I,1)=0.0
      VGX(I,NR)=1.0
      VGY(I,NR)=0.0
   50 CONTINUE
```

```
      DO 120 J=2,NR1
      VR=(-3.*S(1,J)+4.*S(2,J)-S(3,J))/2./B/RG(J)
      VGX(1,J)=VR
      VGY(1,J)=0.0
      VR1=(3.*S(NA,J)-4.*S(NA-1,J)+S(NA-2,J))/2./B/RG(J)
      VGX(NA,J)=-VR1
      VGY(NA,J)=0.0
  120 CONTINUE
      GO TO 280
  260 WRITE(6,9300)
      GO TO 280
  270 WRITE(6,9400)
  280 CONTINUE
      DO 250 KR=MKAP1,MKAP2
      DO 230 I=MSTK1,MSTK2
      YMAX=KSIZE(KR)+1.0
      IF(START.GT.0.98) XPST=-SQRT(RINP*RINP-YMAX*YMAX)
      EPS=1.0E-4
      F19=6765.
      F20=10946.
      STAR=F19/F20+EPS/F20
      YP1=0.0
      YP2=1.0-STAR
      YP3=STAR
      YP4=1.0
      NFIB=19
      IF(P(I).GT.1.0) GO TO 620
      NFIB=29
      F28=514229.
      F29=832040.
      STAR=F28/F29
      YP2=1.0-STAR
      YP3=STAR
  620 WRITE(6,9930) NFIB,P(I),KSIZE(KR),XPST
      WRITE(6,9920)
      YP1D=YP1*YMAX
      YP2D=YP2*YMAX
      YP3D=YP3*YMAX
      YP4D=YP4*YMAX
      CALL FITRAJ(YP1D,I,KR,H1)
      CALL FITRAJ(YP2D,I,KR,H2)
      CALL FITRAJ(YP3D,I,KR,H3)
      CALL FITRAJ(YP4D,I,KR,H4)
      D12=ABS(H1-H2)
      D23=ABS(H2-H3)
      D34=ABS(H3-H4)
      IF(ABS(D12-1.0).LE.1.0E-4) GO TO 60
      IF(ABS(D23-1.0).LE.1.0E-4) GO TO 70
      IF(ABS(D34-1.0).LE.1.0E-4) GO TO 70
   60 YP4=YP3
      H4=H3
      YI=YP1+YP4-YP2
      YTEST=YI*YMAX
      CALL FITRAJ(YTEST,I,KR,HTEST)
      IF(YI.GT.YP2) YP3=YI
      IF(YI.LT.YP2) GO TO 160
      GO TO 170
  160 YP3=YP2
```

```
      H3=H2
      H2=HTEST
      YP2=YI
      GO TO 80
  170 H3=HTEST
      GO TO 80
   70 YP1=YP2
      H1=H2
      YI=YP1+YP4-YP3
      YTEST=YI*YMAX
      CALL FITRAJ(YTEST,I,KR,HTEST)
      IF(YI.LT.YP3) YP2=YI
      IF(YI.GT.YP3) GO TO 140
      GO TO 150
  140 YP2=YP3
      H2=H3
      H3=HTEST
      YP3=YI
      GO TO 80
  150 H2=HTEST
   80 CONTINUE
      DO 90 J=1,NFIB
      D12=ABS(H1-H2)
      D23=ABS(H2-H3)
      D34=ABS(H3-H4)
      IF(ABS(D12-1.0).LE.1.0E-4) GO TO 100
      IF(ABS(D23-1.0).LE.1.0E-4) GO TO 110
      IF(ABS(D34-1.0).LE.1.0E-4) GO TO 110
  100 YP4=YP3
      H4=H3
      YI=YP1+YP4-YP2
      YTEST=YI*YMAX
      CALL FITRAJ(YTEST,I,KR,HTEST)
      IF(YI.GT.YP2) YP3=YI
      IF(YI.LT.YP2) GO TO 180
      GO TO 190
  180 YP3=YP2
      H3=H2
      H2=HTEST
      YP2=YI
      GO TO 130
  190 H3=HTEST
      GO TO 130
  110 YP1=YP2
      H1=H2
      YI=YP1+YP4-YP3
      YTEST=YI*YMAX
      CALL FITRAJ(YTEST,I,KR,HTEST)
      IF(YI.LT.YP3) YP2=YI
      IF(YI.GT.YP3) GO TO 200
      GO TO 210
  200 YP2=YP3
      H2=H3
      H3=HTEST
      YP3=YI
      GO TO 130
  210 H2=HTEST
  130 CONTINUE
```

```
   90 CONTINUE
      D12=ABS(H1-H2)
      D23=ABS(H2-H3)
      D34=ABS(H3-H4)
      EPSIL(I)=0.0
      IF(ABS(D12-1.0).LT.1.0E-5) EPSIL(I)=YP1+YP2
      IF(ABS(D23-1.0).LT.1.0E-5) EPSIL(I)=YP2+YP3
      IF(ABS(D34-1.0).LT.1.0E-5) EPSIL(I)=YP3+YP4
      EPSIL(I)=EPSIL(I)*YMAX/2.0
  230 CONTINUE
      WRITE(6,3300)
      WRITE(6,1100) RINF,RE
      WRITE(6,2500) XPST
      WRITE(6,1800) NA,NR
      WRITE(6,3700) GNUM,JSUB,NUMBA
      WRITE(6,3900)
      IF(JBOUND.EQ.2) GO TO 530
      WRITE(6,5200)
      GO TO 540
  530 WRITE(6,5300)
  540 CONTINUE
      IF(JSUB.EQ.2) GO TO 410
      IF(JSUB.EQ.3) GO TO 420
      WRITE(6,9200)
      GO TO 430
  410 WRITE(6,9300)
      GO TO 430
  420 WRITE(6,9400)
  430 CONTINUE
      IF(JINT.EQ.2) GO TO 580
      WRITE(6,6200)
      GO TO 590
  580 WRITE(6,6300)
  590 CONTINUE
      DO 240 IX=MSTK1,MSTK2
      EPF(IX)=EPSIL(IX)/(1.+KSIZE(KR))
      WRITE(6,2400) P(IX),EPSIL(IX),KSIZE(KR),EPF(IX)
  240 CONTINUE
      WRITE(1,3000) JSUB,JBOUND,JINT
      WRITE(1,2910) RINF,RE,START,GNUM
      WRITE(1,3000) NR,NA,ITER,NCYCL,NUMBA
      DO 370 IX=MSTK1,MSTK2
      WRITE(1,9800) P(IX),KSIZE(KR),EPSIL(IX),EPF(IX)
  370 CONTINUE
  250 CONTINUE
  251 CONTINUE
 1000 FORMAT(2F12.6,E12.7)
 1100 FORMAT(10X,'R-INFINITY=',F10.3,5X,'REYNOLD''S NO.=',F10.3,/)
 1110 FORMAT(10X,'R-INFINITY=INFINITE',7X,'REYNOLD''S NO.=',F10.3/)
 1200 FORMAT(8X,F10.6,7X,F10.6,7X,F8.3,11X,I4)
 1300 FORMAT('1',10X,'X-VALUE',10X,'Y-VALUE',10X,'TIME',10X,
     1 'ITERATIONS'//)
 1400 FORMAT(2F10.6)
 1500 FORMAT('1',5X,'*** IMPACT AT TIME= 'F8.3,1X,'***'//
     1 10X,'BETWEEN XP=', F10.6,2X,'YP=',F10.6//
     2 10X,'AND',5X,'XP=',F10.6,2X,'YP=',F10.6//)
 1600 FORMAT(10X,'VISCOSITY OF FLUID=',E12.6//,10X,
     1  'RADIUS OF PARTICLE=',F10.6,//10X'DENSITY OF PARTICLE=',F10.6//)
```

```
      1700 FORMAT(F12.6)
      1800 FORMAT(10X,'SIZE OF GRID=',1X,I2,' X ',I2/)
      1900 FORMAT(///17X'INITIAL PARTICLE POSITION'///,10X,'X-INITIAL='
     1 F10.6,//10X'Y-INITIAL=',F10.6//)
      2000 FORMAT(10X,'STOKES'' NO.=',F10.3,5X,'DP/DF=',F10.4//)
      2100 FORMAT(2F8.3)
      2200 FORMAT(////18X'******* EPSILIENCY WITH INTERCEPTION *******'///)
      2300 FORMAT(5I4)
      2400 FORMAT(5X,'STOKES'' NO.=',F10.3,5X,'EPSILIENCY=',G14.7,5X
     1 'DP/DF=',F10.6,5X,'I=',G14.7/)
      2500 FORMAT(10X,'XP(1)=',G15.7/)
      2900 FORMAT(8F10.6)
      2910 FORMAT(17G14.7)
      3000 FORMAT(5I5)
      3200 FORMAT(10X,'AFTER ',I3,' ITERATIONS, TIME= ',F6.2,
     1 2X,'X-VALUE=',F10.6,2X,'Y-VALUE=',F10.6/)
      3300 FORMAT('1',20X,'INITIAL VARIABLES'/)
      3400 FORMAT(//'*************** FIBONACCI RESULTS ******************'/
     1 /10X,'YP1=',F10.6,2X,'H1=',F10.6/10X,'YP2=',F10.6,'  H2=',
     2 F10.6/10X,'YP3=',F10.6,'  H3=',F10.6/10X,'YP4=',F10.6,2X,
     3 'H4=',F10.6//)
      3500 FORMAT(//10X,'EPSILIENCY=',F10.6)
      3600 FORMAT(10X,'NUMBER OF STEPS PER GRID CELL=',F10.6//)
C      THIS IS TO TEST THE LENGTH OF THE LINE ENTERED ******************
      3700 FORMAT(10X,'GNUM=',G14.7,5X,'JSUB=',I2,5X,'NUMBER OF ITERATIONS IN
     1 GRID=',G14.7//)
      3800 FORMAT('1',10X)
      3900 FORMAT(22X,'KLYACHKO''S FORMULA FOR DRAG COEFSILIENT USED AT ALL V
     1ALUES OF RE'//)
      4000 FORMAT(/////10X,'AT YMAX=',G14.7,2X,'AND RINF=',G14.7,
     1 2X,'XPST=',G14.7)
      5200 FORMAT(31X,'******* KUWABARA''S ZERO VORTICITY MODEL *******'//)
      5201 FORMAT('1','WRONG SPECIFICATION OF BOUNDARY CONDITIONS'//)
      5300 FORMAT(30X,'********* HAPPEL''S ZERO SHEAR STRESS MODEL *****'/)
      6200 FORMAT(40X,'EPSILIENCY WITH INTERCEPTION'//)
      6201 FORMAT('1','WRONG SPECIFICATION FOR INTERCEPTION EFFECT'//)
      6300 FORMAT(38X,'NO INTERCEPTION: POINT PARTICLES'//)
      9000 FORMAT('1',20X,'******** NEW STOKES'' AND DP/DF ********'/
     1 10X,'STOKES(',I2,')=',F10.6,5X,'DP/DF(',I2,')=',F10.6//)
      9110 FORMAT(3I2)
      9200 FORMAT(35X,'***** NUMERICAL FLOWFIELD USED *******'//)
      9201 FORMAT('1','WRONG SPECIFICATION OF FLOWFIELD'//)
      9300 FORMAT(31X,'******** DAVIES'' BESSEL EQUATIONS USED ********'//)
      9400 FORMAT(33X,'********** POTENTIAL FLOWFIELD USED *******'//)
      9730 FORMAT(//10X,'STOKES(',I2,')=',F7.2)
      9740 FORMAT(//10X,'KSIZE(',I2,')=',F7.4)
      9800 FORMAT(2F12.5,2G14.7)
      9900 FORMAT(//10X,'******* NUMBER OF FIBONACCI CYCLES:',I3)
      9910 FORMAT(1X,'ENTER VALUES OF JSUB,JBOUND,AND JINT'//,1X,
     1 '1=NUMERICAL/KUWA./INT. *** 2=DAVIES/HAPPEL/NO INT. ** 3=POT')
      9920 FORMAT(1X,'ITER',6X,'TIME',11X,'YP(1)',13X,'XP',14X,'YP',13X,
     1 'VPX',15X,'VPY',11X,'VMAG'//4X,'RP',12X,'MIN RP',9X,
     2 'RADIANS',9X,'DEGREES',9X,'COS(ANG)',9X,'MAX RE',9X,
     3 'MIN CD'//)
      9930 FORMAT('1',//5X,'NO. FIBONACCI CYCLES=',1X,I2,5X,'STOKES NO.='
     1,F10.5,5X,'DP/DF=',F8.5,5X,'XPST=',G14.7///)
           STOP
           END
```

```
      SUBROUTINE FITRAJ(YPN,I,KR,H)
      IMPLICIT REAL*8(A-H,O-Z),INTEGER*4(I-N)
      REAL YPN,H
      REAL RG(93),THETAG(51)
      REAL ABS,ALOG
      REAL*8 XP(2000),YP(2000)
      REAL*8 XTES(5),YTES(5)
      REAL VGX(51,93),VGY(51,93)
      REAL*8 VPX(2000),VPY(2000),SUMT(2000),VTOT(2000)
      REAL P(20),KSIZE(20)
      REAL*8 REP(2000),DISXP(2000)
      REAL*8 DELXP(2000),DELYP(2000),RATXY(2000)
      REAL GSPAC(2000)
      REAL*8 VBARX(2000),VBARY(2000),TSTEP(2000),VFX(2000),VFY(2000)
      REAL XPST,RE,RINF,A,B,GNUM
      INTEGER NR,NA,JSUB,JINT
      COMMON XPST,RE,RINF,A,B,NR,NA
      COMMON RG,THETAG,VGX,VGY,P,KSIZE
      COMMON GNUM,JSUB,JINT
      XP(1)=XPST
      ZINF=ALOG(RINF)
      VPX(1)=1.0
      VPY(1)=0.0
      SPANS=5.0
      IF(JSUB.EQ.2) SPANS=0.0
      IF(RINF.LE.10.0) SPANS=ABS(XPST)/1.5
      YP(1)=YPN
      SUMT(1)=0.0
      KITER=0
      KDUN=0
      RPMIN=1.0E6
      REMAX=0.0
      CDMIN=1.0E6
      DO 60 K=1,2000
      XPK=0.0
      YPK=0.0
      VXK=0.0
      VYK=0.0
      VTK=0.0
      NOLD=K
      NEW=K+1
      KITER=KITER+1
      CALL LOCATE(XP,YP,K,RP,THETAP,NT,NZ)
      IF(NZ.EQ.NR) GO TO 10
      IBIG=NZ+1
      ISML=NZ
      GO TO 20
   10 IBIG=NR
      ISML=NR-1
   20 CONTINUE
      DISXP(K)=XP(K)-RINF
      GSPAC(K)=RG(IBIG)-RG(ISML)
      IF(JSUB.EQ.1) GO TO 21
      IF(JSUB.EQ.2) GO TO 22
      CALL POTEN(XP,YP,K,VELX,VELY)
      GO TO 23
   21 CALL CLOSE(RP,THETAP,NT,NZ,VELX,VELY)
      GO TO 23
```

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   22 CALL EQUAT(XP,YP,K,RP,VELX,VELY)
   23 CONTINUE
      VTOT(K)=DSQRT(VPX(K)*VPX(K)+VPY(K)*VPY(K))
      TSTEP(K)=GSPAC(K)/VTOT(K)/GNUM
      NR1=NR-1
      IF(NZ.GE.NR1) TSTEP(K)=GSPAC(K)/VTOT(K)/GNUM/3.0
      IF(TSTEP(K).GE.10.0) TSTEP(K)=10.0
      VPX(K)=VELX
      VPY(K)=VELY
      IF(K.GT.1) GO TO 100
      JKL=1
      XTES(1)=XP(1)+GSPAC(K)/GNUM/3.0
      YTES(1)=YP(1)
      CALL LOCATE(XTES,YTES,JKL,RP,THETAP,NT,NZ)
      IF(JSUB.EQ.1) GO TO 200
      IF(JSUB.EQ.2) GO TO 210
      CALL POTEN(XTES,YTES,JKL,VXTES,VYTES)
      GO TO 220
  200 CALL CLOSE(RP,THETAP,NT,NZ,VXTES,VYTES)
      GO TO 220
  210 CALL EQUAT(XTES,YTES,JKL,RP,VXTES,VYTES)
  220 CONTINUE
      VBARX(1)=(VPX(1)+VXTES)/2.0
      VBARY(1)=(VPY(1)+VYTES)/2.0
      GO TO 110
  100 VBARX(K)=VPX(K)+(VPX(K)-VPX(K-1))*TSTEP(K)/2./TSTEP(K-1)
      VBARY(K)=VPY(K)+(VPY(K)-VPY(K-1))*TSTEP(K)/2./TSTEP(K-1)
  110 CONTINUE
      SUMT(K+1)=SUMT(K)+TSTEP(K)
      RELX=VBARX(K)-VPX(K)
      RELY=VBARY(K)-VPY(K)
      SUBD=(RELX*RELX+RELY*RELY)
      UREL=DSQRT(SUBD)
      REP(K)=RE*UREL*KSIZE(KR)
      IF(REP(K).GT.REMAX) REMAX=REP(K)
      BETA=1./P(I)
      IF(REP(K).GT.0.0) BETA=(1.0+(REP(K)**0.6666666)/6.0)/P(I)
      IF(REP(K).EQ.0.0) GO TO 221
      CDRAG=BETA*24.0*P(I)/REP(K)
      IF(CDRAG.LT.CDMIN) CDMIN=CDRAG
  221 CONTINUE
      C5=1.0/BETA
      ARGE=-BETA*TSTEP(K)
      C4=DEXP(ARGE)
      XP(K+1)=XP(K)+VBARX(K)*(C4*C5-C5+TSTEP(K))+VPX(K)*
     1 (C5-C4*C5)
      YP(K+1)=YP(K)+VBARY(K)*(C4*C5-C5+TSTEP(K))+VPY(K)*
     1 (C5-C4*C5)
      IK1=K+1
      IK2=K+2
      DISXP(K+1)=RINP-XP(K+1)
      DELXP(K+1)=XP(K+1)-XP(K)
      DELYP(K+1)=YP(K+1)-YP(K)
      VPX(K+1)=VBARX(K)*(1.-C4)+VPX(K)*C4
      VPY(K+1)=VBARY(K)*(1.-C4)+VPY(K)*C4
      XPK=XP(K)
      YPK=YP(K)
      VXK=VPX(K)
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```
      VYK=VPY(K)
      VTK=VTOT(K)
      VTOT(K+1)=DSQRT(VPX(K+1)*VPX(K+1)+VPY(K+1)*VPY(K+1))
      CALL LOCATE(XP,YP,NEW,RP,THETAP,NT,NZ)
      IF(RP.LT.RPMIN) RPMIN=RP
      FINSIZ=KSIZE(KR)
      IF(JINT.EQ.2) FINSIZ=0.0
      CLEAR=RP-1.0-FINSIZ
      IF(CLEAR.LE.0.0) GO TO 140
      IF(XP(K).GT.SPANS) GO TO 130
   60 CONTINUE
  140 H=0.0
      GO TO 70
  130 H=1.0
   70 CONTINUE
      XCOSS=DCOS(THETAP)
      THDEG=THETAP*180./3.141592653589793
      WRITE(6,9792) NOLD,SUMT(NOLD),YP(1),XPK,YPK,VXK,
     1 VYK,VTK,RP,RPMIN,THETAP,THDEG,XCOSS,REMAX,CDMIN
 1000 FORMAT(2F12.6,E12.7)
 1700 FORMAT(F12.6)
 2000 FORMAT(10X,'STOKES'' NO.=',F10.6//)
 2100 FORMAT(2F12.6)
 2900 FORMAT(8F10.6)
 2910 FORMAT(17G14.7)
 9000 FORMAT(/15X,'******* FITRAJ: CYCLE COMPLETED ******'/
     1 10X,'SUMT(',I4,')=',F10.6,5X,'SUMT(',I4,')=',F10.6)
 9001 FORMAT(10X,'CURRENT LARGE TIME STEP=',F10.6)
 9200 FORMAT(10X,'DISXP(',I4,')=',F10.6,5X,'DISXP(',I4,')='F10.6/)
 9300 FORMAT(/10X,'STOKES(',I2,')=',F10.6,5X,'DP/DF(',I2,')=',F10.6///)
 9400 FORMAT(/10X,'STARTING Y=',F10.6,5X,'FINAL H=',F10.6,5X,
     1 'AFTER',1X,I4,1X,'ITERATIONS'/)
 9600 FORMAT(10X,'NUMBER OF STEPS=',1X,I4,5X,'VALUE OF K=',I4/)
 9705 FORMAT(///1X,'****************************************************
     1****************************************'/)
 9710 FORMAT(10X,'XP(',I4,')=',F10.6,5X,'XP(',I4,')=',F10.6,5X
     1 ,'YP(',I4,')=',F10.6,5X,'YP(',I4,')=',F10.6/)
 9720 FORMAT(10X,'VPX(',I4,')=',F10.6,4X,'VPX(',I4,')=',F10.6,4X,
     1 'VPY(',I4,')=',F10.6,4X,'VPY(',I4,')=',F10.6/)
 9730 FORMAT(10X,'NT=',I2,4X,'NZ=',I2,5X,'RG(',I4,')=',F10.6,5X,
     1 'RG(',I4,')=',F10.6,5X,'GSPAC(',I4,')=',F10.6/)
 9740 FORMAT(10X,'VFX(',I4,')=',F10.6,5X,'VFY(',I4,')=',F10.6,5X,
     1 'DISXP(',I4,')=',F10.6,5X,'RP=',F10.6/)
 9750 FORMAT(10X,'RELATIVE VELOCITY WRT FLUID=',E12.5,8X,
     1 'REYNOLD''S NO.(',I4,')=',E12.5/)
 9760 FORMAT(1X,'***** TSTEP(',I4,')=',F12.6,2X,'*****',5X,
     1 'TOTAL TIME TO XP(',I4,')=',F12.6/)
 9770 FORMAT(10X,'DELXP(',I4,')=',F10.6,2X,'DELYP(',I4,')=',
     1 F10.6/)
 9780 FORMAT(1X,'ZERO RESILIENCY CONDITION:  VPX(',I4,')=',
     1 E12.5,5X,'DELXP(',I4,')=',E12.5,5X,'XP(',I4,')=',E12.5,
     2 5X,'YP(',I4,')=',E12.5//)
 9790 FORMAT(10X,'STARTING VALUE: YP(1)=',E12.5/)
 9791 FORMAT(10X,'VBARX(',I4,')=',F10.6,3X,'VBARY(',I4,')=',F10.6/)
 9792 FORMAT(I5,7(4X,G12.5)/G12.5,6(4X,G12.5))
      RETURN
      END
      SUBROUTINE LOCATE(XP,YP,K,RP,THETAP,NT,NZ)
```

```
      IMPLICIT REAL*8(A-H,O-Z),INTEGER*4(I-N)
      REAL SNGL
      REAL*8 XP(2000),YP(2000)
      REAL RG(93),THETAG(51),VGX(51,93),VGY(51,93),P(20),KSIZE(20)
      REAL XPST,RE,RINF,A,B,GNUM
      INTEGER NR,NA,JSUB,JINT
      COMMON XPST,RE,RINF,A,B,NR,NA
      COMMON RG,THETAG,VGX,VGY,P,KSIZE
      COMMON GNUM,JSUB,JINT
      R=-XP(K)
      RP=DSQRT(YP(K)*YP(K)+R*R)
      PI=3.141592653589793
      IF(DABS(R).LT.1.0E-5) GO TO 10
      THETAP=DATAN(YP(K)/R)
      IF(R.LT.0.0) THETAP=PI-DATAN(YP(K)/DABS(R))
      GO TO 20
   10 THETAP=PI/2.0
   20 CONTINUE
      NZ=IFIX(SNGL(DLOG(RP)/A))+1
      IF(RP.GE.RINF) NZ=NR
      NT=IFIX(SNGL(THETAP/B))+1
      RETURN
      END
      SUBROUTINE CLOSE(RP,THETAP,NT,NZ,VELX,VELY)
      IMPLICIT REAL*8(A-H,O-Z),INTEGER*4(I-N)
      REAL RG(93),THETAG(51)
      REAL VGX(51,93),VGY(51,93),TH(51,93),W(51,93)
      REAL P(20),KSIZE(20)
      REAL XPST,RE,RINF,A,B,GNUM
      INTEGER NR,NA,JSUB,JINT
      COMMON XPST,RE,RINF,A,B,NR,NA
      COMMON RG,THETAG,VGX,VGY,P,KSIZE
      COMMON GNUM,JSUB,JINT
      VELX=0.0
      VELY=0.0
      IF(RP.GE.RG(NR)) GO TO 400
      NZ1=NZ+1
      ARGW=RP-RG(NZ)
      XL=ARGW/(RG(NZ1)-RG(NZ))
      GO TO 410
  400 XL=0.0
      NZ1=NZ
  410 CONTINUE
      NT1=NT+1
      ARGT=DABS(THETAP-THETAG(NT))
      ALPHA=ARGT/B
      VX1=VGX(NT,NZ)
      VX2=VGX(NT,NZ1)
      VX3=VGX(NT1,NZ)
      VX4=VGX(NT1,NZ1)
      VY1=VGY(NT,NZ)
      VY2=VGY(NT,NZ1)
      VY3=VGY(NT1,NZ)
      VY4=VGY(NT1,NZ1)
      VELX=(1.0-ALPHA)*(VX1*(1.0-XL)+VX2*XL)+ALPHA*(VX3*(1.0-XL)+
     1 VX4*XL)
      VELY=(1.0-ALPHA)*(VY1*(1.0-XL)+VY2*XL)+ALPHA*(VY3*(1.0-XL)+
     1 VY4*XL)
```

```
      RETURN
      END
      SUBROUTINE EQUAT(XS,YS,K,RP,VELX,VELY)
      IMPLICIT REAL*8(A-Z)
      INTEGER*4 K
      REAL BESSK0,BESSK1
      REAL*8 XS(2000),YS(2000)
      REAL RG(93),THETAG(51),VGX(51,93),VGY(51,93),P(20),KSIZE(20)
      REAL J,K1,L,M,N
      REAL XPST,RE,RINF,A,B,GNUM
      INTEGER NR,NA,JSUB,JINT
      COMMON XPST,RE,RINF,A,B,NR,NA
      COMMON RG,THETAG,VGX,VGY,P,KSIZE
      COMMON GNUM,JSUB,JINT
      X=XS(K)
      Y=YS(K)
      X2=XS(K)*XS(K)
      X3=X2*XS(K)
      R2=RP*RP
      R4=R2*R2
      R6=R4*R2
      ARG1=RE/4.0
      ARG2=RE*RP/4.0
      B1=BESSK1(RE/4.0)
      B2=BESSK0(RE/4.0)
      B3=BESSK0(RE*RP/4.0)
      B4=BESSK1(RE*RP/4.0)
      C=DEXP(RE*X/4.)
      ARGK=RE*RP/4.
      C1=DEXP(RE*RP/4.0)
      CK0=B3*C1
      CK1=B4*C1
      D=-1.0/2.0/R2
      F=X/R2
      G=RE/16.*B2
      H=1.0-5./R4
      G1=G*H
      J=RE/64.
      K1=1.0-6./R2
      L=K1+5./R4
      M=X2/R4
      N=X3/R6*RE/8.
      PP=X/RP*B4
      Q=PP+B3
      RB=C*Q
      DEN=B2+0.5
      YA=Y/R2
      YB=RE/16.*B2
      YC=1.0-1./R4
      YD=YB*YC
      YE=RE/64.*(1.-2./R2+1./R4)
      YF=X*Y/R4
      YG=X2*Y/R6*RE/8.
      YH=DEXP(RE*X/4.)
      YK=Y/RP*B4
       VELY=(YA*(B1-YD+YE)+YF+YG-YH*YK)/DEN
      VELX=1.0+(D+F*(B1-G1+J*L)+M+N-RB)/DEN
      RETURN
```

```
      END
      SUBROUTINE POTEN(XP,YP,K,VELX,VELY)
      IMPLICIT REAL*8(A-H,O-Z),INTEGER*4(I-N)
      REAL*8 XP(2000),YP(2000)
      X2=XP(K)*XP(K)
      Y2=YP(K)*YP(K)
      VELX=1.-(X2-Y2)/(X2+Y2)/(X2+Y2)
      VELY=-2.*XP(K)*YP(K)/(X2+Y2)/(X2+Y2)
      RETURN
      END
```

INITIAL VARIABLES

R-INFINITY=   100.000   REYNOLD'S NO.=   10.000

XP(1)= -100.0000

SIZE OF GRID= 33 X 93

NUMBER OF STEPS PER GRID CELL= 3.000000

******* KUWABARA'S ZERO VORTICITY MODEL *******

EFFICIENCY WITH INTERCEPTION

***** NUMERICAL FLOWFIELD USED *******

Sample Output from Efficiency Programme

NO. FIBONACCI CYCLES= 29   STOKES NO.=   1.00000   DP/DP= 0.10000   XPSI= -99.99394

ITER / RP	TIME / MIN RP	YP(1) / RADIANS	XP / DEGREES	YP / COS(ANG)	VPX / MAX RE	VPY / MIN CD	VMAG
277	102.30	0.0	-1.1092	-0.0	0.15476	0.0	0.15476
1.0913	1.0913	0.0	0.0	1.0000	0.20211	125.56	
430	111.85	0.42016	5.0404	1.6841	0.48185	-0.57837D-01	0.48531
5.3949	1.4456	2.8262	161.93	-0.95067	0.15285	164.50	
404	109.29	0.67984	5.0116	2.2342	0.64390	-0.50505D-01	0.64588
5.5694	1.7426	2.7303	156.43	-0.91659	0.13859	180.90	
376	107.71	1.1000	5.0257	2.8355	0.81044	-0.27932D-01	0.81092
5.8546	2.1899	2.6367	151.07	-0.87522	0.11444	217.95	
453	116.21	0.25967	5.0542	1.1404	0.34176	-0.49804D-01	0.34537
5.2605	1.2452	2.9254	167.62	-0.97673	0.17150	147.14	
474	124.82	0.16049	5.0022	0.60195	0.24303	-0.30153D-01	0.24490
5.1211	1.1103	3.0258	173.37	-0.99330	0.18525	136.57	
282	102.58	0.99187D-01	-1.0361	0.37639	0.15746	0.11848	0.19706
1.0930	1.0930	0.36209	20.746	0.93516	0.19367	130.83	
465	120.33	0.19837	5.0786	0.83047	0.28013	-0.39573D-01	0.28291
5.2274	1.1631	2.9843	170.99	-0.98766	0.18024	140.24	
288	102.87	0.13707	-0.95011	0.56273	0.16836	0.16181	0.23351
1.0997	1.0997	0.55037	31.534	0.85233	0.19005	133.24	
471	122.86	0.17496	5.0532	0.69089	0.25803	-0.33791D-01	0.26024
5.1825	1.1307	3.0100	172.46	-0.99135	0.18300	138.19	
296	103.37	0.15154	-0.84120	0.70881	0.16585	0.17226	0.23913
1.0990	1.0990	0.71645	41.050	0.75414	0.18694	135.38	
473	124.06	0.16601	5.0338	0.63470	0.24907	-0.31440D-01	0.25104
5.1563	1.1181	3.0202	173.05	-0.99265	0.18434	137.22	
475	125.49	0.15706	5.0222	0.57647	0.24022	-0.28935D-01	0.24195
5.1382	1.1055	3.0311	173.67	-0.99390	0.18586	136.14	
476	125.90	0.15496	5.0277	0.56125	0.23827	-0.28240D-01	0.23994
5.1421	1.1025	3.0342	173.84	-0.99423	0.18626	135.86	
477	126.29	0.15364	5.0586	0.54833	0.23772	-0.27540D-01	0.23931
5.1714	1.1007	3.0372	174.02	-0.99456	0.18652	135.68	
298	103.51	0.15286	-0.81555	0.73834	0.16547	0.17172	0.23847
1.0997	1.0997	0.75204	43.089	0.73029	0.18667	135.57	
477	126.26	0.15419	5.0782	0.54992	0.23876	-0.27526D-01	0.24034
5.1912	1.1014	3.0373	174.03	-0.99457	0.18641	135.75	
477	126.32	0.15341	5.0558	0.54698	0.23741	-0.27492D-01	0.23900
5.1686	1.1003	3.0374	174.03	-0.99458	0.18656	135.64	
299	103.58	0.15310	-0.80308	0.75176	0.16494	0.17082	0.23746
1.0999	1.0999	0.76871	44.044	0.71881	0.18663	135.60	
477	126.34	0.15333	5.0547	0.54653	0.23730	-0.27477D-01	0.23888
5.1674	1.1002	3.0375	174.04	-0.99459	0.18658	135.63	
477	126.31	0.15318	5.0421	0.54692	0.23683	-0.27547D-01	0.23843
5.1549	1.1000	3.0372	174.02	-0.99455	0.18661	135.61	
477	126.30	0.15325	5.0431	0.54731	0.23692	-0.27560D-01	0.23852
5.1559	1.1001	3.0371	174.01	-0.99455	0.18660	135.62	
299	103.58	0.15317	-0.80307	0.75191	0.16509	0.17094	0.23765
1.1000	1.1000	0.76881	44.050	0.71874	0.18661	135.61	
477	126.30	0.15324	5.0430	0.54723	0.23691	-0.27557D-01	0.23851
5.1559	1.1001	3.0371	174.02	-0.99455	0.18660	135.62	
477	126.31	0.15323	5.0430	0.54716	0.23690	-0.27554D-01	0.23850

5.1559	1.1001	3.0372	174.02	-0.99455	0.18660	135.62	
477	126.31	0.15322	5.0430	0.54708	0.23689	-0.27550D-01	0.23849
5.1558	1.1001	3.0372	174.02	-0.99455	0.18660	135.62	
477	126.31	0.15320	5.0430	0.54700	0.23688	-0.27547D-01	0.23848
5.1558	1.1000	3.0372	174.02	-0.99455	0.18660	135.61	
477	126.31	0.15319	5.0430	0.54693	0.23687	-0.27544D-01	0.23846
5.1558	1.1000	3.0372	174.02	-0.99456	0.18661	135.61	
477	126.31	0.15318	5.0430	0.54685	0.23686	-0.27540D-01	0.23845
5.1558	1.1000	3.0372	174.02	-0.99456	0.18661	135.61	
299	103.58	0.15317	-0.80307	0.75192	0.16510	0.17095	0.23766
1.1000	1.1000	0.76882	44.050	0.71873	0.18661	135.61	
477	126.31	0.15318	5.0421	0.54693	0.23683	-0.27548D-01	0.23843
5.1549	1.1000	3.0372	174.02	-0.99455	0.18661	135.61	
299	103.58	0.15317	-0.80307	0.75193	0.16511	0.17095	0.23766
1.1000	1.1000	0.76882	44.050	0.71873	0.18661	135.61	
299	103.58	0.15317	-0.80307	0.75193	0.16511	0.17095	0.23766
1.1000	1.1000	0.76883	44.050	0.71873	0.18661	135.61	
299	103.58	0.15317	-0.80307	0.75193	0.16511	0.17095	0.23767
1.1000	1.1000	0.76883	44.050	0.71873	0.18661	135.61	

NO. FIBONACCI CYCLES= 19   STOKES NO.= 2.00000   DP/DF= 0.10000   XPST= -99.99394

ITER	TIME	YP(1)	XP	YP	VPX	VPY	VMAG
BP	MIN BP	RADIANS	DEGREES	COS(ANG)	MAX RE	MIN CD	
277	101.24	0.0	-1.1057	-0.0	0.39307	0.0	0.39307
1.0870	1.0870	0.0	0.0	1.0000	0.38413	67.981	
451	115.49	0.42016	5.0432	1.1680	0.35577	-0.52946D-01	0.35969
5.2557	1.1827	2.9199	167.30	-0.97553	0.27622	93.030	
418	110.07	0.67984	5.0851	2.0831	0.61375	-0.43062D-01	0.61526
5.5792	1.5166	2.7602	158.15	-0.92817	0.22633	112.60	
384	107.86	1.1000	5.0043	2.7897	0.81567	-0.29062D-02	0.81567
5.8111	1.9926	2.6410	151.32	-0.87727	0.17944	140.84	
284	101.57	0.25967	-0.94037	0.57519	0.40267	0.15100	0.43005
1.0915	1.0915	0.56187	32.193	0.84626	0.32291	80.154	
436	112.23	0.51935	5.0591	1.6261	0.47967	-0.54836D-01	0.48279
5.3952	1.3174	2.8374	162.57	-0.95409	0.25360	100.96	
300	102.18	0.35886	-0.62971	0.90307	0.39316	0.19687	0.43970
1.0985	1.0985	0.97801	56.036	0.55867	0.29199	88.223	
445	113.93	0.45805	5.0766	1.3668	0.40717	-0.55567D-01	0.41095
5.3396	1.2357	2.8851	165.30	-0.96728	0.26823	95.677	
456	117.02	0.39675	5.0588	1.0142	0.31897	-0.49259D-01	0.32276
5.2392	1.1486	2.9493	168.98	-0.98157	0.28161	91.326	
459	118.23	0.38228	5.0519	0.90709	0.29512	-0.46030D-01	0.29869
5.2131	1.1268	2.9692	170.12	-0.98518	0.28533	90.190	
461	119.24	0.37333	5.0750	0.83096	0.28112	-0.43036D-01	0.28440
5.2235	1.1130	2.9843	170.99	-0.98765	0.28778	89.455	
462	119.76	0.36781	5.0336	0.79016	0.27226	-0.41625D-01	0.27542
5.1764	1.1044	2.9908	171.36	-0.98866	0.28935	88.991	
305	102.38	0.36438	-0.54442	0.95602	0.37903	0.19287	0.42528
1.0995	1.0995	1.0694	61.272	0.48066	0.29035	88.698	
461	119.39	0.36991	5.0039	0.81291	0.27531	-0.42747D-01	0.27861
5.1504	1.1077	2.9856	171.06	-0.98786	0.28876	89.167	
463	120.10	0.36648	5.0816	0.77131	0.27069	-0.40537D-01	0.27371
5.2212	1.1023	2.9957	171.64	-0.98938	0.28974	88.878	
463	120.16	0.36571	5.0683	0.76638	0.26935	-0.40408D-01	0.27236
5.2073	1.1011	2.9963	171.68	-0.98946	0.28997	88.812	
463	120.14	0.36516	5.0451	0.76496	0.26824	-0.40487D-01	0.27128
5.1841	1.1002	2.9959	171.65	-0.98941	0.29013	88.765	
306	102.43	0.36493	-0.52834	0.96518	0.37599	0.19159	0.42199
1.0999	1.0999	1.0862	62.236	0.46583	0.29019	88.745	
463	120.14	0.36548	5.0556	0.76620	0.26885	-0.40477D-01	0.27188
5.1947	1.1007	2.9960	171.66	-0.98942	0.29003	88.792	
463	120.17	0.36524	5.0555	0.76413	0.26849	-0.40388D-01	0.27151
5.1943	1.1004	2.9964	171.68	-0.98947	0.29010	88.772	
307	102.47	0.36501	-0.51239	0.97346	0.37236	0.18992	0.41799
1.1000	1.1000	1.1025	63.171	0.45132	0.29017	88.752	
463	120.14	0.36509	5.0412	0.76492	0.26809	-0.40509D-01	0.27113
5.1802	1.1001	2.9958	171.65	-0.98940	0.29015	88.759	
463	120.14	0.36508	5.0412	0.76482	0.26807	-0.40505D-01	0.27112
5.1802	1.1001	2.9959	171.65	-0.98940	0.29015	88.758	
463	120.15	0.36502	5.0412	0.76429	0.26798	-0.40482D-01	0.27102
5.1801	1.1000	2.9960	171.66	-0.98941	0.29017	88.753	

NO. FIBONACCI CYCLES= 19 STOKES NO.= 3.00000 DP/DP= 0.10000 XPSI= -99.99394

ITER	TIME	YP(1)	XP	YP	VPX	VPY	VMAG
RP	MIN RP	RADIANS	DEGREES	COS(ANG)	MAX RE	MIN CD	
277	100.81	0.0	-1.1050	-0.0	0.52363	0.0	0.52363
1.0871	1.0871	0.0	0.0	1.0000	0.50716	52.338	
289	101.32	0.42016	-0.79006	0.77692	0.53872	0.16061	0.56216
1.0991	1.0991	0.79203	45.380	0.70240	0.37491	69.563	
429	110.96	0.67984	5.0314	1.8229	0.53796	-0.40343D-01	0.53947
5.4328	1.3529	2.8007	160.47	-0.94247	0.29835	85.428	
392	108.14	1.1000	5.0667	2.6524	0.77814	0.10063D-01	0.77821
5.8026	1.8492	2.6666	152.79	-0.88932	0.23103	110.40	
413	109.38	0.84032	5.0467	2.2150	0.65328	-0.19478D-01	0.65357
5.5961	1.5498	2.7352	156.72	-0.91856	0.26357	95.561	
442	112.91	0.58065	5.0195	1.4688	0.43721	-0.50734D-01	0.44014
5.3121	1.2226	2.8635	164.06	-0.96157	0.32291	80.154	
453	115.40	0.51935	5.0778	1.1482	0.35533	-0.51501D-01	0.35904
5.2852	1.1364	2.9250	167.59	-0.97663	0.33932	76.464	
300	101.70	0.48146	-0.56044	0.94879	0.52668	0.17889	0.55624
1.0984	1.0984	1.0532	60.346	0.49477	0.35203	73.842	
448	114.19	0.54276	5.0249	1.2873	0.38910	-0.52282D-01	0.39259
5.2658	1.1700	2.8968	165.98	-0.97020	0.33267	77.917	
455	116.10	0.50487	5.0307	1.0640	0.33384	-0.50658D-01	0.33766
5.2215	1.1151	2.9389	168.38	-0.97952	0.34390	75.498	
457	116.74	0.49594	5.0452	1.0013	0.31927	-0.49561D-01	0.32309
5.2233	1.1017	2.9512	169.09	-0.98193	0.34584	74.889	
304	101.83	0.49039	-0.48273	0.98960	0.51759	0.17910	0.54770
1.0991	1.0991	1.1331	64.925	0.42381	0.34373	74.505	
456	116.51	0.49932	5.0460	1.0245	0.32480	-0.49969D-01	0.32862
5.2286	1.1068	2.9469	168.84	-0.98110	0.34572	75.119	
307	101.93	0.49377	-0.42924	1.0135	0.50947	0.17764	0.53955
1.0997	1.0997	1.1865	67.980	0.37494	0.34758	74.739	
457	116.71	0.49714	5.0637	1.0068	0.32103	-0.49585D-01	0.32484
5.2426	1.1035	2.9508	169.07	-0.98186	0.34544	74.972	
457	116.72	0.49497	5.0144	0.99928	0.31802	-0.49652D-01	0.32187
5.1926	1.1002	2.9505	169.05	-0.98180	0.34717	74.822	
309	102.00	0.49474	-0.39452	1.0272	0.50321	0.17595	0.53309
1.1000	1.1000	1.2204	69.923	0.34328	0.34725	74.806	
457	116.73	0.49572	5.0358	1.0012	0.31901	-0.49598D-01	0.32284
5.2141	1.1014	2.9509	169.07	-0.98187	0.34692	74.873	
457	116.72	0.49549	5.0287	1.0007	0.31872	-0.49619D-01	0.32256
5.2070	1.1010	2.9507	169.06	-0.98184	0.34599	74.858	
457	116.73	0.49527	5.0266	0.99948	0.31837	-0.49605D-01	0.32222
5.2047	1.1007	2.9509	169.07	-0.98187	0.34707	74.842	
457	116.75	0.49504	5.0266	0.99791	0.31800	-0.49576D-01	0.32184
5.2044	1.1003	2.9512	169.09	-0.98193	0.34714	74.827	
457	116.73	0.49482	5.0143	0.99825	0.31777	-0.49634D-01	0.32163
5.1924	1.1000	2.9507	169.06	-0.98183	0.34722	74.812	
457	116.72	0.49489	5.0144	0.99873	0.31789	-0.49642D-01	0.32174
5.1925	1.1001	2.9506	169.06	-0.98182	0.34720	74.816	
310	102.03	0.49481	-0.37760	1.0333	0.49976	0.17488	0.52948
1.1000	1.1000	1.2367	70.859	0.32790	0.34722	74.811	

NO. FIBONACCI CYCLES= 19 STOKES NO.= 5.00000 DP/DP= 0.10000 XPST= -99.99394

ITER	TIME	YP(1)	XP	YP	VPX	VPY	VMAG
RP	MIN RP	RADIANS	DEGREES	COS(ANG)	MAX RE	MIN CD	
277	100.36	0.0	-1.1040	-0.0	0.66039	0.0	0.66039
1.0861	1.0861	0.0	0.0	1.0000	0.64410	41.893	
283	100.66	0.42016	-0.90892	0.62426	0.66648	0.96300D-01	0.67340
1.0895	1.0895	0.61300	35.122	0.81793	0.55412	48.182	
448	112.36	0.67984	5.0093	1.4287	0.42496	-0.35730D-01	0.42646
5.2884	1.1455	2.8694	164.41	-0.96319	0.39955	65.498	
403	108.33	1.1000	5.0382	2.3579	0.70763	0.21044D-01	0.70794
5.6488	1.6609	2.7105	155.30	-0.90849	0.30273	85.236	
428	110.07	0.84032	5.0862	1.8738	0.55776	-0.13922D-01	0.55793
5.5033	1.3518	2.7946	160.12	-0.94040	0.35570	73.118	
293	101.01	0.58065	-0.65061	0.89498	0.67074	0.13171	0.68355
1.0987	1.0987	0.95779	54.877	0.57533	0.47388	55.776	
440	111.32	0.74114	5.0786	1.6185	0.48051	-0.28062D-01	0.48133
5.4136	1.2263	2.8390	162.66	-0.95457	0.38071	68.559	
307	101.43	0.64195	-0.35338	1.0424	0.65253	0.14164	0.66772
1.0988	1.0988	1.2602	72.203	0.30564	0.44892	58.686	
445	111.94	0.70324	5.0480	1.5042	0.44686	-0.33023D-01	0.44808
5.3508	1.1767	2.8579	163.75	-0.96004	0.39193	66.702	
450	112.71	0.66535	5.0047	1.3774	0.41062	-0.37459D-01	0.41232
5.2702	1.1259	2.8787	164.94	-0.96564	0.41164	63.681	
452	113.12	0.65643	5.0715	1.3378	0.40093	-0.38886D-01	0.40281
5.3287	1.1137	2.8895	165.56	-0.96839	0.42705	61.512	
452	113.13	0.65087	5.0130	1.3222	0.39577	-0.39123D-01	0.39770
5.2640	1.1060	2.8894	165.55	-0.96836	0.43667	60.234	
453	113.26	0.64751	5.0238	1.3080	0.39219	-0.39530D-01	0.39418
5.2709	1.1014	2.8925	165.73	-0.96913	0.44323	59.394	
310	101.52	0.64530	-0.29618	1.0595	0.64589	0.14105	0.66111
1.0993	1.0993	1.3145	75.317	0.25348	0.44697	58.927	
453	113.26	0.64866	5.0367	1.3112	0.39327	-0.39484D-01	0.39525
5.2842	1.1030	2.8925	165.73	-0.96914	0.44086	59.694	
312	101.57	0.64645	-0.26023	1.0690	0.64121	0.14035	0.65639
1.1000	1.1000	1.3483	77.253	0.22064	0.44539	59.123	
453	113.25	0.64760	5.0238	1.3084	0.39229	-0.39520D-01	0.39427
5.2710	1.1015	2.8924	165.72	-0.96912	0.44304	59.418	
453	113.23	0.64655	5.0006	1.3066	0.39140	-0.39497D-01	0.39338
5.2480	1.1001	2.8917	165.68	-0.96893	0.44521	59.146	
453	113.26	0.64742	5.0238	1.3077	0.39210	-0.39539D-01	0.39408
5.2708	1.1013	2.8926	165.73	-0.96915	0.44342	59.371	
453	113.26	0.64733	5.0238	1.3073	0.39200	-0.39548D-01	0.39399
5.2707	1.1012	2.8926	165.73	-0.96917	0.44361	59.347	
453	113.25	0.64723	5.0166	1.3077	0.39197	-0.39518D-01	0.39395
5.2639	1.1010	2.8922	165.71	-0.96907	0.44380	59.322	
453	113.25	0.64714	5.0166	1.3073	0.39187	-0.39527D-01	0.39386
5.2638	1.1009	2.8923	165.72	-0.96908	0.44399	59.298	
453	113.23	0.64705	5.0060	1.3080	0.39187	-0.39476D-01	0.39386
5.2537	1.1008	2.8917	165.68	-0.96893	0.44418	59.274	
453	113.23	0.64696	5.0051	1.3078	0.39178	-0.39481D-01	0.39377
5.2527	1.1007	2.8917	165.68	-0.96893	0.44437	59.251	

NO. FIBONACCI CYCLES= 19   STOKES NO.= 7.50000   DP/DP= 0.10000   XPST= -99.99394

ITER	TIME	YP(1)	XP	YP	VPX	VPY	VMAG
RP	MIN RP	RADIANS	DEGREES	COS(ANG)	MAX RE	MIN CD	
277	100.05	0.0	-1.1034	-0.0	0.74602	0.0	0.74602
1.0854	1.0854	0.0	0.0	1.0000	0.72987	37.325	
281	100.29	0.42016	-0.95219	0.55835	0.74889	0.63610D-01	0.75159
1.0892	1.0892	0.53987	30.932	0.85778	0.65607	41.185	
295	100.76	0.67984	-0.57758	0.93686	0.75145	0.10217	0.75836
1.0934	1.0934	1.0334	59.207	0.51194	0.55578	48.048	
413	108.22	1.1000	5.0204	2.0847	0.67008	0.25344D-01	0.67056
5.5197	1.5236	2.7537	157.77	-0.92569	0.35961	72.364	
440	109.83	0.84032	5.0145	1.6274	0.52166	-0.33803D-02	0.52157
5.3566	1.2135	2.8330	162.32	-0.95277	0.42500	61.790	
429	109.07	0.93951	5.0309	1.8182	0.58476	0.79910D-02	0.58481
5.4337	1.3345	2.8002	160.44	-0.94228	0.39566	66.106	
449	110.65	0.77902	5.0884	1.4938	0.47604	-0.11723D-01	0.47618
5.3880	1.1366	2.8611	163.93	-0.96092	0.48976	54.078	
306	101.08	0.74114	-0.32818	1.0512	0.74197	0.10976	0.75004
1.0986	1.0986	1.2843	73.587	0.28256	0.53496	49.791	
445	110.28	0.80244	5.0458	1.5469	0.49419	-0.83682D-02	0.49426
5.3623	1.1662	2.8493	163.25	-0.95758	0.45381	58.091	
450	110.73	0.76455	5.0356	1.4619	0.46589	-0.12808D-01	0.46606
5.3285	1.1182	2.8642	164.10	-0.96177	0.51370	51.714	
451	110.85	0.75561	5.0320	1.4411	0.45902	-0.13826D-01	0.45923
5.3192	1.1067	2.8678	164.31	-0.96275	0.52878	50.334	
312	101.24	0.75008	-0.21144	1.0801	0.73262	0.10983	0.74081
1.1000	1.1000	1.3938	79.859	0.17607	0.53589	49.710	
451	110.84	0.75901	5.0536	1.4484	0.46131	-0.13678D-01	0.46152
5.3420	1.1110	2.8675	164.30	-0.96268	0.52303	50.852	
452	110.97	0.75348	5.0732	1.4348	0.45671	-0.14552D-01	0.45694
5.3572	1.1039	2.8710	164.50	-0.96362	0.53255	50.001	
452	110.92	0.75221	5.0457	1.4326	0.45615	-0.14384D-01	0.45638
5.3301	1.1023	2.8700	164.44	-0.96335	0.53500	49.787	
452	110.92	0.75134	5.0403	1.4307	0.45556	-0.14423D-01	0.45579
5.3244	1.1012	2.8701	164.44	-0.96337	0.53668	49.641	
452	110.90	0.75095	5.0279	1.4302	0.45545	-0.14327D-01	0.45567
5.3123	1.1007	2.8696	164.41	-0.96323	0.53745	49.575	
452	110.90	0.75047	5.0256	1.4291	0.45511	-0.14356D-01	0.45534
5.3098	1.1001	2.8697	164.42	-0.96325	0.53837	49.496	
452	110.90	0.75055	5.0256	1.4293	0.45517	-0.14346D-01	0.45540
5.3098	1.1002	2.8696	164.42	-0.96324	0.53821	49.510	
313	101.26	0.75016	-0.19368	1.0829	0.73075	0.10961	0.73892
1.0997	1.0997	1.4101	80.795	0.15996	0.53759	49.563	
313	101.26	0.75024	-0.19368	1.0830	0.73078	0.10962	0.73895
1.0998	1.0998	1.4102	80.796	0.15995	0.53742	49.577	
313	101.26	0.75032	-0.19239	1.0833	0.73067	0.10962	0.73885
1.0999	1.0999	1.4114	80.865	0.15876	0.53735	49.584	
314	101.29	0.75040	-0.17462	1.0861	0.72878	0.10939	0.73695
1.1000	1.1000	1.4277	81.802	0.14260	0.53812	49.517	
452	110.90	0.75048	5.0256	1.4292	0.45512	-0.14355D-01	0.45534
5.3098	1.1001	2.8696	164.42	-0.96325	0.53835	49.498	

NO. FIBONACCI CYCLES= 19   STOKES NO.= 10.00000   DP/DF= 0.10000   XPST= -99.99394

ITER	TIME	YP(1)	XP	YP	VPX	VPY	VMAG
RP	MIN RP	RADIANS	DEGREES	COS(ANG)	MAX RE	MIN CD	
277	99.860	0.0	-1.1031	-0.0	0.79554	0.0	0.79554
1.0851	1.0851	0.0	0.0	1.0000	0.77945	35.137	
280	100.06	0.42016	-0.97580	0.52595	0.79751	0.47304D-01	0.79892
1.0925	1.0925	0.50344	28.845	0.87593	0.71193	38.191	
290	100.42	0.67984	-0.68341	0.86860	0.80081	0.76410D-01	0.80444
1.0956	1.0956	0.91796	52.595	0.60744	0.61684	43.607	
420	108.03	1.1000	5.0729	1.9032	0.66869	0.26441D-01	0.66922
5.5029	1.4397	2.7878	159.73	-0.93805	0.39727	65.854	
449	109.38	0.84032	5.0770	1.4824	0.53457	0.43605D-02	0.53459
5.3747	1.1327	2.8620	163.98	-0.96118	0.55137	48.406	
437	108.75	0.93951	5.0836	1.6533	0.59107	0.13040D-01	0.59122
5.4311	1.2521	2.8319	162.26	-0.95243	0.43822	60.033	
300	100.72	0.77902	-0.43397	1.0156	0.79756	0.86988D-01	0.80229
1.0993	1.0993	1.1826	67.759	0.37850	0.58284	45.967	
444	109.11	0.87821	5.0731	1.5492	0.55719	0.77795D-02	0.55724
5.3899	1.1787	2.8498	163.28	-0.95774	0.49712	53.327	
451	109.44	0.81691	5.0103	1.4395	0.52167	0.30301D-02	0.52168
5.2946	1.1040	2.8662	164.22	-0.96231	0.58884	45.530	
306	100.88	0.80244	-0.30618	1.0584	0.79225	0.89106D-01	0.79724
1.0990	1.0990	1.3053	74.790	0.26236	0.58479	45.824	
450	109.39	0.82585	5.0236	1.4559	0.52693	0.36770D-02	0.52694
5.3161	1.1150	2.8641	164.10	-0.96174	0.57450	46.587	
311	101.00	0.81138	-0.20537	1.0809	0.78612	0.89526D-01	0.79121
1.0990	1.0990	1.3993	80.176	0.17062	0.58943	45.438	
451	109.51	0.82032	5.0615	1.4460	0.52261	0.27588D-02	0.52261
5.3498	1.1082	2.8678	164.31	-0.96276	0.58343	45.923	
452	109.54	0.81479	5.0529	1.4359	0.51934	0.23645D-02	0.51935
5.3388	1.1014	2.8692	164.39	-0.96314	0.59271	45.254	
314	101.07	0.81350	-0.14978	1.0898	0.78204	0.89357D-01	0.78713
1.0998	1.0998	1.4506	83.110	0.11996	0.59234	45.280	
452	109.56	0.81562	5.0684	1.4374	0.51951	0.22659D-02	0.51951
5.3542	1.1024	2.8697	164.42	-0.96327	0.59118	45.363	
452	109.54	0.81433	5.0518	1.4350	0.51908	0.23372D-02	0.51909
5.3374	1.1008	2.8693	164.40	-0.96316	0.59354	45.195	
452	109.51	0.81396	5.0355	1.4343	0.51923	0.24853D-02	0.51923
5.3216	1.1004	2.8686	164.36	-0.96298	0.59424	45.146	
452	109.51	0.81388	5.0355	1.4341	0.51918	0.24785D-02	0.51918
5.3215	1.1003	2.8687	164.36	-0.96298	0.59438	45.136	
314	101.07	0.81358	-0.14978	1.0899	0.78206	0.89365D-01	0.78715
1.0999	1.0999	1.4506	83.111	0.11995	0.59219	45.231	
314	101.07	0.81365	-0.14978	1.0900	0.78209	0.89373D-01	0.78718
1.1000	1.1000	1.4506	83.112	0.11994	0.59204	45.301	
452	109.51	0.81373	5.0355	1.4338	0.51908	0.24654D-02	0.51909
5.3214	1.1001	2.8687	164.36	-0.96300	0.59465	45.117	
452	109.51	0.81380	5.0355	1.4340	0.51913	0.24717D-02	0.51913
5.3215	1.1002	2.8687	164.36	-0.96299	0.59452	45.126	
452	109.51	0.81373	5.0355	1.4338	0.51908	0.24649D-02	0.51909
5.3214	1.1001	2.8687	164.37	-0.96300	0.59466	45.116	

INITIAL VARIABLES

R-INFINITY= 100.000 REYNOLD'S NO.= 10.000

XP(1)= -99.99394 .

SIZE OF GRID= 33 X 93

GNUM= 3.000000 JSUB= 1 NUMBER OF ITERATIONS IN GRID= 5000

KLYACHKO'S FORMULA FOR DRAG COEFFICIENT USED AT ALL VALUES OF RE

******* KUWABARA'S ZERO VORTICITY MODEL *******

***** NUMERICAL FLOWFIELD USED *******

EFFICIENCY WITH INTERCEPTION

STOKES' NO.=	1.000	EPSIL=	0.1531760	DP/DF=	0.100000	EFF=	0.1392509
STOKES' NO.=	2.000	EPSIL=	0.3650161	DP/DF=	0.100000	EFF=	0.3318329
STOKES' NO.=	3.000	EPSIL=	0.4948146	DP/DF=	0.100000	EFF=	0.4498317
STOKES' NO.=	5.000	EPSIL=	0.6464987	DP/DF=	0.100000	EFF=	0.5877264
STOKES' NO.=	7.500	EPSIL=	0.7504339	DP/DF=	0.100000	EFF=	0.6822130
STOKES' NO.=	10.000	EPSIL=	0.8136897	DP/DF=	0.100000	EFF=	0.7397183

STOP 0
EXECUTION TERMINATED

$SIGNOFF