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# Effects of Independent Variation of Mach and Reynolds Numbers on the Low-Speed Aerodynamic Characteristics of the NACA 0012 Airfoil Section 

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# Effects of Independent Variation of Mach and Reynolds Numbers on the Low-Speed Aerodynamic Characteristics of the NACA 0012 Airfoil Section 

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## Summary

Presented in this report is a description of a test program conducted in the Langley Low-Turbulence Pressure Tunnel to produce the low-speed aerodynamic characteristics of the NACA 0012 airfoil section. During the program, Mach number independently varied from 0.05 to 0.36 and the Reynolds number independently varied from about 2 to $12 \times 10^{6}$. The angle of attack variation covered the range from zero lift coefficient to maximum lift coefficient.

An analysis of the data shows that changes in Mach number affect lift-curve slope and maximum lift coefficient. These changes have little effect on either minimum drag or maximum lift-drag ratio. Changes in Reynolds number affect all parameters to some extent. Theoretical predictions of lift-curve slope generally show the trends of the experimental data with varying Mach number but do not accurately give the trends with Reynolds number. The magnitude of the predictions is generally higher than that of the experiment. Predictions of minimum drag are as much as 0.001 lower than experiment at the higher Mach and Reynolds numbers for the free-transition case. With transition fixed at the 5-percent-chord model station, the agreement between theory and experiment is excellent.

## Introduction

Aeronautical researchers have been and are still using the NACA 0012 airfoil section as a reference model for the assessment of wall interference and correction procedures. This airfoil section is also an AGARD standard used in the testing of numerical solutions (ref. 1) and is in the AGARD two-dimensional experimental data base (ref. 2). Although a large experimental data base exists for this airfoil throughout the subsonic and transonic speed range, there are some areas in which additional data are desirable. One such area is the low-speed regime. In this regime, the independent effects of Mach number and Reynolds number on the aerodynamic characteristics of the airfoil are lacking. To supplement the data available in this area, researchers at Langley Research Center conducted an investigation of this airfoil in the Langley Low-Turbulence Pressure Tunnel in late 1975.

The purpose of this paper is to present a comprehensive data base of the low-speed aerodynamic characteristics of the NACA 0012 airfoil section. Included are the effects of varying Mach number and Reynolds number independently and the effects of fixing transition location. Comparisons of some of the results with previously published data and with
theoretical estimates are also discussed. The Langley Low-Turbulence Pressure Tunnel is the facility used for these tests. The Mach number varied from 0.05 to 0.36 . The Reynolds number, based on model chord, generally varied from about 2 to $12 \times 10^{6}$. One additional run at a Reynolds number of about $19 \times 10^{6}$ and a Mach number of 0.15 with free transition is in the tabulated data base but is not in the summary figures.

## Symbols

All measurements and calculations are in U.S. Customary Units. The International System of Units (SI) values are in parentheses.
$\left.\begin{array}{ll}b & \begin{array}{l}\text { airfoil model span, } 36.00 \text { in. } \\ (91.44 \mathrm{~cm})\end{array} \\ c & \begin{array}{l}\text { airfoil model chord, } 23.66 \text { in. } \\ (60.10 \mathrm{~cm})\end{array} \\ c_{d} & \begin{array}{l}\text { section drag coefficient from } \\ \text { integration of wake survey (CD } \\ \text { in computer-generated figures) }\end{array} \\ c_{d, o} & \begin{array}{l}\text { section drag coefficient at zero } \\ \text { lift }\end{array} \\ c_{\ell} & \begin{array}{l}\text { section lift coefficient from } \\ \text { integration of model surface }\end{array} \\ c_{\ell, \alpha} & \begin{array}{l}\text { pressure coefficients (CL in } \\ \text { computer-generated figures) }\end{array} \\ c_{m} & \begin{array}{l}\text { section lift-curve slope, per deg }\end{array} \\ \text { section pitching-moment coeffi- } \\ \text { cient about 0.25c point from inte- } \\ \text { gration of model surface pressure } \\ \text { coefficients (CM in computer- } \\ \text { generated figures) }\end{array}\right\}$

## Apparatus

## Wind Tunnel

The Langley Low-Turbulence Pressure Tunnel, used to conduct the tests on this model, is a closedthroat, single-return facility. The tunnel operates
at stagnation pressures from 1.0 to 10.0 atm . The Mach number is variable from about 0.05 to 0.46 . An air-to-water heat exchanger maintains the stagnation temperature at or near ambient conditions. The maximum Reynolds number is about $15 \times 10^{6}$ per foot ( $4.92 \times 10^{7}$ per meter) at a Mach number of 0.22 . The test section is 36.0 in . ( 91.4 cm ) wide and 90.0 in . ( 228.6 cm ) high. Descriptions of the operational characteristics and calibration results for this tunnel are in the appendix of reference 3. At the time of this test program the turbulence level of the tunnel was unknown, but there were many indications that it had increased from the original low level measured in the early 1940's. This increase was the result of successive damage to the heat exchanger because of freezing as well as deterioration of the screens. After these tests, the tunnel was refurbished and the turbulence level reduced. A description of the refurbishment and results of calibration are in reference 4.

The tunnel sidewalls contain circular end plates $40.0 \mathrm{in} .(101.6 \mathrm{~cm})$ in diameter. These plates are for positioning and attachment of the two-dimensional airfoil models. These hydraulically actuated plates rotate with the model and are flush with the test section sidewall. The airfoil ends attach to rectangular model attachment blocks in these plates. The airfoil mounting blocks locate the 0.25 c model station on the center of rotation. Air gaps between the rectangular blocks and the circular plates are sealed with flexible sliding metal seals. For a sketch of these seals, see figure 1.

## Wake Survey Rake

A fixed wake survey rake is cantilevered from the test section sidewall. This rake, located at the model midspan, is about $1 c$ downstream of the model trailing edge. The rake consists of 91 total-pressure tubes 0.060 in. ( 0.152 cm ) in diameter and 5 staticpressure tubes 0.125 in. $(0.318 \mathrm{~cm})$ in diameter. The total-pressure tubes are oval in cross section for the last $0.24 \mathrm{in} .(0.61 \mathrm{~cm})$ of the tube. A minimum opening of $0.040 \mathrm{in} .(0.102 \mathrm{~cm})$ remains at the tube end. The static-pressure tubes each have four flush orifices drilled $90^{\circ}$ apart. These orifices, located eight tube diameters from the end of the tube, are in the plane of measurement of the total-pressure tubes. Also located on the test section sidewall in the plane of the total-pressure tubes is an array of flush staticpressure orifices. Shown in figure 2 is a sketch of the wake survey rake.

## Instrumentation

To make measurements of both the airfoil surface static pressures and the wake total pressures,
we use an automatic pressure scanning system and variable-capacitance-type pressure transducers. Precision quartz pressure transducers measure the tunnel stagnation pressure and the reference static pressure. The angle-of-attack measurement device is a calibrated digital shaft encoder operated by a pinion gear. A rack attached to the circular plates drives the pinion gear. A high-speed computer-controlled digital data-acquisition system records the analog output of all measurement devices on magnetic tape. This magnetic tape is the input for post-run data reduction and analysis of the aerodynamic data.

## Accuracy

The differential pressure gauges used to measure the model pressures have a maximum range of 50 psi . The gauges for measurement of wake total-pressure loss have a maximum range of 7.5 psi . These precision transducers have an accuracy of 0.25 percent of reading from 25 percent of negative full scale to 100 percent of positive full scale. The precision quartz gauges used to measure stagnation pressure and the difference between reference static pressure and stagnation pressure have full-scale ranges of 150 psi and 15 psi , respectively. These gauges have an accuracy of about 0.01 percent of full scale at low pressures to about 0.02 percent of full scale at the high end of their range.

The repeatability of data is also an indication of the overall data accuracy. On many of the runs shown in the tabulated data, two points at $\alpha=0^{\circ}$ are listed. An analysis of these repeat points shows that when the two points are within $0.01^{\circ}$ of each other, drag coefficient varies by 0.0002 or less, normalforce coefficient varies by 0.004 or less, and pitchingmoment coefficient varies by 0.0002 or less.

## Model

The model, machined from a solid aluminum billet, had a chord of 23.66 in . $(60.10 \mathrm{~cm}$ ) and a span of 36.00 in . $(91.44 \mathrm{~cm}$ ), which is the span of the tunnel. Instrumentation consisted of a total of 81 orifices. There were 24 orifices located in each chordwise row on both the upper and the lower surface. These chordwise rows were 4.20 in . $(10.67 \mathrm{~cm})$ to the left of the model center line. There were also 33 additional orifices arranged in 3 spanwise rows on the upper surface. Grooves, machined in the surface of the model, accommodated the pressure tubing for each orifice location. After the tube installation, the grooves were covered with a plastic resin. The orifices, drilled through the plastic and into the tubing,
had a diameter of 0.060 in . $(0.152 \mathrm{~cm})$. After completion of this potting process and the drilling of the orifice, the airfoil surface was machined to provide a surface finish of about 32 rms microinches. The surface was then hand polished in a chordwise direction with No. 400 carborundum paper to provide the final aerodynamic surface. The ordinates of the finished model were within $0.0002 c$ of the design ordinates.

## Tests and Procedures

The airfoil test program covered Mach numbers from 0.05 to 0.36 over angles of attack from about $-4^{\circ}$ to $18^{\circ}$. The Reynolds number based on model chord varied from about 2 to $12 \times 10^{6}$. Both the Reynolds number and the Mach number varied independently for this test program.

Included in the program were tests with both fixed and free boundary-layer transition. For the fixed-transition runs, carborundum strips were applied to both the model upper and lower surfaces at the $0.05 c$ station. The strips were about $0.01 c$ in width. The carborundum grit size varied with test Reynolds number to provide enough height to trip the boundary layer but not add incremental drag. The method of reference 5 was used to determine the appropriate grit size. Also included in the test program were tests made with an NACA-type wraparound transition strip. This strip extended from the $0.05 c$ location on the upper surface, around the leading edge, to the $0.05 c$ location on the lower surface. The grit size was No. 60 for these tests. The label " $\# 60-\mathrm{W}$ " indicates these runs on the data plots. This series of tests is for comparison with previously published data on this airfoil.

All data presented include corrections for the standard low-speed wind tunnel boundary effects described in reference 6. This correction amounts to about 2 percent of the measured coefficients.

## Presentation of Results

Computer-generated plots of lift coefficient, drag coefficient, pitching-moment coefficient, and lift-drag ratio as a function of angle of attack present the basic results of this investigation. For a few of the polars presented, data at the angle of attack for maximum lift were not available. On the plots of these data, the lift coefficient was extrapolated to obtain the maximum value. A dashed line indicates these extrapolations. Also included in this report are tabulations of these integrated force and moment
coefficients. These basic data plots and tabulations are presented as follows:

| Mach <br> number | Transition | Figure | Table |
| :---: | :--- | :---: | :--- |
| 0.15 | Free | 3 | I |
| .20 |  | 4 | II |
| .25 |  | 5 | III |
| .30 |  | 6 | IV |
| .36 |  | 7 | V |
| 0.05 | Fixed (No. 60-W grit) | 8 | VI |
| .15 |  | 9 | VII |
| .30 |  | 10 | VIII |
| 0.15 | Fixed (No. 80 grit) | 11 | IX |
| .30 |  | 12 | X |
| 0.15 | Fixed (No. 120 grit) | 13 | XI |
| .30 |  | 14 | XII |
| 0.15 | Fixed (No. 180 grit) | 15 | XIII |
| .30 |  | 16 | XIV |

## Discussion

To summarize the results of these basic data plots, we present some of the important parameters as separate figures. These summary figures show some of the effects of variations of Mach number, Reynolds number, and transition fixing. The discussion which follows is the result of an analysis of these summary figures.

## Lift-Curve Slope

Figures 17 to 23 illustrate the experimental liftcurve slope obtained by a least-squares curve-fit program. This program used data only from the linear angle-of-attack range. Figure 17 illustrates the effects of Mach number and Reynolds number on the lift-curve slope for the free-transition case. There is a gradual increase in the slope with increasing Mach number and Reynolds number. This increase in slope amounts to about 5 percent for increases in Mach number from 0.15 to 0.36 . A similar percentage increase results from increases in Reynolds number from 4 to $12 \times 10^{6}$. It is thus clear that the effects of Mach number and Reynolds number are equally important in these ranges. Ignoring either of these effects in a comparison of data can be misleading.

Illustrated in figure 18 is a comparison of the liftcurve slopes for both free- and fixed-transition cases at a Mach number of 0.15 . Fixing the transition at $0.05 c$ has little effect on the data presented compared with the free-transition case. The effects of grit size are small and not consistent. For the case of wraparound transition (No. 60 grit), however, the
lift-curve slope decreases about 3 percent. This loss is about the same for all Reynolds numbers. Data at a Mach number of 0.30 (fig. 19) show essentially the same trends.

Presented in figures 20 and 21 are comparisons of the experimental and theoretical lift-curve slopes for the free-transition case. The theoretical values labeled Stevens are from the analysis program presented in reference 7, and the values labeled Eppler are from the program presented in reference 8. Figure 20 shows that both theories predict higher values than the experimental data throughout the Mach number range. The trends of the theories with Mach number, however, are very similar to the experimental data. Figure 21 shows that the overprediction of the magnitude of the experimental data reduces from about 7 percent at $R=4 \times 10^{6}$ to about 3 percent at $R=12 \times 10^{6}$. The results are about the same for both Mach numbers shown. This figure also shows that neither theory accurately predicts the trends of the data with increasing Reynolds number. The Eppler theory shows no effect of Reynolds number, and the increase in slope of the Stevens theory is only about half the experimental value.

Figure 22 presents the comparison of theoretical and experimental lift-curve slopes for the fixedtransition case. Like the free-transition results, the theory gives higher slopes and does not give the proper trends with Reynolds number. The Eppler code is in better agreement with experiment than the Stevens code, but it shows essentially no variation with Reynolds number.

Figure 23 shows a comparison of data from reference 9 with results from the present investigation. Both sets of data are from the same facility. The agreement is good for the free-transition case except at the low Reynolds numbers. With the transition fixed with wraparound grit, the lift-curve slopes from the present investigation are higher for Reynolds numbers below $6 \times 10^{6}$. The variation with Reynolds number is much greater for the data of reference 9. The agreement at $R=6 \times 10^{6}$ is a crossover point and is probably not typical of the results. The suspected higher turbulence level of the facility during the present tests may account for some of these differences. The density of the grit may also be a contributing factor.

## Maximum Lift Coefficient

The maximum lift coefficient attained before stall is an important parameter for low-speed airfoil tests. Figures 24 to 26 present this parameter for the present tests. For the free-transition case (fig. 24), the maximum lift coefficient decreases about 25 percent as the Mach number increases from 0.15 to 0.36 .

This percentage decrease is about the same for all Reynolds numbers. The maximum lift coefficient increases with increasing Reynolds number for all test Mach numbers. For $M=0.15$, this increase amounts to 20 percent for $R=2$ to $12 \times 10^{6}$.

As shown in figure 25 for $M=0.15$ and in figure 26 for $M=0.30$, fixing transition at the $0.05 c$ location has very little effect on the maximum lift coefficient. Using the wraparound transition method (No. 60 grit) produces a large loss in maximum lift. This loss is about 25 percent at $M=0.15$ and about half this value at $M=0.30$. Again, these data show that Mach number and Reynolds number effects are appreciable at low speeds. Ignoring these effects in data comparisons can lead to erroneous conclusions.

## Minimum Drag

Figures 27 to 29 summarize the minimum drag characteristics of this airfoil. For the free-transition data (fig. 27) there are no consistent trends in the data. Drag levels remain essentially constant with increasing Mach and Reynolds number. Fixed transition (figs. 28 and 29) increases the drag over that for free transition for both Mach numbers. There is little effect of grit size on drag for transition fixed at the $0.05 c$ location. With the wraparound grit, however, drag increases by about 0.01 for both Mach numbers throughout the Reynolds number range. This increment is greater than expected from the increase in length of turbulent flow. Drag from the grit particles is the probable source of most of this drag increment.

Shown in figure 30 is a comparison of the experimental and theoretical values of minimum drag. Once again, results of both the Stevens code (ref. 7) and the Eppler code (ref. 8) are shown. For both Mach numbers, the experimental drag values with free transition are higher than theoretical values. At the lower Mach number, the experimental values are as much as 0.0006 higher than those from the Stevens theory. The results from the Eppler code show only about half this difference. At the higher Mach number, the data are as much as 0.0010 higher than the Stevens code results. The Eppler code results again show only about half this difference. As stated in the discussion of lift-curve slope, the higher experimental values are probably the result of the tunnel turbulence level. Turbulence will move the transition point forward on the model compared with the theoretical location, thus increasing drag. At $M=0.30$, the experimental drag with free transition approaches that for fixed transition at the higher Reynolds numbers. This shows that the transition location is approaching the $0.05 c$ station on the model. The orifice locations on this model are about 23 percent of the model semispan to the left of the tunnel center line.

This offset reduces the possibility of orifice-induced turbulence on the measurement of wake drag, which is measured on the tunnel center line.

With the transition location fixed, figure 30 shows that the agreement between theory and experiment is excellent. Both theoretical programs give nearly identical results.

Figure 31 presents a comparison of the present test results with those from reference 9 . With free transition, the present test results are about 0.0005 higher at most Reynolds numbers. This again is likely the result of differences in tunnel turbulence levels. With fixed transition, the present test results are lower by about 0.001 for all but the lowest Reynolds number. This difference may be the result of differences in density of grit application.

## Maximum Lift-Drag Ratio

Plotted in figures 32 to 34 are the variations with Mach and Reynolds number of the maximum lift-drag ratio. For free transition, figure 32 shows little variation in this parameter with Mach number. Maximum lift-drag ratio increases with increasing Reynolds number up to about $6 \times 10^{6}$. Above this value little variation occurs.

With fixed transition (figs. 33 and 34), the values of this maximum ratio are slightly less than for free transition. The data also show a continual increase with increasing Reynolds number. The use of wraparound grit produces a 20 - to 30 -percent decrease in maximum lift-drag ratio when compared with that produced for the 0.05 c transition location.

## Conclusions

An investigation conducted in the Langley LowTurbulence Pressure Tunnel has produced the lowspeed aerodynamic characteristics of the NACA 0012 airfoil. This investigation covered a Mach number range of 0.05 to 0.36 . The corresponding Reynolds number range was about 2 to $12 \times 10^{6}$. The angle-of-attack variation covered the range from zero lift coefficient to maximum lift coefficient. An analysis of the data yields the following conclusions:

1. Increasing Mach number at constant Reynolds number increases the lift-curve slope and decreases maximum lift coefficient, but it has little effect on minimum drag and maximum lift-drag ratio.
2. Increasing Reynolds number at constant Mach number increases the lift-curve slope, maximum lift coefficient, and, to some extent, maximum lift-drag ratio. Minimum drag decreases with increasing Reynolds number only for the fixedtransition case.
3. Fixing transition at the 5 -percent-chord location on the model has little effect on either lift-curve
slope or maximum lift coefficient. Minimum drag increases with fixed transition and the maximum lift-drag ratio thus decreases.
4. The theoretical values of lift-curve slope are higher than the experimental values by as much as 7 percent at the lower Reynolds number with free transition. Both theories presented generally predict the experimental trends with variation of Mach number but do not adequately predict the trends with Reynolds number. With fixed transition, the Stevens theory predicts values as much as 10 percent higher than experimental values.
5. With free transition, both theories underestimate the minimum drag level. The Stevens theory is as much as 0.0010 low at the higher Mach numbers and Reynolds numbers. The Eppler code is within 0.0005 for most cases. Theoretical values of minimum drag with fixed transition are in excellent agreement with the data.

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## References

1. Experimental Data Base for Computer Program Assessment. AGARD-AR-138, May 1979.
2. Lock, R. C.: Test Cases for Numerical Methods in TwoDimensional Transonic Flows. AGARD Rep. No. 575, Nov. 1970.
3. Beasley, William D.; and McGhee, Robert J.: Experimental and Theoretical Low-Speed Aerodynamic Characteristics of the NACA 651-219, $a=0.50$, Airfoil. NASA TM X-3160, 1975.
4. McGhee, Robert J.; Beasley, William D.; and Foster, Jean M.: Recent Modifications and Calibration of the Langley Low-Turbulence Pressure Tunnel. NASA TP-2328, 1984.
5. Braslow, Albert L.; and Knox, Eugene C.: Simplified Method for Determination of Critical Height of Distributed Roughness Particles for Boundary-Layer Transition at Mach Numbers From 0 to 5. NACA TN 4363, 1958.
6. Allen, H. Julian; and Vincenti, Walter G.: Wall Interference in a Two-Dimensional-Flow Wind Tunnel, With Consideration of the Effect of Compressibility. NACA Rep. 782, 1944. (Supersedes NACA WR A-63.)
7. Stevens, W. A.; Goradia, S. H.; and Braden, J. A.: Mathematical Model for Two-Dimensional Multicomponent Airfoils in Viscous Flow. NASA CR-1843, 1971.
8. Eppler, Richard; and Somers, Dan M.: A Computer Program for the Design and Analysis of Low-Speed Airfoils. NASA TM-80210, 1980.
9. Loftin, Laurence K., Jr.; and Smith, Hamilton A.: Aerodynamic Characteristics of 15 NACA Airfoil Sections at Seven Reynolds Numbers From $0.7 \times 10^{6}$ to $9.0 \times 10^{6}$. NACA TN 1945, 1949.

Table I. Force Coefficients at $M=0.15$ for Free Transition

| $R=2.00 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $\mathrm{c}_{\mathrm{d}}$ | $\mathrm{C}_{\ell}$ | $\mathrm{c}_{\mathrm{m}}$ | $\ell / d$ |
| -4.25 | . 00730 | -. 4300 | -. 0040 | -58.90 |
| -2.10 | . 00620 | -. 2150 | -. 0020 | -34.68 |
| . 00 | . 00620 | . 0000 | . 0000 | . 00 |
| 1.85 | . 00620 | . 1940 | . 0030 | 31.29 |
| 4.25 | . 00670 | . 4450 | . 0040 | 66.42 |
| 6.05 | . 00870 | . 6250 | . 0070 | 71.84 |
| 8.15 | . 01270 | . 8550 | . 0080 | 67.32 |
| 10.15 | . 01350 | 1.0450 | . 0120 | 77.41 |
| 11.15 | . 01490 | 1.1350 | . 0140 | 76.17 |
| 12.10 | . 01640 | 1.2180 | . 0180 | 74.27 |
| 13.08 | . 01880 | 1.2900 | . 0190 | 68.62 |
| 14.25 | . 02280 | 1.3620 | . 0220 | 59.74 |
| 15.25 | . 02910 | 1.4080 | . 0250 | 48.38 |
| 16.25 |  | . 7530 | -. 1060 |  |
| $\mathrm{R}=3.94 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $\mathrm{C}_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| -4.06 | . 00701 | -. 4019 | . 0022 | -57.33 |
| -. 04 | . 00659 | $-.0033$ | -. 0002 | -. 50 |
| 3.96 | . 00631 | . 4203 | . 0015 | 66.61 |
| 6.00 | . 00712 | . 636 | . 0019 | 89.33 |
| 8.17 | . 00985 | . 8657 | . 0077 | 87.89 |
| 10.02 | . 00934 | 1.0629 | . 0071 | 113.79 |
| 11.07 | . 01069 | 1.1622 | . 0080 | 108.72 |
| 12.08 | . 01289 | 1.2489 | . 0095 | 96.93 |
| 13.37 | . 01523 | 1.3587 | . 0116 | 89.22 |
| 14.10 | . 01725 | 1.4215 | . 0145 | 82.41 |
| 15.14 | . 02045 | 1.4844 | . 0196 | 72.60 |
| 18.09 | . 22773 | 1.0946 | -. 0800 | 4.81 |
| $\mathrm{R}=5.97 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | ${ }^{\text {c }}$ d | ${ }^{C}$ | $c_{m}$ | $\ell / d$ |
| -4.05 | . 00700 | -. 4280 | . 0000 | -61.14 |
| -2.00 | . 00650 | -. 2150 | . 0000 | -33.08 |
| . 05 | . 00650 | . 0040 | . 0000 | . 62 |
| 1.98 | . 00680 | . 2080 | . 0020 | 30.59 |
| 4.18 | . 00760 | . 4520 | . 0030 | 59.47 |
| 6.20 | . 00680 | . 6630 | . 0040 | 97.50 |
| 8.22 | . 00800 | . 8800 | . 0050 | 110.00 |
| 10.18 | . 01050 | 1.0880 | . 0070 | 103.62 |
| 11.08 | . 01140 | 1.1800 | . 0080 | 103.51 |
| 12.25 | . 01250 | 1.2920 | . 0090 | 103.36 |
| 13.10 | . 01300 | 1.3680 | . 0110 | 105.23 |
| 14.28 | . 01620 | 1.4580 | . 0150 | 90.00 |
| 15.20 | . 01870 | 1.5280 | . 0180 | 81.71 |
| 16.18 | . 02180 | 1.5900 | . 0210 | 72.94 |
| 16.90 | . 02440 | 1.6180 | . 0230 | 66.31 |
| 17.35 | . 02750 | 1.6600 | . 0250 | 60.36 |
| 17.65 |  | 1.6450 | . 0270 |  |
| 18.65 |  | 1.0050 | -. 1080 |  |

Table I. Concluded

| $R=8.86 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha, \mathrm{deg}$. | ${ }^{c}$ | $C_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -4.00 | . 00680 | -. 4300 | . 0030 | -63.24 |
| -1.98 | . 00630 | -. 2150 | . 0010 | -34.13 |
| -. 10 | . 00630 | -. 0050 | . 0000 | -. 79 |
| 2.13 | . 00650 | .2300 | . 0020 | 35.38 |
| 4.13 | . 00700 | . 4500 | . 0030 | 64.29 |
| 6.08 | . 00720 | . 6650 | . 0050 | 92.36 |
| 8.02 | . 00850 | . 8750 | . 0060 | 102.94 |
| 10.30 | . 00980 | 1.1150 | . 0080 | 113.78 |
| 11.18 | . 01050 | 1.2050 | . 0080 | 114.76 |
| 12.22 | . 01150 | 1.3050 | . 0090 | 113.48 |
| 13.42 | . 01280 | 1.4120 | . 0130 | 110.31 |
| 14.13 | . 01480 | 1.4700 | . 0150 | 99.32 |
| 15.12 | . 01680 | 1.5430 | . 0180 | 91.85 |
| 16.48 | . 02250 | 1.6300 | . 0240 | 72.44 |
| 17.38 | . 02470 | 1.6730 | . 0280 | 67.73 |
| 18.42 | . 02950 | 1.6930 | . 0320 | 57.39 |
| $\mathrm{R}=11.90 \times 10^{6}$ |  |  |  |  |
| $\alpha, \operatorname{deg}$. | $\mathrm{C}_{\text {d }}$ | $c_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -4.20 | . 00684 | -. 4665 | . 0006 | -68.23 |
| -2.01 | . 00611 | -. 2286 | . 0006 | -37.45 |
| -. 05 | . 00637 | -. 0111 | . 0001 | -1.74 |
| -. 03 | . 00634 | -. 0090 | . 0003 | -1.42 |
| 2.00 | . 00692 | . 2159 | -. 0001 | 31.20 |
| 4.17 | . 00687 | . 4575 | . 0002 | 66.60 |
| 6.10 | . 00713 | . 6693 | . 0007 | 93.84 |
| 8.11 | . 00826 | . 8885 | . 0016 | 107.53 |
| 10.40 | . 00975 | 1.1289 | . 0040 | 115.84 |
| 11.43 | . 01058 | 1.2308 | . 0057 | 116.28 |
| 12.52 | . 01166 | 1.3331 | . 0078 | 114.31 |
| 13.25 | . 01293 | 1.3963 | . 0096 | 107.95 |
| 16.05 | . 02156 | 1.6004 | . 0198 | 74.25 |
| 18.04 | . 05429 | 1.6174 | . 0225 | 29.79 |
| 18.25 | . 25587 | 1.2188 | -. 1341 | 4.76 |
| 19.46 | . 29135 | 1.1064 | -. 1823 | 3.80 |
| $\mathrm{R}=18.90 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | $c_{d}$ | $\mathrm{c}_{\ell}$ | $\mathrm{c}_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| -2.07 | . 00617 | -. 2369 | . 0009 | -38.36 |
| -. 03 | . 00655 | -. 0091 | . 0006 | -1.39 |
| . 03 | . 00664 | -. 0019 | . 0005 | -. 28 |
| 1.99 | . 00716 | .2177 | -. 0001 | 30.40 |
| 4.20 | . 00716 | . 4644 | -. 0001 | 64.90 |
| 6.05 | . 00737 | . 6694 | . 0000 | 90.82 |
| 8.37 | . 00916 | . 9290 | . 0016 | 101.44 |
| 10.02 | . 01075 | 1.1007 | . 0036 | 102.40 |
| 11.57 | . 01203 | 1.2557 | . 0060 | 104.42 |
| 12.40 | . 01292 | 1.3339 | . 0079 | 103.25 |
| 13.12 | . 01345 | 1.3968 | . 0094 | 103.86 |
| 14.16 | . 01514 | 1.4833 | . 0127 | 97.96 |
| 15.14 | . 01900 | 1.5541 | . 0167 | 81.79 |
| 16.17 | . 02175 | 1.6169 | . 0215 | 74.35 |
| 17.84 | . 03728 | 1.6593 | . 0288 | 44.51 |
| 18.69 | . 26619 | 1.0867 | -. 1108 | 4.08 |
| 20.17 | . 32534 | 1.1321 | -. 1148 | 3.48 |

Table II. Force Coefficients at $M=0.20$ for Free Transition

| $\alpha$, deg. | $c_{d}$ | $\mathrm{C}_{\ell}$ | $\mathrm{C}_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| :---: | :---: | :---: | :---: | :---: |
| -4.11 | . 00729 | -. 4265 | -. 0034 | -58.53 |
| -2.00 | . 00655 | -. 2138 | $-.0012$ | -32.63 |
| . 00 | . 00599 | -. 0058 | . 0006 | -. 97 |
| . 00 | . 00607 | -. 0062 | . 0004 | -1.02 |
| 2.07 | . 00612 | . 2138 | . 0016 | 34.96 |
| 4.27 | . 00663 | . 4457 | . 0033 | 67.25 |
| 6.03 | . 00771 | . 6304 | . 0051 | 81.80 |
| 8.21 |  | . 8590 | . 0052 |  |
| 10.19 | . 01318 | 1.0593 | . 0099 | 80.39 |
| 11.15 | . 01410 | 1.1497 | . 0116 | 81.55 |
| 12.25 | . 01549 | 1.2444 | . 0139 | 80.36 |
| 13.27 | . 01784 | 1.3246 | . 0165 | 74.25 |
| 14.29 | . 02140 | 1.3937 | . 0198 | 65.13 |
| 15.18 | . 02592 | 1.4420 | . 0233 | 55.63 |
| 16.28 | . 03599 | 1.4604 | . 0266 | 40.58 |
| 17.25 | . 25283 | 1.1140 | -. 0827 | 4.41 |
| 18.16 | . 26666 | 1.1328 | -. 0830 | 4.25 |
| 19.24 | . 28507 | 1.1597 | -. 0846 | 4.07 |
| $R=3.99 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $\mathrm{c}_{\mathrm{m}}$ | $\ell / d$ |
| -4.09 | . 00695 | -. 4416 | -. 0002 | -63.54 |
| -2.04 | . 00638 | -. 2219 | -. 0009 | -34.78 |
| -. 04 | . 00648 | -. 0097 | . 0000 | -1.49 |
| . 03 | . 00670 | -. 0016 | -. 0001 | -. 25 |
| 2.04 | . 00687 | . 2119 | . 0016 | 30.84 |
| 4.02 | . 00654 | . 4220 | . 0023 | 64.53 |
| 6.08 | . 00717 | . 6446 | . 0034 | 89.91 |
| 8.07 | . 00963 | . 8553 | . 0060 | 88.80 |
| 10.18 | . 01178 | 1.0789 | . 0070 | 91.61 |
| 11.19 | . 01242 | 1.1749 | . 0094 | 94.58 |
| 12.45 | . 01412 | 1.2902 | . 0122 | 91.40 |
| 13.08 | . 01532 | 1.3430 | . 0140 | 87.65 |
| 14.24 | . 01817 | 1.4299 | . 0177 | 78.68 |
| 15.27 | . 02136 | 1.4976 | . 0220 | 70.12 |
| 16.34 | . 02660 | 1.5489 | . 0263 | 58.23 |
| 17.34 | . 07842 | 1.5745 | . 0146 | 20.08 |
| 18.08 | . 29925 | 1.0123 | -. 1022 | 3.38 |
| 19.00 | . 28959 | 1.1632 | -. 0839 | 4.02 |
| $R=5.95 \times 10^{6}$ |  |  |  |  |


| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $c_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| ---: | :---: | ---: | ---: | ---: |
| -4.08 | .00688 | -.4313 | -.0007 | -62.65 |
| -2.11 | .00631 | -.2210 | .0002 | -35.01 |
| -.12 | .00637 | -.0080 | .0003 | -1.25 |
| -.11 | .00638 | -.0042 | .0002 | -.65 |
| 1.95 | .00680 | .2152 | .0001 | 31.66 |
| 3.97 | .00731 | .4375 | .0008 | 59.82 |
| 6.03 | .00686 | .6623 | .0018 | 96.51 |
| 7.91 | .00796 | .8674 | .0033 | 108.93 |
| 9.99 | .01044 | 1.0843 | .0053 | 103.85 |
| 11.15 | .01156 | 1.1994 | .0073 | 103.78 |
| 12.12 | .01244 | 1.2902 | .0093 | 103.72 |
| 13.13 | .01422 | 1.3792 | .0121 | 96.99 |
| 14.04 | .01591 | 1.4539 | .0153 | 91.37 |
| 15.03 | .01918 | 1.5238 | .0189 | 79.43 |
| 16.29 | .02339 | 1.5966 | .0244 | 68.26 |
| 17.08 | .02723 | 1.6258 | .0279 | 59.70 |
| 18.00 | .26026 | 1.1169 | -.1062 | 4.29 |
| 19.04 | .28442 | .9393 | -.1086 | 3.30 |

Table II. Concluded

| $R=8.93 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $\mathrm{c}_{\mathrm{d}}$ | $c_{\ell}$ | $c_{m}$ | $\ell / \mathrm{d}$ |
| -4.05 | . 00696 | -. 4490 | . 0002 | -64.53 |
| -2.17 | . 00638 | -. 2464 | . 0002 | -38.62 |
| -. 03 | . 00619 | -. 0101 | -. 0001 | -1.63 |
| . 02 | . 00625 | -. 0025 | -. 0004 | -. 40 |
| 2.07 | . 00685 | . 2245 | -. 0003 | 32.78 |
| 4.03 | . 00721 | . 4431 | . 0002 | 61.47 |
| 6.05 | . 00719 | . 6683 | . 0009 | 92.94 |
| 8.21 | . 00864 | . 9046 | . 0023 | 104.67 |
| 10.22 | . 00995 | 1.1147 | . 0047 | 112.04 |
| 11.09 | . 01117 | 1.2070 | . 0061 | 108.01 |
| 12.13 | . 01189 | 1.3089 | . 0084 | 110.12 |
| 13.33 | . 01359 | 1.4162 | . 0116 | 104.22 |
| 14.17 | . 01553 | 1.4845 | . 0145 | 95.60 |
| 15.16 | . 01835 | 1.5586 | . 0181 | 84.93 |
| 16.24 | . 02220 | 1.6231 | . 0230 | 73.10 |
| 17.53 | . 02784 | 1.6681 | . 0283 | 59.92 |
| 18.23 | . 26063 | 1.2387 | -. 1230 | 4.75 |
| 19.08 | . 28015 | 1.1290 | -. 1032 | 4.03 |
| $R=11.95 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | $\mathrm{c}_{\mathrm{d}}$ | $c_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -4.08 | . 00679 | -. 4602 | . 0007 | -67.76 |
| -2.12 | . 00626 | -. 2422 | -. 0004 | -38.69 |
| -. 05 | . 00633 | -. 0101 | . 0001 | -1.60 |
| 2.00 | . 00694 | . 2190 | -. 0001 | 31.54 |
| 4.12 | . 00705 | . 4576 | . 0002 | 64.93 |
| 6.05 | . 00711 | . 6719 | . 0007 | 94.49 |
| 8.12 | . 00830 | . 9056 | . 0020 | 109.08 |
| 10.47 | . 00978 | 1.1547 | . 0052 | 118.06 |
| 11.32 | . 01082 | 1.2400 | . 0066 | 114.60 |
| 13.13 | . 01309 | 1.4101 | . 0109 | 107.69 |
| 14.73 | . 01738 | 1.5376 | . 0164 | 88.47 |
| 15.21 | . 01886 | 1.5713 | . 0185 | 83.33 |
| 16.18 | . 02249 | 1.6279 | . 0237 | 72.39 |
| 17.46 | . 03427 | 1.6669 | . 0295 | 48.64 |
| 18.35 | . 25142 | 1.2593 | -. 0980 | 5.01 |
| 19.10 | . 30417 | 1.0541 | -. 1288 | 3.47 |

Table III. Force Coefficients at $M=0.25$ for Free Transition


| $\alpha$, deg. | $c_{d}$ | $\mathrm{c}_{\ell}$ | $c_{m}$ | $\ell / d$ |
| :---: | :---: | :---: | :---: | :---: |
| -4.00 | . 00717 | -. 4284 | -. 0024 | -59.76 |
| -2.08 | . 00648 | -. 2274 | -. 0010 | -35.11 |
| . 01 | . 00653 | -. 0019 | . 0000 | -. 29 |
| 1.99 | . 00688 | . 2104 | . 0010 | 30.57 |
| 4.04 | . 00655 | . 4326 | . 0023 | 66.01 |
| 6.24 | . 00723 | . 6542 | . 0154 | 90.49 |
| 8.19 | . 01047 | . 8794 | . 0067 | 83.98 |
| 10.36 | . 01229 | 1.1089 | . 0091 | 90.22 |
| 12.51 | . 01490 | 1.3071 | . 0147 | 87.76 |
| 13.24 | . 01677 | 1.3658 | . 0172 | 81.45 |
| 14.11 | . 01953 | 1.4269 | . 0209 | 73.05 |
| 15.17 | . 02487 | 1.4860 | . 0258 | 59.75 |
| 16.34 | . 05556 | 1.4104 | . 0183 | 25.39 |
| 17.11 | . 25278 | 1.1775 | -. 0904 | 4.66 |
| 18.19 | . 26552 | 1.1703 | -. 0897 | 4.41 |
| 19.12 | . 28717 | 1.1760 | -. 0881 | 4.10 |


| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $c_{m}$ | $\ell / \mathrm{d}$ |
| ---: | :---: | :---: | ---: | ---: |
| -4.22 | .00715 | -.4512 | .0010 | -63.12 |
| -2.13 | .00630 | -.2329 | -.0040 | -36.97 |
| -.03 | .00623 | -.0119 | -.0002 | -1.92 |
| -.01 | .00634 | -.0078 | -.0002 | -1.23 |
| 2.09 | .00672 | .2245 | .0005 | 33.41 |
| 3.99 | .00725 | .4325 | .0012 | 59.66 |
| 6.00 | .00694 | .6557 | .0026 | 94.45 |
| 8.06 | .00803 | .8740 | .0046 | 108.84 |
| 10.13 | .01173 | 1.1034 | .0074 | 94.10 |
| 11.17 | .01189 | 1.2096 | .0092 | 101.73 |
| 12.09 | .01262 | 1.2960 | .0116 | 102.69 |
| 13.14 | .01465 | 1.3929 | .0152 | 95.07 |
| 14.34 | .01784 | 1.4835 | .0204 | 83.16 |
| 15.15 | .02157 | 1.5364 | .0248 | 71.22 |
| 16.21 | .02903 | 1.5616 | .0310 | 53.80 |
| 17.32 | .23316 | 1.1335 | -.0924 | 4.86 |
| 18.41 | .25539 | 1.1233 | -.1069 | 4.40 |

Table III. Concluded

| $\mathrm{R}=8.92 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $c_{d}$ | $\mathrm{c}_{\ell}$ | $\mathrm{c}_{\mathrm{m}}$ | e/d |
| -4.01 | . 00696 | -. 4493 | . 0001 | -64.58 |
| -2.02 | . 00638 | -. 2327 | . 0001 | -36.49 |
| . 00 | . 00673 | -. 0043 | -. 0004 | -. 63 |
| 1.93 | . 00728 | . 2116 | -. 0002 | 29.07 |
| 4.13 | . 00744 | . 4625 | . 0002 | 62.17 |
| 6.07 | . 00778 | . 6801 | . 0014 | 87.39 |
| 8.09 | . 00874 | . 9081 | . 0031 | 103.86 |
| 10.12 | . 01006 | 1.1258 | . 0060 | 111.94 |
| 11.20 | . 01165 | 1.2352 | . 0080 | 106.05 |
| 12.15 | . 01218 | 1.3285 | . 0109 | 109.03 |
| 13.14 | . 01412 | 1.4188 | . 0141 | 100.46 |
| 14.14 | . 01646 | 1.5002 | . 0183 | 91.14 |
| 15.28 | . 02061 | 1.5724 | . 0241 | 76.28 |
| 16.13 | . 02642 | 1.5948 | . 0297 | 60.37 |
| 17.29 | . 23437 | 1.2748 | -. 1173 | 5.44 |
| 18.21 | . 26412 | 1.1905 | -. 0907 | 4.51 |
| $\mathrm{R}=11.95 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $c_{m}$ | ו/d |
| -4.04 | . 00680 | -. 4630 | . 0004 | -68.13 |
| -2.10 | . 00629 | -. 2443 | . 0006 | -38.86 |
| -. 03 | . 00653 | -. 0078 | . 0000 | -1.20 |
| -. 03 | . 00633 | -. 0085 | . 0001 | -1.34 |
| 1.99 | . 00705 | . 2211 | -. 0003 | 31.37 |
| 3.97 | . 00719 | . 4464 | . 0001 | 62.08 |
| 6.23 | . 00742 | . 7028 | . 0011 | 94.73 |
| 8.13 | . 00879 | . 9203 | . 0029 | 104.64 |
| 10.10 | . 01076 | 1.1327 | . 0056 | 105.31 |
| 11.08 | . 01085 | 1.2321 | . 0078 | 113.61 |
| 12.09 | . 01225 | 1.3329 | . 0103 | 108.77 |
| 13.23 | . 01406 | 1.4385 | . 0141 | 102.29 |
| 14.29 | . 01683 | 1.5240 | . 0184 | 90.56 |
| 15.26 | . 02065 | 1.5807 | . 0234 | 76.54 |
| 16.19 | . 02770 | 1.6007 | . 0284 | 57.79 |
| 17.43 | . 24160 | 1.2119 | -. 0942 | 5.02 |
| 18.19 | . 26570 | 1.1466 | -. 1001 | 4.32 |

Table IV. Force Coefficients at $M=0.30$ for Free Transition

| $R=3.90 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $c_{m}$ | $\ell / \mathrm{d}$ |
| -4.11 | . 00727 | -. 4479 | -. 0026 | -61.60 |
| -1.96 | . 00651 | -. 2191 | -. 00011 | -33.66 |
| . 04 | . 00657 | . 0001 | . 0000 | . 02 |
| . 05 | . 00657 | . 0013 | . 0001 | . 19 |
| 2.05 | . 00698 | . 2216 | . 0011 | 31.73 |
| 4.19 | . 00672 | . 4561 | . 0028 | 67.93 |
| 6.20 | . 00743 | . 6781 | . 0048 | 91.27 |
| 8.06 | . 01030 | . 8821 | . 0074 | 85.62 |
| 10.15 | . 01270 | 1. 1089 | . 0112 | 87.32 |
| 11.11 | . 01374 | 1.2014 | . 0139 | 87.46 |
| 12.10 | . 01569 | 1.284 | . 0167 | 81.84 |
| 13.16 | . 02122 | 1.3468 | . 0221 | 63.48 |
| 14.13 | . 03118 | 1.3466 | . 0292 | 43.18 |
| 15.33 | . 17380 | 1.0964 | -. 0656 | 6.31 |
| 16.46 | . 24760 | 1.1197 | -. 0995 | 4.52 |
| 17.09 | . 25661 | 1.1578 | -. 0878 | 4.51 |
| 18.61 | . 27777 | 1.1636 | -. 0868 | 4.19 |
| $\mathrm{R}=5.93 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | ${ }^{\text {c }}$ d | $c_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -4.37 | . 00648 | -. 4894 | -. 0015 | -75.54 |
| -2.02 | . 00630 | -. 2316 | -. 0005 | -36.80 |
| -. 01 | . 00635 | -. 0079 | -. 0002 | -1.25 |
| . 03 | . 00659 | -. 0026 | -. 0002 | -. 40 |
| 4.03 | . 00728 | . 4452 | . 0015 | 61.19 |
| 6.08 | . 00711 | . 6762 | . 0031 | 95.13 |
| 8.13 | . 00822 | . 9039 | . 0057 | 110.01 |
| 10.12 | . 01200 | 1.1251 | . 0094 | 93.78 |
| 11.13 | . 01232 | 1.2273 | . 0117 | 99.58 |
| 12.12 | . 01397 | 1.3172 | . 0155 | 94.26 |
| 13.32 | . 01994 | 1.3939 | . 0226 | 69.91 |
| 14.27 | . 03023 | 1.3917 | . 0294 | 46.04 |
| 15.14 | . 12487 | 1.2273 | . 0278 | 9.83 |
| 16.25 | . 20698 | 1.1132 | . 0124 | 5.38 |
| $\mathrm{R}=8.96 \times 10^{6}$ |  |  |  |  |
| $\alpha$, deg. | $c_{\text {d }}$ | $c_{\ell}$ | $\mathrm{C}_{\mathrm{m}}$ | e/d |
| -4. 12 | . 00706 | -. 4587 | -. 0001 | -64.96 |
| -2.14 | . 00649 | -. 2367 | . 0001 | -36.50 |
| -. 12 | . 00673 | -. 0065 | -. 0001 | -. 96 |
| 1.85 | . 00729 | . 2184 | . 0000 | 29.95 |
| 3.96 | . 00752 | . 4608 | . 0004 | 61.30 |
| 6.04 | . 00783 | . 6995 | . 0019 | 89.35 |
| 7.97 | . 00918 | . 9228 | . 0041 | 100.54 |
| 10.02 | . 01023 | 1.1454 | . 0079 | 111.99 |
| 11.09 | . 01215 | 1.2536 | . 0105 | 103.20 |
| 12.01 | . 01336 | 1.3442 | . 0147 | 100.58 |
| 13.13 | . 01829 | 1.4241 | . 0223 | 77.87 |
| 14.14 | . 02821 | 1.4274 | . 0298 | 50.59 |
| 15.20 | . 16128 | 1.3001 | -. 0772 | 8.06 |
| 15.99 | . 20284 | 1.2011 | -. 0818 | 5.92 |

Table IV. Concluded

| $\mathrm{R}=11.90 \times 10^{6}$ |  |  |  |  |
| ---: | :---: | :---: | :---: | ---: |
| $\alpha$, deg. | $C_{\mathrm{d}}$ | $c_{\ell}$ | $c_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
|  |  |  |  |  |
| -4.03 | .00720 | -.4620 | .0010 | -64.17 |
| -2.01 | .00680 | -.2330 | .0000 | -34.26 |
| .02 | .00680 | .0030 | .0000 | .44 |
| 2.02 | .00780 | .2350 | .0010 | 30.13 |
| 3.92 | .00770 | .4550 | .0020 | 59.09 |
| 6.05 | .00800 | .7030 | .0050 | 87.88 |
| 8.08 | .00890 | .9350 | .0060 | 105.06 |
| 10.05 | .01120 | 1.1580 | .0100 | 103.39 |
| 11.13 | .01170 | 1.2700 | .0130 | 108.55 |
| 12.10 | .01300 | 1.3700 | .0150 | 105.38 |
| 13.20 | .01780 | 1.4500 | .0240 | 81.46 |
| 14.28 | .02910 | 1.4400 | .0330 | 49.48 |
| 15.30 |  | 1.2950 | -.0550 |  |

Table V. Force Coefficients at $M=0.36$ for Free Transition

| $\alpha$, deg. | $R=3.93 \times 10^{6}$ |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | ${ }^{c} d$ | $\mathrm{C}_{\ell}$ | $\mathrm{C}_{\mathrm{m}}$ | $\ell / d$ |
| -3.97 | . 00727 | -. 4467 | -. 0026 | -61.48 |
| -2.03 | . 00659 | -. 2335 | -. 0009 | -35.41 |
| -. 03 | . 00668 | -. 0108 | . 0000 | -1.61 |
| . 00 | . 00672 | -. 0075 | . 0001 | -1. 12 |
| 2.06 | . 00702 | . 2243 | . 0010 | 31.97 |
| 4.01 | . 00678 | . 4460 | . 0027 | 65.77 |
| 6.34 | . 00777 | . 7097 | . 0053 | 91.38 |
| 8.03 | . 01036 | . 8981 | . 0090 | 86.69 |
| 10.15 | . 01415 | 1.1260 | . 0163 | 79.60 |
| 11.27 | . 02119 | 1.1828 | . 0269 | 55.81 |
| 12.14 | . 03128 | 1.2044 | . 0322 | 38.51 |
| 13.36 | . 14591 | 1.1093 | -. 0394 | 7.60 |
| 14.12 | . 18655 | 1.0554 | -. 0774 | 5.65 |
| $R=5.88 \times 10^{6}$ |  |  |  |  |


| $\alpha$, deg. | $\mathrm{c}_{\text {d }}$ | $\mathrm{C}_{\ell}$ | $\mathrm{C}_{\mathrm{m}}$ | $\ell / a$ |
| :---: | :---: | :---: | :---: | :---: |
| -4.00 | . 00618 | -. 4722 | -. 0017 | -76.41 |
| -2.04 | . 00636 | -. 2387 | -. 0005 | -37.54 |
| -. 02 | . 00646 | -. 0096 | -. 00003 | -1. 49 |
| 2.03 | . 00685 | . 2291 | . 0016 | 33.44 |
| 4.08 | . 00737 | . 4682 | . 0019 | 63.52 |
| 6.06 | . 00789 | . 6843 | . 0052 | 86.70 |
| 8.12 | . 00865 | . 9171 | . 0070 | 105.98 |
| 10.18 | . 01357 | 1.1439 | . 0112 | 84,27 |
| 11.23 | . 02008 | 1.2171 | . 0259 | 60.61 |
| 12.12 | . 02867 | 1.2274 | . 0322 | 42.81 |
| 13.30 | . 09164 | 1.1671 | . 0048 | 12.74 |
| 14.24 | . 15857 | 1.1641 | -. 0434 | 7.34 |
| 15.18 | . 19763 | 1.1281 | -. 0670 | 5.71 |
| $\mathrm{R}=8.90 \times 10^{6}$ |  |  |  |  |


| $\alpha$, deg. | $\mathrm{C}_{\mathrm{d}}$ | $\mathrm{C}_{\ell}$ | $\mathrm{C}_{\mathrm{m}}$ | $\boldsymbol{l} \mathrm{d}$ |
| ---: | :---: | ---: | ---: | ---: |
|  |  |  |  |  |
| -4.27 | .00718 | -.4743 | .0003 | -66.06 |
| -2.01 | .00755 | -.2377 | -.0017 | -31.48 |
| 1.95 | .00780 | .2229 | .0021 | 28.58 |
| 3.92 | .00800 | .4604 | .0009 | 57.55 |
| 5.94 | .00798 | .6971 | .0027 | 87.36 |
| 8.03 | .00975 | .9135 | .0007 | 93.69 |
| 10.81 | .01785 | 1.2265 | .0233 | 68.71 |
| 12.21 | .03055 | 1.2398 | .0294 | 40.58 |
| 13.26 | .05821 | 1.2466 | .0190 | 21.42 |
| 13.99 | .72320 | 1.2193 | .0228 | 1.69 |

Table VI. Force Coefficients at $M=0.05$ for Transition Fixed With No. 60-W Grit

| $\mathrm{R}=0.70 \times 10^{6}$ |  |  |  |  |
| ---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $c_{\mathrm{d}}$ | $c_{\ell}$ | $c_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| -4.03 | .01121 | -.3507 | -.0055 | -31.29 |
| -1.98 | .00857 | -.1716 | -.0050 | -20.03 |
| .00 | .00872 | -.0094 | -.0003 | -1.08 |
| 2.00 | .00847 | .1545 | .0032 | 18.24 |
| 4.00 | .01080 | .3283 | .0070 | 30.39 |
| 6.06 | .01237 | .5327 | .0025 | 43.07 |
| 8.12 | .01450 | .6878 | .0086 | 47.43 |
| 10.15 | .01853 | .8030 | .0171 | 43.34 |
| 11.12 | .02147 | .8495 | .0200 | 39.56 |
| 12.18 | .02716 | .8957 | .0233 | 32.98 |
| 13.19 | .08334 | .8918 | -.0089 | 10.70 |
| 14.10 | .15345 | .9391 | -.0479 | 6.12 |
| 15.32 | .16754 | .8626 | -.0580 | 5.15 |
| 16.03 | .21721 | .7506 | -.0669 | 3.46 |
| 17.29 | .23011 | .9005 | -.0762 | 3.91 |
| 18.15 | .23479 | .9382 | -.0672 | 4.00 |

Table VII. Force Coefficients at $M=0.15$ for Transition Fixed With No. 60-W Grit

| $\mathrm{R}=2.00 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha, \operatorname{deg}$. | $c_{d}$ | $\mathrm{c}_{\ell}$ | $\mathrm{c}_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| -4.16 | . 01213 | -. 4300 | -. 0041 | -35.44 |
| -2.14 | . 01080 | -. 2271 | -. 0022 | -21.03 |
| $-.03$ | . 01091 | -. 0102 | -. 0005 | -. 93 |
| . 00 | . 01100 | -. 0060 | -. 0001 | -. 54 |
| 1.97 | . 01084 | . 1970 | . 0017 | 18.17 |
| 4.14 | . 01152 | . 4219 | . 0039 | 36.63 |
| 5.98 | . 01336 | . 6084 | . 0063 | 45.54 |
| 8.10 | . 01631 | . 8123 | . 0098 | 49.82 |
| 10.04 | . 02093 | . 9789 | . 0143 | 46.78 |
| 11.22 | . 02497 | 1.0644 | . 0170 | 42.63 |
| 12.25 | . 02921 | 1.1276 | . 0194 | 38.60 |
| 13.15 | . 03599 | 1.1647 | . 0221 | 32.36 |
| 14.15 | . 21056 | . 9020 | -. 0828 | 4.28 |
| 15.17 | . 23758 | . 9025 | -. 0939 | 3.80 |
| $\mathrm{R}=4.00 \times 10^{6}$ |  |  |  |  |
| -4.07 | . 01099 | -. 4332 | -. 0032 | -39.42 |
| -2.06 | . 00952 | -. 2243 | -. 0016 | -23.55 |
| . 00 | . 00954 | -. 0075 | -. 0003 | -. 78 |
| . 02 | . 00952 | -. 0052 | -. 0003 | -. 54 |
| 2.08 | . 00991 | . 2130 | . 0011 | 21.48 |
| 3.93 | . 01015 | . 4102 | . 0024 | 40.42 |
| 5.99 | . 01119 | . 6256 | . 0044 | 55.90 |
| 8.06 | . 01448 | . 8262 | . 0088 | 57.04 |
| 10.04 | . 01939 | 1.0068 | . 0121 | 51.91 |
| 11.04 | . 02247 | 1.0844 | . 0152 | 48.26 |
| 12.06 | . 02668 | 1.1518 | . 0183 | 43.17 |
| 13.18 | . 03355 | 1.2003 | . 0222 | 35.78 |
| 14.26 | . 04445 | 1.2068 | . 0249 | 27.15 |
| 15.03 | . 22424 | . 9101 | -. 0845 | 4.06 |
| $\mathrm{R}=6.00 \times 10^{6}$ |  |  |  |  |
| -4.15 | . 01048 | -. 4455 | -. 0022 | -42.53 |
| -2.13 | . 00905 | -. 2321 | -. 0011 | -25.64 |
| . 00 | . 00895 | -. 0043 | -. 0002 | -. 48 |
| 2.06 | . 00945 | . 2145 | . 0008 | 22.69 |
| 4.06 | . 00976 | . 4296 | . 0020 | 44.04 |
| 6.01 | . 01116 | . 6359 | . 0037 | 56.99 |
| 8.03 | . 01406 | . 8354 | . 0066 | 59.43 |
| 10.12 | . 01928 | 1.0209 | . 0112 | 52.96 |
| 11.17 | . 02188 | 1.1002 | . 0146 | 50.28 |
| 12.05 | . 02551 | 1.1585 | . 0177 | 45.42 |
| 13.24 | . 03200 | 1.2083 | . 0221 | 37.76 |
| 14.02 | . 03891 | 1.2169 | . 0246 | 31.27 |
| 15.06 | . 21816 | . 9470 | -. 0828 | 4.34 |
| 16.16 | . 25187 | . 8884 | -. 0940 | 3.53 |

Table VII. Concluded

| $\mathrm{R}=8.95 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -4.09 | . 01.008 | -. 4498 | -. 0020 | -44.62 |
| -2.05 | . 00867 | -. 2331 | -. 0007 | -26.88 |
| -. 01 | . 00862 | -. 0107 | -. 0002 | -1.24 |
| . 01 | . 00847 | -. 0093 | . 0000 | -1. 10 |
| 2.03 | . 00905 | . 2100 | . 0005 | 23.21 |
| 4.03 | . 00926 | . 4262 | . 0015 | 46.04 |
| 6.12 | . 01048 | . 6467 | . 0042 | 61.71 |
| 8.05 | . 01340 | . 8438 | . 0059 | 62.97 |
| 10.09 | . 01840 | 1.0279 | . 0107 | 55.85 |
| 11.15 | . 02110 | 1.1102 | . 0141 | 52.61 |
| 12.26 | . 02538 | 1.1800 | . 0181 | 46.49 |
| 13.18 | . 03068 | 1.2209 | . 0214 | 39.79 |
| 14.17 | . 03814 | 1.2289 | . 0243 | 32.22 |
| 15.08 | . 21771 | . 7151 | . 0767 | 3.28 |
| 16.27 | . 25842 | . 9974 | -. 1008 | 3.86 |
| $R=12.10 \times 10^{6}$ |  |  |  |  |
| -4.07 | . 01004 | -. 4506 | -. 0016 | -44.86 |
| -2.01 | . 00834 | -. 2310 | -. 0004 | -27.70 |
| . 01 | . 00842 | -. 0088 | . 0001 | -1.04 |
| . 08 | . 00827 | -. 0024 | -. 0001 | -. 29 |
| 2.01 | . 00882 | . 2074 | . 0006 | 23.51 |
| 4.01 | . 00917 | . 4262 | . 0013 | 46.46 |
| 6.13 | . 01036 | . 6514 | . 0034 | 62.85 |
| 8.07 | . 01286 | . 8474 | . 0060 | 65.90 |
| 10.26 | . 01845 | 1.0438 | . 0116 | 56.57 |
| 11.23 | . 02131 | 1.1209 | . 0139 | 52.61 |
| 12.37 | . 02305 | . 9704 | . 1128 | 42.10 |

Table VIII. Force Coefficients at $M=0.30$ for Transition Fixed With No. 60-W Grit

| $R=4.00 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $\mathrm{c}_{\text {d }}$ | $\mathrm{C}_{\ell}$ | $c_{\text {m }}$ | $\ell / d$ |
| -4.18 | . 01124 | -. 4607 | -. 0040 | -40.99 |
| -2.14 | . 00969 | -. 2421 | -. 0021 | -24.98 |
| -. 04 | . 00964 | -. 0100 | -. 0004 | -1.04 |
| -. 03 | . 00967 | -. 0112 | -. 0004 | -1.16 |
| 2.03 | . 00986 | . 2171 | . 0013 | 22.02 |
| 4.03 | . 01049 | . 4365 | . 0033 | 41.59 |
| 6.03 | . 01203 | . 6515 | . 0061 | 54.18 |
| 8.09 | . 01534 | . 8647 | . 0106 | 56.36 |
| 10.09 | . 02138 | 1.0389 | . 0170 | 48.60 |
| 11.58 | . 02910 | 1.1333 | . 0232 | 38.94 |
| 12.26 | . 11061 | . 9854 | $-.0357$ | 8.91 |
| 13.04 | . 18059 | . 9263 | -. 0596 | 5.13 |
|  | $\mathrm{R}=6.00 \times 10^{6}$ |  |  |  |
| -4.20 | . 01067 | -. 4719 | -. 0033 | -44.21 |
| -2.01 | . 00914 | -. 2313 | -. 0014 | -25.31 |
| -. 04 | . 00921 | -. 0115 | -. 0003 | -1.25 |
| . 01 | . 00925 | -. 0060 | -. 0003 | -. 65 |
| 1.92 | . 00947 | . 2075 | . 0010 | 21.92 |
| 4.05 | . 00999 | . 4456 | . 0028 | 44.58 |
| 6.00 | . 01144 | . 6588 | . 0053 | 57.61 |
| 8.02 | . 01458 | . 8673 | . 0096 | 59.50 |
| 10.11 | . 02073 | 1.0546 | . 0167 | 50.87 |
| 11.09 | . 02524 | 1.1243 | . 0210 | 44.54 |
| 12.17 | . 03259 | 1.1685 | . 0257 | 35.86 |
| 13.07 | . 17991 | .9609 | -. 0638 | 5.34 |
| 14.03 | . 20761 | . 9278 | -. 0690 | 4.47 |
| $\mathrm{R}=8.95 \times 10^{6}$ |  |  |  |  |
| -4.26 | . 01040 | -. 4872 | -. 0028 | -46.85 |
| -2.19 | . 00880 | -. 2562 | -. 0012 | -29.12 |
| -. 01 | . 00860 | -. 0084 | -. 0002 | -. 97 |
| . 00 | . 00863 | -. 0063 | -. 0001 | -. 73 |
| 2.08 | . 00927 | . 2285 | . 0008 | 24.66 |
| 3.94 | . 00956 | . 4379 | . 0023 | 45.81 |
| 6.18 | . 01117 | . 6859 | . 0053 | 61.41 |
| 8.21 | . 01450 | . 8984 | . 0100 | 61.98 |
| 10.08 | . 02016 | 1.0672 | . 0167 | 52.93 |
| 11.27 | . 02559 | 1.1490 | . 0217 | 44.90 |
| 12.12 | . 03171 | 1.1816 | . 0263 | 37.26 |
| 13.31 | . 18204 | . 9565 | -. 0710 | 5.25 |
| 14.21 | . 21204 | . 9134 | -. 0724 | 4.31 |
| $R=12.00 \times 10^{6}$ |  |  |  |  |
| -4.07 | . 01004 | -. 4707 | -. 0022 | -46.87 |
| -1.96 | . 00851 | -. 2351 | -. 0009 | -27.62 |
| -. 02 | . 00826 | -. 0112 | -. 0001 | -1.35 |
| . 00 | . 00838 | -. 0088 | . 0000 | -1.05 |
| 2.05 | . 00893 | . 2237 | . 0010 | 25.04 |
| 4.03 | . 00939 | . 4511 | . 0023 | 48.05 |
| 6.04 | . 01070 | . 6724 | . 0048 | 62.86 |
| 8.15 | . 01377 | . 8957 | . 0095 | 65.02 |
| 11.38 | . 02580 | 1.1595 | . 0228 | 44.94 |
| 12.23 | . 03140 | 1.1906 | . 0263 | 37.92 |
| 13.12 | . 16692 | . 9603 | -. 0588 | 5.75 |

Table IX. Force Coefficients at $M=0.15$ for Transition Fixed With No. 80-W Grit


Table X. Force Coefficients at $M=0.30$ for Transition Fixed With No. 80 Grit

| $\mathrm{R}=4.00 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha, \operatorname{deg}$. | ${ }^{\text {c }}$ d | $c_{\ell}$ | $c_{m}$ | $\ell / \mathrm{d}$ |
| -4.16 | . 00958 | -. 4637 | -. 0012 | -48.40 |
| -2.10 | . 00869 | -. 2379 | -. 0005 | -27.38 |
| . 00 | . 00876 | -. 0043 | . 0000 | -. 49 |
| . 01 | . 00874 | $-.0045$ | . 0001 | -. 52 |
| 2.13 | . 00879 | . 2338 | . 0007 | 26.61 |
| 4.10 | . 00888 | . 4546 | . 0015 | 51.17 |
| 6.02 | . 00947 | . 6661 | . 0032 | 70.37 |
| 8.22 | . 01156 | . 9038 | . 0069 | 78.20 |
| 10.20 | . 01424 | 1.1102 | . 0116 | 77.95 |
| 11.18 | . 01541 | 1.2050 | . 0144 | 78.19 |
| 12.22 | . 01775 | 1.2899 | . 0174 | 72.66 |
| 13.29 | . 02341 | 1.3474 | . 0239 | 57.56 |
| 14.21 | . 03608 | 1.3485 | . 0286 | 37.38 |
| 15.03 | . 19522 | 1.1712 | -. 0647 | 6.00 |
| 16.06 | . 24735 | 1.1447 | -. 0903 | 4.63 |
| 17.37 | . 26673 | 1.1407 | -. 0835 | 4.28 |
| $\mathrm{R}=6.00 \times 10^{6}$ |  |  |  |  |
| -4.17 | . 00881 | -. 4746 | -. 0007 | -53.87 |
| -2.04 | . 00810 | -. 2377 | -. 0002 | -29.36 |
| . 00 | . 00824 | -. 0058 | . 0001 | -. 70 |
| . 04 | . 00826 | -. 0023 | . 0000 | -. 28 |
| 2.06 | . 00828 | . 2285 | . 0002 | 27.59 |
| 4.02 | . 00832 | . 4527 | . 0008 | 54.40 |
| 6.14 | . 00913 | . 6895 | . 0025 | 75.54 |
| 8.11 | . 01060 | . 9065 | . 0053 | 85.52 |
| 10.12 | . 01420 | 1.1231 | . 0096 | 79.10 |
| 11.13 | . 01598 | 1.2230 | . 0121 | 76.54 |
| 12.09 | . 01605 | 1.3117 | . 0161 | 81.75 |
| 13.40 | . 02360 | 1.3900 | . 0236 | 58.90 |
| 14.31 | . 03430 | 1.3824 | . 0296 | 40.30 |
| 15.08 | . 14073 | 1.2059 | -. 0485 | 8.57 |
| 16.12 | . 20900 | 1.1508 | -. 0893 | 5.51 |

Table XI. Force Coefficients at $M=0.15$ for Transition Fixed With No. 120 Grit


Table XII. Force Coefficients at $M=0.30$ for Transition Fixed With No. 120 Grit

| $\mathrm{R}=3.90 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $c_{\text {d }}$ | $c_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -4.06 | . 00936 | -. 4610 | -. 0011 | -49.23 |
| -1.93 | . 00853 | -. 2252 | -. 0004 | -26.41 |
| . 01 | . 00881 | -. 0073 | . 0000 | -. 83 |
| . 05 | . 00874 | -. 0044 | . 0001 | -. 50 |
| 2.05 | . 00876 | . 2205 | . 0007 | 25.18 |
| 4.13 | . 00889 | . 4565 | . 0015 | 51.37 |
| 6.09 | . 00952 | . 6745 | . 0033 | 70.89 |
| 8.19 | . 01160 | . 9025 | . 0067 | 77.79 |
| 10.17 | . 01397 | 1.1102 | . 0114 | 79.46 |
| 11.15 | . 01502 | 1.2047 | . 0141 | 80.20 |
| 12.15 | . 01702 | 1.2880 | . 0169 | 75.68 |
| 13.21 | . 02194 | 1.3482 | . 0231 | 61.45 |
| 14.11 | . 03255 | 1.3517 | . 0276 | 41.53 |
| 15.12 | . 16052 | 1.1447 | -. 0590 | 7.13 |
| 16.07 | . 25551 | . 8559 | -. 1171 | 3.35 |
| $\mathrm{R}=5.95 \times 10^{6}$ |  |  |  |  |
| -4.02 | . 00876 | -. 4646 | -. 0004 | -53.02 |
| -2.08 | . 00799 | -. 2472 | . 0000 | -30.93 |
| . 02 | . 00823 | -. 0088 | . 0001 | -1.07 |
| . 03 | . 00825 | -. 0064 | . 0001 | -. 78 |
| 1.99 | . 00824 | . 2168 | . 0003 | 26.32 |
| 4.06 | . 00835 | . 4544 | . 0009 | 54.42 |
| 6.21 | . 00903 | . 6975 | . 0024 | 77.27 |
| 8.29 | . 01069 | . 9270 | . 0054 | 86.70 |
| 10.21 | . 01290 | 1.1345 | . 0096 | 87.96 |
| 11.11 | . 01380 | 1.2247 | . 0119 | 88.77 |
| 12.22 | . 01591 | 1.3268 | . 0162 | 83.40 |
| 13.23 | . 02009 | 1.3908 | . 0220 | 69.23 |
| 14.32 | . 03175 | 1.3941 | . 0289 | 43.91 |
| 15.18 | . 14253 | 1.2873 | -. 0635 | 9.03 |
| 16.02 | . 20164 | 1.1514 | -. 0843 | 5.71 |
| $R=8.90 \times 10^{6}$ |  |  |  |  |
| -4.07 | . 00834 | -. 4784 | . 0001 | -57.40 |
| -2.11 | . 00757 | -. 2557 | . 0005 | -33.77 |
| . 01 | . 00766 | -. 0101 | . 0002 | -1. 32 |
| . 05 | . 00765 | -. 0052 | . 0003 | -. 69 |
| 2.22 | . 00785 | . 2459 | . 0001 | 31.33 |
| 4.15 | . 00778 | . 4691 | . 0004 | 60.29 |
| 6.29 | . 00843 | . 7238 | -. 0012 | 85.87 |
| 8.13 | . 00976 | . 9263 | . 0042 | 94.91 |
| 10.16 | . 01204 | 1.1468 | . 0081 | 95.22 |
| 11.10 | . 01290 | 1.2435 | . 0107 | 96.36 |
| 12.31 | . 01496 | 1.3570 | . 0159 | 90.70 |
| 13.47 | . 02043 | 1.4266 | . 0236 | 69.83 |
| 14.29 | . 03011 | 1.4195 | . 0303 | 47.15 |
| 15.29 | . 14155 | 1.2813 | -. 0358 | 9.05 |
| 16.20 | . 20968 | 1.2531 | -. 0894 | 5.98 |
| 17.08 | . 23815 | 1.1755 | -. 0853 | 4.94 |

Table XIII. Force Coefficients at $M=0.15$ for Transition Fixed With No. 180 Grit

| $\mathrm{R}=5.95 \times 10^{6}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| $\alpha$, deg. | $c_{d}$ | $c_{\ell}$ | $c_{m}$ | $\ell / d$ |
| -3.99 | . 00871 | -. 4363 | -. 0004 | -50.11 |
| -1.98 | . 00792 | -. 2213 | . 0000 | -27.93 |
| -. 03 | . 00803 | -. 0115 | . 0000 | -1.44 |
| . 04 | . 00811 | -. 0013 | . 0002 | -. 15 |
| 2.00 | . 00814 | . 2113 | . 0001 | 25.97 |
| 4.06 | . 00814 | . 4365 | . 0003 | 53.59 |
| 6.09 | . 00851 | . 6558 | . 0011 | 77.10 |
| 8.09 | . 00985 | . 8689 | . 0027 | 88.24 |
| 10.18 | . 01165 | 1.0809 | . 0050 | 92.80 |
| 11.13 | . 01247 | 1.1731 | . 0064 | 94.07 |
| 12.10 | . 01299 | 1.2644 | . 0082 | 97.35 |
| 13.31 | . 01408 | 1.3676 | . 0111 | 97.16 |
| 14.08 | . 01533 | 1.4316 | . 0133 | 93.38 |
| 15.24 | . 01870 | 1.5169 | . 0173 | 81.14 |
| 16.33 | . 02186 | 1.5855 | . 0213 | 72.53 |
| 17.13 | . 02513 | 1.6219 | . 0247 | 64.54 |
| 18.21 | . 25899 | 1.0104 | -. 1070 | 3.90 |
| 19.27 | . 43446 | 1.0664 | -. 0693 | 2.45 |
| $\mathrm{R}=8.95 \times 10^{6}$ |  |  |  |  |
| -4.07 | . 00843 | -. 4550 | . 0004 | -53.99 |
| -2.11 | . 00753 | -. 2428 | . 0005 | -32.26 |
| . 03 | . 00765 | -. 0052 | . 0001 | -. 68 |
| 2.04 | . 00793 | . 2150 | -. 0001 | 27.10 |
| 4.06 | . 00780 | . 4410 | -. 0001 | 56.52 |
| 6.12 | . 00808 | . 6655 | . 0004 | 82.41 |
| 8.15 | . 00929 | . 8868 | . 0014 | 95.48 |
| 10.16 | . 01147 | 1.0947 | . 0037 | 95.48 |
| 11.10 | . 01173 | 1.1852 | . 0051 | 101.03 |
| 12.11 | . 01218 | 1.2813 | . 0071 | 105.17 |
| 13.11 | . 01316 | 1.3716 | . 0091 | 104.21 |
| 14.36 | . 01511 | 1.4750 | . 0128 | 97.63 |
| 15.31 | . 01722 | 1.5487 | . 0163 | 89.93 |
| 16.46 | . 02025 | 1.6187 | . 0193 | 79.92 |
| 17.33 | . 02220 | 1.6611 | . 0238 | 74.83 |
| 18.59 | . 25066 | 1.1825 | -. 0461 | 4.72 |
| 19.22 | . 26933 | 1.2901 | -. 1036 | 4.79 |
| $R=11.95 \times 10^{6}$ |  |  |  |  |
| -4.05 | . 00810 | -. 4594 | . 0008 | -56.70 |
| -1.98 | . 00719 | -. 2337 | . 0007 | -32.50 |
| . 01 | . 00736 | -. 0121 | . 0003 | -1.65 |
| . 03 | . 00726 | -. 0097 | . 0003 | -1.34 |
| 2.07 | . 00763 | . 2183 | . 0001 | 28.60 |
| 4.09 | . 00746 | . 4437 | -. 0002 | 59.45 |
| 6.01 | . 00768 | . 6571 | . 0003 | 85.60 |
| 8.03 | . 00907 | . 8777 | . 0011 | 96.81 |
| 10.12 | . 01092 | 1.0983 | . 0032 | 100.60 |
| 11.27 | . 01126 | 1.2150 | . 0047 | 107.93 |
| 12.12 | . 01175 | 1.2954 | . 0062 | 110.26 |
| 13.24 | . 01376 | 1.3965 | . 0093 | 101.48 |
| 14.16 | . 01491 | 1.4736 | . 0117 | 98.83 |
| 15.15 | . 01683 | 1.5514 | . 0143 | 92.20 |
| 16.27 | . 01996 | 1.6212 | . 0190 | 81.23 |
| 17.28 | . 02378 | 1.6693 | .0236 | 70.18 |
| 18.18 | . 23217 | 1.3948 | -. 1218 | 6.01 |

Table XIV. Force Coefficients at $M=0.30$ for Transition Fixed With No. 180 Grit

| $\alpha$, deg. | $\mathrm{c}_{\text {d }}$ | $c_{\ell}$ | $\mathrm{c}_{\mathrm{m}}$ | $\ell / \mathrm{d}$ |
| :---: | :---: | :---: | :---: | :---: |
| -4.04 | . 00891 | -. 4610 | -. 00007 | -51.74 |
| -2.03 | . 00800 | -. 2363 | -. 0002 | -29.53 |
| . 00 | . 00816 | -. 0045 | -. 0001 | -. 56 |
| 2.09 | . 00819 | . 2321 | . 0002 | 28.36 |
| 4.00 | . 00826 | . 4508 | . 0007 | 54.55 |
| 6.13 | . 00893 | . 6906 | . 0023 | 77.30 |
| 8.08 | . 01043 | . 9074 | . 0050 | 87.01 |
| 10.23 | . 01303 | 1.1359 | . 0095 | 87.16 |
| 11.10 | . 01382 | 1.2241 | . 0119 | 88.56 |
| 12.34 | . 01633 | 1.3354 | . 0170 | 81.79 |
| 13.23 | . 02069 | 1.3693 | . 0203 | 66.19 |
| 14.15 | . 03180 | 1.3815 | . 0287 | 43.44 |
| 15.06 | . 14715 | 1.2390 | -. 0308 | 8.42 |
| 16.09 | . 20338 | 1.2505 | -. 1093 | 6.15 |
|  | $\mathrm{R}=8.85 \times 10^{6}$ |  |  |  |
| -4.11 | . 00856 | -. 4753 | -. 0003 | -55.52 |
| -2.06 | . 00769 | -. 2430 | . 0002 | -31.60 |
| -. 02 | . 00767 | -. 0094 | . 0001 | -1.23 |
| -. 02 | . 00765 | -. 0090 | . 0001 | -1.17 |
| 2.04 | . 00793 | . 2282 | . 0002 | 28.79 |
| 4.07 | . 00774 | . 4638 | . 0003 | 59.91 |
| 6.04 | . 00828 | . 6909 | . 0016 | 83.48 |
| 8.12 | . 00959 | . 9276 | . 0042 | 96.73 |
| 10.09 | . 01175 | 1.1582 | . 0125 | 98.54 |
| 11.17 | . 01294 | 1.2515 | . 0110 | 96.71 |
| 12.16 | . 01456 | 1.3433 | . 0151 | 92.26 |
| 13.17 | . 01886 | 1.4155 | . 0220 | 75.05 |
| 14.12 | . 02817 | 1.4173 | . 0295 | 50.31 |
| 15.35 | . 15957 | 1.2265 | -. 0315 | 7.69 |
| 16.30 | . 21003 | 1.2134 | -. 0704 | 5.78 |
| $\mathrm{R}=11.90 \times 10^{6}$ |  |  |  |  |
| -4.04 | . 00811 | -. 4714 | -. 0004 | -58.14 |
| -1.94 | . 00738 | -. 2358 | . 0006 | -31.94 |
| -. 05 | . 00737 | -. 0144 | . 0001 | -1.96 |
| -. 03 | . 00732 | -. 0126 | . 0004 | -1. 72 |
| . 00 | . 00737 | -. 0102 | . 0005 | -1.38 |
| 2.03 | . 00774 | .2290 | . 0001 | 29.59 |
| 4.08 | . 00755 | . 4714 | . 0002 | 62.47 |
| 6.01 | . 00798 | . 6956 | . 0014 | 87.19 |
| 8.06 | . 00910 | . 9285 | . 0036 | 102.05 |
| 10.24 | . 01148 | 1.1684 | . 0077 | 101.77 |
| 11.18 | . 01250 | 1.2678 | . 0106 | 101.46 |
| 12.28 | . 01417 | 1.3711 | . 0152 | 96.77 |
| 13.34 | . 01971 | 1.4250 | . 0250 | 72.31 |
| 14.35 | . 03165 | 1.4225 | . 0321 | 44.95 |
| 15.27 | . 16237 | 1.3117 | -. 0581 | 8.08 |



End view, section A-A

Figure 1. Airfoil mounted in wind tunnel. All dimensions are in terms of airfoil span. $b=36.00 \mathrm{in} .(91.44 \mathrm{~cm})$.


Figure 2. Wake survey rake. All dimensions are in terms of airfoil span. $b=36.00 \mathrm{in}$. ( 91.44 cm ).


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(b) $R=3.9 \times 10^{6}$.
Figure 3. Continued.






(c) $R=6.0 \times 10^{6}$.
Figure 3. Continued.




(d) $R=8.9 \times 10^{6}$.
Figure 3. Continued.


(e) $R=11.9 \times 10^{6}$.


Figure 3. Continued.





(a) $R=2.7 \times 10^{6}$.
Figure 4. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at





(b) $R=4.0 \times 10^{6}$.
Figure 4. Continued.




(c) $R=6.0 \times 10^{6}$.
Figure 4. Continued.




(d) $R=8.9 \times 10^{6}$.
Figure 4. Continued.




(e) $R=12.0 \times 10^{6}$.
Figure 4. Concluded.




(a) $R=3.3 \times 10^{6}$.
Figure 5. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at



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(b) $R=4.0 \times 10^{6}$.
Figure 5. Continued.




(c) $R=6.0 \times 10^{6}$.
Figure 5. Continued.




(d) $R=8.9 \times 10^{6}$.
Figure 5. Continued.

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(e) $R=12.0 \times 10^{6}$.
Figure 5. Concluded.

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(a) $R=3.9 \times 10^{6}$.
Figure 6. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at




(b) $R=5.9 \times 10^{6}$.
Figure 6. Continued.




(c) $R=9.0 \times 10^{6}$.
Figure 6. Continued.




(d) $R=11.9 \times 10^{6}$.
Figure 6. Concluded.



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(a) $R=3.9 \times 10^{6}$.
Figure 7. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at $M=0.36$ for free transition.




Alpha, deg.
(b) $R=5.9 \times 10^{6}$.
Figure 7. Continued.




(c) $R=8.9 \times 10^{6}$.
Figure 7 . Concluded.


Figure 8. Variation of basic aerodynamic characteristics with angle of attack for $R=0.7 \times 10^{6}$ and $M=0.05$
 for transition fixed with No. 60-W grit.




(a) $R=2.0 \times 10^{6}$.
Figure 9. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at





(b) $R=4.0 \times 10^{6}$.
Figure 9 . Continued.




(c) $R=6.0 \times 10^{6}$.
Figure 9. Continued.


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(e) $R=12.1 \times 10^{6}$.
Figure 9. Concluded.





Figure 10. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at $M=0.30$ for transition fixed with No. $60-\mathrm{W}$ grit.



(b) $R=6.0 \times 10^{6}$.
Figure 10. Continued.

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(c) $R=9.0 \times 10^{6}$.
Figure 10. Continued.





(d) $R=12.0 \times 10^{6}$.
Figure 10. Concluded.



(a) $R=2.0 \times 10^{6}$.




(b) $R=4.0 \times 10^{6}$.
Figure 11. Continued.





(c) $R=6.0 \times 10^{6}$.
Figure 11. Concluded.




(a) $R=4.0 \times 10^{6}$.
Figure 12. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers




(b) $R=6.0 \times 10^{6}$.
Figure 12. Concluded.


(a) $R=4.0 \times 10^{6}$.


Figure 13. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at $M=0.15$ for transition fixed with No. 120 grit.




(b) $R=6.0 \times 10^{6}$.
Figure 13. Continued.




(c) $R=8.9 \times 10^{6}$.
Figure 13. Concluded.




(a) $R=3.9 \times 10^{6}$.
Figure 14. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers
at $M=0.30$ for transition fixed with No. 120 grit.




(b) $R=6.0 \times 10^{6}$.
Figure 14. Continued.




(c) $R=8.9 \times 10^{6}$.
Figure 14. Concluded.




(a) $R=6.0 \times 10^{6}$.
Figure 15. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at $M=0.15$ for transition fixed with No. 180 grit.




(b) $R=9.0 \times 10^{6}$.
Figure 15. Continued.




(c) $R=12.0 \times 10^{6}$.
Figure 15. Concluded.




(a) $R=6.0 \times 10^{6}$.
Figure 16. Variation of basic aerodynamic characteristics with angle of attack for various Reynolds numbers at $M=0.30$ for transition fixed with No. 180 grit.




(b) $R=8.9 \times 10^{6}$.
Figure 16. Continued.




(c) $R=11.9 \times 10^{6}$.
Figure 16. Concluded.


Figure 17. Variation of lift-curve slope with Mach number and Reynolds number for free-transition case.

(a) Free transition.

(b) Fixed transition.

Figure 18. Variation of lift-curve slope with Reynolds number for free and fixed transition at $M=\mathbf{0 . 1 5}$.

(a) Free transition.

(b) Fixed transition.

Figure 19. Variation of lift-curve slope with Reynolds number for free and fixed transition at $M=0.30$.

(a) $R=4 \times 10^{6}$

(b) $R=12 \times 10^{6}$.

Figure 20. Theoretical and experimental lift-curve slopes as function of Mach number for free-transition case.


Figure 21. Theoretical and experimental lift-curve slopes as function of Reynolds number for free-transition case.


Figure 22. Theoretical and experimental lift-curve slopes as function of Reynolds number for fixedtransition case.

(a) Free transition.

(b) Fixed transition (No. 60-W grit).

Figure 23. Comparison of lift-curve slope with previously published data (ref. 9) from same facility as function of Reynolds number for $M \leq 0.15$.


Figure 24. Variation of maximum lift coefficient with Mach number and Reynolds number for free-transition case.

(a) Free transition.

(b) Fixed transition.

Figure 25. Variation of maximum lift coefficient with Reynolds number for free and fixed transition at $M=0.15$.

(a) Free transition.

(b) Fixed transition.

Figure 26. Variation of maximum lift coefficient with Reynolds number for free and fixed transition at $M=0.30$.


Figure 27. Variation of drag coefficient at zero lift with Mach number and Reynolds number for free-transition case.

(a) Free transition.

(b) Fixed transition.

Figure 28. Variation of drag coefficient at zero lift with Reynolds number for free and fixed transition at $M=0.15$.


(b) Fixed transition.

Figure 29. Variation of drag coefficient at zero lift with Reynolds number for free and fixed transition at $M=0.30$.

(a) $M=0.15$.

(b) $M=0.30$.

Figure 30. Theoretical and experimental drag coefficients at zero lift as function of Reynolds number.

(a) Free transition.

(b) Fixed transition (No. 60-W).

Figure 31. Comparison of drag coefficient at zero lift with previously published data (ref. 9) from same facility as function of Reynolds number for $M \leq 0.15$.

(b) Variation with Reynolds number.

Figure 32. Variation of maximum lift-drag ratio with Mach number and Reynolds number for free-transition case.

(a) Free transition.

(b) Fixed transition.

Figure 33. Variation of maximum lift-drag ratio with Reynolds number for free and fixed transition at $M=0.15$.

(a) Free transition.

(b) Fixed transition.

Figure 34. Variation of maximum lift-drag ratio with Reynolds number for free and fixed transition at $M=0.30$.


