NASA-TP-2318 19840017876

NASA
Technical
Paper
2318

June 1984

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Drag of Two-Dimensional Small-Amplitude Symmetric and Asymmetric Wavy Walls in Turbulent Boundary Layers

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SUMMARY

The results of an experimental investigation of low-speed turbulent flow over multiple two-dimensional transverse rigid wavy surfaces having a wavelength on the order of the boundary-layer thickness are presented. These small-amplitude symmetric and asymmetric wavy walls have a ratio of wave height to wavelength (h/λ) between 0.0027 and 0.020. Waveforms include sine waves, spliced sine waves, sine waves and straight ramps, transverse V-grooves, and circular arcs and straight ramps. Data include surface pressure and total drag measurements under a low-speed turbulent boundary layer with the free-stream velocity (U_∞) varied between 7.6 m/s and 43 m/s. Within the experimental scatter, no total drag reduction was found for the parameter space examined. However, several asymmetric waves with $h/\lambda = 0.015$ and the steeper surface facing upstream exhibited total drag levels below the equivalent symmetric (sine) wave by up to 6 percent. Experimental trends indicate a possible total drag reduction at higher Reynolds numbers for some small-amplitude configurations. The experimental results compare favorably with numerical predictions from a Reynolds-averaged Navier-Stokes spectral code for pressure coefficient (C_p) distributions and drag levels. The Navier-Stokes code uses an equilibrium zero equation turbulence model which is applied directly in the transformed coordinate system. The reported results are of particular interest for the estimation of drag, the minimization of fabrication waviness effects, and the study of wind-wave interactions.

INTRODUCTION

Transverse wavy surfaces (wavy walls) have been investigated at the Langley Research Center as part of a program to reduce turbulent viscous drag in external flows (refs. 1 and 2). The original objective of the wavy wall investigation was to determine whether such surface geometries could have lower aerodynamic drag than smooth, planar surfaces.

The problem of fluid flow over wavy surfaces has been of significant interest for many years, particularly in the area of wind-wave interaction. Several previous experiments on low-speed turbulent flow over a train of sinusoidal waves have been reported (refs. 3 to 15). References 3, 4, 5, 6, 10, and 11 examined wavy walls in wind-tunnel boundary layers; reference 12 examined a wavy wall pipe flow; and references 7, 8, 9, 13, 14, and 15 examined wavy walls in water channel boundary layers. Table 1, obtained from reference 14 and updated to include the more recent works, provides a summary of these experiments. In addition, wave-induced roughness drag data were presented in references 16, 17, and 18. A reduction in average skin friction compared with flat plate values was found in references 3, 4, 5, 6, 7, and 12. Furthermore, reference 12 indicates a net drag reduction on the order of 10 percent (with respect to a straight pipe of equivalent mean diameter) for wavy wall pipe flow with a ratio of wave height to wavelength (h/λ) equal to 0.011. However, with the exception of the internal wavy pipe flow of reference 12, none of these experiments produced a reduction in total drag. All experiments (refs. 3 to 15), with the exception of references 6, 10, and 14, were designed to have a wave height to wavelength ratio such that the flow did not separate ($0.006 \leq h/\lambda \leq 0.031$). Thus, as a possible method of drag reduction, shallow wavy walls with h/λ values on the order of 0.01 are of particular interest (see fig. 1), since the flow remains attached over these wavy surfaces. The average local skin friction over the wavy walls is typically less than that for a flat plate. For example, Kendall (ref. 3) reported a 20-percent reduction with $h/\lambda = 0.031$ and with wavelength over boundary-layer thickness (λ/δ) equal to 1.6, and Sigal (ref. 4) found a reduction as large as 10 percent for $h/\lambda = 0.028$ ($\lambda/\delta = 4$). This reduced skin-friction drag is probably caused by the combined effect of pressure gradient and curvature over the wavy surface (ref. 19). However, for subsonic flow, there is an interaction between the boundary layer and the pressure field which causes the pressure distribution to shift downstream relative to the physical surface geometry. (See fig. 1.) This phase shift produces a pressure drag which, for all cases reported in the literature (except ref. 12), results in an increase in total drag for the wavy surface. There was some speculation that a properly designed wavy surface could be capable of producing a total drag reduction through simultaneous minimization of pressure drag and skin friction (refs. 19, 20, and 21).

Cary et al. (ref. 21) presented the results of a detailed analytical and experimental study of the drag of sinusoidal wavy wall surfaces with small h/λ values and λ/δ values approximately the order of 1. This earlier study used a boundary-layer calculation method (ref. 22) and measured pressure data to predict the viscous drag. The boundary-layer calculation was later replaced by a Navier-Stokes spectral code (refs. 23 through 28) to improve the prediction capability for turbulent boundary layers over both sine wave surfaces and asymmetric waves. Reference 23 highlighted some results of the recent experimental investigation on short-wavelength sinusoidal and asymmetric wavy walls.

The purposes of the present investigation were to (1) determine if drag reduction could be obtained with symmetric sinusoidal wavy walls having wave height to wavelength ratios less than or equal to 0.02; (2) determine if asymmetric waves could be designed to shift the pressure distribution sufficiently to reduce the pressure drag while maintaining skin-friction reductions; and (3) examine the prediction capability of a Navier-Stokes code for small-amplitude wavy walls.

SYMBOLS

C_D total drag coefficient

$C_{D,p}$ pressure drag coefficient

C_F average skin-friction coefficient

c_f local skin-friction coefficient, $2\tau_w/\rho U_\infty^2$

C_p pressure coefficient, $2(p - p_\infty)/\rho U_\infty^2$

D/D_o drag of test surface nondimensionalized by drag of flat plate reference

g matrix of transformation

h wave height, or amplitude

h^+ wave height in wall variables, hu_τ/ν

L_1/L_2 upstream to downstream length ratio of waves (see fig. 3)

$\ell, \mathcal{L}$	mixing length in physical and conformal coordinate systems, respectively
p	static pressure
R	model in reverse flow direction
R_θ	Reynolds number based on momentum thickness, $U_\infty \theta/\nu$
t	time
U_∞	free-stream velocity
u,v	velocity components along and normal to horizontal plane, respectively
u_τ	shear velocity, $(\tau_w/\rho_w)^{1/2}$
X,Y	coordinates along and normal to conformal plane, respectively
x,y	coordinates along and normal to physical plane, respectively
δ	boundary-layer thickness
θ	momentum thickness
κ	von Karman constant (κ = 0.41)
λ	wavelength
ν	kinematic viscosity
ρ	density
τ	shear stress
ϕ	pressure phase angle

Subscripts:

max	maximum
min	minimum
o	flat plate
t	$\partial/\partial t$
w	wall
X	$\partial/\partial X$
x	$\partial/\partial x$
xx	$\partial^2/\partial x^2$
Y	$\partial/\partial Y$

y $\partial/\partial y$

yy $\partial^2/\partial y^2$

∞ free stream

Superscript:

' fluctuating

A bar (-) over a symbol denotes a mean. A tilde (~) over a symbol denotes the conformal coordinate system.

APPARATUS AND TESTS

Wind-Tunnel Test Facility

The wavy wall investigation was conducted in the 15-inch low-turbulence wind tunnel at the Langley Research Center. This facility is an open-circuit wind tunnel which has a test section 2.74 m long with a 0.381-m square cross section. (See fig. 2.) The velocity for the experiment was varied between 7.6 m/s and 43 m/s. The boundary layer which develops along the contraction is removed 142.2 cm ahead of the test section by a 1.27-cm-wide transverse suction slot. The new boundary layer developing downstream of the suction slot is artificially tripped with a strip of No. 40 grit sandpaper, 25.4 cm in length, which spans the width of the tunnel floor. The trip was selected to give an equilibrium turbulent boundary layer with minimum variation in spanwise momentum thickness at the beginning of the test section. Spanwise momentum thickness measurements were uniform (within ±5 percent) over the central 25.4 cm of the test surface for free-stream velocities between 7.6 m/s and 21.3 m/s and the turbulent boundary layer over the last 0.91 m of the test section exhibited conventional turbulent boundary-layer characteristics; i.e., (1) the velocity profiles in defect coordinates were in good agreement with Coles' law of the wake (see ref. 29), and (2) the local skin friction determined from Clauser charts (ref. 30) was in good agreement with that obtained from the Karman-Schoenherr skin-friction formula (ref. 31). The turbulent-boundary-layer profiles just upstream of the wavy wall test surface are documented in table 2. The wavy wall models were mounted on a drag balance over the last 0.91 m of the test section with the mean test surface positioned flush with the wind-tunnel floor. The upper wall over this region of the test section was adjusted to minimize the longitudinal pressure gradient. The ratio of the maximum free-stream pressure gradient over the test surface to the dynamic pressure was less than 0.0002 cm^{-1}. The free-stream turbulence level was on the order of 0.05 percent at the beginning of the test surface, the boundary-layer thickness was approximately 3 cm, and the Reynolds number based on momentum thickness (R_θ) was 4700 for a free-stream velocity (U_∞) of 22.9 m/s.

Wavy Wall Models

The wavy wall models tested in the current study were designed with wavelengths such that λ/δ is on the order of 1. The waveforms, shown in figure 3, include both sine waves and asymmetric (nonsinusoidal) waves. The waveforms in figure 3 were repeated along the test plate and typically started 1.27 cm downstream of the leading edge and ended 1.27 cm upstream of the trailing edge of the test plate. The asymmetric waves consisted of combinations of sine waves and straight ramps, spliced sine waves, transverse V-grooves, and circular arcs and straight ramps. As shown in figure 3, the ratio of wave height to wavelength (h/λ) varied from 0.0027 to 0.020. Each wavy wall model was machined from an aluminum plate with overall dimensions of 35.6 cm × 91.4 cm × 1.27 cm. After the surface contour was machined, the surface coordinates in the vicinity of the pressure orifices (which were located near the center of each model) were carefully measured. The accuracy of the surface measurement was within ±0.007 mm. Seven symmetric models (six sine wave models and one V-groove model) and 14 asymmetric models were employed in the present study. In addition, the asymmetric models were tested in two directions (forward and reverse). Thus, 28 different asymmetric geometries were evaluated. The symmetric models were also tested in two directions to check data repeatability. The nondimensionalized measurements of the surface coordinates (x/λ, y/λ) in the vicinity of the pressure orifices are listed in the appendix (tables A1 to A21) for each model.

Direct Drag Measurements

The experimental measurements consisted of two parts: (1) a direct-drag measurement of the total drag, and (2) a pressure distribution measurement that was used to calculate the pressure drag portion of the total drag. The skin friction was then determined by subtracting the pressure drag from the total drag. The direct-drag measuring system was similar to that reported in reference 32. The test surfaces (35.6 cm × 91.4 cm) were mounted on a free-floating drag balance as shown in figure 2 with narrow gaps along the sides and at the leading and trailing edges. The free-floating drag balance consisted of an air bearing and a deflection sensor. To minimize errors associated with mass transfer at the gaps, an enclosure was built around the drag balance. An automatic variable suction system was then used to maintain a zero pressure difference between the pressure under the drag balance and the static pressure in the test section. Theoretically, if the drag balance enclosure had been completely airtight, the suction system would not have been needed. But practically, the suction system was required. The repeatability of the drag measurements was established by conducting numerous flat-plate runs; the model was removed from the tunnel and reinstalled before each run. All tests indicated that the repeatability of the direct-drag measuring system was within ±1.5 percent. The average skin-friction coefficient (C_F) for the flat plate determined from drag balance measurements was within 3 percent of the C_F determined from the Karman-Schoenherr skin-friction formula (ref. 31) using the Reynolds number based on momentum thickness (R_θ). The momentum thickness was determined from measured velocity profiles. The wavy wall direct-drag (or total drag) measurements have been nondimensionalized by the average flat-plate drag (see table 3) over the entire velocity range. The nondimensionalized total drag measurements are given in the appendix (tables A22 to A42).

Pressure Distribution Measurements

From 19 to 30 static pressure orifices with a 0.508-mm inner diameter were distributed longitudinally over a distance of one wavelength near the center of each wavy wall model. The orifices were staggered at a 45° angle to the model centerline. The orifice pressure tubes were connected to a motor-driven valve (scanner valve) which sequentially connected each orifice to a single differential pressure gage. The pressure distribution was measured at four velocities: 15.2 m/s, 22.9 m/s, 30.5 m/s, and 38.1 m/s. The corresponding Reynolds numbers based on momentum thickness (R_θ) were 3300, 4700, 5800, and 7300, respectively. The resulting C_p distributions at the four different speeds for all wavy wall geometries with their relative pressure orifice locations (x/λ) are given in the appendix (tables A43 to A63). An integration of the measured pressure distribution over one wavelength of its corresponding surface geometry was used to determine (when multiplied by the number of waves and the actual surface area) the pressure drag contribution to the total drag of the wavy wall models.

NAVIER-STOKES SOLVER

Numerical predictions of turbulent boundary-layer flow over the present wavy surfaces were obtained by using a two-dimensional Navier-Stokes solver employing spectral methods and a conformal mapping technique (ref. 33). The geometrical coordinates of the wave surface (over one wavelength) were input into a precursor program that used fast and efficient conformal mapping techniques to develop an orthogonal grid system. The mapping coefficients and the physical grid coordinates are stored in a mass storage device. A linear interpolation of the input velocity field is used to obtain the velocity field in the computational domain at a time $t = 0$. The flow evolution at subsequent times is determined by solving the Reynolds-averaged Navier-Stokes equations with higher order Fourier-Chebyshev spectral techniques (ref. 34).

The time-averaged two-dimensional Navier-Stokes equations for constant density turbulent flows can be written as

$$\left.\begin{aligned} & u_x + v_y = 0 \\ & u_t + uu_x + vu_y = -\frac{1}{\rho} p_x + \nu\left(u_{xx} + u_{yy}\right) - \left[\left(\bar{u}'^2\right)_x + \left(\overline{u'v'}\right)_y\right] \\ & v_t + uv_x + vv_y = -\frac{1}{\rho} p_y + \nu\left(v_{xx} + v_{yy}\right) - \left[\left(\overline{u'v'}\right)_x + \left(\bar{v}'^2\right)_y\right] \end{aligned}\right\} \tag{1}$$

Turbulent closure is required to evaluate the Reynolds stress terms $-\overline{u'v'}$.

The boundary conditions appropriate to the problem are

$$\left.\begin{aligned} & u = 0 \quad \text{at} \quad y = f(x) \\ & p - p_\infty \to 0 \quad \text{at} \quad y = \infty \end{aligned}\right\} \tag{2}$$

where $y = f(x)$ is the wavy surface. For the study of flow over a wave train, the assumption of periodicity in the flow direction has been made; that is,

$$\left.\begin{aligned} u(x) &= u(x + \lambda) \\ v(x) &= v(x + \lambda) \\ p(x) &= p(x + \lambda) \end{aligned}\right\} \qquad (3)$$

where λ is the wavelength of the wavy surface.

The Reynolds stress terms

$$\left.\begin{aligned} \overline{u'u'} &= \overline{v'v'} = 0 \\ \overline{u'v'} &= \ell^2(u_y + v_x)|u_y + v_x| \end{aligned}\right\} \qquad (4)$$

are modeled by using a mixing length/eddy viscosity (or equilibrium zero equation) model (ref. 24)

$$\frac{\ell}{\delta} = \left(\frac{\ell}{\delta}\right)_{max} \tanh\left[\frac{\kappa(y/\delta)}{(\ell/\delta)_{max}}\right]\left[1 - \exp\left(-\frac{y}{A}\right)\right] \qquad (5)$$

with $(\ell/\delta)_{max} = 0.09$, $A = A^+\nu/u_\tau$ where $A^+ = 26$, and $\kappa = 0.41$.

Evaluation of $\overline{u'v'}$ in the physical (x,y) plane is fraught with difficulties because of the complication of the nonplanar boundary. Assumptions such as $\left(\overline{u'^2}\right)_x << \left(\overline{u'v'}\right)_y$ do not hold as in the planar boundary case. A way out of the difficulty is to develop relations for Reynolds stresses and their derivatives in the conformal (X,Y) plane; that is,

$$\overline{u'v'} = g\overline{\tilde{u}'\tilde{v}'} \qquad (6)$$

where g is a metric of transformation and $\tilde{}$ denotes the conformal coordinate system. It is justifiable to assume in this case that $\left(\tilde{u}'^2\right)_X << \left(\tilde{u}'\tilde{v}'\right)_Y$, since the boundary layer develops normal to the surface and boundary-layer simplifications can hence be invoked. It can be shown that

$$\left.\begin{aligned} \left(\overline{u'^2}\right)_x + \left(\overline{u'v'}\right)_y &\approx g_1\left(\overline{\tilde{u}'\tilde{v}'}\right)_Y \\ \left(\overline{u'v'}\right)_x + \left(\overline{v'^2}\right)_y &\approx 0 \end{aligned}\right\} \qquad (7)$$

where g_1 is on the order of 1, and the terms that are neglected on the right-hand side of equations (7) are terms involving $(\tilde{\bar{u}}'^2)_X$, $(\overline{\tilde{u}'\tilde{u}'})_X$, $(\tilde{\bar{v}}'^2)_X$, etc. By analogy to the usual modeling in the physical plane, equations (4) become

$$\overline{\tilde{u}'\tilde{v}'} = \mathcal{L}^2(\tilde{u}_Y + \tilde{v}_X)|\tilde{u}_Y + \tilde{v}_X| \tag{8}$$

where $\mathcal{L} = \kappa Y$ is now the typical eddy size, and $\tilde{u},\tilde{v}$ are the mean velocities in the conformal plane. Substituting this relation in equations (7) (after converting $\tilde{u}$ to u by using the mapping transformation) yields

$$\left.\begin{aligned} (\bar{u}'^2)_x + (\overline{u'v'})_y &\approx g_2\left[\mathcal{L}^2(u_Y + v_X)|u_Y + v_X|\right]_Y \\ (\overline{u'v'})_x + (\bar{v}'^2)_y &\approx 0 \end{aligned}\right\} \tag{9}$$

where, again, $g_2 \approx 1$. These relations were typical of the Reynolds stress terms used in the present calculations.

Typically, flow simulations were achieved on a 32 × 33 grid system (which is mapped to ∞ in the normal direction); that is, 32 Fourier modes (streamwise direction) and 32 Chebyshev modes (normal direction) were used to describe flow variables. A typical simulation utilized a nondimensional time step of 0.01 (nondimensionalized by λ/U_∞) and required an evolution time of approximately six units (i.e., 600 steps). Comparisons between simulations and experimental measurements were made around this evolution time, since the R_θ level of the mean flow at the measurement station matched very well with the mean R_θ level of the Navier-Stokes solution at this point. On CDC CYBER 173 machines, a complete evolution requires approximately 2400 central processor seconds (i.e., 4 milliseconds per point per time step of CYBER 173 time.)

The results of the numerical flow simulations include both C_p and C_f distributions. For all wave geometries at U_∞ = 22.9 m/s, the predicted C_p and $C_f/C_{f,o}$ ($C_{f,o}$ = 0.00305) variations are presented in the appendix (tables A64 to A84). In addition, the predicted C_p and C_f distributions were integrated over one wavelength to determine the average pressure and skin-friction drag. The summation of these drag components then gives the predicted total drag for a particular waveform. A free-stream velocity of 22.9 m/s was used for the Navier-Stokes simulations because this velocity was representative for each wavy wall geometry investigated.

A small number of the wavy wall geometries had extremely steep gradients in localized regions of the waves. For these waves, where the geometry was not resolved properly by the 32-mode solution, 64 modes were required in the flow direction to obtain a reasonable simulation of the C_p distributions. Most of the wavy wall geometries had surface geometry deviations from design specifications. Since small changes in surface geometry do induce changes in the pressure and skin-friction distributions, the actual measured surface coordinates of the geometry were used as inputs to the Navier-Stokes simulations. A small numerical oscillation was present in some of the predicted $C_f/C_{f,o}$ distributions. An increase in the number of

Fourier modes (streamwise direction) to 64 decreased the oscillations in the $C_f/C_{f,o}$ distributions, but it did not always eliminate the oscillations. However, the average level of the predicted $C_f/C_{f,o}$ distribution was unchanged by the increase in numerical resolution. Therefore, an averaged $C_f/C_{f,o}$ "smooth" curve was drawn through these oscillations for all predicted distribution figures shown herein. An example of the typical oscillation in the $C_f/C_{f,o}$ prediction and its smooth curve fit is shown in figure 4.

RESULTS AND DISCUSSION

Sine Waves Models

The drag data for a sine wave surface (see fig. 3(a)) having a fixed wavelength (λ) are presented in figure 5 for the entire R_θ range tested. The wavy wall drag is nondimensionalized by the drag of the reference flat plate (D/D_o) and plotted against the Reynolds number based on momentum thickness (R_θ). The data indicate that for the same λ (2.54 cm) and number of waves (35), the total drag increases as h/λ increases. Although model 1 ($h/\lambda = 0.005$) indicated a slight total drag reduction of about 1 percent at high tunnel velocities, this reduction is within the ±1.5-percent experimental error. Hence, within the experimental scatter and the Reynolds number range tested, none of the sine wave models produced a total drag reduction. Figure 6 separates the total drag measurements of figure 5 into the skin-friction and pressure drag components for $R_\theta = 4700$ and 7800. As shown in figure 6, the increase in total drag for the sine wave surfaces is mainly due to an increase in pressure drag, since the skin friction drag is only slightly reduced. Also shown in figure 6 are the data of Kendall and Sigal from references 3 and 4, respectively, for higher h/λ values. An extrapolation of the present skin-friction "measurements" (total drag minus pressure drag) to larger h/λ values indicates much less average skin-friction reduction due to wall waviness as compared with the data of Kendall (and, to a lesser extent, Sigal). Since the skin-friction measurement techniques used in these previous studies were not properly calibrated for pressure gradient effects (even though pressure gradient effects are significant in these experiments), the present data may be more reasonable.

Figures 7 to 12 show the measured C_p distributions for all six sine wave geometries at four tunnel velocities and two flow directions. The difference in the sine wave nondimensional pressure drag is within 0.5 percent for the two flow directions. Notice from these figures the slight downstream "skewness" of the C_p distribution; this is more noticeable at lower velocities, and the skewness decreases as the velocity increases. The decreased skewness or smaller pressure phase shift as Reynolds number was increased is probably the reason for the trend of the total drag levels shown in figure 5. The decreased phase shift results in lower pressure drag. There is some speculation that the wavy walls may give drag reductions at much higher Reynolds numbers than tested in the present investigation because of the negative slope of the total drag curves in figure 5.

Figure 13 illustrates the effect of λ/δ on drag for a sine wave with $h/\lambda = 0.005$. The total drag increase for the waves shown is within 4 percent of the flat plate level with the pressure drag contribution less than 3 percent. At h/λ as small as 0.005, there seems to be no significant effect of λ/δ on measured total drag.

Figures 14(a) and 14(b) indicate comparisons between results obtained in references 3, 4, and 21, and in the current experiments for maximum pressure coefficient

($C_{p,max}$) and pressure phase angle (ϕ), respectively. Both comparisons show a good agreement between the current experimental data, the experimental results from those references and the empirical curve fit developed by Cary (ref. 21).

The total drag, pressure drag, and skin-friction drag determined by the Navier-Stokes spectral code at $R_\theta = 4700$ are shown as solid lines in figures 6 and 13. (The data are given in table 4.) The agreement with the experimental data for the sinusoidal waves is excellent. All pressure drag results in figures 6 and 13 were obtained from integrating the pressure distributions over the wave surfaces. Figures 15 to 20 show the experimental C_p distribution and its comparison with the Navier-Stokes predictions and the predicted $C_f/C_{f,o}$ distribution for all sine wave models at $U_\infty = 22.9$ m/s ($R_\theta = 4700$). Figure 15 shows very little difference between simulations using either 32 or 64 Fourier modes for predicted C_p and $C_f/C_{f,o}$ distributions over the model 1 sine wave. The good agreement between the Navier-Stokes predictions and experimental results for C_p distribution is representative, since the excellent agreement persists at other velocities. For example, figure 17(b) shows that the excellent agreement for the C_p distribution of model 16 (sine wave) continues at the highest velocity ($U_\infty = 38.1$ m/s).

As discussed earlier in the section entitled "Navier-Stokes Solver," there was an oscillation in the predicted skin-friction-coefficient distribution for some sine wave geometries. This oscillation was caused by inadequate numerical resolution probably resulting from small deviations in actual surface coordinates which were used as an input to the code. This is illustrated in figure 18, where the theoretical sine wave surface (model 3) resulted in a smoother $C_f/C_{f,o}$ distribution than the one generated by actual surface coordinates.

The excellent agreement between the measured and predicted total drag, skin friction, and pressure drag (figs. 6 and 13 and table 4) suggests that the zero equation turbulence modeling (ref. 24) used in the Navier-Stokes code is adequate when applied directly in the transformed plane. Table 4 also shows excellent agreement between the experimental and Navier-Stokes values of ϕ for sine waves.

As shown in figures 5, 6, and 13, the sine wave surfaces investigated did not produce a total drag reduction. When h/λ was further decreased to reduce the pressure drag, the skin-friction reduction also decreased. In an attempt to reduce the pressure drag while maintaining the skin-friction reduction, asymmetric waves were designed and tested. Results for these geometries are discussed next.

Spliced Sine Wave Model

The spliced sine wave (model V) shown in figure 3(b) is an asymmetric wave consisting of two sine waves having the same wave height but different wavelengths. These wave geometries were joined at the crest and valley to form a new skewed wavy surface. Figure 21 indicates that the spliced sine wave had a 2- to 3-percent total drag increase compared with a sine wave surface having approximately the same wave height and wavelength (model 1) over the R_θ range tested. The orientation of the waveform did not affect the averaged total drag results. (See table A28.) The h/λ value of the spliced sine wave was small enough (0.005) that the drag levels were not appreciably affected by the wave direction. The Navier-Stokes prediction of total drag, pressure drag, and skin-friction drag at $R_\theta = 4700$ is also in excellent agreement with the experimental results for the spliced sine wave. (See table 4.) Figure 22 shows the measured C_p distributions for the model V spliced sine wave at four tunnel velocities and two flow directions, and figure 23 shows the predicted and measured C_p distributions, predicted $C_f/C_{f,o}$ distributions, and surface geometries for model V at $U_\infty = 22.9$ m/s. Again the Navier-Stokes predictions of C_p agree very well with the experimental results.

Sine Wave and Straight Ramp Models

The sine wave and straight ramp geometry (see fig. 3(c)) was a combination of a sine wave on the steeper, upstream-facing slope and a linear region on the downstream-facing slope. Figure 24 presents the averaged total drag data for models I, II, III, and IV. Each of these models had the same wave height but differing waveforms. The total drag levels were approximately the same as those obtained for the flat plate. As would be expected based on the wavy wall data for $h/\lambda = 0.005$, the pressure drag for these very small wave height models was also negligible; table 4 shows that the pressure drag was no more than 2 percent of the total drag for each of the four models, even though the shape of the C_p distribution varied for the different geometries. (See figs. 25 to 28.) As shown in figures 29 to 32, these C_p distributions were accurately predicted by the Navier-Stokes code at $U_\infty = 22.9$ m/s.

The total drag measurements for models I, II, III, and IV were not appreciably affected by whether the steeper surface was facing upstream or downstream apparently because these models had very small h/λ values (0.0027 to 0.0039). However, with $h/\lambda = 0.015$ (models 12, 13, 14, and 15), differences in total drag level were observed in the two directions (see fig. 33). Of the two directions, models with the steeper surface facing upstream (forward direction) always had the smaller total drag. Figures 24 and 33 seem to indicate the lowest total drag was obtained with $L_1/L_2 \approx 0.5$. Compared with a sine wave having the same h/λ, model 13 with the steeper surface facing upstream decreased the total drag to a value that was 6 percent less than that of the sine wave. (See fig. 33.) Figures 34 to 37 present the measured C_p distributions at four velocities for all sine wave and straight ramp geometries with $h/\lambda = 0.015$.

Figure 38 presents the pressure drag and skin-friction contribution to the total drag measurements. The agreement between the Navier-Stokes predictions and experimental results is very good. Values of L_1/L_2 greater than 1 correspond to the steeper surface facing downstream (i.e., reverse direction). Most of the total drag increase for waves with $h/\lambda = 0.015$ was caused by pressure forces. There is no significant change in skin friction. The predicted C_p distributions for the sine wave and straight ramp geometries with $h/\lambda = 0.015$ at $U_\infty = 22.9$ m/s were generally in very good agreement with the measured C_p distributions. (See figs. 39 to 42.) However, models 12, 13, and 15 with their steeper surface facing downstream show a slight discrepancy in the C_p comparison. (See figs. 39(b), 40(b), and 42(b).) This was probably caused by a small separation region (negative $C_f/C_{f,o}$) that was predicted near the valley of the wavy wall and perhaps amplified by the Taylor-Görtler vortices generated by the concave curvature of the waves.

Transverse V-Groove Models

Symmetric (model 17) and asymmetric (models 18 and 19) transverse V-groove geometries (see fig. 3(d)) were also examined. The V-groove geometries had wave heights and wavelength values equal to those of the sine wave model 16 ($h/\lambda = 0.015$). Figure 43 and table 4 indicate that the symmetric V-groove and asymmetric V-grooves with the steeper surface facing upstream had approximately 2 to 5 percent less total drag than the sinusoidal model 16 at $R_\theta = 4700$. Figures 44 to 46 present the measured C_p distributions for all V-groove geometries at four tunnel velocities. Again, the predicted C_p distributions shown in figures 47 to 49 are in very good agreement with the measurements at $U_\infty = 22.9$ m/s for models in the forward direction. Figure 50 presents the total drag, skin-friction drag, and pressure drag as a function of L_1/L_2 for the V-groove geometries. The data show essentially very little or no effect of L_1/L_2 on skin-friction drag, pressure drag, or total drag with $L_1/L_2 \leq 1$; however, with $L_1/L_2 > 1$ (the steeper surface facing downstream), the data show a slight increase in pressure drag and total drag. The slight flow separation predicted in figure 49(b) could be one reason for the increase in drag. The predicted pressure drag, skin friction, and total drag are also in good agreement (within 3 percent) with the experimental results as shown in table 4 and figure 50 at $U_\infty = 22.9$ m/s.

Circular Arc and Straight Ramp Models

The circular arc and straight ramp geometry (see fig. 3(e)) was a combination of a linear region on both the upstream- and downstream-facing slopes, joined near the crest and valley by arc segments. Figure 51 presents the total drag data for these nonsinusoidal models. The pressure drag contribution, shown in figure 52, accounts for most of the total drag increase. Figures 53 to 55 indicate the measured C_p distributions for all circular arc and straight ramp geometries at four tunnel speeds. The agreement between the predicted and measured C_p distributions for the steeper surface facing upstream was very good (see figs. 56(a), 57(a), and 58(a)); however, the agreement between the predicted and measured distributions is not as good for all three models with the steeper surface facing downstream. (See figs. 56(b), 57(b), and 58(b).) This discrepancy most likely results from flow separation over the wave valley for the latter case. As shown in figure 57(b), the most severe case of flow separation apparently occurred on model 34 (the predicted $(C_f/C_{f,o})_{min} \approx -1$); the largest disagreement between the measured and predicted C_p distributions also occurred for this case, with measured data showing the lower $C_{p,max}$. Other evidence of flow separation can be seen in figure 51, where the total drag increases sharply as R_θ (velocity) increases for models 24 and 34 with the steeper surface facing downstream (reverse direction).

As discussed earlier in the section entitled "Navier-Stokes Solver," when the slope of an asymmetric wave was steep and short, the 32-grid-point computer simulations sometimes did not predict the C_p distribution well. When the geometry was not resolved properly, the simulation produced a mean level shift in the C_p distribution. The only example of this phenomenon is illustrated in figure 57(a) for the forward direction of model 34. Figure 57(a) shows that the C_p distribution improved substantially by simply increasing the number of grid points in the streamwise direction from 32 to 64. Since the 64-grid-point simulation required approximately 2 1/2 times as much computation time as that for the 32 grid points, the calculations with 64 grid points were only used when the 32-grid-point simulation produced a mean level shift in the C_p distribution. (Model 34 is the only case where this shift in level appeared.) Although the 64-point simulation with the steeper surface facing upstream for model 34 eliminated the mean level shift in the C_p distribution, it did not improve the C_p distribution for the steeper surface facing downstream, perhaps because of the predicted flow separation. (See fig. 57(b).)

CONCLUDING REMARKS

Pressure distribution and drag for turbulent boundary-layer flow over two-dimensional stationary symmetric and asymmetric wave trains with ratios of wave height to wavelength (h/λ) between 0.0027 and 0.020 have been examined experimentally and compared with theoretical predictions obtained with a Navier-Stokes code as well as previous experimental data. Within the experimental scatter, no net reduction in total drag was found for the parameter space examined, since the pressure drag increase associated with the wavy surfaces was always greater than or equal to the skin-friction drag reduction. However, experimental trends indicate a possible total drag reduction at higher Reynolds numbers based on momentum thickness (R_θ). Except for a few cases with the steeper facing surface downstream (where the Navier-Stokes code indicates flow separation), predictions of pressure and total drag from a Navier-Stokes spectral code agree well with the measurements. The disagreement for the flow separation case is presumably caused by inadequate turbulence modeling in the separated flow region. Certain asymmetric waves with $h/\lambda = 0.015$, in particular those having the steeper surface facing upstream, were found to have considerably lower total drag (up to 6 percent lower) than sine waves of the same h/λ when both are compared with a flat plate. These asymmetric waves may have potential applications for reducing the drag of surfaces where surface waviness is unavoidable, such as on an aircraft fuselage.

Of particular interest from this work is the success of the Navier-Stokes code in simulating attached turbulent boundary-layer flows over wavy surfaces. These boundary layers are highly nonequilibrium in nature (i.e., rapid alterations in pressure gradient and surface curvature), yet a simple equilibrium turbulence model "worked" quite well when applied directly in the transformed coordinate system.

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TABLE 1.- SUMMARY OF EXPERIMENTAL STUDIES OF FLOW OVER A TRAIN OF STATIONARY SINUSOIDAL WAVES

Investigators	Wavelength, λ, cm	Height/length, h/λ	Reynolds number, $\lambda U_\infty/\nu$	Fluid	Measurements
Stanton et al. (1932, ref. 10)	2.6 7.62	0.2 0.2	23 400, 70 600 24 000	Air	Wall pressure
Motzfeld (1937, ref. 11)	30 30	0.025 0.05	330 000 330 000	Air	Pressure Average velocity
Zagustin et al. (1966, ref. 15)	91.44 60.96	0.021 0.0105	147 000, 317 000 147 000, 317 000	Water	Wall pressure, average velocity over crest
Kendall (1970, ref. 3)	10.16	0.031	19 000 to 64 000	Air	Pressure, wall shear stress, fluctuating velocities, average velocity at two loctions
Sigal (1971, ref. 4) Lees et al. (1972, ref. 5)	15.24 30.48	0.026 0.028	154 000, 306 000 154 000, 306 000	Air	Pressure, wall shear stress, average velocity, fluctuating velocities
Hsu & Kennedy (1971, ref. 12)	25.4 50.8	0.022 0.011	238 000 to 476 000 238 000 to 476 000	Air	Pressure, wall shear, average velocity, fluctuating velocities
Beebe (1972, ref. 6)	10.67	0.085, 0.20	21 400 to 85 600	Air	Pressure, wall shear, visual studies, average velocity over creast, fluctuating velocities
Thorsness (1975, ref. 7)	5.08	0.006	11 000 to 64 000	Water	Wall shear
Zilker et al. (1977, ref. 13) Zilker (1976, ref. 9) Cook (1970, ref. 8)	5.08	0.006, 0.0156, 0.025	11 000 to 64 000 11 000 to 64 000	Water	Wall pressure, wall shear average velocity, fluctuating velocities, visual studies
Zilker & Hanratty (1979, ref. 14)	5.08	0.025, 0.0625, 0.10	11 000 to 64 000	Water	Wall pressure, wall shear stress, average velocity, fluctuating velocities, visual studies
Cary et al. (1980, ref. 21)	2.54	0.005, 0.010, 0.020	22 000 to 68 000	Air	Wall pressure, direct drag, average velocity
Lin et al. (1983, ref. 23)	2.54 1.27 5.08	0.005, 0.010, 0.015, 0.020 0.005 0.005	12 400 to 69 000 6 200 to 34 500 24 800 to 138 000	Air	Wall pressure, direct drag

TABLE 2.- TURBULENT-BOUNDARY-LAYER PROFILES JUST UPSTREAM OF TEST SURFACE

U_∞ = 15.2 m/s; R_θ = 3300; δ = 3.1 cm; $C_{f,o}$ = 0.00327	
y/δ	u/U_∞
0.009	0.372
.016	.483
.022	.545
.028	.572
.034	.587
.040	.600
.046	.609
.052	.618
.058	.633
.064	.641
.071	.661
.077	.658
.083	.667
.094	.668
.107	.681
.118	.687
.130	.707
.143	.726
.154	.731
.167	.736
.190	.746
.214	.756
.238	.773
.261	.785
.283	.798
.306	.806
.330	.812
.377	.835
.424	.846
.471	.876
.516	.893
.563	.904
.611	.920
.658	.931
.704	.939
.752	.953
.802	.969
.850	.981
.896	.986
.920	.987
.943	.992
.965	.993
.989	.994
1.011	.996
1.035	.998
1.057	.997
1.080	.999
1.103	.999
1.126	1.000
1.148	.999
1.169	.999
1.192	1.000
1.215	1.000
1.237	1.000
1.258	1.000
1.281	1.000
1.302	1.000

U_∞ = 22.9 m/s; R_θ = 4700; δ = 3.0 cm; $C_{f,o}$ = 0.00305	
y/δ	u/U_∞
0.009	0.405
.017	.403
.024	.488
.031	.558
.038	.585
.045	.611
.052	.626
.059	.637
.066	.651
.073	.661
.080	.667
.088	.671
.101	.691
.115	.701
.129	.710
.142	.719
.157	.731
.170	.734
.197	.751
.224	.770
.249	.780
.274	.799
.300	.810
.325	.821
.376	.839
.430	.863
.481	.879
.532	.894
.583	.910
.635	.927
.686	.946
.736	.955
.785	.965
.836	.973
.887	.983
.936	.989
.960	.992
.984	.993
1.009	.996
1.036	.998
1.060	.998
1.085	.998
1.110	.999
1.136	1.000
1.160	.999
1.185	1.000
1.210	1.000
1.236	1.000
1.261	1.000
1.286	1.000
1.311	1.000
1.337	.999
1.361	1.000
1.386	1.000

TABLE 2.- Concluded

U_∞ = 30.5 m/s; R_θ = 5800; δ = 2.9 cm; $C_{f,o}$ = 0.00292	
y/δ	u/U_∞
0.010	0.441
.016	.552
.023	.585
.029	.609
.036	.626
.043	.640
.050	.650
.057	.663
.063	.669
.070	.677
.077	.689
.083	.698
.090	.699
.103	.708
.116	.719
.129	.730
.142	.739
.155	.745
.168	.757
.182	.760
.207	.773
.233	.788
.258	.798
.283	.811
.307	.825
.357	.848
.407	.864
.458	.881
.506	.897
.556	.912
.607	.927
.658	.942
.708	.952
.758	.965
.808	.971
.859	.981
.909	.987
.935	.990
.959	.993
.984	.994
1.007	.995
1.032	.997
1.057	.997
1.082	.998
1.107	.999
1.132	1.000
1.156	1.000
1.181	1.000
1.205	1.000
1.228	1.000
1.254	1.000
1.277	1.000
1.302	1.000
1.326	1.000
1.350	1.000

U_∞ = 38.1 m/s; R_θ = 7300; δ = 3.0 cm; $C_{f,o}$ = 0.00280	
y/δ	u/U_∞
0.009	0.473
.015	.557
.021	.591
.027	.617
.033	.627
.039	.642
.045	.662
.051	.664
.057	.673
.064	.685
.070	.684
.076	.697
.081	.703
.087	.709
.100	.719
.111	.728
.123	.735
.136	.744
.147	.755
.159	.760
.172	.772
.196	.782
.220	.794
.244	.805
.267	.812
.313	.836
.366	.856
.415	.871
.462	.887
.509	.902
.555	.915
.604	.931
.651	.940
.699	.952
.747	.963
.795	.972
.845	.980
.894	.985
.942	.991
.965	.992
.993	.995
1.017	.995
1.041	.998
1.064	.997
1.087	.998
1.111	.999
1.135	.999
1.157	1.000
1.181	1.000
1.205	.999
1.228	1.000
1.252	1.000
1.275	1.000
1.298	1.000
1.321	1.000
1.344	1.000
1.366	1.000

TABLE 3.- AVERAGE FLAT PLATE DRAG

Velocity, m/s	Drag, N
7.62	0.0443
9.14	.0608
10.67	.0793
12.19	.1003
13.72	.1236
15.24	.1492
16.76	.1770
18.29	.2077
19.81	.2403
21.34	.2755
22.86	.3130
24.38	.3531
25.91	.3959
27.43	.4414
28.96	.4892
30.48	.5390
32.00	.5916
33.53	.6473
35.05	.7059
36.58	.7655
38.10	.8282
39.32	.8783

TABLE 4.- COMPARISON OF EXPERIMENTAL RESULTS AND NAVIER-STOKES PREDICTIONS FOR SKIN FRICTION, PRESSURE DRAG, TOTAL DRAG, AND PHASE ANGLE AT $U_\infty = 22.9$ m/s

Waveform	*Model no.	λ, cm	$\frac{h}{\lambda}$	$\frac{L_1}{L_2}$	Experimental results				Navier-Stokes predictions			
					$\frac{C_{D,p}}{C_{D,o}}$	$\frac{C_F}{C_{D,o}}$	$\frac{C_D}{C_{D,o}}$	†ϕ, deg	$\frac{C_{D,p}}{C_{D,o}}$	$\frac{C_F}{C_{D,o}}$	$\frac{C_D}{C_{D,o}}$	†ϕ, deg
Sine waves	1	2.54	0.005	1.0	0.02	0.99	1.01	20	0.02	1.0	1.02	20
	2	2.54	.010	1.0	.07	.99	1.06	22	.07	.99	1.06	18
	16	2.54	.015	1.0	.17	.97	1.14	20	.15	.98	1.13	17
	3	2.54	.020	1.0	.27	.98	1.25	27	.28	.97	1.25	28
	VI	1.27	.005	1.0	.02	1.03	1.05	22	.02	1.03	1.05	21
	VII	5.08	.005	1.0	.01	1.01	1.02	7	.01	.98	.99	8
Spliced sine waves	V	2.54	0.005	2.0	0.02	1.01	1.03		0.02	1.0	1.02	
	V-R	2.54	.005	.5	.02	1.01	1.03		.02	1.0	1.02	
Sine waves and straight ramps	I	4.62	0.0027	0.4	0.01	1.01	1.02		0.01	0.98	0.99	
	I-R	4.62	.0027	2.5	.01	1.01	1.02		.01	.98	.99	
	II	4.01	.0032	.49	.01	.99	1.0		.01	.98	.99	
	II-R	4.01	.0032	2.04	.01	.99	1.0		.01	.98	.99	
	III	3.23	.0039	.74	.02	1.0	1.02		.01	.99	1.0	
	III-R	3.23	.0039	1.35	.02	1.0	1.02		.01	.99	1.0	
	IV	3.86	.0033	.39	.01	1.0	1.01		.01	.98	.99	
	IV-R	3.86	.0033	2.56	.01	1.0	1.01		.01	.98	.99	
	‡12	4.62	.015	.38	.15	.97	1.12		.15	.93	1.08	
	12-R	4.62	.015	2.63	.24	.98	1.22		.25	.95	1.20	
	‡13	4.01	.015	.47	.11	.97	1.08		.13	.95	1.08	
	13-R	4.01	.015	2.13	.21	.96	1.17		.19	.95	1.14	
	14	3.23	.015	.65	.12	.98	1.10		.13	.97	1.10	
	14-R	3.23	.015	1.54	.18	.97	1.15		.18	.96	1.14	
	‡15	3.86	.015	.37	.15	.98	1.13		.15	.93	1.08	
	15-R	3.86	.015	2.70	.27	.98	1.25		.26	.97	1.23	
Transverse V-grooves	17	2.54	0.015	1.0	0.13	0.98	1.11		1.12	0.98	1.10	
	18	2.54	.015	.5	.15	.94	1.09		.13	.96	1.09	
	18-R	2.54	.015	2.0	.16	.99	1.15		.14	.99	1.13	
	‡19	2.54	.015	.33	.14	.98	1.12		.14	.98	1.12	
	19-R	2.54	.015	3.0	.22	.95	1.17		.21	.98	1.19	
Circular arcs and straight ramps	‡24	2.54	0.015	0.30	0.17	0.99	1.16		0.17	0.95	1.12	
	24-R	2.54	.015	3.3	.26	.99	1.25		.27	.98	1.25	
	‡34	1.27	.015	.29	.19	.94	1.13		.18	.96	1.14	
	34-R	1.27	.015	3.4	.22	.94	1.16		.31	1.03	1.34	
	‡44	5.08	.015	.29	.21	.91	1.12		.19	.91	1.10	
	44-R	5.08	.015	3.4	.39	.89	1.28		.30	.95	1.25	

*R after model number indicates reverse flow direction.
†Phase angle errors within ±5°.
‡Navier-Stokes calculation indicates a flow separation.

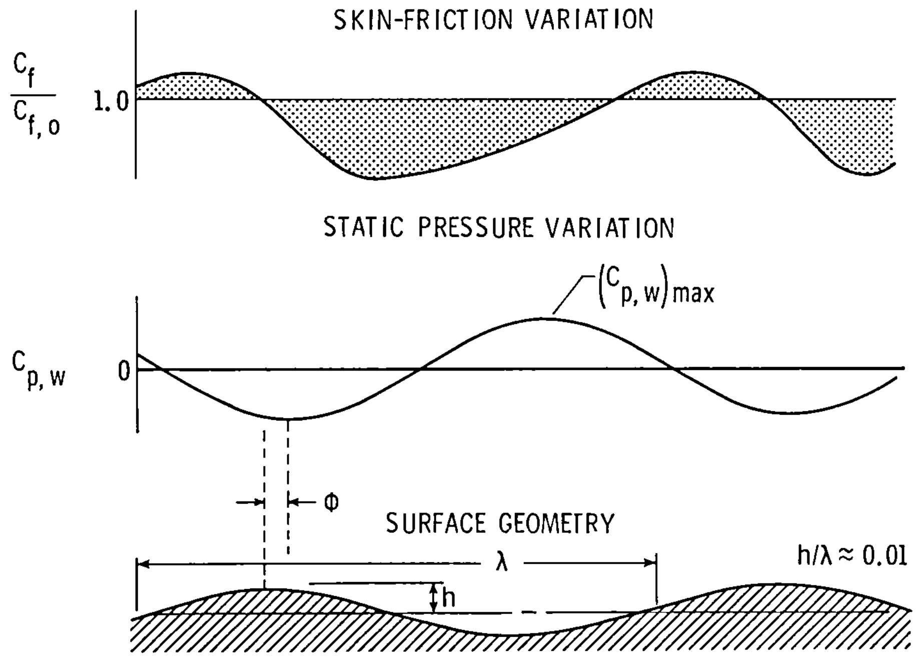


Figure 1.- Typical skin-friction drag and pressure distributions over a rigid sine wave surface with small h/λ.

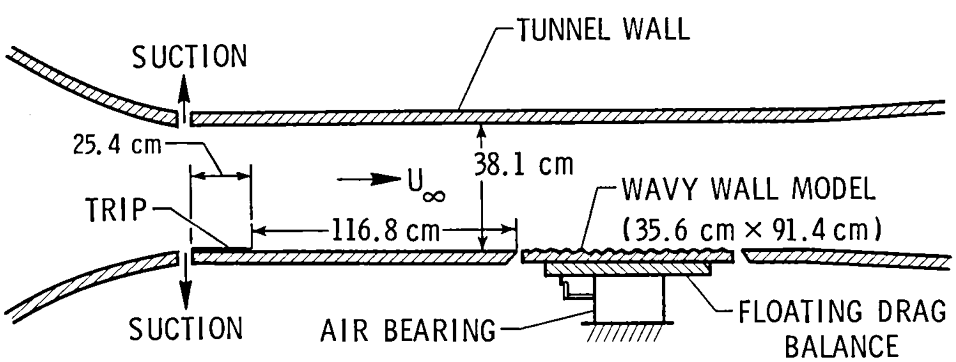
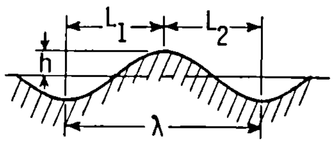
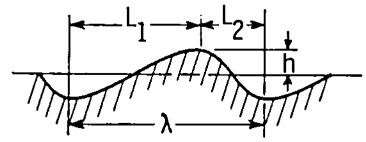


Figure 2.- Test configuration in tunnel.



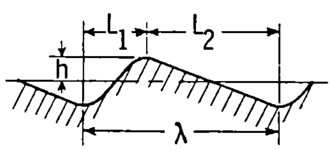
MODEL	L_1/L_2	h/λ	λ, cm
1	1	0.005	2.54
2	1	0.01	2.54
16	1	0.015	2.54
3	1	0.02	2.54
VI	1	0.005	1.27
VII	1	0.005	5.08

(a) Sine waves.



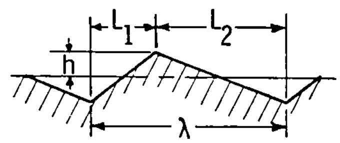
MODEL	L_1/L_2	h/λ	λ, cm
V	2	0.005	2.54

(b) Spliced sine waves.



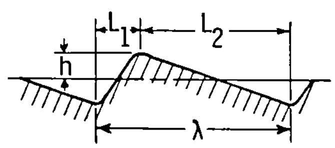
MODEL	L_1/L_2	h/λ	λ, cm
I	0.40	0.0027	4.62
II	0.49	0.0032	4.01
III	0.74	0.0039	3.23
IV	0.39	0.0033	3.86
12	0.38	0.015	4.62
13	0.47	0.015	4.01
14	0.65	0.015	3.23
15	0.37	0.015	3.86

(c) Sine waves and straight ramps.



MODEL	L_1/L_2	h/λ	λ, cm
17	1	0.015	2.54
18	0.5	0.015	2.54
19	0.33	0.015	2.54

(d) Transverse V-grooves.



MODEL	L_1/L_2	h/λ	λ, cm
24	0.30	0.015	2.54
34	0.29	0.015	1.27
44	0.29	0.015	5.08

(e) Circular arcs and straight ramps.

Figure 3.- Surface configurations tested.

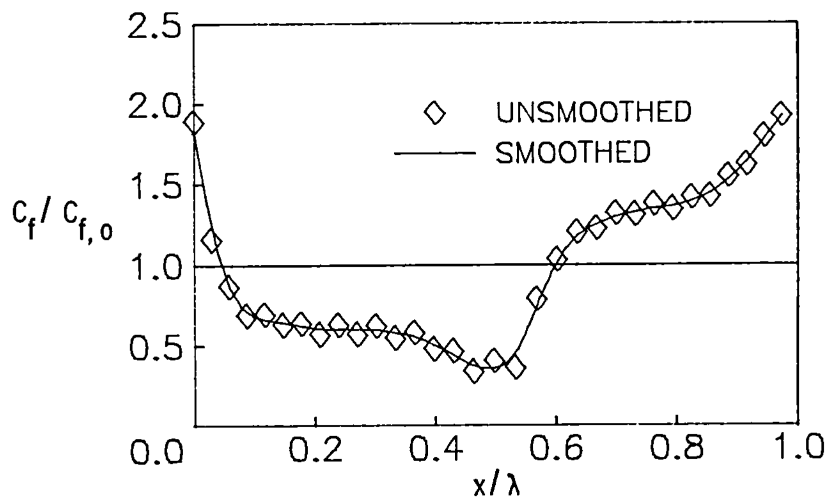


Figure 4.- Typical oscillation in Navier-Stokes $C_f/C_{f,o}$ prediction and smooth curve fit. Model 19; transverse V-grooves.

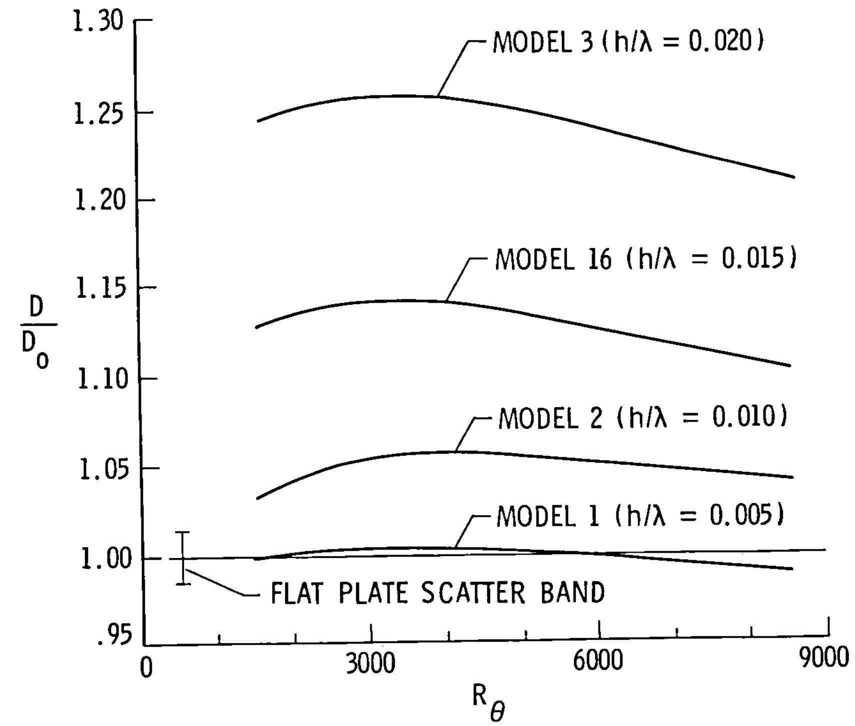


Figure 5.- Measured total drag of sine waves. (λ = 2.54 cm, 35 waves.)

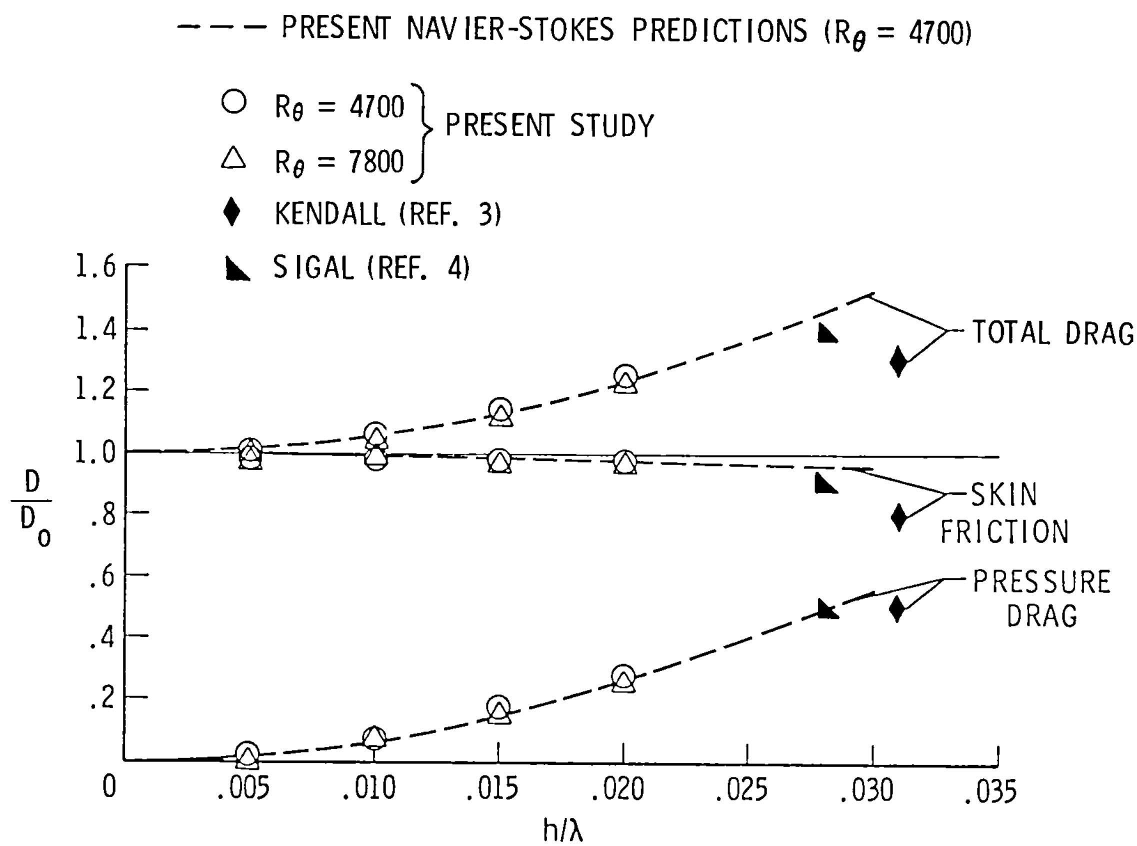


Figure 6.- Drag contributions of sine waves with λ = 2.54 cm.

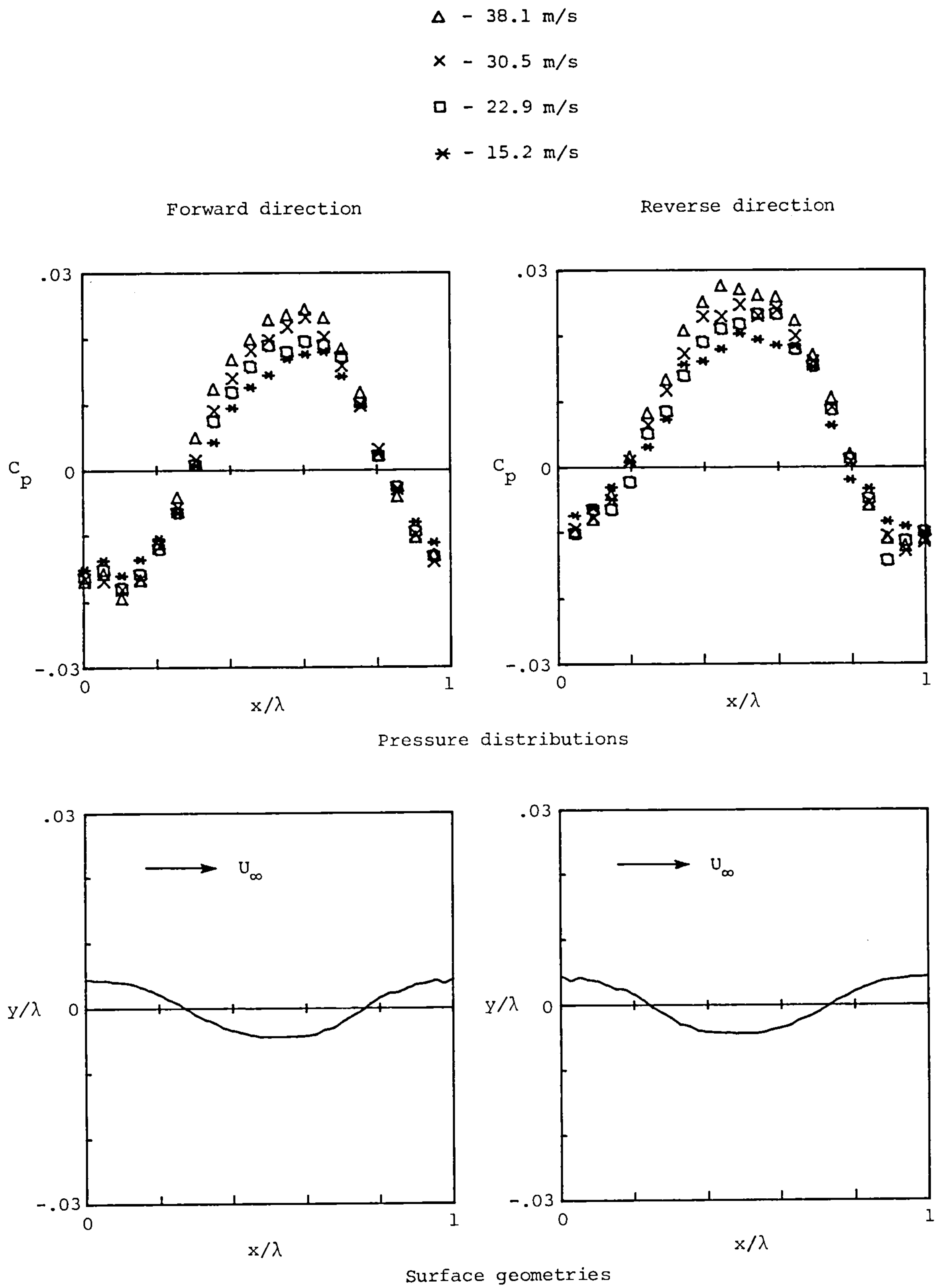


Figure 7.- Measured C_p values for model 1 (sine waves, $h/\lambda = 0.005$, $\lambda = 2.54$ cm).

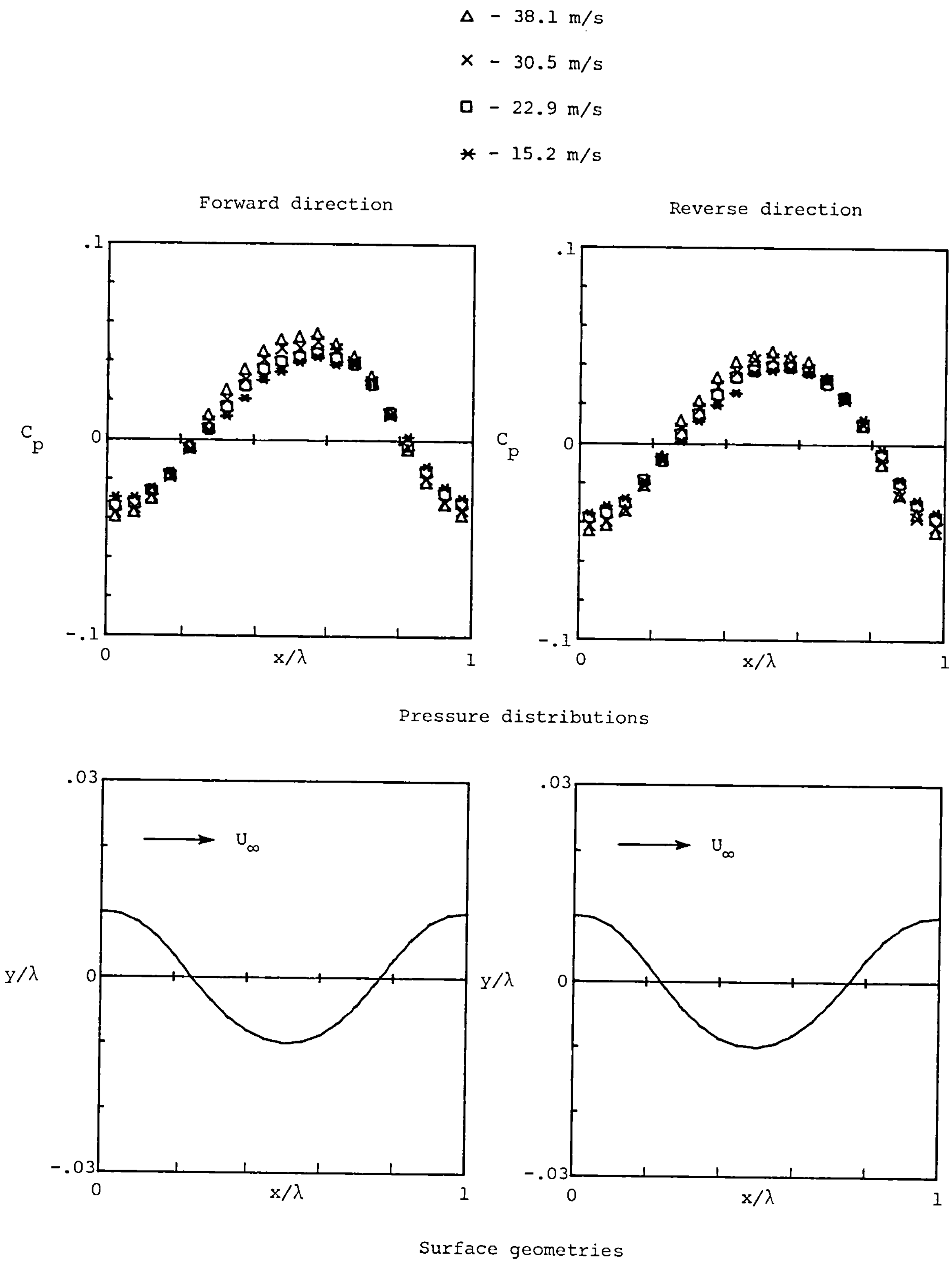


Figure 8.- Measured C_p values for model 2 (sine waves, $h/\lambda = 0.01$, $\lambda = 2.54$ cm).

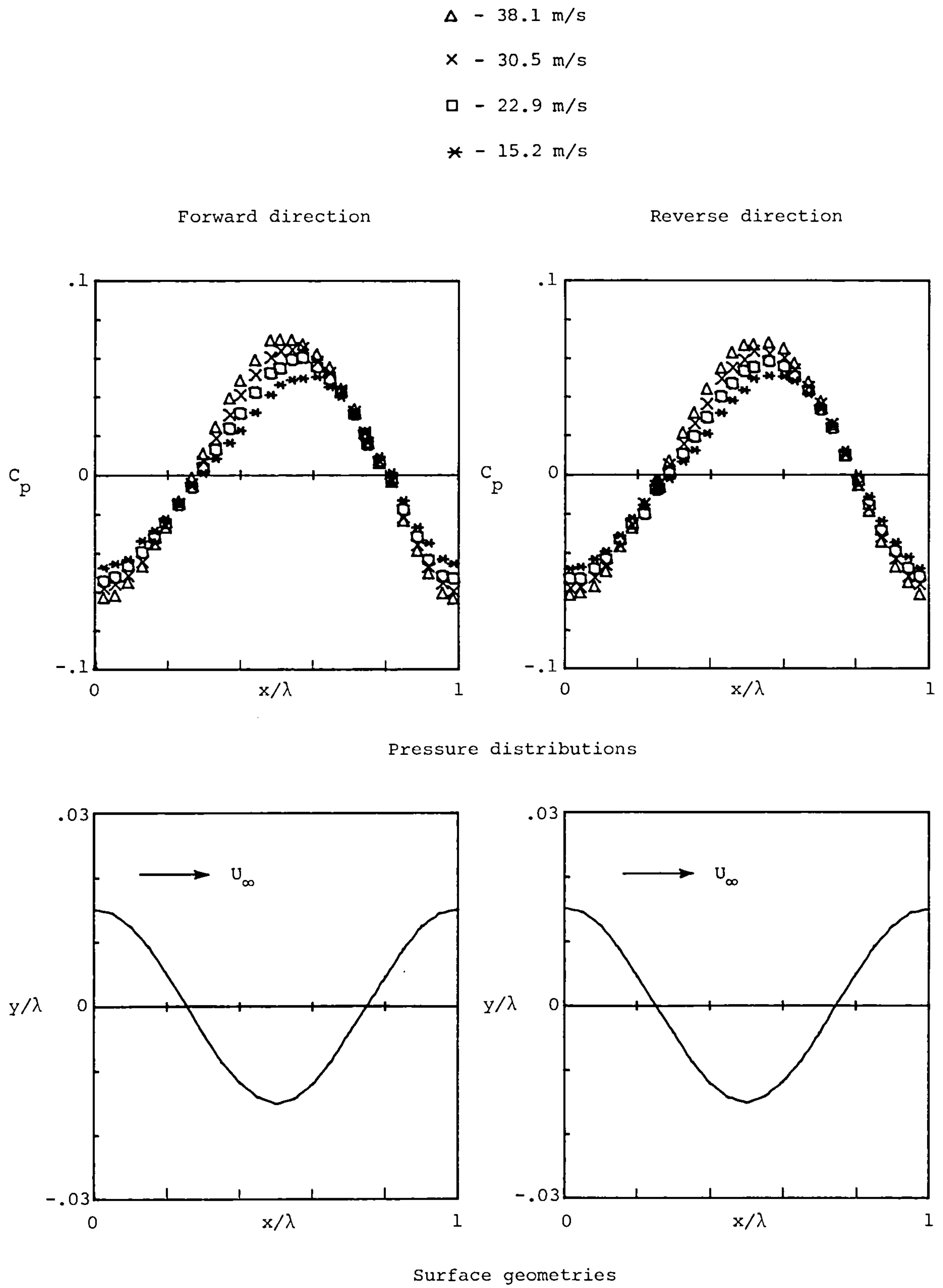


Figure 9.- Measured C_p values for model 16 (sine waves, $h/\lambda = 0.015$, $\lambda = 2.54$ cm).

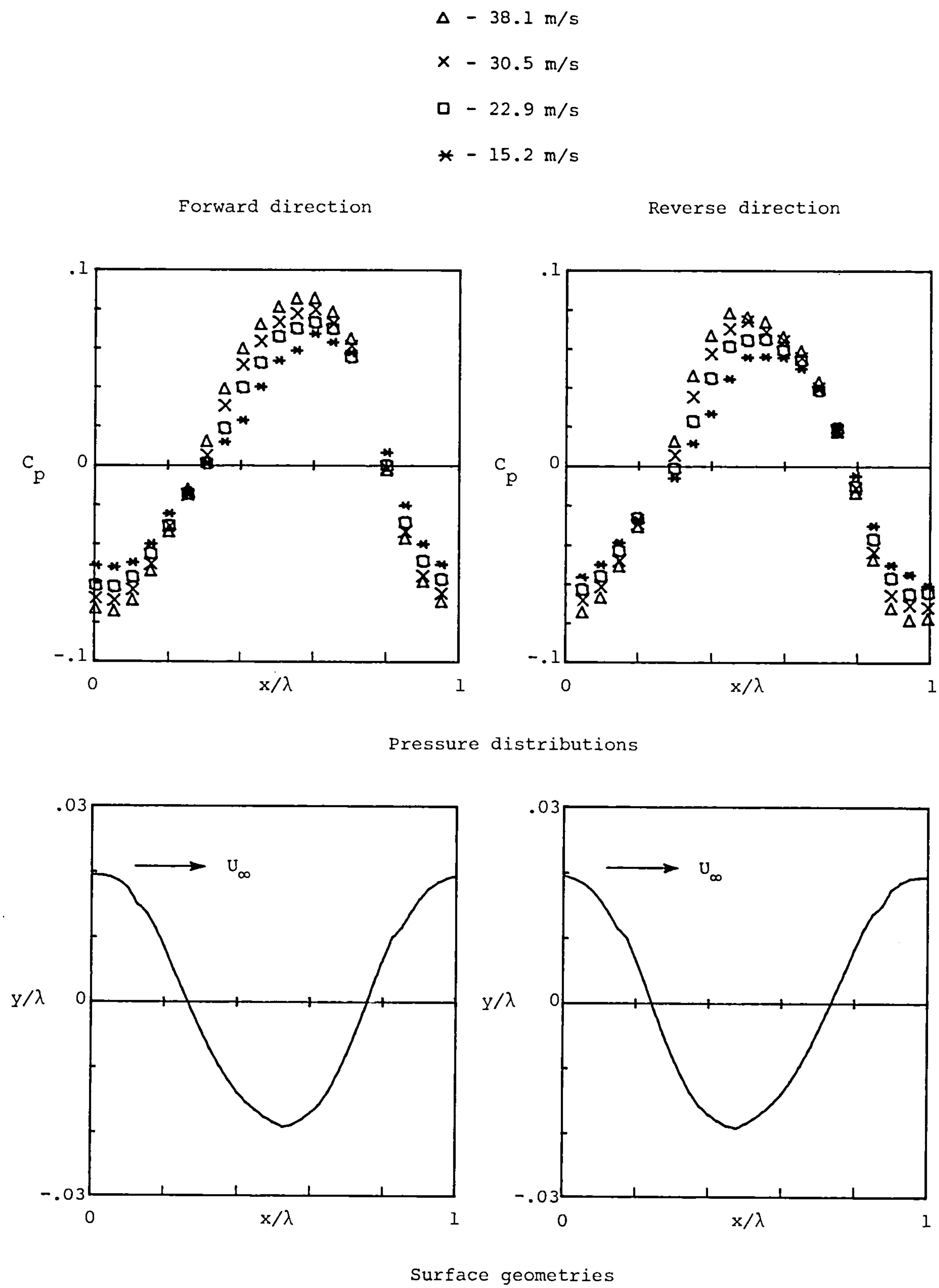


Figure 10.- Measured C_p values for model 3 (sine waves, $h/\lambda = 0.02$, $\lambda = 2.54$ cm).

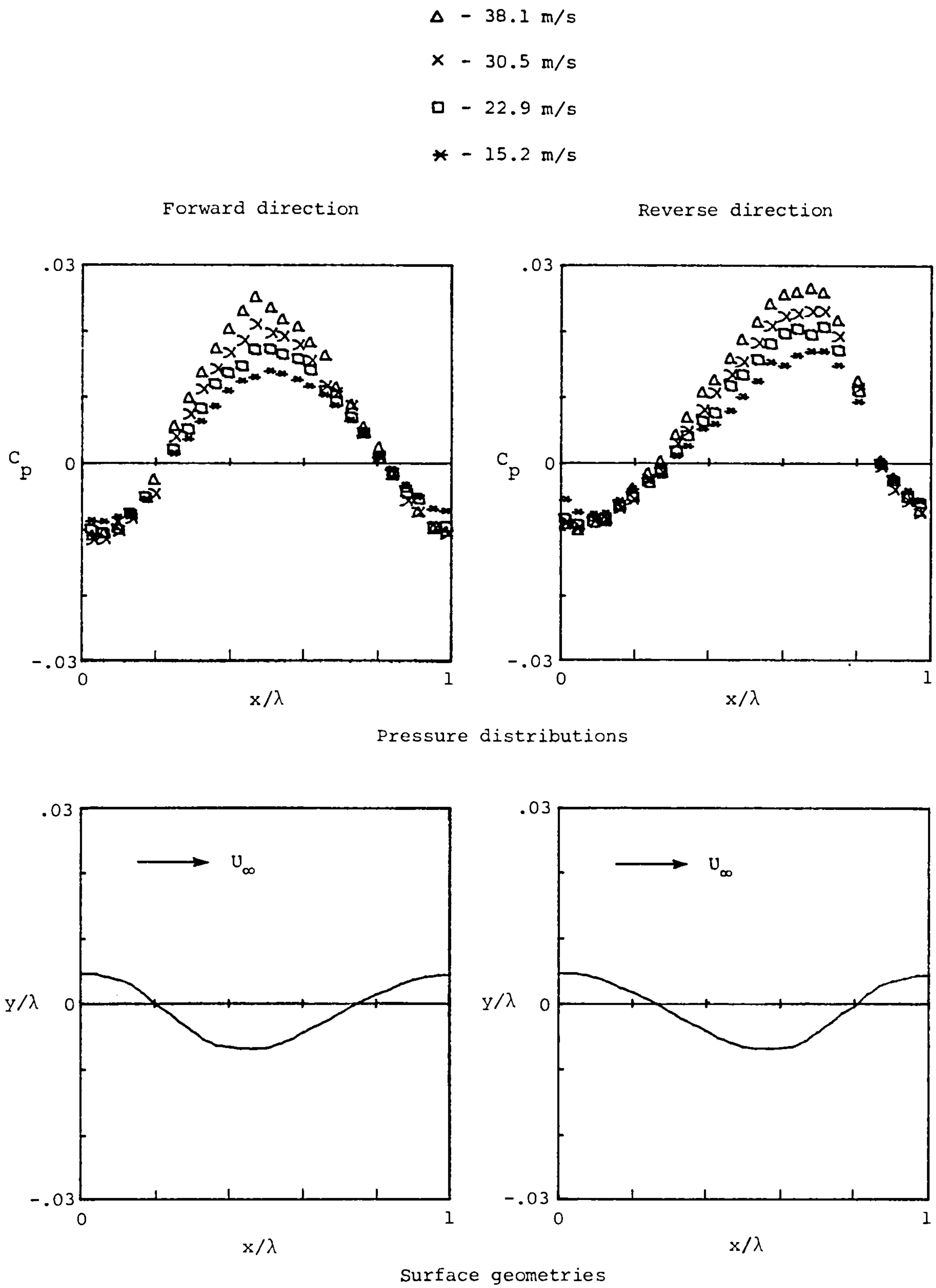


Figure 11.- Measured C_p values for model VI (sine waves, $h/\lambda = 0.005$, $\lambda = 1.27$ cm).

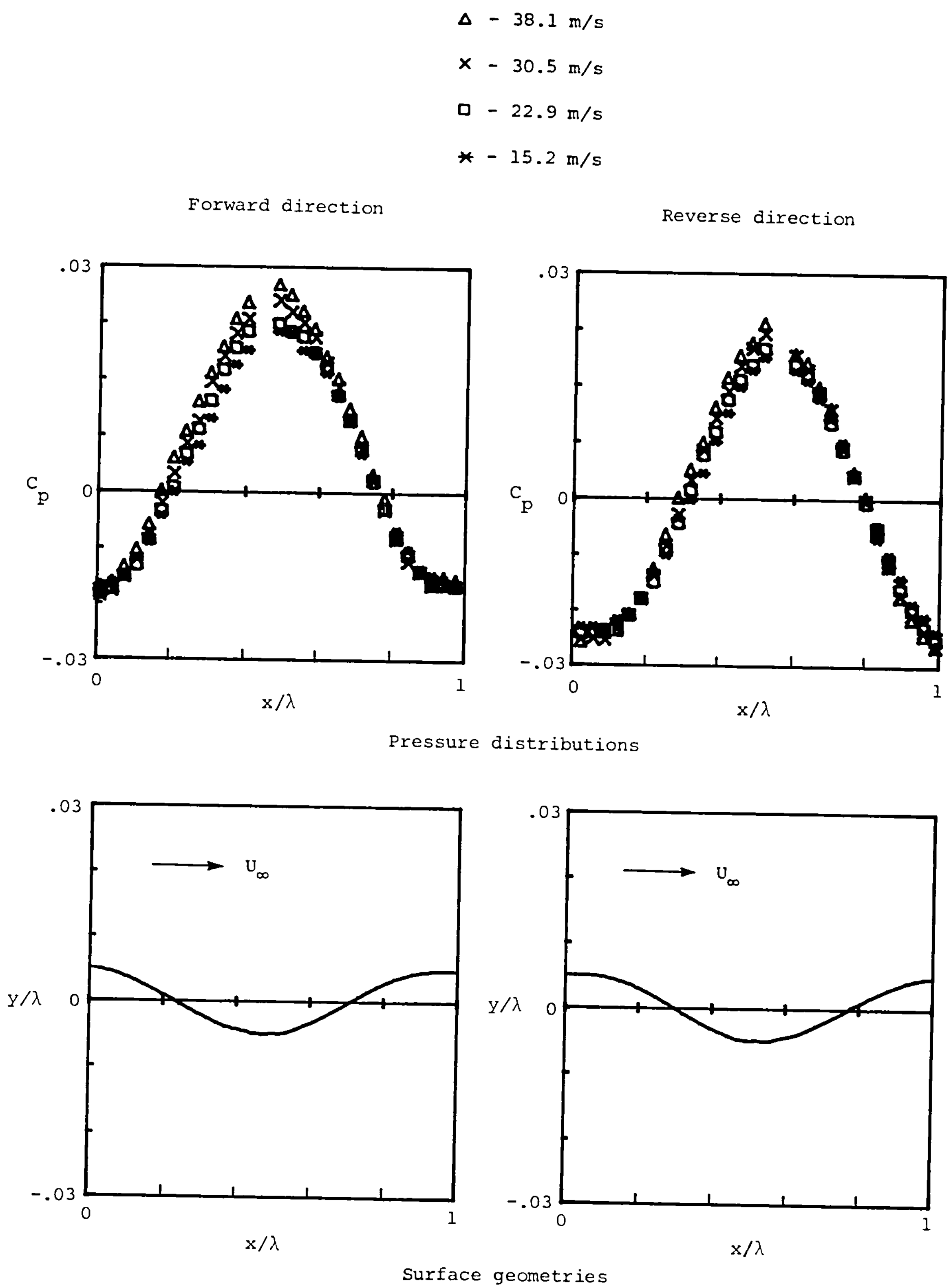


Figure 12.- Measured C_p values for model VII (sine waves, $h/\lambda = 0.005$, $\lambda = 5.08$ cm).

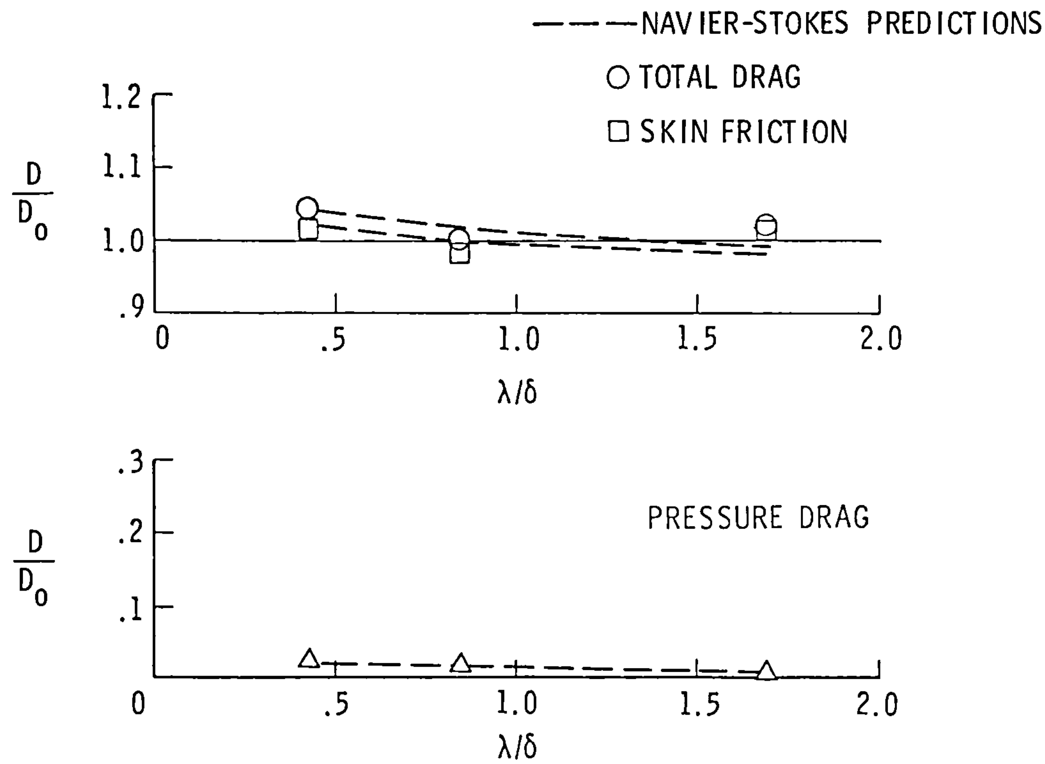
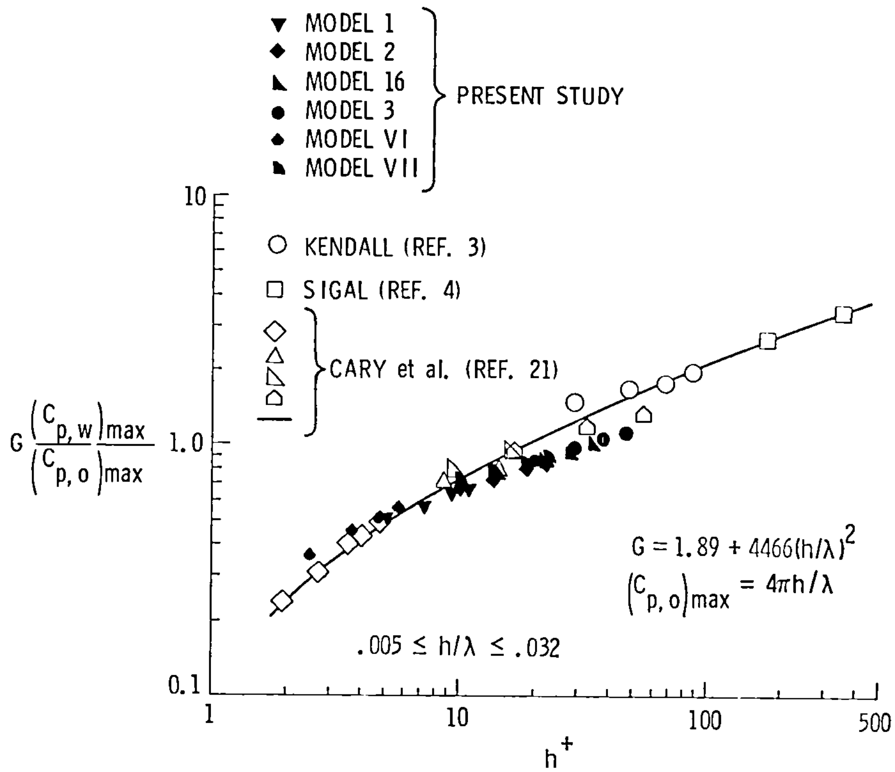
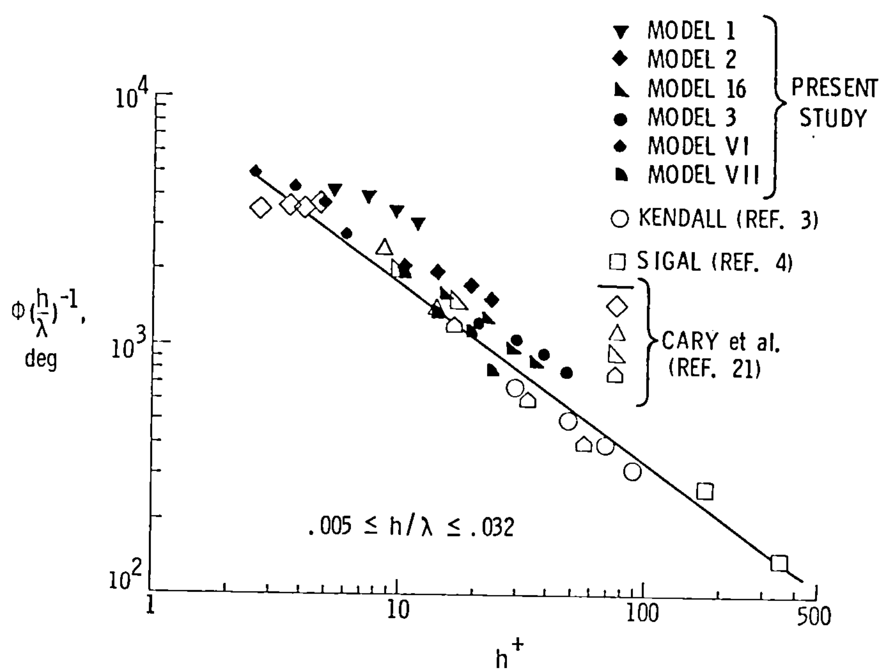


Figure 13.- Drag contributions of sine waves with $h/\lambda = 0.005$ at $R_\theta = 4700$, $\delta = 3.0$ cm.



(a) Maximum pressure coefficient.



(b) Pressure phase angle.

Figure 14.- Comparison of results for rigid sine wave walls with small h/λ. Low-speed flow.

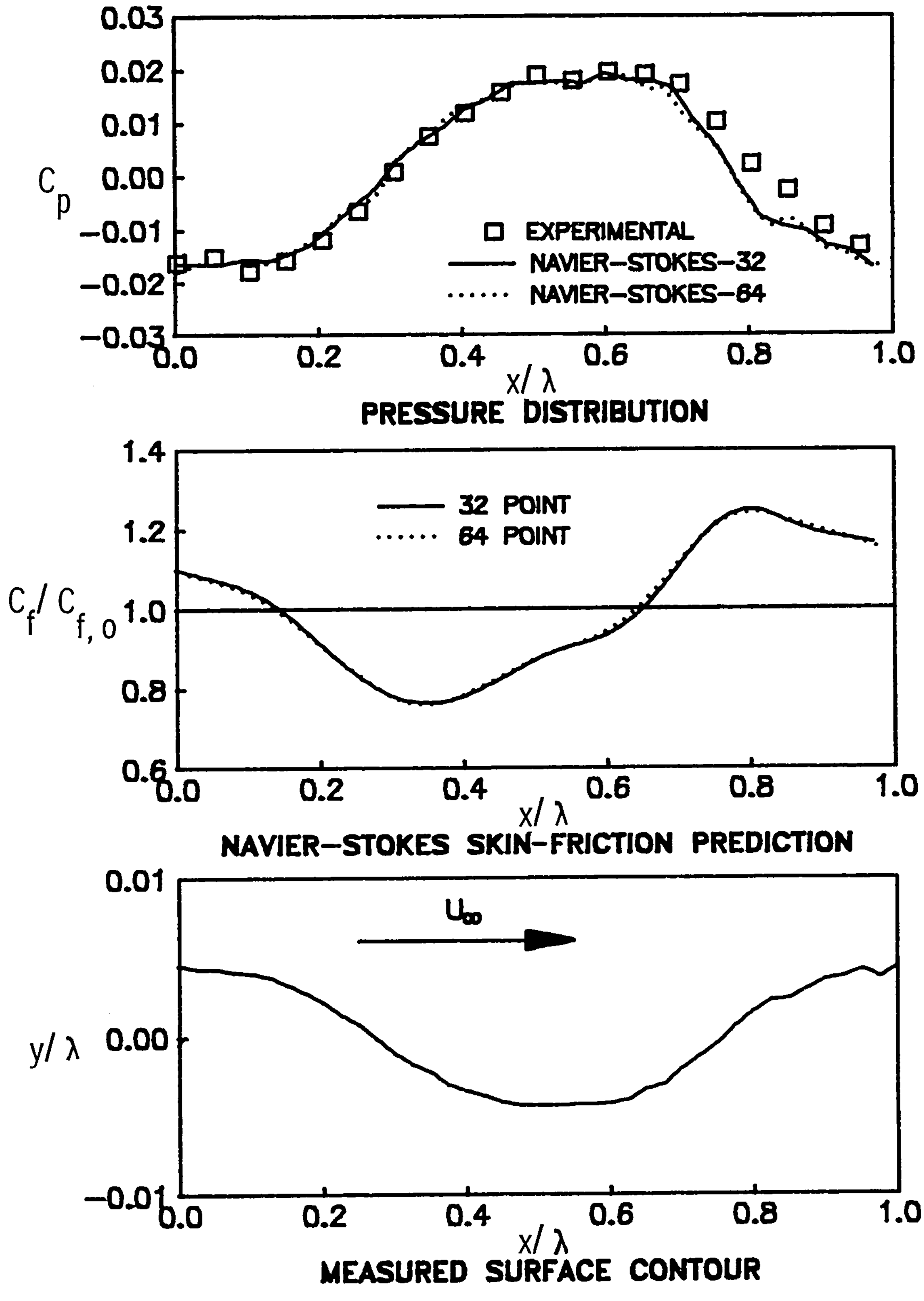


Figure 15.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 1 (sine waves, h/λ = 0.005, λ = 2.54 cm).

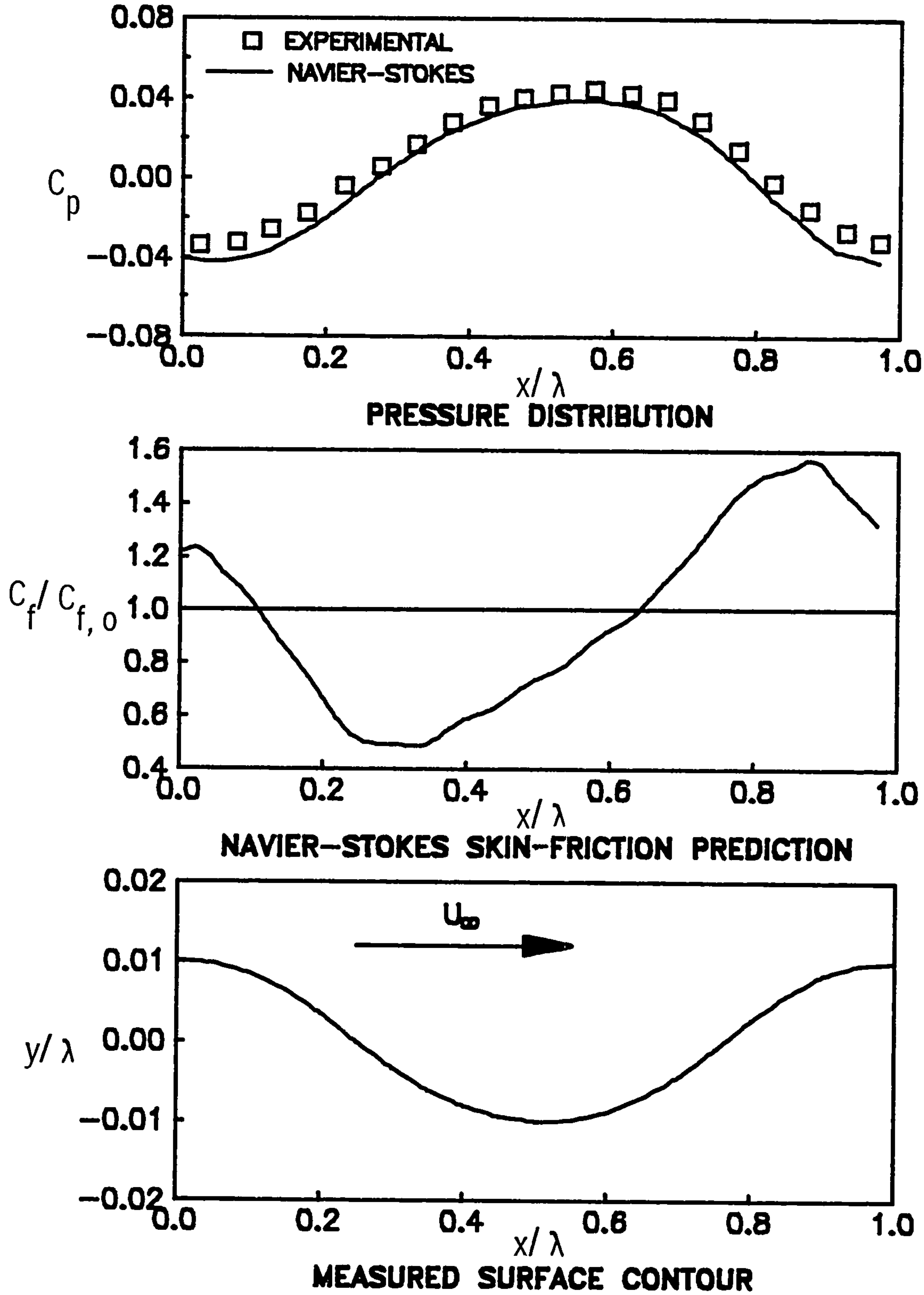
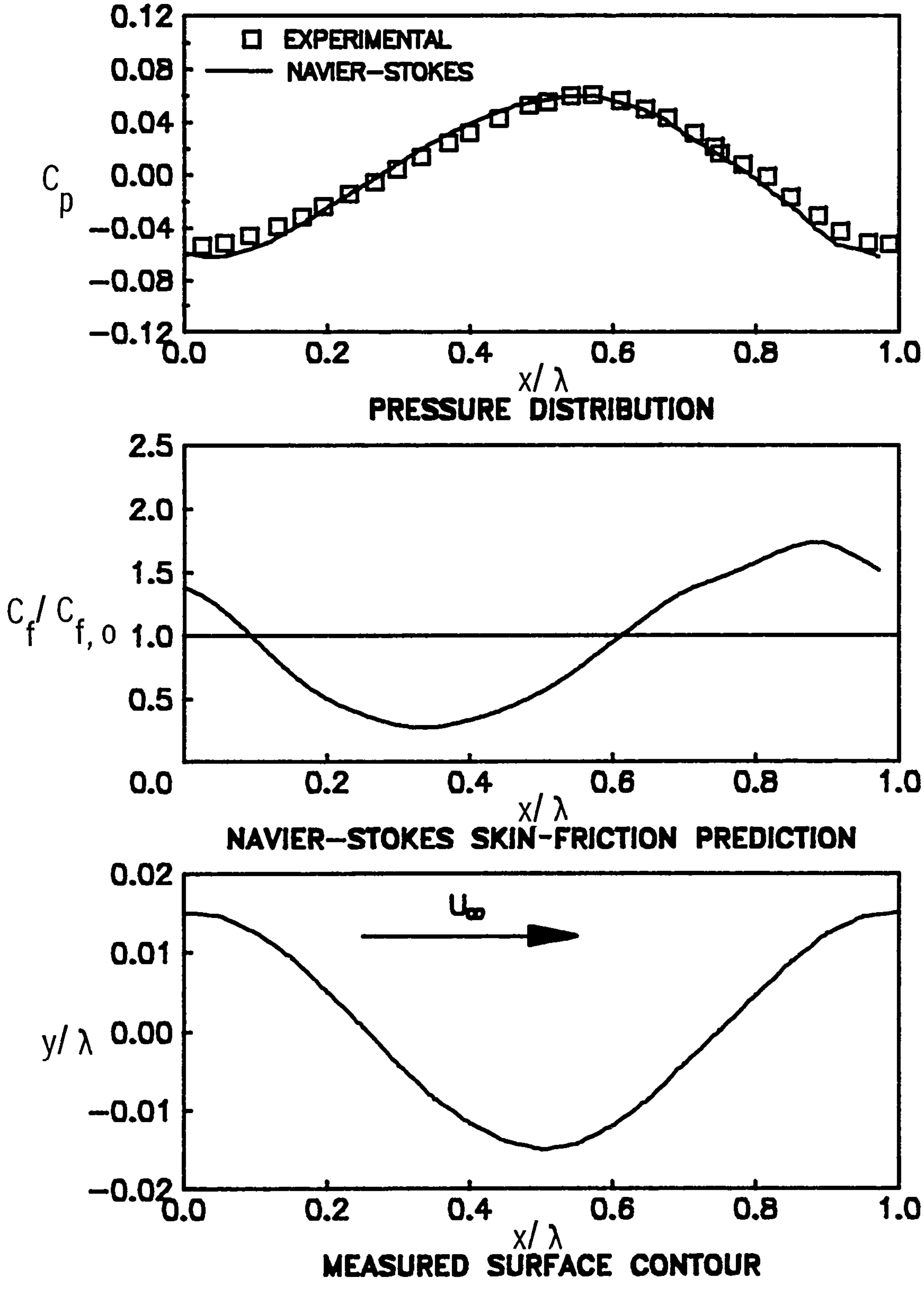
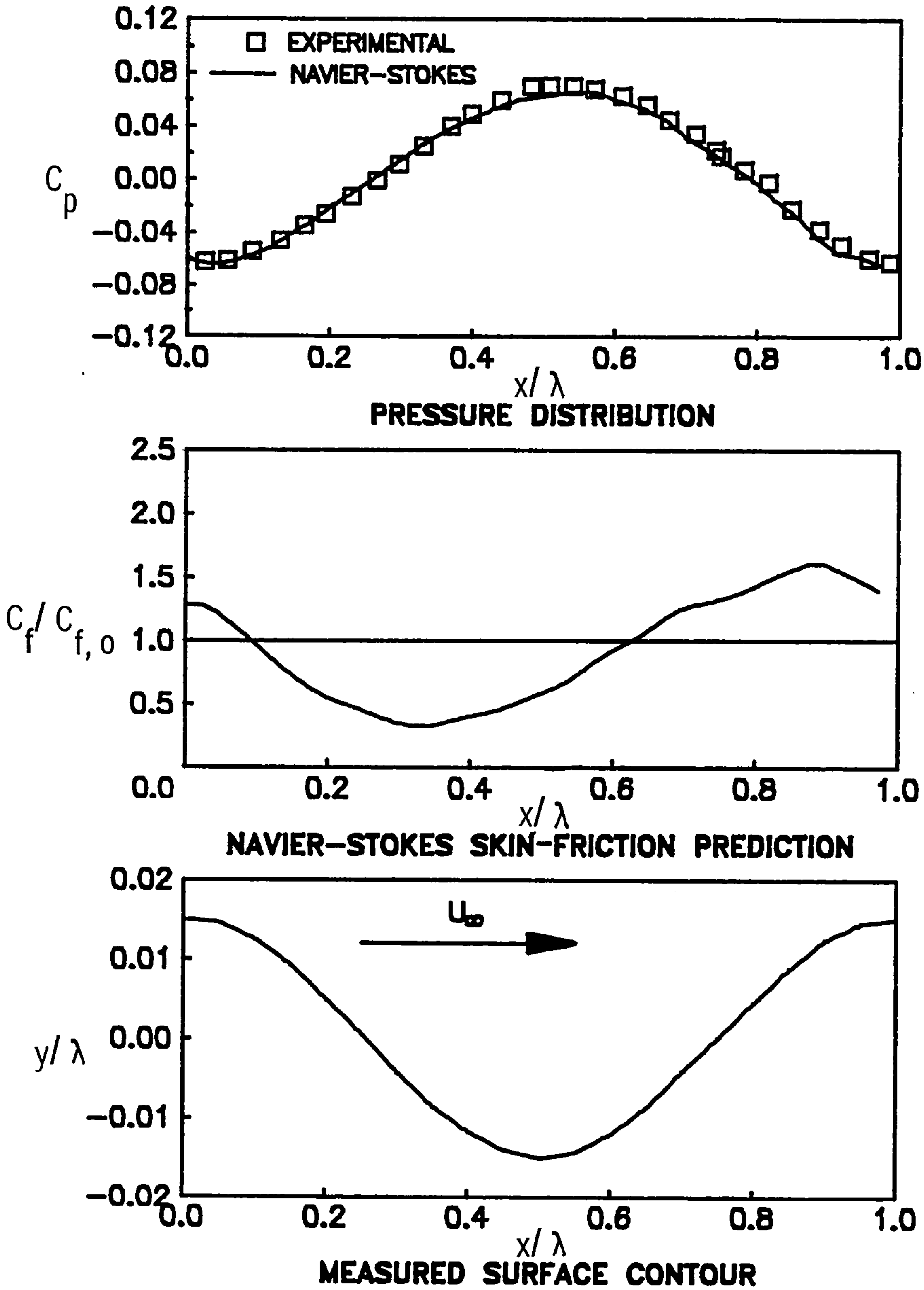


Figure 16.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 2 (sine waves, h/λ = 0.01, λ = 2.54 cm).



(a) U_∞ = 22.9 m/s.

Figure 17.- C_p and $C_f/C_{f,o}$ predictions for model 16 (sine waves, h/λ = 0.015, λ = 2.54 cm).



(b) U_∞ = 38.1 m/s.

Figure 17.- Concluded.

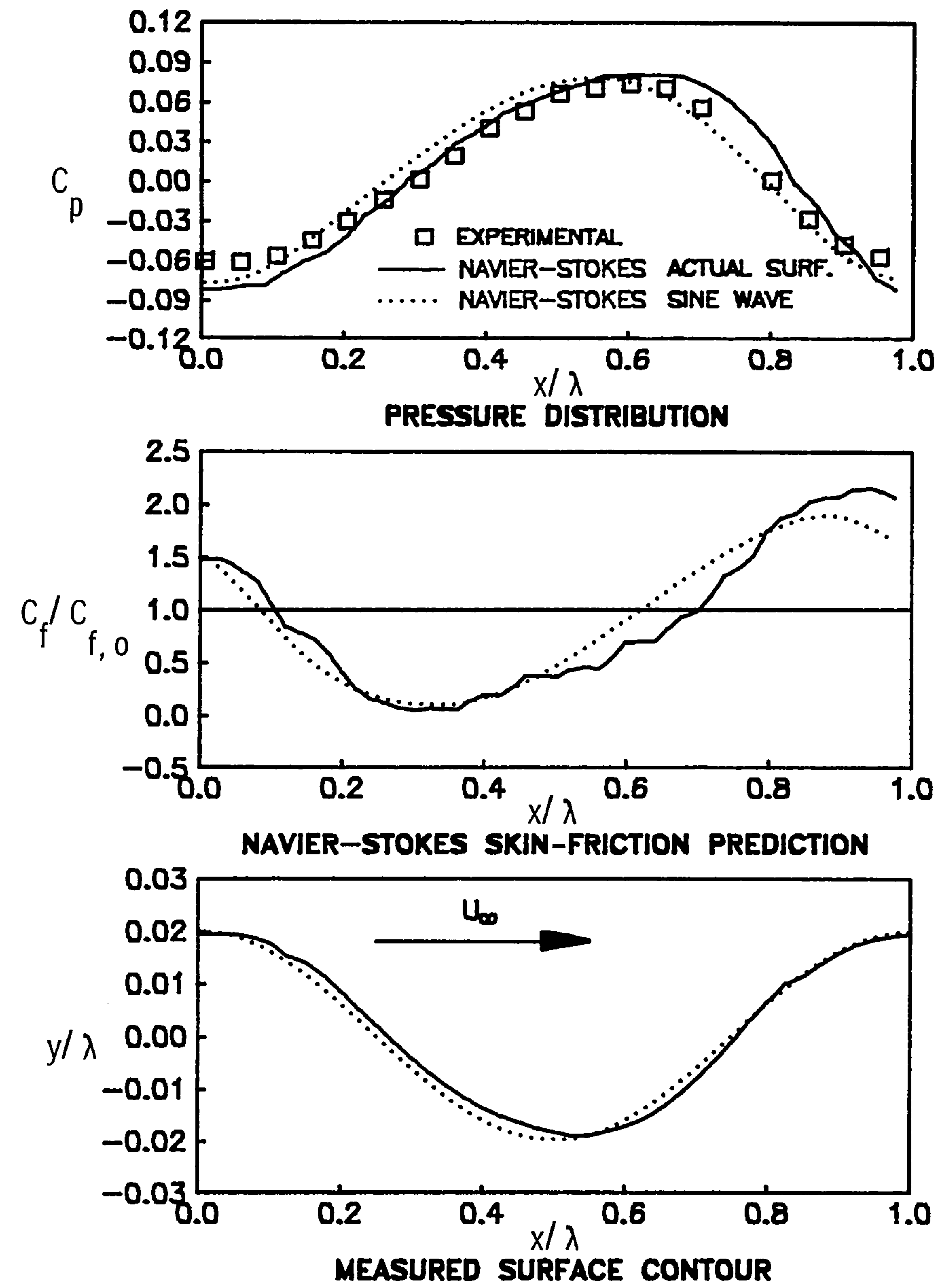


Figure 18.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 3 (sine waves, h/λ = 0.02, λ = 2.54 cm).

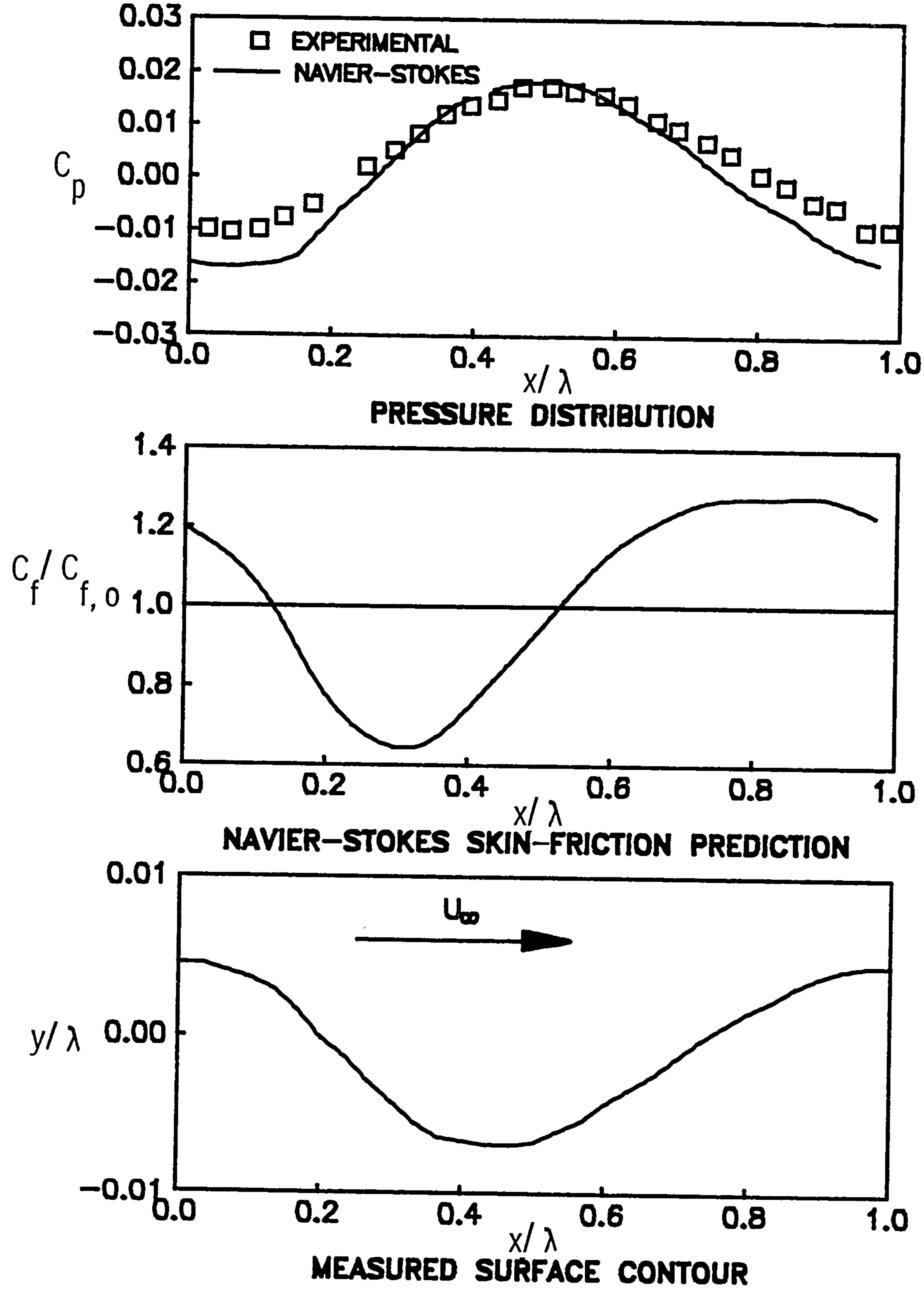


Figure 19.- C_p and $C_f/C_{f,o}$ predictions at $U_\infty = 22.9$ m/s for model VI (sine waves, $h/\lambda = 0.005$, $\lambda = 1.27$ cm).

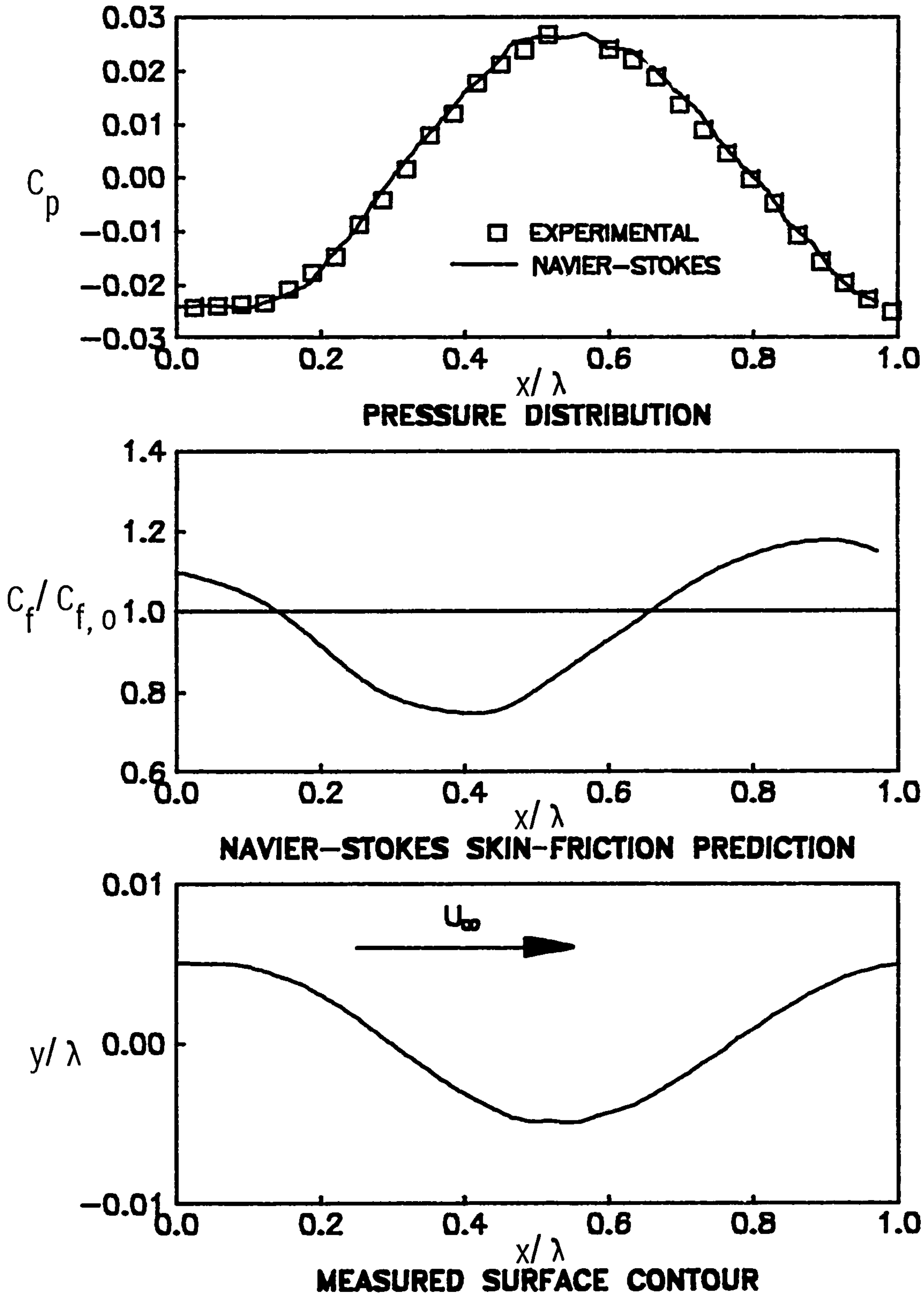


Figure 20.- C_p and $C_f/C_{f,o}$ predictions at $U_\infty = 22.9$ m/s for model VII (sine waves, $h/\lambda = 0.005$, $\lambda = 5.08$ cm).

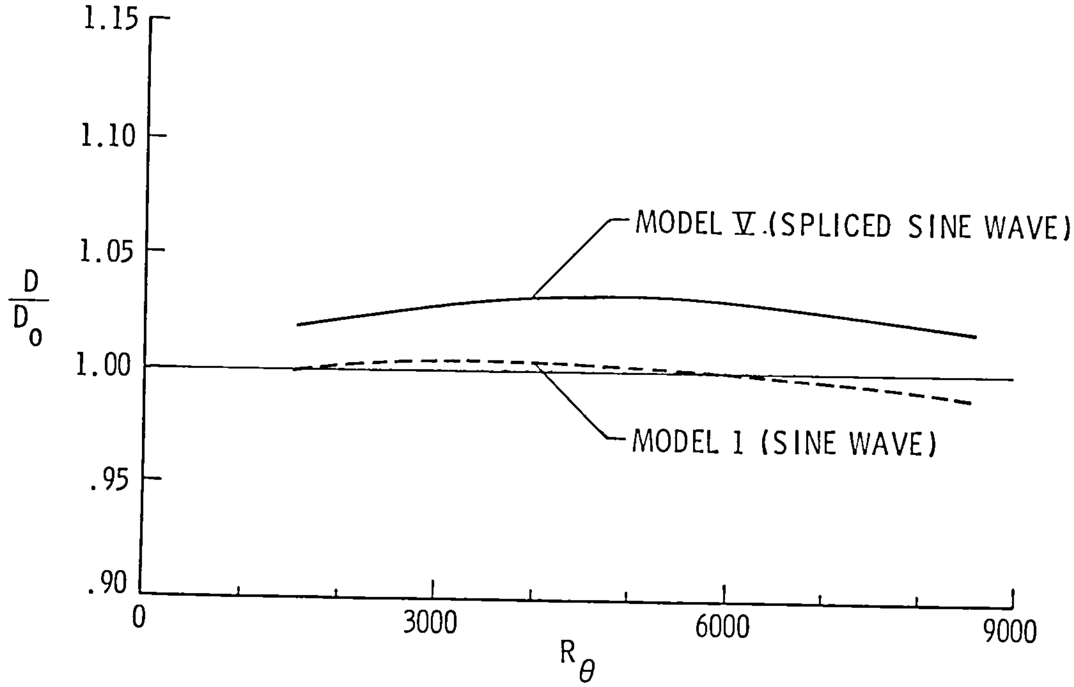


Figure 21.- Measured total drag of spliced sine wave model ($h/\lambda = 0.005$, $\lambda = 2.54$ cm).

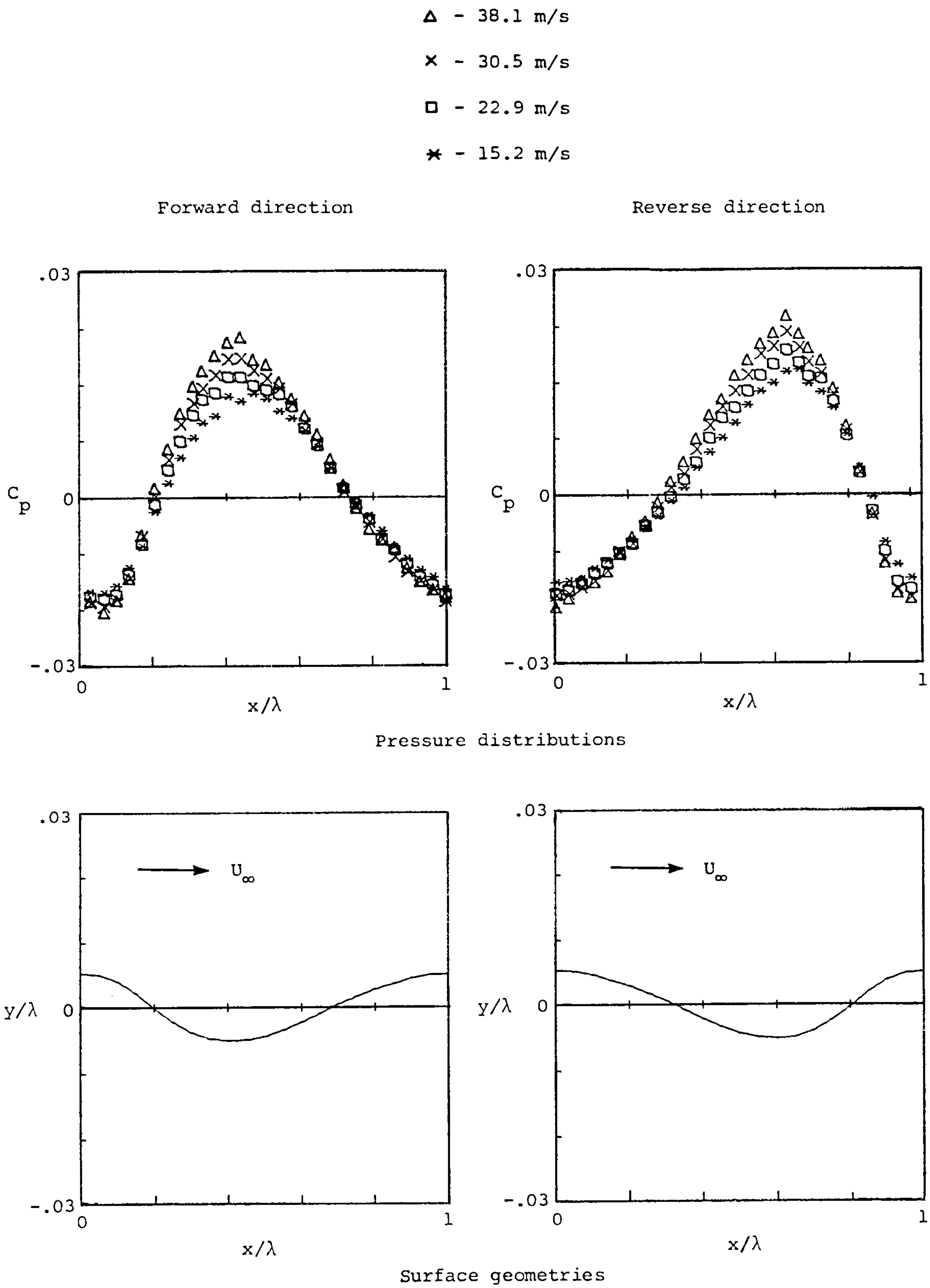
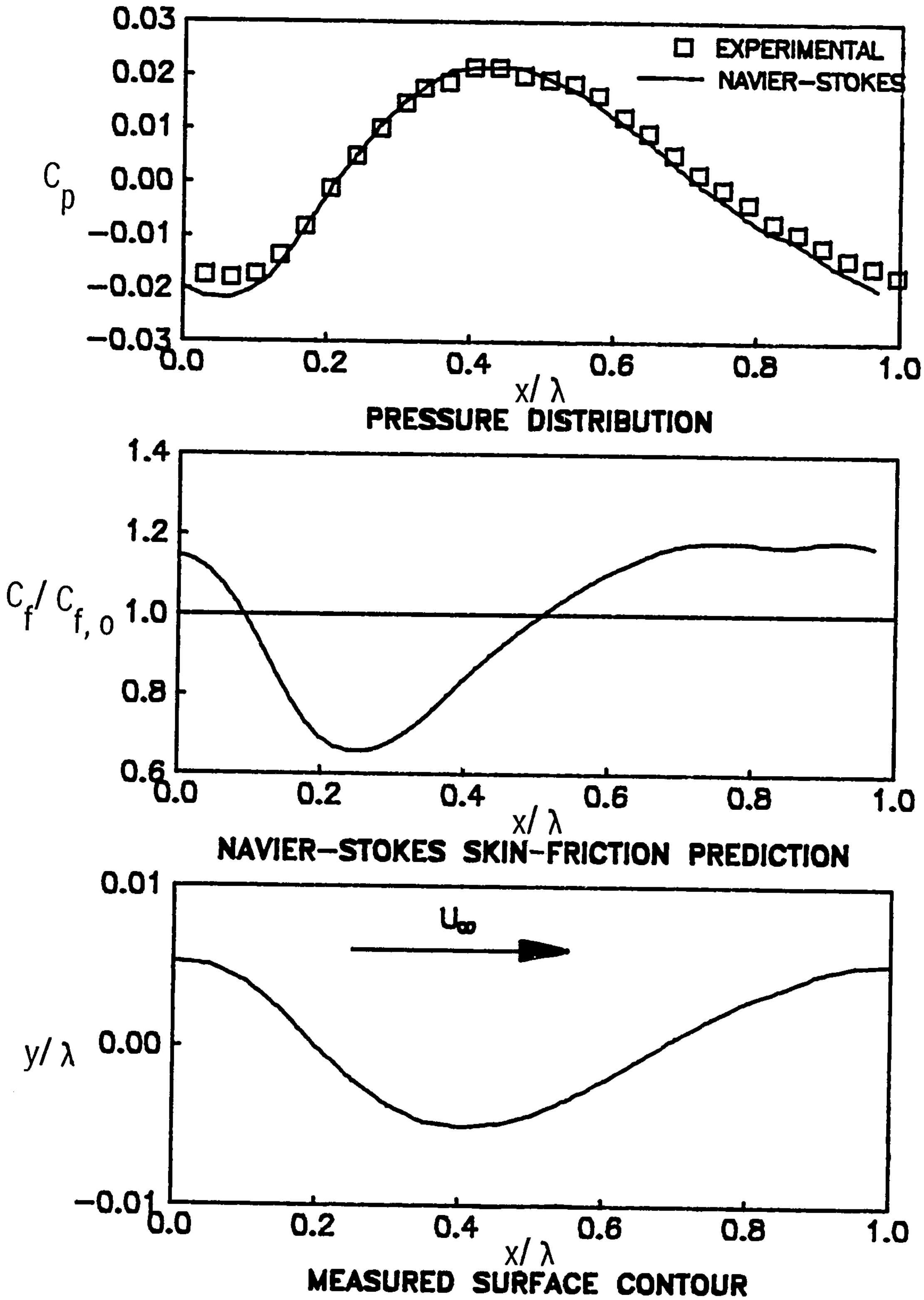
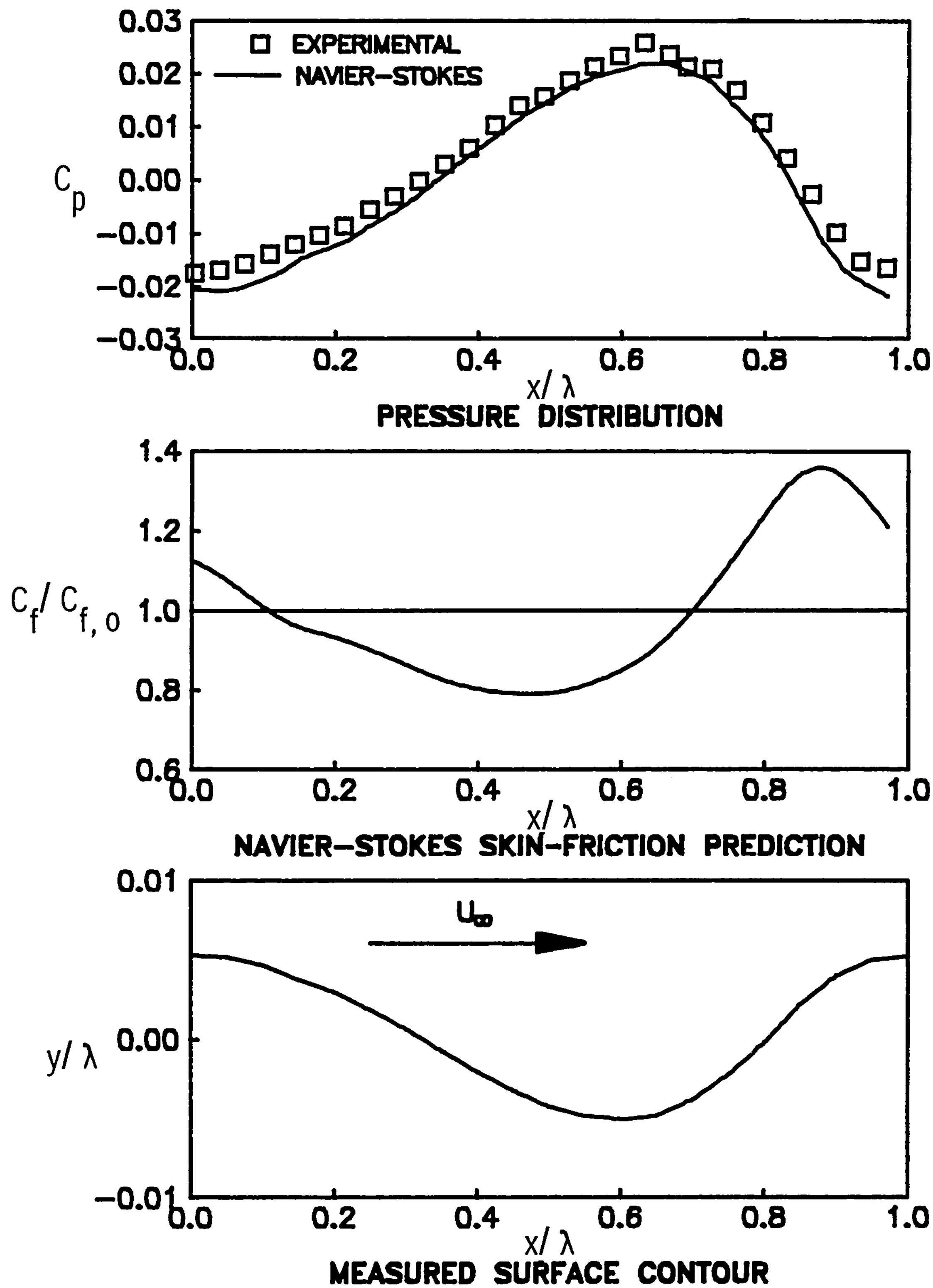


Figure 22.- Measured C_p values for model V (spliced sine waves, $h/\lambda = 0.005$, $\lambda = 2.54$ cm).



(a) Forward direction.

Figure 23.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model V (spliced sine waves, h/λ = 0.005, λ = 2.54 cm).



(b) Reverse direction.

Figure 23.- Concluded.

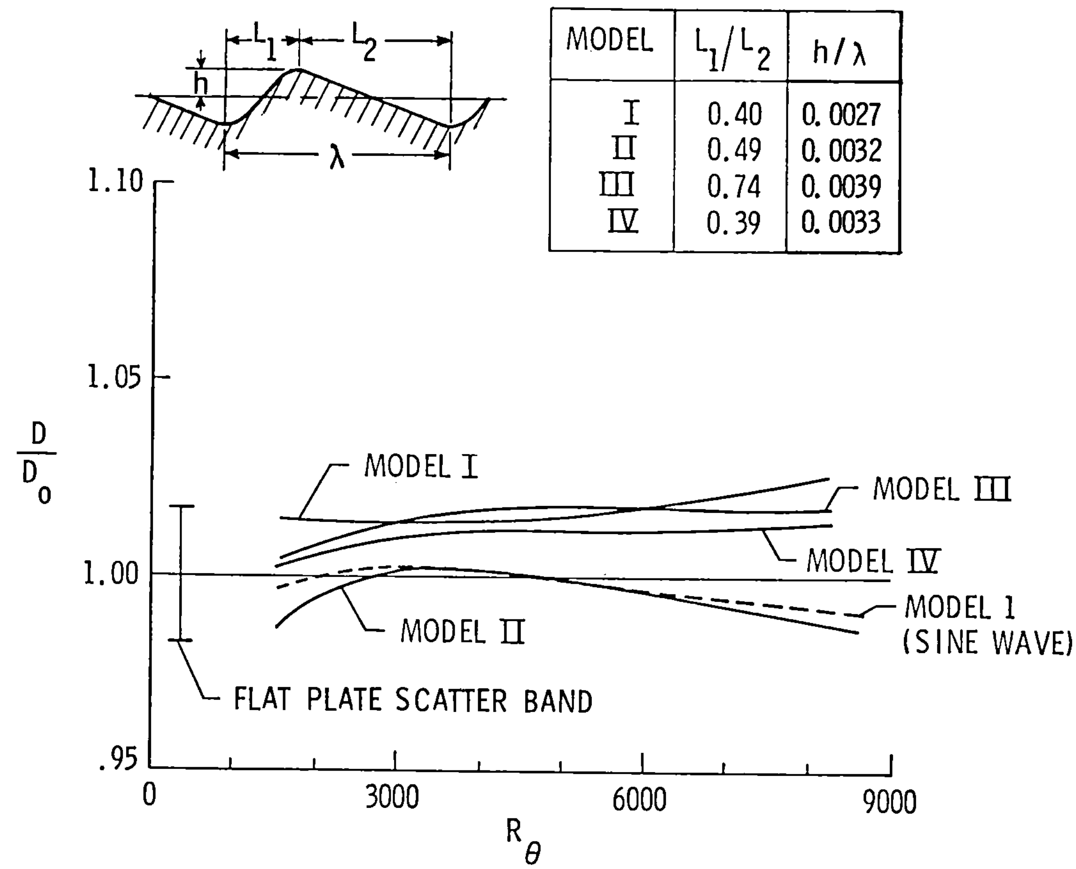


Figure 24.- Measured total drag of sine wave and straight ramp geometries (both directions). h = 0.0127 cm.

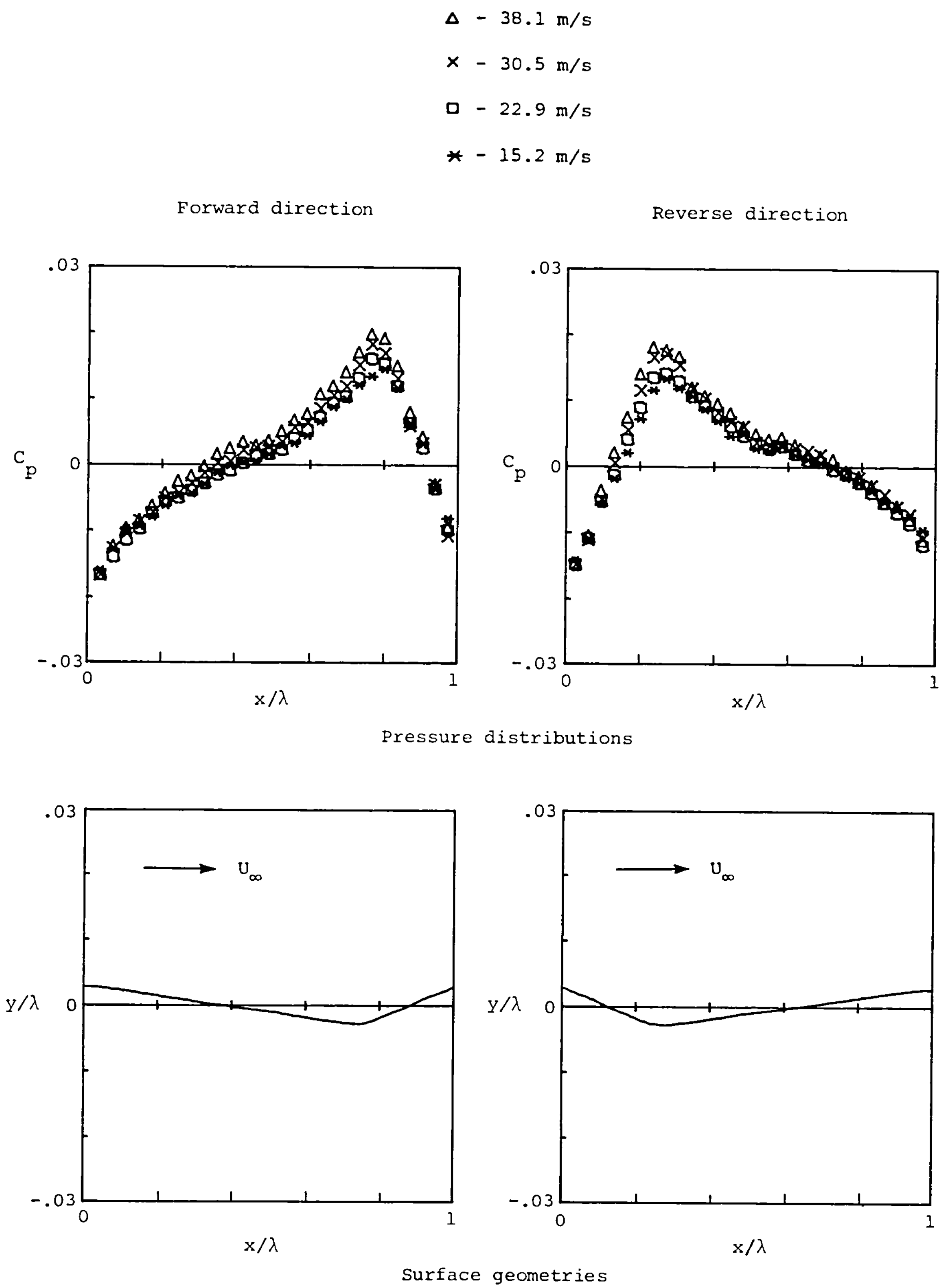


Figure 25.- Measured C_p values for model I (sine waves and straight ramps, $h/\lambda = 0.0027$, $\lambda = 4.62$ cm).

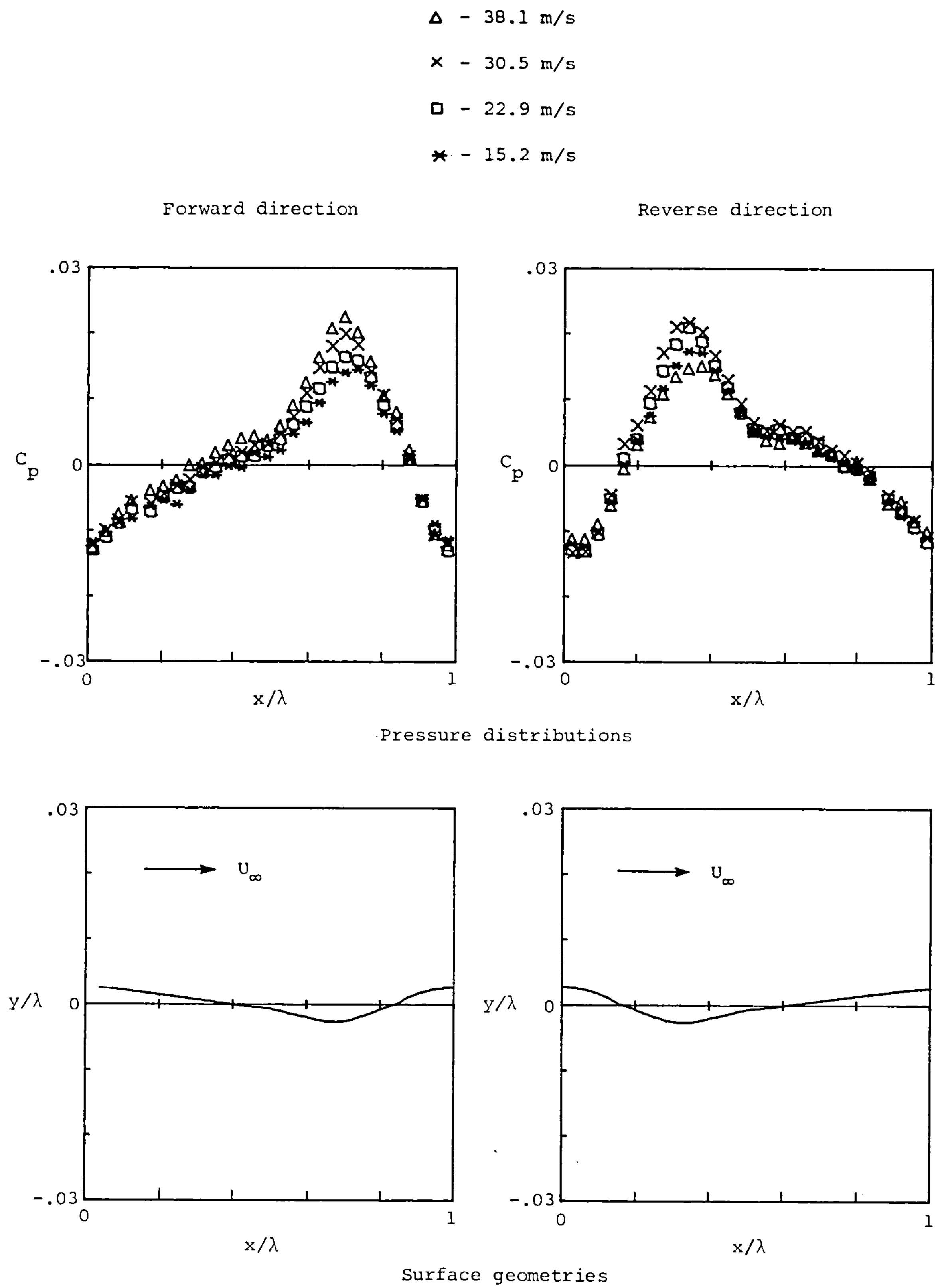


Figure 26.- Measured C_p values for model II (sine waves and straight ramps, $h/\lambda = 0.0032$, $\lambda = 4.01$ cm).

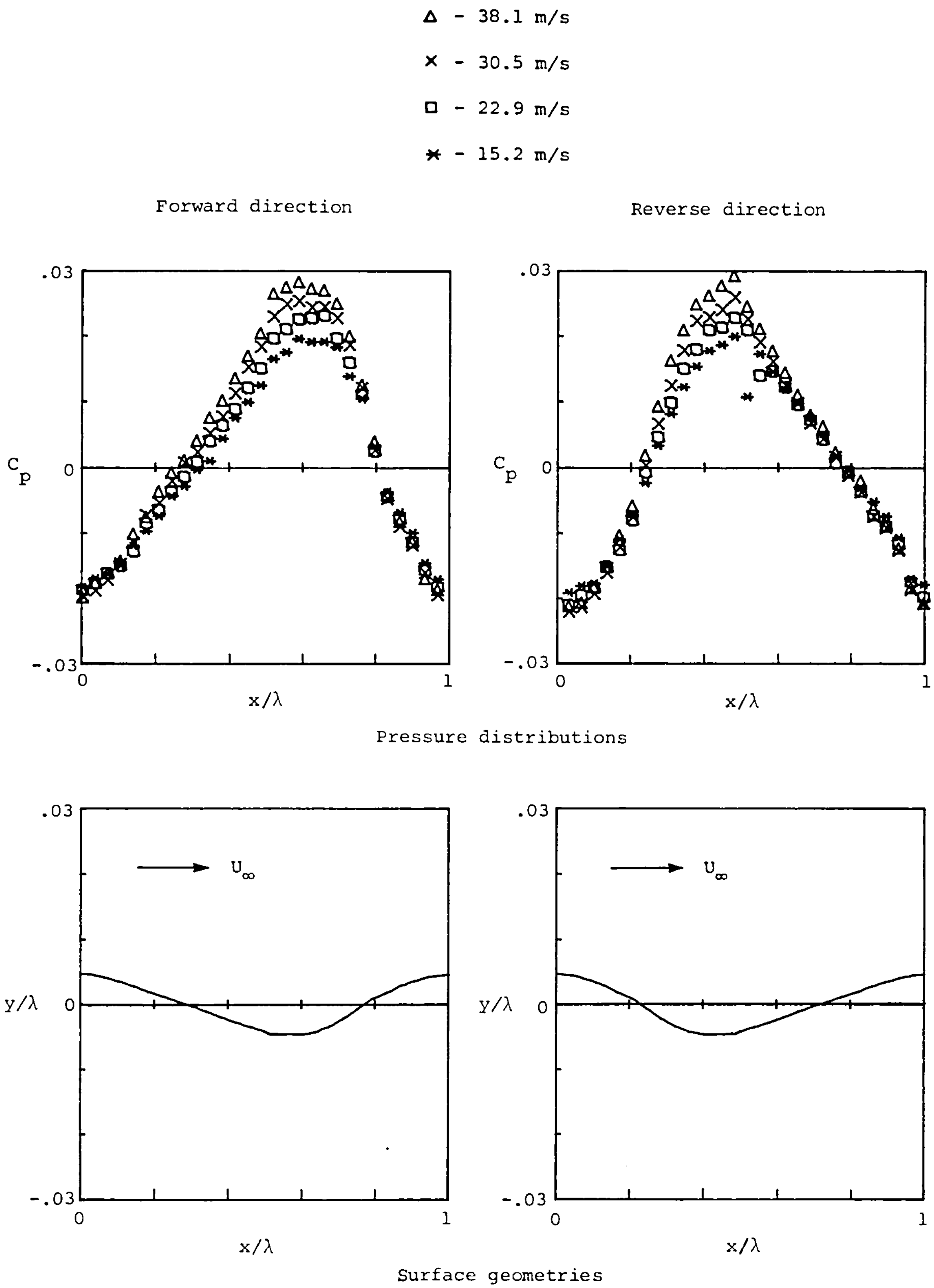


Figure 27.- Measured C_p values for model III (sine waves and straight ramps, $h/\lambda = 0.0039$, $\lambda = 3.23$ cm).

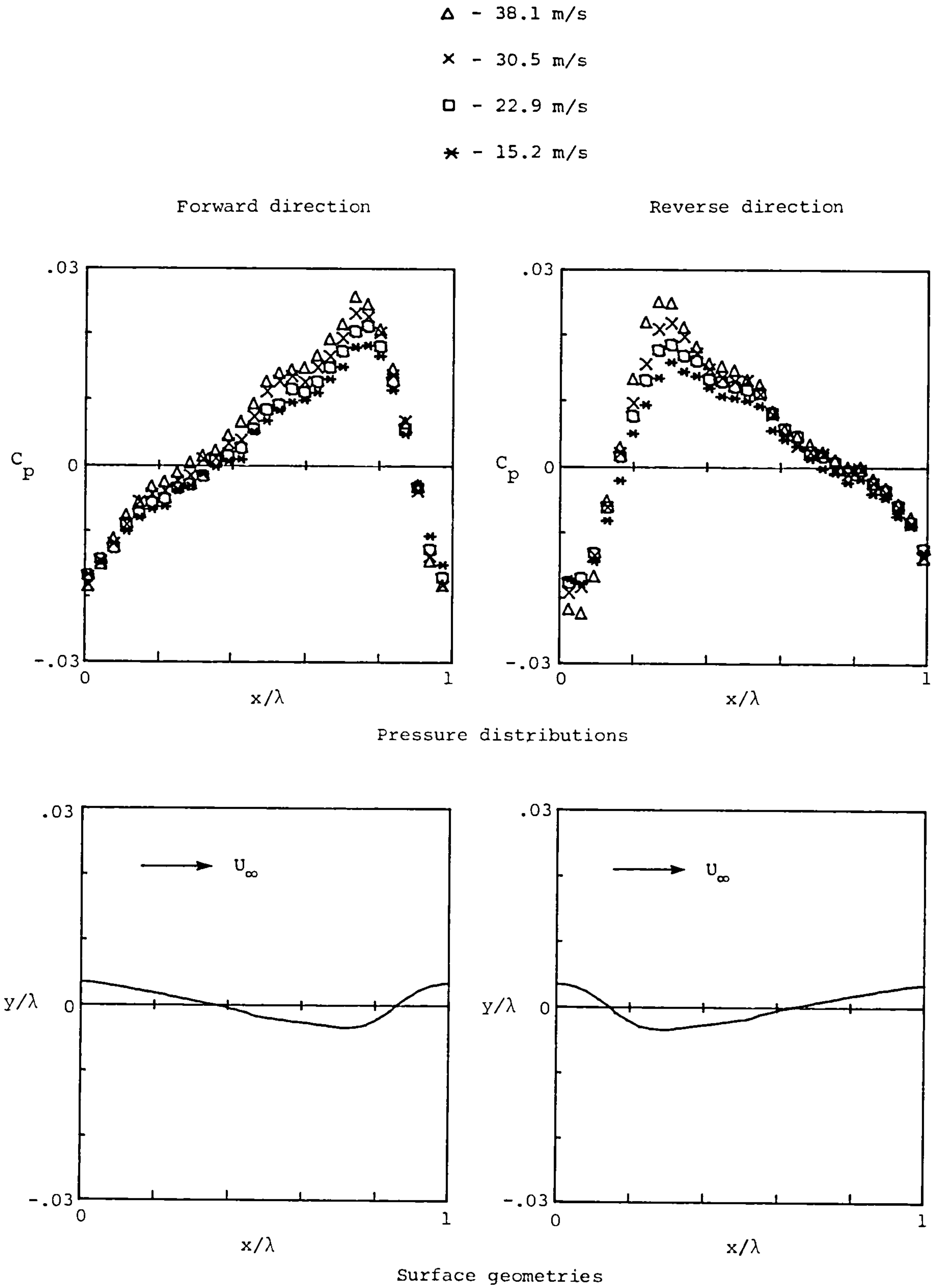
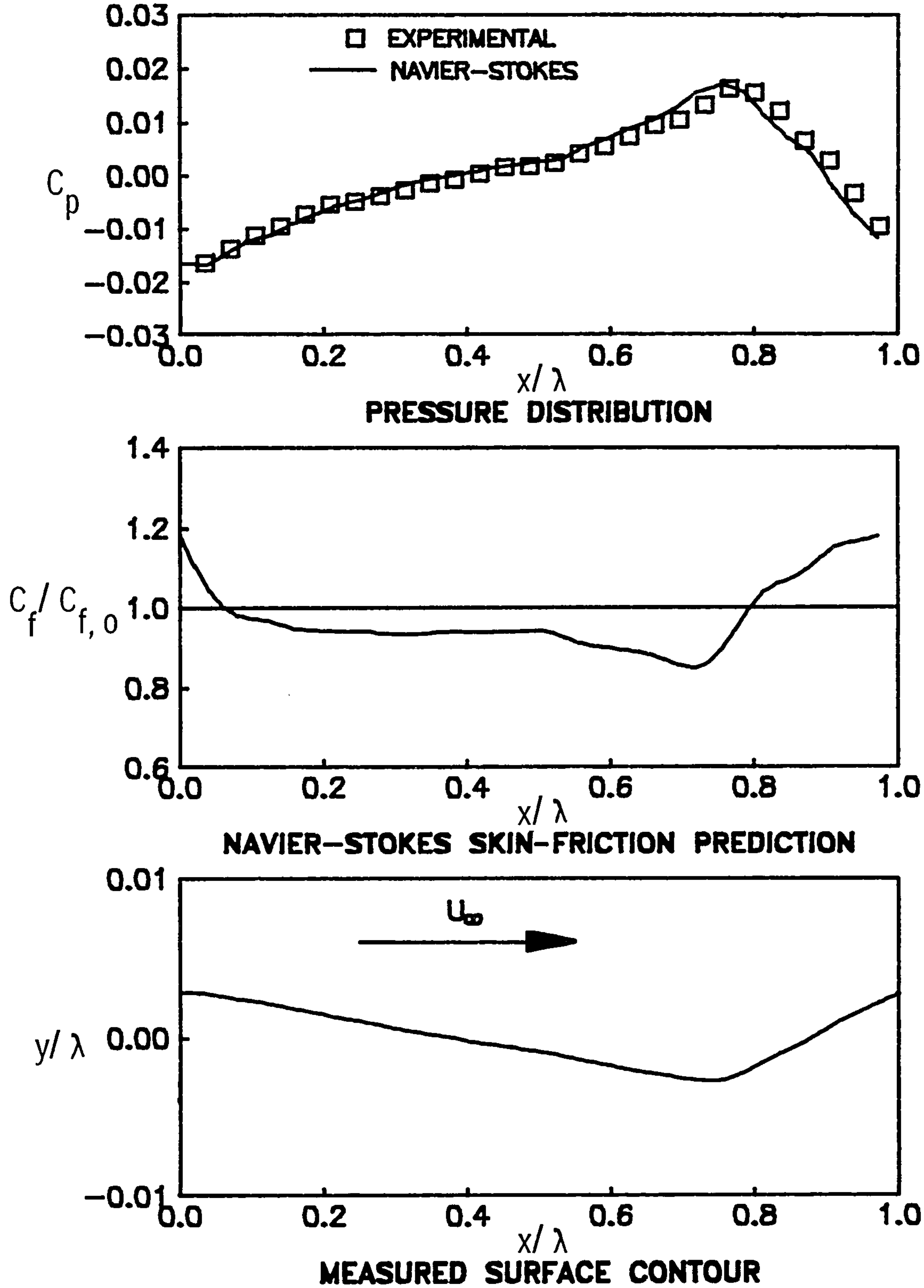
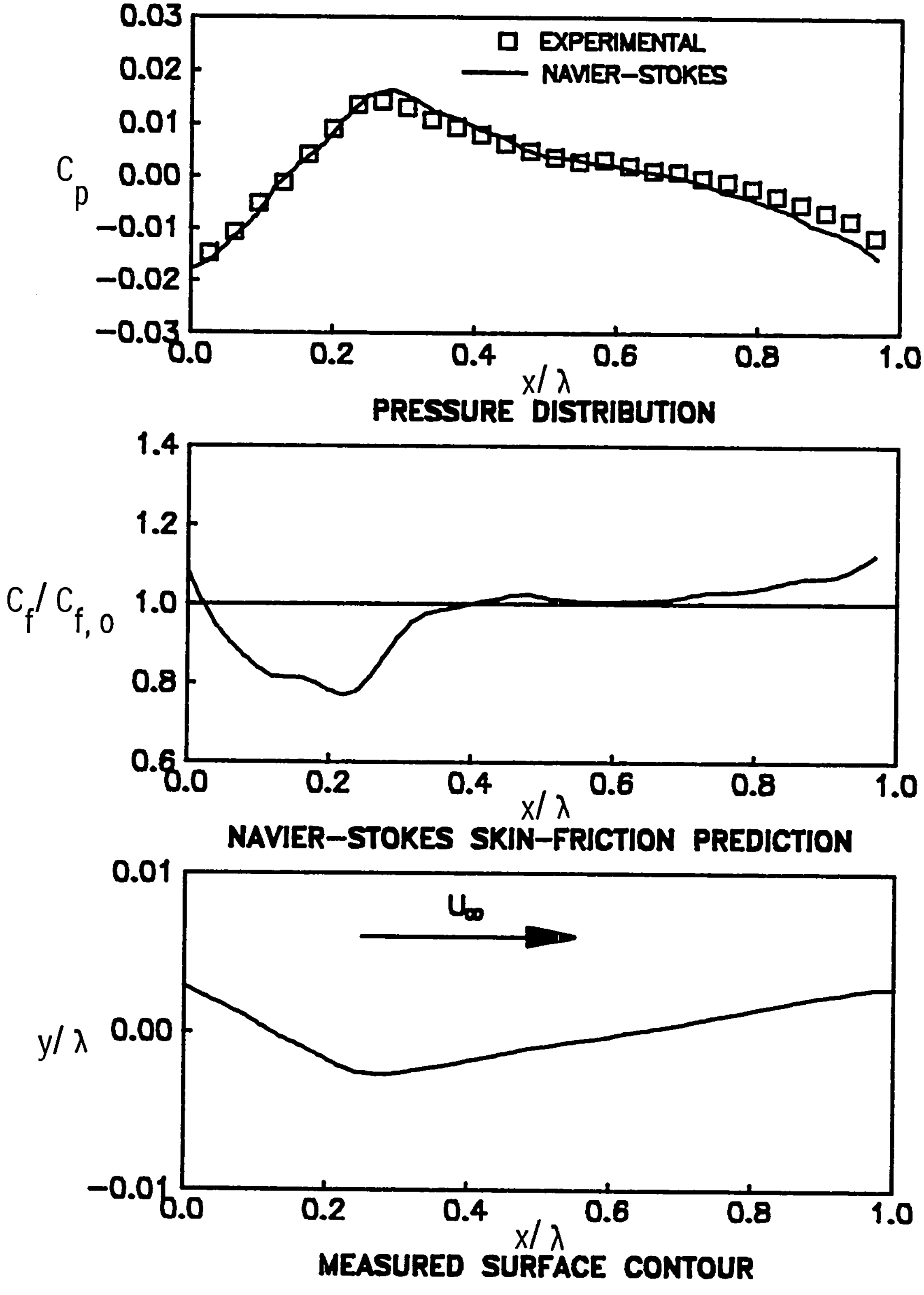


Figure 28.- Measured C_p values for model IV (sine waves and straight ramps, $h/\lambda = 0.0033$, $\lambda = 3.86$ cm).



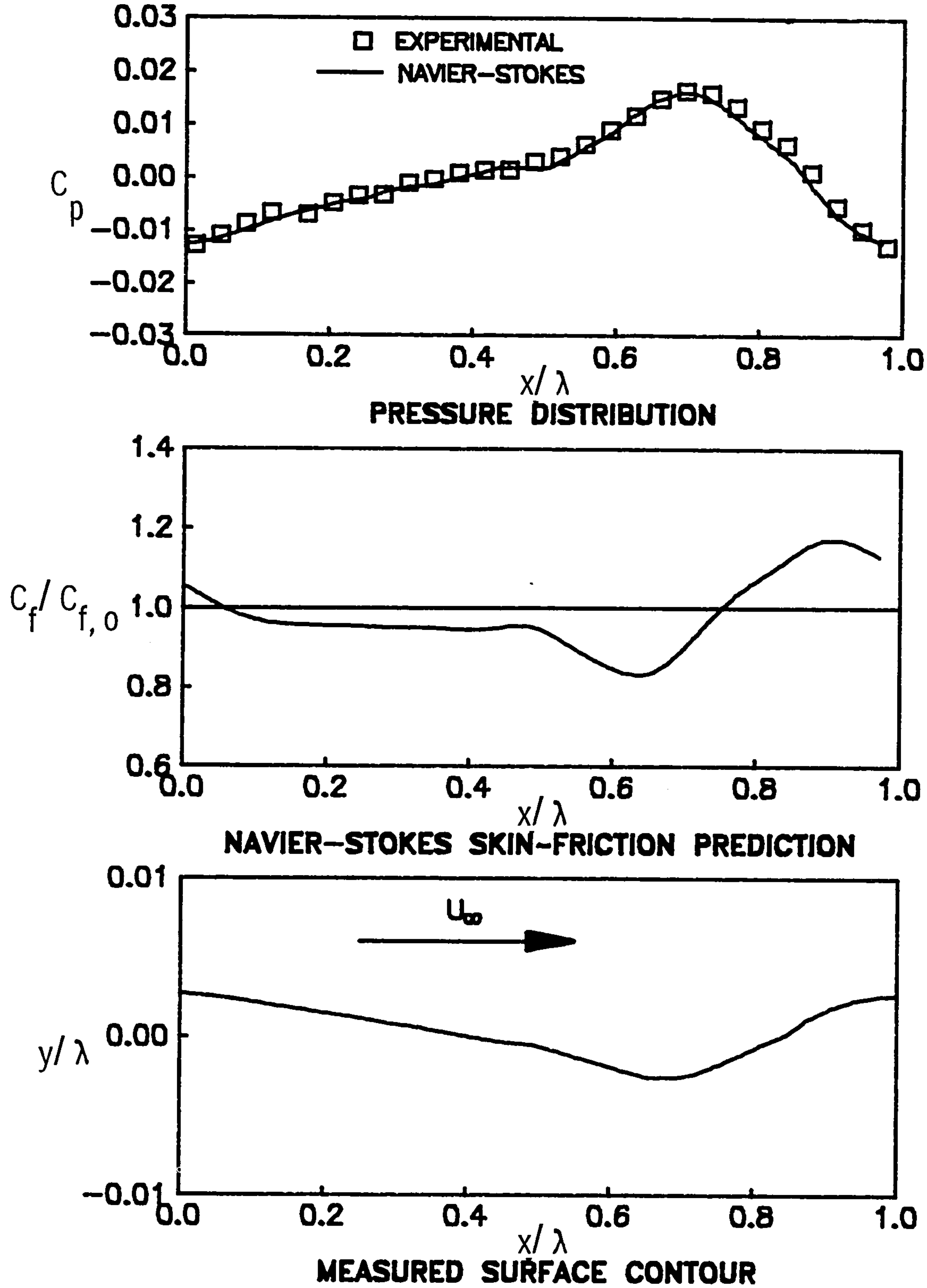
(a) Forward direction.

Figure 29.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model I (sine waves and straight ramps, h/λ = 0.0027, λ = 4.62 cm).



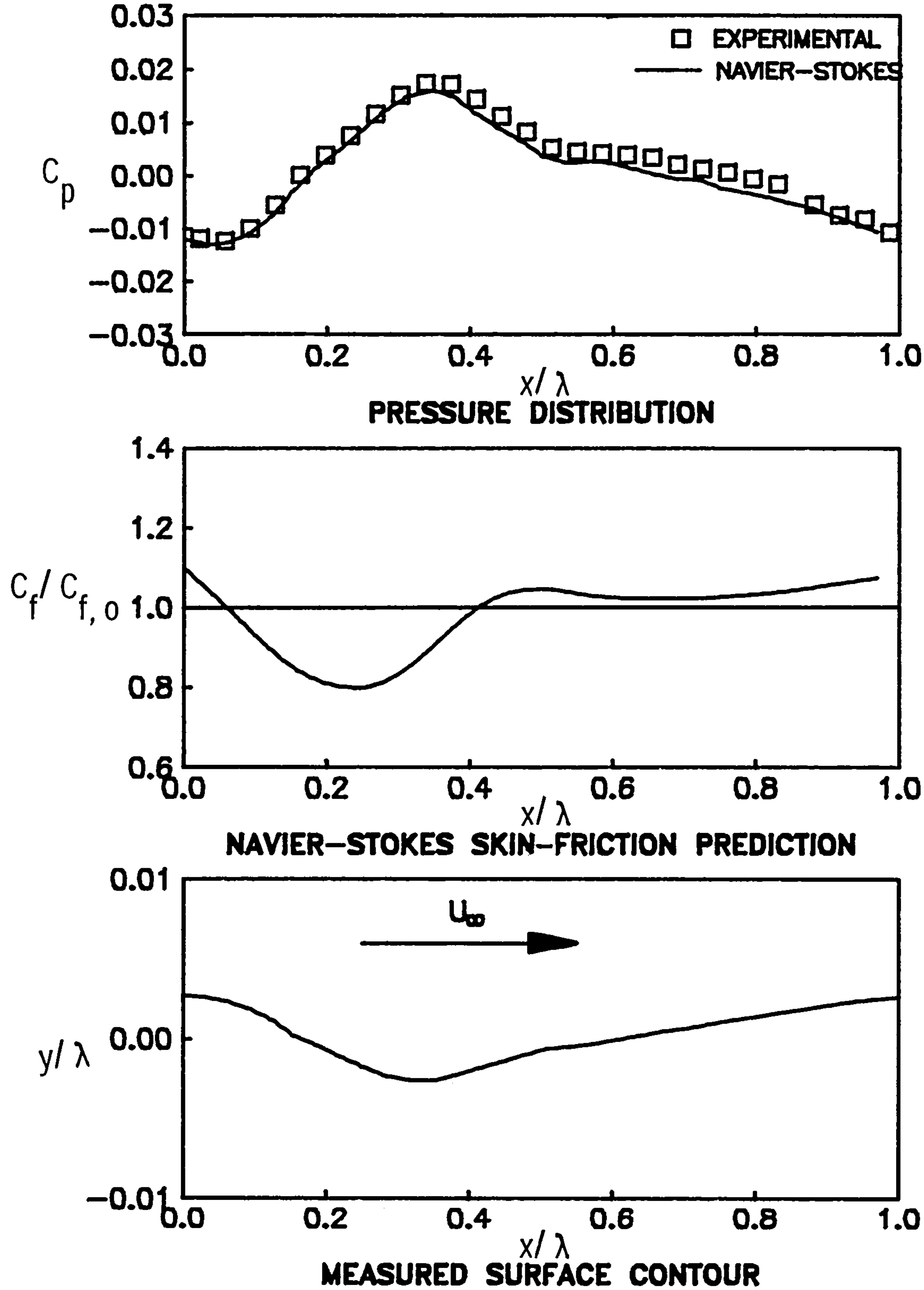
(b) Reverse direction.

Figure 29.- Concluded.



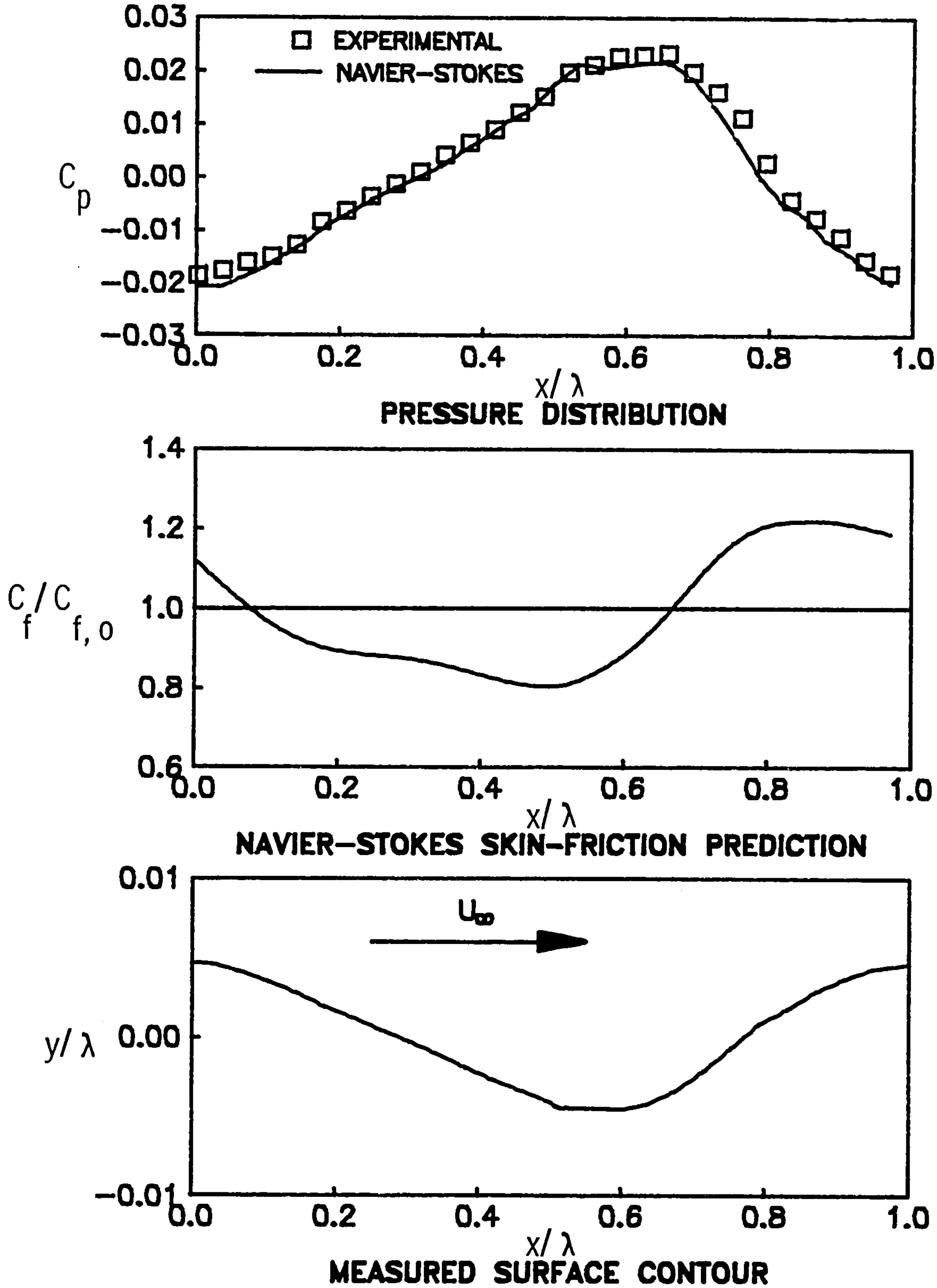
(a) Forward direction.

Figure 30.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model II (sine waves and straight ramps, h/λ = 0.0032, λ = 4.01 cm).



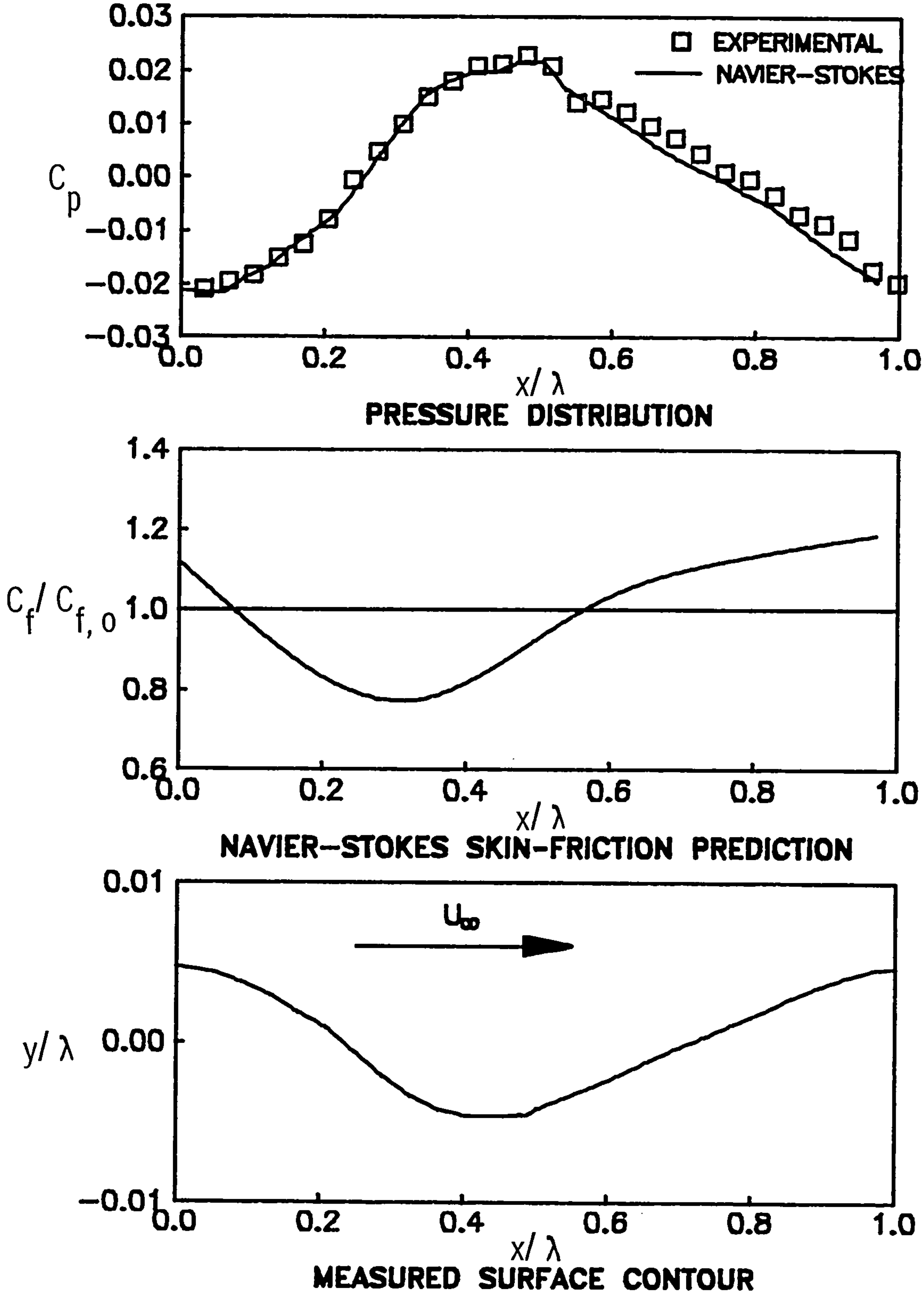
(b) Reverse direction.

Figure 30.- Concluded.



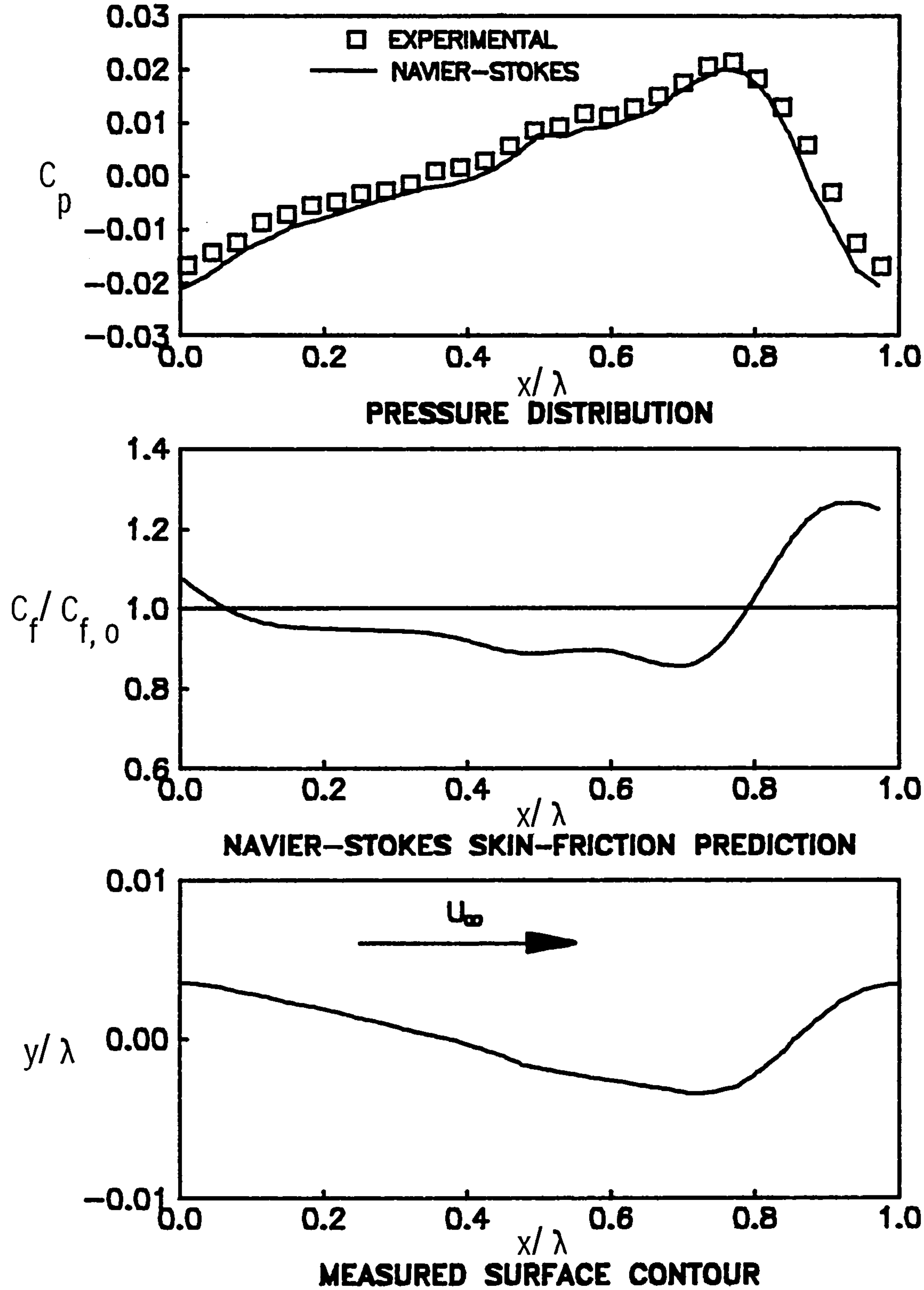
(a) Forward direction.

Figure 31.- C_p and $C_f/C_{f,o}$ predictions at U_∞= 22.9 m/s for model III (sine waves and straight ramps, h/λ = 0.0039, λ = 3.23 cm).



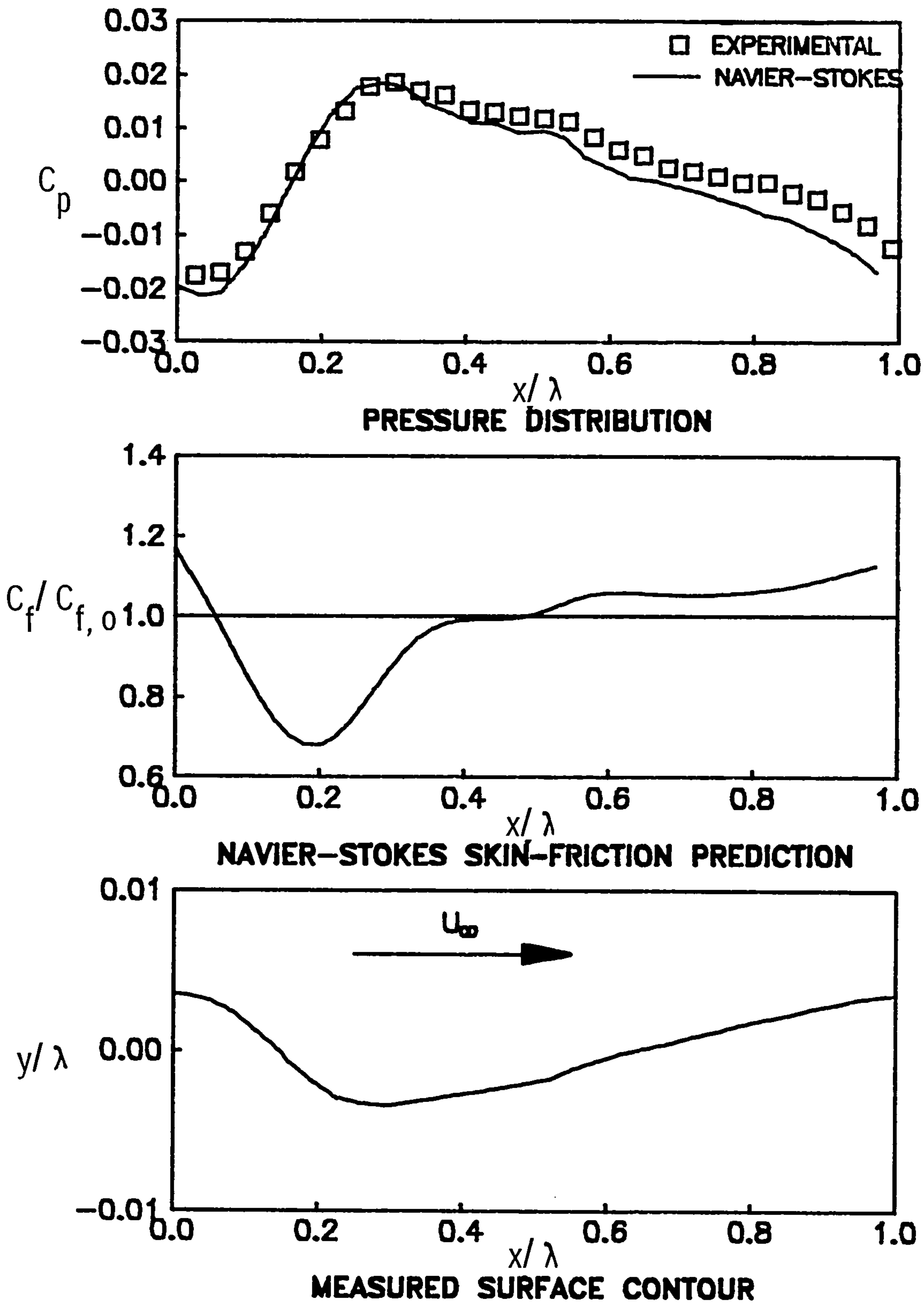
(b) Reverse direction.

Figure 31.- Concluded.



(a) Forward direction.

Figure 32.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model IV (sine waves and straight ramps, h/λ = 0.0033, λ = 3.86 cm).



(b) Reverse direction.

Figure 32.- Concluded.

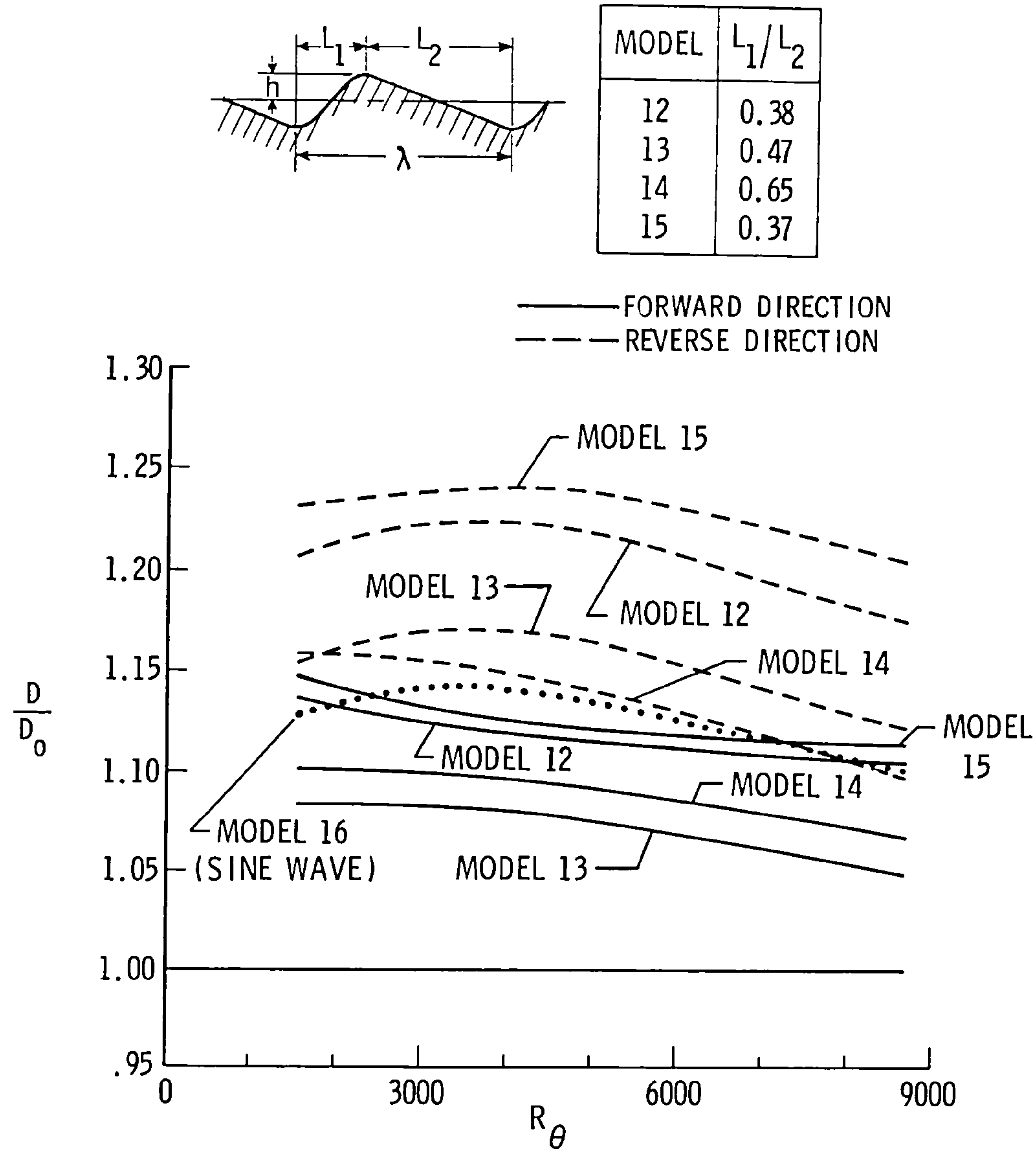


Figure 33.- Measured total drag of sine wave and straight ramp geometries with $h/\lambda = 0.015$.

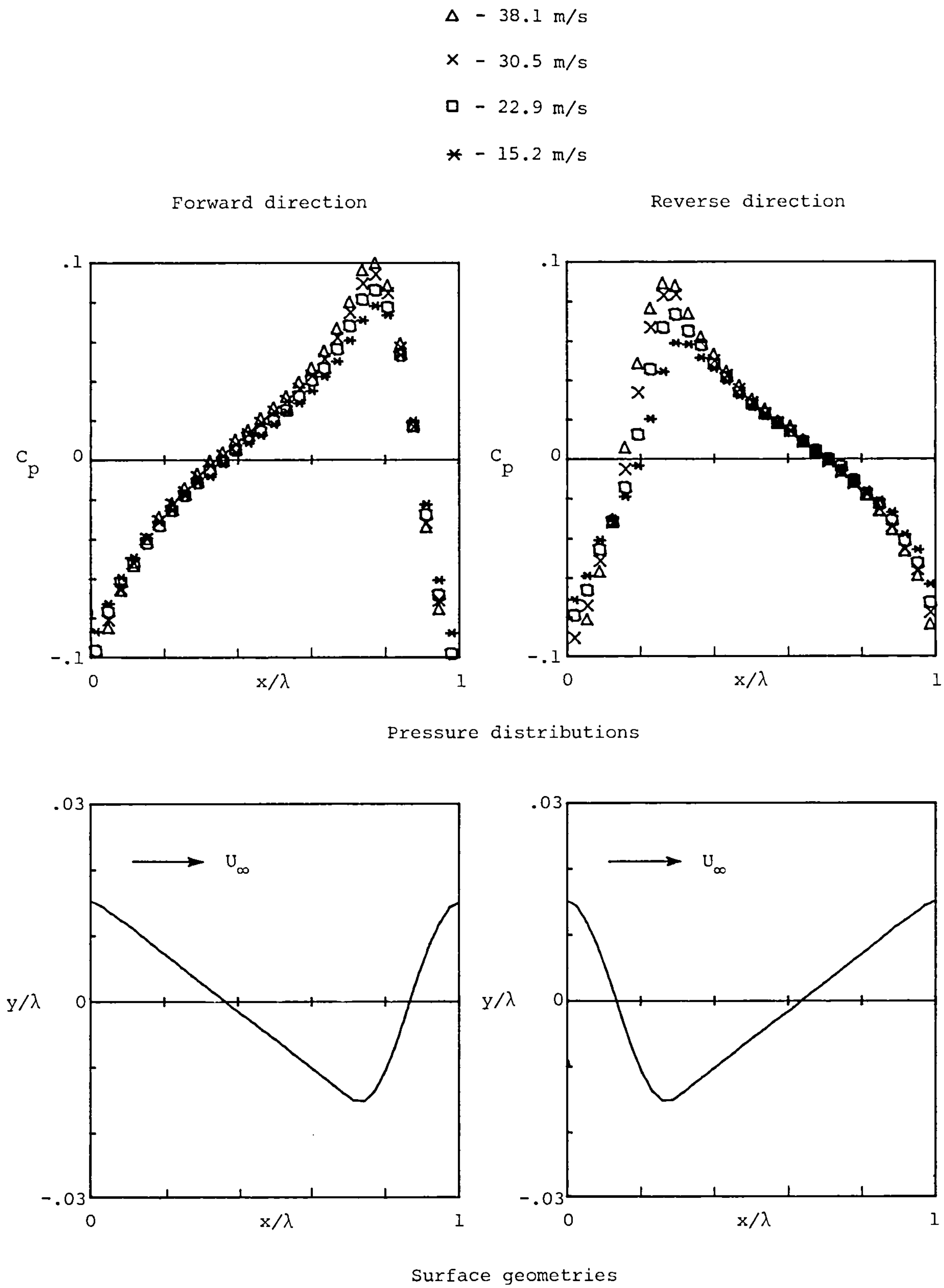


Figure 34.- Measured C_p values for model 12 (sine waves and straight ramps, $h/\lambda = 0.015$, $\lambda = 4.62$ cm).

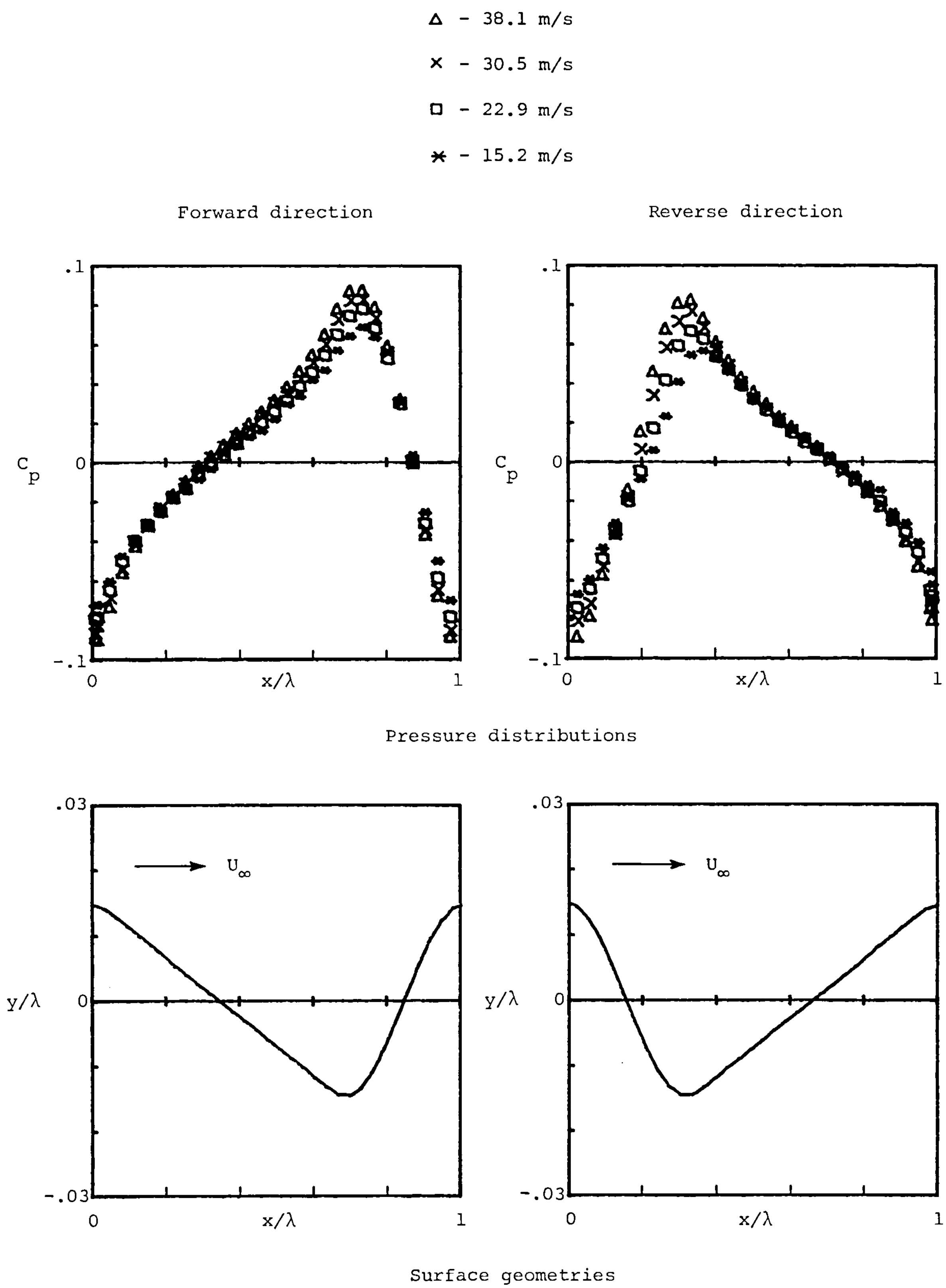


Figure 35.- Measured C_p values for model 13 (sine waves and straight ramps, $h/\lambda = 0.015$, $\lambda = 4.01$ cm).

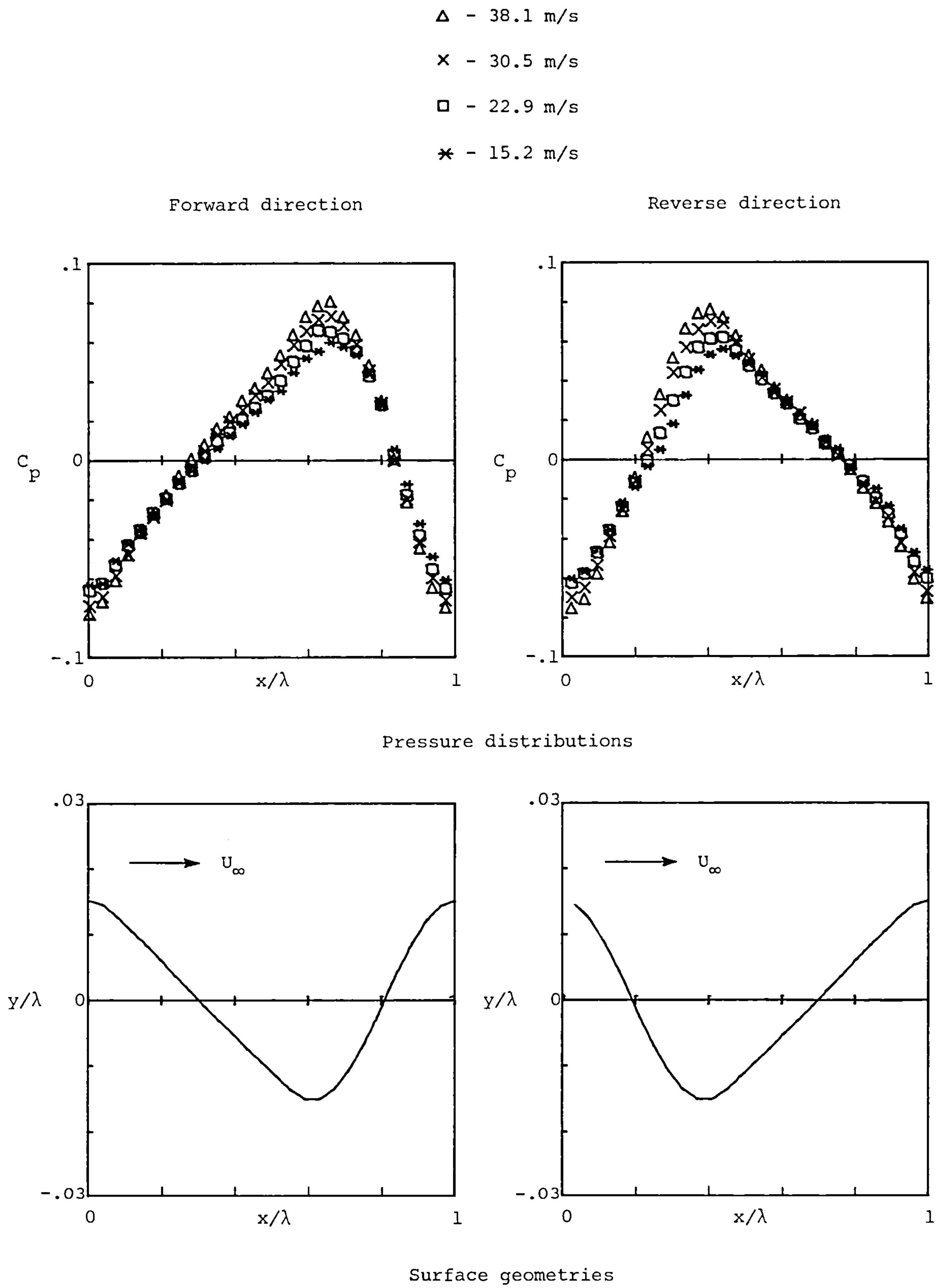


Figure 36.- Measured C_p values for model 14 (sine waves and straight ramps, $h/\lambda = 0.015$, $\lambda = 3.23$ cm).

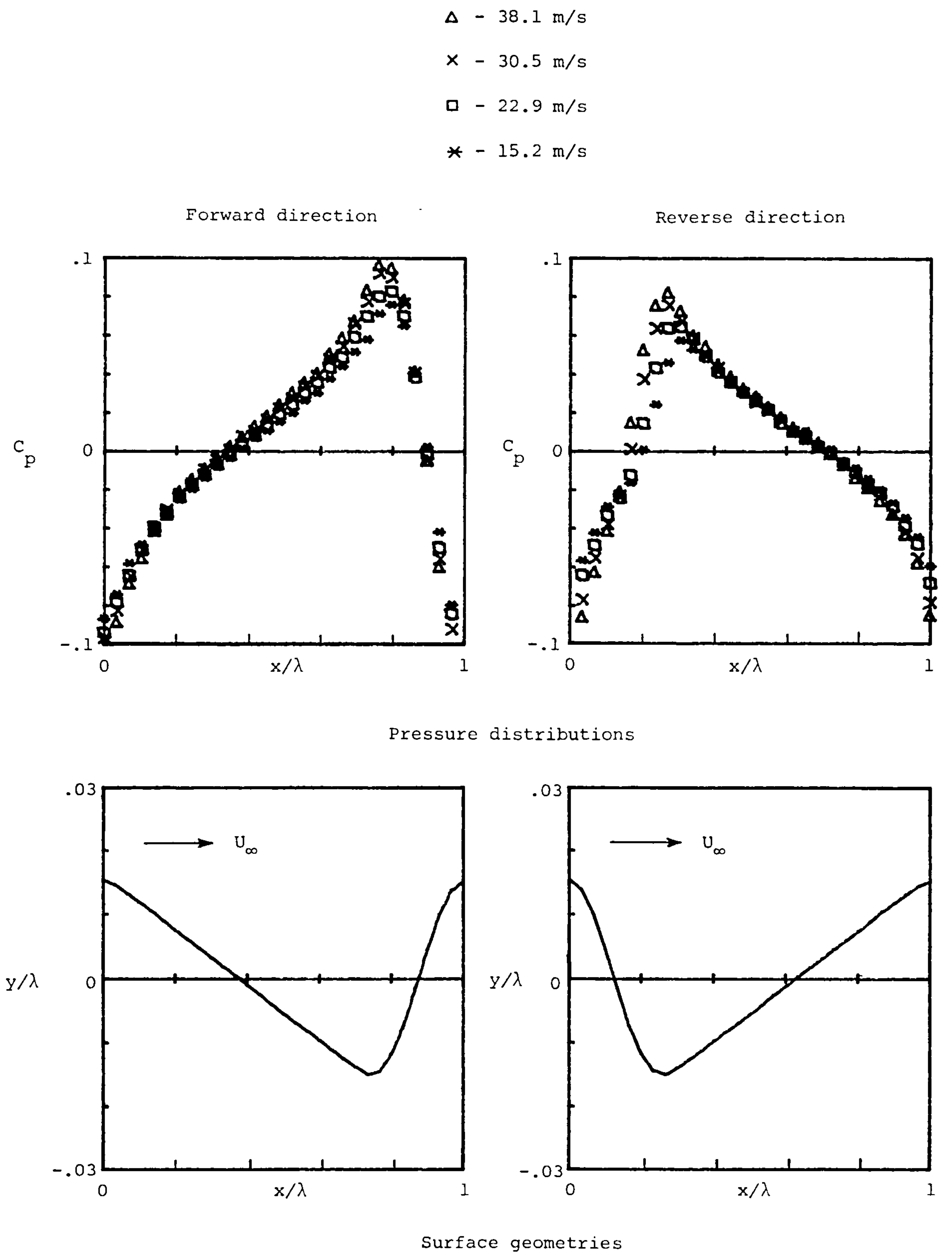
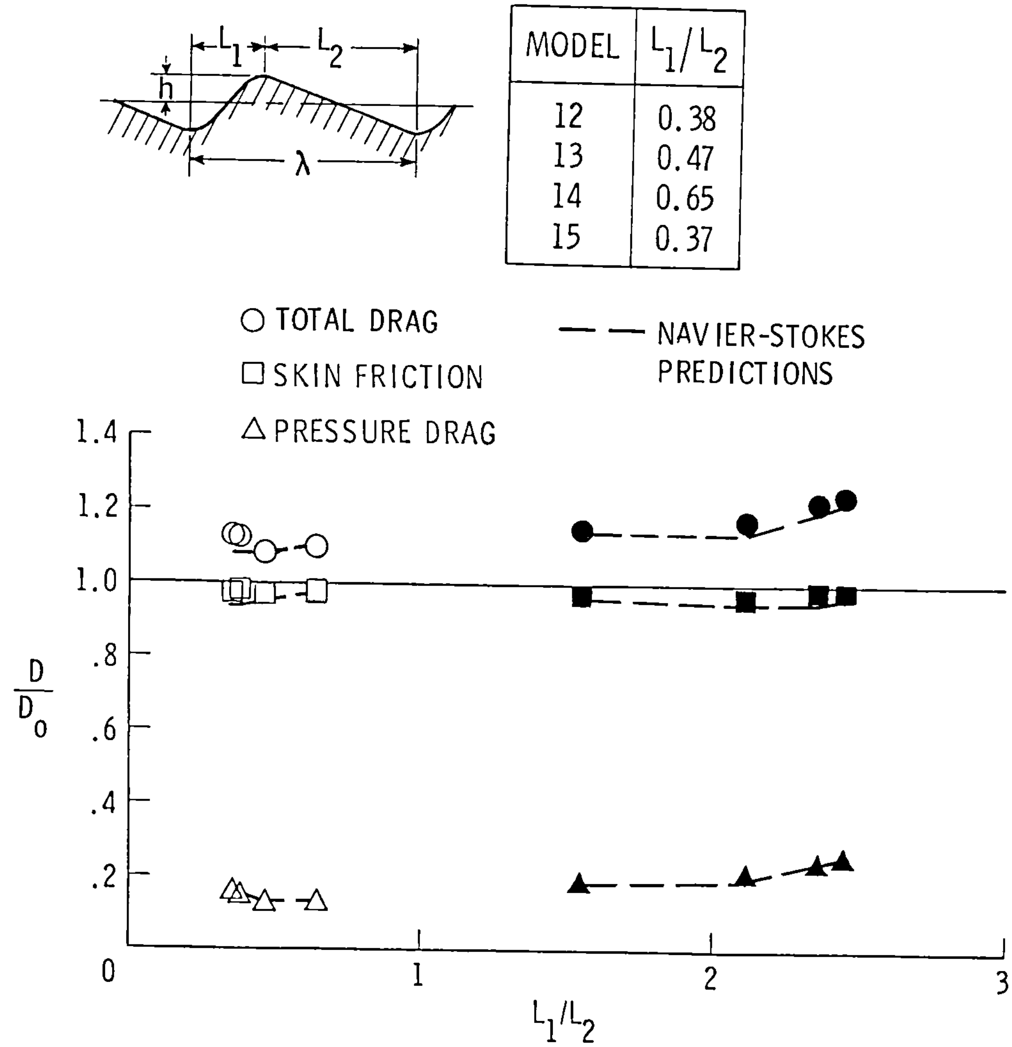
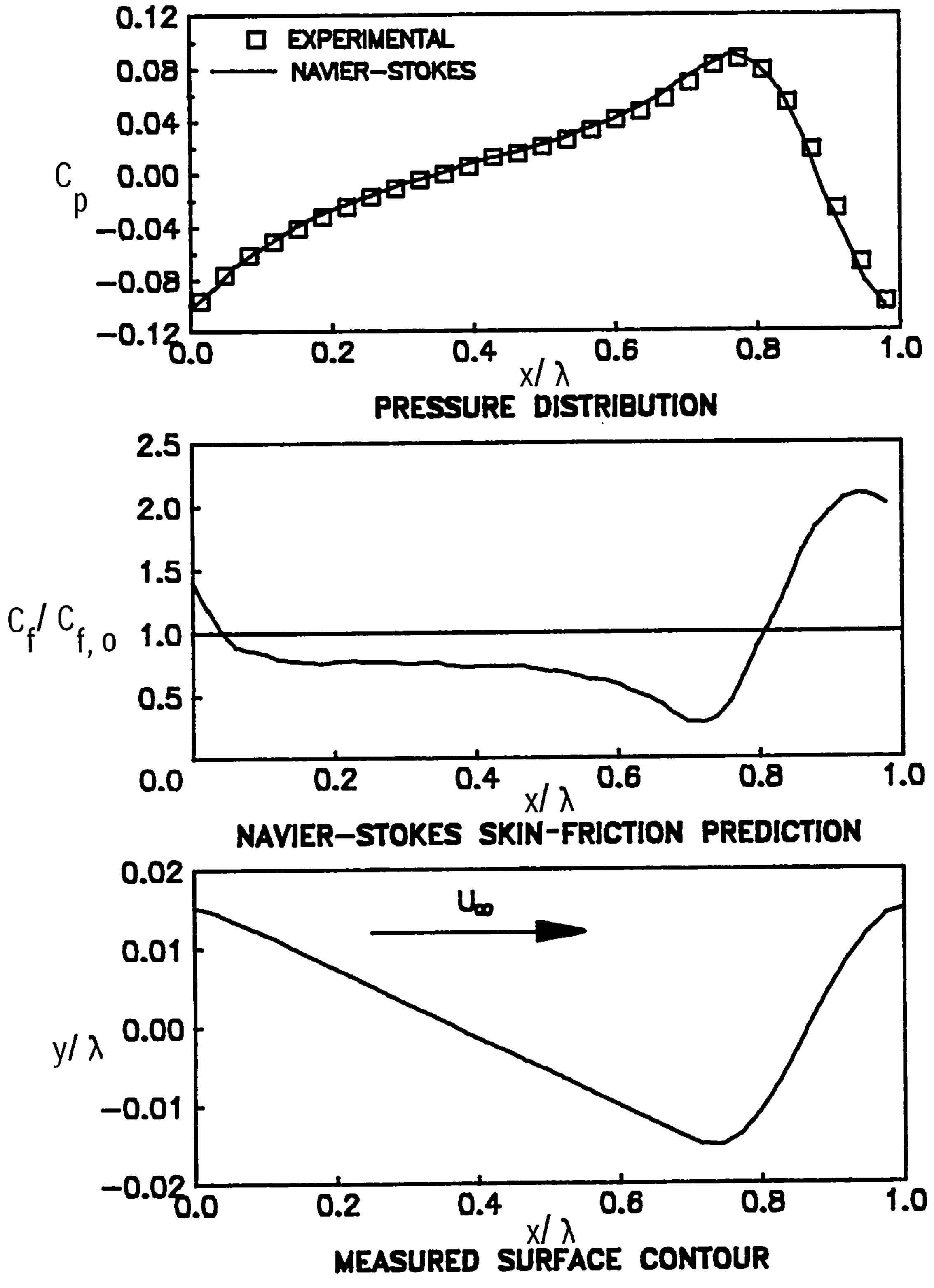


Figure 37.- Measured C_p values for model 15 (sine waves and straight ramps, $h/\lambda = 0.015$, $\lambda = 3.86$ cm).



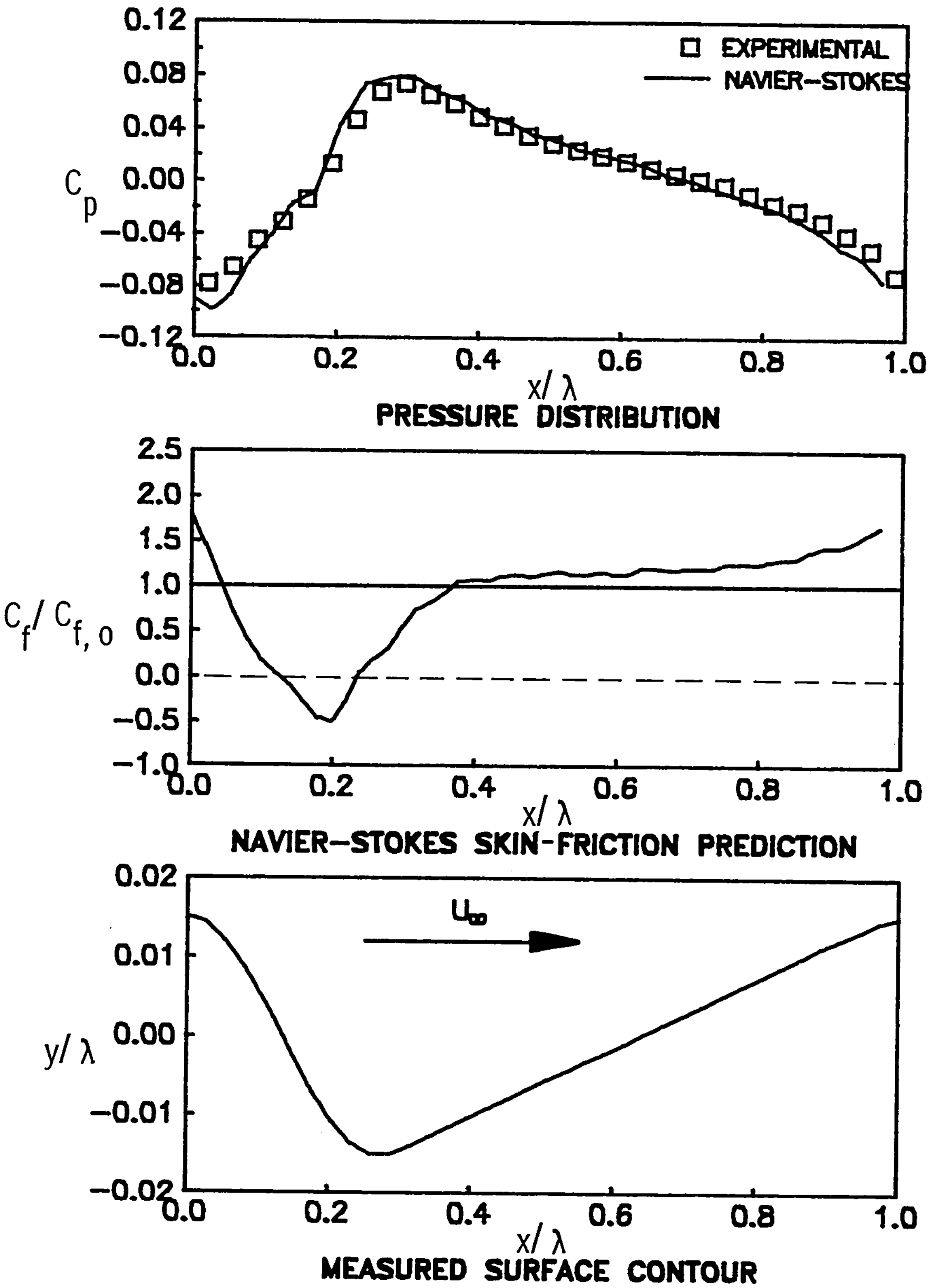
MODEL	L_1/L_2
12	0.38
13	0.47
14	0.65
15	0.37

Figure 38.- Drag contributions of sine wave and straight ramp geometries with $h/\lambda = 0.015$ at $R_\theta = 4700$. Open symbols, forward direction; filled symbols, reverse direction.



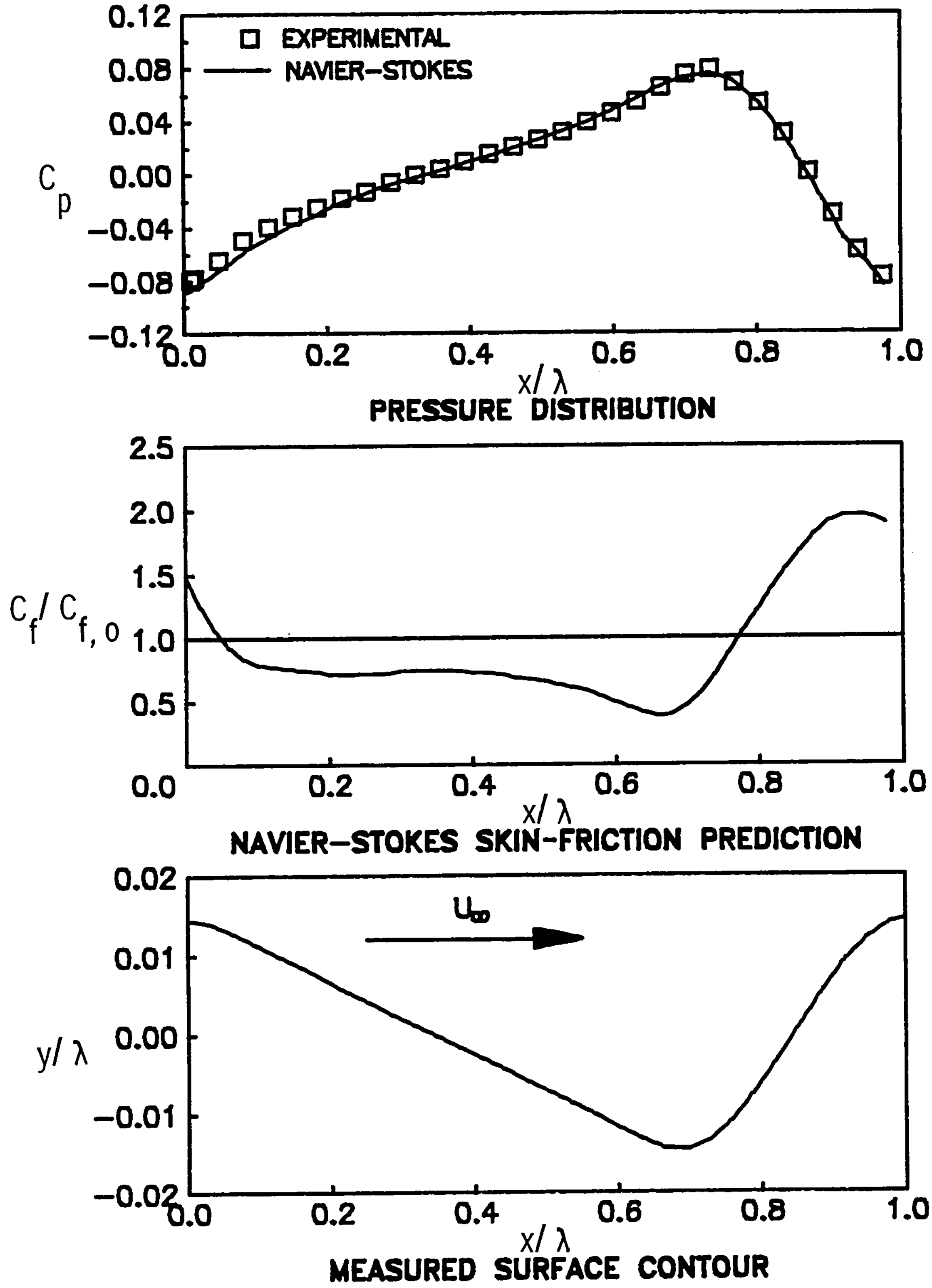
(a) Forward direction.

Figure 39.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 12 (sine waves and straight ramps, h/λ = 0.015, λ = 4.62 cm).



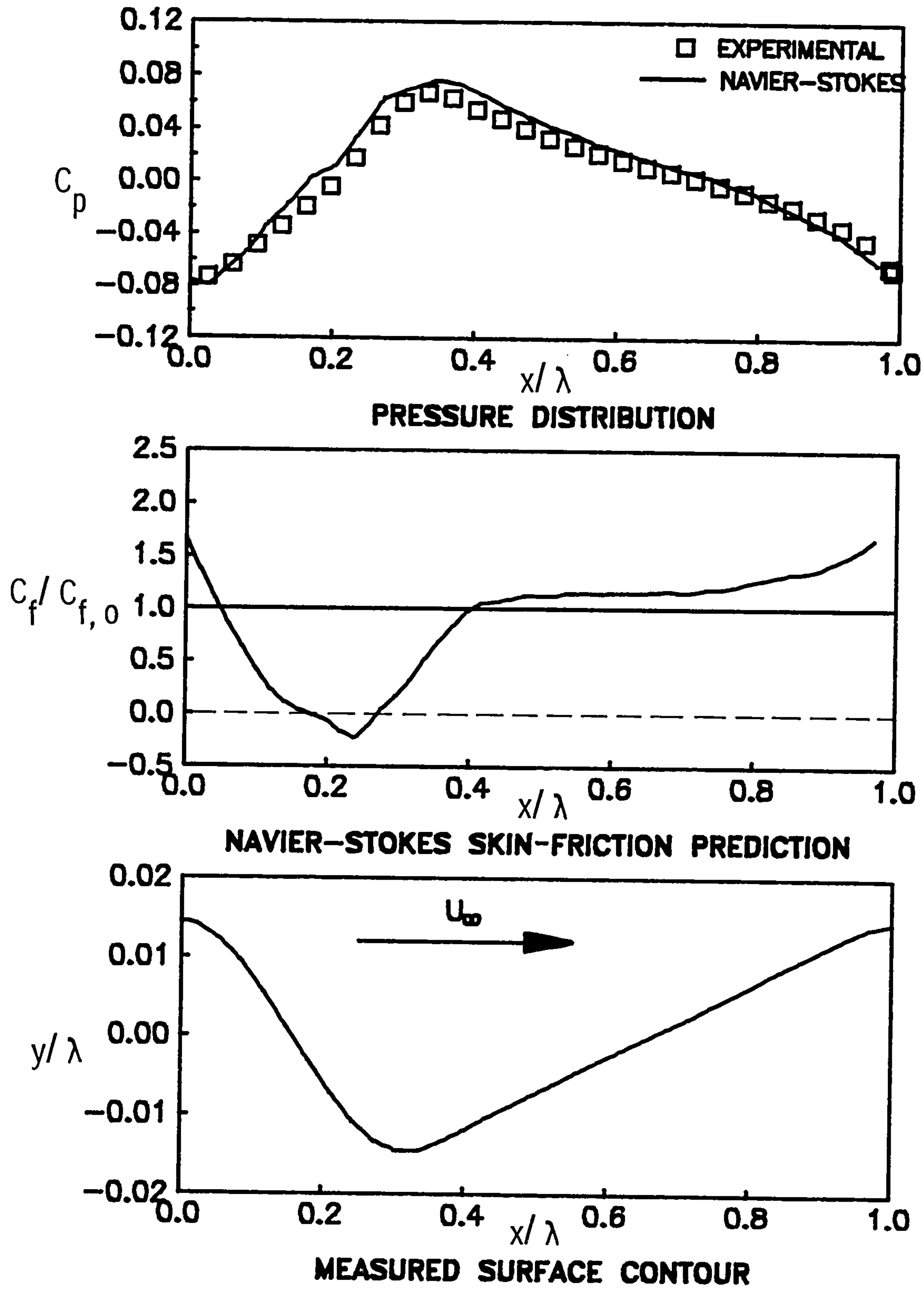
(b) Reverse direction.

Figure 39.- Concluded.



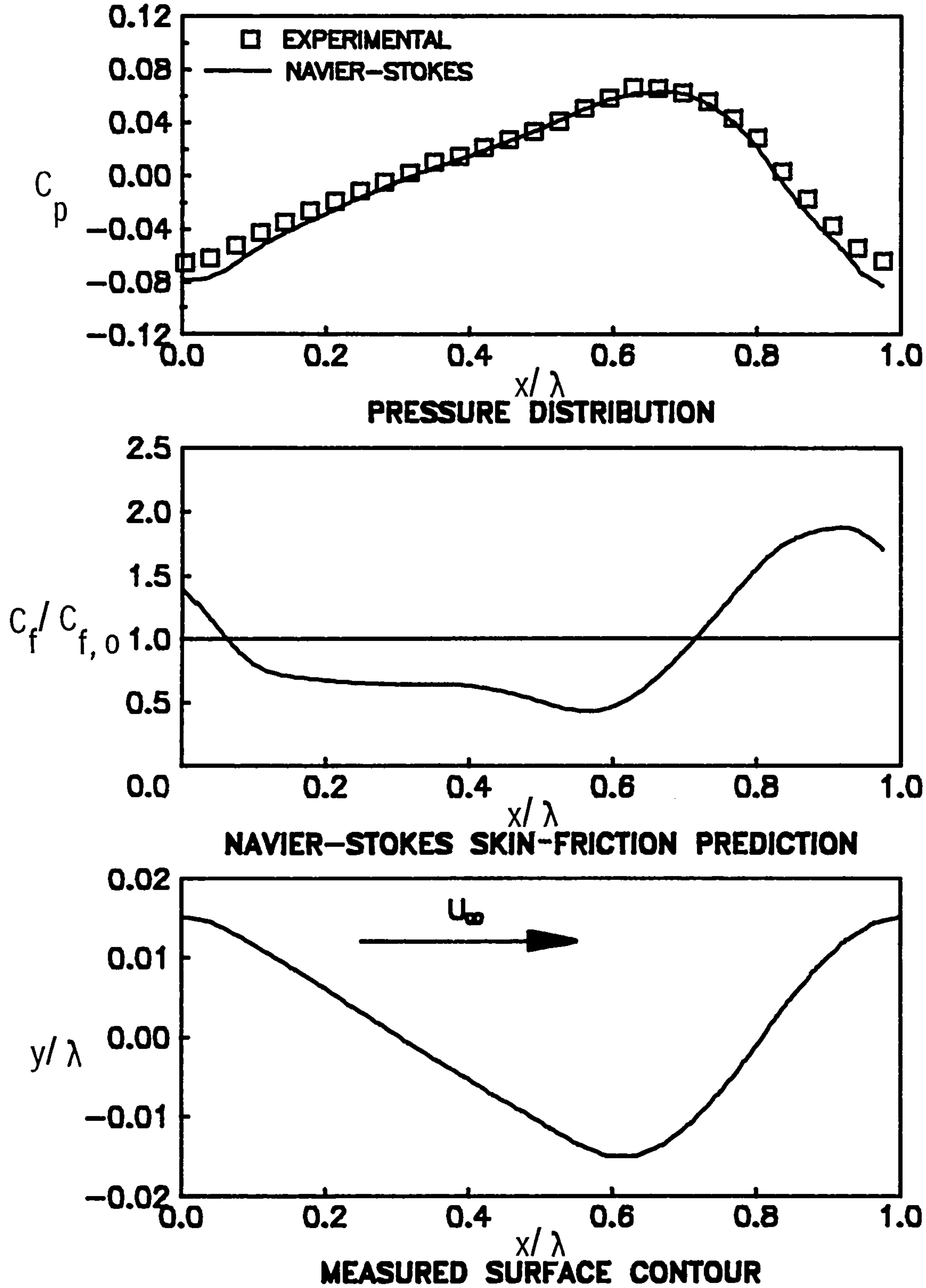
(a) Forward direction.

Figure 40.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 13 (sine waves and straight ramps, h/λ = 0.015, λ = 4.01 cm).



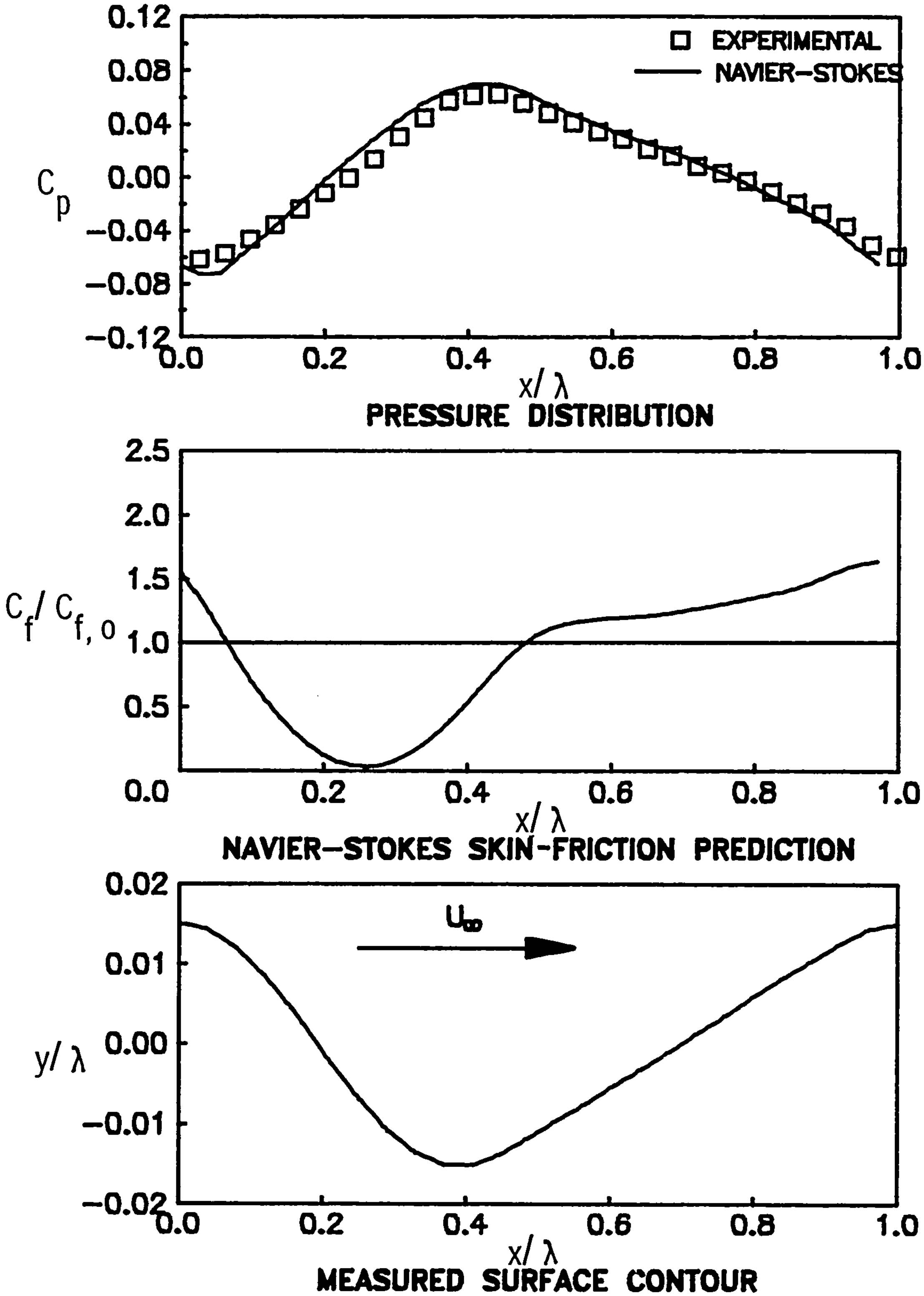
(b) Reverse direction.

Figure 40.- Concluded.



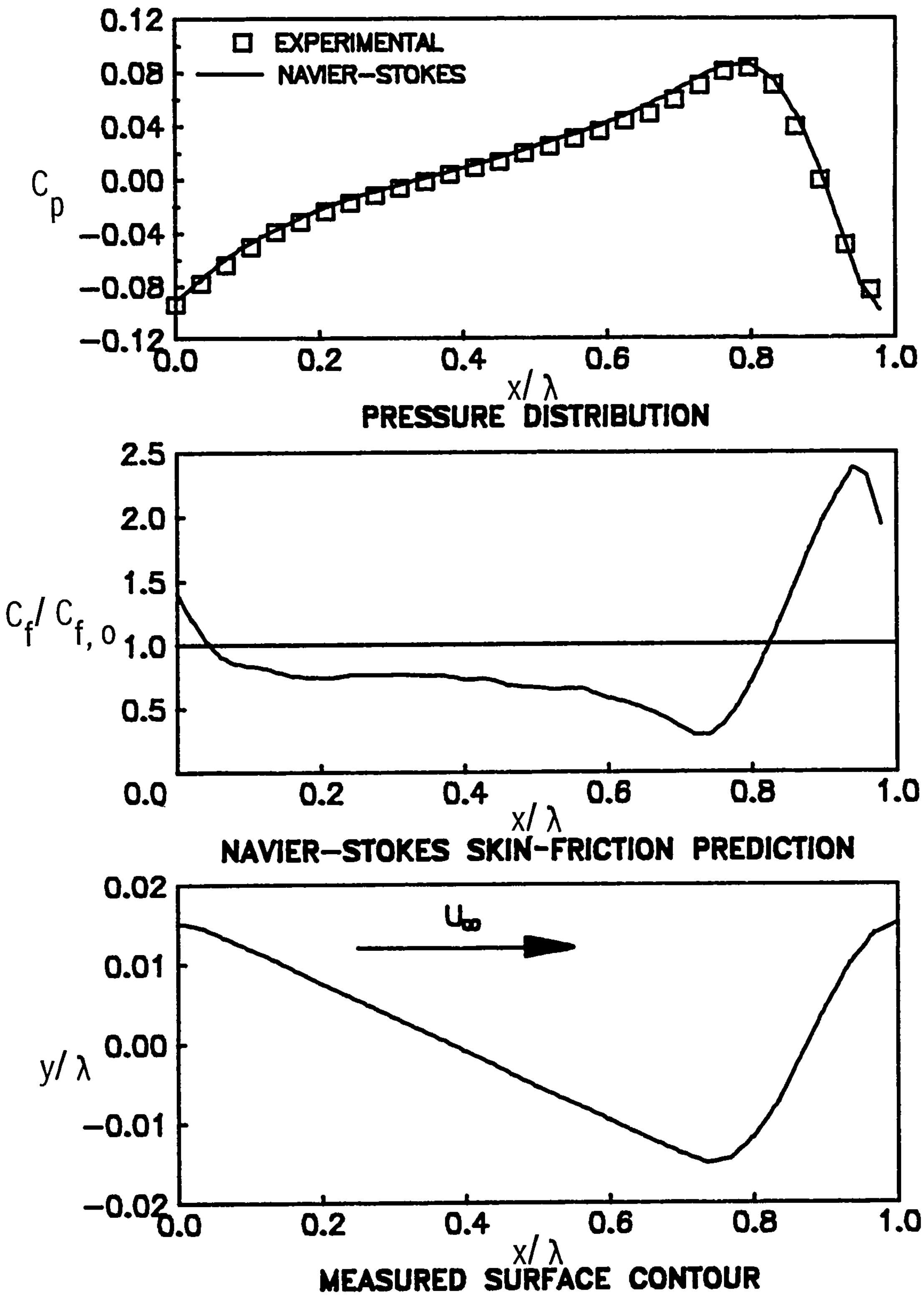
(a) Forward direction.

Figure 41.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 14 (sine waves and straight ramps, h/λ = 0.015, λ = 3.23 cm).



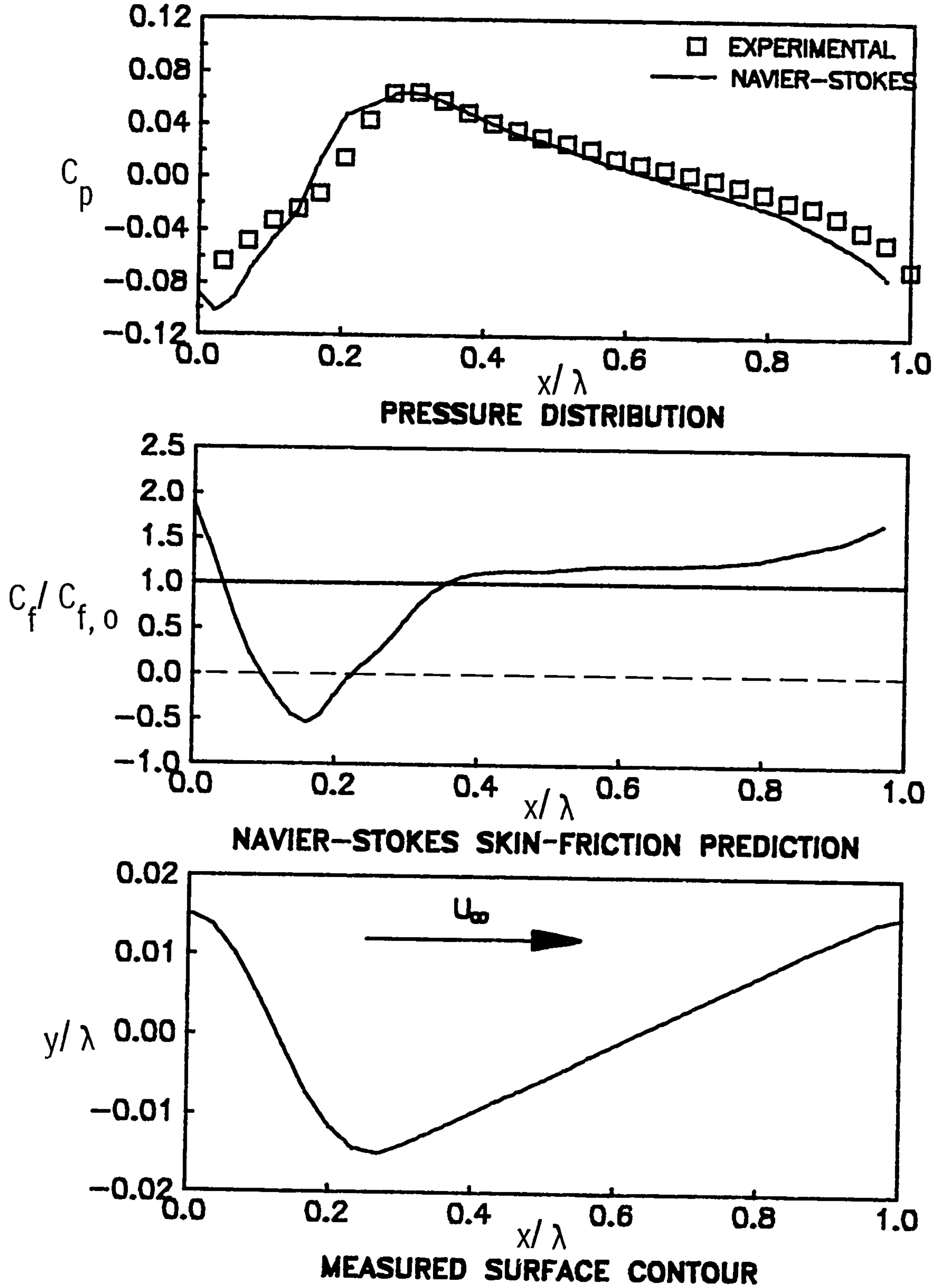
(b) Reverse direction.

Figure 41.- Concluded.



(a) Forward direction.

Figure 42.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 15 (sine waves and straight ramps, h/λ = 0.015, λ = 3.86 cm).



(b) Reverse direction.

Figure 42.- Concluded.

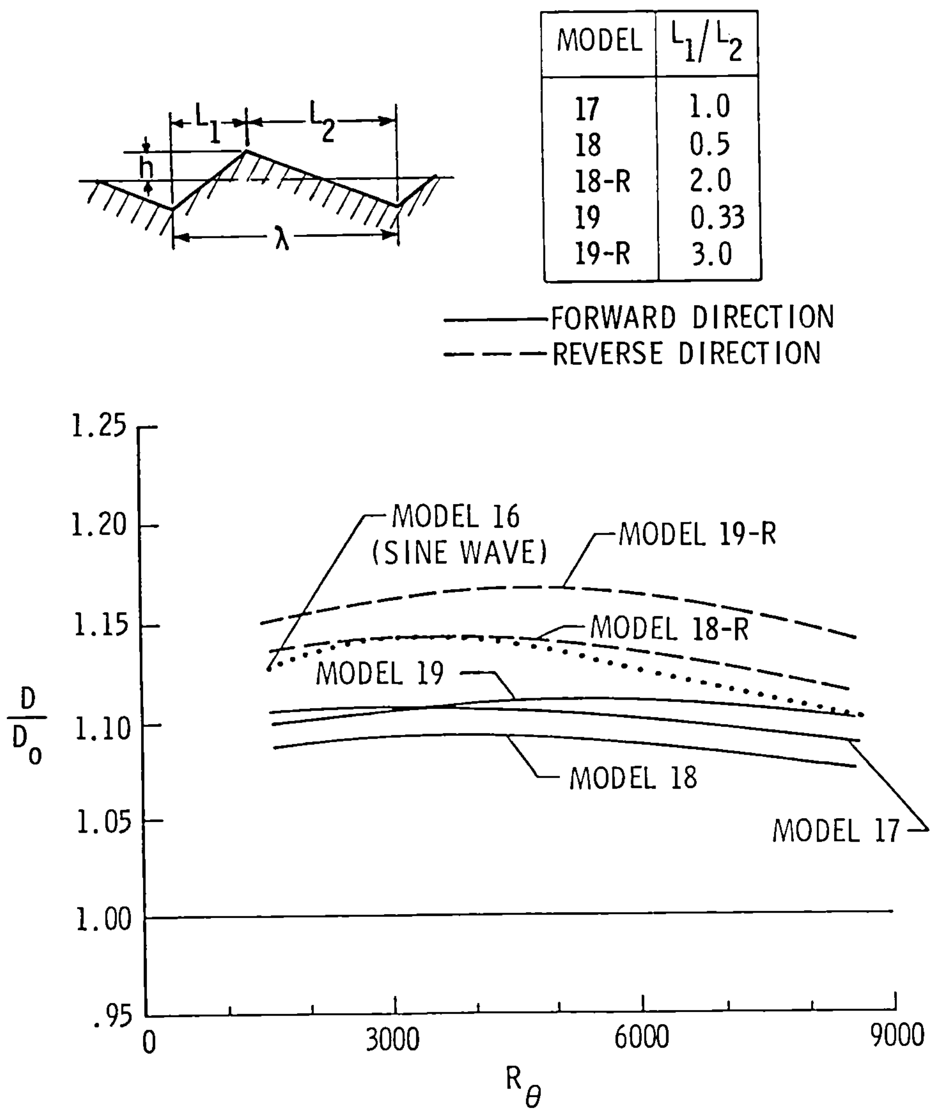


Figure 43.- Measured total drag of transverse V-groove geometries ($h/\lambda = 0.015$, $\lambda = 2.54$ cm).

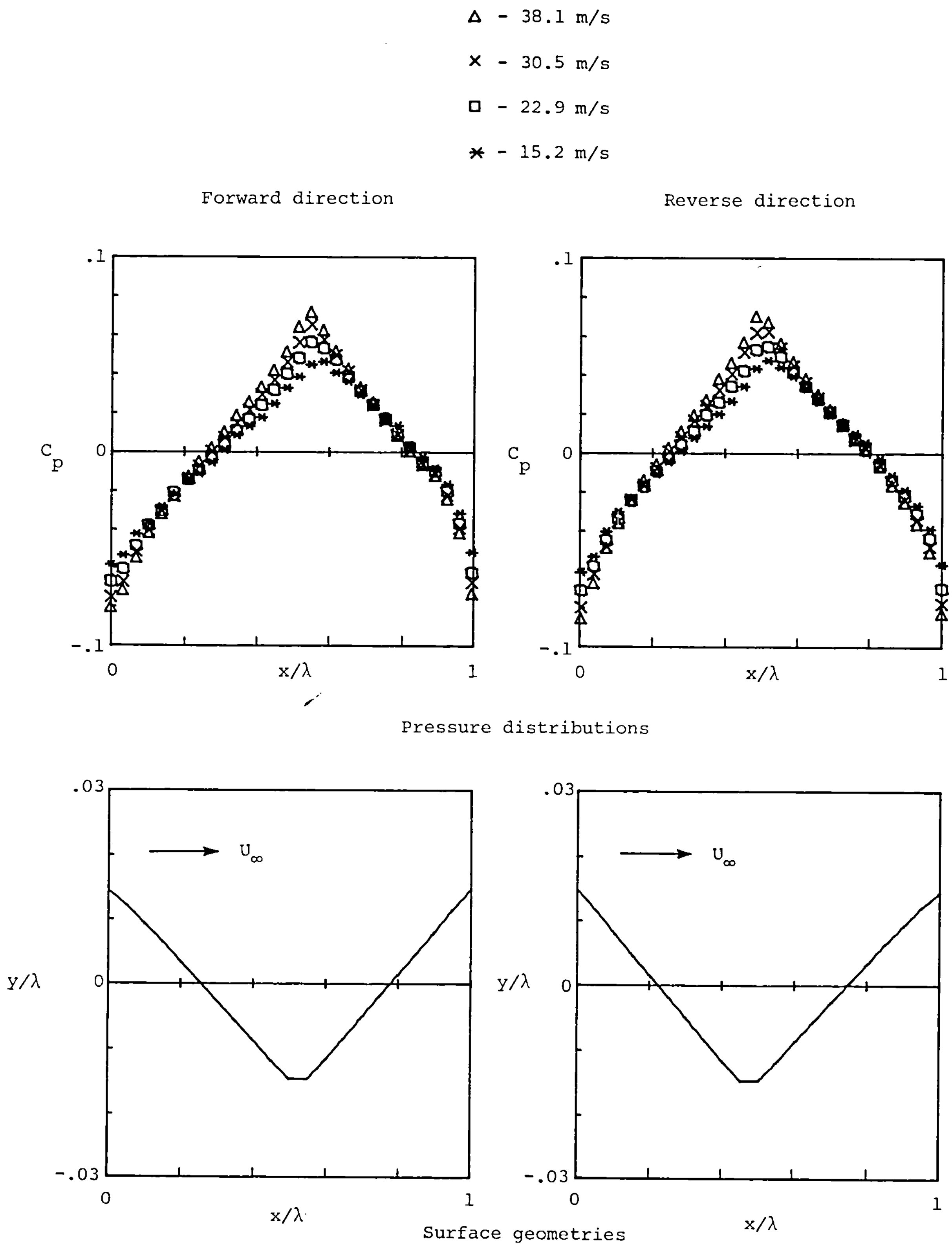


Figure 44.- Measured C_p values for model 17 (transverse V-grooves, $h/\lambda = 0.015$, $\lambda = 2.54$ cm).

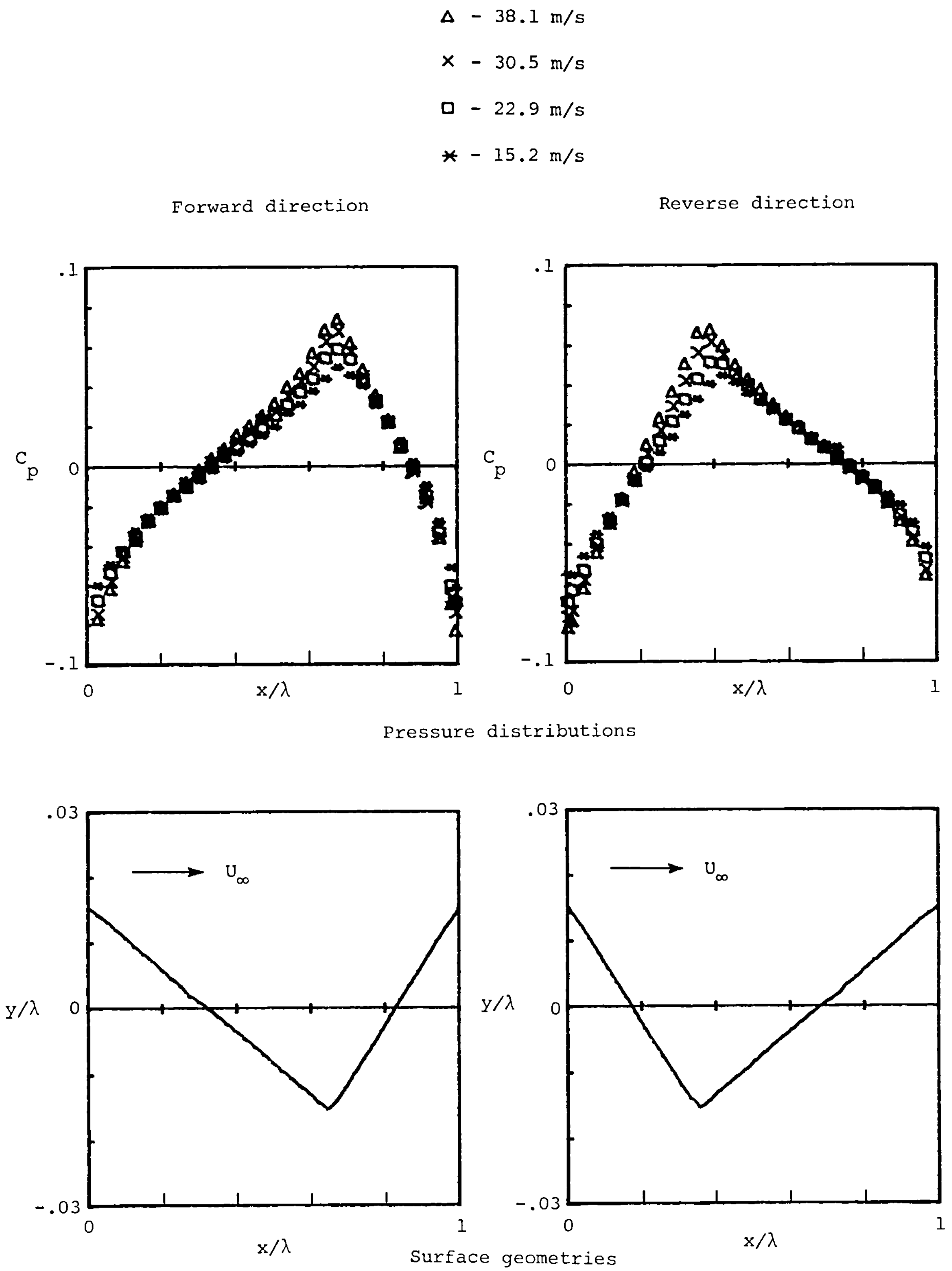


Figure 45.- Measured C_p values for model 18 (transverse V-grooves, $h/\lambda = 0.015$, $\lambda = 2.54$ cm).

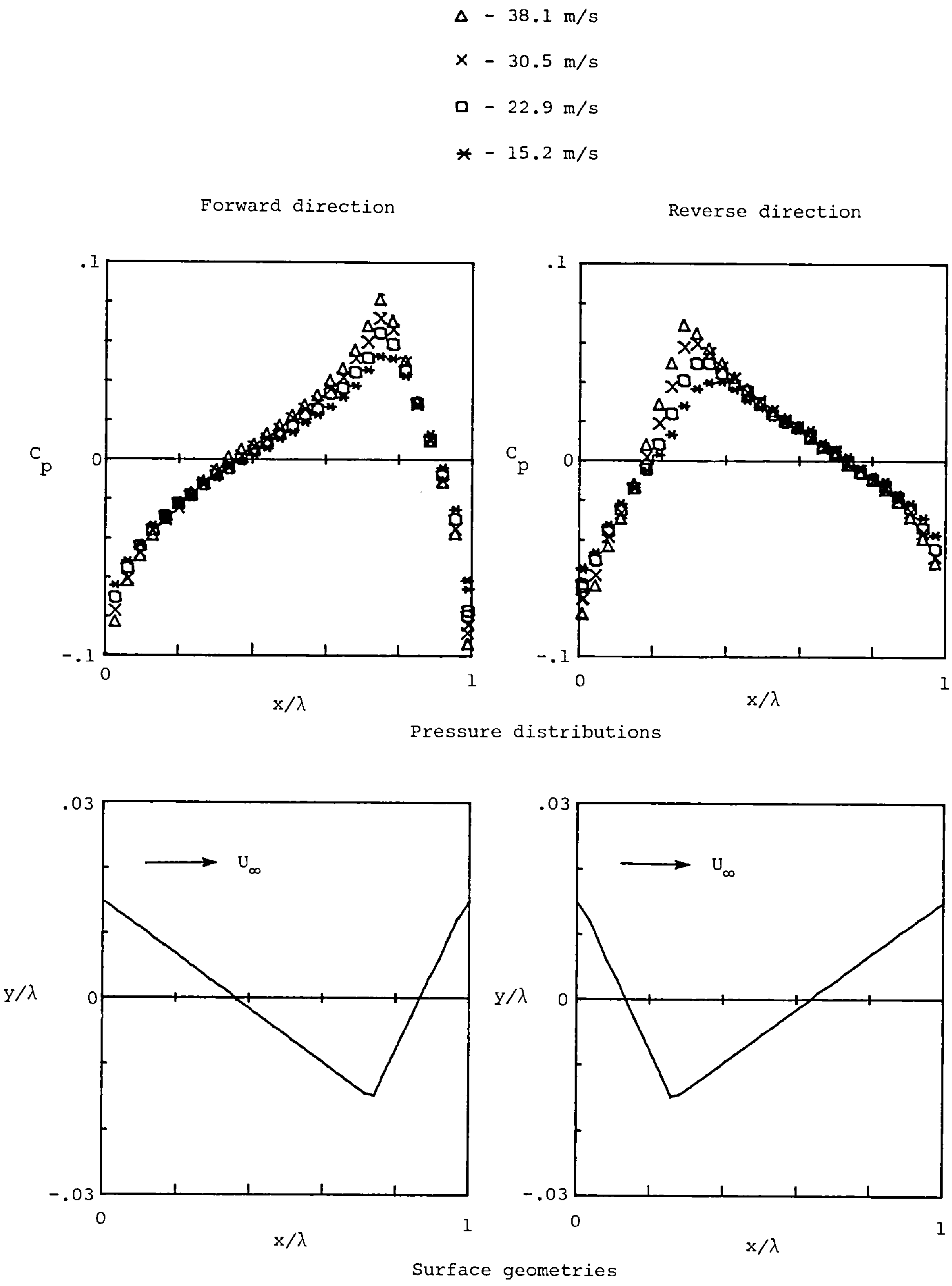


Figure 46.- Measured C_p values for model 19 (transverse V-grooves, $h/\lambda = 0.015$, $\lambda = 2.54$ cm).

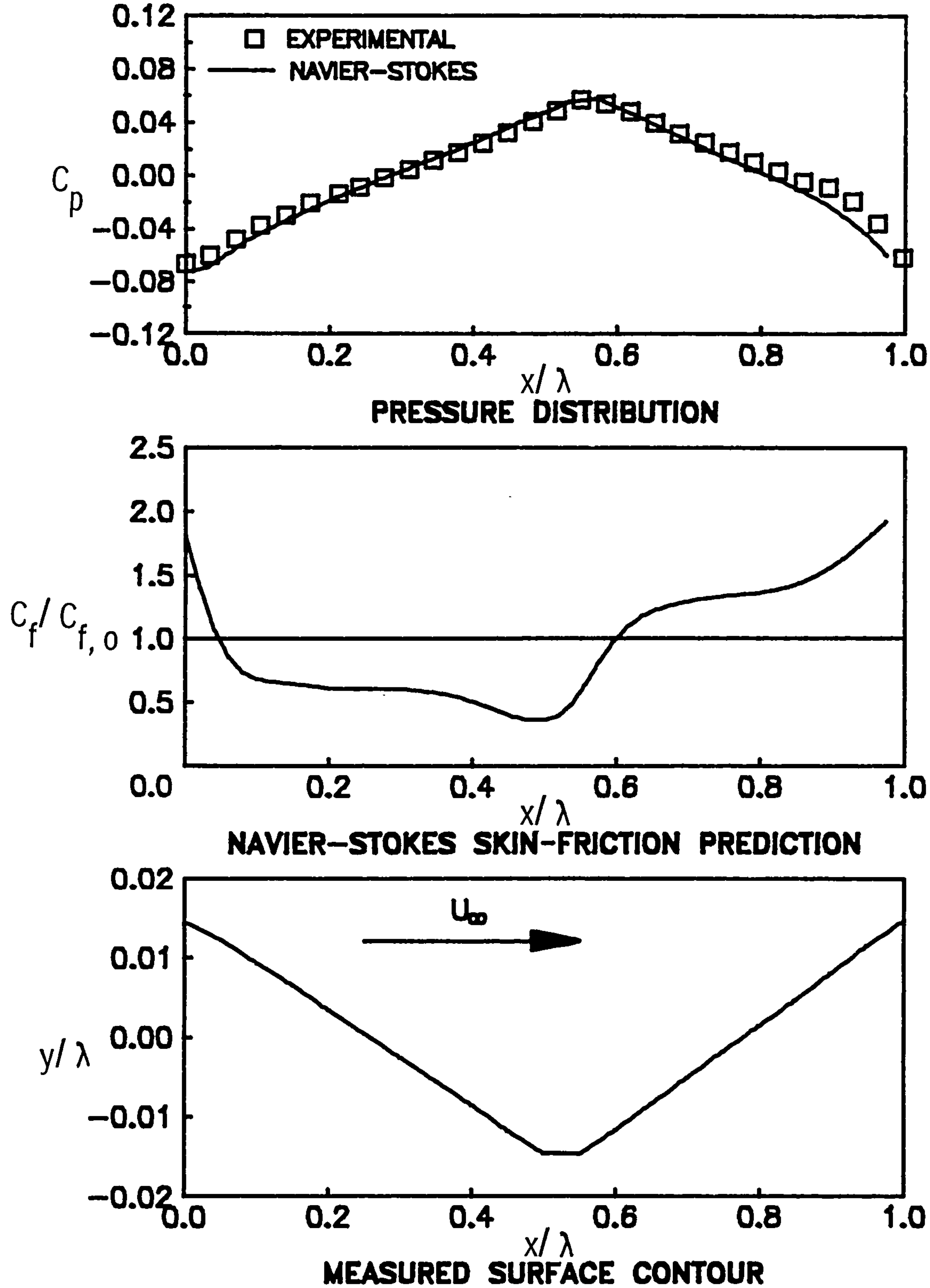
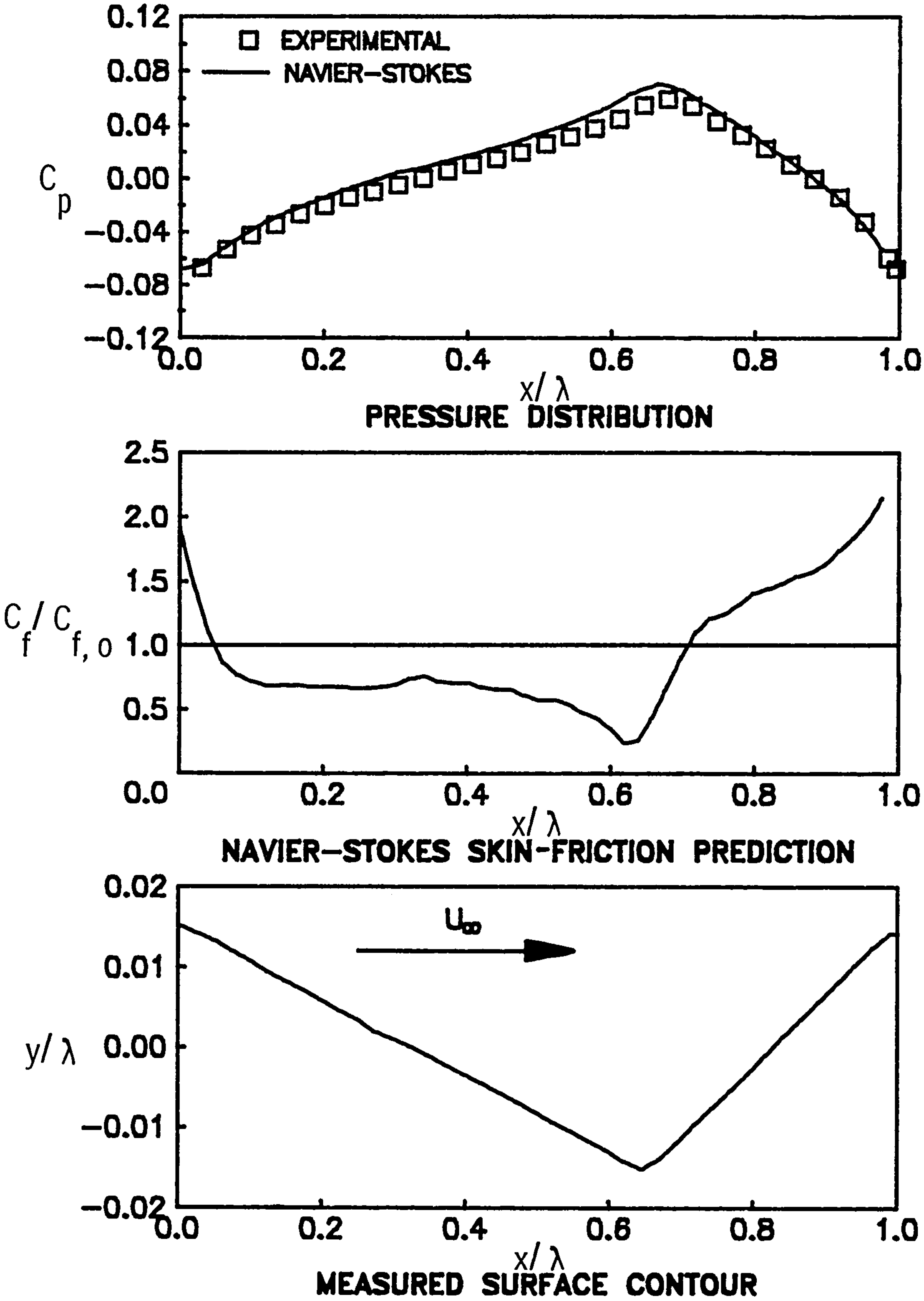
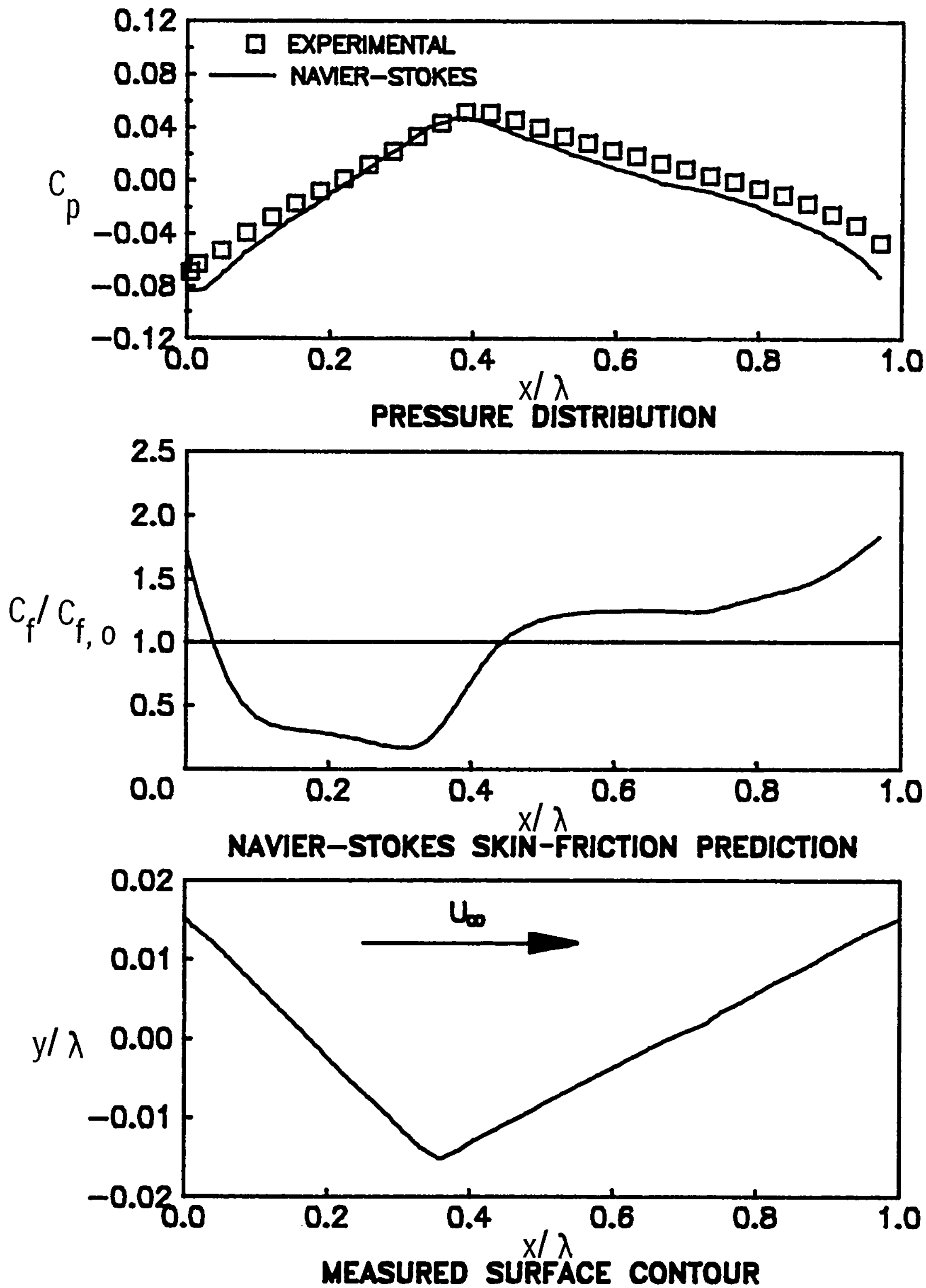


Figure 47.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 17 (transverse V-grooves, h/λ = 0.015, λ = 2.54 cm).



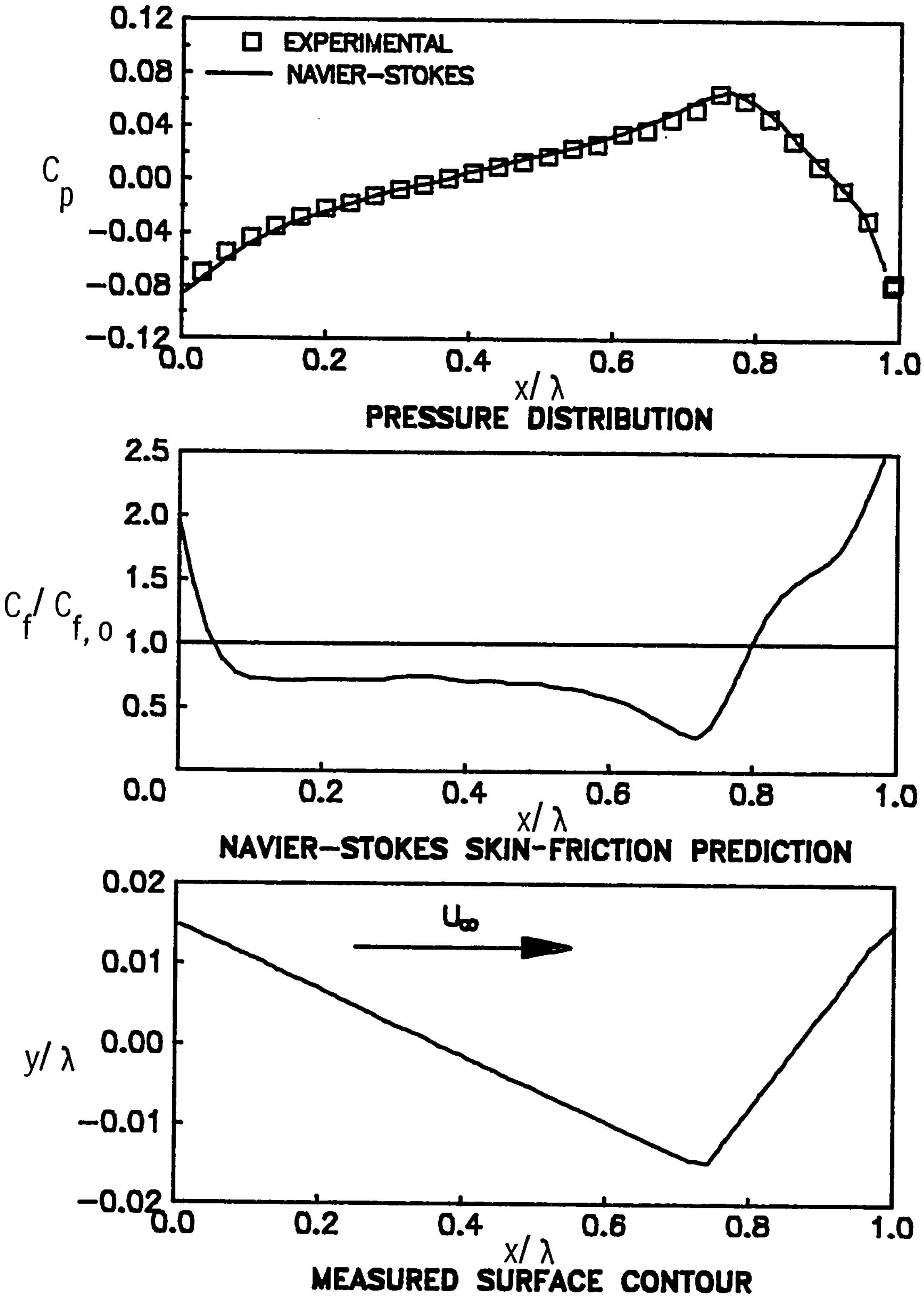
(a) Forward direction.

Figure 48.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 18 (transverse V-grooves, h/λ = 0.015, λ = 2.54 cm).



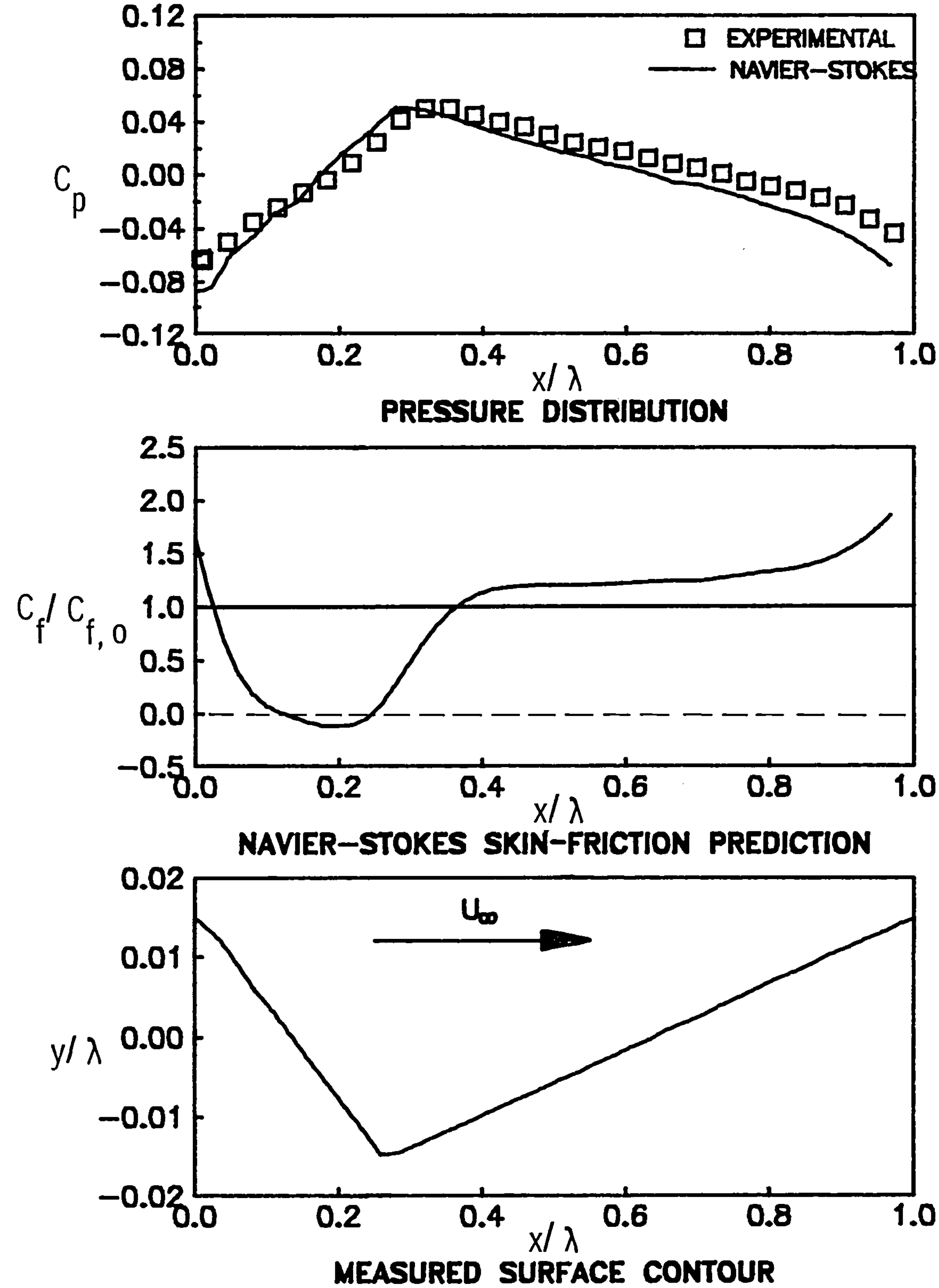
(b) Reverse direction.

Figure 48.- Concluded.



(a) Forward direction.

Figure 49.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 19 (transverse V-grooves, h/λ = 0.015, λ = 2.54 cm).



(b) Reverse direction.

Figure 49.- Concluded.

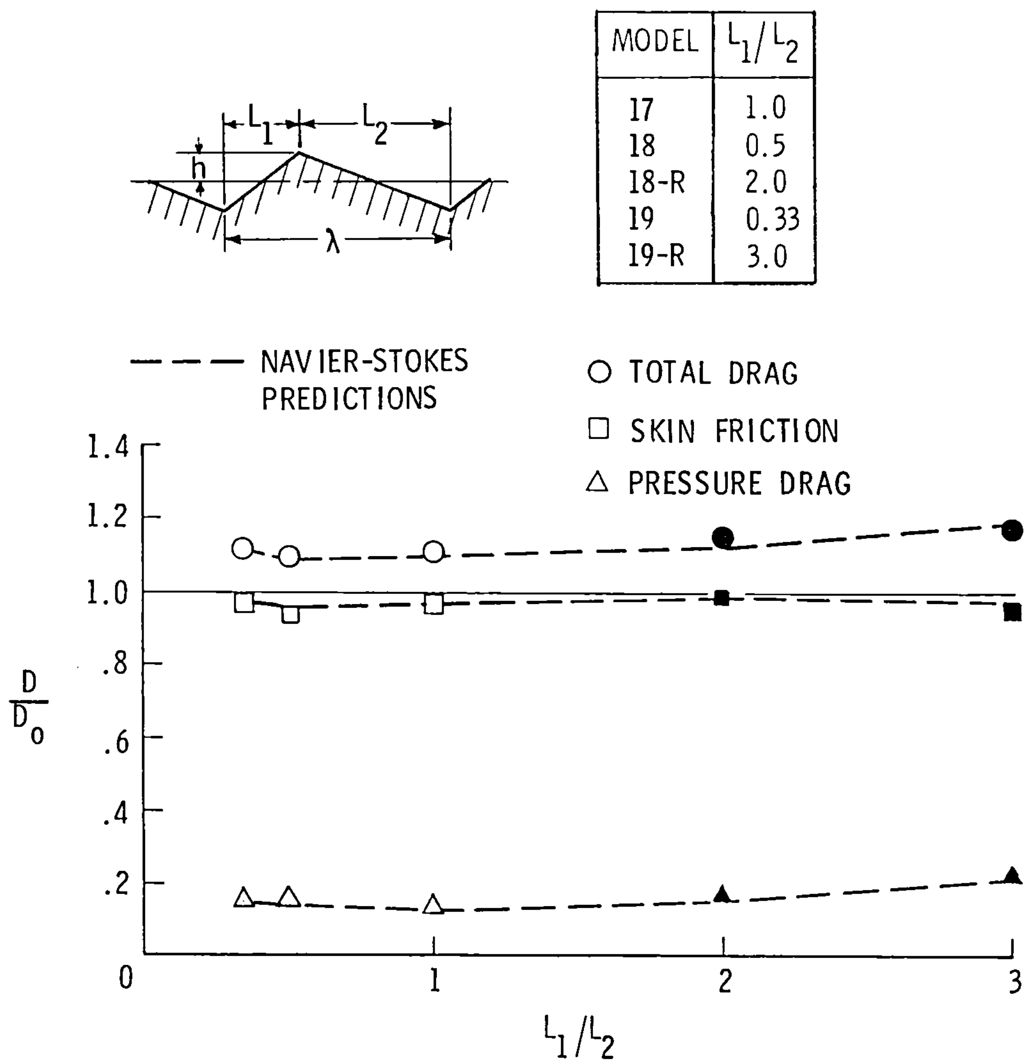


Figure 50.- Drag contributions of transverse V-groove geometries with $h/\lambda = 0.015$ at $R_\theta = 4700$. Open symbols, forward direction; filled symbols, reverse direction.

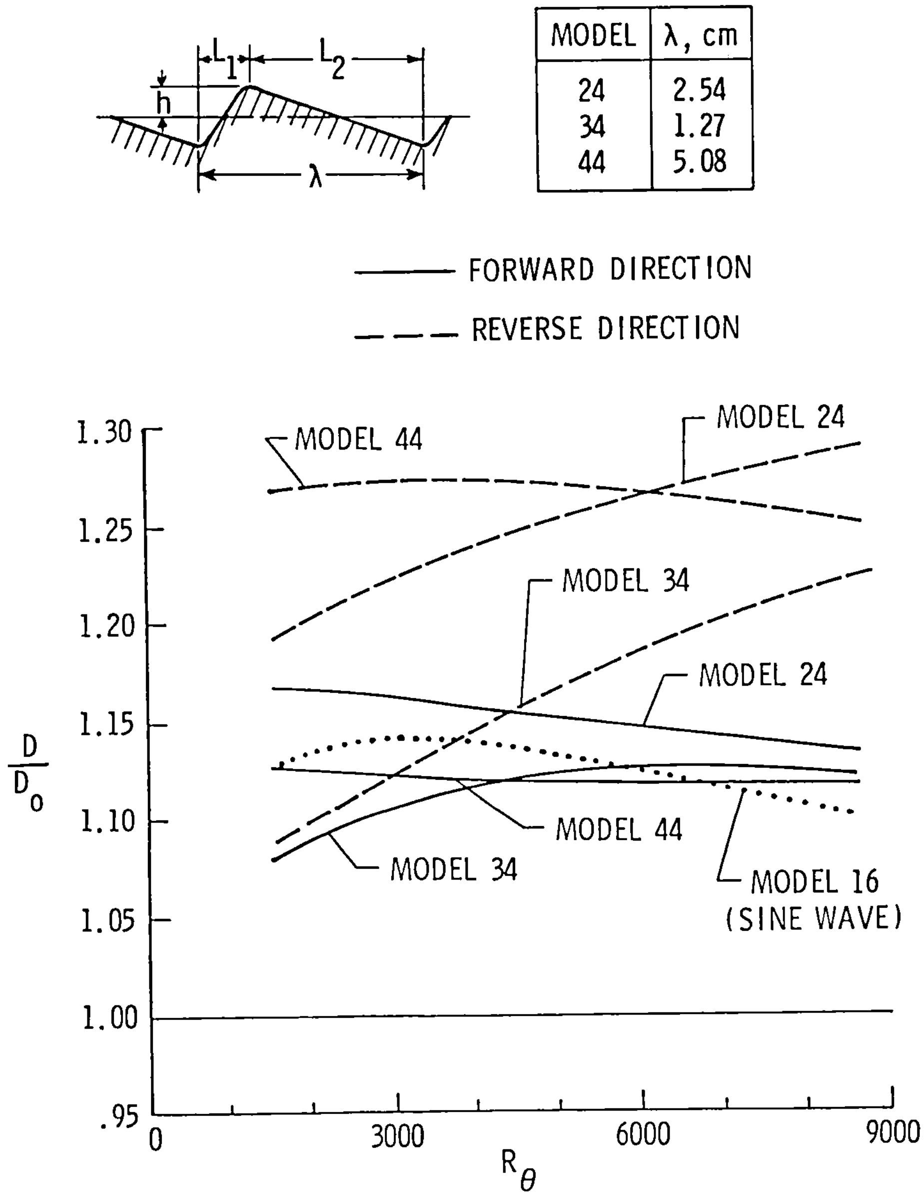


Figure 51.- Measured total drag of circular arc and straight ramp geometries $(h/\lambda = 0.015)$.

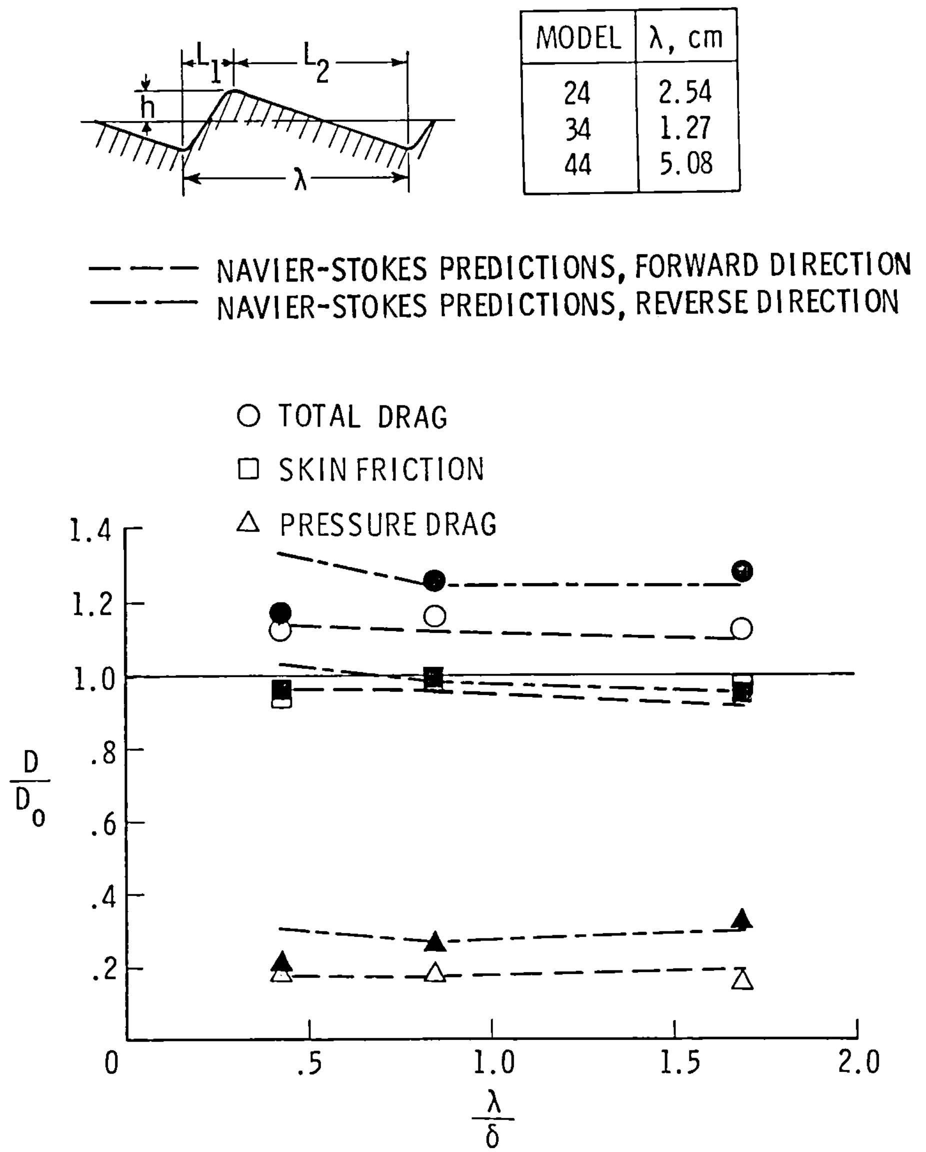


Figure 52.- Drag contributions of circular arcs and straight ramps with $h/\lambda = 0.015$ at $R_\theta = 4700$, $\delta = 3.0$ cm. Open symbols, forward direction; filled symbols, reverse direction.

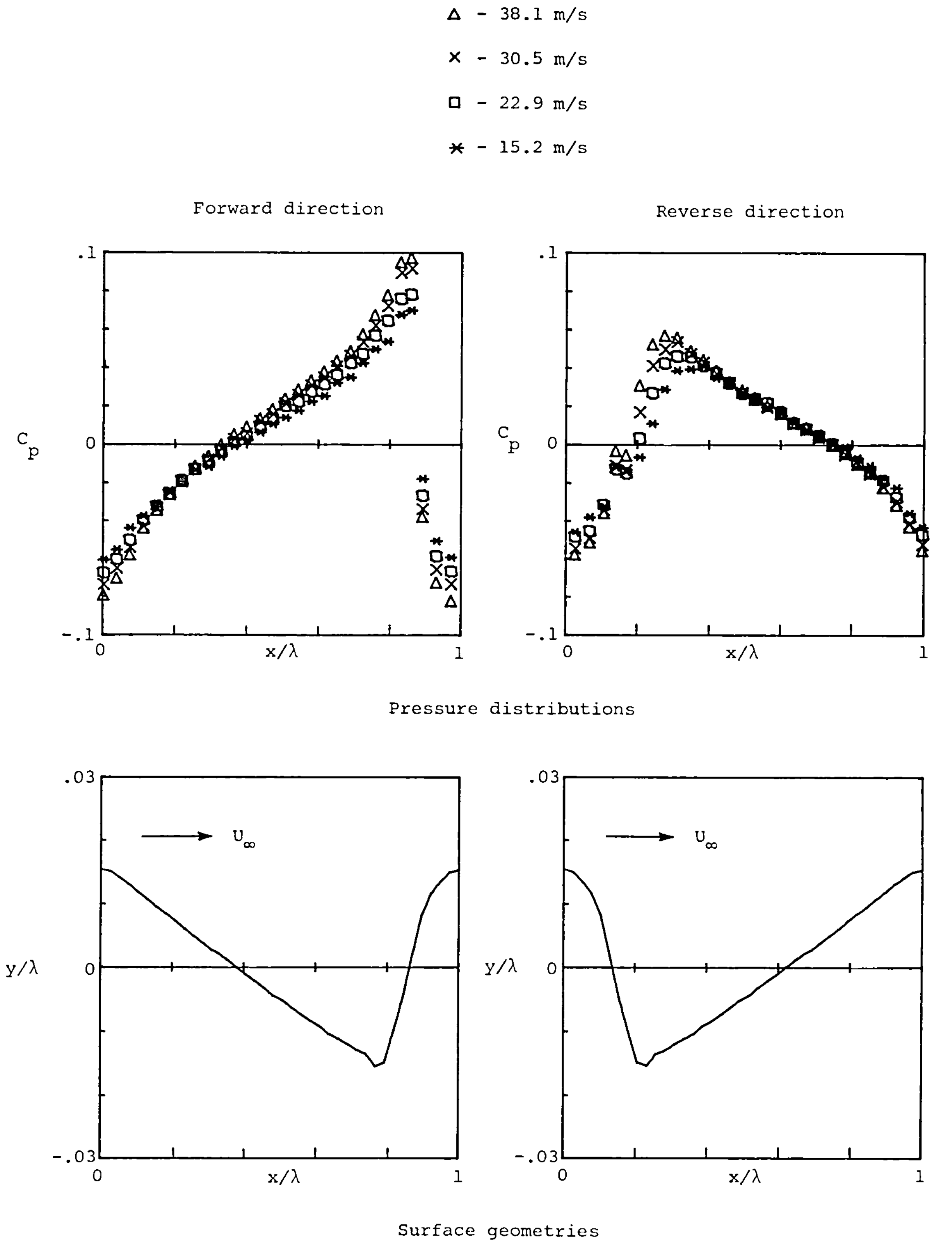


Figure 53.- Measured C_p values for model 24 (circular arcs and straight ramps, $h/\lambda = 0.015$, $\lambda = 2.54$ cm).

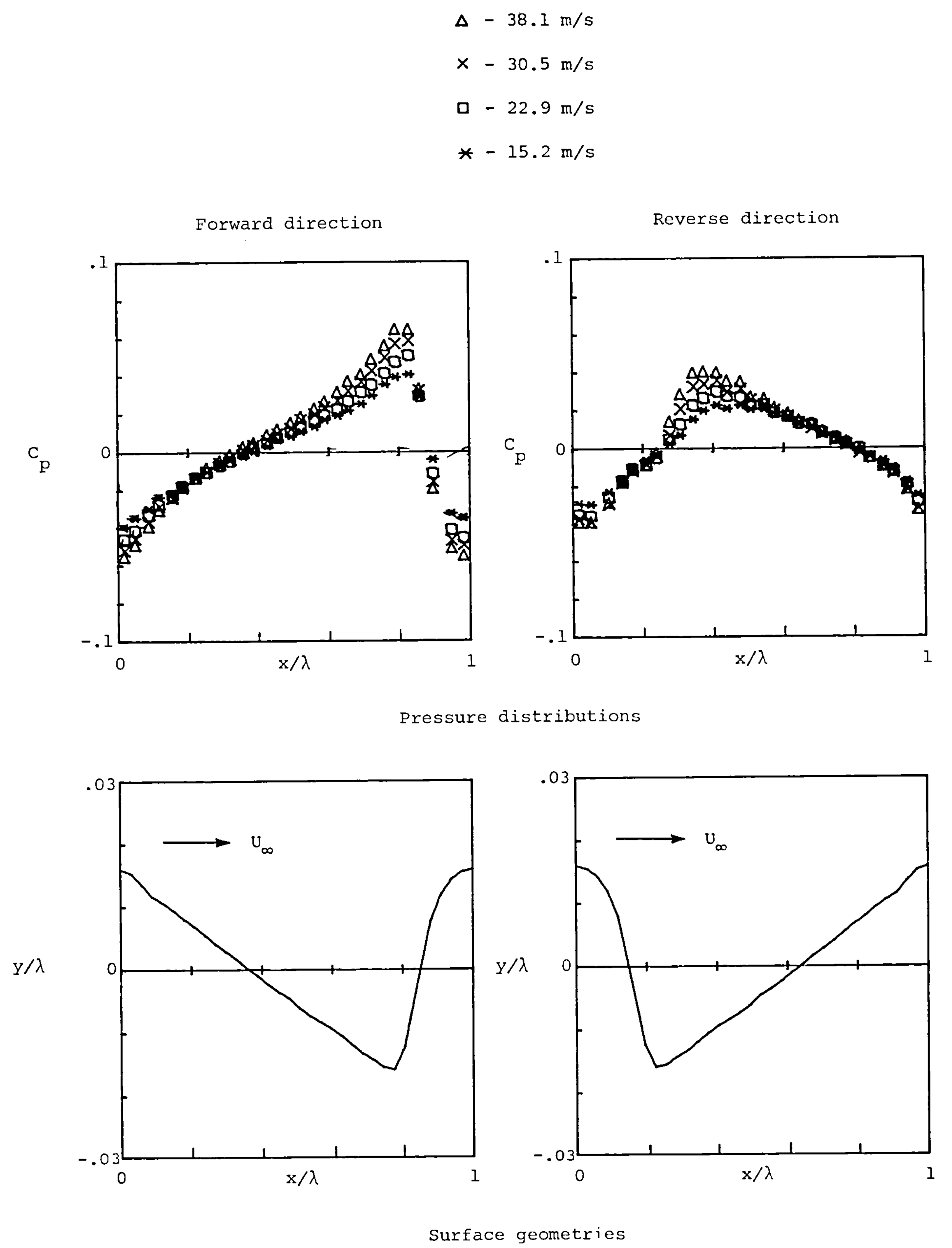


Figure 54.- Measured C_p values for model 34 (circular arcs and straight ramps, $h/\lambda = 0.015$, $\lambda = 1.27$ cm).

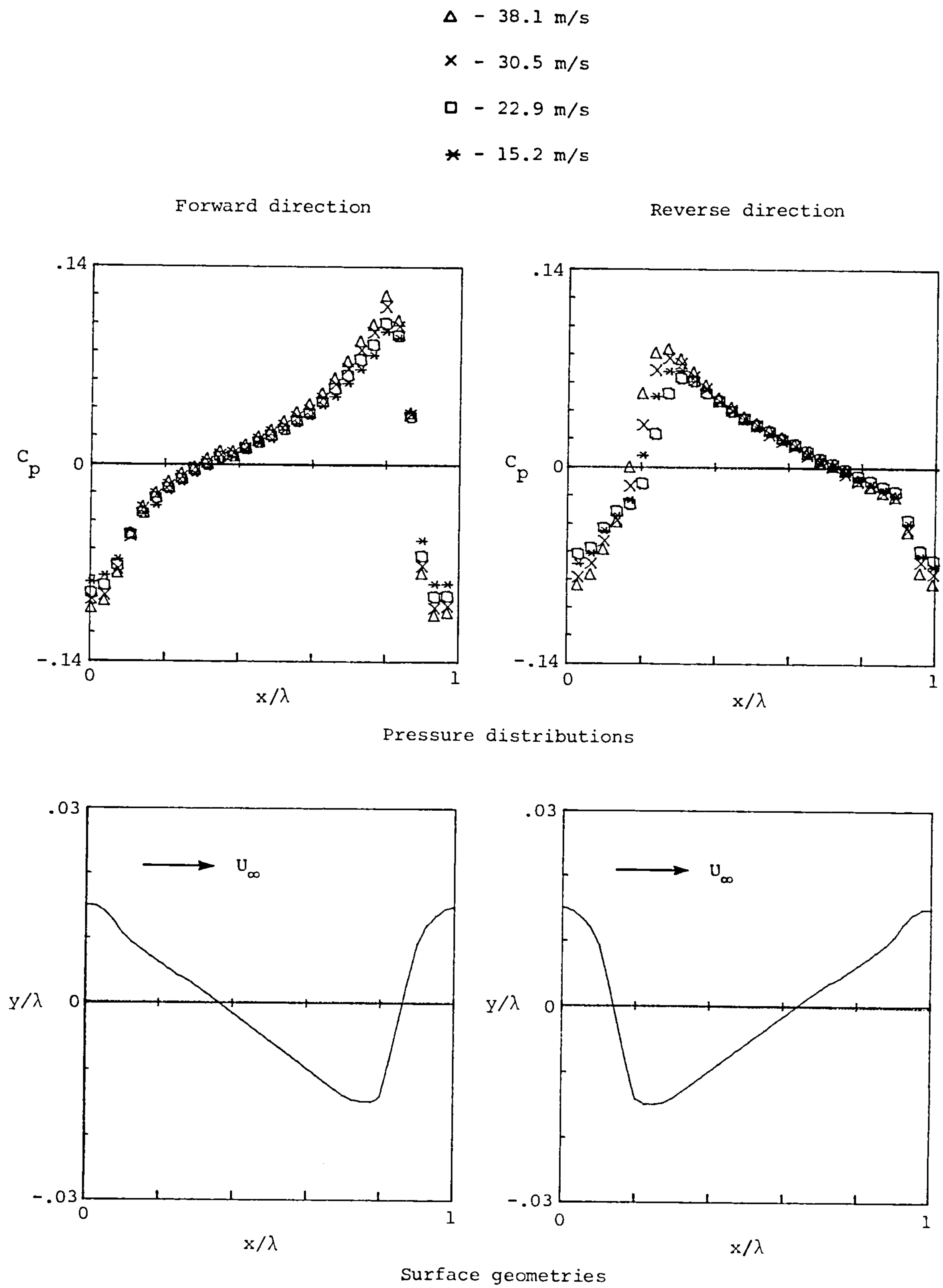
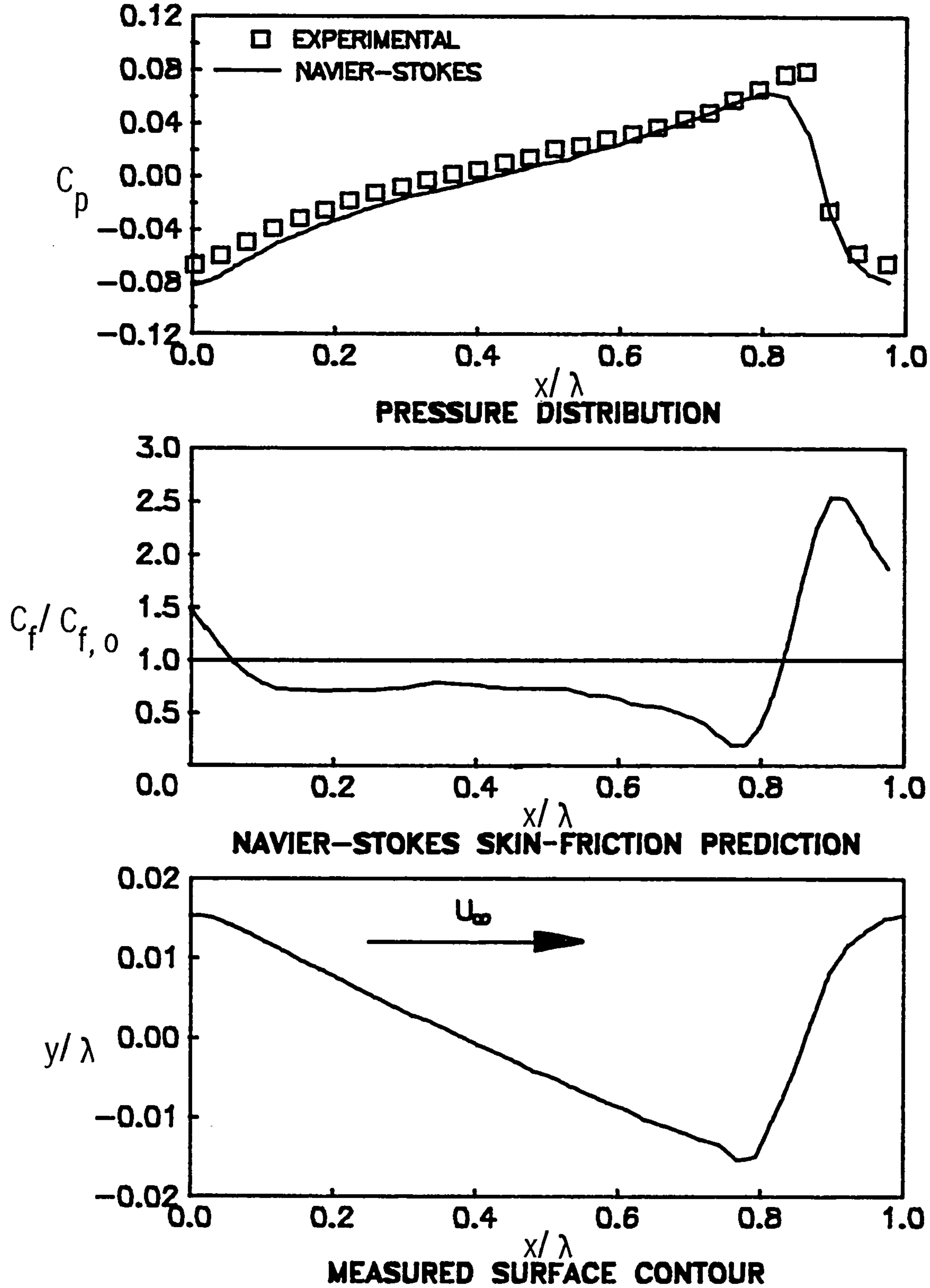
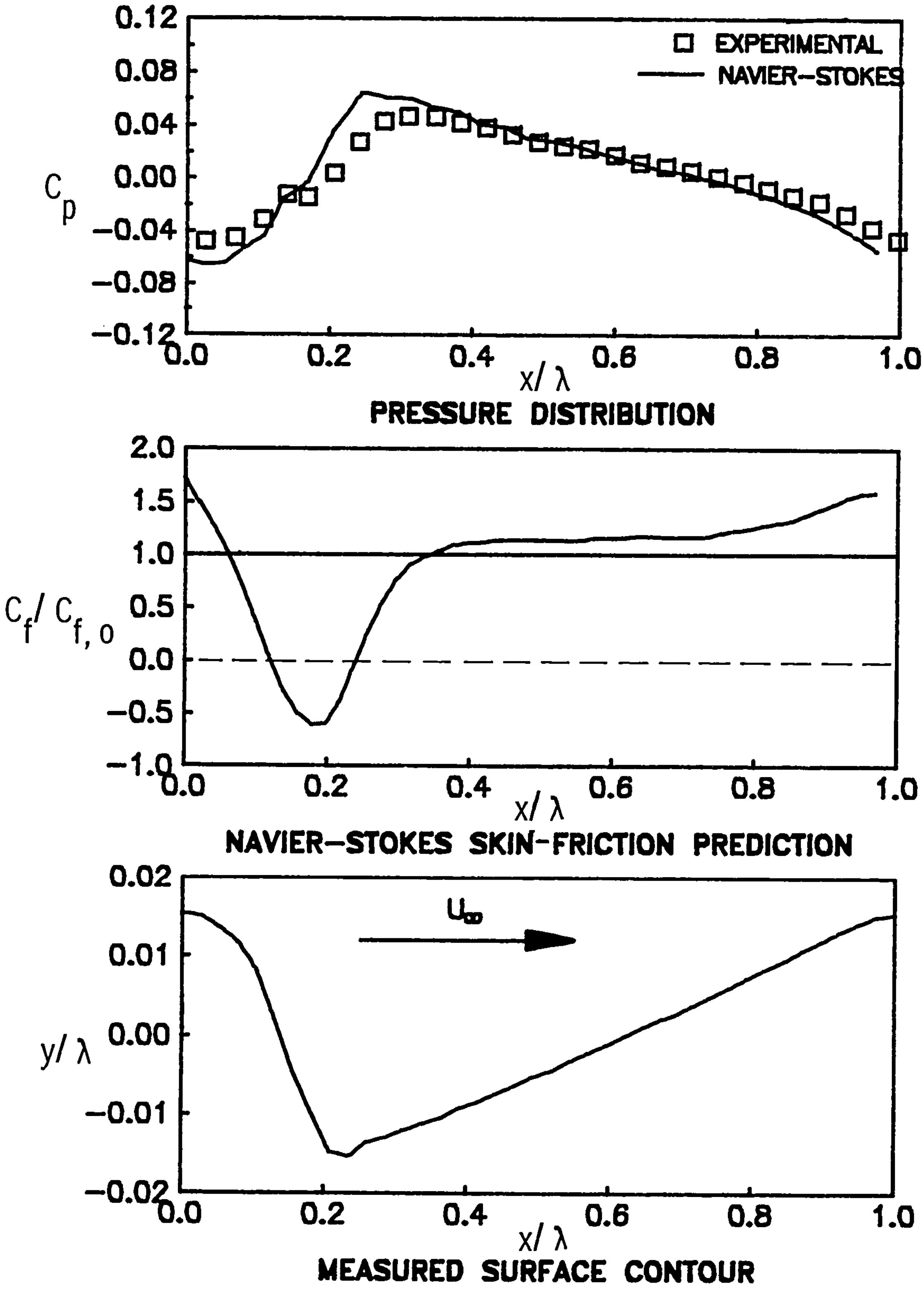


Figure 55.- Measured C_p values for model 44 (circular arcs and straight ramps, $h/\lambda = 0.015$, $\lambda = 5.08$ cm).



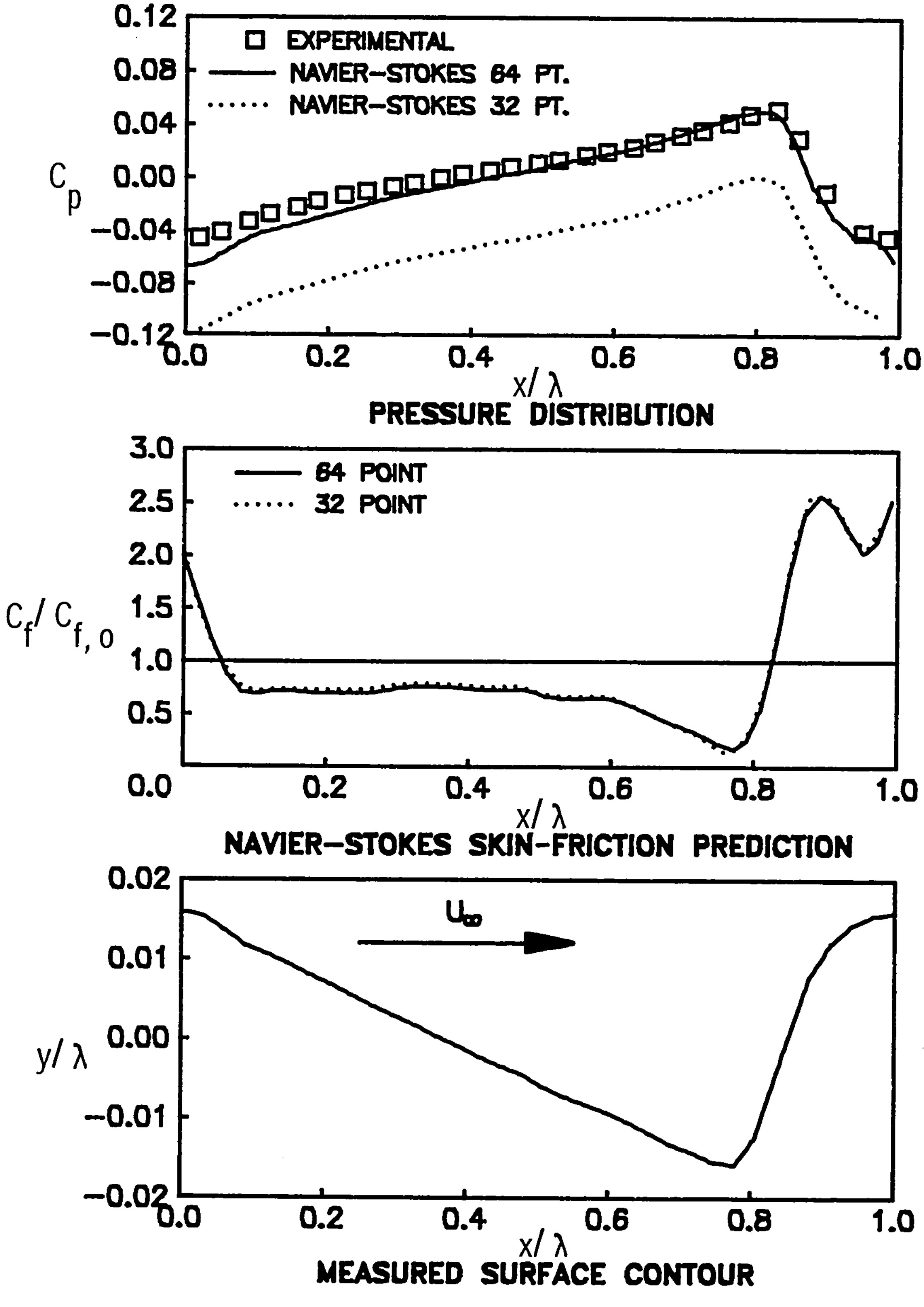
(a) Forward direction.

Figure 56.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 24 (circular arcs and straight ramps, h/λ = 0.015, λ = 2.54 cm).



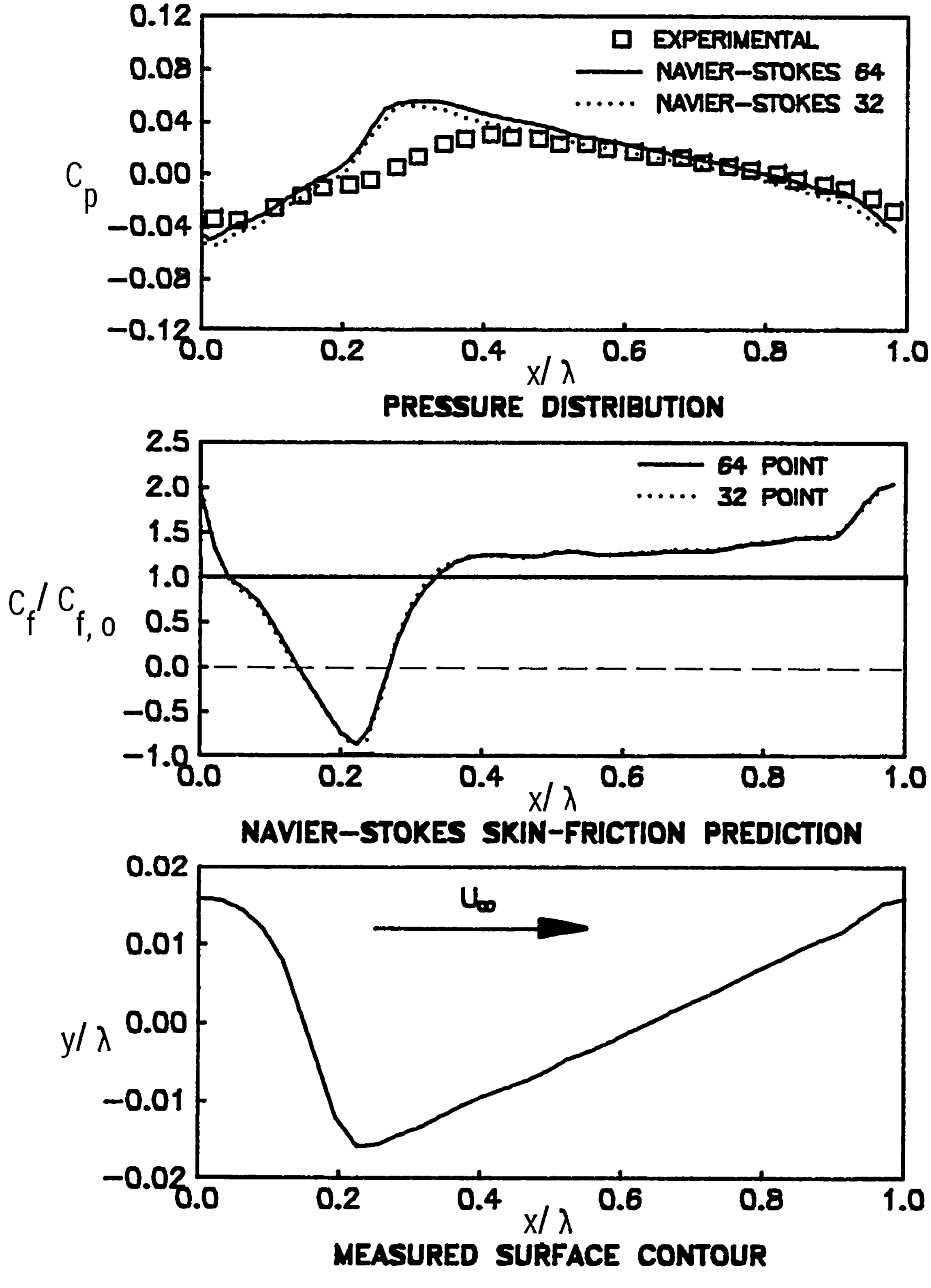
(b) Reverse direction.

Figure 56.- Concluded.



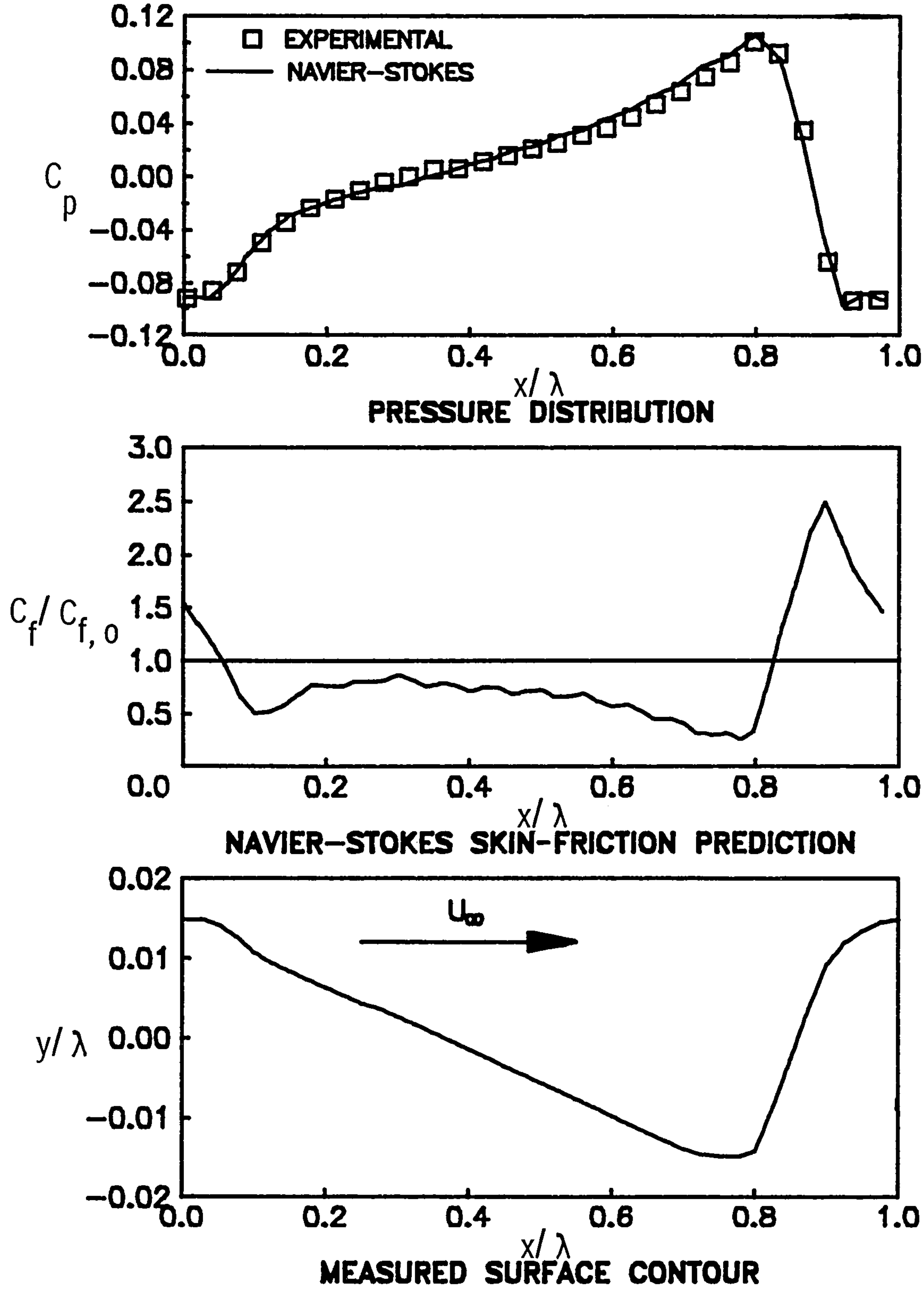
(a) Forward direction.

Figure 57.- Comparison between 32- and 64-grid-point simulations for model 34 (circular arcs and straight ramps, $h/\lambda = 0.015$, $\lambda = 1.27$ cm).



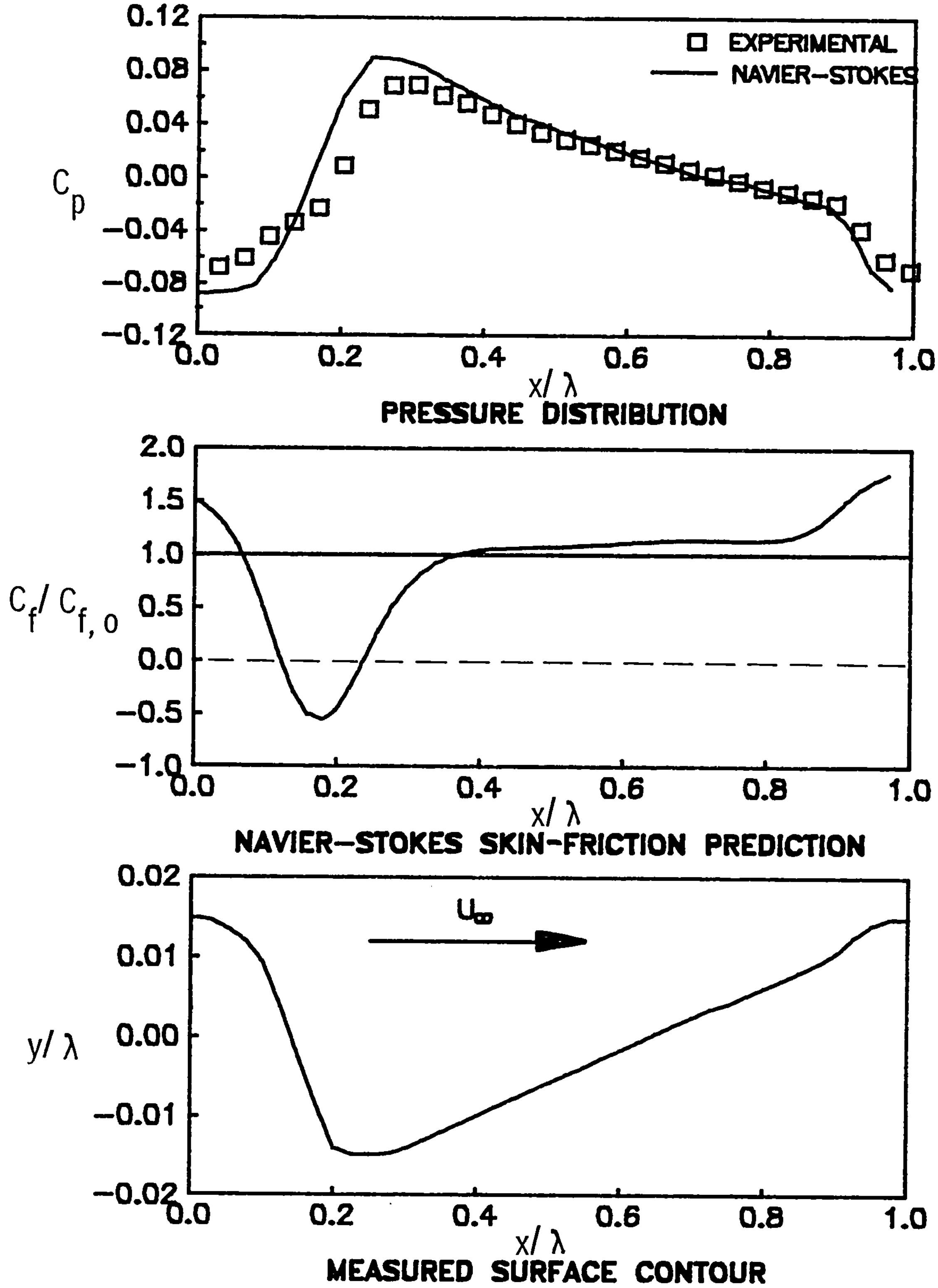
(b) Reverse direction.

Figure 57.- Concluded.



(a) Forward direction.

Figure 58.- C_p and $C_f/C_{f,o}$ predictions at U_∞ = 22.9 m/s for model 44 (circular arcs and straight ramps, h/λ = 0.015, λ = 5.08 cm).



(b) Reverse direction.

Figure 58.- Concluded.

APPENDIX

PRESENTATION OF DATA TABLES

Because of the large number of wavy wall models involved, all data used to support the figures in this paper are listed in the appendix. Tables A1 to A21 present the nondimensionalized measurements of the surface coordinates $(x/\lambda,\ y/\lambda)$ for each wavy wall model over one wavelength. The nondimensionalized total drag measurements D/D_o for all models are listed in tables A22 to A42. Repeat runs are presented when available. Tables A43 to A63 show the C_p measurements at four velocities for each model. Finally, the C_p and $C_f/C_{f,o}$ distributions predicted by the Navier-Stokes code for all wave geometries are listed in tables A64 to A84.

APPENDIX

TABLE A1.- SURFACE COORDINATES OF MODEL 1
(SINE WAVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0044	0.0000	.0044
.0250	.0037	.0250	.0042
.0500	.0042	.0500	.0042
.0750	.0038	.0750	.0040
.1000	.0036	.1000	.0039
.1250	.0030	.1250	.0037
.1500	.0024	.1500	.0032
.1750	.0023	.1750	.0027
.2000	.0016	.2000	.0021
.2250	.0007	.2250	.0013
.2500	-.0004	.2500	.0007
.2750	-.0012	.2750	-.0002
.3000	-.0020	.3001	-.0011
.3250	-.0030	.3250	-.0018
.3500	-.0033	.3500	-.0023
.3750	-.0040	.3752	-.0031
.4000	-.0042	.4000	-.0035
.4250	-.0043	.4250	-.0038
.4499	-.0043	.4500	-.0042
.4750	-.0044	.4750	-.0044
.5000	-.0044	.5000	-.0044
.5250	-.0044	.5250	-.0044
.5500	-.0042	.5501	-.0043
.5750	-.0038	.5750	-.0043
.6000	-.0035	.6000	-.0042
.6248	-.0031	.6250	-.0040
.6500	-.0023	.6500	-.0033
.6750	-.0018	.6750	-.0030
.6999	-.0011	.7000	-.0020
.7250	-.0002	.7250	-.0012
.7500	.0007	.7500	-.0004
.7750	.0013	.7750	.0007
.8000	.0021	.8000	.0016
.8250	.0027	.8250	.0023
.8500	.0032	.8500	.0024
.8750	.0037	.8750	.0030
.9000	.0039	.9000	.0036
.9250	.0040	.9250	.0038
.9500	.0042	.9500	.0042
.9750	.0042	.9750	.0037
1.0000	.0044	1.0000	.0044

TABLE A2.- SURFACE COORDINATES OF MODEL 2
(SINE WAVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0100	0.0000	.0100
.0500	.0097	.0500	.0097
.1000	.0084	.1000	.0085
.1500	.0059	.1500	.0064
.2000	.0027	.2000	.0034
.2500	-.0009	.2500	-.0002
.3000	-.0043	.3000	-.0034
.3500	-.0069	.3500	-.0062
.4000	-.0088	.4000	-.0082
.4500	-.0098	.4500	-.0095
.5000	-.0101	.5000	-.0101
.5500	-.0095	.5500	-.0098
.6000	-.0082	.6000	-.0088
.6500	-.0062	.6500	-.0069
.7000	-.0034	.7000	-.0043
.7500	-.0002	.7500	-.0009
.8000	.0034	.8000	.0027
.8500	.0064	.8500	.0059
.9000	.0085	.9000	.0084
.9500	.0097	.9500	.0097
1.0000	.0100	1.0000	.0100

TABLE A3.- SURFACE COORDINATES OF MODEL 16
(SINE WAVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0150	0.0000	.0151
.0498	.0145	.0499	.0145
.1000	.0124	.1002	.0124
.1502	.0092	.1501	.0088
.1999	.0049	.2000	.0045
.2500	.0005	.2502	.0001
.3000	-.0043	.2998	-.0041
.3499	-.0086	.3498	-.0086
.4002	-.0118	.4001	-.0120
.4502	-.0141	.4500	-.0143
.4998	-.0151	.5002	-.0151
.5500	-.0143	.5498	-.0141
.5999	-.0120	.5998	-.0118
.6502	-.0086	.6501	-.0086
.7002	-.0041	.7000	-.0043
.7498	.0001	.7500	.0005
.8000	.0045	.8001	.0049
.8499	.0088	.8498	.0092
.8998	.0124	.9000	.0124
.9501	.0145	.9502	.0145
1.0000	.0151	1.0000	.0150

TABLE A4.- SURFACE COORDINATES OF MODEL 3
(SINE WAVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0195	0.0000	.0195
.0250	.0194	.0250	.0191
.0500	.0192	.0500	.0185
.0750	.0186	.0750	.0175
.1000	.0175	.0999	.0159
.1250	.0150	.1249	.0138
.1500	.0138	.1500	.0114
.1750	.0114	.1750	.0100
.2000	.0084	.2000	.0066
.2250	.0050	.2250	.0030
.2501	.0019	.2500	-.0010
.2750	-.0013	.2750	-.0047
.3000	-.0043	.3000	-.0081
.3251	-.0072	.3249	-.0111
.3500	-.0097	.3500	-.0138
.3750	-.0119	.3750	-.0158
.4000	-.0139	.4000	-.0171
.4250	-.0154	.4249	-.0181
.4500	-.0166	.4500	-.0189
.4750	-.0177	.4750	-.0192
.5000	-.0185	.5000	-.0185
.5250	-.0192	.5250	-.0177
.5500	-.0189	.5500	-.0166
.5751	-.0181	.5750	-.0154
.6000	-.0171	.6000	-.0139
.6250	-.0158	.6250	-.0119
.6500	-.0138	.6500	-.0097
.6751	-.0111	.6749	-.0072
.7000	-.0081	.7000	-.0043
.7250	-.0047	.7250	-.0013
.7500	-.0010	.7499	.0019
.7750	.0030	.7750	.0050
.8000	.0066	.8000	.0084
.8250	.0100	.8250	.0114
.8500	.0114	.8500	.0138
.8751	.0138	.8750	.0150
.9001	.0159	.9000	.0175
.9250	.0175	.9250	.0186
.9500	.0185	.9500	.0192
.9750	.0191	.9750	.0194
1.0000	.0195	1.0000	.0195

TABLE A5.- SURFACE COORDINATES OF MODEL VI
(SINE WAVES, λ = 1.27 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0044	0.0000	.0044
.0333	.0044	.0331	.0044
.0664	.0040	.0667	.0042
.1000	.0036	.0998	.0038
.1331	.0029	.1333	.0031
.1664	.0016	.1669	.0022
.2002	-.0002	.2000	.0016
.2333	-.0013	.2336	.0007
.2664	-.0029	.2664	-.0002
.3002	-.0042	.3000	-.0013
.3333	-.0056	.3333	-.0024
.3667	-.0064	.3669	-.0033
.4000	-.0067	.4000	-.0042
.4333	-.0069	.4331	-.0053
.4667	-.0069	.4667	-.0060
.5002	-.0067	.4998	-.0067
.5333	-.0060	.5333	-.0069
.5669	-.0053	.5667	-.0069
.6000	-.0042	.6000	-.0067
.6331	-.0033	.6333	-.0064
.6667	-.0024	.6667	-.0056
.7000	-.0013	.6998	-.0042
.7336	-.0002	.7336	-.0029
.7664	.0007	.7667	-.0013
.8000	.0016	.7998	-.0002
.8331	.0022	.8336	.0016
.8667	.0031	.8669	.0029
.9002	.0038	.9000	.0036
.9333	.0042	.9336	.0040
.9669	.0044	.9667	.0044
1.0000	.0044	1.0000	.0044

TABLE A6.- SURFACE COORDINATES OF MODEL VII
(SINE WAVES, λ = 5.08 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0050	0.0000	.0050
.0245	.0048	.0245	.0049
.0490	.0045	.0490	.0049
.0735	.0042	.0735	.0049
.0981	.0037	.0980	.0047
.1225	.0031	.1226	.0044
.1471	.0024	.1471	.0040
.1716	.0018	.1716	.0037
.1961	.0010	.1961	.0030
.2206	.0004	.2206	.0024
.2451	-.0005	.2451	.0016
.2696	-.0012	.2696	.0008
.2941	-.0019	.2941	.0000
.3186	-.0026	.3186	-.0008
.3431	-.0033	.3431	-.0015
.3676	-.0038	.3677	-.0023
.3922	-.0042	.3922	-.0030
.4167	-.0045	.4167	-.0036
.4412	-.0049	.4412	-.0042
.4657	-.0050	.4657	-.0047
.4902	-.0048	.4902	-.0049
.5098	-.0049	.5098	-.0048
.5343	-.0047	.5343	-.0050
.5588	-.0042	.5588	-.0049
.5833	-.0036	.5833	-.0045
.6078	-.0030	.6078	-.0042
.6323	-.0023	.6324	-.0038
.6569	-.0015	.6569	-.0033
.6814	-.0008	.6814	-.0026
.7059	.0000	.7059	-.0019
.7304	.0008	.7304	-.0012
.7549	.0016	.7549	-.0005
.7794	.0024	.7794	.0004
.8039	.0030	.8039	.0010
.8284	.0037	.8284	.0018
.8529	.0040	.8529	.0024
.8774	.0044	.8775	.0031
.9020	.0047	.9019	.0037
.9265	.0049	.9265	.0042
.9510	.0049	.9510	.0045
.9755	.0049	.9755	.0048
1.0000	.0050	1.0000	.0050

TABLE A7.- SURFACE COORDINATES OF MODEL V
(SPLICED SINE WAVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0052	0.0000	.0052
.0500	.0050	.0500	.0051
.1000	.0040	.1000	.0046
.1500	.0022	.1500	.0037
.1750	.0010	.2000	.0029
.2000	-.0002	.2500	.0018
.2500	-.0022	.3000	.0006
.3000	-.0038	.3500	-.0008
.3500	-.0048	.4000	-.0021
.4000	-.0051	.4500	-.0033
.4500	-.0048	.5000	-.0043
.4500	-.0049	.5500	-.0049
.5000	-.0043	.5500	-.0048
.5500	-.0033	.6000	-.0051
.6000	-.0021	.6500	-.0048
.6500	-.0008	.7000	-.0038
.7000	.0006	.7500	-.0022
.7500	.0018	.8000	-.0002
.8000	.0029	.8250	.0010
.8500	.0037	.8500	.0022
.9000	.0046	.9000	.0040
.9500	.0051	.9500	.0050
1.0000	.0052	1.0000	.0052

TABLE A8.- SURFACE COORDINATES OF MODEL I
(SINE WAVES AND STRAIGHT RAMPS,
λ = 4.62 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0028	0.0000	.0028
.0270	.0028	.0270	.0022
.0541	.0026	.0811	.0011
.0811	.0024	.1081	.0003
.1081	.0022	.1351	-.0004
.1351	.0020	.1622	-.0009
.1622	.0017	.1892	-.0016
.1892	.0015	.2162	-.0022
.2162	.0012	.2432	-.0026
.2432	.0010	.2703	-.0028
.2703	.0008	.2973	-.0026
.2973	.0005	.3243	-.0024
.3243	.0003	.3514	-.0023
.3514	.0001	.3784	-.0021
.3784	-.0001	.4054	-.0018
.4054	-.0003	.4324	-.0016
.4324	-.0005	.4595	-.0013
.4595	-.0006	.4865	-.0010
.4865	-.0009	.5135	-.0009
.5135	-.0010	.5405	-.0006
.5405	-.0013	.5676	-.0005
.5676	-.0016	.5946	-.0003
.5946	-.0018	.6216	-.0001
.6216	-.0021	.6486	.0001
.6486	-.0023	.6757	.0003
.6757	-.0024	.7027	.0005
.7027	-.0026	.7297	.0008
.7297	-.0028	.7568	.0010
.7568	-.0026	.7838	.0012
.7838	-.0022	.8108	.0015
.8108	-.0016	.8378	.0017
.8378	-.0009	.8649	.0020
.8649	-.0004	.8919	.0022
.8919	.0003	.9189	.0024
.9189	.0011	.9459	.0026
.9730	.0022	.9730	.0028
1.0000	.0028	1.0000	.0028

TABLE A9.- SURFACE COORDINATES OF MODEL II
(SINE WAVES AND STRAIGHT RAMPS,
λ = 4.01 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0026	0.0000	.0027
.0387	.0025	.0265	.0026
.0710	.0023	.0587	.0023
.1026	.0021	.0903	.0019
.1355	.0019	.1232	.0012
.1677	.0017	.1548	.0001
.2000	.0014	.1871	-.0005
.2323	.0012	.2194	-.0012
.2645	.0010	.2516	-.0018
.2968	.0007	.2839	-.0024
.3290	.0005	.3161	-.0026
.3613	.0003	.3484	-.0026
.3935	-.0000	.3806	-.0023
.4258	-.0003	.4129	-.0018
.4581	-.0005	.4452	-.0014
.4903	-.0006	.4774	-.0010
.5226	-.0010	.5097	-.0006
.5548	-.0014	.5419	-.0005
.5871	-.0018	.5742	-.0003
.6194	-.0023	.6065	-.0000
.6516	-.0026	.6387	.0003
.6839	-.0026	.6710	.0005
.7161	-.0024	.7032	.0007
.7484	-.0018	.7355	.0010
.7806	-.0012	.7677	.0012
.8129	-.0005	.8000	.0014
.8452	.0001	.8323	.0017
.8768	.0012	.8645	.0019
.9097	.0019	.8974	.0021
.9413	.0023	.9290	.0023
.9735	.0026	.9613	.0025
1.0000	.0027	1.0000	.0026

TABLE A10.- SURFACE COORDINATES OF MODEL III
(SINE WAVES AND STRAIGHT RAMPS,
λ = 3.23 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0046	0.0000	.0046
.0275	.0045	.0511	.0043
.0668	.0041	.0904	.0037
.1061	.0034	.1297	.0029
.1454	.0027	.1690	.0018
.1847	.0019	.2083	.0009
.2241	.0012	.2469	-.0006
.2634	.0004	.2862	-.0021
.3027	-.0003	.3255	-.0034
.3412	-.0011	.3648	-.0043
.3813	-.0020	.4041	-.0046
.4206	-.0028	.4693	-.0046
.4599	-.0035	.4733	-.0046
.4992	-.0042	.4772	-.0045
.5071	-.0044	.4811	-.0046
.5102	-.0045	.4851	-.0046
.5149	-.0046	.4898	-.0045
.5189	-.0046	.4929	-.0044
.5228	-.0045	.5008	-.0042
.5267	-.0046	.5401	-.0035
.5307	-.0046	.5794	-.0028
.5959	-.0046	.6187	-.0020
.6352	-.0043	.6588	-.0011
.6745	-.0034	.6973	-.0003
.7138	-.0021	.7366	.0004
.7531	-.0006	.7759	.0012
.7917	.0009	.8153	.0019
.8310	.0018	.8546	.0027
.8703	.0029	.8939	.0034
.9096	.0037	.9332	.0041
.9489	.0043	.9725	.0045
1.0000	.0046	1.0000	.0046

TABLE A11.- SURFACE COORDINATES OF MODEL IV
(SINE WAVES AND STRAIGHT RAMPS,
λ = 3.86 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0034	0.0000	.0034
.0178	.0034	.0151	.0034
.0507	.0032	.0480	.0031
.0829	.0029	.0809	.0024
.1164	.0026	.1138	.0012
.1493	.0022	.1467	-.0001
.1822	.0020	.1599	-.0008
.2151	.0016	.1934	-.0020
.2480	.0012	.2257	-.0030
.2809	.0009	.2586	-.0033
.3138	.0005	.2914	-.0034
.3467	.0002	.3250	-.0032
.3796	-.0001	.3572	-.0030
.4125	-.0006	.3901	-.0027
.4454	-.0011	.4230	-.0025
.4783	-.0017	.4559	-.0023
.5112	-.0020	.4888	-.0020
.5441	-.0023	.5217	-.0017
.5770	-.0025	.5546	-.0011
.6099	-.0027	.5875	-.0006
.6428	-.0030	.6204	-.0001
.6750	-.0032	.6533	.0002
.7086	-.0034	.6862	.0005
.7414	-.0033	.7191	.0009
.7743	-.0030	.7520	.0012
.8066	-.0020	.7849	.0016
.8401	-.0008	.8178	.0020
.8533	-.0001	.8507	.0022
.8862	.0012	.8836	.0026
.9191	.0024	.9171	.0029
.9520	.0031	.9493	.0032
.9849	.0034	.9822	.0034
1.0000	.0034	1.0000	.0034

TABLE A12.- SURFACE COORDINATES OF MODEL 12
(SINE WAVES AND STRAIGHT RAMPS,
λ = 4.62 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0152	0.0000	.0150
.0275	.0145	.0246	.0143
.0550	.0134	.0523	.0119
.0824	.0123	.0796	.0087
.1099	.0113	.1071	.0046
.1374	.0099	.1209	.0023
.1649	.0087	.1346	-.0001
.1923	.0075	.1483	-.0026
.2198	.0064	.1757	-.0071
.2473	.0052	.2032	-.0109
.2746	.0039	.2307	-.0137
.3023	.0027	.2582	-.0152
.3297	.0015	.2857	-.0151
.3572	.0004	.3132	-.0140
.3845	-.0009	.3407	-.0127
.4121	-.0021	.3682	-.0115
.4396	-.0032	.3956	-.0103
.4671	-.0044	.4231	-.0091
.4945	-.0055	.4505	-.0080
.5219	-.0067	.4781	-.0067
.5495	-.0080	.5055	-.0055
.5769	-.0091	.5329	-.0044
.6044	-.0103	.5604	-.0032
.6318	-.0115	.5879	-.0021
.6593	-.0127	.6155	-.0009
.6868	-.0140	.6428	.0004
.7143	-.0151	.6703	.0015
.7418	-.0152	.6977	.0027
.7693	-.0137	.7254	.0039
.7968	-.0109	.7527	.0052
.8243	-.0071	.7802	.0064
.8517	-.0026	.8077	.0075
.8654	-.0001	.8351	.0087
.8791	.0023	.8626	.0099
.8929	.0046	.8901	.0113
.9204	.0087	.9176	.0123
.9477	.0119	.9450	.0134
.9754	.0143	.9725	.0145
1.0000	.0150	1.0000	.0152

TABLE A13.- SURFACE COORDINATES OF MODEL 13
(SINE WAVES AND STRAIGHT RAMPS,
λ = 4.01 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0145	0.0000	.0145
.0316	.0139	.0202	.0141
.0632	.0126	.0518	.0123
.0948	.0112	.0834	.0095
.1264	.0098	.1150	.0055
.1580	.0084	.1466	.0012
.2212	.0053	.1783	-.0032
.2528	.0039	.2099	-.0073
.2845	.0024	.2415	-.0108
.3161	.0011	.2731	-.0134
.3477	-.0003	.3047	-.0146
.3793	-.0017	.3363	-.0144
.4109	-.0031	.3679	-.0132
.4425	-.0045	.3995	-.0118
.4741	-.0060	.4311	-.0103
.5057	-.0074	.4627	-.0089
.5373	-.0089	.4943	-.0074
.5689	-.0103	.5259	-.0060
.6005	-.0118	.5575	-.0045
.6321	-.0132	.5891	-.0031
.6637	-.0144	.6207	-.0017
.6953	-.0146	.6523	-.0003
.7269	-.0134	.6839	.0011
.7585	-.0108	.7155	.0024
.7901	-.0073	.7472	.0039
.8217	-.0032	.7788	.0053
.8534	.0012	.8420	.0084
.8850	.0055	.8736	.0098
.9166	.0095	.9052	.0112
.9482	.0123	.9368	.0126
.9798	.0141	.9684	.0139
1.0000	.0145	1.0000	.0145

TABLE A14.- SURFACE COORDINATES OF MODEL 14
(SINE WAVES AND STRAIGHT RAMPS,
λ = 3.23 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0151	0.0000	.0151
.0394	.0144	.0371	.0144
.0789	.0126	.0765	.0121
.1182	.0105	.1159	.0087
.1577	.0084	.1552	.0045
.1972	.0062	.1719	.0025
.2366	.0037	.2114	-.0025
.2760	.0015	.2508	-.0069
.3155	-.0009	.2904	-.0108
.3550	-.0031	.3296	-.0136
.3942	-.0051	.3692	-.0151
.4337	-.0074	.4086	-.0151
.4733	-.0095	.4480	-.0136
.5125	-.0116	.4875	-.0116
.5520	-.0136	.5267	-.0095
.5914	-.0151	.5663	-.0074
.6308	-.0151	.6058	-.0051
.6704	-.0136	.6450	-.0031
.7096	-.0108	.6845	-.0009
.7492	-.0069	.7240	.0015
.7886	-.0025	.7634	.0037
.8281	.0025	.8028	.0062
.8448	.0045	.8423	.0084
.8841	.0087	.8818	.0105
.9235	.0121	.9211	.0126
.9629	.0144	.9606	.0144
1.0000	.0151	1.0000	.0151

TABLE A15.- SURFACE COORDINATES OF MODEL 15
(SINE WAVES AND STRAIGHT RAMPS,
λ = 3.86 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0151	0.0000	.0151
.0333	.0144	.0333	.0137
.0667	.0131	.0667	.0100
.1000	.0118	.1000	.0046
.1333	.0104	.1333	-.0015
.1667	.0089	.1667	-.0074
.2000	.0074	.2000	-.0118
.2333	.0060	.2333	-.0145
.2667	.0046	.2667	-.0151
.3000	.0032	.3000	-.0140
.3333	.0018	.3333	-.0126
.3667	.0004	.3667	-.0112
.4000	-.0011	.4000	-.0098
.4333	-.0025	.4333	-.0083
.4667	-.0041	.4667	-.0070
.5000	-.0056	.5000	-.0056
.5333	-.0070	.5333	-.0041
.5667	-.0083	.5667	-.0025
.6000	-.0098	.6000	-.0011
.6333	-.0112	.6333	.0004
.6667	-.0126	.6667	.0018
.7000	-.0140	.7000	.0032
.7333	-.0151	.7333	.0046
.7667	-.0145	.7667	.0060
.8000	-.0118	.8000	.0074
.8333	-.0074	.8333	.0089
.8667	-.0015	.8667	.0104
.9000	.0046	.9000	.0118
.9333	.0100	.9333	.0131
.9667	.0137	.9667	.0144
1.0000	.0151	1.0000	.0151

TABLE A16.- SURFACE COORDINATES OF MODEL 17
(TRANSVERSE V-GROOVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0144	0.0000	.0147
.0499	.0121	.0527	.0114
.0997	.0092	.1027	.0079
.1496	.0064	.1524	.0045
.1994	.0033	.2023	.0013
.2493	.0003	.2522	-.0018
.2991	-.0026	.3021	-.0051
.3490	-.0056	.3519	-.0084
.3988	-.0086	.4018	-.0117
.4487	-.0118	.4516	-.0147
.4985	-.0146	.5015	-.0146
.5484	-.0147	.5513	-.0118
.5982	-.0117	.6012	-.0086
.6481	-.0084	.6510	-.0056
.6979	-.0051	.7009	-.0026
.7478	-.0018	.7507	.0003
.7977	.0013	.8006	.0033
.8476	.0045	.8504	.0064
.8973	.0079	.9003	.0092
.9473	.0114	.9501	.0121
1.0000	.0147	1.0000	.0144

TABLE A17.- SURFACE COORDINATES OF MODEL 18
(TRANSVERSE V-GROOVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0152	0.0000	.0152
.0248	.0142	.0099	.0142
.0495	.0132	.0347	.0124
.0743	.0119	.0594	.0102
.0990	.0107	.0842	.0080
.1238	.0094	.1089	.0057
.1485	.0082	.1337	.0035
.1733	.0071	.1584	.0013
.1980	.0058	.1832	-.0009
.2228	.0045	.2079	-.0033
.2475	.0034	.2327	-.0055
.2723	.0018	.2574	-.0076
.2970	.0009	.2822	-.0097
.3218	-.0000	.3069	-.0119
.3465	-.0011	.3317	-.0139
.3713	-.0023	.3564	-.0152
.3960	-.0035	.3812	-.0142
.4208	-.0046	.4059	-.0128
.4455	-.0058	.4307	-.0117
.4703	-.0070	.4554	-.0105
.4950	-.0082	.4802	-.0095
.5198	-.0095	.5050	-.0082
.5446	-.0105	.5297	-.0070
.5693	-.0117	.5545	-.0058
.5941	-.0128	.5792	-.0046
.6188	-.0142	.6040	-.0035
.6436	-.0152	.6287	-.0023
.6683	-.0139	.6535	-.0011
.6931	-.0119	.6782	-.0000
.7178	-.0097	.7030	.0009
.7426	-.0076	.7277	.0018
.7673	-.0055	.7525	.0034
.7921	-.0033	.7772	.0045
.8168	-.0009	.8020	.0058
.8416	.0013	.8267	.0071
.8663	.0035	.8515	.0082
.8911	.0057	.8762	.0094
.9158	.0080	.9010	.0107
.9406	.0102	.9257	.0119
.9653	.0124	.9505	.0132
.9901	.0142	.9752	.0142
1.0000	.0152	1.0000	.0152

TABLE A18.- SURFACE COORDINATES OF MODEL 19 (TRANSVERSE V-GROOVES, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0148	0.0000	.0148
.0172	.0143	.0330	.0122
.0421	.0132	.0581	.0091
.0670	.0123	.0830	.0058
.0919	.0112	.1080	.0032
.1168	.0103	.1329	.0002
.1421	.0091	.1580	-.0029
.1670	.0081	.1829	-.0058
.1920	.0072	.2080	-.0088
.2170	.0061	.2329	-.0117
.2420	.0050	.2580	-.0148
.2669	.0040	.2830	-.0145
.2922	.0028	.3080	-.0135
.3171	.0019	.3329	-.0125
.3420	.0010	.3579	-.0115
.3672	-.0003	.3831	-.0105
.3920	-.0012	.4080	-.0094
.4171	-.0023	.4329	-.0084
.4420	-.0033	.4580	-.0074
.4670	-.0044	.4830	-.0064
.4920	-.0053	.5080	-.0053
.5170	-.0064	.5330	-.0044
.5420	-.0074	.5580	-.0033
.5671	-.0084	.5829	-.0023
.5920	-.0094	.6080	-.0012
.6169	-.0105	.6328	-.0003
.6421	-.0115	.6580	.0010
.6671	-.0125	.6829	.0019
.6920	-.0135	.7078	.0028
.7170	-.0145	.7331	.0040
.7420	-.0148	.7580	.0050
.7671	-.0117	.7830	.0061
.7920	-.0088	.8080	.0072
.8171	-.0058	.8330	.0081
.8420	-.0029	.8579	.0091
.8671	.0002	.8832	.0103
.8920	.0032	.9081	.0112
.9170	.0058	.9330	.0123
.9419	.0091	.9579	.0132
.9670	.0122	.9828	.0143
1.0000	.0148	1.0000	.0148

TABLE A19.- SURFACE COORDINATES OF MODEL 24 (CIRCULAR ARCS AND STRAIGHT RAMPS, λ = 2.54 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0154	0.0000	.0154
.0259	.0151	.0259	.0150
.0518	.0141	.0518	.0135
.0777	.0131	.0777	.0117
.1036	.0119	.1036	.0082
.1295	.0107	.1295	.0019
.1554	.0095	.1554	-.0046
.1813	.0084	.1813	-.0099
.2073	.0073	.2073	-.0149
.2332	.0061	.2332	-.0154
.2591	.0049	.2591	-.0135
.2850	.0038	.2850	-.0129
.3109	.0026	.3109	-.0120
.3264	.0022	.3368	-.0111
.3523	.0012	.3627	-.0104
.3782	.0001	.3886	-.0092
.4041	-.0011	.4145	-.0083
.4301	-.0021	.4404	-.0073
.4560	-.0032	.4663	-.0063
.4819	-.0044	.4922	-.0051
.5078	-.0051	.5181	-.0044
.5337	-.0063	.5440	-.0032
.5596	-.0073	.5699	-.0021
.5855	-.0083	.5959	-.0011
.6114	-.0092	.6218	.0001
.6373	-.0104	.6477	.0012
.6632	-.0111	.6736	.0022
.6891	-.0120	.6891	.0026
.7150	-.0129	.7150	.0038
.7409	-.0135	.7409	.0049
.7668	-.0154	.7668	.0061
.7927	-.0149	.7927	.0073
.8187	-.0099	.8187	.0084
.8446	-.0046	.8446	.0095
.8705	.0019	.8705	.0107
.8964	.0082	.8964	.0119
.9223	.0117	.9223	.0131
.9482	.0135	.9482	.0141
.9741	.0150	.9741	.0151
1.0000	.0154	1.0000	.0154

TABLE A20.- SURFACE COORDINATES OF MODEL 34
(CIRCULAR ARCS AND STRAIGHT RAMPS,
λ = 1.27 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0159	0.0000	.0159
.0298	.0153	.0300	.0155
.0594	.0135	.0598	.0143
.0895	.0115	.0897	.0119
.1191	.0105	.1195	.0078
.1491	.0093	.1493	0.0000
.1787	.0080	.1791	-.0080
.2085	.0068	.1948	-.0123
.2386	.0054	.2247	-.0159
.2684	.0040	.2547	-.0155
.2980	.0028	.2843	-.0143
.3280	.0016	.3141	-.0133
.3577	.0002	.3439	-.0119
.3877	-.0010	.3740	-.0105
.4175	-.0024	.4036	-.0093
.4473	-.0036	.4334	-.0083
.4771	-.0046	.4632	-.0074
.5070	-.0062	.4930	-.0062
.5368	-.0074	.5229	-.0046
.5666	-.0083	.5527	-.0036
.5964	-.0093	.5825	-.0024
.6260	-.0105	.6123	-.0010
.6561	-.0119	.6423	.0002
.6859	-.0133	.6720	.0016
.7157	-.0143	.7020	.0028
.7453	-.0155	.7316	.0040
.7753	-.0159	.7614	.0054
.8052	-.0123	.7915	.0068
.8209	-.0080	.8213	.0080
.8507	0.0000	.8509	.0093
.8805	.0078	.8809	.0105
.9103	.0119	.9105	.0115
.9402	.0143	.9406	.0135
.9700	.0155	.9702	.0153
1.0000	.0159	1.0000	.0159

TABLE A21.- SURFACE COORDINATES OF MODEL 44
(CIRCULAR ARCS AND STRAIGHT RAMPS,
λ = 5.08 cm)

Forward direction		Reverse direction	
x/λ	y/λ	x/λ	y/λ
0.0000	.0149	0.0000	.0149
.0250	.0149	.0250	.0145
.0500	.0141	.0500	.0135
.0750	.0126	.0751	.0120
.1002	.0106	.1000	.0092
.1250	.0093	.1249	.0037
.1500	.0082	.1501	-.0026
.1750	.0072	.1749	-.0087
.2000	.0062	.2000	-.0141
.2250	.0052	.2250	-.0149
.2500	.0042	.2499	-.0149
.2750	.0036	.2749	-.0147
.3000	.0026	.3001	-.0140
.3251	.0016	.3250	-.0130
.3500	.0005	.3500	-.0120
.3750	-.0005	.3750	-.0109
.4000	-.0016	.4000	-.0099
.4250	-.0026	.4250	-.0088
.4500	-.0037	.4500	-.0078
.4750	-.0047	.4750	-.0067
.5000	-.0057	.5000	-.0057
.5250	-.0067	.5250	-.0047
.5500	-.0078	.5500	-.0037
.5750	-.0088	.5750	-.0026
.6000	-.0099	.6000	-.0016
.6250	-.0109	.6250	-.0005
.6500	-.0120	.6500	.0005
.6750	-.0130	.6749	.0016
.6999	-.0140	.7000	.0026
.7251	-.0147	.7250	.0036
.7501	-.0149	.7500	.0042
.7750	-.0149	.7750	.0052
.8000	-.0141	.8001	.0062
.8251	-.0087	.8249	.0072
.8499	-.0026	.8500	.0082
.8751	.0037	.8750	.0093
.9000	.0092	.8999	.0106
.9249	.0120	.9250	.0126
.9500	.0135	.9500	.0141
.9750	.0145	.9750	.0149
1.0000	.0149	1.0000	.0149

TABLE A22.- MEASURED TOTAL DRAG DATA FOR MODEL 1 (SINE WAVES)

Forward direction				Reverse direction	
Run 37		Run 38		Run 39	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.1	1.026	7.1	.986	7.2	.982
8.3	1.027	8.3	1.006	8.4	1.003
9.5	1.010	9.6	1.010	9.6	1.004
10.6	1.006	10.7	.999	10.7	.989
11.8	1.004	11.9	1.001	11.9	1.002
13.0	1.017	13.0	1.012	13.1	1.004
14.2	1.007	14.2	1.008	14.3	1.004
15.3	1.007	15.4	1.001	15.3	1.002
16.4	1.005	16.4	1.005	16.5	1.004
17.5	1.013	17.5	1.002	17.6	1.005
18.5	1.011	18.6	1.001	18.7	1.004
19.7	1.015	19.7	1.004	19.8	1.003
20.9	1.016	20.9	1.001	20.9	1.000
22.0	1.011	22.0	1.002	22.1	1.001
23.1	1.007	23.2	1.000	23.3	1.000
24.4	1.010	24.4	1.000	24.5	.998
25.6	1.009	25.6	1.002	25.7	.998
26.8	1.007	26.8	.996	26.9	1.000
28.1	1.005	28.0	1.000	28.1	.999
29.3	1.006	29.2	.998	29.5	.995
30.6	1.005	30.5	.997	30.7	.995
31.9	1.005	31.8	.996	32.1	.992
33.3	1.005	33.3	.997	33.4	.993
34.6	1.005	34.7	.995	35.0	.987
36.2	.999	36.1	.996	36.2	.990
37.7	1.003	37.5	.994	37.8	.992
39.1	1.004	38.9	.994	39.1	.991
		40.3	.995	40.5	.988
		41.5	.995	41.8	.988
		42.8	.993	43.0	.984
		44.0	.996		

TABLE A23.- MEASURED TOTAL DRAG DATA FOR MODEL 2 (SINE WAVES)

Forward direction				Reverse direction	
Run 86		Run 84		Run 85	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.1	1.020	7.1	1.016	7.1	1.031
8.3	1.033	8.3	1.013	8.3	1.043
9.4	1.037	9.5	1.032	9.5	1.039
10.6	1.043	10.6	1.054	10.6	1.059
11.8	1.042	11.8	1.056	11.8	1.065
12.9	1.051	12.9	1.062	13.0	1.071
14.1	1.051	14.1	1.065	14.1	1.066
15.2	1.047	15.1	1.066	15.2	1.066
16.3	1.051	16.3	1.065	16.4	1.065
18.4	1.052	17.4	1.072	17.4	1.066
20.8	1.052	18.5	1.068	18.5	1.062
22.0	1.054	19.7	1.065	19.6	1.063
23.2	1.060	20.8	1.066	20.9	1.063
24.4	1.059	21.9	1.065	22.0	1.060
25.6	1.055	23.1	1.064	23.2	1.059
26.8	1.055	24.4	1.060	24.4	1.059
29.4	1.051	25.5	1.060	25.6	1.056
32.1	1.050	26.8	1.060	28.1	1.053
34.8	1.050	28.0	1.056	30.6	1.049
36.5	1.047	29.2	1.057	32.0	1.051
37.8	1.051	30.5	1.054	33.4	1.049
39.2	1.052	33.3	1.054	34.8	1.057
40.6	1.054	36.1	1.052	36.3	1.044
41.8	1.054	37.6	1.052	39.2	1.049
42.8	1.055	39.0	1.054	41.7	1.049
		40.3	1.054	42.8	1.044
		41.7	1.056		
		42.7	1.057		

TABLE A24.- MEASURED TOTAL DRAG DATA FOR MODEL 16 (SINE WAVES)

Forward direction				Reverse direction			
Run 73		Run 74		Run 75		Run 76	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.2	1.127	6.8	1.080	6.9	1.058	7.0	1.099
7.8	1.126	7.5	1.133	7.5	1.100	7.5	1.129
8.4	1.129	8.0	1.125	8.1	1.107	8.1	1.129
8.9	1.135	9.2	1.143	8.7	1.104	8.6	1.111
9.5	1.147	10.4	1.134	9.3	1.106	9.3	1.137
10.1	1.122	11.5	1.144	10.4	1.126	9.9	1.130
10.7	1.141	12.6	1.140	11.6	1.117	10.4	1.131
11.8	1.153	13.8	1.147	12.7	1.127	11.6	1.133
12.9	1.145	14.9	1.145	13.9	1.141	12.6	1.139
14.1	1.145	16.0	1.146	15.0	1.136	13.9	1.143
15.2	1.148	17.0	1.147	16.1	1.141	14.9	1.155
16.2	1.146	18.2	1.144	17.2	1.144	16.0	1.151
17.4	1.147	19.3	1.138	18.3	1.136	17.1	1.151
18.5	1.150	20.5	1.138	19.5	1.133	18.2	1.150
19.7	1.146	21.6	1.138	21.8	1.133	19.3	1.129
20.8	1.150	22.8	1.136	24.2	1.137	20.5	1.146
22.0	1.142	24.0	1.134	26.6	1.130	21.8	1.147
23.3	1.141	25.2	1.130	29.1	1.124	22.9	1.145
24.4	1.141	26.4	1.125	31.8	1.117	24.1	1.141
25.7	1.134	27.7	1.123	34.7	1.111	25.3	1.142
26.9	1.132	28.9	1.120	36.1	1.108	26.5	1.137
28.0	1.130	30.2	1.116	37.5	1.104	27.8	1.135
29.3	1.128	31.5	1.111	38.7	1.105	29.1	1.131
30.6	1.127	33.0	1.104			30.4	1.129
32.0	1.122	34.4	1.103			31.8	1.127
33.5	1.119	35.8	1.095			33.3	1.117
34.9	1.112	37.1	1.094			34.5	1.121
36.3	1.110	38.6	1.093			36.0	1.116
37.6	1.110					37.3	1.112
39.0	1.109					38.6	1.111

TABLE A25.- MEASURED TOTAL DRAG DATA FOR MODEL 3 (SINE WAVES)

Forward direction				Reverse direction			
Run 21		Run 22		Run 23		Run 24	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.7	1.230	7.5	1.228	7.2	1.239	7.4	1.219
8.9	1.239	8.7	1.235	8.5	1.245	8.4	1.239
10.0	1.249	9.9	1.233	9.7	1.252	9.6	1.248
11.2	1.256	11.0	1.248	10.9	1.259	10.9	1.267
12.5	1.251	12.2	1.244	12.0	1.255	12.0	1.267
13.7	1.261	13.3	1.244	13.2	1.264	13.2	1.266
14.8	1.255	14.5	1.247	14.4	1.273	14.3	1.272
15.9	1.260	15.6	1.247	15.4	1.274	15.4	1.279
17.1	1.263	16.8	1.254	16.6	1.280	16.6	1.271
18.1	1.259	17.9	1.251	17.7	1.280	17.7	1.280
19.2	1.260	19.0	1.245	19.0	1.277	18.8	1.274
20.4	1.256	20.0	1.247	20.0	1.275	21.1	1.275
21.5	1.249	21.3	1.240	21.2	1.274	23.4	1.268
22.2	1.247	22.4	1.239	23.4	1.269	25.8	1.267
22.5	1.248	23.6	1.235	25.8	1.268	28.3	1.258
23.8	1.242	24.8	1.232	28.2	1.261	30.8	1.255
25.0	1.239	25.9	1.228	29.4	1.259	33.5	1.243
26.2	1.238	27.3	1.221	30.7	1.256	36.4	1.237
27.5	1.237	28.5	1.221	32.2	1.251	37.7	1.235
28.7	1.229	29.8	1.217	33.5	1.250	39.3	1.233
30.0	1.226	31.3	1.212	35.0	1.245		
31.4	1.224	32.5	1.209	36.5	1.240		
32.8	1.216	34.0	1.201	37.8	1.241		
34.2	1.215	35.4	1.201	39.2	1.236		
35.6	1.211	36.8	1.198				
37.0	1.207	38.3	1.195				
38.4	1.204	39.4	1.193				
39.7	1.204						

TABLE A26.- MEASURED TOTAL DRAG DATA FOR MODEL VI (SINE WAVES)

Forward direction				Reverse direction			
Run 80		Run 82		Run 81		Run 83	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.2	1.017	7.1	1.061	7.2	1.026	7.0	1.024
8.4	1.026	8.3	1.047	8.3	1.032	8.3	1.042
9.5	1.027	9.4	1.056	9.4	1.030	9.4	1.031
10.7	1.043	10.5	1.038	10.7	1.035	10.6	1.052
11.9	1.043	11.7	1.030	11.9	1.042	11.7	1.041
13.1	1.047	12.9	1.045	14.2	1.042	12.9	1.048
14.2	1.049	14.0	1.053	16.5	1.045	14.1	1.043
15.4	1.049	15.2	1.056	18.7	1.042	15.2	1.049
16.4	1.046	16.3	1.054	20.9	1.042	16.3	1.051
17.5	1.052	17.4	1.053	22.0	1.040	17.3	1.051
18.7	1.050	18.5	1.051	23.2	1.040	18.5	1.046
19.9	1.048	19.6	1.052	24.4	1.039	19.6	1.044
20.9	1.047	20.8	1.050	26.9	1.036	20.7	1.045
22.0	1.047	21.9	1.047	29.4	1.033	22.0	1.041
23.3	1.046	23.1	1.049	32.1	1.032	23.1	1.039
24.4	1.042	24.4	1.047	35.0	1.028	24.3	1.041
25.7	1.042	26.9	1.043	37.8	1.024	25.6	1.034
26.9	1.041	29.3	1.042	39.2	1.035	26.8	1.035
29.5	1.038	31.9	1.038	41.9	1.034	28.1	1.038
32.2	1.035	34.8	1.040			29.3	1.036
35.0	1.033	37.8	1.034			30.7	1.033
37.7	1.034	39.3	1.034			32.0	1.029
39.1	1.034	40.6	1.036			33.4	1.031
40.6	1.027	41.8	1.030			34.8	1.032
41.9	1.033	41.8	1.032			36.3	1.029
43.0	1.032	42.9	1.027			37.8	1.032
						39.2	1.034
						40.5	1.026
						42.4	1.031

TABLE A27.- MEASURED TOTAL DRAG DATA FOR MODEL VII (SINE WAVES)

Forward direction				Reverse direction			
Run 35		Run 36		Run 33		Run 34	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.0	1.014	7.1	1.026	7.1	1.027	7.0	1.028
8.3	1.016	8.3	1.020	7.7	1.016	8.1	1.029
9.4	1.009	9.6	1.022	8.4	1.023	9.3	1.019
10.6	1.021	10.6	1.020	9.0	1.034	10.5	1.011
11.8	1.010	11.8	1.013	9.5	1.036	11.6	1.023
12.9	1.018	13.0	1.023	10.1	1.035	12.8	1.029
14.2	1.017	14.2	1.022	10.6	1.033	14.0	1.023
15.3	1.021	15.2	1.029	11.3	1.036	15.0	1.019
16.4	1.024	16.4	1.030	11.9	1.033	16.2	1.026
17.6	1.023	17.5	1.029	13.0	1.035	17.3	1.027
18.7	1.028	18.7	1.026	14.2	1.036	18.5	1.026
19.7	1.028	19.7	1.023	15.3	1.029	19.6	1.030
22.1	1.023	20.8	1.024	16.5	1.035	20.7	1.029
24.4	1.021	22.0	1.023	17.7	1.039	21.9	1.026
25.7	1.024	23.2	1.024	18.7	1.036	23.1	1.024
28.0	1.020	24.4	1.024	19.8	1.035	24.3	1.022
30.6	1.020	25.7	1.022	21.0	1.033	25.5	1.026
33.4	1.018	28.1	1.022	22.1	1.032	26.8	1.025
36.3	1.006	29.4	1.017	23.2	1.030	27.9	1.023
38.9	1.009	30.7	1.019	24.5	1.032	29.2	1.026
		33.3	1.017	25.6	1.030	30.6	1.026
		34.8	1.017	26.8	1.030	31.9	1.022
		36.4	1.014	28.1	1.032	33.2	1.025
		39.1	1.004	28.1	1.028	34.6	1.023
		40.2	1.012	29.5	1.027	36.3	1.019
				30.8	1.031	37.6	1.021
				32.0	1.029	39.0	1.023
				33.4	1.029		
				34.9	1.027		
				36.5	1.023		
				38.0	1.024		
				39.2	1.026		

TABLE A28.- MEASURED TOTAL DRAG DATA FOR MODEL V (SPLICED SINE WAVES)

Forward direction				Reverse direction			
Run 51		Run 64		Run 52		Run 59	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
6.9	.979	7.0	1.053	7.1	1.027	7.1	1.010
8.1	.980	8.3	1.028	8.4	1.021	8.3	1.013
9.3	.998	9.5	1.026	9.6	1.021	9.5	1.015
10.4	1.019	10.7	1.030	10.7	1.017	10.7	1.023
11.6	1.018	11.9	1.029	11.8	1.018	11.9	1.020
12.8	1.023	13.1	1.032	13.0	1.027	13.0	1.027
13.9	1.029	14.2	1.031	14.1	1.031	14.3	1.033
15.1	1.032	15.4	1.029	15.3	1.027	15.4	1.027
16.2	1.028	16.4	1.036	16.4	1.032	16.5	1.033
17.2	1.032	17.5	1.035	17.5	1.037	17.5	1.030
18.3	1.033	18.6	1.035	18.6	1.035	18.7	1.035
19.6	1.036	19.7	1.035	19.8	1.033	19.7	1.033
20.7	1.034	20.9	1.038	21.0	1.037	20.9	1.034
22.0	1.034	22.1	1.031	22.1	1.035	22.1	1.034
23.1	1.037	23.2	1.034	23.3	1.033	23.2	1.037
24.3	1.034	24.4	1.036	24.4	1.034	24.4	1.036
25.5	1.035	25.5	1.036	25.7	1.034	25.6	1.036
26.6	1.036	26.8	1.030	26.9	1.034	26.9	1.033
27.9	1.036	28.1	1.032	28.1	1.034	28.0	1.036
29.2	1.033	29.3	1.027	29.4	1.029	29.3	1.033
30.5	1.036	30.7	1.028	30.6	1.031	30.5	1.035
31.7	1.035	32.0	1.027	32.0	1.029	31.8	1.031
33.1	1.035	33.4	1.023	33.4	1.031	33.2	1.029
34.7	1.031	34.8	1.021	34.8	1.031	34.7	1.027
36.1	1.029	36.2	1.018	36.4	1.027	36.2	1.018
37.6	1.028	37.6	1.018	37.7	1.028	37.6	1.022
38.9	1.030	39.0	1.018	39.0	1.025	38.9	1.019
40.2	1.032	40.3	1.019	40.4	1.026	40.3	1.017
41.5	1.031	41.6	1.018	41.7	1.024	41.7	1.016
42.8	1.032	42.8	1.018	42.9	1.015	43.0	1.010

TABLE A29.- MEASURED TOTAL DRAG DATA FOR MODEL I (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 6		Run 10		Run 11		Run 12	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.3	1.034	6.9	1.034	6.9	1.091	6.9	1.032
8.6	1.018	8.0	.974	8.1	1.027	8.1	1.017
9.7	1.020	8.2	1.019	9.4	1.028	9.3	1.024
10.9	1.019	9.3	1.010	10.5	1.013	10.5	1.026
12.1	1.026	10.5	1.025	11.7	1.014	11.6	1.021
13.2	1.023	11.7	1.009	12.9	1.015	12.8	1.018
14.4	1.016	12.8	1.016	14.0	1.012	13.9	1.019
15.4	1.015	13.9	1.015	15.1	1.012	15.0	1.025
16.6	1.019	15.0	1.012	16.2	1.021	16.1	1.031
17.7	1.020	16.1	1.014	17.3	1.020	17.2	1.033
18.8	1.018	17.2	1.019	18.4	1.018	18.3	1.031
19.9	1.020	17.2	1.022	19.7	1.017	19.5	1.031
21.0	1.015	18.3	1.016	20.8	1.015	20.6	1.025
22.3	1.019	19.5	1.017	21.9	1.016	21.8	1.024
23.4	1.014	20.7	1.013	23.2	1.018	23.0	1.024
24.5	1.017	21.9	1.016	24.4	1.012	24.2	1.028
25.7	1.019	23.1	1.020	25.5	1.016	25.4	1.024
27.0	1.018	24.2	1.021	26.7	1.016	26.5	.998
28.2	1.019	25.4	1.019	28.0	1.014	26.6	1.026
29.5	1.015	26.6	1.018	29.2	1.018	26.6	1.024
30.7	1.018	27.9	1.021	30.5	1.014	27.9	1.027
32.1	1.012	29.2	1.022	30.5	1.021	29.1	1.028
33.6	1.013	30.5	1.021	31.9	1.031	30.4	1.025
35.0	1.011	31.8	1.021	33.3	1.032	31.8	1.025
36.4	1.013	33.2	1.022	34.8	1.032	33.2	1.027
37.8	1.008	34.7	1.023	36.3	1.032	34.5	1.028
39.1	1.012	36.1	1.026	37.7	1.032	36.1	1.024
40.4	1.010	37.5	1.024	39.0	1.032	37.5	1.027
		38.9	1.023			38.9	1.022

TABLE A30.- MEASURED TOTAL DRAG DATA FOR MODEL II (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 40		Run 49		Run 42		Run 43	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.1	.975	7.1	.974	7.2	.981	7.3	1.022
8.4	.991	7.7	.966	8.4	1.013	8.5	1.005
9.6	.997	8.2	.992	9.6	1.000	9.7	.999
10.7	1.007	9.5	.990	10.8	1.009	10.9	1.003
12.0	.997	10.7	.996	12.0	1.003	12.1	1.003
13.1	1.003	11.8	.990	13.2	1.004	13.2	1.010
14.3	1.000	13.0	1.001	14.3	1.006	14.3	.997
15.5	1.000	14.2	1.002	15.4	1.003	15.4	.999
16.5	.994	15.2	1.009	16.6	1.002	16.6	1.000
17.6	1.002	16.4	1.007	17.6	1.006	17.6	1.002
18.8	1.003	17.4	1.010	18.8	1.006	18.7	1.005
19.8	1.005	18.6	1.009	19.8	1.004	19.9	1.006
21.0	1.002	19.8	1.009	21.0	1.003	21.0	1.001
22.2	1.001	20.9	1.009	22.2	1.004	22.2	1.000
23.4	1.000	22.1	1.006	23.3	1.004	23.3	1.002
24.5	1.002	23.2	1.007	24.5	1.005	24.6	1.001
25.8	1.000	24.4	1.002	25.7	1.004	25.7	.999
27.0	1.000	25.6	1.003	27.1	1.004	27.0	1.001
28.2	1.000	26.8	1.000	28.2	1.003	28.2	.996
29.4	.996	28.1	.999	29.5	.997	29.4	.999
30.8	1.000	29.4	.997	30.7	.991	30.7	.997
32.0	.995	30.6	.997	32.0	.995	32.1	.994
33.6	.995	31.9	.996	33.5	.987	33.4	.996
34.9	.995	33.3	.991	34.8	.977	34.9	.991
36.4	.996	34.8	.992	36.3	.973	36.3	.989
37.9	.990	36.2	.991	37.7	.978	37.7	.985
39.1	.990	37.7	.986	39.1	.979	39.1	.986
40.4	.991	39.1	.985	40.4	.968	40.5	.987
		40.3	.987	41.7	.975	41.9	.983
		41.7	.984	43.1	.961		
		42.8	.984				

TABLE A31.- MEASURED TOTAL DRAG DATA FOR MODEL III (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 45		Run 46		Run 47		Run 48	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.1	1.035	7.1	1.012	7.1	.983	7.1	1.011
7.7	1.017	8.4	1.007	8.4	.996	8.3	1.005
8.4	1.028	9.5	1.003	9.6	1.003	9.5	1.006
8.9	1.016	10.7	1.017	10.6	1.007	10.6	1.015
9.5	1.024	11.9	1.014	11.8	1.011	11.8	1.000
10.1	1.007	13.1	1.025	13.0	1.015	12.9	1.009
10.7	1.012	14.2	1.022	14.1	1.011	14.1	1.011
11.8	1.019	15.3	1.025	15.2	1.005	15.1	1.019
13.0	1.020	16.4	1.025	16.3	1.015	16.2	1.016
14.2	1.016	17.5	1.024	17.4	1.014	17.4	1.020
15.3	1.015	18.6	1.026	18.5	1.015	18.5	1.019
16.4	1.029	19.7	1.026	19.7	1.015	19.7	1.018
17.5	1.022	20.9	1.024	20.8	1.017	20.8	1.017
18.6	1.029	22.1	1.024	22.1	1.015	21.9	1.017
19.7	1.025	23.2	1.028	23.2	1.014	23.0	1.020
20.9	1.020	24.5	1.027	24.3	1.017	24.3	1.020
22.0	1.019	25.7	1.026	25.6	1.017	25.5	1.017
23.3	1.019	27.0	1.023	26.7	1.018	26.6	1.018
24.4	1.020	28.1	1.027	28.1	1.016	27.9	1.022
25.7	1.019	29.4	1.022	29.4	1.017	29.2	1.022
26.9	1.018	30.7	1.022	30.5	1.019	30.4	1.021
28.1	1.017	32.1	1.021	31.9	1.019	31.7	1.018
29.4	1.015	33.5	1.018	33.4	1.017	33.1	1.021
30.7	1.014	34.9	1.019	34.8	1.019	34.6	1.024
32.0	1.015	36.4	1.020	36.3	1.016	36.0	1.022
33.4	1.011	37.7	1.016	37.6	1.014	37.3	1.022
34.7	1.015	39.1	1.020	38.9	1.016	38.7	1.025
36.4	1.011	40.4	1.020	40.3	1.015	40.0	1.022
37.7	1.009	41.7	1.025	41.7	1.018	41.3	1.022
39.0	1.011	43.0	1.020	42.8	1.015	42.5	1.022
40.3	1.015	44.0	1.019	43.5	1.011		
41.7	1.010						
42.8	1.012						

TABLE A32.- MEASURED TOTAL DRAG DATA FOR MODEL IV (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction	
Run 50		Run 75		Run 79	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.0	.994	7.1	1.011	7.0	1.006
8.1	.998	8.4	1.012	8.2	1.008
9.4	1.004	9.6	1.016	9.5	1.000
10.5	.996	10.7	1.020	10.5	1.014
11.6	1.006	11.8	1.018	11.7	.995
12.8	1.008	13.0	1.013	12.9	1.006
13.9	1.004	14.2	1.004	14.0	1.023
15.1	1.010	15.2	1.013	15.2	1.022
16.2	1.010	16.4	1.015	16.3	1.027
17.3	1.014	17.4	1.018	17.4	1.024
18.4	1.014	18.5	1.018	18.4	1.022
19.5	1.016	19.7	1.013	19.7	1.018
20.7	1.013	20.9	1.011	20.8	1.016
21.9	1.013	22.0	1.014	22.0	1.013
23.0	1.012	23.2	1.017	23.2	1.013
24.4	1.013	24.4	1.014	24.3	1.012
25.5	1.014	25.6	1.014	25.6	1.014
26.7	1.015	26.8	1.016	26.8	1.013
28.0	1.016	28.0	1.016	28.0	1.012
29.3	1.016	29.3	1.011	29.4	1.012
30.6	1.014	30.7	1.013	30.8	1.013
31.8	1.013	32.0	1.012	32.1	1.013
33.2	1.011	33.4	1.017	33.4	1.012
34.7	1.014	34.8	1.011	34.9	1.017
36.2	1.013	36.3	1.013	36.4	1.011
37.6	1.013	37.7	1.015	37.7	1.014
38.9	1.010	39.1	1.017	39.1	1.012
40.2	1.015	40.4	1.019	40.5	1.016
41.5	1.015	41.7	1.020	41.9	1.011
42.8	1.015	42.8	1.016	42.8	1.012

TABLE A33.- MEASURED TOTAL DRAG DATA FOR MODEL 12 (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 63		Run 64		Run 65		Run 66	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.2	1.105	7.1	1.126	7.1	1.167	7.1	1.164
7.8	1.127	7.7	1.135	7.7	1.200	7.7	1.191
8.4	1.113	8.4	1.139	8.3	1.202	8.3	1.198
8.9	1.121	9.0	1.136	8.9	1.210	8.9	1.206
9.6	1.120	9.6	1.140	9.5	1.214	9.5	1.212
10.1	1.128	10.1	1.140	10.1	1.224	10.0	1.212
10.7	1.128	10.6	1.139	10.6	1.223	10.6	1.225
11.2	1.125	11.3	1.127	11.2	1.223	11.2	1.223
11.8	1.121	11.8	1.134	11.9	1.222	11.8	1.223
12.9	1.116	13.0	1.129	13.0	1.224	12.9	1.219
14.1	1.123	14.1	1.137	14.2	1.227	14.1	1.227
15.2	1.124	15.3	1.136	15.3	1.236	15.3	1.225
16.3	1.121	16.4	1.130	16.3	1.240	16.3	1.229
17.4	1.119	17.5	1.130	17.4	1.240	17.4	1.231
18.5	1.124	18.7	1.126	18.5	1.233	18.5	1.225
19.7	1.123	19.8	1.127	19.7	1.230	19.6	1.228
20.9	1.121	20.9	1.130	20.9	1.233	20.8	1.226
22.0	1.118	22.0	1.129	22.0	1.232	22.0	1.225
23.2	1.118	23.3	1.130	23.1	1.233	23.1	1.223
24.4	1.115	24.4	1.123	24.3	1.231	24.3	1.219
25.6	1.118	25.5	1.124	25.6	1.226	25.5	1.211
26.8	1.111	26.8	1.122	26.8	1.222	26.7	1.208
28.0	1.111	28.0	1.120	28.0	1.219	27.9	1.205
29.3	1.112	29.3	1.120	28.0	1.220	29.2	1.198
30.6	1.110	30.5	1.117	29.2	1.218	30.6	1.195
32.1	1.108	32.0	1.115	30.6	1.215	31.9	1.190
33.4	1.104	33.4	1.111	31.9	1.211	33.5	1.179
35.0	1.097	34.8	1.108	33.3	1.207	34.8	1.178
36.3	1.097	36.2	1.110	34.7	1.198	36.2	1.176
37.6	1.100	37.6	1.110	36.2	1.192	37.5	1.173
39.0	1.100	38.9	1.113	37.5	1.189	38.8	1.172
				38.9	1.189		

TABLE A34.- MEASURED TOTAL DRAG DATA FOR MODEL 13 (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 68		Run 69		Run 70		Run 71	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.3	1.061	7.2	1.073	7.3	1.128	7.3	1.144
7.9	1.077	7.8	1.074	7.9	1.141	7.9	1.146
8.4	1.085	8.4	1.073	8.5	1.150	8.6	1.152
9.0	1.087	8.9	1.087	9.1	1.142	9.2	1.156
9.6	1.090	9.6	1.085	9.7	1.149	9.8	1.158
10.2	1.089	10.7	1.083	10.8	1.156	10.9	1.160
10.8	1.085	11.9	1.088	12.0	1.155	12.1	1.166
11.4	1.084	13.1	1.082	13.1	1.166	13.3	1.173
12.0	1.084	14.2	1.087	14.2	1.169	14.4	1.175
13.2	1.085	15.3	1.077	15.4	1.167	15.5	1.178
14.3	1.085	16.4	1.090	16.4	1.172	16.6	1.183
15.4	1.090	17.5	1.082	17.5	1.168	17.7	1.177
16.5	1.081	18.6	1.079	18.8	1.166	18.8	1.176
17.6	1.080	19.8	1.081	19.9	1.171	19.9	1.180
18.7	1.078	21.0	1.082	21.2	1.170	21.1	1.179
19.9	1.085	22.1	1.081	22.3	1.162	22.2	1.177
21.0	1.081	23.3	1.081	23.5	1.162	23.4	1.181
22.2	1.081	24.6	1.077	24.6	1.162	24.6	1.176
23.5	1.077	25.7	1.078	25.9	1.156	25.8	1.173
24.6	1.070	27.0	1.074	27.1	1.149	27.1	1.169
25.8	1.074	28.4	1.070	28.4	1.143	28.3	1.165
27.1	1.068	30.8	1.068	29.6	1.143	30.9	1.159
28.4	1.069	32.2	1.066	30.9	1.142	33.7	1.146
29.6	1.070	33.7	1.062	32.4	1.134	35.1	1.145
30.9	1.069	35.1	1.057	33.9	1.128	36.6	1.141
32.4	1.062	36.6	1.057	35.3	1.123	37.9	1.140
33.8	1.058	38.0	1.053	36.8	1.117	39.3	1.140
35.2	1.053	39.2	1.060	38.0	1.114		
36.6	1.053			39.3	1.113		
38.0	1.051						
39.3	1.051						

TABLE A35.- MEASURED TOTAL DRAG DATA FOR MODEL 14 (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 2		Run 4		Run 3		Run 5	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.2	1.093	7.1	1.122	7.1	1.131	7.1	1.161
8.5	1.103	8.3	1.105	7.6	1.133	8.2	1.179
9.6	1.086	9.5	1.104	8.2	1.146	9.4	1.163
10.8	1.102	10.7	1.114	9.4	1.159	10.7	1.169
11.9	1.096	11.8	1.113	10.6	1.156	11.9	1.165
13.2	1.100	13.0	1.110	11.2	1.153	13.1	1.164
14.2	1.091	14.1	1.112	11.8	1.159	14.3	1.158
15.3	1.098	15.3	1.107	12.4	1.157	15.4	1.156
16.5	1.103	16.4	1.102	13.1	1.160	16.5	1.169
17.6	1.103	17.5	1.111	14.2	1.161	17.6	1.163
18.7	1.108	18.6	1.109	15.3	1.153	18.7	1.160
19.8	1.102	19.7	1.104	16.4	1.158	19.8	1.160
21.0	1.099	20.9	1.100	17.5	1.156	20.9	1.152
22.1	1.100	22.0	1.095	18.5	1.155	22.0	1.148
23.4	1.097	23.2	1.096	19.7	1.153	23.2	1.147
24.5	1.096	24.5	1.091	20.8	1.149	24.5	1.144
25.8	1.091	25.7	1.092	22.0	1.146	25.6	1.140
26.9	1.089	26.8	1.092	23.2	1.145	26.8	1.139
28.1	1.088	28.1	1.086	24.3	1.143	28.1	1.132
29.4	1.087	29.4	1.086	25.5	1.140	29.3	1.131
30.9	1.087	30.7	1.082	26.7	1.138	30.6	1.129
32.1	1.087	32.0	1.078	28.0	1.134	31.9	1.124
33.4	1.086	33.4	1.079	29.2	1.132	33.3	1.121
34.9	1.088	34.7	1.080	29.2	1.136	34.8	1.114
36.3	1.089	36.3	1.076	30.6	1.130	36.2	1.114
39.1	1.087	37.8	1.074	31.9	1.127	37.6	1.111
40.3	1.090	39.1	1.072	33.3	1.123	39.1	1.110
		40.2	1.065	34.8	1.123	40.4	1.107
		40.3	1.074	36.2	1.117		
				37.7	1.117		
				39.0	1.113		
				40.3	1.105		

TABLE A36.- MEASURED TOTAL DRAG DATA FOR MODEL 15 (SINE WAVES AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 93		Run 95		Run 96		Run 97	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
6.9	1.109	6.9	1.099	6.9	1.170	7.0	1.177
7.5	1.148	7.4	1.141	8.1	1.218	7.6	1.231
8.0	1.162	8.0	1.140	9.2	1.220	8.1	1.221
8.7	1.140	8.0	1.134	9.3	1.232	8.8	1.230
9.3	1.157	9.3	1.131	10.0	1.234	9.3	1.229
9.9	1.148	10.5	1.134	10.5	1.227	9.9	1.231
10.5	1.154	11.7	1.129	11.0	1.243	10.5	1.241
11.0	1.149	12.8	1.123	11.7	1.241	11.2	1.241
11.6	1.142	14.0	1.125	12.2	1.245	11.8	1.240
12.3	1.141	15.1	1.133	12.8	1.244	12.4	1.233
12.9	1.136	16.2	1.133	13.9	1.237	13.0	1.242
14.0	1.136	17.3	1.135	14.9	1.248	14.0	1.242
15.1	1.134	18.3	1.133	16.1	1.246	15.2	1.246
16.2	1.134	19.6	1.126	17.2	1.251	16.2	1.242
17.3	1.130	20.7	1.134	18.3	1.249	17.3	1.251
18.4	1.132	21.9	1.131	19.5	1.246	18.5	1.248
19.5	1.125	24.3	1.134	20.6	1.252	19.6	1.241
20.7	1.129	26.7	1.126	21.8	1.246	20.7	1.248
21.8	1.125	29.2	1.126	23.1	1.250	22.0	1.247
23.0	1.124	31.9	1.122	24.2	1.245	23.1	1.249
24.1	1.125	34.7	1.121	25.4	1.242	24.3	1.246
25.4	1.119	34.8	1.120	26.7	1.236	25.5	1.241
26.6	1.116	34.7	1.123	27.9	1.233	26.7	1.240
27.8	1.115	37.5	1.122	29.2	1.232	28.0	1.235
29.1	1.112	38.9	1.125	30.5	1.230	29.2	1.234
30.4	1.113			31.9	1.226	30.6	1.231
31.8	1.110			33.3	1.217	31.9	1.227
33.1	1.109			34.8	1.207	33.4	1.219
34.7	1.106			36.4	1.206	34.9	1.217
36.2	1.101			37.7	1.206	36.2	1.215
37.5	1.102			39.0	1.208	37.6	1.210
38.8	1.105					38.9	1.213
						40.3	1.201

TABLE A37.- MEASURED TOTAL DRAG DATA FOR MODEL 17 (TRANSVERSE V-GROOVES)

Forward direction

Run 77		Run 78	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.0	1.063	7.1	1.086
7.5	1.114	8.2	1.103
8.1	1.114	9.5	1.094
8.8	1.103	10.6	1.109
9.3	1.113	11.7	1.105
9.9	1.112	12.9	1.104
10.4	1.115	14.0	1.114
11.6	1.107	15.1	1.118
12.8	1.104	16.3	1.116
13.9	1.115	17.3	1.117
15.0	1.116	19.5	1.109
16.2	1.125	20.7	1.113
17.2	1.123	21.8	1.110
18.3	1.123	22.9	1.111
19.5	1.123	24.1	1.108
20.6	1.117	25.3	1.109
21.8	1.116	26.5	1.109
23.0	1.120	27.8	1.107
24.1	1.116	29.0	1.106
25.3	1.117	30.3	1.105
26.5	1.110	31.7	1.102
27.8	1.109	33.0	1.102
29.0	1.109	34.5	1.096
30.3	1.106	35.9	1.095
31.6	1.102	37.3	1.097
33.0	1.103	38.6	1.093
34.5	1.099		
35.9	1.095		
37.3	1.098		
38.7	1.099		

Reverse direction

Run 79		Run 81	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.1	1.067	7.0	1.090
7.6	1.077	7.5	1.094
8.3	1.101	8.1	1.105
9.4	1.091	8.7	1.106
10.6	1.095	9.3	1.113
11.8	1.102	9.9	1.113
12.9	1.099	10.5	1.117
14.2	1.104	11.0	1.114
15.2	1.109	11.7	1.106
16.3	1.108	12.8	1.112
17.4	1.111	13.9	1.106
19.6	1.113	13.9	1.111
21.8	1.106	15.1	1.104
24.2	1.109	16.1	1.101
26.5	1.106	17.3	1.100
29.1	1.101	18.4	1.105
31.7	1.096	19.5	1.102
34.4	1.085	20.7	1.095
36.0	1.087	21.8	1.102
37.3	1.088	23.0	1.103
38.7	1.085	24.3	1.097
		25.4	1.099
		26.6	1.093
		27.9	1.093
		29.2	1.089
		30.5	1.088
		31.9	1.084
		33.2	1.082
		34.7	1.076
		36.0	1.075
		37.6	1.070
		38.7	1.075

TABLE A38.- MEASURED TOTAL DRAG DATA FOR MODEL 18 (TRANSVERSE V-GROOVES)

Forward direction				Reverse direction			
Run 80		Run 82		Run 84		Run 85	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.1	1.069	7.1	1.040	7.1	1.128	7.1	1.089
7.6	1.084	8.2	1.051	7.8	1.143	8.3	1.119
8.2	1.090	9.3	1.071	8.2	1.131	9.5	1.132
8.8	1.085	10.5	1.091	8.8	1.130	10.6	1.139
9.4	1.101	11.7	1.088	9.4	1.134	11.8	1.136
10.4	1.093	12.9	1.084	10.0	1.147	12.9	1.142
11.7	1.091	14.1	1.094	10.6	1.150	14.0	1.145
12.9	1.090	15.2	1.093	11.2	1.151	15.1	1.147
14.0	1.093	16.3	1.096	11.8	1.148	16.3	1.151
15.1	1.097	17.3	1.097	12.9	1.151	17.4	1.149
16.3	1.100	18.5	1.092	14.1	1.143	18.5	1.152
17.3	1.100	19.5	1.096	15.2	1.145	19.6	1.154
18.4	1.099	20.7	1.091	16.4	1.149	20.7	1.149
19.6	1.097	23.6	1.092	17.4	1.143	21.9	1.149
20.7	1.099	26.7	1.088	18.5	1.141	23.0	1.150
21.8	1.098	29.2	1.084	20.8	1.145	24.4	1.146
23.0	1.096	31.8	1.083	23.0	1.147	25.5	1.139
24.3	1.094	33.3	1.081	25.4	1.144	26.7	1.141
25.5	1.095	34.7	1.079	28.0	1.135	27.9	1.142
26.7	1.093	36.1	1.076	30.6	1.132	29.2	1.138
28.0	1.091	37.5	1.078	31.9	1.130	30.5	1.137
29.2	1.087	38.9	1.076	33.4	1.124	32.1	1.135
30.5	1.086			34.7	1.118	33.5	1.127
31.7	1.084			36.2	1.120	34.8	1.122
33.3	1.079			37.5	1.117	36.2	1.120
34.6	1.078			38.9	1.110	37.6	1.119
36.2	1.074					38.9	1.115
37.4	1.073						
38.8	1.075						

TABLE A39.- MEASURED TOTAL DRAG DATA FOR MODEL 19 (TRANSVERSE V-GROOVES)

Forward direction				Reverse direction			
Run 86		Run 87		Run 88		Run 89	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.0	1.052	7.1	1.092	7.2	1.123	7.1	1.135
8.2	1.072	8.3	1.116	8.3	1.144	8.4	1.142
9.5	1.085	9.6	1.095	9.6	1.138	9.7	1.148
10.5	1.095	10.8	1.102	10.8	1.148	10.8	1.148
11.6	1.101	11.9	1.110	12.0	1.159	11.9	1.148
12.7	1.106	13.0	1.102	13.0	1.158	13.1	1.144
13.9	1.106	14.1	1.107	14.2	1.164	14.2	1.158
15.0	1.113	15.2	1.115	15.3	1.166	15.4	1.162
16.1	1.105	16.4	1.115	16.4	1.171	16.5	1.167
17.2	1.111	17.4	1.116	17.6	1.171	17.6	1.172
18.3	1.113	18.5	1.118	18.7	1.176	18.7	1.172
19.5	1.114	19.6	1.114	19.8	1.173	19.8	1.173
20.7	1.117	20.8	1.113	20.9	1.176	20.9	1.173
21.8	1.115	21.9	1.114	22.1	1.171	22.1	1.170
23.0	1.116	23.1	1.114	23.3	1.175	23.2	1.172
24.3	1.114	24.3	1.114	24.4	1.166	24.4	1.172
25.4	1.113	25.4	1.111	25.6	1.171	25.6	1.170
26.7	1.112	26.7	1.108	26.8	1.170	27.0	1.171
27.9	1.112	27.8	1.109	28.2	1.165	28.2	1.170
29.3	1.108	29.2	1.104	29.3	1.167	29.5	1.170
30.6	1.108	30.4	1.104	30.6	1.165	30.8	1.167
31.9	1.109	31.8	1.103	32.0	1.161	33.5	1.155
33.3	1.107	33.0	1.102	33.4	1.154	35.0	1.149
34.8	1.103	34.5	1.096	34.7	1.151	36.3	1.150
36.2	1.104	35.9	1.094	36.2	1.148	37.7	1.141
37.6	1.108	37.2	1.097	37.5	1.143	39.1	1.146
38.9	1.110	38.6	1.097	38.9	1.135		
				40.2	1.138		

TABLE A40.- MEASURED TOTAL DRAG DATA FOR MODEL 24 (CIRCULAR ARCS AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 49		Run 50		Run 51		Run 52	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.2	1.153	7.2	1.125	7.4	1.186	7.2	1.156
7.8	1.162	7.8	1.153	7.9	1.190	7.8	1.173
8.4	1.175	8.5	1.152	8.6	1.198	8.5	1.183
9.1	1.172	9.1	1.164	9.2	1.191	9.1	1.186
9.7	1.177	9.7	1.160	9.8	1.201	9.6	1.205
10.3	1.178	10.3	1.165	10.4	1.210	10.2	1.201
10.8	1.176	10.9	1.169	11.0	1.214	10.8	1.207
11.4	1.164	11.5	1.164	11.6	1.213	11.5	1.215
12.0	1.178	11.5	1.171	12.2	1.213	12.0	1.207
13.1	1.170	12.1	1.172	13.3	1.219	13.2	1.221
14.2	1.164	13.3	1.167	14.5	1.231	14.3	1.226
15.3	1.168	14.4	1.171	15.6	1.237	15.4	1.232
16.5	1.166	15.0	1.170	16.7	1.244	16.5	1.233
17.6	1.163	15.6	1.172	17.8	1.243	17.6	1.244
18.8	1.166	16.7	1.168	18.9	1.242	18.8	1.244
20.0	1.161	17.8	1.171	20.0	1.250	20.0	1.244
21.1	1.159	18.9	1.166	21.2	1.254	21.1	1.252
22.3	1.157	20.1	1.164	22.4	1.250	22.3	1.252
23.5	1.157	21.2	1.164	23.5	1.257	23.6	1.251
24.7	1.154	22.3	1.161	24.7	1.257	24.6	1.256
25.9	1.154	23.5	1.159	25.9	1.257	25.9	1.256
27.1	1.148	24.7	1.157	27.1	1.258	27.1	1.259
28.3	1.147	25.9	1.159	28.3	1.260	28.3	1.259
29.7	1.146	27.1	1.147	29.7	1.261	29.7	1.258
31.0	1.146	28.4	1.147	30.9	1.266	31.0	1.260
32.4	1.141	29.6	1.149	32.3	1.263	32.3	1.265
35.2	1.134	31.0	1.147	33.7	1.265	33.7	1.263
36.6	1.135	32.4	1.144	35.2	1.266	35.1	1.260
38.0	1.132	33.8	1.140	36.6	1.279	36.6	1.264
39.4	1.133	35.1	1.138	38.0	1.282	37.9	1.263
		36.7	1.132	39.4	1.282	39.3	1.262
		38.1	1.134				
		39.4	1.134				

TABLE A41.- MEASURED TOTAL DRAG DATA FOR MODEL 34 (CIRCULAR ARCS AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 58		Run 59		Run 60		Run 61	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.2	1.066	7.2	1.084	7.4	1.082	7.5	1.182
7.9	1.067	7.8	1.084	8.0	1.075	8.0	1.214
8.4	1.087	8.4	1.083	8.6	1.087	8.6	1.149
9.0	1.085	9.0	1.089	9.2	1.090	9.2	1.104
9.6	1.089	9.6	1.102	9.8	1.105	9.8	1.097
10.2	1.093	10.2	1.088	11.0	1.106	10.4	1.105
10.8	1.098	10.8	1.096	12.1	1.102	11.0	1.105
11.4	1.102	11.4	1.094	13.4	1.121	11.5	1.109
12.0	1.101	12.0	1.101	14.4	1.121	12.2	1.114
13.0	1.103	13.1	1.099	15.6	1.124	13.3	1.120
14.2	1.111	14.2	1.108	16.7	1.135	14.4	1.124
15.2	1.111	15.3	1.113	17.8	1.142	15.5	1.127
16.3	1.113	16.5	1.119	18.9	1.147	16.7	1.141
17.5	1.118	17.5	1.124	20.1	1.154	17.8	1.142
18.6	1.119	18.6	1.124	21.3	1.161	18.9	1.147
19.9	1.121	19.9	1.124	22.4	1.163	20.0	1.156
21.0	1.122	21.1	1.127	23.6	1.170	21.2	1.154
22.1	1.122	22.2	1.126	24.8	1.173	22.4	1.160
23.4	1.126	23.4	1.128	25.9	1.177	23.5	1.169
24.5	1.125	24.6	1.125	27.2	1.178	24.7	1.173
25.7	1.125	25.8	1.128	29.7	1.184	25.9	1.177
26.9	1.125	27.0	1.129	32.4	1.195	27.1	1.178
28.2	1.124	28.3	1.125	35.2	1.190	28.4	1.181
29.4	1.126	29.5	1.124	38.1	1.193	29.6	1.187
30.8	1.123	30.9	1.126	39.4	1.207	30.9	1.194
32.2	1.124	32.2	1.123			32.3	1.198
33.6	1.123	33.6	1.125			33.8	1.197
35.0	1.120	35.1	1.121			35.2	1.201
36.4	1.117	36.6	1.121			36.6	1.206
37.7	1.120	38.0	1.122			38.0	1.212
39.1	1.119	39.3	1.126			39.3	1.216

TABLE A42.- MEASURED TOTAL DRAG DATA FOR MODEL 44 (CIRCULAR ARCS AND STRAIGHT RAMPS)

Forward direction				Reverse direction			
Run 54		Run 55		Run 57		Run 56	
U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o	U_∞, m/s	D/D_o
7.3	1.119	7.4	1.108	7.5	1.339	7.4	1.258
7.9	1.118	8.0	1.128	8.1	1.275	7.4	1.254
8.5	1.118	8.6	1.119	8.7	1.231	8.0	1.253
9.1	1.123	9.2	1.121	9.3	1.245	8.6	1.272
9.7	1.127	9.8	1.120	9.9	1.252	9.3	1.256
10.3	1.126	10.4	1.124	10.6	1.242	9.9	1.268
10.9	1.121	11.0	1.125	11.1	1.244	10.5	1.273
11.5	1.123	11.6	1.125	12.3	1.256	11.1	1.273
12.1	1.129	12.2	1.130	13.5	1.267	11.7	1.277
13.2	1.132	13.3	1.125	14.6	1.272	12.2	1.270
14.4	1.132	14.4	1.124	15.7	1.271	13.4	1.278
15.5	1.130	15.6	1.121	16.8	1.275	14.6	1.275
16.6	1.132	16.7	1.127	17.9	1.273	15.7	1.281
17.7	1.130	17.8	1.122	19.0	1.279	16.8	1.280
18.8	1.129	18.9	1.125	20.2	1.277	17.9	1.281
20.0	1.126	20.1	1.125	21.3	1.283	19.0	1.281
21.2	1.125	21.3	1.122	22.4	1.283	20.1	1.276
22.3	1.125	22.4	1.124	23.7	1.283	21.3	1.277
23.5	1.126	23.6	1.121	24.8	1.279	22.4	1.279
24.6	1.123	24.8	1.123	26.0	1.276	23.6	1.272
25.9	1.122	26.0	1.118	27.2	1.272	24.9	1.276
27.1	1.121	27.2	1.119	28.5	1.269	26.0	1.272
28.4	1.120	28.5	1.119	29.8	1.270	27.2	1.268
29.6	1.121	29.7	1.120	31.0	1.269	28.4	1.265
30.9	1.122	31.0	1.119	32.3	1.266	29.8	1.265
32.3	1.122	32.3	1.117	33.8	1.262	31.0	1.260
33.8	1.118	33.8	1.114	35.2	1.261	32.4	1.255
35.2	1.118	35.3	1.109	36.6	1.253	33.7	1.257
36.6	1.120	36.7	1.111	38.1	1.251	35.2	1.249
38.0	1.117	38.1	1.112	39.4	1.250	36.7	1.241
39.4	1.116	39.4	1.115			38.0	1.244
						39.3	1.243

TABLE A43.- MEASURED C_p DATA FOR MODEL 1 (SINE WAVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.003	-.0151	-.0163	-.0165	-.0169
.055	-.0137	-.0151	-.0168	-.0157
.104	-.0160	-.0179	-.0181	-.0194
.155	-.0136	-.0158	-.0164	-.0167
.205	-.0105	-.0120	-.0116	-.0112
.256	-.0065	-.0065	-.0058	-.0042
.305	.0007	.0008	.0015	.0049
.354	.0042	.0075	.0090	.0123
.405	.0094	.0119	.0139	.0168
.455	.0126	.0157	.0181	.0198
.505	.0144	.0189	.0197	.0228
.555	.0168	.0179	.0217	.0235
.604	.0176	.0195	.0232	.0243
.656	.0179	.0190	.0202	.0231
.704	.0142	.0172	.0158	.0183
.755	.0099	.0102	.0098	.0117
.804	.0025	.0022	.0031	.0022
.855	-.0030	-.0027	-.0030	-.0041
.905	-.0081	-.0095	-.0100	-.0104
.955	-.0112	-.0132	-.0140	-.0130

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.045	-.0074	-.0102	-.0095	-.0099
.095	-.0063	-.0065	-.0078	-.0081
.145	-.0031	-.0065	-.0051	-.0043
.196	.0008	-.0023	.0010	.0016
.245	.0031	.0052	.0064	.0082
.296	.0073	.0085	.0117	.0133
.344	.0156	.0139	.0173	.0207
.396	.0161	.0190	.0229	.0251
.445	.0179	.0210	.0229	.0276
.495	.0203	.0217	.0247	.0270
.545	.0194	.0233	.0229	.0261
.595	.0185	.0233	.0239	.0258
.646	.0184	.0179	.0199	.0223
.695	.0151	.0154	.0160	.0169
.745	.0063	.0087	.0090	.0104
.795	-.0020	.0012	.0008	.0019
.845	-.0034	-.0049	-.0055	-.0059
.896	-.0084	-.0143	-.0106	-.0110
.945	-.0092	-.0113	-.0129	-.0121
.997	-.0103	-.0100	-.0115	-.0111

TABLE A44.- MEASURED C_p DATA FOR MODEL 2 (SINE WAVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.024	-.0293	-.0340	-.0372	-.0392
.076	-.0293	-.0325	-.0348	-.0369
.123	-.0246	-.0259	-.0284	-.0299
.173	-.0163	-.0177	-.0186	-.0175
.225	-.0053	-.0040	-.0045	-.0028
.277	.0045	.0056	.0087	.0125
.326	.0119	.0167	.0201	.0252
.376	.0209	.0276	.0304	.0357
.426	.0302	.0359	.0407	.0452
.474	.0345	.0399	.0467	.0512
.524	.0393	.0423	.0468	.0525
.573	.0421	.0440	.0501	.0541
.625	.0382	.0418	.0463	.0489
.675	.0382	.0387	.0395	.0425
.723	.0280	.0285	.0294	.0323
.775	.0126	.0139	.0130	.0135
.823	.0018	-.0024	-.0034	-.0046
.874	-.0131	-.0159	-.0192	-.0212
.926	-.0236	-.0270	-.0316	-.0324
.973	-.0291	-.0320	-.0353	-.0379

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.027	-.0358	-.0377	-.0419	-.0444
.074	-.0318	-.0355	-.0396	-.0417
.126	-.0281	-.0302	-.0345	-.0341
.177	-.0191	-.0186	-.0216	-.0213
.225	-.0090	-.0087	-.0080	-.0066
.277	.0012	.0047	.0074	.0114
.325	.0114	.0149	.0176	.0216
.375	.0194	.0249	.0289	.0334
.427	.0257	.0337	.0363	.0415
.476	.0357	.0371	.0426	.0443
.526	.0369	.0393	.0432	.0466
.574	.0376	.0389	.0422	.0441
.625	.0353	.0367	.0377	.0415
.674	.0332	.0306	.0321	.0329
.723	.0233	.0233	.0223	.0233
.775	.0125	.0098	.0098	.0093
.827	-.0026	-.0061	-.0086	-.0102
.877	-.0179	-.0195	-.0261	-.0256
.924	-.0284	-.0304	-.0372	-.0354
.976	-.0346	-.0379	-.0416	-.0444

TABLE A45.- MEASURED C_p DATA FOR MODEL 16 (SINE WAVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.025	-.0476	-.0542	-.0580	-.0628
.056	-.0455	-.0520	-.0558	-.0616
.091	-.0432	-.0462	-.0515	-.0548
.130	-.0336	-.0392	-.0442	-.0464
.164	-.0283	-.0320	-.0346	-.0350
.194	-.0223	-.0242	-.0256	-.0265
.231	-.0144	-.0148	-.0143	-.0134
.266	-.0054	-.0059	-.0044	-.0014
.297	.0010	.0039	.0068	.0107
.332	.0083	.0130	.0186	.0244
.370	.0163	.0238	.0307	.0393
.399	.0226	.0316	.0410	.0484
.440	.0319	.0424	.0514	.0590
.483	.0411	.0523	.0605	.0692
.509	.0463	.0548	.0637	.0695
.541	.0488	.0594	.0642	.0693
.571	.0495	.0604	.0653	.0671
.610	.0502	.0556	.0582	.0620
.645	.0451	.0491	.0523	.0551
.676	.0398	.0425	.0431	.0439
.714	.0305	.0310	.0323	.0335
.742	.0212	.0206	.0215	.0213
.749	.0171	.0157	.0165	.0167
.782	.0093	.0072	.0066	.0062
.816	.0011	-.0019	-.0031	-.0032
.849	-.0130	-.0175	-.0215	-.0231
.887	-.0266	-.0314	-.0357	-.0386
.918	-.0348	-.0434	-.0470	-.0503
.957	-.0430	-.0518	-.0555	-.0606
.986	-.0453	-.0529	-.0597	-.0635

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.014	-.0484	-.0531	-.0583	-.0617
.043	-.0473	-.0533	-.0578	-.0604
.082	-.0432	-.0481	-.0526	-.0573
.113	-.0392	-.0430	-.0462	-.0494
.151	-.0311	-.0331	-.0365	-.0367
.184	-.0222	-.0250	-.0259	-.0271
.218	-.0154	-.0198	-.0149	-.0152
.251	-.0086	-.0075	-.0058	-.0031
.258	-.0081	-.0067	-.0048	-.0028
.286	-.0019	.0010	.0049	.0069
.324	.0067	.0105	.0156	.0212
.355	.0124	.0195	.0261	.0314
.390	.0208	.0293	.0362	.0438
.429	.0315	.0400	.0492	.0545
.459	.0379	.0468	.0549	.0627
.491	.0432	.0531	.0588	.0663
.517	.0492	.0551	.0635	.0667
.560	.0506	.0583	.0620	.0677
.601	.0503	.0555	.0599	.0646
.630	.0479	.0504	.0537	.0570
.668	.0412	.0430	.0447	.0472
.703	.0332	.0332	.0360	.0372
.734	.0244	.0237	.0254	.0250
.769	.0123	.0099	.0097	.0097
.806	-.0003	-.0031	-.0051	-.0053
.836	-.0113	-.0153	-.0170	-.0185
.870	-.0236	-.0285	-.0316	-.0342
.909	-.0347	-.0392	-.0430	-.0472
.944	-.0421	-.0478	-.0522	-.0552
.975	-.0481	-.0522	-.0562	-.0614

TABLE A46.- MEASURED C_p DATA FOR MODEL 3 (SINE WAVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.004	-.0509	-.0610	-.0675	-.0729
.055	-.0517	-.0617	-.0687	-.0743
.106	-.0493	-.0567	-.0631	-.0686
.155	-.0398	-.0447	-.0501	-.0534
.204	-.0244	-.0305	-.0308	-.0335
.256	-.0129	-.0142	-.0148	-.0124
.307	.0014	.0011	.0050	.0122
.355	.0119	.0188	.0304	.0392
.405	.0228	.0399	.0515	.0598
.454	.0401	.0526	.0636	.0722
.503	.0536	.0661	.0734	.0811
.553	.0588	.0701	.0778	.0854
.603	.0673	.0732	.0798	.0856
.652	.0630	.0699	.0726	.0785
.702	.0575	.0553	.0611	.0648
.802	.0066	.0002	-.0013	-.0022
.853	-.0201	-.0288	-.0336	-.0369
.903	-.0400	-.0485	-.0561	-.0588
.954	-.0502	-.0578	-.0650	-.0692

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.046	-.0565	-.0628	-.0684	-.0745
.097	-.0500	-.0559	-.0613	-.0668
.147	-.0389	-.0429	-.0480	-.0508
.198	-.0273	-.0265	-.0293	-.0308
.298	-.0060	-.0012	.0055	.0125
.348	.0114	.0227	.0353	.0461
.397	.0264	.0449	.0574	.0666
.447	.0445	.0611	.0701	.0783
.497	.0556	.0644	.0742	.0762
.546	.0557	.0648	.0685	.0737
.595	.0554	.0591	.0641	.0660
.645	.0497	.0541	.0553	.0587
.693	.0391	.0387	.0398	.0428
.744	.0203	.0190	.0180	.0175
.796	-.0048	-.0101	-.0111	-.0133
.845	-.0302	-.0369	-.0435	-.0473
.894	-.0502	-.0567	-.0656	-.0721
.945	-.0550	-.0647	-.0707	-.0781
.995	-.0607	-.0641	-.0718	-.0773

TABLE A47.- MEASURED C_p DATA FOR MODEL VI (SINE WAVES, λ = 1.27 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.026	-.0087	-.0100	-.0116	-.0110
.059	-.0088	-.0105	-.0115	-.0107
.098	-.0082	-.0100	-.0103	-.0095
.132	-.0076	-.0076	-.0084	-.0078
.173	-.0055	-.0052	-.0048	-.0026
.248	.0014	.0019	.0037	.0054
.287	.0035	.0050	.0072	.0097
.321	.0062	.0082	.0110	.0136
.359	.0085	.0119	.0141	.0172
.394	.0108	.0136	.0165	.0202
.431	.0123	.0146	.0184	.0229
.466	.0129	.0171	.0209	.0250
.507	.0139	.0172	.0195	.0234
.539	.0134	.0164	.0191	.0216
.581	.0126	.0156	.0177	.0205
.614	.0115	.0139	.0154	.0181
.656	.0102	.0108	.0115	.0161
.685	.0086	.0092	.0105	.0113
.726	.0064	.0068	.0085	.0087
.760	.0041	.0044	.0043	.0053
.802	.0008	.0006	.0007	.0022
.838	-.0010	-.0015	-.0017	-.0019
.876	-.0034	-.0046	-.0057	-.0038
.908	-.0051	-.0054	-.0075	-.0074
.951	-.0069	-.0097	-.0099	-.0100
.985	-.0072	-.0096	-.0108	-.0104

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.015	-.0055	-.0084	-.0089	-.0092
.049	-.0074	-.0093	-.0096	-.0101
.092	-.0077	-.0089	-.0087	-.0081
.124	-.0075	-.0084	-.0085	-.0087
.162	-.0056	-.0063	-.0068	-.0065
.198	-.0039	-.0051	-.0055	-.0039
.240	-.0027	-.0030	-.0025	-.0016
.274	-.0020	-.0014	-.0014	.0002
.315	.0011	.0018	.0028	.0042
.344	.0025	.0041	.0047	.0068
.386	.0051	.0063	.0080	.0107
.419	.0059	.0076	.0106	.0125
.461	.0079	.0117	.0133	.0158
.493	.0100	.0134	.0153	.0187
.534	.0124	.0156	.0182	.0213
.569	.0152	.0181	.0208	.0241
.606	.0147	.0197	.0222	.0255
.641	.0163	.0203	.0226	.0259
.679	.0169	.0195	.0230	.0264
.713	.0169	.0206	.0230	.0258
.752	.0147	.0170	.0191	.0216
.807	.0092	.0108	.0113	.0124
.868	.0003	-.0002	-.0006	.0002
.902	-.0026	-.0026	-.0041	-.0023
.941	-.0042	-.0052	-.0058	-.0051
.974	-.0057	-.0060	-.0076	-.0073

TABLE A48.- MEASURED C_p DATA FOR MODEL VII (SINE WAVES, λ = 5.08 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.008	-.0168	-.0183	-.0186	-.0170
.041	-.0163	-.0174	-.0177	-.0162
.074	-.0149	-.0150	-.0153	-.0134
.107	-.0119	-.0131	-.0121	-.0103
.139	-.0089	-.0085	-.0076	-.0059
.172	-.0043	-.0033	-.0020	.0002
.205	-.0001	.0008	.0033	.0060
.237	.0053	.0067	.0086	.0107
.270	.0082	.0112	.0125	.0160
.303	.0130	.0162	.0195	.0211
.335	.0181	.0217	.0241	.0257
.368	.0226	.0256	.0281	.0306
.401	.0252	.0286	.0307	.0335
.485	.0285	.0298	.0340	.0367
.518	.0282	.0284	.0319	.0349
.551	.0252	.0276	.0300	.0320
.583	.0248	.0248	.0275	.0289
.616	.0211	.0218	.0230	.0240
.649	.0173	.0172	.0187	.0201
.681	.0131	.0128	.0128	.0148
.714	.0068	.0075	.0077	.0099
.747	.0022	.0019	.0022	.0031
.780	-.0021	-.0028	-.0031	-.0011
.812	-.0068	-.0081	-.0082	-.0073
.845	-.0102	-.0112	-.0122	-.0105
.878	-.0135	-.0140	-.0141	-.0140
.910	-.0146	-.0163	-.0164	-.0158
.943	-.0154	-.0163	-.0163	-.0150
.976	-.0166	-.0166	-.0165	-.0155

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.024	-.0231	-.0244	-.0253	-.0257
.057	-.0231	-.0240	-.0251	-.0239
.090	-.0236	-.0237	-.0253	-.0241
.122	-.0217	-.0235	-.0233	-.0237
.155	-.0208	-.0209	-.0208	-.0207
.188	-.0179	-.0178	-.0178	-.0179
.220	-.0132	-.0149	-.0137	-.0126
.253	-.0101	-.0089	-.0084	-.0065
.286	-.0035	-.0044	-.0028	.0001
.319	-.0003	.0014	.0032	.0051
.351	.0045	.0078	.0086	.0099
.384	.0102	.0119	.0143	.0161
.417	.0152	.0176	.0190	.0214
.449	.0197	.0211	.0235	.0254
.482	.0227	.0237	.0267	.0276
.515	.0250	.0266	.0292	.0310
.599	.0227	.0238	.0254	.0256
.632	.0208	.0218	.0229	.0241
.665	.0176	.0186	.0188	.0198
.697	.0142	.0135	.0159	.0159
.730	.0101	.0088	.0089	.0095
.763	.0041	.0043	.0040	.0047
.795	-.0003	-.0006	-.0002	.0003
.828	-.0070	-.0051	-.0059	-.0055
.861	-.0099	-.0111	-.0116	-.0119
.893	-.0140	-.0159	-.0171	-.0174
.926	-.0186	-.0199	-.0206	-.0214
.959	-.0209	-.0229	-.0235	-.0243
.992	-.0236	-.0252	-.0263	-.0263

TABLE A49.- MEASURED C_p DATA FOR MODEL V (SPLICED SINE WAVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.030	-.0168	-.0176	-.0187	-.0185
.067	-.0170	-.0180	-.0195	-.0205
.101	-.0157	-.0172	-.0181	-.0183
.135	-.0125	-.0137	-.0143	-.0144
.170	-.0086	-.0083	-.0069	-.0067
.205	-.0025	-.0012	.0001	.0015
.241	.0026	.0048	.0066	.0085
.275	.0070	.0099	.0129	.0148
.309	.0105	.0146	.0166	.0196
.334	.0132	.0173	.0193	.0224
.369	.0144	.0185	.0217	.0251
.404	.0179	.0213	.0245	.0274
.439	.0170	.0213	.0246	.0283
.474	.0184	.0198	.0225	.0243
.509	.0174	.0190	.0211	.0235
.544	.0153	.0183	.0193	.0203
.577	.0140	.0161	.0165	.0174
.613	.0117	.0121	.0130	.0143
.648	.0089	.0091	.0096	.0110
.683	.0051	.0052	.0050	.0066
.718	.0020	.0015	.0009	.0020
.752	-.0011	-.0012	-.0016	-.0020
.788	-.0034	-.0040	-.0045	-.0058
.823	-.0060	-.0075	-.0075	-.0077
.857	-.0089	-.0095	-.0107	-.0091
.892	-.0110	-.0119	-.0133	-.0127
.927	-.0131	-.0143	-.0150	-.0151
.962	-.0143	-.0157	-.0166	-.0166
.997	-.0165	-.0175	-.0187	-.0180

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.004	-.0155	-.0176	-.0178	-.0200
.038	-.0152	-.0170	-.0176	-.0183
.073	-.0149	-.0158	-.0164	-.0152
.108	-.0130	-.0140	-.0152	-.0155
.143	-.0116	-.0121	-.0134	-.0136
.177	-.0103	-.0104	-.0100	-.0106
.212	-.0078	-.0087	-.0086	-.0074
.248	-.0058	-.0055	-.0054	-.0047
.282	-.0038	-.0031	-.0022	-.0014
.317	-.0010	-.0003	.0014	.0024
.352	.0013	.0029	.0038	.0059
.387	.0049	.0059	.0082	.0100
.423	.0077	.0102	.0123	.0142
.456	.0102	.0138	.0158	.0170
.491	.0128	.0156	.0186	.0212
.526	.0160	.0186	.0214	.0240
.561	.0185	.0213	.0251	.0268
.596	.0199	.0233	.0264	.0287
.631	.0220	.0258	.0290	.0318
.666	.0223	.0235	.0262	.0286
.691	.0198	.0211	.0236	.0260
.725	.0183	.0207	.0216	.0238
.759	.0155	.0167	.0180	.0189
.795	.0107	.0106	.0114	.0122
.830	.0049	.0040	.0040	.0046
.865	-.0004	-.0027	-.0036	-.0033
.899	-.0083	-.0099	-.0116	-.0121
.933	-.0124	-.0155	-.0168	-.0174
.970	-.0148	-.0167	-.0182	-.0185

TABLE A50.- MEASURED C_p DATA FOR MODEL I (SINE WAVES AND STRAIGHT RAMPS, λ = 4.62 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.035	-.0160	-.0165	-.0167	-.0166
.070	-.0128	-.0139	-.0127	-.0123
.105	-.0098	-.0114	-.0104	-.0097
.140	-.0094	-.0096	-.0085	-.0084
.174	-.0080	-.0073	-.0072	-.0062
.209	-.0062	-.0055	-.0050	-.0044
.244	-.0047	-.0050	-.0043	-.0025
.279	-.0044	-.0039	-.0029	-.0017
.313	-.0030	-.0028	-.0013	-.0003
.348	-.0013	-.0015	.0003	.0016
.382	-.0002	-.0009	.0005	.0025
.418	.0004	.0003	.0022	.0035
.452	.0005	.0015	.0025	.0029
.487	.0015	.0017	.0028	.0036
.522	.0029	.0023	.0034	.0051
.557	.0032	.0040	.0057	.0068
.591	.0044	.0054	.0064	.0077
.626	.0065	.0073	.0086	.0107
.661	.0087	.0094	.0105	.0119
.696	.0100	.0103	.0119	.0140
.731	.0121	.0131	.0151	.0170
.765	.0134	.0161	.0183	.0198
.800	.0144	.0153	.0169	.0191
.835	.0116	.0119	.0131	.0149
.870	.0064	.0064	.0059	.0080
.905	.0032	.0027	.0033	.0042
.939	-.0036	-.0035	-.0030	-.0029
.974	-.0081	-.0098	-.0107	-.0094

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.026	-.0143	-.0149	-.0149	-.0147
.061	-.0109	-.0109	-.0111	-.0105
.095	-.0057	-.0053	-.0050	-.0037
.130	-.0019	-.0013	.0005	.0021
.165	.0020	.0041	.0055	.0074
.200	.0072	.0089	.0115	.0139
.235	.0116	.0135	.0165	.0180
.269	.0132	.0141	.0170	.0176
.304	.0118	.0129	.0154	.0166
.339	.0106	.0106	.0118	.0120
.374	.0086	.0092	.0103	.0106
.409	.0069	.0078	.0082	.0095
.443	.0046	.0061	.0068	.0081
.478	.0049	.0047	.0061	.0060
.513	.0027	.0035	.0037	.0049
.547	.0024	.0027	.0032	.0041
.582	.0030	.0031	.0032	.0044
.618	.0017	.0019	.0027	.0032
.652	.0011	.0010	.0024	.0018
.687	.0006	.0008	.0018	.0015
.721	.0000	-.0005	-.0001	.0011
.756	-.0016	-.0012	-.0008	-.0007
.791	-.0025	-.0024	-.0016	-.0014
.826	-.0037	-.0039	-.0028	-.0029
.860	-.0053	-.0054	-.0041	-.0054
.895	-.0065	-.0069	-.0060	-.0059
.930	-.0075	-.0086	-.0072	-.0080
.965	-.0095	-.0118	-.0108	-.0111

TABLE A51.- MEASURED C_p DATA FOR MODEL II (SINE WAVES AND STRAIGHT RAMPS, λ = 4.01 cm

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.014	-.0118	-.0130	-.0122	-.0127
.049	-.0102	-.0110	-.0100	-.0102
.084	-.0088	-.0088	-.0084	-.0075
.119	-.0082	-.0067	-.0056	-.0054
.170	-.0062	-.0071	-.0059	-.0039
.205	-.0053	-.0049	-.0044	-.0032
.240	-.0060	-.0035	-.0032	-.0024
.275	-.0038	-.0034	-.0023	-.0001
.310	-.0016	-.0012	-.0005	.0001
.345	-.0016	-.0004	.0003	.0018
.381	-.0002	.0007	.0016	.0030
.416	-.0004	.0013	.0019	.0040
.451	.0018	.0013	.0030	.0043
.486	.0012	.0029	.0031	.0037
.521	.0022	.0039	.0047	.0059
.556	.0047	.0062	.0073	.0090
.592	.0064	.0089	.0108	.0124
.627	.0094	.0116	.0147	.0162
.662	.0125	.0148	.0180	.0207
.697	.0139	.0163	.0199	.0224
.732	.0144	.0157	.0182	.0200
.767	.0119	.0132	.0140	.0156
.803	.0078	.0091	.0106	.0104
.838	.0052	.0061	.0069	.0080
.873	.0009	.0009	.0014	.0023
.908	-.0051	-.0055	-.0053	-.0054
.943	-.0089	-.0099	-.0107	-.0105
.978	-.0114	-.0131	-.0119	-.0122

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.022	-.0112	-.0120	-.0130	-.0134
.057	-.0113	-.0124	-.0131	-.0132
.092	-.0090	-.0101	-.0105	-.0103
.127	-.0060	-.0056	-.0051	-.0045
.162	-.0006	.0001	.0010	.0032
.197	.0031	.0038	.0040	.0061
.233	.0073	.0075	.0094	.0112
.268	.0108	.0115	.0143	.0170
.303	.0134	.0151	.0183	.0209
.338	.0146	.0172	.0209	.0216
.373	.0149	.0170	.0187	.0202
.408	.0136	.0143	.0150	.0165
.444	.0109	.0111	.0118	.0128
.479	.0083	.0081	.0080	.0093
.514	.0052	.0051	.0056	.0065
.549	.0038	.0044	.0049	.0053
.584	.0034	.0041	.0055	.0061
.619	.0042	.0038	.0043	.0052
.655	.0034	.0033	.0043	.0051
.690	.0023	.0020	.0034	.0037
.725	.0019	.0011	.0016	.0023
.760	-.0000	.0005	-.0001	.0015
.795	.0005	-.0008	-.0005	.0004
.830	-.0020	-.0018	-.0015	-.0009
.881	-.0058	-.0056	-.0050	-.0046
.916	-.0054	-.0076	-.0071	-.0062
.951	-.0085	-.0084	-.0093	-.0083
.986	-.0101	-.0109	-.0116	-.0108

TABLE A52.- MEASURED C_p DATA FOR MODEL III (SINE WAVES AND STRAIGHT RAMPS, λ = 3.23 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.003	-.0183	-.0187	-.0196	-.0199
.037	-.0169	-.0177	-.0188	-.0177
.071	-.0163	-.0161	-.0172	-.0162
.105	-.0151	-.0150	-.0147	-.0143
.140	-.0119	-.0128	-.0114	-.0101
.174	-.0097	-.0084	-.0072	-.0075
.209	-.0074	-.0064	-.0054	-.0037
.243	-.0043	-.0037	-.0021	-.0008
.278	-.0028	-.0014	.0008	.0011
.312	-.0003	.0009	.0024	.0040
.347	.0010	.0041	.0052	.0075
.381	.0044	.0064	.0077	.0101
.416	.0075	.0089	.0112	.0135
.450	.0099	.0121	.0152	.0169
.485	.0124	.0151	.0184	.0204
.519	.0165	.0197	.0230	.0265
.554	.0175	.0211	.0249	.0275
.588	.0195	.0226	.0254	.0283
.623	.0191	.0228	.0244	.0273
.657	.0191	.0231	.0245	.0270
.692	.0183	.0196	.0227	.0250
.726	.0138	.0160	.0186	.0199
.761	.0104	.0110	.0120	.0125
.796	.0033	.0026	.0027	.0039
.830	-.0037	-.0044	-.0047	-.0040
.865	-.0068	-.0078	-.0090	-.0082
.899	-.0100	-.0114	-.0119	-.0114
.934	-.0146	-.0157	-.0161	-.0170
.968	-.0171	-.0183	-.0195	-.0187

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.032	-.0192	-.0210	-.0220	-.0212
.066	-.0181	-.0195	-.0214	-.0207
.101	-.0177	-.0183	-.0193	-.0183
.135	-.0151	-.0151	-.0161	-.0152
.170	-.0109	-.0126	-.0122	-.0104
.204	-.0072	-.0080	-.0076	-.0058
.239	-.0023	-.0007	.0003	.0019
.274	.0034	.0046	.0066	.0092
.308	.0082	.0098	.0124	.0162
.343	.0122	.0150	.0178	.0209
.377	.0153	.0180	.0223	.0249
.412	.0177	.0209	.0229	.0262
.446	.0187	.0213	.0241	.0277
.481	.0199	.0228	.0260	.0292
.515	.0107	.0209	.0226	.0245
.550	.0172	.0139	.0190	.0210
.584	.0145	.0146	.0160	.0177
.619	.0118	.0122	.0124	.0143
.653	.0096	.0095	.0097	.0109
.688	.0075	.0072	.0067	.0079
.722	.0049	.0043	.0044	.0062
.757	.0019	.0007	.0016	.0022
.791	-.0005	-.0006	-.0012	-.0007
.826	-.0031	-.0035	-.0037	-.0020
.860	-.0052	-.0072	-.0075	-.0062
.895	-.0074	-.0089	-.0092	-.0089
.929	-.0107	-.0117	-.0126	-.0124
.963	-.0170	-.0175	-.0186	-.0184
.997	-.0179	-.0198	-.0208	-.0208

TABLE A53.- MEASURED C_p DATA FOR MODEL IV (SINE WAVES AND STRAIGHT RAMPS, λ = 3.86 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.010	-.0168	-.0168	-.0183	-.0185
.044	-.0147	-.0144	-.0147	-.0151
.079	-.0119	-.0126	-.0119	-.0111
.113	-.0100	-.0088	-.0090	-.0076
.148	-.0079	-.0073	-.0055	-.0055
.182	-.0067	-.0056	-.0044	-.0032
.217	-.0062	-.0050	-.0039	-.0025
.251	-.0037	-.0034	-.0024	-.0011
.286	-.0031	-.0029	-.0015	.0004
.320	-.0013	-.0016	.0010	.0014
.355	-.0002	.0008	.0011	.0022
.389	.0006	.0015	.0033	.0045
.424	.0009	.0027	.0038	.0066
.458	.0051	.0055	.0074	.0093
.493	.0067	.0084	.0112	.0127
.527	.0083	.0092	.0127	.0139
.561	.0095	.0116	.0135	.0144
.596	.0099	.0110	.0126	.0147
.630	.0110	.0127	.0148	.0166
.665	.0130	.0148	.0165	.0191
.699	.0149	.0173	.0193	.0214
.734	.0179	.0203	.0231	.0256
.768	.0181	.0211	.0225	.0245
.803	.0165	.0180	.0201	.0206
.837	.0113	.0127	.0136	.0146
.872	.0048	.0056	.0066	.0065
.906	-.0028	-.0033	-.0038	-.0030
.941	-.0107	-.0128	-.0138	-.0145
.975	-.0152	-.0171	-.0182	-.0182

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.025	-.0173	-.0177	-.0192	-.0218
.059	-.0179	-.0171	-.0183	-.0224
.094	-.0145	-.0132	-.0135	-.0167
.128	-.0082	-.0061	-.0061	-.0052
.163	-.0021	.0016	.0021	.0029
.197	.0050	.0077	.0096	.0132
.232	.0094	.0131	.0155	.0219
.266	.0134	.0176	.0208	.0250
.301	.0158	.0185	.0217	.0248
.335	.0144	.0168	.0197	.0211
.370	.0137	.0160	.0172	.0182
.404	.0119	.0132	.0147	.0156
.439	.0106	.0129	.0134	.0152
.473	.0104	.0121	.0129	.0145
.507	.0100	.0117	.0130	.0131
.542	.0092	.0111	.0110	.0124
.576	.0056	.0081	.0079	.0083
.611	.0041	.0058	.0049	.0056
.645	.0031	.0047	.0032	.0046
.680	.0013	.0023	.0023	.0034
.714	-.0002	.0017	.0020	.0022
.749	-.0009	.0007	-.0003	.0011
.783	-.0023	-.0005	-.0010	.0000
.818	-.0018	-.0004	-.0004	.0001
.852	-.0040	-.0024	-.0025	-.0018
.887	-.0047	-.0035	-.0039	-.0032
.921	-.0074	-.0059	-.0061	-.0056
.956	-.0089	-.0084	-.0086	-.0076
.990	-.0129	-.0125	-.0136	-.0139

TABLE A54.- MEASURED C_p DATA FOR MODEL 12 (SINE WAVES AND STRAIGHT RAMPS, λ = 4.62 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.014	-.0869	-.0964	-.1021	-.1078
.048	-.0725	-.0766	-.0809	-.0847
.083	-.0592	-.0615	-.0651	-.0657
.117	-.0490	-.0514	-.0519	-.0532
.152	-.0390	-.0416	-.0396	-.0396
.186	-.0309	-.0328	-.0306	-.0286
.221	-.0250	-.0251	-.0225	-.0219
.255	-.0179	-.0177	-.0163	-.0142
.290	-.0114	-.0114	-.0087	-.0071
.324	-.0084	-.0051	-.0028	-.0006
.359	-.0021	-.0007	.0020	.0038
.393	.0036	.0048	.0078	.0101
.428	.0084	.0119	.0130	.0150
.462	.0124	.0146	.0186	.0210
.497	.0180	.0200	.0244	.0265
.531	.0243	.0250	.0298	.0321
.566	.0287	.0325	.0362	.0394
.600	.0351	.0405	.0428	.0465
.635	.0424	.0464	.0511	.0552
.669	.0500	.0563	.0620	.0667
.704	.0606	.0680	.0747	.0800
.739	.0707	.0813	.0894	.0961
.773	.0780	.0861	.0940	.0997
.807	.0733	.0773	.0845	.0882
.842	.0530	.0530	.0568	.0589
.876	.0196	.0171	.0166	.0173
.911	-.0226	-.0276	-.0317	-.0338
.946	-.0608	-.0685	-.0711	-.0755
.980	-.0878	-.0983	-.1049	-.1065

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.020	-.0712	-.0790	-.0905	-.1011
.054	-.0589	-.0662	-.0740	-.0811
.089	-.0408	-.0455	-.0513	-.0568
.124	-.0299	-.0315	-.0318	-.0305
.158	-.0190	-.0145	-.0052	.0057
.193	-.0035	.0125	.0338	.0485
.227	.0203	.0457	.0668	.0763
.261	.0443	.0668	.0829	.0891
.296	.0589	.0733	.0834	.0877
.331	.0582	.0649	.0703	.0737
.365	.0513	.0579	.0587	.0618
.400	.0459	.0480	.0498	.0530
.434	.0394	.0414	.0423	.0442
.469	.0319	.0338	.0353	.0371
.503	.0262	.0276	.0285	.0301
.538	.0216	.0229	.0229	.0250
.572	.0178	.0183	.0182	.0189
.607	.0142	.0142	.0140	.0164
.641	.0095	.0088	.0086	.0097
.676	.0033	.0042	.0038	.0036
.710	-.0001	-.0000	-.0015	-.0003
.745	-.0048	-.0040	-.0067	-.0060
.779	-.0108	-.0107	-.0125	-.0118
.814	-.0162	-.0177	-.0179	-.0183
.848	-.0211	-.0226	-.0253	-.0260
.883	-.0269	-.0310	-.0340	-.0355
.917	-.0381	-.0413	-.0453	-.0463
.952	-.0457	-.0525	-.0558	-.0589
.986	-.0634	-.0724	-.0776	-.0835

TABLE A55.- MEASURED C_p DATA FOR MODEL 13 (SINE WAVES AND STRAIGHT RAMPS, λ = 4.01 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.010	-.0724	-.0796	-.0867	-.0890
.014	-.0724	-.0783	-.0827	-.0897
.049	-.0602	-.0647	-.0687	-.0730
.083	-.0477	-.0498	-.0541	-.0558
.118	-.0387	-.0398	-.0415	-.0427
.152	-.0314	-.0317	-.0326	-.0324
.186	-.0243	-.0251	-.0234	-.0239
.221	-.0184	-.0181	-.0173	-.0164
.255	-.0133	-.0133	-.0107	-.0098
.289	-.0087	-.0061	-.0043	-.0020
.324	-.0034	-.0006	.0023	.0030
.358	.0043	.0037	.0078	.0088
.392	.0085	.0094	.0131	.0147
.426	.0129	.0149	.0170	.0195
.460	.0160	.0203	.0236	.0256
.495	.0219	.0257	.0301	.0316
.529	.0293	.0313	.0356	.0382
.564	.0337	.0389	.0424	.0460
.598	.0417	.0457	.0507	.0544
.632	.0468	.0544	.0598	.0647
.666	.0566	.0648	.0723	.0777
.701	.0639	.0742	.0819	.0869
.735	.0682	.0779	.0824	.0871
.769	.0632	.0679	.0729	.0785
.803	.0557	.0527	.0557	.0587
.837	.0311	.0297	.0302	.0317
.871	.0035	.0006	.0002	-.0005
.906	-.0257	-.0312	-.0346	-.0370
.940	-.0502	-.0586	-.0649	-.0678
.975	-.0702	-.0784	-.0854	-.0884

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.025	-.0674	-.0741	-.0808	-.0888
.060	-.0596	-.0643	-.0718	-.0780
.094	-.0439	-.0491	-.0531	-.0572
.129	-.0312	-.0347	-.0350	-.0368
.163	-.0189	-.0199	-.0177	-.0142
.197	-.0090	-.0046	.0063	.0155
.231	.0058	.0172	.0340	.0459
.265	.0231	.0416	.0580	.0675
.299	.0407	.0591	.0712	.0806
.334	.0542	.0664	.0764	.0821
.368	.0563	.0624	.0682	.0727
.402	.0528	.0534	.0581	.0607
.436	.0457	.0467	.0488	.0512
.471	.0386	.0390	.0402	.0427
.505	.0313	.0319	.0325	.0357
.540	.0278	.0261	.0267	.0292
.574	.0199	.0204	.0215	.0226
.608	.0159	.0150	.0159	.0177
.642	.0126	.0099	.0113	.0119
.676	.0075	.0061	.0063	.0075
.711	.0029	.0014	.0003	.0014
.745	-.0026	-.0038	-.0051	-.0036
.779	-.0068	-.0090	-.0100	-.0092
.814	-.0118	-.0151	-.0159	-.0160
.848	-.0147	-.0202	-.0221	-.0230
.882	-.0261	-.0285	-.0301	-.0299
.917	-.0314	-.0361	-.0395	-.0406
.951	-.0411	-.0462	-.0507	-.0532
.986	-.0559	-.0654	-.0703	-.0742
.990	-.0624	-.0681	-.0738	-.0801

TABLE A56.- MEASURED C_p DATA FOR MODEL 14 (SINE WAVES AND STRAIGHT RAMPS, λ = 3.23 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.004	-.0633	-.0661	-.0739	-.0779
.039	-.0624	-.0622	-.0691	-.0716
.075	-.0508	-.0527	-.0582	-.0608
.109	-.0422	-.0428	-.0477	-.0477
.142	-.0347	-.0351	-.0369	-.0363
.178	-.0277	-.0267	-.0287	-.0273
.212	-.0201	-.0193	-.0201	-.0178
.247	-.0116	-.0117	-.0108	-.0079
.281	-.0054	-.0052	-.0031	.0008
.317	.0001	.0017	.0047	.0078
.351	.0059	.0097	.0130	.0160
.386	.0126	.0141	.0195	.0219
.420	.0182	.0208	.0254	.0303
.455	.0243	.0267	.0331	.0366
.489	.0309	.0329	.0396	.0444
.525	.0353	.0405	.0489	.0534
.559	.0445	.0501	.0585	.0636
.594	.0517	.0581	.0655	.0728
.628	.0552	.0659	.0713	.0782
.662	.0598	.0651	.0730	.0804
.696	.0574	.0618	.0685	.0725
.732	.0533	.0553	.0585	.0633
.767	.0433	.0427	.0455	.0481
.801	.0274	.0279	.0290	.0299
.835	.0053	.0028	-.0001	.0005
.870	-.0125	-.0179	-.0200	-.0215
.905	-.0324	-.0381	-.0413	-.0446
.940	-.0490	-.0551	-.0597	-.0647
.975	-.0607	-.0650	-.0711	-.0748

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.025	-.0605	-.0624	-.0698	-.0752
.060	-.0566	-.0576	-.0648	-.0707
.095	-.0461	-.0469	-.0534	-.0576
.130	-.0356	-.0357	-.0387	-.0419
.165	-.0219	-.0240	-.0257	-.0262
.199	-.0142	-.0119	-.0110	-.0094
.233	-.0035	-.0007	.0052	.0110
.268	.0049	.0133	.0249	.0329
.304	.0179	.0301	.0440	.0515
.338	.0326	.0443	.0566	.0662
.372	.0455	.0568	.0659	.0740
.406	.0531	.0611	.0700	.0759
.441	.0559	.0619	.0690	.0719
.475	.0524	.0550	.0597	.0625
.511	.0484	.0475	.0508	.0524
.545	.0436	.0405	.0414	.0449
.580	.0338	.0335	.0354	.0358
.614	.0277	.0282	.0290	.0298
.649	.0224	.0205	.0233	.0223
.683	.0165	.0157	.0167	.0173
.719	.0100	.0079	.0086	.0089
.753	.0053	.0029	.0018	.0027
.788	-.0038	-.0032	-.0053	-.0052
.822	-.0126	-.0114	-.0135	-.0148
.858	-.0152	-.0199	-.0214	-.0223
.891	-.0237	-.0275	-.0293	-.0316
.925	-.0353	-.0374	-.0423	-.0441
.961	-.0471	-.0516	-.0572	-.0604
.996	-.0559	-.0601	-.0668	-.0702

TABLE A57.- MEASURED C_p DATA FOR MODEL 15 (SINE WAVES AND STRAIGHT RAMPS, λ = 3.86 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.000	-.0870	-.0943	-.0967	-.1064
.036	-.0741	-.0782	-.0826	-.0885
.070	-.0583	-.0643	-.0649	-.0685
.105	-.0486	-.0508	-.0513	-.0555
.139	-.0397	-.0394	-.0401	-.0417
.174	-.0327	-.0320	-.0307	-.0332
.209	-.0255	-.0239	-.0225	-.0213
.243	-.0200	-.0178	-.0170	-.0150
.278	-.0139	-.0123	-.0098	-.0095
.312	-.0083	-.0071	-.0046	-.0035
.348	-.0036	-.0022	.0004	.0021
.382	.0011	.0032	.0075	.0071
.417	.0067	.0081	.0102	.0126
.451	.0104	.0126	.0161	.0177
.485	.0151	.0191	.0219	.0235
.521	.0196	.0241	.0271	.0300
.555	.0261	.0300	.0333	.0352
.590	.0300	.0354	.0387	.0400
.624	.0374	.0431	.0473	.0499
.659	.0438	.0483	.0541	.0580
.693	.0509	.0588	.0655	.0667
.729	.0574	.0693	.0770	.0828
.762	.0707	.0798	.0918	.0959
.797	.0753	.0824	.0896	.0942
.831	.0645	.0694	.0760	.0777
.861	.0404	.0383	.0403	.0408
.896	.0021	-.0017	-.0043	-.0051
.931	-.0422	-.0502	-.0560	-.0601
.966	-.0796	-.0844	-.0923	-.1015

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.034	-.0567	-.0643	-.0770	-.0859
.069	-.0425	-.0488	-.0553	-.0626
.104	-.0289	-.0334	-.0381	-.0416
.139	-.0239	-.0244	-.0231	-.0211
.169	-.0164	-.0126	.0009	.0147
.203	.0006	.0144	.0372	.0521
.238	.0241	.0432	.0633	.0751
.271	.0458	.0635	.0752	.0818
.307	.0572	.0642	.0668	.0721
.341	.0523	.0576	.0585	.0596
.376	.0493	.0488	.0495	.0540
.410	.0415	.0409	.0429	.0445
.445	.0364	.0356	.0357	.0384
.479	.0299	.0304	.0316	.0321
.515	.0279	.0259	.0253	.0280
.549	.0207	.0216	.0211	.0226
.583	.0173	.0144	.0158	.0174
.618	.0112	.0103	.0102	.0122
.652	.0103	.0066	.0066	.0090
.688	.0034	.0027	.0017	.0043
.722	.0009	-.0014	-.0011	-.0013
.757	-.0058	-.0062	-.0066	-.0071
.791	-.0089	-.0112	-.0118	-.0140
.826	-.0146	-.0176	-.0177	-.0192
.861	-.0203	-.0215	-.0225	-.0260
.895	-.0271	-.0289	-.0322	-.0329
.930	-.0346	-.0390	-.0417	-.0433
.964	-.0446	-.0482	-.0554	-.0580
1.000	-.0595	-.0682	-.0782	-.0849

TABLE A58.- MEASURED C_p DATA FOR MODEL 17 (TRANSVERSE V-GROOVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
0.000	-.0586	-.0671	-.0752	-.0804
.033	-.0535	-.0607	-.0671	-.0715
.069	-.0424	-.0485	-.0515	-.0547
.103	-.0372	-.0378	-.0404	-.0417
.139	-.0283	-.0302	-.0304	-.0319
.172	-.0227	-.0209	-.0228	-.0225
.212	-.0148	-.0139	-.0136	-.0127
.241	-.0110	-.0091	-.0072	-.0049
.275	-.0053	-.0020	.0002	.0019
.311	.0011	.0042	.0076	.0103
.344	.0086	.0111	.0146	.0186
.378	.0133	.0168	.0214	.0255
.413	.0177	.0240	.0293	.0331
.447	.0247	.0318	.0368	.0418
.482	.0327	.0402	.0460	.0513
.515	.0385	.0483	.0562	.0640
.549	.0449	.0565	.0653	.0716
.583	.0463	.0534	.0575	.0622
.618	.0406	.0475	.0497	.0517
.652	.0361	.0390	.0413	.0426
.686	.0293	.0310	.0315	.0329
.721	.0240	.0243	.0242	.0253
.756	.0171	.0171	.0163	.0173
.789	.0136	.0096	.0089	.0085
.823	.0032	.0025	.0009	.0006
.859	-.0024	-.0054	-.0062	-.0064
.894	-.0082	-.0096	-.0110	-.0119
.927	-.0166	-.0200	-.0222	-.0242
.962	-.0315	-.0368	-.0393	-.0418
.997	-.0517	-.0626	-.0676	-.0733

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.003	-.0619	-.0711	-.0800	-.0855
.038	-.0536	-.0587	-.0628	-.0674
.073	-.0403	-.0448	-.0482	-.0490
.106	-.0302	-.0338	-.0351	-.0361
.141	-.0236	-.0244	-.0240	-.0241
.177	-.0168	-.0171	-.0162	-.0140
.211	-.0108	-.0091	-.0077	-.0058
.244	-.0042	-.0025	.0009	.0025
.279	.0011	.0045	.0083	.0111
.314	.0078	.0113	.0167	.0193
.348	.0140	.0197	.0243	.0271
.382	.0201	.0261	.0322	.0378
.417	.0266	.0343	.0405	.0462
.451	.0341	.0422	.0517	.0567
.485	.0434	.0531	.0616	.0700
.518	.0474	.0546	.0622	.0669
.553	.0439	.0493	.0539	.0561
.587	.0392	.0414	.0446	.0466
.622	.0333	.0342	.0361	.0380
.656	.0268	.0276	.0282	.0298
.689	.0207	.0211	.0211	.0221
.725	.0151	.0148	.0144	.0152
.759	.0101	.0082	.0068	.0070
.788	.0053	.0019	.0024	.0020
.828	-.0027	-.0060	-.0065	-.0067
.861	-.0113	-.0137	-.0156	-.0164
.897	-.0189	-.0220	-.0240	-.0252
.931	-.0269	-.0311	-.0343	-.0365
.967	-.0389	-.0436	-.0481	-.0512
1.000	-.0576	-.0698	-.0777	-.0827

TABLE A59.- MEASURED C_p DATA FOR MODEL 18 (TRANSVERSE V-GROOVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.030	-.0603	-.0677	-.0748	-.0774
.064	-.0493	-.0536	-.0581	-.0620
.098	-.0419	-.0428	-.0455	-.0477
.132	-.0322	-.0350	-.0367	-.0372
.166	-.0251	-.0269	-.0276	-.0277
.200	-.0205	-.0206	-.0205	-.0201
.235	-.0152	-.0144	-.0145	-.0134
.269	-.0100	-.0101	-.0084	-.0079
.303	-.0059	-.0052	-.0029	-.0018
.338	-.0016	-.0003	.0021	.0039
.372	.0034	.0053	.0067	.0087
.406	.0071	.0100	.0125	.0155
.440	.0113	.0144	.0173	.0201
.474	.0155	.0192	.0231	.0252
.508	.0200	.0256	.0276	.0315
.542	.0266	.0308	.0352	.0397
.576	.0310	.0372	.0426	.0461
.610	.0379	.0439	.0499	.0566
.645	.0439	.0543	.0624	.0681
.678	.0495	.0587	.0674	.0733
.712	.0455	.0536	.0573	.0616
.746	.0404	.0421	.0448	.0481
.781	.0304	.0321	.0327	.0353
.814	.0209	.0219	.0219	.0228
.849	.0122	.0096	.0097	.0107
.882	.0018	-.0010	-.0028	-.0021
.917	-.0097	-.0146	-.0183	-.0162
.952	-.0281	-.0333	-.0357	-.0368
.984	-.0515	-.0606	-.0668	-.0700
.995	-.0619	-.0688	-.0745	-.0837

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.005	-.0555	-.0696	-.0773	-.0826
.016	-.0559	-.0635	-.0741	-.0792
.048	-.0461	-.0532	-.0584	-.0628
.083	-.0348	-.0396	-.0414	-.0446
.118	-.0257	-.0278	-.0296	-.0298
.151	-.0178	-.0175	-.0185	-.0170
.186	-.0085	-.0081	-.0070	-.0038
.219	-.0021	.0010	.0050	.0098
.254	.0059	.0116	.0169	.0229
.288	.0136	.0216	.0290	.0362
.322	.0248	.0327	.0418	.0503
.355	.0327	.0428	.0559	.0657
.390	.0402	.0513	.0614	.0672
.424	.0445	.0503	.0550	.0591
.458	.0407	.0450	.0456	.0496
.492	.0352	.0392	.0396	.0424
.526	.0309	.0326	.0328	.0373
.560	.0270	.0276	.0270	.0297
.594	.0211	.0221	.0219	.0236
.628	.0194	.0179	.0175	.0185
.662	.0132	.0124	.0122	.0127
.697	.0082	.0081	.0080	.0088
.731	.0083	.0032	.0031	.0019
.765	-.0009	-.0010	-.0025	-.0022
.800	-.0058	-.0065	-.0078	-.0065
.834	-.0116	-.0112	-.0131	-.0124
.868	-.0157	-.0176	-.0191	-.0197
.902	-.0207	-.0257	-.0270	-.0291
.936	-.0295	-.0339	-.0372	-.0392
.970	-.0420	-.0476	-.0539	-.0564

TABLE A60.- MEASURED C_p DATA FOR MODEL 19 (TRANSVERSE V-GROOVES, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.028	-.0642	-.0703	-.0771	-.0824
.061	-.0516	-.0551	-.0606	-.0618
.096	-.0431	-.0439	-.0474	-.0488
.130	-.0334	-.0356	-.0359	-.0382
.165	-.0279	-.0286	-.0305	-.0298
.199	-.0224	-.0222	-.0244	-.0223
.234	-.0180	-.0182	-.0181	-.0170
.267	-.0127	-.0127	-.0120	-.0110
.303	-.0095	-.0078	-.0062	-.0053
.336	-.0042	-.0044	-.0025	.0011
.370	-.0011	.0003	.0016	.0049
.405	.0019	.0045	.0063	.0077
.440	.0056	.0090	.0103	.0131
.474	.0105	.0126	.0154	.0173
.509	.0138	.0168	.0209	.0226
.543	.0189	.0228	.0256	.0278
.578	.0227	.0258	.0296	.0327
.612	.0269	.0336	.0359	.0403
.647	.0315	.0364	.0417	.0462
.681	.0376	.0446	.0516	.0556
.715	.0456	.0518	.0598	.0679
.749	.0525	.0643	.0719	.0813
.783	.0514	.0588	.0661	.0703
.818	.0424	.0455	.0493	.0503
.851	.0277	.0289	.0280	.0293
.886	.0129	.0100	.0097	.0095
.920	-.0041	-.0078	-.0105	-.0113
.956	-.0251	-.0300	-.0350	-.0373
.990	-.0615	-.0794	-.0884	-.0938
.992	-.0658	-.0770	-.0842	-.0939

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.008	-.0546	-.0631	-.0709	-.0779
.010	-.0555	-.0644	-.0702	-.0782
.045	-.0467	-.0505	-.0582	-.0635
.080	-.0325	-.0357	-.0385	-.0434
.114	-.0218	-.0250	-.0266	-.0293
.149	-.0134	-.0138	-.0141	-.0119
.182	-.0049	-.0043	.0018	.0080
.217	.0028	.0083	.0190	.0287
.251	.0133	.0240	.0377	.0495
.285	.0278	.0408	.0577	.0688
.319	.0366	.0494	.0594	.0644
.353	.0396	.0494	.0548	.0570
.388	.0402	.0442	.0474	.0494
.422	.0362	.0389	.0417	.0422
.457	.0306	.0356	.0345	.0364
.491	.0272	.0293	.0301	.0289
.526	.0255	.0235	.0252	.0253
.560	.0195	.0198	.0206	.0213
.595	.0161	.0169	.0172	.0171
.630	.0157	.0117	.0117	.0127
.664	.0090	.0072	.0064	.0073
.697	.0049	.0044	.0048	.0034
.733	.0021	-.0001	-.0010	-.0017
.766	-.0034	-.0060	-.0046	-.0054
.801	-.0078	-.0094	-.0096	-.0088
.835	-.0102	-.0129	-.0144	-.0144
.870	-.0171	-.0180	-.0192	-.0204
.904	-.0216	-.0240	-.0257	-.0285
.939	-.0288	-.0341	-.0363	-.0392
.972	-.0375	-.0446	-.0488	-.0518

TABLE A61.- MEASURED C_p DATA FOR MODEL 24 (CIRCULAR ARCS AND STRAIGHT RAMPS, λ = 2.54 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.003	-.0608	-.0675	-.0738	-.0792
.039	-.0554	-.0603	-.0651	-.0703
.076	-.0439	-.0501	-.0540	-.0579
.113	-.0375	-.0396	-.0429	-.0440
.150	-.0312	-.0322	-.0334	-.0345
.185	-.0241	-.0258	-.0254	-.0262
.220	-.0196	-.0187	-.0191	-.0193
.256	-.0133	-.0129	-.0130	-.0114
.293	-.0117	-.0085	-.0080	-.0064
.328	-.0064	-.0034	-.0025	-.0004
.365	-.0010	.0011	.0026	.0049
.400	.0022	.0041	.0057	.0088
.437	.0061	.0096	.0120	.0133
.473	.0105	.0134	.0156	.0181
.508	.0139	.0201	.0212	.0236
.544	.0175	.0224	.0258	.0284
.580	.0223	.0276	.0308	.0332
.617	.0252	.0313	.0349	.0378
.652	.0321	.0363	.0407	.0434
.690	.0350	.0425	.0461	.0485
.724	.0424	.0473	.0533	.0573
.759	.0496	.0568	.0619	.0673
.794	.0536	.0645	.0721	.0777
.831	.0676	.0760	.0895	.0949
.860	.0698	.0782	.0917	.0971
.893	-.0179	-.0267	-.0339	-.0380
.933	-.0508	-.0588	-.0659	-.0728
.974	-.0594	-.0668	-.0736	-.0823

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of -			
	15.2	22.9	30.5	38.1
.026	-.0462	-.0485	-.0547	-.0579
.067	-.0381	-.0454	-.0491	-.0515
.107	-.0323	-.0316	-.0344	-.0359
.140	-.0119	-.0127	-.0111	-.0035
.169	-.0142	-.0149	-.0133	-.0057
.206	-.0067	.0033	.0169	.0307
.241	.0108	.0269	.0411	.0522
.276	.0288	.0425	.0497	.0567
.310	.0387	.0462	.0535	.0555
.348	.0394	.0457	.0473	.0486
.383	.0407	.0413	.0428	.0440
.420	.0347	.0375	.0369	.0384
.456	.0318	.0322	.0323	.0327
.492	.0255	.0267	.0270	.0282
.527	.0249	.0236	.0236	.0244
.563	.0194	.0217	.0193	.0201
.600	.0171	.0170	.0162	.0160
.635	.0123	.0112	.0109	.0115
.672	.0078	.0082	.0078	.0087
.707	.0056	.0046	.0036	.0038
.744	-.0003	.0004	.0000	-.0003
.780	-.0014	-.0039	-.0053	-.0046
.815	-.0070	-.0090	-.0102	-.0102
.850	-.0111	-.0139	-.0153	-.0148
.887	-.0178	-.0186	-.0220	-.0224
.924	-.0225	-.0276	-.0300	-.0317
.961	-.0359	-.0382	-.0414	-.0431
.997	-.0434	-.0472	-.0524	-.0555

TABLE A62.- MEASURED C_p DATA FOR MODEL 34 (CIRCULAR ARCS AND STRAIGHT RAMPS, λ = 1.27 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.019	-.0398	-.0459	-.0520	-.0555
.049	-.0346	-.0413	-.0457	-.0491
.088	-.0299	-.0333	-.0367	-.0392
.117	-.0235	-.0275	-.0286	-.0305
.156	-.0213	-.0225	-.0241	-.0236
.184	-.0168	-.0178	-.0187	-.0183
.222	-.0132	-.0133	-.0135	-.0132
.253	-.0104	-.0105	-.0102	-.0081
.290	-.0076	-.0068	-.0056	-.0044
.320	-.0042	-.0045	-.0034	-.0011
.357	-.0019	-.0006	.0012	.0029
.387	.0002	.0026	.0036	.0049
.426	.0033	.0048	.0062	.0091
.455	.0066	.0078	.0097	.0119
.493	.0082	.0106	.0124	.0154
.522	.0109	.0127	.0169	.0186
.561	.0133	.0165	.0198	.0227
.590	.0169	.0194	.0235	.0264
.627	.0191	.0224	.0269	.0314
.657	.0218	.0267	.0319	.0370
.693	.0251	.0314	.0367	.0406
.724	.0296	.0352	.0426	.0487
.761	.0354	.0412	.0494	.0558
.791	.0390	.0472	.0568	.0643
.829	.0404	.0506	.0584	.0642
.858	.0285	.0291	.0319	.0328
.897	-.0041	-.0114	-.0159	-.0194
.949	-.0329	-.0414	-.0472	-.0513
.983	-.0354	-.0458	-.0496	-.0553

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.017	-.0294	-.0350	-.0375	-.0392
.051	-.0298	-.0359	-.0393	-.0391
.103	-.0232	-.0261	-.0297	-.0288
.142	-.0168	-.0171	-.0181	-.0178
.171	-.0104	-.0106	-.0121	-.0112
.209	-.0063	-.0086	-.0087	-.0089
.239	-.0033	-.0050	-.0041	-.0025
.276	.0022	.0048	.0068	.0140
.307	.0069	.0127	.0207	.0282
.343	.0151	.0226	.0322	.0396
.373	.0197	.0264	.0335	.0401
.410	.0225	.0298	.0355	.0397
.439	.0207	.0274	.0294	.0351
.478	.0225	.0265	.0310	.0347
.507	.0202	.0227	.0253	.0267
.545	.0204	.0226	.0227	.0257
.574	.0177	.0185	.0197	.0211
.613	.0154	.0164	.0166	.0181
.643	.0125	.0130	.0132	.0142
.680	.0113	.0122	.0105	.0127
.710	.0080	.0082	.0076	.0086
.747	.0062	.0054	.0041	.0045
.778	.0033	.0025	.0018	.0032
.816	-.0013	-.0002	-.0025	-.0006
.844	-.0043	-.0051	-.0050	-.0050
.883	-.0068	-.0088	-.0095	-.0098
.912	-.0109	-.0118	-.0134	-.0125
.951	-.0177	-.0191	-.0224	-.0220
.981	-.0251	-.0286	-.0322	-.0329

TABLE A63.- MEASURED C_p DATA FOR MODEL 44 (CIRCULAR ARCS AND STRAIGHT RAMPS, λ = 5.08 cm)

Forward direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.004	-.0841	-.0919	-.0964	-.1028
.039	-.0792	-.0861	-.0934	-.0974
.074	-.0677	-.0722	-.0749	-.0777
.108	-.0493	-.0498	-.0512	-.0495
.142	-.0354	-.0346	-.0315	-.0305
.176	-.0292	-.0238	-.0220	-.0208
.211	-.0193	-.0171	-.0151	-.0129
.245	-.0130	-.0106	-.0090	-.0070
.279	-.0071	-.0045	-.0027	-.0026
.314	-.0025	-.0003	.0010	.0034
.349	.0027	.0049	.0062	.0086
.383	.0044	.0055	.0074	.0083
.418	.0090	.0108	.0114	.0133
.453	.0144	.0155	.0172	.0189
.487	.0174	.0204	.0225	.0237
.521	.0238	.0247	.0271	.0300
.556	.0287	.0307	.0335	.0366
.590	.0340	.0359	.0383	.0423
.625	.0413	.0444	.0468	.0501
.659	.0482	.0538	.0567	.0606
.694	.0576	.0631	.0677	.0728
.728	.0674	.0742	.0809	.0869
.763	.0773	.0847	.0935	.0986
.797	.0941	.1000	.1115	.1191
.831	.0897	.0912	.0976	.1016
.866	.0358	.0340	.0352	.0362
.900	-.0538	-.0648	-.0723	-.0775
.935	-.0850	-.0939	-.1022	-.1075
.970	-.0848	-.0934	-.1009	-.1055

Reverse direction

x/λ	C_p at velocity U_∞, m/s, of - 15.2	22.9	30.5	38.1
.030	-.0617	-.0687	-.0782	-.0840
.065	-.0572	-.0614	-.0683	-.0762
.100	-.0431	-.0451	-.0522	-.0582
.134	-.0309	-.0344	-.0375	-.0389
.169	-.0258	-.0235	-.0131	.0001
.203	-.0113	.0084	.0301	.0525
.237	.0237	.0503	.0690	.0811
.272	.0526	.0681	.0774	.0838
.306	.0635	.0685	.0737	.0766
.341	.0612	.0607	.0643	.0674
.375	.0529	.0551	.0560	.0583
.410	.0472	.0465	.0467	.0491
.444	.0398	.0393	.0406	.0425
.479	.0346	.0327	.0346	.0359
.513	.0299	.0275	.0297	.0314
.547	.0256	.0239	.0235	.0264
.582	.0202	.0196	.0189	.0213
.617	.0166	.0146	.0152	.0165
.651	.0115	.0104	.0086	.0102
.686	.0063	.0052	.0034	.0050
.721	.0028	.0014	.0009	.0012
.755	-.0014	-.0030	-.0043	-.0020
.789	-.0060	-.0080	-.0096	-.0086
.824	-.0095	-.0117	-.0122	-.0134
.858	-.0135	-.0157	-.0174	-.0176
.892	-.0167	-.0199	-.0205	-.0201
.926	-.0366	-.0394	-.0437	-.0453
.961	-.0585	-.0627	-.0669	-.0745
.996	-.0656	-.0704	-.0753	-.0823

TABLE A64.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 1 (SINE WAVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0165	1.0962
.0308	-.0167	1.0735
.0614	-.0164	1.0578
.0920	-.0156	1.0399
.1225	-.0161	1.0783
.1530	-.0146	.9607
.1836	-.0130	.9716
.2144	-.0095	.8300
.2455	-.0056	.8736
.2764	-.0023	.8049
.3078	.0031	.7270
.3396	.0066	.7770
.3713	.0091	.7741
.4034	.0128	.7663
.4353	.0145	.8361
.4674	.0175	.7966
.4996	.0176	.9297
.5316	.0179	.8964
.5635	.0172	.9612
.5956	.0192	.8532
.6279	.0178	1.0260
.6598	.0177	.9125
.6921	.0162	1.1285
.7236	.0099	1.1559
.7551	.0050	1.2462
.7861	-.0023	1.2953
.8167	-.0082	1.3159
.8473	-.0097	1.1003
.8783	-.0105	1.2126
.9088	-.0135	1.1609
.9394	-.0142	1.1946
.9698	-.0173	1.1599

TABLE A65.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 2 (SINE WAVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0412	1.2131
.0297	-.0425	1.2468
.0592	-.0419	1.1154
.0888	-.0398	1.0803
.1183	-.0370	.9492
.1482	-.0309	.8417
.1782	-.0250	.7540
.2086	-.0173	.6202
.2395	-.0085	.5198
.2710	.0003	.4907
.3028	.0079	.4999
.3350	.0157	.4766
.3676	.0226	.5364
.4004	.0273	.6004
.4333	.0320	.6144
.4664	.0357	.6887
.4995	.0372	.7487
.5327	.0389	.7750
.5659	.0392	.8656
.5990	.0372	.9300
.6319	.0355	.9720
.6647	.0320	1.0851
.6971	.0257	1.1703
.7291	.0190	1.2675
.7607	.0096	1.3912
.7917	-.0005	1.4688
.8223	-.0113	1.5239
.8524	-.0196	1.5140
.8823	-.0297	1.3967
.9118	-.0372	1.4617
.9413	-.0395	1.4023
.9707	-.0426	1.3207

TABLE A66.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 16 (SINE WAVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0603	1.3244
.0288	-.0625	1.3805
.0574	-.0609	1.1417
.0863	-.0565	1.0577
.1153	-.0511	.8510
.1447	-.0418	.7151
.1743	-.0331	.5826
.2046	-.0221	.4511
.2353	-.0124	.4327
.2664	-.0019	.3381
.2982	.0088	.2877
.3306	.0200	.2443
.3638	.0300	.2975
.3972	.0385	.3540
.4310	.0465	.3770
.4653	.0533	.4624
.4998	.0568	.5769
.5344	.0599	.6361
.5689	.0599	.8342
.6028	.0546	.9925
.6363	.0495	1.0640
.6694	.0418	1.2541
.7016	.0289	1.4105
.7332	.0191	1.3933
.7646	.0083	1.4940
.7954	-.0025	1.5329
.8258	-.0158	1.6669
.8556	-.0276	1.6647
.8851	-.0423	1.8358
.9139	-.0541	1.6521
.9428	-.0572	1.5974
.9713	-.0627	1.4950

TABLE A67.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 3 (SINE WAVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0922	1.4666
.0310	-.0904	1.5177
.0589	-.0879	1.2622
.0867	-.0879	1.3017
.1144	-.0777	.6810
.1436	-.0687	.3363
.1719	-.0628	.6766
.2007	-.0515	.3721
.2304	-.0337	.1350
.2611	-.0230	.1605
.2925	-.0063	-.0223
.3246	.0041	.1529
.3576	.0203	-.0596
.3911	.0304	.3097
.4252	.0433	.0658
.4596	.0510	.5162
.4941	.0587	.2340
.5290	.0644	.5867
.5647	.0712	.2960
.6002	.0721	.8778
.6353	.0712	.5441
.6705	.0699	1.0533
.7053	.0627	.8799
.7390	.0518	1.5142
.7717	.0352	1.2777
.8034	.0166	2.0027
.8337	-.0118	1.7625
.8633	-.0277	2.1860
.8921	-.0511	1.9470
.9206	-.0639	2.2330
.9484	-.0842	2.1086
.9756	-.0922	2.0463

TABLE A68.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL IV (SINE WAVES, λ = 1.27 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0166	1.1735
.0297	-.0172	1.1827
.0600	-.0171	1.0997
.0903	-.0166	1.0906
.1206	-.0162	1.0543
.1507	-.0149	.9559
.1812	-.0105	.7381
.2125	-.0058	.7422
.2437	-.0023	.7060
.2752	.0021	.6641
.3071	.0061	.6367
.3393	.0104	.6308
.3719	.0138	.6838
.4044	.0159	.7881
.4368	.0173	.8236
.4692	.0181	.8875
.5017	.0183	.9296
.5340	.0175	1.0309
.5662	.0161	1.0635
.5981	.0137	1.1749
.6297	.0110	1.1746
.6613	.0086	1.1992
.6928	.0060	1.2271
.7240	.0024	1.2992
.7550	-.0007	1.2629
.7859	-.0035	1.2944
.8167	-.0058	1.2323
.8476	-.0078	1.2826
.8781	-.0110	1.2977
.9085	-.0132	1.2862
.9389	-.0149	1.2466
.9691	-.0160	1.2214

TABLE A69.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL VII (SINE WAVES, λ = 5.08 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0239	1.1019
.0313	-.0234	1.0594
.0617	-.0238	1.0778
.0922	-.0242	1.0503
.1226	-.0226	1.0064
.1531	-.0212	.9973
.1836	-.0192	.9402
.2143	-.0139	.8733
.2451	-.0097	.8585
.2761	-.0035	.7799
.3074	.0019	.7864
.3389	.0071	.7624
.3705	.0118	.7603
.4024	.0170	.7406
.4344	.0205	.7634
.4667	.0258	.7145
.4991	.0267	.8619
.5313	.0264	.8268
.5637	.0273	.8953
.5958	.0244	.9411
.6280	.0239	.9376
.6600	.0206	1.0173
.6918	.0163	1.0533
.7235	.0125	1.0705
.7549	.0065	1.1356
.7862	.0018	1.1119
.8173	-.0023	1.1641
.8482	-.0087	1.1689
.8790	-.0119	1.1644
.9096	-.0176	1.2029
.9401	-.0214	1.1599
.9705	-.0231	1.1369

TABLE A70.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL V
(SPLICED SINE WAVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0201	1.1145	0.0000	-.0208	1.1104
.0293	-.0217	1.1646	.0313	-.0211	1.1172
.0595	-.0220	1.0639	.0617	-.0204	1.0517
.0897	-.0204	1.0289	.0921	-.0189	1.0217
.1200	-.0177	.9028	.1226	-.0172	.9683
.1506	-.0122	.8040	.1534	-.0145	.9302
.1814	-.0061	.6957	.1842	-.0130	.9630
.2129	.0004	.6664	.2149	-.0113	.9229
.2445	.0056	.6651	.2458	-.0086	.8963
.2765	.0109	.6614	.2768	-.0062	.8847
.3086	.0151	.7010	.3079	-.0035	.8577
.3409	.0183	.7348	.3392	-.0001	.8197
.3733	.0209	.7880	.3706	.0031	.8132
.4057	.0214	.8717	.4021	.0062	.8017
.4379	.0215	.8920	.4338	.0093	.7893
.4702	.0211	.9564	.4657	.0125	.7862
.5023	.0193	.9943	.4977	.0149	.7972
.5343	.0174	1.0350	.5298	.0177	.7904
.5662	.0151	1.0715	.5621	.0196	.8335
.5979	.0119	1.1135	.5943	.0207	.8452
.6294	.0091	1.1169	.6267	.0219	.8682
.6608	.0059	1.1593	.6591	.0219	.9278
.6921	.0023	1.1757	.6914	.0202	.9899
.7232	-.0011	1.1854	.7236	.0183	1.0458
.7542	-.0037	1.1658	.7555	.0138	1.1475
.7851	-.0068	1.2019	.7871	.0095	1.1700
.8158	-.0095	1.1584	.8186	.0034	1.2998
.8466	-.0107	1.1493	.8494	-.0043	1.3577
.8774	-.0133	1.1894	.8800	-.0118	1.3913
.9079	-.0160	1.1946	.9103	-.0172	1.3109
.9383	-.0180	1.1789	.9405	-.0199	1.2817
.9687	-.0200	1.1632	.9707	-.0221	1.1915

TABLE A71.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL I (SINE WAVES AND STRAIGHT RAMPS, λ = 4.62 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0167	1.1914	0.0000	-.0179	1.0971
.0319	-.0170	1.0550	.0289	-.0158	.9532
.0625	-.0145	.9868	.0597	-.0116	.9059
.0934	-.0122	.9722	.0906	-.0077	.8571
.1243	-.0111	.9762	.1218	-.0014	.7878
.1552	-.0089	.9335	.1532	.0027	.8328
.1862	-.0071	.9484	.1847	.0061	.7990
.2173	-.0055	.9305	.2164	.0111	.7565
.2485	-.0044	.9504	.2485	.0153	.7888
.2796	-.0030	.9249	.2806	.0164	.8803
.3108	-.0016	.9359	.3124	.0145	.9607
.3421	-.0006	.9315	.3441	.0120	.9810
.3733	.0001	.9508	.3757	.0107	.9825
.4046	.0008	.9268	.4073	.0086	1.0126
.4359	.0016	.9464	.4388	.0073	1.0023
.4672	.0022	.9337	.4702	.0049	1.0429
.4986	.0028	.9514	.5014	.0036	1.0009
.5298	.0032	.9255	.5328	.0032	1.0115
.5613	.0055	.8978	.5641	.0024	.9987
.5927	.0070	.9034	.5954	.0019	1.0078
.6243	.0089	.8842	.6267	.0010	1.0092
.6559	.0105	.8878	.6579	.0004	1.0112
.6876	.0126	.8609	.6892	-.0004	1.0104
.7194	.0157	.8379	.7204	-.0015	1.0348
.7515	.0170	.8866	.7515	-.0032	1.0319
.7836	.0154	.9717	.7827	-.0041	1.0326
.8153	.0107	1.0699	.8138	-.0056	1.0440
.8468	.0067	1.0576	.8448	-.0071	1.0580
.8782	.0038	1.0926	.8757	-.0096	1.0761
.9094	-.0025	1.1741	.9066	-.0109	1.0606
.9403	-.0078	1.1560	.9375	-.0127	1.0904
.9711	-.0120	1.1815	.9681	-.0158	1.1256

TABLE A72.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL II (SINE WAVES AND STRAIGHT RAMPS, λ = 4.01 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0128	1.0545	0.0000	-.0124	1.0898
.0315	-.0120	1.0269	.0299	-.0132	1.0480
.0623	-.0107	.9772	.0606	-.0126	1.0192
.0932	-.0093	.9815	.0913	-.0108	.9580
.1242	-.0078	.9446	.1220	-.0077	.8946
.1552	-.0065	.9696	.1532	-.0026	.7933
.1863	-.0056	.9422	.1846	.0016	.8318
.2174	-.0044	.9645	.2160	.0049	.8094
.2485	-.0040	.9503	.2477	.0086	.8021
.2797	-.0025	.9419	.2795	.0122	.7804
.3109	-.0017	.9506	.3116	.0150	.8291
.3421	-.0013	.9605	.3436	.0159	.8731
.3734	-.0002	.9328	.3756	.0146	.9783
.4046	.0008	.9459	.4073	.0114	1.0234
.4360	.0019	.9298	.4388	.0087	1.0445
.4673	.0017	.9842	.4703	.0063	1.0520
.4985	.0016	.9476	.5015	.0033	1.0821
.5297	.0036	.9078	.5327	.0022	1.0090
.5612	.0061	.8724	.5640	.0027	1.0030
.5927	.0085	.8695	.5954	.0021	1.0122
.6244	.0119	.8107	.6266	.0011	1.0311
.6564	.0148	.8361	.6579	-.0001	1.0254
.6884	.0161	.8671	.6891	-.0009	1.0236
.7205	.0153	.9583	.7203	-.0011	1.0116
.7523	.0127	1.0074	.7515	-.0027	1.0536
.7840	.0091	1.0740	.7826	-.0034	1.0137
.8154	.0059	1.0640	.8137	-.0043	1.0485
.8468	.0027	1.1131	.8447	-.0054	1.0297
.8780	-.0027	1.1841	.8758	-.0064	1.0569
.9087	-.0076	1.1928	.9068	-.0079	1.0549
.9394	-.0106	1.1400	.9377	-.0094	1.0774
.9701	-.0125	1.1226	.9685	-.0110	1.0716

TABLE A73.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL III
(SINE WAVES AND STRAIGHT RAMPS, λ = 3.23 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0208	1.1237	0.0000	-.0215	1.1552
.0306	-.0209	1.0916	.0300	-.0217	1.0815
.0611	-.0190	.9942	.0603	-.0214	1.0522
.0916	-.0171	.9850	.0908	-.0184	.9515
.1223	-.0145	.9209	.1214	-.0166	.9767
.1531	-.0120	.9210	.1520	-.0130	.8559
.1841	-.0086	.8593	.1830	-.0099	.9063
.2152	-.0064	.9112	.2138	-.0070	.8286
.2463	-.0040	.8611	.2449	-.0017	.7603
.2775	-.0019	.9039	.2764	.0043	.6849
.3087	.0001	.8670	.3082	.0103	.6897
.3401	.0021	.8844	.3403	.0157	.6854
.3715	.0050	.8246	.3726	.0182	.7902
.4030	.0076	.8524	.4049	.0199	.7976
.4347	.0107	.8054	.4371	.0199	.9063
.4665	.0129	.8458	.4693	.0218	.8157
.4983	.0177	.7103	.5017	.0217	.9990
.5307	.0212	.8312	.5335	.0164	1.0530
.5629	.0204	.8735	.5653	.0138	1.0570
.5951	.0211	.8753	.5970	.0111	1.0536
.6274	.0215	.8828	.6285	.0085	1.0985
.6597	.0211	.9667	.6599	.0055	1.0864
.6918	.0183	1.0392	.6913	.0030	1.1179
.7236	.0126	1.1637	.7225	.0009	1.0744
.7551	.0065	1.1842	.7537	-.0009	1.1181
.7862	-.0004	1.2818	.7848	-.0035	1.0978
.8170	-.0051	1.1686	.8159	-.0053	1.1280
.8480	-.0075	1.2145	.8469	-.0084	1.1457
.8786	-.0123	1.2125	.8777	-.0116	1.1799
.9092	-.0147	1.2045	.9084	-.0145	1.1570
.9397	-.0183	1.2066	.9389	-.0170	1.1895
.9700	-.0204	1.1695	.9694	-.0197	1.1736

TABLE A74.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL IV (SINE WAVES AND STRAIGHT RAMPS, λ = 3.86 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0210	1.0896	0.0000	-.0199	1.1617
.0316	-.0190	1.0438	.0292	-.0214	1.0690
.0623	-.0161	.9629	.0595	-.0207	1.0405
.0931	-.0134	.9809	.0899	-.0160	.8581
.1239	-.0116	.9451	.1206	-.0099	.8222
.1549	-.0094	.9569	.1517	-.0018	.6525
.1858	-.0084	.9512	.1834	.0066	.6719
.2168	-.0071	.9610	.2153	.0132	.6378
.2479	-.0057	.9275	.2477	.0175	.7746
.2790	-.0045	.9540	.2798	.0183	.8195
.3102	-.0033	.9211	.3119	.0174	.9577
.3414	-.0022	.9514	.3437	.0142	.9637
.3726	-.0016	.9364	.3755	.0127	1.0089
.4038	-.0005	.9320	.4071	.0108	.9744
.4351	.0012	.8947	.4387	.0105	1.0030
.4664	.0040	.8513	.4703	.0090	.9860
.4981	.0077	.8504	.5019	.0094	.9754
.5297	.0073	.9428	.5336	.0081	1.0244
.5613	.0089	.8728	.5649	.0041	1.1013
.5929	.0092	.9414	.5962	.0022	1.0423
.6245	.0108	.8656	.6274	.0002	1.0852
.6563	.0122	.9074	.6586	-.0003	1.0121
.6881	.0153	.8057	.6898	-.0013	1.0706
.7202	.0180	.8682	.7210	-.0023	1.0272
.7523	.0199	.8393	.7521	-.0037	1.0798
.7847	.0189	.9904	.7832	-.0049	1.0410
.8166	.0146	1.0475	.8142	-.0066	1.0944
.8483	.0072	1.2384	.8451	-.0073	1.0286
.8794	-.0031	1.2579	.8761	-.0093	1.1197
.9101	-.0105	1.3089	.9069	-.0112	1.0610
.9405	-.0180	1.2625	.9377	-.0136	1.1463
.9708	-.0208	1.1968	.9684	-.0170	1.1162

TABLE A75.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 12

(SINE WAVES AND STRAIGHT RAMPS, λ = 4.62 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.1010	1.4124	0.0000	-.0918	1.7712
.0324	-.0867	1.0801	.0228	-.0990	1.4479
.0613	-.0694	.8089	.0501	-.0869	.8132
.0906	-.0589	.9205	.0782	-.0595	.4174
.1202	-.0486	.7404	.1072	-.0409	.0513
.1502	-.0387	.7987	.1373	-.0165	-.0218
.1805	-.0303	.7190	.1695	-.0073	-.3916
.2110	-.0240	.8272	.2035	.0432	-.6107
.2416	-.0179	.7284	.2392	.0740	.2467
.2724	-.0123	.8023	.2758	.0786	.1639
.3034	-.0062	.7042	.3112	.0762	.8277
.3345	-.0022	.8261	.3451	.0652	.7497
.3657	.0032	.6785	.3784	.0589	1.1753
.3971	.0088	.7647	.4112	.0477	.9499
.4287	.0129	.6997	.4436	.0428	1.2208
.4604	.0169	.7654	.4759	.0344	1.0119
.4922	.0222	.6568	.5078	.0296	1.2561
.5241	.0270	.7148	.5396	.0229	1.0268
.5564	.0338	.5819	.5713	.0191	1.2521
.5888	.0396	.6470	.6029	.0148	1.0132
.6216	.0482	.4787	.6343	.0101	1.3068
.6549	.0568	.4971	.6655	.0024	1.0882
.6888	.0693	.2705	.6966	-.0005	1.2760
.7242	.0810	.3052	.7276	-.0066	1.1200
.7608	.0900	.4206	.7584	-.0118	1.3459
.7965	.0822	.9847	.7890	-.0185	1.1593
.8305	.0619	1.1725	.8195	-.0234	1.3720
.8627	.0280	1.7933	.8498	-.0312	1.2303
.8928	-.0169	1.8637	.8798	-.0397	1.5124
.9218	-.0484	2.1106	.9094	-.0523	1.3698
.9499	-.0830	2.0761	.9387	-.0593	1.5541
.9772	-.1011	1.9933	.9676	-.0764	1.6604

TABLE A76.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 13
(SINE WAVES AND STRAIGHT RAMPS, λ = 4.01 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0892	1.5205	0.0000	-.0777	1.6661
.0316	-.0781	1.0676	.0241	-.0806	1.3222
.0604	-.0674	.9467	.0521	-.0666	.8951
.0898	-.0553	.7544	.0804	-.0535	.6557
.1195	-.0466	.8145	.1093	-.0321	.2727
.1496	-.0379	.7138	.1394	-.0162	.1039
.1798	-.0312	.7767	.1706	.0037	-.0266
.2103	-.0224	.6443	.2030	.0120	.0036
.2411	-.0164	.7801	.2366	.0366	-.3571
.2720	-.0099	.6647	.2715	.0626	.1083
.3032	-.0048	.7955	.3071	.0702	.1914
.3343	-.0003	.7046	.3423	.0761	.6122
.3656	.0045	.7791	.3766	.0728	.8162
.3971	.0098	.6766	.4100	.0642	1.0987
.4287	.0143	.7652	.4428	.0551	1.0212
.4604	.0201	.6251	.4753	.0478	1.1808
.4925	.0257	.7045	.5075	.0401	1.0691
.5247	.0320	.5700	.5396	.0343	1.2051
.5572	.0386	.6234	.5713	.0270	1.1052
.5900	.0462	.4721	.6029	.0223	1.2021
.6234	.0547	.4797	.6344	.0167	1.1086
.6577	.0645	.3339	.6657	.0116	1.2313
.6929	.0719	.4814	.6968	.0067	1.0993
.7285	.0751	.5816	.7280	.0027	1.2398
.7634	.0693	1.0089	.7589	-.0040	1.1664
.7970	.0542	1.1620	.7897	-.0087	1.2859
.8294	.0334	1.5535	.8202	-.0175	1.2764
.8606	.0061	1.6331	.8504	-.0245	1.3770
.8907	-.0206	1.9525	.8805	-.0325	1.3271
.9196	-.0497	1.9370	.9102	-.0404	1.4776
.9479	-.0665	1.9586	.9396	-.0523	1.5132
.9759	-.0850	1.8667	.9684	-.0638	1.6797

TABLE A77.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 14
(SINE WAVES AND STRAIGHT RAMPS, λ = 3.23 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0793	1.3694	0.0000	-.0684	1.4944
.0303	-.0775	1.3125	.0263	-.0739	1.4631
.0588	-.0714	.9837	.0543	-.0718	1.0875
.0879	-.0601	.7993	.0828	-.0582	.7621
.1176	-.0498	.7215	.1117	-.0450	.5979
.1475	-.0412	.7173	.1411	-.0308	.4078
.1777	-.0336	.6953	.1711	-.0161	.2415
.2081	-.0261	.6683	.2021	-.0001	.0876
.2389	-.0179	.6236	.2341	.0141	.0533
.2699	-.0111	.6673	.2671	.0288	.0339
.3011	-.0041	.6188	.3009	.0424	.1046
.3326	.0028	.6366	.3353	.0554	.1908
.3643	.0087	.6357	.3703	.0646	.3784
.3961	.0143	.6452	.4053	.0698	.5388
.4281	.0207	.5745	.4399	.0694	.8115
.4605	.0273	.5811	.4737	.0633	.9867
.4932	.0341	.5115	.5068	.0546	1.1360
.5263	.0421	.4587	.5395	.0466	1.1277
.5601	.0505	.4010	.5719	.0401	1.1840
.5947	.0575	.4593	.6039	.0326	1.2037
.6297	.0619	.5420	.6357	.0266	1.2106
.6647	.0631	.7289	.6674	.0213	1.1940
.6991	.0604	.8952	.6989	.0148	1.2794
.7329	.0525	1.1462	.7301	.0071	1.2803
.7659	.0395	1.3095	.7611	.0009	1.3021
.7979	.0218	1.5562	.7919	-.0072	1.3640
.8289	-.0021	1.7520	.8223	-.0157	1.4040
.8589	-.0231	1.7988	.8525	-.0230	1.3910
.8883	-.0406	1.8131	.8824	-.0311	1.4745
.9172	-.0562	1.8868	.9121	-.0413	1.5447
.9457	-.0750	1.9167	.9412	-.0547	1.6929
.9737	-.0841	1.6225	.9697	-.0658	1.5951

TABLE A78.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 15
(SINE WAVES AND STRAIGHT RAMPS, λ = 3.86 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0904	1.4079	0.0000	-.0899	1.8352
.0331	-.0759	1.0791	.0220	-.1019	1.5133
.0617	-.0621	.8939	.0491	-.0909	.8040
.0910	-.0509	.8344	.0769	-.0649	.1371
.1207	-.0420	.8107	.1061	-.0451	-.0094
.1506	-.0339	.7610	.1370	-.0262	-.4761
.1808	-.0262	.7385	.1700	.0151	-.6273
.2113	-.0194	.7413	.2050	.0479	-.0277
.2419	-.0141	.7680	.2412	.0554	.1209
.2727	-.0091	.7587	.2773	.0640	.3536
.3036	-.0046	.7694	.3120	.0621	.7862
.3346	-.0001	.7536	.3457	.0554	.9637
.3657	.0040	.7584	.3788	.0474	1.0937
.3970	.0086	.7210	.4115	.0396	1.1162
.4285	.0130	.7303	.4438	.0323	1.1651
.4600	.0181	.6731	.4760	.0275	1.1035
.4919	.0238	.6603	.5081	.0220	1.1830
.5240	.0293	.6423	.5400	.0160	1.1698
.5562	.0342	.6617	.5715	.0099	1.2354
.5885	.0400	.5895	.6030	.0052	1.1701
.6212	.0473	.5438	.6343	.0002	1.2474
.6543	.0551	.4773	.6654	-.0044	1.1862
.6880	.0643	.3871	.6964	-.0086	1.2539
.7227	.0751	.2790	.7273	-.0132	1.2094
.7588	.0843	.3699	.7581	-.0176	1.2853
.7950	.0855	.6760	.7887	-.0225	1.2422
.8300	.0735	1.0984	.8192	-.0278	1.3557
.8630	.0468	1.5366	.8494	-.0358	1.3623
.8939	.0086	1.9413	.8793	-.0435	1.4639
.9231	-.0360	2.2413	.9090	-.0521	1.4453
.9509	-.0800	2.3759	.9383	-.0615	1.6051
.9780	-.0997	1.9308	.9669	-.0753	1.6857

TABLE A79.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 17 (TRANSVERSE V-GROOVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0727	1.8850
.0285	-.0693	1.1548
.0573	-.0590	.8658
.0867	-.0480	.6863
.1166	-.0393	.6945
.1467	-.0312	.6276
.1771	-.0240	.6375
.2078	-.0162	.5689
.2388	-.0094	.6289
.2700	-.0023	.5696
.3014	.0040	.6217
.3331	.0109	.5450
.3650	.0172	.5805
.3972	.0244	.4768
.4298	.0317	.4647
.4632	.0405	.3370
.4975	.0475	.4034
.5324	.0556	.3610
.5676	.0577	.7858
.6013	.0497	1.0308
.6342	.0418	1.2000
.6666	.0328	1.2243
.6987	.0252	1.3155
.7304	.0168	1.3080
.7618	.0098	1.3720
.7930	.0023	1.3417
.8239	-.0043	1.4126
.8547	-.0124	1.4218
.8850	-.0209	1.5448
.9150	-.0321	1.6161
.9445	-.0445	1.7912
.9732	-.0608	1.9203

TABLE A80.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 18
(TRANSVERSE V-GROOVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0684	1.9292	0.0000	-.0842	1.9123
.0310	-.0639	1.2353	.0238	-.0822	1.0916
.0596	-.0519	.8284	.0523	-.0687	.6619
.0890	-.0412	.7711	.0818	-.0537	.4322
.1188	-.0321	.6547	.1119	-.0422	.4256
.1490	-.0247	.7152	.1425	-.0298	.2919
.1793	-.0182	.6535	.1735	-.0197	.3653
.2098	-.0117	.6839	.2049	-.0075	.2079
.2407	-.0055	.6485	.2370	.0036	.3021
.2717	-.0004	.6860	.2696	.0161	.1716
.3031	.0052	.6674	.3028	.0269	.2382
.3343	.0080	.8064	.3374	.0403	.0217
.3656	.0128	.6520	.3741	.0470	.4999
.3972	.0170	.7387	.4084	.0445	.7827
.4289	.0221	.6130	.4417	.0377	1.1472
.4608	.0268	.6849	.4744	.0303	1.0359
.4930	.0330	.5246	.5070	.0254	1.2501
.5256	.0385	.6061	.5392	.0182	1.1624
.5583	.0454	.4324	.5711	.0132	1.3074
.5916	.0531	.4430	.6028	.0073	1.1772
.6259	.0639	.1583	.6344	.0030	1.3210
.6626	.0703	.5154	.6657	-.0033	1.2285
.6972	.0650	.8963	.6969	-.0060	1.2508
.7304	.0541	1.2297	.7283	-.0090	1.1664
.7630	.0432	1.2087	.7593	-.0140	1.3803
.7951	.0321	1.4440	.7902	-.0187	1.2755
.8265	.0191	1.4252	.8207	-.0259	1.4980
.8575	.0086	1.5697	.8510	-.0322	1.3352
.8881	-.0040	1.5588	.8812	-.0388	1.5512
.9182	-.0170	1.7814	.9110	-.0477	1.4993
.9477	-.0345	1.8685	.9404	-.0581	1.7819
.9762	-.0544	2.1533	.9690	-.0735	1.8235

TABLE A81.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 19
(TRANSVERSE V-GROOVES, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0828	2.1079	0.0000	-.0880	1.9458
.0333	-.0699	1.0563	.0206	-.0842	.9037
.0620	-.0570	.9517	.0490	-.0590	.2475
.0912	-.0459	.7240	.0788	-.0462	.2232
.1210	-.0380	.8291	.1093	-.0286	.0326
.1509	-.0304	.6593	.1403	-.0201	.1449
.1813	-.0248	.8177	.1724	.0000	-.2963
.2116	-.0196	.6870	.2053	.0172	.1272
.2422	-.0142	.7942	.2399	.0316	-.3301
.2730	-.0087	.6779	.2771	.0501	.3158
.3040	-.0043	.8119	.3118	0481	.6514
.3351	-.0011	.7427	.3454	0434	1.0060
.3661	.0023	.7978	.3785	.0372	1.0045
.3975	.0085	.6419	.4111	.0316	1.2432
.4290	.0113	.8306	.4435	.0256	1.0938
.4606	.0161	.6157	.4756	.0208	1.2909
.4925	.0199	.7974	.5075	.0156	1.1058
.5244	.0239	.6055	.5394	.0123	1.2805
.5565	.0285	.7256	.5710	.0063	1.1545
.5889	.0338	.5392	.6025	.0036	1.2610
.6215	.0392	.6296	.6339	-.0017	1.2085
.6546	.0466	.3942	.6649	-.0074	1.3358
.6882	.0536	.4783	.6960	-.0090	1.1139
.7229	.0639	.1433	.7270	-.0131	1.3685
.7601	.0685	.6030	.7578	-.0176	1.2094
.7947	.0603	.9666	.7884	-.0235	1.4493
.8276	.0475	1.4221	.8187	-.0285	1.2395
.8597	.0297	1.4490	.8491	-.0332	1.4611
.8907	.0123	1.7835	.8790	-.0397	1.3672
.9212	-.0065	1.6465	.9088	-.0472	1.6185
.9510	-.0240	2.1230	.9380	-.0573	1.5498
.9794	-.0625	2.5215	.9667	-.0690	1.9262

TABLE A82.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 24 (CIRCULAR ARCS AND STRAIGHT RAMPS, λ = 2.54 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0828	1.4920	0.0000	-.0642	1.7427
.0323	-.0767	1.2191	.0237	-.0662	1.3311
.0610	-.0673	.8989	.0515	-.0642	1.2066
.0903	-.0589	.8481	.0791	-.0525	.7895
.1200	-.0495	.6638	.1064	-.0435	.2960
.1501	-.0432	.7696	.1354	-.0149	-.4227
.1805	-.0361	.6407	.1682	-.0025	-.4061
.2109	-.0308	.7947	.2044	.0363	-.9848
.2416	-.0244	.6346	.2433	.0641	.3836
.2725	-.0197	.8092	.2779	.0598	.5088
.3036	-.0145	.6608	.3118	.0589	1.0747
.3348	-.0111	.8788	.3450	.0525	.7858
.3660	-.0076	.6990	.3782	.0494	1.2756
.3973	-.0033	.8117	.4107	.0394	.9719
.4289	.0011	.6725	.4431	.0377	1.2555
.4606	.0054	.7758	.4753	.0294	1.0494
.4927	.0102	.6591	.5071	.0269	1.2281
.5245	.0126	.8097	.5391	.0238	.9823
.5567	.0190	.5467	.5708	.0190	1.3287
.5892	.0228	.7566	.6023	.0143	.9941
.6217	.0290	.4558	.6337	.0101	1.3544
.6549	.0349	.6299	.6648	.0048	1.0176
.6883	.0408	.3944	.6960	.0026	1.2838
.7223	.0468	.5174	.7272	-.0017	1.0319
.7570	.0551	.1003	.7581	-.0054	1.3650
.7963	.0623	.3563	.7888	-.0113	1.1251
.8326	.0583	.8893	.8193	-.0160	1.4317
.8653	.0287	2.0417	.8497	-.0218	1.1768
.8941	-.0291	2.7025	.8798	-.0277	1.5287
.9213	-.0622	2.5053	.9096	-.0361	1.3493
.9489	-.0756	1.9603	.9389	-.0454	1.7158
.9765	-.0811	1.9039	.9677	-.0558	1.5323

TABLE A83.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 34
(CIRCULAR ARCS AND STRAIGHT RAMPS,
λ = 1.27 cm, 64 GRID POINTS)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Forward direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0679	1.9533	.4922	.0068	.7096
.0181	-.0654	1.6414	.5082	.0092	.6115
.0318	-.0634	1.3900	.5244	.0111	.6676
.0458	-.0585	1.0369	.5406	.0132	.6129
.0602	-.0538	.8790	.5568	.0148	.6772
.0748	-.0489	.7124	.5730	.0166	.6300
.0899	-.0445	.6402	.5892	.0182	.6684
.1051	-.0411	.7122	.6054	.0201	.6064
.1200	-.0392	.7534	.6217	.0220	.6060
.1350	-.0369	.7187	.6380	.0244	.5220
.1500	-.0352	.7428	.6545	.0267	.5055
.1651	-.0327	.6710	.6712	.0296	.4140
.1803	-.0305	.6951	.6881	.0323	.4006
.1956	-.0281	.6781	.7054	.0355	.3379
.2108	-.0262	.7322	.7225	.0380	.3397
.2261	-.0237	.6728	.7403	.0416	.2226
.2415	-.0215	.7224	.7583	.0443	.2376
.2569	-.0189	.6718	.7779	.0482	.1242
.2724	-.0167	.7338	.7977	.0500	.4029
.2879	-.0145	.7108	.8167	.0505	.5847
.3034	-.0128	.7834	.8342	.0435	1.3173
.3190	-.0110	.7432	.8499	.0296	1.7881
.3345	-.0096	.7967	.8648	.0105	2.5242
.3501	-.0076	.7126	.8788	-.0084	2.4946
.3658	-.0060	.7704	.8930	-.0188	2.5308
.3815	-.0043	.7255	.9069	-.0311	2.4994
.3972	-.0029	.7689	.9210	-.0373	2.3592
.4129	-.0009	.6959	.9348	-.0447	2.2846
.4288	.0007	.7423	.9489	-.0454	1.8454
.4447	.0025	.6887	.9634	-.0474	1.9795
.4606	.0039	.7667	.9776	-.0529	2.2628
.4764	.0053	.7303	.9912	-.0635	2.5962

TABLE A83.- Concluded

Reverse direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0483	2.0218	.5078	.0316	1.3122
.0088	-.0512	1.6801	.5236	.0287	1.3387
.0224	-.0470	1.0742	.5394	.0269	1.2263
.0366	-.0419	.9078	.5553	.0258	1.2321
.0511	-.0376	.8853	.5712	.0241	1.2220
.0652	-.0354	.9776	.5871	.0227	1.2544
.0790	-.0323	.7370	.6028	.0205	1.2806
.0931	-.0281	.6184	.6185	.0188	1.2749
.1070	-.0233	.3717	.6342	.0171	1.2556
.1212	-.0180	.2147	.6499	.0157	1.2824
.1352	-.0130	.0309	.6655	.0135	1.3203
.1501	-.0081	-.1605	.6810	.0119	1.2941
.1658	-.0030	-.3427	.6966	.0103	1.2958
.1833	.0017	-.4938	.7121	.0090	1.2783
.2023	.0085	-.7410	.7276	.0075	1.2929
.2221	.0197	-.9483	.7431	.0059	1.3184
.2417	.0369	-.8480	.7585	.0038	1.3611
.2597	.0501	-.1128	.7739	.0018	1.3675
.2775	.0542	.3600	.7892	-.0005	1.4100
.2946	.0556	.6116	.8044	-.0023	1.3640
.3119	.0558	.7697	.8197	-.0039	1.3826
.3288	.0546	.9791	.8349	-.0061	1.4278
.3455	.0527	1.0635	.8500	-.0086	1.4787
.3620	.0503	1.1965	.8650	-.0109	1.4434
.3783	.0478	1.2036	.8800	-.0128	1.4713
.3946	.0454	1.2781	.8949	-.0147	1.4104
.4108	.0432	1.2228	.9101	-.0155	1.4011
.4270	.0414	1.2587	.9252	-.0194	1.7012
.4432	.0396	1.1997	.9398	-.0252	1.8111
.4594	.0381	1.2256	.9542	-.0312	1.9762
.4756	.0362	1.2082	.9682	-.0388	2.1141
.4918	.0344	1.2488	.9819	-.0440	1.9642

TABLE A84.- PREDICTED C_p AND $C_f/C_{f,o}$ DATA FOR MODEL 44
(CIRCULAR ARCS AND STRAIGHT RAMPS, λ = 5.08 cm)

[Navier-Stokes spectral code; U_∞ = 22.9 m/s]

Forward direction			Reverse direction		
x/λ	C_p	$C_f/C_{f,o}$	x/λ	C_p	$C_f/C_{f,o}$
0.0000	-.0911	1.5571	0.0000	-.0893	1.4054
.0318	-.0920	1.2016	.0240	-.0872	1.3871
.0600	-.0801	1.0133	.0518	-.0856	1.1871
.0889	-.0579	.4590	.0793	-.0810	1.0976
.1193	-.0401	.5676	.1061	-.0623	.2920
.1498	-.0279	.5772	.1346	-.0323	-.4227
.1804	-.0223	.8464	.1665	.0127	-.7343
.2111	-.0165	.6675	.2031	.0610	-.4751
.2420	-.0115	.8712	.2411	.0895	.1472
.2730	-.0072	.7360	.2767	.0871	.6882
.3038	-.0058	.9475	.3114	.0814	.7146
.3349	-.0003	.6673	.3451	.0712	1.0494
.3661	.0035	.8702	.3783	.0620	.9149
.3974	.0097	.6305	.4110	.0532	1.1492
.4289	.0136	.8402	.4434	.0448	.9787
.4606	.0203	.5976	.4756	.0394	1.1476
.4924	.0238	.8205	.5076	.0326	1.0107
.5244	.0312	.5526	.5394	.0275	1.1625
.5566	.0352	.7817	.5711	.0219	1.0330
.5890	.0435	.4845	.6026	.0164	1.1991
.6217	.0498	.6611	.6339	.0111	1.0514
.6549	.0608	.3755	.6651	.0061	1.2300
.6886	.0685	.5085	.6962	.0002	1.0909
.7233	.0828	.2234	.7270	-.0027	1.1940
.7589	.0897	.4186	.7580	-.0041	1.0279
.7969	.1052	.1933	.7889	-.0096	1.2604
.8335	.0864	1.3903	.8196	-.0138	1.0790
.8654	.0250	1.7332	.8502	-.0187	1.2819
.8939	-.0455	2.6030	.8807	-.0221	1.1145
.9207	-.0974	1.8892	.9111	-.0382	1.6808
.9482	-.0884	1.7359	.9400	-.0703	1.7294
.9760	-.0934	1.4619	.9682	-.0837	1.6992

1. Report No. NASA TP-2318	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DRAG OF TWO-DIMENSIONAL SMALL-AMPLITUDE SYMMETRIC AND ASYMMETRIC WAVY WALLS IN TURBULENT BOUNDARY LAYERS		5. Report Date June 1984
		6. Performing Organization Code 505-31-13-05
7. Author(s) John C. Lin, Michael J. Walsh, and R. Balasubramanian		8. Performing Organization Report No. L-15761
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Paper
		14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

Included are results of an experimental investigation of low-speed turbulent flow over multiple two-dimensional transverse rigid wavy surfaces having a wavelength on the order of the boundary-layer thickness. Data include surface pressure and total drag measurements on symmetric and asymmetric wall waves under a low-speed turbulent boundary-layer flow. Several asymmetric wave configurations exhibited drag levels below the equivalent symmetric (sine) wave. The experimental results compare favorably with numerical predictions from a Reynolds-averaged Navier-Stokes spectral code. The reported results are of particular interest for the estimation of drag, the minimization of fabrication waviness effects, and the study of wind-wave interactions.

17. Key Words (Suggested by Author(s)) Wavy walls Drag measurement Turbulent boundary layer Navier-Stokes spectral code Pressure measurement	18. Distribution Statement Unclassified - Unlimited Subject Category 34

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 163	22. Price A08

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