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TASK II STAGE DATA AND PERFORMANCE REPORT
FOR
UNDISTORTED INLET FLOW TESTING

VOLUME I
EVALUATION OF RANGE AND DISTORTION TOLERANCE
FOR HIGH MACH NUMBER TRANSONIC FAN STAGES

By

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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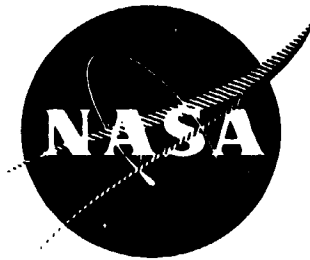
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ABSTRACT

A compressor stage consisting of a 1500 ft/sec tip speed rotor, a variable-camber inlet guide vane, and an adjustable stator, was tested with undistorted inlet flow at several inlet guide vane and stator settings. The objectives of the tests were to obtain blade element data and to evaluate the effectiveness of the variable geometry blading at several key points in an operating envelope typical of a Mach 3 turbofan engine. The overall performance and the blade element data obtained at the three combinations of IGV-stator settings at 50, 70, 80, 90, 100, and 110 percent design speed are presented in two volumes. This volume, the first of the two, presents details of the test equipment, test procedure, data reduction methods, overall performance data and plots of blade element data. Volume II contains tabulations of all the overall performance and blade element data.

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SECTION I

SUMMARY

A single-stage compressor consisting of a 1500 ft/sec tip speed rotor, a variable-camber inlet guide vane, and an adjustable stator was tested with undistorted inlet flow at several inlet guide vane and stator settings. Data and performance obtained in these tests are presented in this report.

The compressor was designed with a rotor inlet hub/tip radius ratio of 0.5 with zero rotor inlet swirl at the design inlet guide vane setting angle of zero degrees and axial stator exit flow at design stator setting angle of zero degrees. The design stage pressure ratio and efficiency were 1.66 and 85.4 percent respectively at a corrected weight flow of 226 lbs/sec. From the performance map at design IGV and stator setting angles, on a constant throttle line through the design point, a stage total pressure ratio of 1.65, efficiency of 83.4 percent and a weight flow of 224 lbs/sec were achieved at design speed.

The off-design cruise condition corresponded to 70 percent design corrected speed and 54 percent design corrected weight flow. The cruise IGV setting angle was 40 degrees with a corresponding stator setting angle of 8 degrees; an intermediate schedule of 20 degrees IGV setting angle and 4 degrees stator setting angle was also tested.

At each of the three IGV/stator setting combinations, overall performance and blade element performance data were obtained at 50, 70, 80, 90, 100 and 110 percent design speeds up to the maximum possible weight flow. Blade element data were obtained to show the variation of deviation angle, diffusion factor, loss coefficient, and loss parameter as functions of incidence angle. The compressor was stalled at each speed and IGV/stator schedule to obtain the performance at the stall point and to determine which blade row was stall-limiting.

SECTION II

INTRODUCTION

The need to reduce the size and weight of gas turbine engines for advanced military and commercial aircraft has led to the use of high-tip-speed fan and compressor stages. Such stages frequently have been required to operate satisfactorily at off-design conditions and with distorted inlet flows. A turbofan engine for a Mach 3 aircraft, for example, would need fan stages meeting severe performance requirements at both design and off-design corrected speeds, and also could encounter severely distorted inlet air flows. It is therefore necessary to obtain data on the efficiency, stall margin, and distortion tolerance of high-tip-speed stages and to investigate the use of variable-geometry features to maintain performance at off-design operating conditions. This research program, NASA Contract NAS3-11157, was instituted to provide these data. The program involved the design and testing of two single-stage compressors designed for rotor tip speeds of 1400 and 1500 ft/sec respectively, using a common variable stagger stator. The higher speed stage was also provided with variable-geometry inlet guide vanes. Experimental data and performance of the Task I Stage with clean and distorted inlet flows are presented in Reference 1.

The Task II Stage, reported upon here, had a 1500 ft/sec tip speed rotor, a variable inlet guide vane, and an adjustable stator. Details of the aerodynamic and aeromechanical design of the IGV, rotor, and stator blading and the test vehicle for the Task II Stage are presented in Reference 2. Objectives of Task II Stage tests were to obtain blade element data and to evaluate the effectiveness of the variable geometry blading at several key points in an operating envelope typical of a Mach 3 turbofan engine. Another major objective of Task II was to determine the tolerance of the compressor stage to distorted inlet flows and to obtain extensive data on the structure of the distorted flow fields. The inlet flow distortion testing with the Task II Stage was also intended to

evaluate the effectiveness of variable-geometry blading in improving stable operating range with inlet flow distortions.

This report, in two volumes, presents the data obtained during the testing of the Task II Stage with undistorted inlet flow. Volume I presents details of the test equipment, test procedure, data reduction methods, overall performance data, and plots of blade element data. Volume II contains tabulations of all the overall performance data and blade element data. Detailed analysis and interpretations of the results will be presented in a later report.

SECTION III

APPARATUS AND PROCEDURE

1. TEST COMPRESSOR STAGE

a. FLOWPATH

Figure 1 shows the flowpath for the Task II Stage. A converging section preceded the IGV inlet station. The hub contour converged from a radius of 7.10 inches at IGV inlet to a radius of 11.11 inches at the stator exit. The casing contour similarly converged from a radius of 18.41 inches at the IGV inlet to 17.84 inches at stator exit. The hub/tip ratio at rotor inlet (station 1.00) was 0.5. Further details are presented in Reference 2.

b. INLET GUIDE VANE

The variable geometry IGV was designed to produce no turning of the flow at the 100 percent speed, 100 percent flow design point. At the 70 percent speed, 54 percent flow cruise condition, it was designed to impart up to 45 degrees of swirl to the flow at all radii. The design leading edge blade angle was 0 degrees at all conditions and the trailing edge blade angle could be varied from 0 degrees to 45 degrees. The discharge air angle could thus be varied without incurring excessive losses from high incidence angles. Figures 2(a) and 2(b) show pictures of IGV at zero degrees (nominal) and + 40 degrees respectively. The vane was made up of two parts to accomplish this camber variation. The nose part was fixed in the axial direction, while the rear flap could be rotated to vary the trailing edge angle. There were 24 inlet guide vanes, approximately half the number of stator vanes (46). With 24 IGV's, the stator exit wake rakes, which spanned two stator passages, also spanned approximately one IGV passage. Thus, the total pressure losses contributed by the IGV and stator wakes were measured in the proper proportion by the stage discharge instrumentation.

The IGV airfoil sections were made geometrically similar at all radii by scaling a single master section. This master section was derived from an airfoil having an uncambered meanline with a NACA 65-008 thickness distribution scaled up to a maximum thickness/chord ratio of 10 percent. Leading and trailing edge thicknesses of the 65-series airfoil were 1.0 percent and 1.5 percent of chord respectively. The nose and flap sections were formed by dividing the 65-series airfoil into two parts. Contours around the rear part of the nose and the leading edge of the flap were chosen so that an aerodynamic slot would be formed when the vane was in a cambered configuration. The nose section moved circumferentially when the flap was rotated. Figure 2(c) indicates the way in which the two parts of the guide vane were aligned in the uncambered position at the design point and in a cambered position at 30 degrees turning. Tables I and II list some of the IGV design parameters. Further details of aerodynamic design and actuation mechanism are discussed in Reference 2.

c. ROTOR

The rotor consisted of 44 blades designed with fully arbitrary blade sections selected in order to better control throat areas and suction surface Mach numbers. The design point rotor inlet specific weight flow was $41.62 \text{ lbs/sec-ft}^2$ of annulus area, and the relative inlet Mach number at the tip was 1.526 with zero inlet guide vane turning. Tip diffusion factor at design point was 0.368 with a tip solidity of 1.40. Chord length was varied slightly, increasing from hub to tip. A part-span shroud was used at approximately 63 percent span from the hub to insure aeromechanical stability. Table I contains some of the rotor design and performance specifications. Table III(a) gives design values of aerodynamic parameters and blading geometry on design streamlines. In general, the design stream-surfaces were different from the blade element data measurement sections and, hence, the blading geometry parameters on the blade element data sections are presented in Table IV. Design values of incidence angle, deviation angle, diffusion factor, and loss coefficient on the blade element data sections are shown along with respective test data in the section on Results and Discussions.

A view of a portion of the assembled rotor appears in Figure 3. After manufacture, the blading was inspected by means of contour layouts at several sections. For this, five blades chosen at random from the batch were inspected at five sections along the blade height. A meridional view of the rotor appears in Figure 4 and the inspected sections are identified by asterisks. At each inspected section the average of these five blades was obtained and was compared with the design intent. The results and comparisons are shown in Figure 5. It was judged that the blading was adequate to achieve design intent.

d. STATOR

Design specifications for the stator vanes are contained in Tables I, III(b), and IV. The stator consisted of 46 vanes and was designed with variable-setting-angle capability. Mechanical limits of 15 degrees open to 20 degrees closed were provided. At the design point setting of zero degrees, the exit air flow was designed to be axial. The outer half of the vane was made up of double-circular-arc airfoils. An arbitrary airfoil section was employed for the hub to obtain suction surface Mach numbers which were lower than those produced by a double-circular-arc hub section. The sections between the arbitrary hub and double-circular-arc pitch were selected to form a smooth transition. The design stator inlet Mach number was 0.61 at the tip, 0.66 at the pitch, and 0.77 at the hub. Figure 6 shows a picture of a typical stator vane. Additional design details are contained in Reference 2.

The stator blading was also inspected by means of contour layouts at several sections and was judged adequate to achieve design intent. The results and comparisons are presented in Reference 1.

2. TEST FACILITY

Performance tests of this stage were conducted in General Electric's House Compressor Test Facility at Lynn, Massachusetts. The general aspects of the test set-up are shown in Figure 7. The test rotor drew air from

the atmosphere through two banks of filters. The first filter bank was intended to remove 22 percent of the particles larger than 3 to 5 microns (dust spot test). The second and final filter bank was intended to remove 90 to 95 percent of the remaining particles down to the same size. The air then passed through a coarse wire inlet screen and into the bellmouth. In the exit assembly the air was split into two streams. The inner air stream passed into an exit pipe containing a flow straightener and a venturi flow meter and then exhausted to atmosphere. The outer air stream passed through a slide cylindrical throttle valve and into a collector, then into two pipes, each of which contained a flow straightener and a venturi flow meter, and finally discharged to atmosphere. Power to drive the test rotor was provided by a high-pressure noncondensing steam turbine rated at 15,000 horsepower.

3. INSTRUMENTATION

Table V lists the major fixed and traverse instruments provided for the different phases of testing. The locations of these instruments and of the hub and casing static taps are shown in the instrumentation schematics, Figures 8 and 9. Photographs of the rakes themselves are shown in Figure 10.

All traverse probes were calibrated for Mach number and pitch angle effects and these calibrations were used in the data reduction calculations. Fixed temperature and pressure rakes were calibrated for Mach number effects, but the corrections for the pressure elements were small enough to be neglected.

The total pressure at the vehicle inlet plane 0.01 was obtained from six 7-element radial pitot-static rakes equally distributed circumferentially. The inlet total temperature was obtained from 24 chromel-alumel thermocouples distributed over the face of the vehicle inlet screen at plane 0.01.

Static pressure at the IGV inlet plane 0.09, used to determine IGV inlet Mach numbers, was measured by five hub and five casing static pressure

taps. These were equally spaced around the circumference of hub and casing walls.

In general, measurements were obtained at seven radial immersions chosen to correspond to 5, 10, 30, 50, 70, 90 and 95 percent of annulus height from the tip at the rotor exit plane, 1.51. Immersions at each other instrumentation plane upstream and downstream of Plane 1.51 were established to correspond to the radial locations at which design streamlines that passed through the selected immersions at Plane 1.51 intersected the instrumentation plane.

During shakedown tests only, a 14-element IGV wake rake was installed at each of the seven radial immersions and these were used to measure total pressure behind the IGV. The IGV wake rake elements were located one inch from the trailing edge of the vanes and thus were not in a radial plane. The rake elements were oriented at 15 degrees from the axial direction to permit acceptable measurement of the total pressure of the airstream at all IGV settings from 0 up to 40 degrees. These IGV wake rakes were removed on completion of shakedown testing and were not used in performance and traverse testing.

Static pressure at rotor inlet plane 0.95 was obtained from five hub and five casing static taps. This plane was also a traverse plane. Traverse measurements of flow angle and static pressure at each immersion at this plane were made by an angle-seeking static-pressure wedge traverse probe. This probe was also capable of traversing circumferentially to enable measurements to be made at mid-passage between adjacent IGV's when the IGV's were set at other than 0 degrees.

At the rotor exit/stator inlet, Plane 1.51, total pressure, total temperature, and absolute flow angle were measured at each immersion by a cobra traverse probe. A traversible 8 degree wedge probe was used to measure static pressures at various immersions.

For overall performance readings, static pressure at the stator exit (Plane 2.2) was obtained by means of eight hub and eight casing static taps. The static pressure taps were so distributed that there was one hub and one casing static tap on either side of each wake rake. Total pressure and total temperature at each of the seven immersions were obtained by a 14-element wake rake fixed at each immersion at this plane. These were used during traverse readings also. For blade element data, static pressure at each immersion was obtained with an angle-seeking wedge probe. A generous number of additional static pressure taps were located on the hub and casing throughout the flow path as shown in Figure 9.

During all stall tests three hot wire anemometer probes (designated T-5, T-7, and T-10 in Figure 9) were used at Plane 1.51 at the 10, 50 and 90 percent immersions to detect the initiation of stall and determine the radial extent of the stall cells. For all other testing these hot wires were removed from the airstream.

The inlet guide vanes, rotor blades, and stator vanes were instrumented with strain gages to measure vibratory stresses.

4. DATA REDUCTION METHODS

a. INTRODUCTION

Two separate computer programs were used to reduce the test data. The Overall Performance Data Program computed fluid properties at each measuring station from data measured by fixed instruments and calculated overall stage and rotor performance parameters, such as total pressure ratio and adiabatic efficiency. The Blade Element Data Program calculated vector diagram and blade element performance parameters for seven streamline sections of the IGV, rotor, and stator. This program reduced data from both fixed and traverse instruments.

Several assumptions were made that were common to both of the data reduction programs. First, it was assumed that the radial position and meridional slope angle of each stream surface on which data were recorded were fixed at the design value for all operating conditions. Second, all

mass-averaging calculations used to determine average total temperature and total pressure were formulated in terms of enthalpy and entropy. Finally, the real gas properties of dry air were used in all thermodynamic calculations.

Additional details of the data reduction methods used appear in the following sections.

b. OVERALL PERFORMANCE DATA PROGRAM

This section presents only the methods for analyzing the data obtained from performance tests without the IGV wake rakes in the airstream. The special methods used to determine the IGV loss coefficients are described in the section on Results and Discussion.

Input data for overall performance calculations were obtained from fixed instrumentation. While all total pressures, wall static pressures, and inlet total temperatures did not require any correction for Mach number or pitch angle, the discharge total temperature measured by fixed wake rakes at Plane 2.2 was corrected for Mach number effects.

The total pressure and total temperature at compressor inlet, Plane 0.01 were obtained by arithmetically averaging the relevant indications of the forty-two inlet pitot-static sensors and twenty-four inlet temperature thermocouples. These total properties were then assumed uniform throughout the annulus. Hub and casing static pressures at IGV inlet, Plane 0.09, were obtained by arithmetically averaging the readings from the pressure taps located on the respective walls. Static pressures at each of the seven intermediate immersions resulted from a linear interpolation versus radius between the hub and casing values. The total temperature and total pressure at IGV inlet, Plane 0.09 were assumed equal to those measured at the compressor inlet plane. The flow angle at this plane was assumed to be equal to zero degrees.

Static pressures and total temperature at rotor inlet Plane 0.95 were obtained in the same manner as at the IGV inlet plane. The total pressure at each immersion at this station was deduced from the IGV loss coefficients (calculated by methods explained in Results and Discussion and corresponding to the inlet Mach number and IGV setting angle) and the upstream dynamic pressure. The average total pressure was then calculated from a radial mass-average of entropy rise along streamlines between vehicle inlet and rotor inlet.

At the rotor exit plane the average total temperature and the total temperature at each immersion were assumed equal to the values measured on corresponding streamlines at the stator exit Plane 2.2. Total pressure at rotor exit at each immersion was calculated by arithmetically averaging the three highest total pressure readings from the corresponding stator exit wake rake. The average total pressure at this plane was determined from a radial mass-average of the change in entropy and enthalpy along a streamline between the vehicle inlet and the rotor exit using a weight flow at each radial position calculated from stage exit properties and flow angles.

Stator exit conditions were obtained from instrumentation provided at Plane 2.20. The hub and casing static pressures were obtained by arithmetically averaging the two wall static pressure taps associated with the appropriate wake rake. The static pressure at each immersion was calculated by a linear interpolation between the hub and casing values of static pressure. Total temperature at each immersion was obtained by circumferential mass-average of the enthalpy at that immersion obtained from the 14-element wake rake. The average total temperature at this station was determined by a two-dimensional mass-average of the enthalpy. The total pressure at each immersion resulted from a circumferential mass-average of the enthalpy and the change in entropy between compressor inlet and the stator exit plane. The average stagnation pressure was calculated from a two-dimensional mass-average of the enthalpy and the change in entropy between the compressor inlet and the stator exit plane. Flow angles at

Plane 2.2 were assumed equal to zero degrees plus or minus any stator stagger adjustment. These methods of obtaining discharge conditions were believed to offer excellent accuracy for axisymmetric flow fields expected with undistorted inlet conditions.

c. BLADE ELEMENT DATA PROGRAM

The locations of the traverse probes and the quantities measured by them are discussed in the Instrumentation section. Input for Blade Element Data Program was obtained from traverse probes and from the results of the Overall Performance Data Program. Circumferential uniformity was assumed for all traverse data.

The meridional Mach number and all velocity components at each measurement plane were calculated by using the design meridional streamline angle and the measured total pressure, total temperature, static pressure, and flow angle at each immersion at the measuring station. Since measuring stations for the traverse probes were different from the blade row edges, all such measured data were translated to the blade row edges by a method based on conservation of mass, energy, and angular momentum. Application of the condition of constant angular momentum along design streamlines yielded the tangential velocity at each blade edge. It was assumed that the shape of each meridional stream tube, between a measurement plane and its adjacent blade edge, remains fixed at the design shape for all data conditions. The calculated meridional Mach number at the measurement plane was then used to determine the meridional Mach number at the blade edges by use of the streamtube convergence relationship shown in Figure 11. This method is not strictly correct at rotor trailing edge where there may be appreciable swirl velocity together with a change in radius between the edge and the measurement plane. Nevertheless, since the radius changes are not large, the method is considered a good approximation and has been used at the rotor trailing edges also. With the tangential velocities and the meridional Mach numbers at the edges thus obtained, and with measured stagnation conditions assumed to be constant along the design streamlines, the velocities, Mach numbers and all of their components were

determined at the blade edges. The constant physical quantities used in these computations, at the measurement planes and at the edges, are given in Table VI.

The efficiency, total pressure loss coefficient, and loss parameter for both rotor and stator were obtained by two different methods. The first method, which was the preferred one, used the standard vector diagram data obtained from the traversing cobra probe at Plane 1.51 for Mach numbers and velocities. However, this method used the total pressure and total temperature at Plane 1.51 inferred from the fixed rakes at Plane 2.2. The total pressure at each immersion at Plane 1.51 was obtained as the arithmetic average of the three highest readings of total pressure from the corresponding stator exit wake rake. These values were calculated by the Overall Performance Data Program and were used as inputs to this blade element data calculation.

The second method used the vector diagram data mentioned above together with the total pressure and total temperature measured by the traversing cobra probe at Plane 1.51. These stagnation properties measured at Plane 1.51 were taken to represent both rotor exit and stator inlet conditions.

The reasons for the choice of the first method for presentation of data are discussed in the section on Results and Discussion.

5. TEST PROCEDURE

a. SHAKEDOWN TEST

A shakedown test was conducted in the initial phase of the Task II testing with uniform inlet flow. The objective of this shakedown testing was manifold. First, it was intended to demonstrate the mechanical integrity of blading and the test vehicle and to check out instrumentation and data reduction procedures. Second, it was intended to establish the limits of stall-free operation over the range of speeds from 50 to 110 percent of design speed. Third, it was required to determine the optimum combinations of off-design inlet guide vane and stator settings. Having

determined these settings, it was then required to determine the IGV wake losses at seven different immersions with IGV wake rakes immersed in the airstream behind the IGV at the selected immersions. These wake rakes were removed for subsequent blade element and overall performance data tests, and the values of IGV losses obtained during the shakedown testing were used in obtaining rotor inlet conditions.

Since one of the objectives was to establish the safe limits of operation, the most open safe throttle setting was first determined at each speed. The throttle was then closed slowly until hot wire anemometer and strain gage signals indicated the formation of rotating stall cells. The radial extent of the stall cells was established from the strength of the signals observed on the three hot wire anemometer probes located at the rotor exit, Plane 1.51 at the 10, 50 and 90 percent immersions. These probes were used only during stall testing and were removed from the airstream during all other readings. The discharge throttle valve setting and ICPAC* system weight flow were recorded at stall. The corrected inlet weight flow at stall was determined from a correlation of ICPAC flow with corrected inlet flow for all throttle settings at each speed. This defined the limits of stall-free operation.

Overall performance readings were then taken at points near stall, near peak efficiency, and at open throttle positions for each speed. Two blade element traverses were obtained at nominal IGV setting and IGV setting of 40 degrees at 100 percent speed near peak efficiency during the shakedown testing. The four traverse probes referred to in an earlier section were each immersed to seven radial positions. The static-pressure wedge probe at Plane 1.51 was manually set at the same flow angle as that indicated by the nulled yaw position of the cobra probe at Plane 1.51.

*The ICPAC system (Instantaneous Compressor Performance Analysis Computer) is an analog circuit which senses weight flow and pressure ratio and which plots these quantities nearly instantaneously to provide an approximate on-line compressor map.

Other static-pressure wedge probes, located at Planes 0.95 and 2.20, were angle-seeking type. An overall performance point was taken immediately preceding or following each blade element traverse at the same throttle setting with all traverse probes removed from the airstream.

Although off-design analysis explained in Reference 1 had been made only for IGV turning angles up to 35 degrees, initial shakedown tests indicated that an IGV setting angle of 40 degrees would give lower corrected weight flow at stall without excessive efficiency penalty. Hence an IGV setting angle of 40 degrees was chosen for cruise condition testing. Overall performance tests and stalls made at different stator settings to determine the best stator setting corresponding to the chosen IGV setting of 40 degrees indicated an optimum stator setting of 8 degrees. An intermediate configuration of IGV and stator settings of 20 and 4 degrees respectively was also chosen, thus giving three IGV/stator schedules for further blade element and overall performance testing.

b. UNDISTORTED INLET FLOW PERFORMANCE TEST

Having chosen the optimum design and off-design IGV/stator vane schedules, a series of stall tests was then done at each speed at the three schedules. With design IGV and stator settings, the vehicle was accelerated to 50 percent design speed at the open throttle position and stabilized. The discharge throttle valve was then closed until stall was indicated by the hot-wires and strain gages. An overall performance reading was taken at a throttle valve setting close to stall. A similar procedure was performed at the two off-design schedules. The vehicle was then accelerated to the next higher speed and the procedure repeated at the three schedules.

With the stall limits thus defined, five additional operating conditions, equally spaced between near stall and open throttle conditions along each speed line at each IGV/stator schedule, were chosen at which blade element and overall performance data were obtained.

Two detailed traverses at 100 percent speed and one at 110 percent speed were conducted to more clearly define the effect of the part-span

shroud wake on rotor exit conditions. The cobra probe located at Plane 1.51 was immersed to numerous closely spaced radial positions and total pressure, total temperature, and flow angle measurements were obtained.

SECTION IV

RESULTS AND DISCUSSION

Testing with undistorted inlet flow for the Task II stage was conducted during the shakedown tests and undistorted inlet flow performance tests. The following sections contain data from these tests as well as brief discussions.

1. SHAKEDOWN TESTING

One of the principal objectives of the shakedown testing was to determine the IGV total pressure loss coefficients at each immersion as a function of Mach number and IGV turning angle. Hence, part of the shakedown testing was conducted with IGV wake rakes installed in the test rig. Tables VII(a) and VII(b) list the overall performance parameters measured from the shakedown tests with and without the IGV wake rakes immersed in the airstream respectively. For convenience, at each speed the points have been arranged in an ascending order of IGV setting angles and at each IGV setting angle in an ascending order of total pressure ratios. The determination of IGV wake losses is discussed in a separate section.

Another feature of the shakedown testing was to determine off-design IGV/stator schedules at 70 percent design speed to meet the objective cruise condition weight flow of 122 lbs/sec. A series of performance and stall tests were conducted at 70 percent design speed with the IGV setting angle varied between 20 and 40 degrees at a stator setting angle of 8 degrees. A plot of stalling weight flow versus IGV setting angle, given in Figure 12(a), shows that some IGV closure was required and the margin between the cruise weight flow and the weight flow at stall increased as the IGV setting angle was increased. Figure 12(b) shows 70 percent speed stage adiabatic efficiency at stall at two constant throttle valve settings and at a weight flow of 122 lbs/sec as a function of IGV setting angle. Although the efficiency dropped with increasing IGV setting angle along the two constant throttle lines, at the 122 lbs/sec cruise weight

flow condition the efficiency increased to a maximum at IGV setting angle of 40 degrees. Mechanical limitations prevented turning the IGV beyond 40 degrees. Rapidly increasing IGV losses at IGV turning angles above 35 degrees indicated that the efficiency probably would have started to decrease with any further IGV turning beyond 40 degrees. Hence, an IGV setting angle of 40 degrees was chosen for the cruise condition testing. An intermediate IGV setting angle of 20 degrees was also chosen for further performance tests.

The stator setting angles giving best performance at the two selected IGV settings were determined during overall performance tests in which the stator setting angle was varied between 0 and 12 degrees at 70 percent design speed. Figure 12(c) shows plots of total pressure ratio and adiabatic efficiency for the IGV-Rotor combination and for the stage at the two IGV setting angles at 70 percent design speed and a constant throttle valve setting. A small drop in efficiency between 8 and 12 degrees stator setting angles occurred with either IGV setting in spite of a small increase in total pressure ratio. This was caused by a decrease in weight flow and a higher resulting work input. Based on the results shown in Figure 12(c), stator setting angles of 8 and 4 degrees were chosen for use with IGV setting angles of 40 and 20 degrees, respectively.

2. DETERMINATION OF IGV TOTAL-PRESSURE LOSSES

As mentioned earlier, the undistorted inlet flow performance tests were conducted with the IGV wake rakes removed from the airstream. A table of IGV loss coefficients versus Mach number and IGV setting angle at the seven immersions obtained during shakedown tests was provided to the Overall Performance Data Program to calculate the rotor inlet total pressure. This section presents a discussion of the three different techniques that were used to obtain the table of IGV loss coefficients. The first technique, used only for IGV setting angle of 40 degrees for reasons stated later, consisted of using the data as obtained directly from the IGV wake rakes to evaluate the losses. The second technique

consisted of turning the IGV by 0.5 degree increments from 0 to 5 degrees to obtain a more detailed wake profile. The third technique was to circumferentially traverse a combination probe behind the IGV in small angular increments to closely map out the profile of the wake from one vane. The three techniques are discussed below in greater detail.

The IGV wake losses were to be measured during shakedown tests at all speeds and at the three IGV setting angles by means of seven 14-element total pressure wake rakes located at Plane 0.95. The initial shakedown tests showed that the rakes were not giving consistent measurements of the IGV losses at nominal and 20 degree IGV setting angles. The widths of the wakes appeared to be less than two rake element spacings. Usually the wake indication was limited to one element which could not measure the width and the depth of the wake at the same time. It was also observed that an arithmetic average of the total pressure readings from all of the ten or eleven elements clearly outside the wake provided a substantially lower estimate of the IGV inlet total pressure than the arithmetic average of the three highest readings as had been proposed earlier in the test plan. It was considered that the difference between these two estimates was not a loss that could be ascribed to the IGV.

At the off-design IGV setting angle of 40 degrees, it was found that the wake profiles obtained with the wake rakes were nearly symmetric about the one element usually in the wake indicating the bottom of the wake and gave consistent loss data. Figure 13 shows the profiles obtained at 50 percent immersion from the tip at 50, 70, 80, 90, 100 and 110 percent design speeds for the IGV set at 40 degrees.

In order to reduce the difficulty in accurately defining the shape of the wake at 0 and 20 degrees IGV settings by wake rake measurement, another technique was investigated. Overall Performance readings were taken at 100 percent design speed with the IGV wake rakes in place, while the IGV was turned in steps of 0.5 degree from 0 to 5 degrees. This process assumed that the wake profile relative to the vane would not change for

small deflections, so that the IGV deflections would sweep true profiles past the wake rake elements. Figures 14(a) through 14(g) show the profiles thus developed at the seven immersions. The pressure measured by the three elements G, H and I, which were in the wake at one or more IGV settings, was first plotted against the turning angle. In order to obtain some correspondence to relate the IGV turning angle to the linear displacement of the wake profile with respect to the element spacing, the angular spacing of the profiles was displaced for best compatibility. The most appropriate offset to get good correspondence was well defined at all immersions except at 95 percent immersion from the tip, which is shown in Figure 14(g). It should be observed that the rotation of the IGV in the direction of rotation of the rotor actually provides profile information in the direction contrary to rotation. Mass-averaging the pressures from the profiles yielded the IGV exit total pressure at each immersion which was used in evaluating the loss coefficient. Curve A in Figure 15 shows a radial plot of the loss coefficients thus obtained for nominal IGV setting at 100 percent design speed.

A third technique was next used at IGV setting angles of 0 and 20 degrees at 70 percent design speed and at a setting angle of 20 degrees at 100 percent speed. The procedure followed in this series was different, but was considered equally effective as the one in the earlier series mentioned above. At the time of this series of tests, a circumferential distortion screen had been installed for distorted inlet flow tests and the IGV wake rakes had been removed from the airstream. Hence, for convenient adaptability to the test program, the combination probe at 343 degrees at Plane 0.95 was circumferentially traversed in short steps of a few tenths of a degree at a time behind the IGV. This probe was outside the range of the distorted flow and this series of tests was thus not affected by the distortion screen. Figure 16 shows the wake profiles thus obtained at 70 and 100 percent speeds at the seven immersions. These were used as a basis for obtaining the loss coefficient at these conditions. The IGV inlet total pressure was obtained by arithmetically averaging the

pressures at all the recorded points clearly outside the wake. A mass-average of all the points recorded on the profile yielded the IGV exit pressure. The static pressures at IGV inlet and exit were obtained from the static pressure taps mounted on hub and casing at Planes 0.18 and 0.95 respectively. A scrutiny of the profiles at 95 percent immersion at both 70 and 100 percent speeds showed that the wake profiles would not give a reliable measurement of the IGV inlet total pressure. Hence, for this immersion alone, the IGV inlet total pressures were obtained from a total pressure distortion rake mounted at Plane 0.18 outside the region of distorted flow. Curves B, C, and D in Figure 15 present radial plots of the values of loss coefficients thus obtained. Figure 15 thus contains all the data obtained by the last two techniques.

A careful scrutiny of the data did not reveal any measurement errors to explain the reason for the values of IGV total pressure loss coefficient at 5 and 10 percent immersions on Curve A of Figure 15 (100 percent speed) being lower than those at the same immersions at 70 percent speed. Under the circumstances, it was considered justifiable to raise the values of the loss coefficient for these two immersions as shown by the dashed lines to make the profile consistent with the other profiles. The profile at 70 percent speed for an IGV setting angle of 20 degrees, curve B, also required a similar readjustment at 5 and 10 percent immersions as shown.

The final results from these three techniques are presented in Figures 17(a) through 17(g) for the seven immersions as a function of Mach number. These data were input to the Overall Performance Data Program in the form of a table of loss coefficient versus Mach number and IGV setting angle at each immersion.

Figure 18 shows a plot of IGV total pressure loss coefficient versus IGV setting angle at different immersions at a Mach number of 0.2. The values of loss coefficient at IGV setting angles of 30 and 35 degrees were

obtained by the first technique mentioned above. It may be noticed that the value of loss coefficient at 70 percent immersion is higher than those at 50 and 90 percent immersions. This fact is more conspicuous with increasing turning angle. Two checks were made to ascertain that no errors due to faulty instrumentation were introduced. Figure 19 shows a radial plot of loss coefficient at different IGV turning angles at 100 percent design speed. The curves for 0, 20, and 40 degrees IGV setting angles were obtained by the appropriate techniques mentioned above. The remaining curves were obtained by the first technique. It is clearly seen that the high-loss region at 70 percent immersion shows an increasing tendency with IGV turning angle, indicating the likelihood of an aerodynamic phenomenon rather than an instrument problem. As a further check to ensure that the instrumentation at 70 percent immersion or 90 percent immersion did not give erroneous results, the values of loss coefficient obtained from Reading 113 with IGV turning of 1 degree are also plotted on Figure 19. This reading was taken on the same day soon after Reading 108 which had an IGV setting of 40 degrees and which is also shown in the same figure. Since the instrumentation was the same for both readings, and since the high-loss region appears only at the higher IGV setting angles, it was concluded that the high-loss region was due to a phenomenon other than faulty instruments. The nature of this phenomenon is being studied.

3. OVERALL PERFORMANCE DATA

A listing of all overall performance data points taken during the Task II Stage undistorted inlet flow performance testing is given in Table VII(c). At each IGV/stator schedule and speed, the data have been arranged in the order of increasing total pressure ratios.

The compressor stage performance maps based on the data in Tables VII(b) and VII(c) are presented in Figure 20 for the design IGV/stator schedule, in Figure 21 for the IGV/stator schedule of 20/4 degrees, and in

Figure 22 for IGV/stator schedule of 40/8 degrees. Shakedown test data obtained with IGV wake rakes in the airstream have not been included in these maps.

A series of stall tests was conducted to determine the nature and location of initiation of stall. At nominal IGV/stator schedules stall occurred initially at the rotor tip at all speeds, as evidenced by strong signals from the hot-wire anemometer at 10 percent immersion behind the rotor. High vibratory stresses were indicated by the stator strain gages before rotor stall was initiated at 110 percent design speed. At the two off-design schedules, stall occurred at the rotor tip at all speeds. High vibratory stresses were observed on the stator at 90, 100, and 110 percent design speeds before the rotor stalled. The stall lines on the performance maps were obtained in the following manner. The method of obtaining the corrected weight flow at stall has been explained in the section on Test Procedure. The stage total pressure ratio at stall was obtained by extrapolation to the discharge valve setting at stall of a plot of stage total pressure ratio versus discharge throttle valve setting at each speed.

On a constant throttle line through the design point at design IGV/stator schedule, the achieved stage pressure ratio and adiabatic efficiency at design speed were 1.65 and 83.4 percent at a corrected weight flow of 224 lbs/sec. The design pressure ratio and efficiency were 1.66 and 85.4 percent, respectively, at a weight flow of 226 lbs/sec.

Figures 23, 24, and 25 show the performance maps for the rotor alone at the three IGV/stator schedules.

4. BLADE ELEMENT DATA

Blade element data traverse readings were obtained at five operating conditions at each speed. The readings at which blade element data were obtained are indicated in Table VII(c) which lists the measured overall performance parameters for each reading.

A discussion of the determination of the IGV loss coefficients and plots of the loss coefficients versus Mach number and IGV setting angle

at the seven immersions have been presented in an earlier section. Figure 26(a) shows a radial plot of IGV deviation angle at 100 percent speed and nominal setting. Figures 26(b) and 26(c) show radial plots of the same parameter at IGV setting angles of 20 and 40 degrees respectively at 70 percent design speed and 54 percent design weight flow. Additional IGV blade element data and vector diagram data are presented in Table VIII of Volume II.

Plots of rotor diffusion factor, deviation angle, total pressure loss coefficient, and loss parameter versus rotor incidence angle at the seven immersions at 50, 70, 80, 90, 100 and 110 percent design speed at nominal IGV/stator schedule are presented in Figures 27(a) through 27(g). Design values of these parameters on the rotor blade element data sections are also presented in Figures 27(a) through 27(g) for comparison. Figures 28(a) through 28(g) and Figures 29(a) through 29(g) show these plots for IGV/stator schedules of 20/4 and 40/8 degrees respectively. Additional rotor blade element data are presented in Table VIII of Volume II.

Plots of stator diffusion factor, deviation angle, total pressure loss coefficient, and loss parameter versus stator incidence angle, obtained from fixed instrumentation at the seven immersions described elsewhere, at speeds of 50, 70, 80, 90, 100 and 110 percent of design rotor speed at design IGV/stator schedule are presented in Figures 30(a) through 30(g). Design values of these parameters on the stator blade element data sections are also presented in Figures 30(a) through 30(g) for comparison. Figures 31(a) through 31(g) show these parameters for IGV/stator schedule of 20/4 degrees. Figures 32(a) through 32(g) are for the cases with IGV/stator schedule of 40/8 degrees. Additional stator blade element data are presented in Table VIII of Volume II.

For both the rotor and the stator blade element data, the reported values of loss coefficient, loss parameter, and blade element efficiency were based on total-pressure and total-temperature ratios determined from the discharge wake rakes rather than using the readings from the Plane

1.51 cobra probe. These data thus were obtained by the first method described in the section on Data Reduction Methods. The agreement between the momentum work input based on flow angle measurements and the temperature rise obtained by this method were much closer than that when the traverse probe temperature measurements were used. The traverse probe measurements of rotor exit total temperature were considered high and were not consistent with the discharge instrument readings. It was suspected that local throttling caused by the probe itself in the short axial space between rotor trailing edge and stator leading edge was responsible for the high temperatures measured by the traverse probe.

5. ROTOR EXIT TRAVERSE DATA

At two operating conditions at 100 percent speed and one condition at 110 percent speed, the rotor exit cobra probe at Plane 1.51 was traversed to thirty-six radial positions. Radial profiles of total pressure ratio, total temperature ratio, and absolute flow angle were obtained which showed the wall boundary layers and the part span shroud wake in more detail than was possible from the 7-immersion blade element data traverses. Figure 33 presents plots of these radial profiles; the radial position of the part-span shroud is indicated on the plots.

APPENDIX A

SYMBOLS

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
A	Annulus or streamtube area	In. ²
C	Chord length of cylindrical section	In.
C _h	Enthalpy - equivalent static pressure rise coefficient	
	$C_h = \frac{2gJ c_p t_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] - (U_2^2 - U_1^2)}{V_1'^2}$	
C _p	Static pressure rise coefficient,	---
	$C_p = \frac{p_2 - p_1}{p_1' - p_1}$	
c _p	Specific heat at constant pressure	BTU/Lb-°R
D	Diffusion factor:	---
	$D_{\text{rotor}} = 1 - \frac{V_2'}{V_1'} + \frac{r_2 V_{\theta 2} - r_1 V_{\theta 1}}{2F \sigma V_1'}$	
	$D_{\text{stator}} = 1 - \frac{V_2}{V_1} + \frac{r_1 V_{\theta 1} - r_2 V_{\theta 2}}{2F \sigma V_1}$	
g	Acceleration due to gravity	32.174 Ft/Sec ²
i	Incidence angle, difference between flow angle and camber line angle at leading edge in cascade projection	Degrees
J	Mechanical equivalent of heat	778.161 Ft-Lb/BTU

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
K_{bl}	Effective-area coefficient due to wall boundary layer blockage	---
M	Mach number	---
N	Rotational speed	RPM
P	Total or stagnation pressure	PSIA
p	Static pressure	PSIA
r	Radius	In.
$\bar{r}$	Mean radius, average of streamline leading-trailing edge radii	In.
S	Spacing between blades	In.
T	Total or stagnation temperature	°R
t	Airfoil thickness	In.
t_m	Airfoil maximum thickness	In.
U	Rotor speed	Ft/Sec
V	Air velocity	Ft/Sec
W	Weight flow	Lbs/Sec
Z	Displacement along compressor axis	In.
β	Flow angle, angle whose tangent is the ratio of tangential to axial velocity	Degrees
$\Delta\beta$	Air turning angle, $\Delta\beta = \beta_1 - \beta_2$	Degrees
γ°	Blade-chord angle (stagger), angle in cascade projection between blade chord and axial direction	Degrees
γ	Ratio of specific heats	---
δ°	Deviation angle, difference between flow angle and camber line angle at trailing edge in cascade projection	Degrees

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
δ	Pressure correction, $\frac{P_{\text{actual}}}{14.696 \text{ psia}}$	---
$\Delta r\theta$	Circumferential displacement about compressor axis, Figure 2(c)	In.
ϵ°	Slope of meridional streamline	Degrees
θ	Temperature correction, $\frac{T_{\text{actual}}}{518.7^\circ\text{R}}$	---
η	Efficiency	---
K°	Angle between tangent to blade meanline and the axial direction	Degrees
σ	Solidity, ratio of chord to spacing	---
φ°	Camber angle, difference between angles in cascade projection of tangents to camberline at extremes of camberline arc	Degrees
$\bar{w}$	Total pressure loss coefficient	---
	Rotor, $\bar{w}' = \frac{P'_{2id} - P'_2}{P'_1 - p_1}$,	
	Stator and IGV $\bar{w} = \frac{P_1 - P_2}{P_1 - p_1}$	
$\frac{\bar{w} \cos \beta_2}{2\sigma}$	Total Pressure Loss Parameter	---

<u>Subscripts</u>	<u>Description</u>
ad	Adiabatic
an	Annulus
d	Downstream measurement plane (Table VI)
e	Edge of blade
F	Flap portion of Inlet Guide Vane
id	Ideal
j	Immersion
m	Meridional direction
N	Nose portion of Inlet Guide Vane
p	Polytropic
S	Measurement Plane - (Figure 11)
t	Tip at Station 1.0
u	Upstream measurement plane (Table VI)
z	Axial direction
θ	Tangential direction
1	Leading edge
2	Trailing edge
0.01, 0.18 0.95, 1.51, 2.20	Measurement station designations (Figures 8 and 9)
<u>Superscript</u>	
'	Relative to rotor
*	Critical Flow Condition

REFERENCES

- (1) Doyle, V.L. and Koch, C.C., "Evaluation of Range and Distortion Tolerance For High Mach Number Transonic Fan Stages", Task I Final Report, NASA CR - 72786
- (2) Doyle, V.L. and Koch, C.C., "Evaluation of Range and Distortion Tolerance For High Mach Number Transonic Stages", Design Report, NASA CR - 72720, July 23, 1970

Table I. Summary of NASA Task II Stage Design Specifications

Rotor inlet corrected tip speed, ft/sec	1500
Stage inlet corrected weight flow, lbs/sec	226.0
Stage total-pressure ratio	1.659
Stage adiabatic efficiency	0.854
Number of inlet guide vanes	24
Inlet guide vane total-pressure loss, percent inlet total pressure	0.37
Inlet guide vane exit flow angle, degrees	0
Rotor inlet tip diameter, inches	36.5
Rotor inlet hub/tip radius ratio	0.5
Rotor inlet corrected weight flow per unit annulus area, lbs/sec-sq ft	41.62
Rotor inlet tip relative Mach number	1.526
Rotor tip diffusion factor	0.368
Rotor total-pressure ratio	1.686
Rotor adiabatic efficiency	0.883
Rotor tip solidity	1.4
Rotor aspect ratio	2.36
Number of rotor blades	44
Stator inlet hub absolute Mach number	0.766
Stator exit flow angle, degrees	0
Stator hub diffusion factor	0.435
Stator total-pressure loss, percent stator inlet total pressure	1.22
Stator hub solidity	2.155
Stator aspect ratio	2.065
Number of stator vanes	46

Table II. Inlet Guide Vane Design Parameters (Number of Vanes = 24)

Design Parameter	Manufacturing Section									Units
	1	2	3	4	5	6	7	8	9	
r	18.389	17.885	17.435	15.485	13.465	11.375	8.940	8.100	7.390	Inches
r/r_t	1.0076	0.9800	0.9553	0.8485	0.7378	0.6233	0.4899	0.4433	0.4049	---
C_N	1.280	1.254	1.230	1.129	1.024	0.915	0.788	0.745	0.708	Inches
C_F	4.975	4.873	4.782	4.388	3.979	3.557	3.064	2.894	2.751	Inches
ΣC	6.255	6.127	6.012	5.517	5.003	4.472	3.852	3.639	3.459	Inches
σ	1.299	1.309	1.317	1.361	1.419	1.502	1.646	1.716	1.788	Inches
Z_N	2.706	2.658	2.613	2.425	2.228	2.028	1.793	1.711	1.642	Inches
Z_F	1.279	1.253	1.230	1.128	1.023	0.914	0.788	0.744	0.707	Inches
$\Delta r\theta^\circ/\sin\theta^\circ$	1.1800	1.1477	1.1188	0.9936	0.8640	0.7299	0.5737	0.5198	0.4742	Inches

Table III. Aerodynamic and Geometric Design Parameters on Design Streamlines

(a) Rotor

Number of Blades = 44

Design Parameter	Streamline									Hub		Units
	Tip SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	SL 7	SL 8	SL 9			
$\bar{r}$	18.03	17.60	17.22	15.57	13.93	12.28	10.54	10.06	9.63			Inches
r_1	18.173	17.706	17.308	15.581	13.860	12.097	10.171	9.620	9.128			Inches
r_2	17.891	17.493	17.139	15.567	14.008	12.466	10.904	10.493	10.141			Inches
V_1	1652	1610	1591	1452	1345	1208	1042	996	945			Ft/sec
V_2	1200	1164	1132	998	868	746	643	622	610			Ft/sec
M_1	1.526	1.510	1.490	1.374	1.258	1.130	0.983	0.941	0.907			---
M_2	1.023	0.992	0.966	0.856	0.747	0.648	0.571	0.557	0.551			---
$\bar{u}$	0.1634	0.1486	0.1355	0.1004	0.0803	0.0668	0.0707	0.0766	0.0821			---
C	3.601	3.599	3.596	3.587	3.527	3.446	3.388	3.374	3.361			Inches
σ	1.400	1.431	1.462	1.610	1.777	1.967	2.251	2.331	2.443			---
tm/C	0.0227	0.0259	0.0287	0.0437	0.0562	0.0660	0.0747	0.0768	0.0785			---
D	0.368	0.371	0.381	0.409	0.456	0.495	0.514	0.515	0.501			---
β_1	66.3	64.4	63.5	60.9	58.2	55.7	53.4	52.7	51.7			Degrees
β_2	59.3	59.5	59.3	56.1	50.6	42.0	27.9	22.9	18.4			Degrees
$\Delta\beta'$	7.0	4.9	4.2	4.8	7.6	13.7	25.5	29.8	33.3			Degrees
K°_1	63.30	61.28	60.22	57.01	53.75	50.70	48.50	48.00	47.50			Degrees
K°_2	57.27	57.52	57.18	52.85	46.10	35.05	16.84	10.35	4.56			Degrees
i	3.00	3.12	3.28	3.89	4.45	5.00	4.90	4.70	4.20			Degrees
δ°	2.03	1.98	2.12	3.25	4.50	6.95	11.06	12.55	13.84			Degrees
γ°	61.94	60.79	59.85	55.32	49.56	41.59	31.46	28.65	25.95			Degrees
φ°	6.03	3.76	3.04	4.16	7.65	15.65	31.66	37.65	42.94			Degrees

Table III. Aerodynamic and Geometric Design Parameters on Design Streamlines (Concluded).

(b) Stator

Number of Blades = 46

Design Parameter	Streamline									Hub		Units
	Tip SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	SL 7	SL 8	SL 9			
$\bar{r}$	17.836	17.443	17.103	15.642	14.228	12.855	11.489	11.134	10.831			Inches
$r1.6$	17.836	17.432	17.083	15.586	14.132	12.706	11.263	10.882	10.553			Inches
$r2.0$	17.836	17.454	17.123	15.697	14.325	13.005	11.715	11.386	11.109			Inches
$V1.6$	725	729	732	744	764	796	844	860	874			Ft/Sec
$V2.0$	597	596	595	595	598	605	621	627	634			Ft/Sec
$M1.6$	0.615	0.620	0.624	0.639	0.659	0.690	0.737	0.753	0.766			---
$M2.0$	0.500	0.500	0.501	0.503	0.507	0.515	0.529	0.535	0.541			---
$\bar{w}$	0.0404	0.0393	0.0383	0.0396	0.0451	0.0520	0.0650	0.0707	0.0754			---
C	3.650	3.633	3.606	3.493	3.396	3.299	3.222	3.199	3.184			Inches
σ	1.4983	1.5197	1.5438	1.6288	1.7386	1.8794	2.0536	2.1045	2.1557			---
tm/C	0.0650	0.0640	0.0629	0.0588	0.0548	0.0507	0.0468	0.0458	0.0450			---
D	0.3784	0.3790	0.3787	0.3847	0.3954	0.4100	0.4273	0.4317	0.4346			---
β_1	37.12	36.73	36.48	37.00	38.57	40.52	43.43	44.45	45.43			Degrees
β_2	0	0	0	0	0	0	0	0	0			Degrees
K°_1	40.09	39.48	39.06	39.10	40.15	41.24	42.85	43.55	44.00			Degrees
K°_2	-13.11	-10.99	-10.21	-8.94	-8.80	-9.17	-10.41	-11.31	-12.54			Degrees
i	-2.97	-2.75	-2.58	-2.10	-1.58	-0.72	0.58	0.90	1.43			Degrees
δ°	13.11	10.99	10.21	8.44	8.80	9.17	10.41	11.31	12.54			Degrees
γ°	13.46	14.21	14.24	14.58	15.76	16.99	18.89	19.43	19.62			Degrees
φ°	53.20	50.57	49.27	48.04	48.95	50.41	53.26	54.86	56.54			Degrees

Table IV. Geometric Parameters on Rotor and Stator Blade Element Sections

	r_j		K_j^0		$\bar{r}$	φ°	σ_j	t_m/C	C	γ°
	Edge 1	Edge 2	Edge 1	Edge 2						
Rotor	17.706	17.525	61.28	57.52	17.616	3.76	1.431	0.0256	3.6	60.9
	17.350	17.138	60.25	57.18	17.244	3.07	1.461	0.0285	3.596	60.0
	15.610	15.567	57.07	52.85	15.589	4.22	1.612	0.044	3.587	55.40
	13.900	14.008	53.90	46.10	13.954	7.80	1.773	0.0562	3.530	49.6
	12.150	12.425	50.80	34.70	12.288	16.10	1.964	0.066	3.446	41.59
	10.212	10.904	48.58	16.84	10.558	31.74	2.248	0.0747	3.388	31.50
	9.625	10.500	48.02	10.70	10.063	37.32	2.347	0.0768	3.374	28.65
Stator	17.459	17.463	39.47	-11.13	17.457	50.60	1.523	0.064	3.633	14.21
	17.075	17.125	39.11	-10.10	17.100	49.21	1.544	0.0629	3.606	14.24
	15.610	15.700	39.01	-8.87	15.655	47.88	1.631	0.0590	3.492	14.57
	14.175	14.363	39.80	-8.75	14.269	48.55	1.742	0.0550	3.392	15.72
	12.725	12.980	40.86	-9.10	12.853	49.96	1.880	0.0507	3.299	16.99
	11.300	11.720	42.22	-10.58	11.510	52.80	2.051	0.0470	3.225	18.87
	10.950	11.388	42.76	-12.36	11.169	55.12	2.098	0.0460	3.202	19.41

Table V. Major Instrumentation List for Task II Stage Testing

Location	Shakedown Stall Test	Shakedown Performance Test	Undistorted Inlet Flow Tests
0.01 Vehicle Inlet	6 7-element P, p rakes 24 T t/c's		
0.95 Rotor Inlet		7 14-element P wake rakes 1 p, β wedge probe with C.T.* 1 P, T, p, β combination probe with C.T.*	
1.51 Stator Inlet		1 P, T, β Cobra Probe 3 hot wire probes	1 p wedge probe #
2.20 Stage Exit	7 14-element P, T wake rakes	1 p, β wedge probe	

* C.T. = Circumferential Traverse capability

Radial Traverse probes

Table VI. Summary of Blade Element Data Reduction Constants

(a) IGV - Task II

Parameter	% Immersion	Plane 0.18	Edge 1	Edge 2	Plane 0.95
No K_{bl} included	5	88.40			78.50
	10	133.95			119.70
	30	198.79			177.58
	50	179.55			157.38
	70	163.26			149.51
A_J	90	93.31			86.66
	95	51.94			49.60
r_J	0	18.412	18.108	18.370	18.323
	5	17.893	17.900	17.870	17.835
	10	17.415	17.420	17.450	17.420
	30	15.388	15.39	15.580	15.604
	50	13.300	13.330	13.600	13.797
	70	11.080	11.160	11.590	11.972
	90	8.580	8.700	9.180	9.910
	95	7.781	7.820	8.380	9.285
	100	7.099	7.099	7.580	8.737
	0	-0.99	-0.01	-1.34	-2.68
c_J	5	-1.05	0.12	-0.78	-2.37
	10	-1.29	0.290	-0.35	-1.91
	30	-1.44	0.90	1.80	1.05
	50	-1.08	1.70	1.46	4.85
	70	-0.66	2.65	7.80	9.38
	90	-0.33	3.05	12.70	15.45
	95	-0.17	2.35	15.15	17.55
	100	0	1.80	17.80	19.59
	0		0	Equal to guide vane setting angle	
	5				
K_J	10				
	30				
	50				
	70				
	90				
	95				
	100				

Radii are in inches
Areas are in square inches

Table VI. Summary of Blade Element Data Reduction Constants (Continued).

(b) Rotor - Task II

Parameter	% Immersion	Plane 0.95	Edge 1	Edge 2	Plane 1.51
No K_{bl} included	5	78.50			62.89
	10	119.70			99.21
	30	177.58			148.69
	50	137.38			133.36
	70	145.51			111.39
F_j	90	86.66			71.96
	95	49.60			36.51
	0	18.323	18.173	17.890	17.838
	5	17.835	17.706	17.525	17.162
	10	17.420	17.350	17.138	17.081
F_j	30	15.601	15.610	15.567	15.568
	50	13.797	12.900	11.008	11.056
	70	11.972	12.150	12.125	12.513
	90	9.910	10.212	10.901	11.030
	95	9.265	9.625	10.500	10.652
F_j	100	8.737	9.125	10.111	10.287
	0	-2.68	-8.77	-5.89	-0.28
	5	-2.37	-6.58	-5.30	-0.70
	10	-1.92	-4.95	-4.17	-0.83
	30	1.05	0.28	-0.97	0.36
F_j	50	4.85	4.53	2.81	3.11
	70	9.40	9.41	7.20	6.80
	90	15.60	16.20	12.31	11.17
	95	17.55	18.02	13.50	12.28
	100	19.59	19.46	14.86	13.12
K_j	0		63.30	57.27	
	5		61.28	57.52	
	10		60.25	57.18	
	30		57.07	52.85	
	50		53.90	46.10	
K_j	70		50.80	31.70	
	90		48.58	16.84	
	95		48.02	10.70	
	100		47.50	4.56	

Radii are in inches
Areas are in square inches

Table VI. Summary of Blade Element Data Reduction Constants (Concluded).

(c) Stator - Task I:

Parameter	% Immersion	Plane 1.51	Edge 1	Edge 2	Plane 2.20
No K_{bl} included	5	62.89			58.73
	10	99.21			91.59
	30	146.69			134.20
	50	133.36			121.11
	70	111.59			108.76
A_J	90	74.96			64.09
	95	36.54			29.08
r_J	0	17.838	17.836	17.836	17.836
	5	17.462	17.450	17.463	17.478
	10	17.081	17.075	17.125	17.130
	30	15.568	15.610	15.700	15.750
	50	14.056	14.175	14.363	14.420
	70	12.543	12.725	12.980	13.075
	90	11.030	11.300	11.720	11.775
	95	10.652	10.950	11.388	11.475
	100	10.287	10.625	11.100	11.168
c_J^3	0	-0.28	0	0	0
	5	-0.70	0.24	0.22	0.12
	10	-0.83	0.50	0.42	0.24
	30	0.50	1.70	1.28	0.71
	50	3.14	3.52	2.18	1.13
	70	6.80	6.04	3.25	1.38
	90	11.17	9.40	4.39	1.14
	95	12.28	10.31	4.80	0.92
	100	13.42	11.38	4.70	0.65
K_J' (At nominal stator setting)	0		40.09	-13.08	
	5		39.47	-11.13	
	10		39.11	-10.10	
	30		39.01	-8.87	
	50		39.80	-8.75	
	70		40.86	-9.10	
	90		42.22	-10.58	
	95		42.76	-12.36	
	100		43.32	-12.88	

Radii are in inches
Areas are in square inches

Parameter	% Immersion	
$\frac{(w_j/w^*)_l}{(w_j/w^*)_u}$	5	0.9992
	10	1.0043
	30	1.0229
	50	1.0327
	70	1.0385
	90	1.0378
	95	1.0334
$\frac{(w_j/w^*)_2}{(w_j/w^*)_d}$	5	0.9880
	10	0.9873
	30	0.9904
	50	0.9932
	70	0.9987
	90	1.0158
	95	1.0254
$\bar{r}_J$ (Used for Diffusion Factor)	5	17.457
	10	17.100
	30	15.655
	50	14.269
	70	12.853
	90	11.510
	95	11.169
σ_J (Used for Diffusion Factor)	5	1.523
	10	1.544
	30	1.631
	50	1.742
	70	1.880
	90	2.051
	95	2.098

Table VII. Overall Performance Based on Fixed Instrumentation.

a. Shakedown Tests - IGV Wake Rakes Installed

Reading Number	Corrected Speed % Design	IGV Setting Deg	Stator Setting Deg	Throttle Valve Setting	Stg Inlet Corrected Weight Flow W/8-Lb/Sec	Stage Total Pressure Ratio	Stage Adiabatic Efficiency	Type Point
2	50	0	0	30	126.8	1.090	0.796	O.P.*
86	50	0	0	30	125.2	1.091	0.754	O.P.
87	50	0	0	5	101.78	1.142	0.782	O.P.
3	50	0	0	2	94.45	1.150	0.7996	O.P.
88	50	15	4	5	96.3	1.1296	0.7472	O.P.
90	50	20	4	30	112.1	1.0718	0.7316	O.P.
89	50	20	4	5	93.3	1.1221	0.7843	O.P.
91	50	25	4	5	91.2	1.1162	0.7751	O.P.
92	50	30	4	5	88.2	1.1107	0.7697	O.P.
93	50	35	4	5	85.3	1.1060	0.7868	O.P.
95	50	40	8	30	97.6	1.0556	0.7464	O.P.
94	50	40	8	5	81.6	1.1009	0.7678	O.P.
4	60	0	0	2	114.3	1.223	0.788	O.P.
98	70	0	0	30	172.44	1.174	0.734	O.P.
5	70	0	0	29.95	173.35	1.170	0.735	O.P.
6	70	0	0	15	168.13	1.224	0.828	O.P.
7	70	0	0	10	162.0	1.261	0.857	O.P.
9	70	0	0	6	150.25	1.293	0.828	O.P.
99	70	0	0	6	146.73	1.293	0.811	O.P.

* Overall Performance

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

a. Shakedown Tests - IGV Wake Rakes Installed (Continued)

Reading Number	Corrected Speed % Design	IGV Setting Deg	Stator Setting Deg	Throttle Valve Setting	Stg Total Corrected Weight Flow W/8/8-Lb/Sec	Stage Total Pressure Ratio	Stage Adiabatic Efficiency	Type Point
8	70	0	0	2.5	135.31	1.314	0.7816	O.P.
97	70	20	4	30	153.3	1.1315	0.7407	O.P.
96	70	40	8	30	132.1	1.1316	0.7217	O.P.
10	80	0	0	30	191.89	1.214	0.683	O.P.
100	80	0	0	30	190.8	1.222	0.685	O.P.
107	80	0	0	15	188.49	1.288	0.795	O.P.
101	80	20	4	30	171.2	1.1756	0.7160	O.P.
102	80	40	8	30	145.1	1.1288	0.7113	O.P.
11	90	0	0	30	209.4	1.2745	0.645	O.P.
105	90	0	0	30	208.39	1.278	0.645	O.P.
16	90	0	0	15	207.32	1.3705	0.7747	O.P.
104	90	20	4	30	186.0	1.2105	0.6597	O.P.
128	90	20	4	10	180.6	1.3748	0.8449	O.P.
103	90	40	8	30	158.1	1.1566	0.7053	O.P.
129	90	40	8	10	150.7	1.2786	0.7905	O.P.
12	100	0	0	29.95	224.72	1.3407	0.6261	O.P.
13	100	0	0	15	225.72	1.4524	0.7611	O.P.
106	100	0	0	15	224.73	1.481	0.769	O.P.
14	100	0	-5.6	15	225.39	1.4527	0.7674	O.P.
15	100	0	+5	15	224.96	1.471	0.7251	O.P.

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

a. Shakedown Tests - IGV Wake Rake Installed (Concluded)

Reading Number	Corrected Speed % Design	IGV Setting Deg	Stator Setting Deg	Throttle Valve Setting	Stg Inlet Corrected Weight Flow W/6/b-Lb/Sec	Stage Total Pressure Ratio	Stage Adiabatic Efficiency	Type Point
112	100	0.5	0	30	223.6	1.3474	0.6351	O.P.
113	100	1.0	0	30	222.8	1.3435	0.6354	O.P.
114	100	1.5	0	30	223.4	1.3414	0.6378	O.P.
115	100	2.0	0	30	222.1	1.3394	0.6359	C.P.
116	100	2.5	0	30	222.5	1.3376	0.6394	O.P.
117	100	3.0	0	30	221.7	1.3369	0.6518	O.P.
118	100	3.5	0	30	221.0	1.3324	0.6442	O.P.
119	100	4.0	0	30	220.5	1.3289	0.6463	O.P.
120	100	4.5	0	30	219.6	1.3258	0.6474	O.P.
121	100	5.0	0	30	219.3	1.3212	0.6469	O.P.
122	100	15	4	30	205.5	1.2879	0.6132	O.P.
127	100	20	4	30	199.4	1.256	0.6142	O.P.
127	100	20	4	10	197.3	1.470	0.808	O.P.
123	100	25	4	30	191.2	1.2381	0.56	O.P.
124	100	30	4	30	184.2	1.2127	0.6387	O.P.
125	100	35	4	30	176.9	1.1951	0.6505	O.P.
128	100	40	8	30	167.7	1.1801	0.6242	O.P.
126	100	40	8	10	164.1	1.3468	0.7584	O.P.
111	110	0	0	15	234.17	1.549	0.728	O.P.
110	110	20	4	30	213.5	1.3277	0.6156	O.P.
109	110	40	8	30	175.3	1.2058	0.5746	O.P.

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

b. Shakedown Tests - IGV Wake Rakes Removed From Airstream

Reading Number	Corrected Speed % Design	IGV Setting Deg	Stator Setting Deg	Throttle Valve Setting	Stg Inlet Corrected Weight Flow $W/\delta/\delta\text{-Lb./Sec}$	Stage Total Pressure Ratio	Stage Adiabatic Efficiency	Type Point
18	50	0	0	15	118.2	1.115	0.845	O.P.
19	70	0	0	15	167.0	1.234	0.838	O.P.
40	70	0	0	10	159.48	1.270	0.851	O.P.
64	70	0	0	10	158.7	1.268	0.854	O.P.
55	70	20	0	10	141.89	1.212	0.847	O.P.
56	70	20	0	2.5	122.44	1.203	0.794	O.P.
54	70	20	4	10	142.18	1.214	0.850	O.P.
52	70	20	8	10	141.52	1.217	0.846	O.P.
51	70	20	8	2	122.68	1.278	0.814	O.P.
53	70	20	12	10	140.48	1.218	0.835	O.P.
50	70	25	8	2	119.58	1.266	0.815	O.P.
47	70	30	8	2	116.11	1.253	0.812	O.P.
46	70	35	8	2.5	117.6	1.236	0.807	O.P.
41	70	40	0	10	121.47	1.159	0.774	O.P.
44	70	40	0	4.5	110.68	1.190	0.715	O.P.
43	70	40	4	10	121.8	1.161	0.813	O.P.
42	70	40	8	10	122.28	1.165	0.827	O.P.
48	70	40	8	10	121.26	1.165	0.829	O.P.
63	70	40	8	10	121.52	1.166	0.833	O.P.
45	70	40	8	3	109.22	1.213	0.796	O.P.

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

b. Shakedown Tests - IGV Wake Rakes Removed From Airstream (Continued)

Reading Number	Corrected Speed % Design	IGV Setting Deg	Stator Setting Deg	Throttle Valve Setting	Stg Inlet Co. rected Weight Flow W/5/5-Lb/Sec	Stage Total Pressure Ratio	Stage Adiabatic Efficiency	Type Point
49	70	40	12	10	120.8	1.166	0.827	O.P.
20	80	0	0	15	188.8	1.305	0.821	O.P.
21	80	0	0	3.5	155.0	1.430	0.789	O.P.
57	80	20	8	10	160.47	1.289	0.854	O.P.
60	80	40	8	10	136.93	1.215	0.831	O.P.
22	90	0	0	15	208.7	1.393	0.789	O.P.
24	90	0	0	8.5	201.9	1.529	0.848	O.P.
23	90	0	0	5.5	189.2	1.583	0.824	O.P.
58	90	20	+8	10	180.28	1.378	0.848	O.P.
61	90	40	+8	10	152.08	1.272	0.824	O.P.
25	100	0	0	15	225.9	1.482	0.778	O.P.
26	100	0	0	10	225.0	1.617	0.830	O.P.
39	100	0	0	9	224.5	1.658	0.832	O.P.
28	100	0	0	8	222.4	1.697	0.840	O.P.
34	100	0	0	8	223.05	1.702	0.843	B.E.*
27	100	0	0	6.5	215.7	1.749	0.824	O.P.
29	100	0	-2	8	221.34	1.694	0.835	O.P.
30	100	0	-4	8	220.31	1.695	0.833	O.P.
31	100	0	+2	8	233.4	1.698	0.840	O.P.
32	100	0	+4	8	233.6	1.702	0.843	O.P.

* Blade Element Traverse

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

b. Shakedown Tests - IGV Wake Rakes Removed From Airstream (Concluded)

Reading Number	Corrected Speed % Design	IGV Setting Deg	Stator Setting Deg	Throttle Valve Setting	Stg Inlet Corrected Weight Flow W/5/6-Lb/Sec	Stage Total Pressure Ratio	Stage Adiabatic Efficiency	Type Point
33	100	0	+6	8	233.4	1.708	0.840	O.P.
59	100	20	+8	10	195.28	1.472	0.829	O.P.
62	100	40	+8	10	165.53	1.329	0.806	O.P.
65	100	40	+8	10	164.1	1.328	0.801	B.E.
66	100	40	+8	10	164.2	1.327	0.812	O.P.
35	110	0	0	15	234.49	1.554	0.737	O.P.
36	110	0	0	10	235.01	1.704	0.770	O.P.
38	110	0	0	8	234.06	1.789	0.779	O.P.
37	110	0	0	7	233.98	1.843	0.789	O.P.

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests

Corrected Speed = 50% Design, IGV: 0° Deg., Stator: 0° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/δ/δ-Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
67	B.E.*	30	126.4	1.091	0.785	1.0923	0.7964	1.1031	0.8861
73	O.P.**	30	127.6	1.091	0.809	1.0928	0.8208	1.1035	0.9121
68	B.E.	18	120.5	1.107	0.838	1.1079	0.8480	1.1159	0.9087
69	B.E.	15	118.1	1.113	0.842	1.1145	0.8513	1.1211	0.8986
130	O.P.	15	118.01	1.1138	0.7977	1.1151	0.8062	1.1218	0.8514
164	O.P.	15	118.25	1.1146	0.8253	1.1159	0.9339	1.1221	0.8766
70	B.E.	5	102.2	1.142	0.844	1.1425	0.8491	1.1467	0.8728
72	B.E.	2	93.6	1.151	0.797	1.1514	0.8006	1.1572	0.8299
150	O.P.	2	94.15	1.1512	0.7826	1.1520	0.7864	1.1582	0.8168

* Blade Element Traverse

** Overall Performance

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 70% Design, IGV: 0° Deg., Stator: 0° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/δ -Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
74	B.E.	30	173.7	1.177	0.766	1.1796	0.7792	1.2038	0.8773
79	O.P.	30	172.2	1.175	0.740	---	---	---	---
75	B.E.	15	167.2	1.231	0.839	1.2344	0.8490	1.2485	0.8962
76	D.E.	10	159.2	1.268	0.848	1.2703	0.8557	1.2809	0.8866
77	B.E.	6	147.9	1.296	0.835	1.2985	0.8411	1.3090	0.8680
78	B.E.	2.5	133.3	1.313	0.785	1.3146	0.7892	1.3272	0.8178
155	O.P.	2.5	132.8	1.3148	0.7757	1.3167	0.7800	1.3298	0.8092

Tabel VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 80% Design, IGV: 0° Deg., Stator: 0° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\delta}/\delta$ -Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
80	B.E.	30	191.2	1.224	0.710	1.2284	0.7226	1.2649	0.8290
85	O.P.	30	191.28	1.226	0.708	---	---	---	---
81	B.E.	15	187.75	1.305	0.810	1.3096	0.8205	1.3266	0.8612
82	B.E.	10	182.30	1.368	0.857	1.3725	0.8660	1.3889	0.8999
83	B.E.	6	170.51	1.418	0.840	1.4219	0.8450	1.4369	0.8714
84	B.E.	3.5	154.87	1.429	0.788	1.4322	0.7930	1.4509	0.8232
156	O.P.	3.5	154.94	1.4365	0.7794	1.4395	0.7841	1.4592	0.8150

Tabel VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 90% Design, IGV: 0° Deg., Stator: 0° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/g/s Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
132	B.E.	30	209.21	1.2807	0.635	1.2863	0.6467	1.3493	0.7748
133	B.E.	15	208.47	1.3933	0.780	1.3993	0.7907	1.4231	0.8324
136	B.E.	10	204.3	1.495	0.834	1.5010	0.8428	1.5205	0.8713
135	B.E.	8	199.4	1.5434	0.8345	1.5494	0.8424	1.5687	0.8678
134	B.E.	5.5	188.37	1.5878	0.8182	1.5931	0.8245	1.6184	0.8543
161	O.P.	5.5	187.65	1.5923	0.8183	---	---	---	---

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 100% Design, IGV: 0° Deg., Stator: 0° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\delta}$ Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
137	B.E.	15	224.3	1.480	0.771	1.4882	0.7816	1.5189	0.8243
165	O.P.	15	225.48	1.4909	0.7733	1.4989	0.7843	1.5274	0.8231
138	B.E.	10.5	225.5	1.601	0.826	1.6094	0.8360	1.6331	0.8635
139	B.E.	9	223.8	1.655	0.834	1.6641	0.8430	1.6881	0.8685
148	C.T.*	9	224.3	1.670	0.838	---	---	---	---
140	B.E.	7.5	220.7	1.720	0.8336	1.7287	0.8420	1.7553	0.8675
141	B.E.	6.5	215.95	1.752	0.8264	1.7604	0.8340	1.7937	0.8641
149	C.T.*	6.5	215.56	1.759	0.8197	---	---	---	---
162	O.P.	6.5	215.48	1.7612	0.8192	1.7695	0.8266	1.8042	0.8572

* Continuous Traverse

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 110% Design, IGV: 0° Deg., Stator: 0° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/δ/δ-Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
142	B.E.	15	234.74	1.5542	0.7328	1.5637	0.7435	1.5988	0.7830
143	B.E.	11	234.24	1.670	0.7607	1.6801	0.7704	1.7134	0.8018
144	B.E.	9	234.08	1.7463	0.7721	1.7568	0.7811	1.7930	0.8118
145	B.E.	8	234.24	1.7958	0.7825	1.8066	0.7913	1.8452	0.8221
147	C.T.*	8	233.57	1.7994	0.7791	---	---	---	---
146	B.E.	7	233.65	1.8563	0.7931	1.8674	0.8014	1.9091	0.8325
169	O.P.	6.5	232.76	1.9054	0.7906	1.9167	0.7985	1.9663	0.8330

* Continuous Traverse

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 50% Design, IGV: 20° Deg., Stator: 4° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\delta}$ -Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
131	B.E.	30	113.09	1.0727	0.8006	1.0742	0.8169	1.0822	0.9028
173	B.E.	15	106.3	1.094	0.871	1.0952	0.8827	1.1008	0.9334
172	B.E.	9	100.1	1.110	0.874	1.1113	0.8832	1.1171	0.9273
171	B.E.	5	94.0	1.123	0.859	1.1243	0.8663	1.1294	0.9000
151	O.P.	2	86.68	1.1331	0.8023	1.1340	0.8075	1.1412	0.8486
170	B.E.	2	87.2	1.135	0.806	1.1354	0.8113	1.1429	0.8542

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 70% Design, IGV: 20° Deg., Stator: 4° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\theta}/\delta$ Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
184	B.E.	30	154.2	1.138	0.778	1.1411	0.7971	1.1605	0.9011
188	B.E.	13	146.9	1.196	0.859	1.1995	0.8724	1.2117	0.9224
187	B.E.	7.5	138.6	1.235	0.851	1.2379	0.8602	1.2507	0.9027
186	B.E.	4.5	132.2	1.259	0.836	1.2620	0.8438	1.2743	0.8804
154	O.P.	2.5	123.97	1.2728	0.8091	1.2751	0.8152	1.2900	0.8557
185	B.E.	2.5	123.5	1.273	0.813	1.2754	0.8195	1.2912	0.8627

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 80% Speed, IGV: 20° Deg., Stator: 4° Deg.

Running Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\theta}/\delta$ Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
189	B.E.	30	172.5	1.175	0.743	1.1794	0.7629	1.2055	0.8667
193	B.E.	11	163.2	1.278	0.857	1.2821	0.8700	1.2995	0.9191
192	B.E.	7	157.1	1.326	0.851	1.3306	0.8612	1.3469	0.8997
191	B.E.	4.5	149.2	1.358	0.828	1.3616	0.8357	1.3803	0.8743
190	B.E.	3	142.6	1.372	0.807	1.3759	0.8134	1.3972	0.8544
157	O.P.	3	143.34	1.372	0.8073	---	---	---	---

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 90% Design, IGV: 20° Deg., Stator: 4° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $\frac{W}{\sqrt{\delta}}/\text{Sec}$	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
200	B.E.	30	185.6	1.209	0.665	1.2155	0.6834	1.2588	0.8101
204	B.E.	11.5	182.4	1.347	0.825	1.3536	0.8388	1.3749	0.8841
203	B.E.	7.5	176.1	1.425	0.848	1.4308	0.8594	1.4518	0.8964
202	B.E.	6	171.8	1.456	0.831	1.4620	0.8402	1.4864	0.8789
201	B.E.	5	168.2	1.475	0.826	1.4807	0.8345	1.5071	0.8743
160	O.P.	4.5	166.2	1.4831	0.8215	1.4887	0.8297	1.5186	0.8737

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 100% Design, IGV: 20° Deg., Stator: 4° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\theta}$ -Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
205	B.E.	30	198.7	1.254	0.623	1.2615	0.6405	1.3202	0.7711
209	B.E.	14	199.0	1.362	0.771	1.3706	0.7873	1.4034	0.8493
208	B.E.	11	197.4	1.443	0.823	1.4515	0.8279	1.4781	0.8707
207	B.E.	8.5	195.4	1.519	0.836	1.5283	0.8487	1.5580	0.8896
206	B.E.	6.55	190.7	1.584	0.834	1.5925	0.8444	1.6288	0.8882
163	C.P.	6	190.86	1.6011	0.8279	1.6098	0.8381	1.6486	0.8831

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 110% Design, IGV: 20° Deg., Stator: 4° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/δ -Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
210	B.E.	15	212.9	1.434	0.749	1.4449	0.7656	1.4835	0.8236
213	O.P.	13	213.7	1.479	0.774	1.4907	0.7898	1.5254	0.8381
212	B.E.	11	212.1	1.541	0.800	1.5527	0.8147	1.5858	0.8565
211	B.E.	9.5	211.6	1.593	0.812	1.6053	0.8261	1.6403	0.8664
168	O.P.	8.5	213.03	1.6434	0.820	1.6559	0.8334	1.6910	0.8707

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 50% Design, IGV: 40° Deg., Stator: 8° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\delta}$ Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
174	B.E.	30	96.6	1.055	0.831	1.0577	0.8762	1.0635	0.9637
178	B.E.	16	91.6	1.071	0.846	1.0735	0.8780	1.0782	0.9338
177	B.E.	10	88.5	1.085	0.845	1.0876	0.8695	1.0932	0.9237
176	B.E.	6	82.2	1.098	0.843	1.1004	0.8621	1.1077	0.9224
152	O.P.	2.5	77.06	1.109	0.7957	1.1110	0.8098	1.1215	0.8837
175	B.E.	2.5	77.6	1.109	0.800	1.1112	0.8143	1.1219	0.8900

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 70% Design, IGV: 40° Deg., Stator: 8° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow $W/\sqrt{\theta}/\delta$ Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
179	B.E.	30	131.4	1.101	0.790	1.1071	0.8379	1.1185	0.9234
183	B.E.	16	126.6	1.136	0.838	1.1421	0.8732	1.1538	0.9415
182	B.E.	10	120.1	1.168	0.843	1.1736	0.8691	1.1868	0.9315
181	B.E.	5	113.3	1.203	0.817	1.2081	0.8356	1.2265	0.9040
153	O.P.	3	109.09	1.2167	0.7961	1.2213	0.8118	1.2439	0.8885
180	B.E.	3	109.5	1.217	0.804	1.2218	0.8202	1.2438	0.8957

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 80% Design, IGV: 40° Deg., Stator: 8° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/5/6-Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
194	B.E.	30	147.1	1.127	0.771	1.1361	0.8229	1.1523	0.9162
196	O.P.	30	146.1	1.126	0.764	1.1348	0.8144	1.1505	0.9047
199	B.E.	15.5	141.0	1.176	0.800	1.1840	0.8362	1.2001	0.9047
198	B.E.	11	137.9	1.209	0.830	1.2170	0.8600	1.2344	0.9239
197	B.E.	7.5	132.2	1.238	0.811	1.2456	0.8346	1.2668	0.9005
158	O.P.	4.5	127.12	1.274	0.8042	1.2809	0.8231	1.3084	0.8963
195	B.E.	4.5	129.5	1.274	0.809	1.2811	0.8278	1.3089	0.9026

Table VII. Overall Performance Based on Fixed Instrumentation (Continued).

c. Overall Performance Tests (Continued)

Corrected Speed = 90% Design, IGV: 40° Deg., Stator: 8° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/δ -Lbs/Sec	STAGE		ROTOR & STATOR		ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Adiabatic Efficiency
220	B.E.	15	156.1	1.225	0.811	1.2372	0.8527	1.2578	0.9210
223	B.E.	11	151.2	1.263	0.815	1.2747	0.8478	1.2974	0.9120
222	B.E.	8.5	149.4	1.295	0.813	1.3055	0.8408	1.3320	0.9069
159	O.P.	6.5	147.32	1.3267	0.8146	1.3374	0.8382	1.3708	0.9131
221	B.E.	6.5	147.8	1.330	0.817	1.3413	0.8413	1.3728	0.9110

Table VII. Overall Performance Based on Fixed Instrumentation (Concluded).

c. Overall Performance Tests (Concluded).

Corrected Speed = 100% Design, IGV: 40° Deg., Stator: 8° Deg.

Reading Number	Type Point	Throttle Valve Setting	Stage Inlet Corrected Weight Flow W/δ/δ-Lbs/Sec	STAGE			ROTOR & STATOR			ROTOR	
				Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Total Pressure Ratio	Adiabatic Efficiency	Total Pressure Ratio	Total Pressure Ratio	Adiabatic Efficiency
225	B.E.	30	167.7	1.178	0.653	1.1946	1.1946	0.7087	1.2262	0.8158	
217	B.E.	15	167.3	1.265	0.762	1.2819	1.2819	0.8076	1.3095	0.8794	
219	B.E.	12	166.6	1.306	0.789	1.3233	1.3233	0.8300	1.3516	0.8953	
224	B.E.	10	164.0	1.333	0.796	1.3490	1.3490	0.8315	1.3812	0.8999	
166	O.P.	8	161.82	1.3796	0.8052	1.3923	1.3923	0.8349	1.4349	0.9151	
218	B.E.	8	163.7	1.377	0.801	1.3940	1.3940	0.8328	1.4313	0.9026	
Corrected Speed = 110% Design, IGV: 40° Deg., Stator: 8° Deg.											
214	B.E.	15	176.4	1.302	0.719	1.3247	1.3247	0.7694	1.3648	0.8548	
216	B.E.	12	177.3	1.349	0.755	1.3728	1.3728	0.8013	1.4137	0.8793	
167	O.P.	10	174.8	1.3789	0.7604	1.4015	1.4015	0.8007	1.4457	0.8783	
215	B.E.	10	176.7	1.387	0.764	1.4112	1.4112	0.8070	1.4558	0.8840	

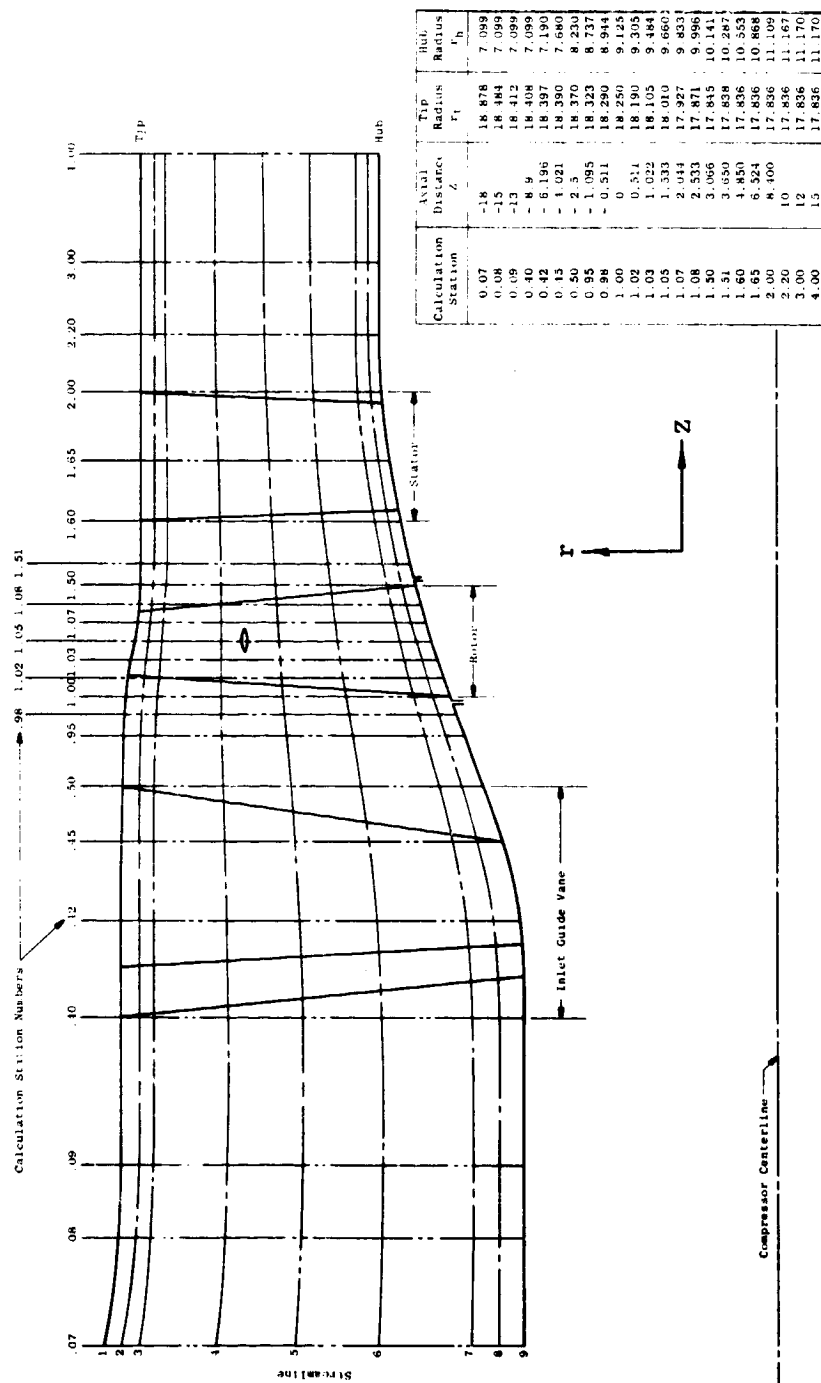
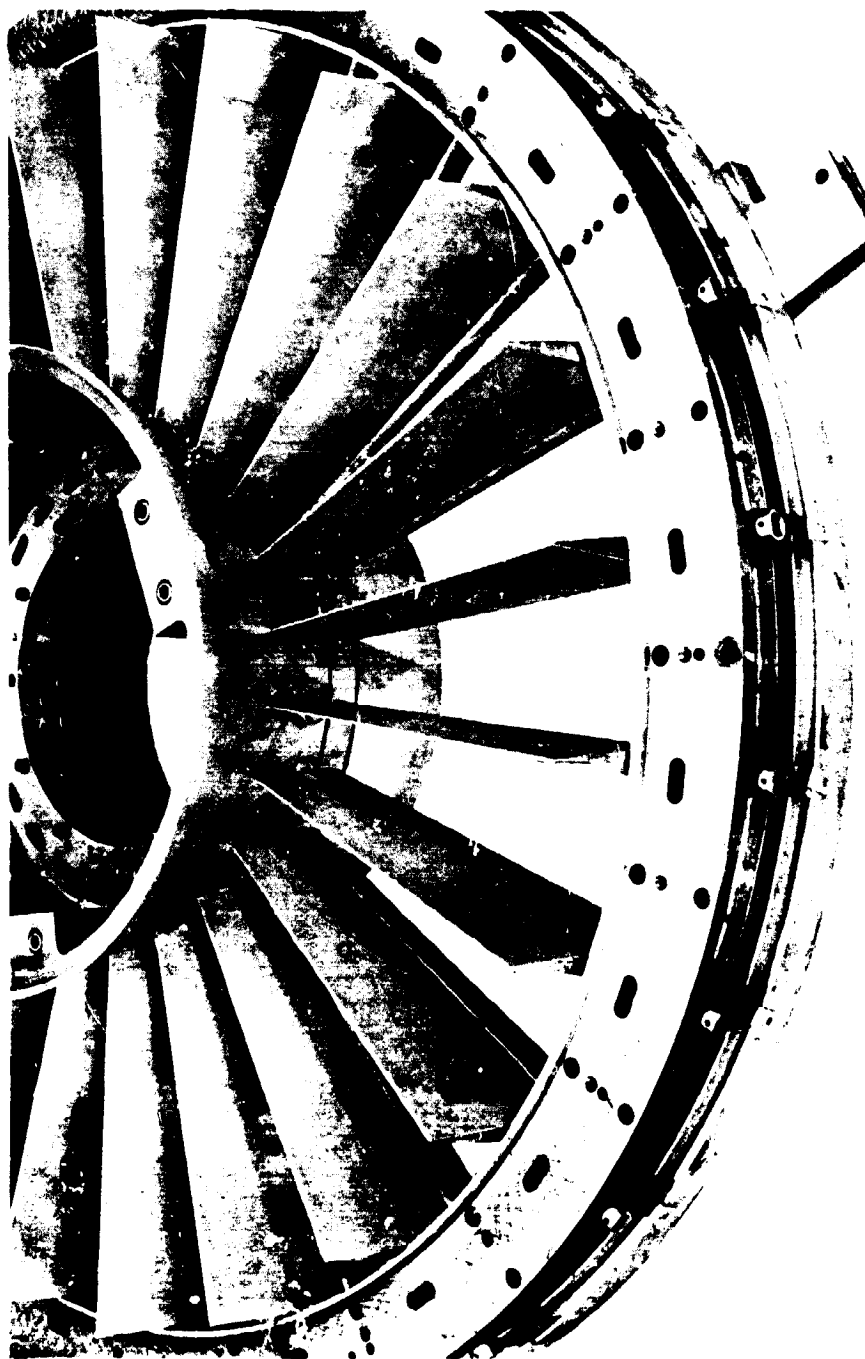
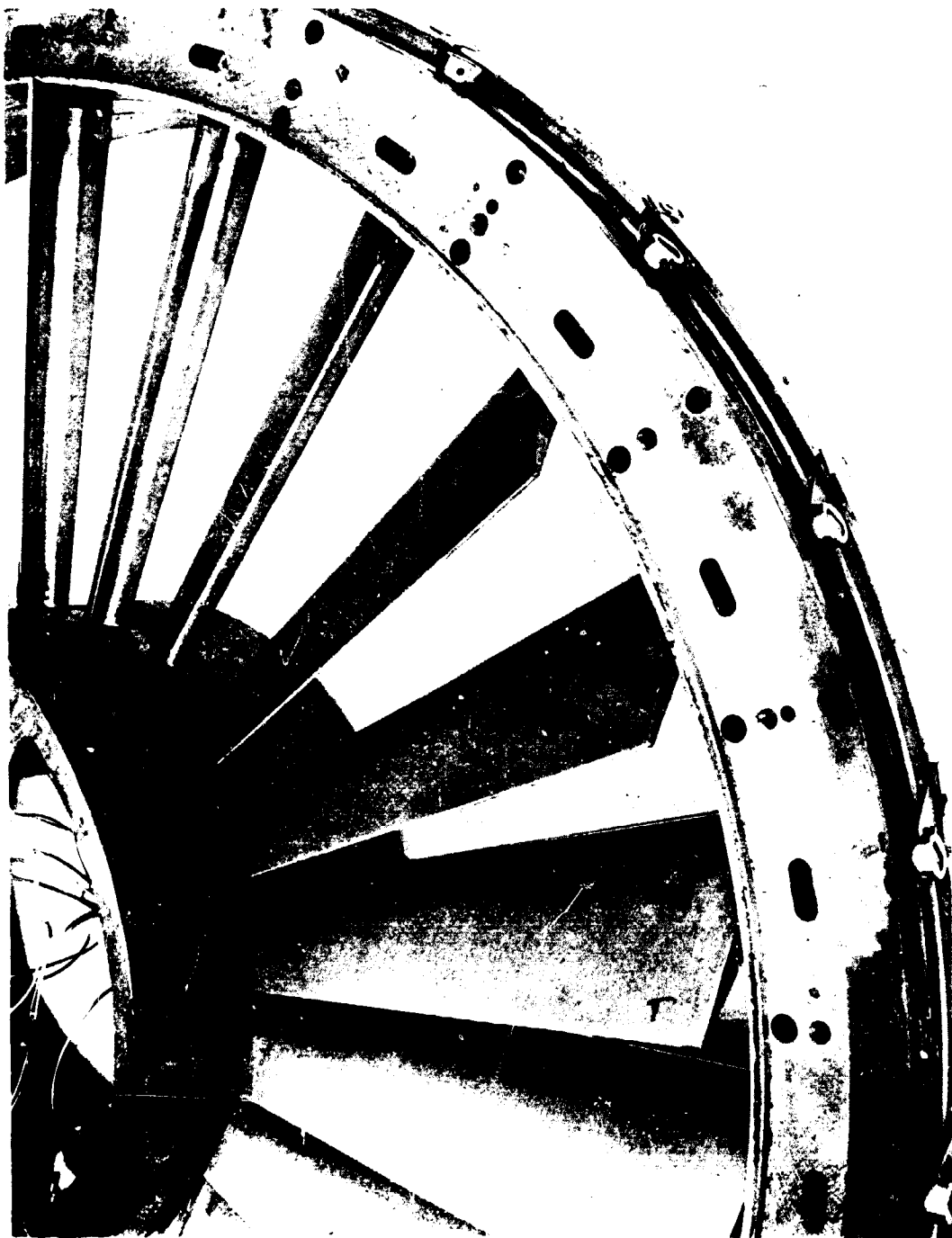


Figure 1. Compressor Flowpath.



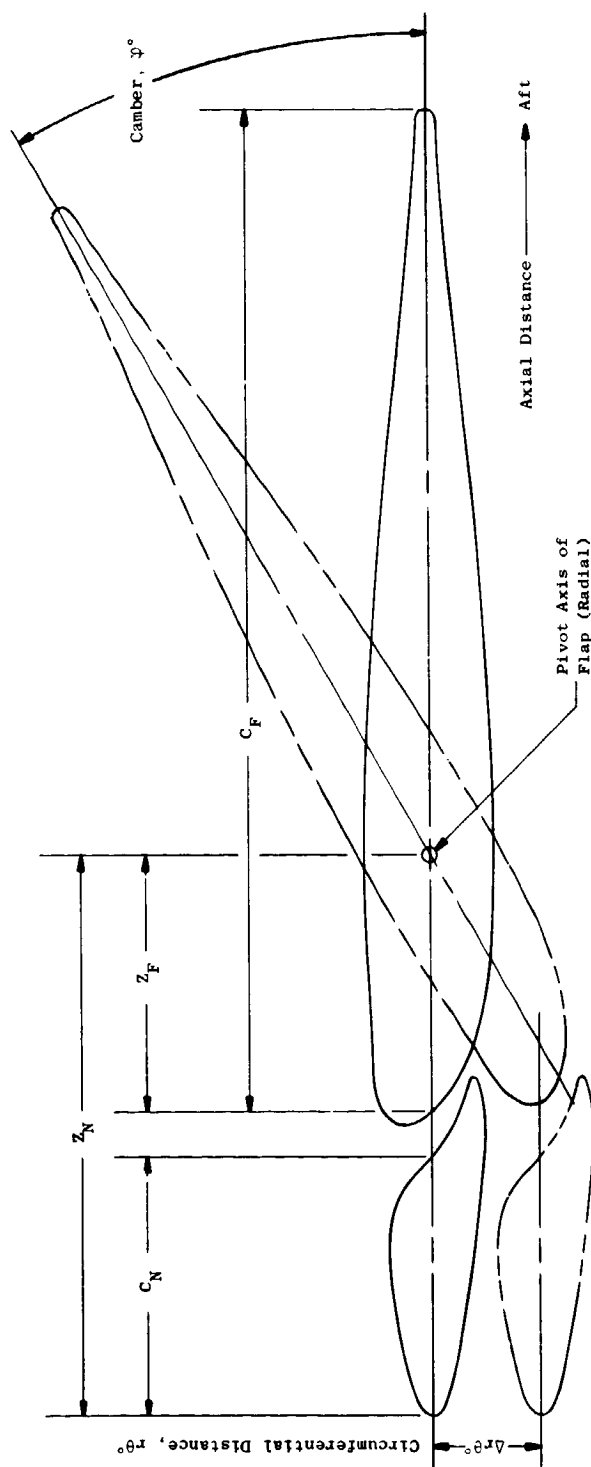
(a) Photograph at 0° (Nominal) Setting Angle

Figure 2. Views of Variable Camber Inlet Guide Vane.



(b) Photograph at 40° Setting Angle

Figure 2. Views of Variable Camber Inlet Guide Vane (Continued).



(c) Pitchline Section at 0° and 30° Turning

Figure 2. Views of Variable Camber Inlet Guide Vane (Concluded).

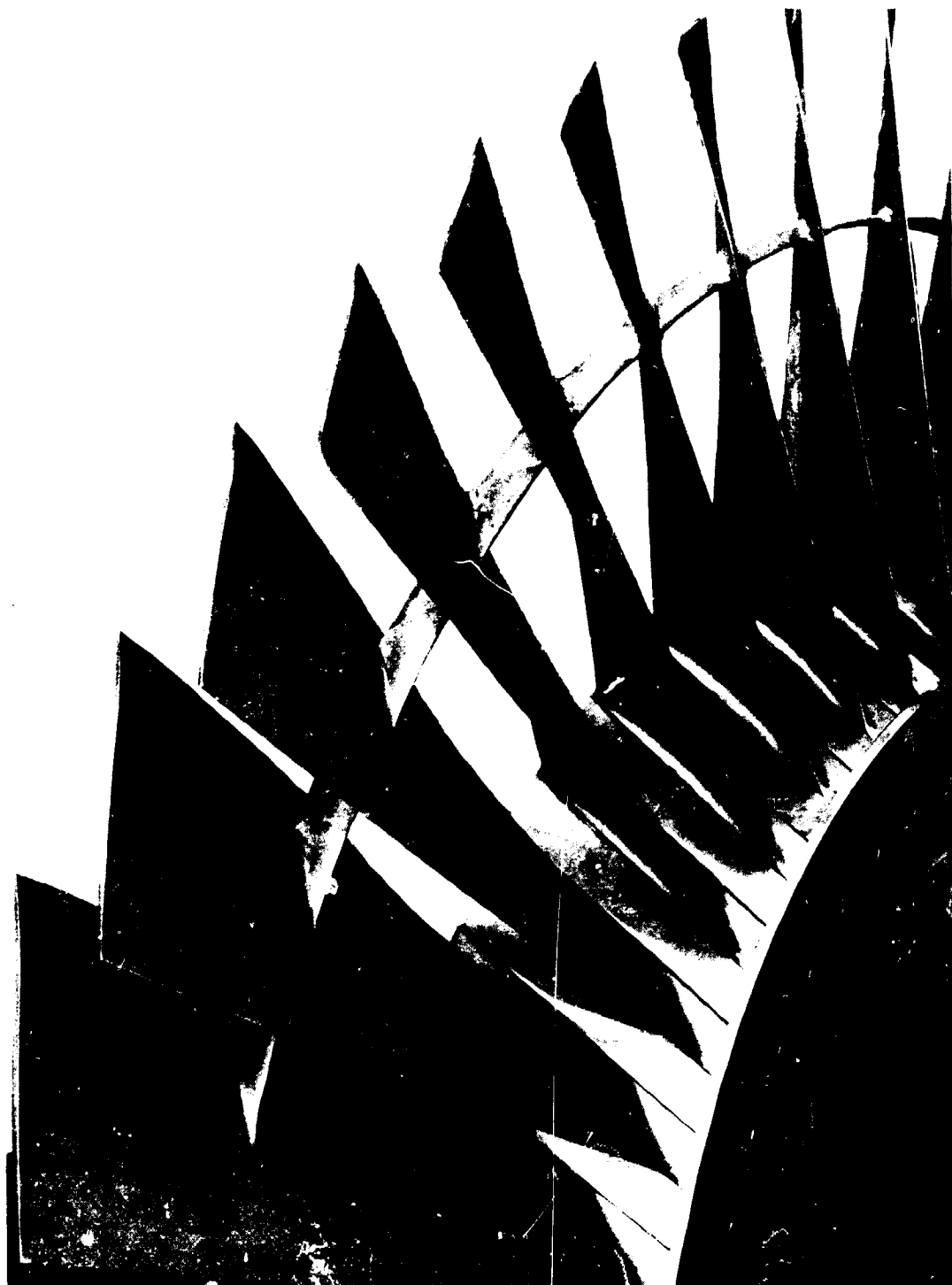


Figure 3. Photograph of Rotor.

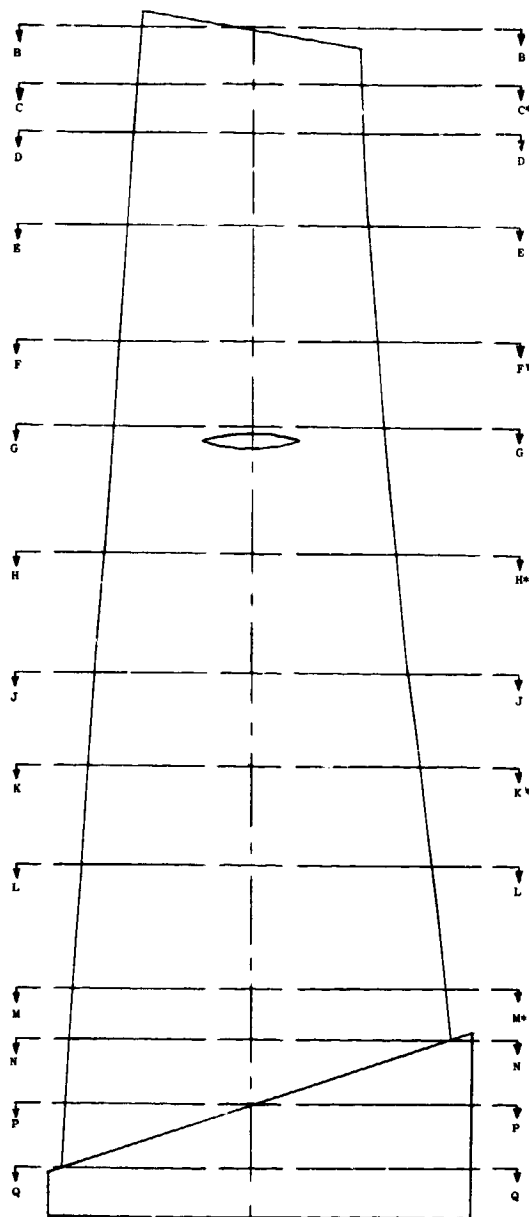


Figure 4. Meridional View of Rotor.
Probograph Inspection
Sections are Indicated by
Asterisks.

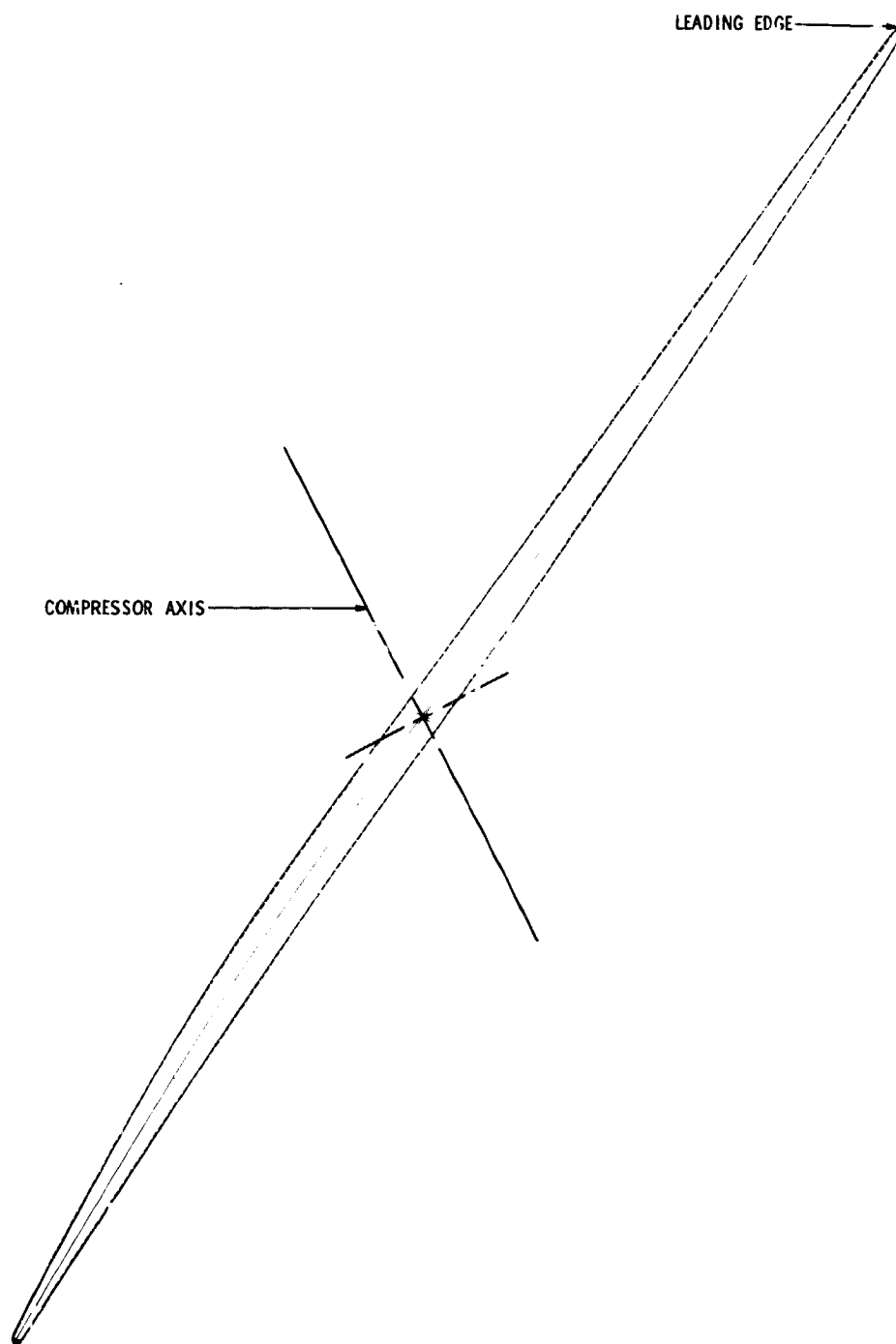


Figure 5 (a). Cylindrical Cut of Rotor Blade at Section C-C.
(The solid line represents design intent and
the dashed line represents the average of five
measured samples.)

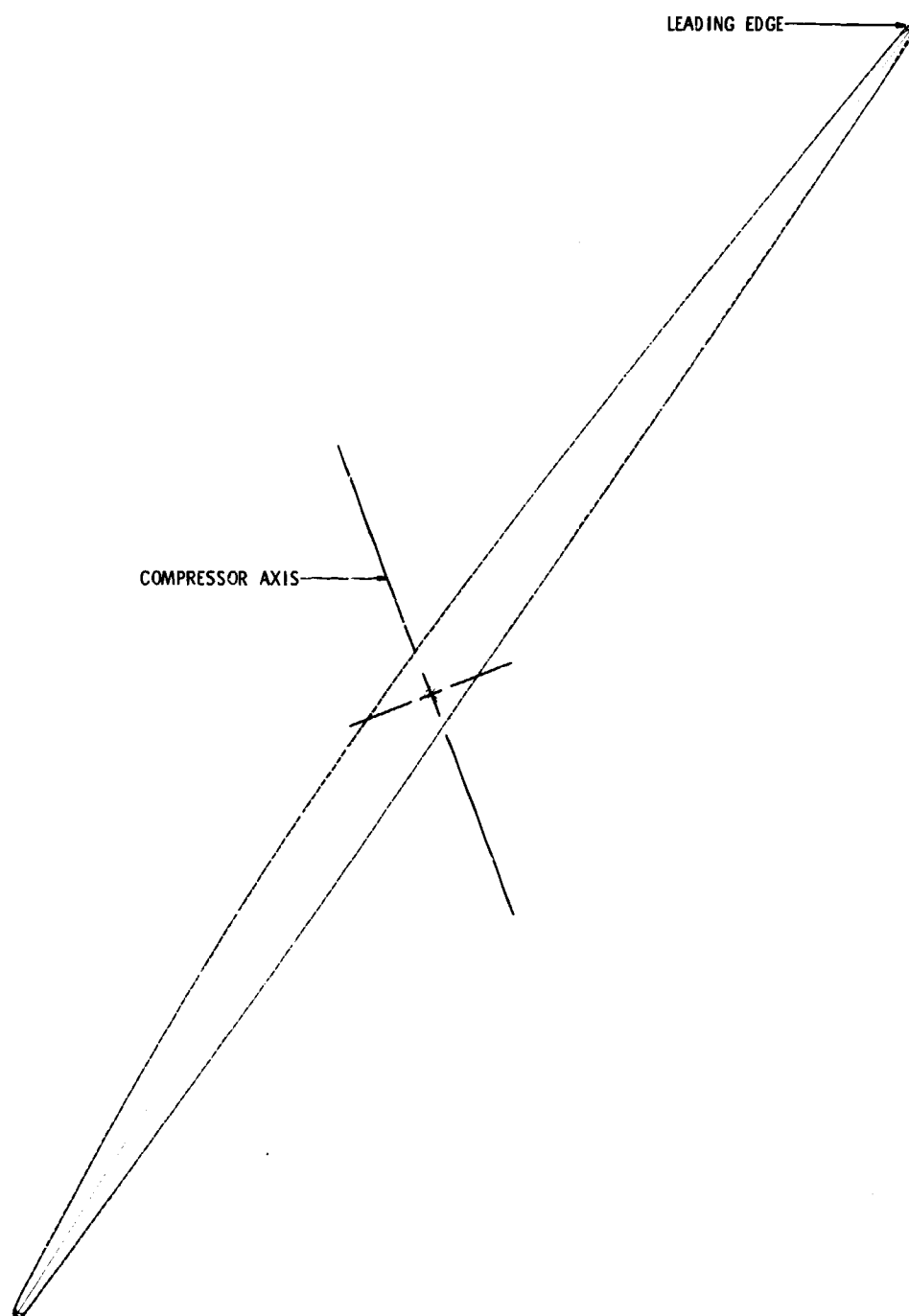


Figure 5 (b). Cylindrical Cut of Rotor Blade at Section F-F.
(The solid line represents design intent and
the dashed line represents the average of five
measured samples.)

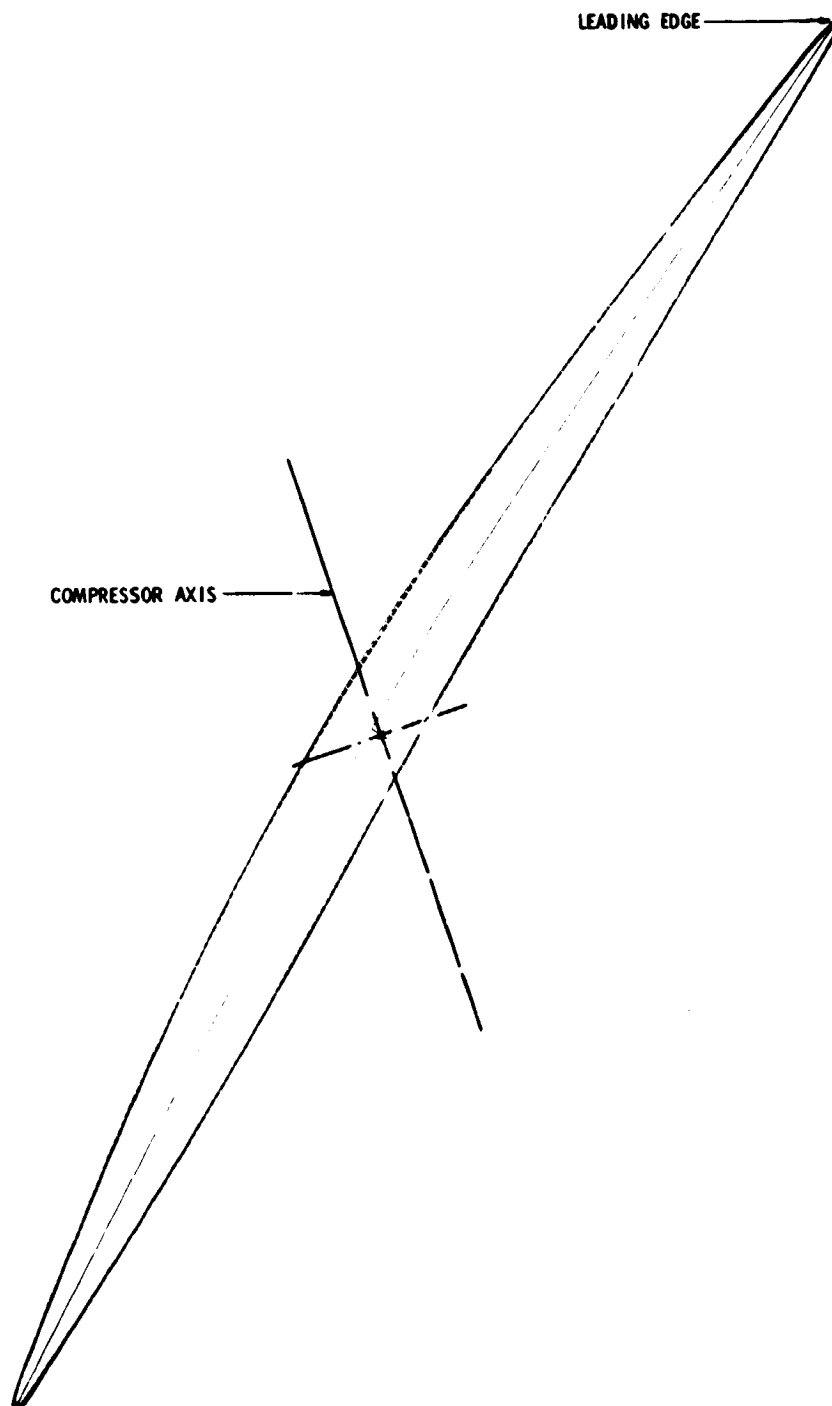


Figure 5 (c). Cylindrical Cut of Rotor Blade at Section H-H.
(The solid line represents design intent and
the dashed line represents the average of five
measured samples.)

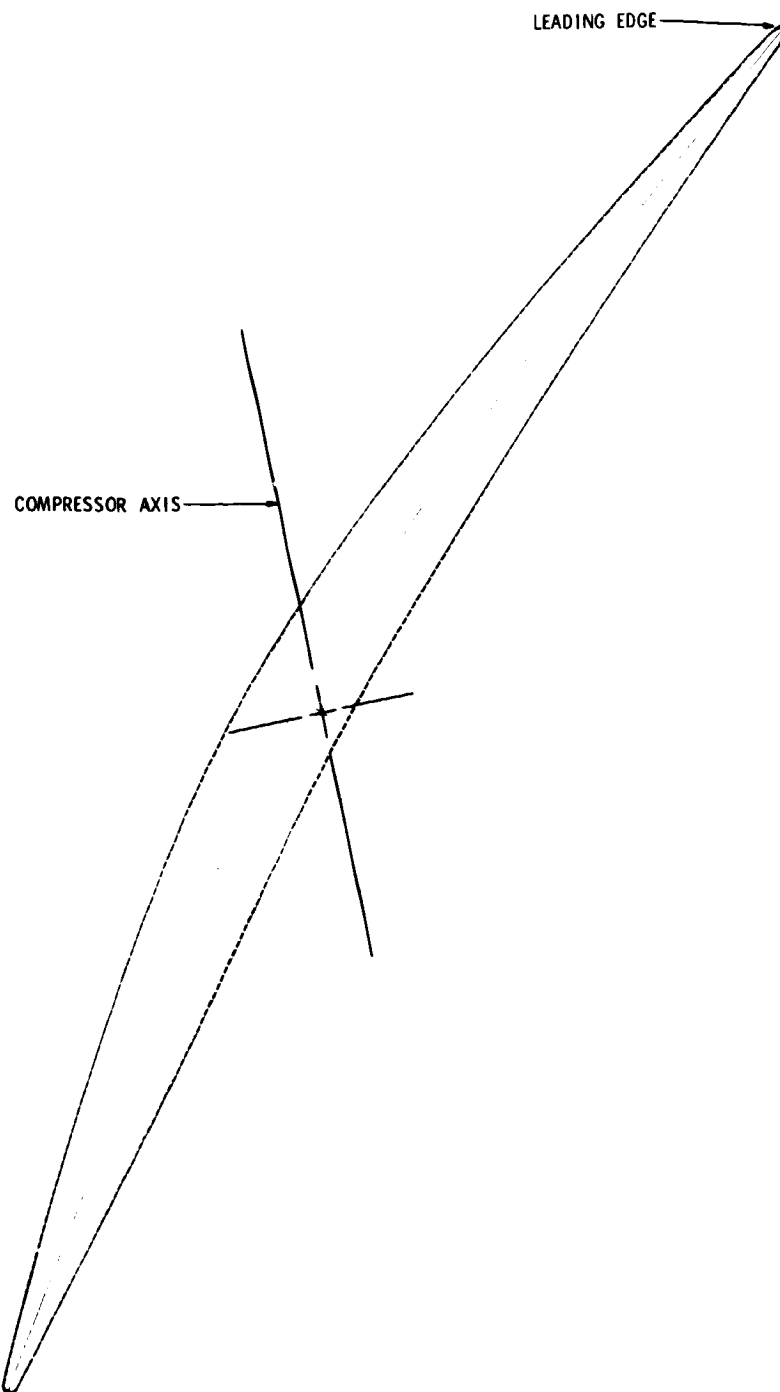


Figure 5 (d). Cylindrical Cut of Rotor Blade at Section K-K.
(The solid line represents design intent and
the dashed line represents the average of five
measured samples.)

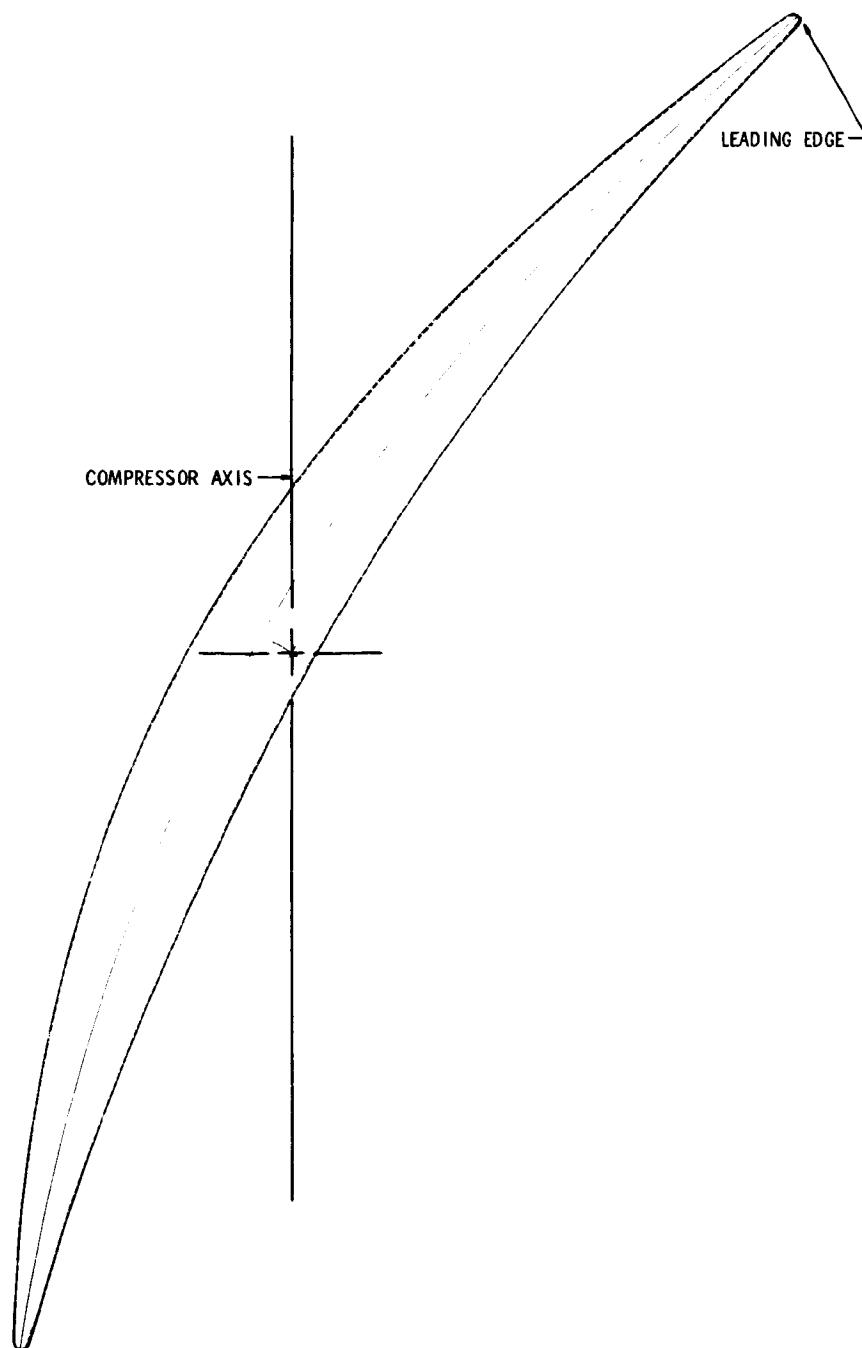


Figure 5 (e). Cylindrical Cut of Rotor Blade at Section M-M.
(The solid line represents design intent and
the dashed line represents the average of five
measured samples.)

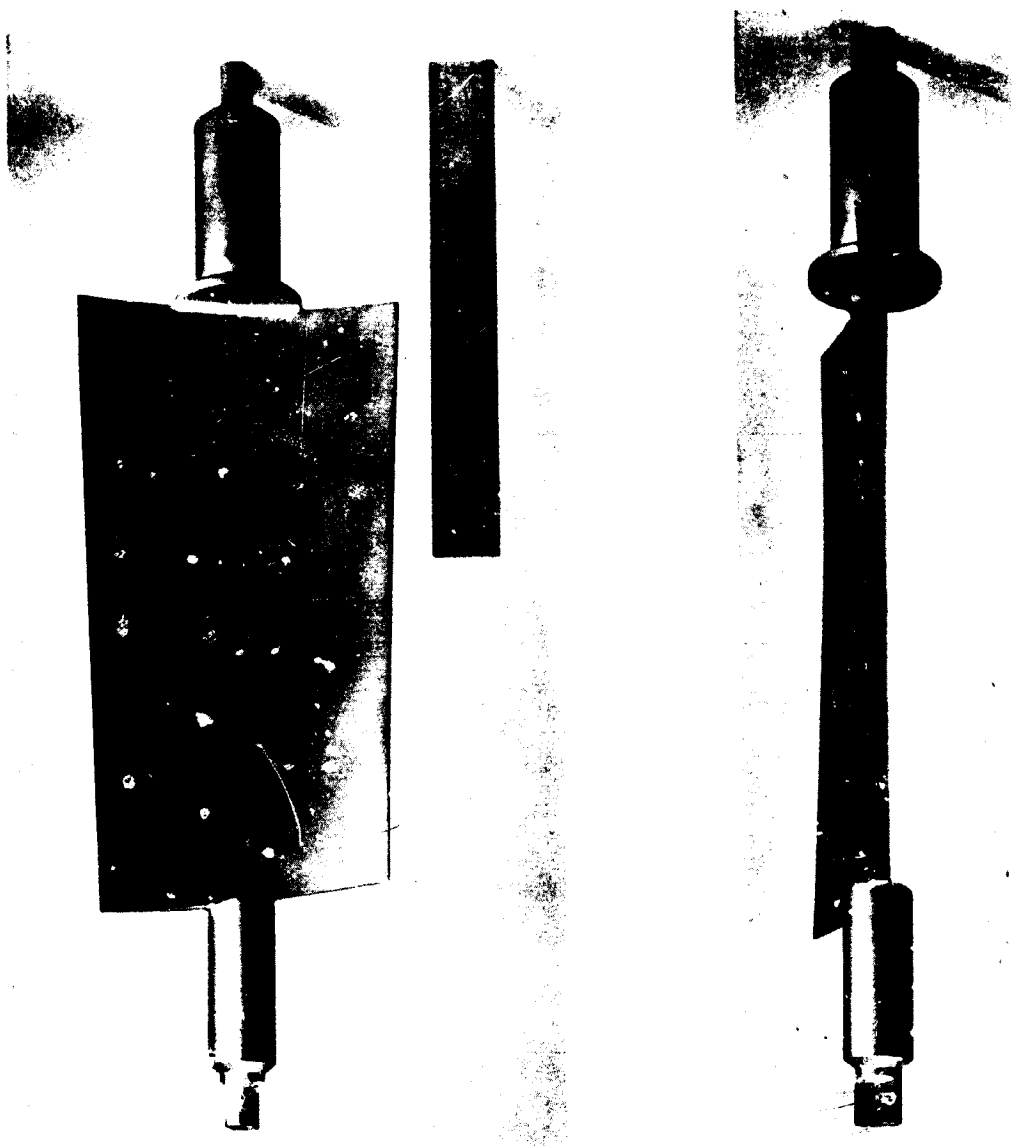


Figure 6. Photographs of A Variable-Stagger Stator Vane.

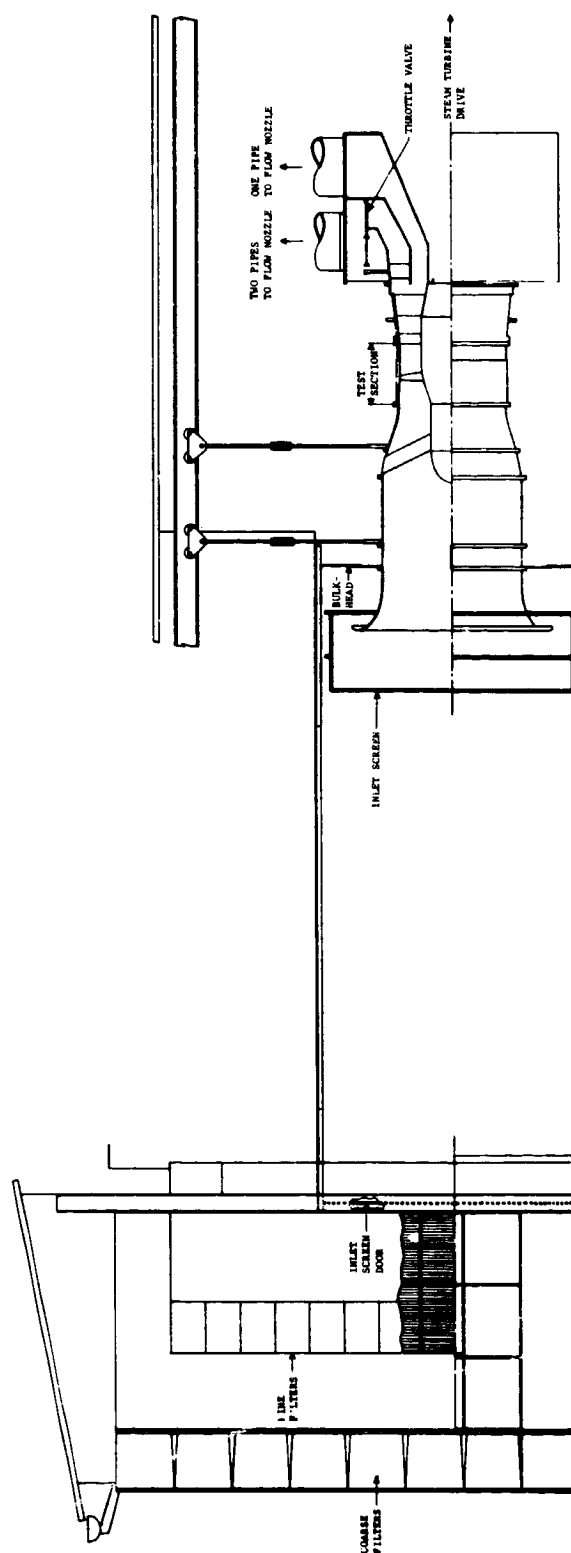


Figure 7. Schematic Diagram of House Compressor Test Facility.

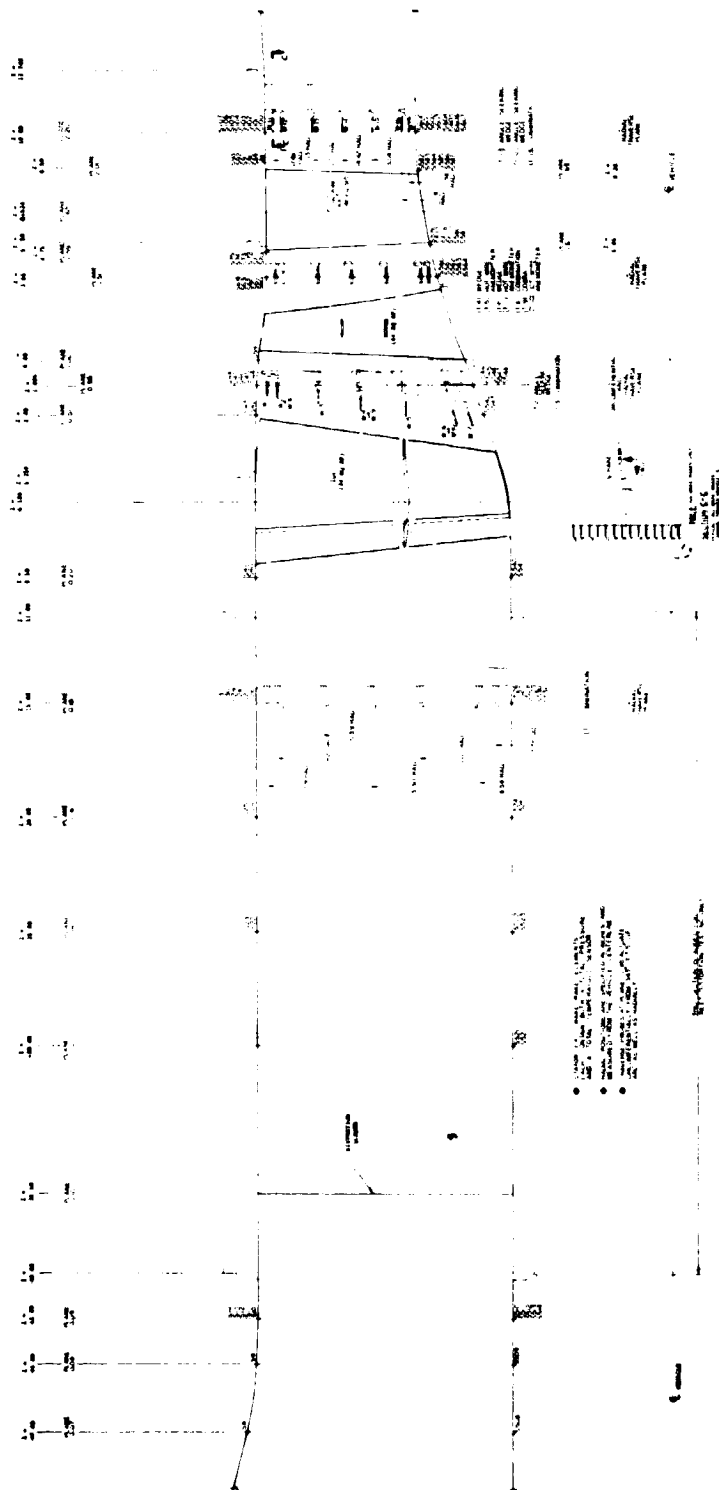
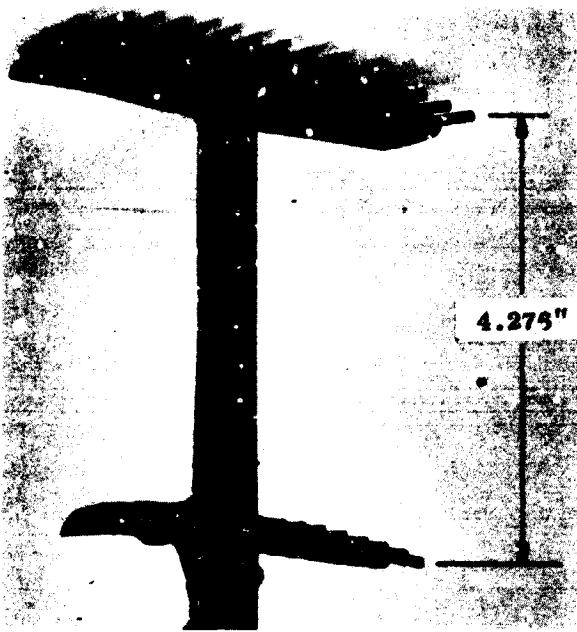
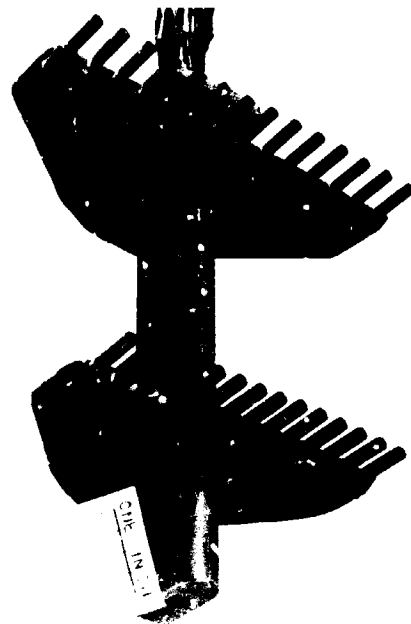


Figure 8. Meridional View Showing Location of Instrumentation.

Figure 9. Development Showing Circumferential Location of Instrumentation.

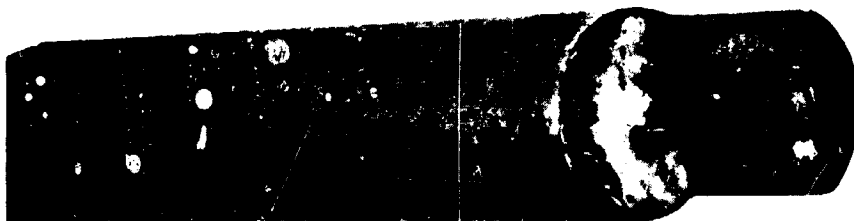


(a) Fixed IGV Total Pressure Wake Rake
Located at Plane 0.95.

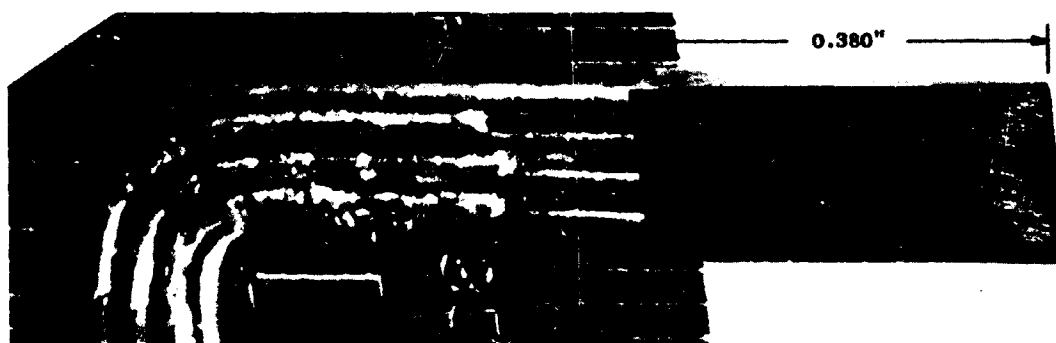


(b) Fixed Discharge Total Pressure
and Total Temperature Wake Rake
Located at Plane 2.20.

Figure 10. Photographs of Fixed and Traverse Instrumentation Used in Undistorted Inlet Flow Testing.

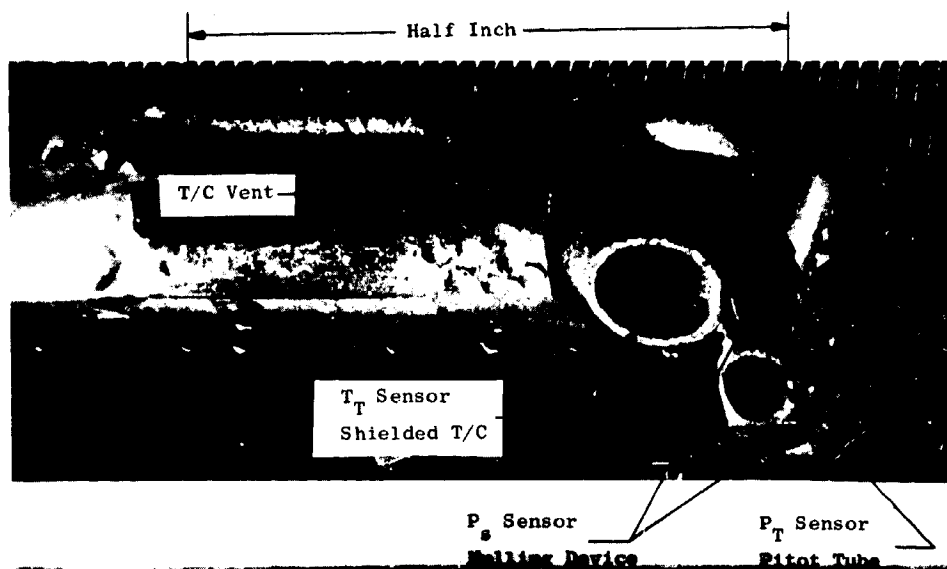


(c) Shielded Hot Wire Traverse Probe Located at Plane 1.51.

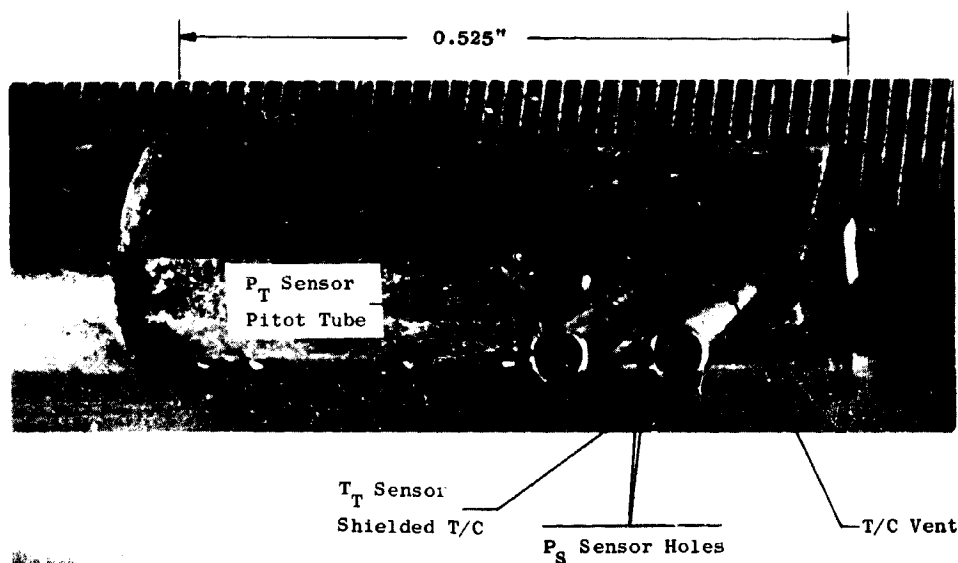


(d) Angle-Seeking Static Pressure Wedge Traverse Probe Located at Planes 0.95 and 2.20.

Figure 10. Photographs of Fixed and Traverse Instrumentation Used in Undistorted Inlet Flow Testing (Continued).



(e) Cobra Traverse Probe for Sensing Flow Angle, Total Pressure, and Total Temperature Located at Plane 1.51.



(f) Four-Parameter Combination Traverse Probe with Circumferential Traverse Capability Located at Plane 0.95.

Figure 10. Photographs of Fixed and Traverse Instrumentation Used in Undistorted Inlet Flow Testing (Concluded).

(Dashed lines with arrows and inset formulas indicate calculation sequence for sample case.)

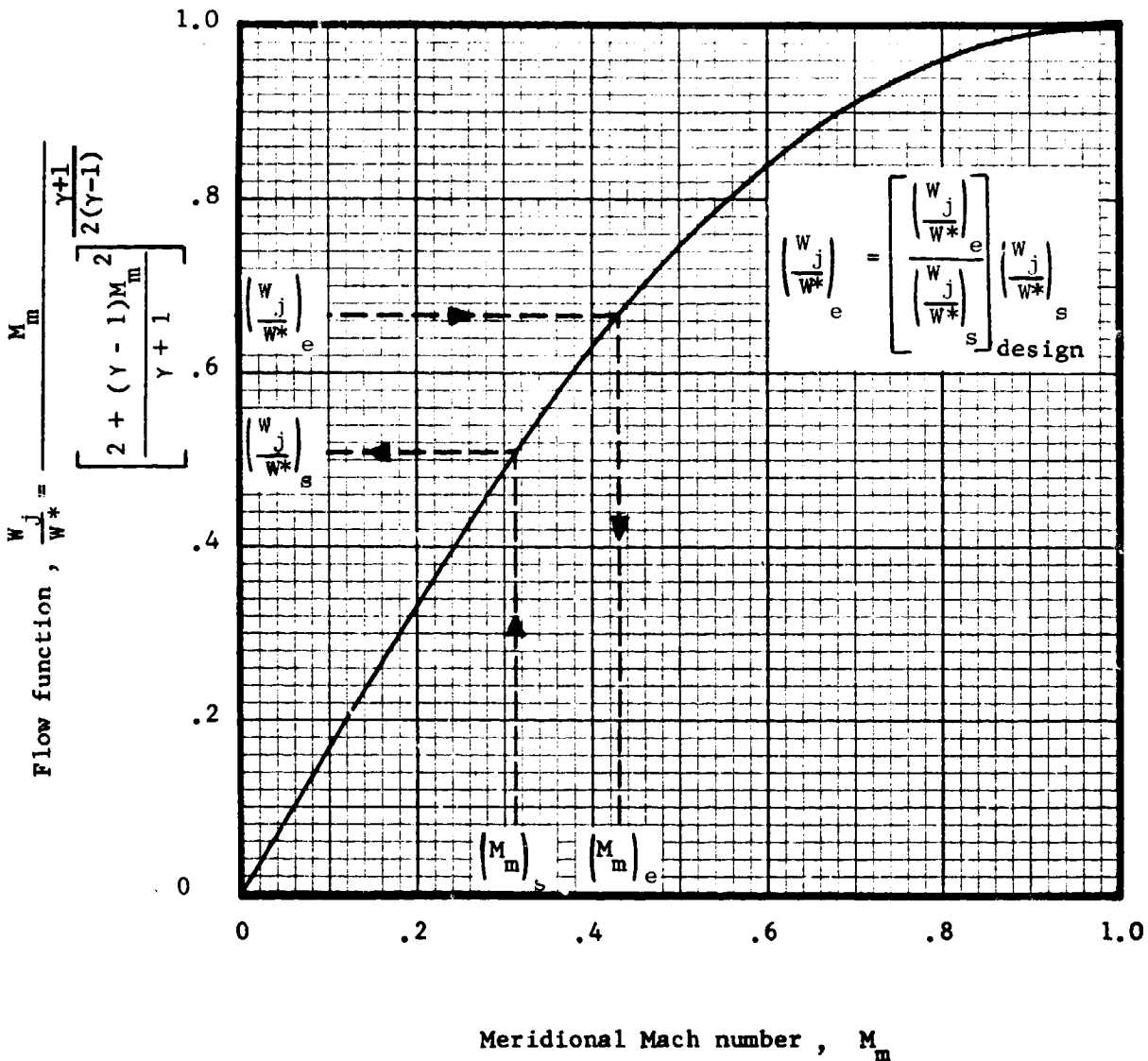
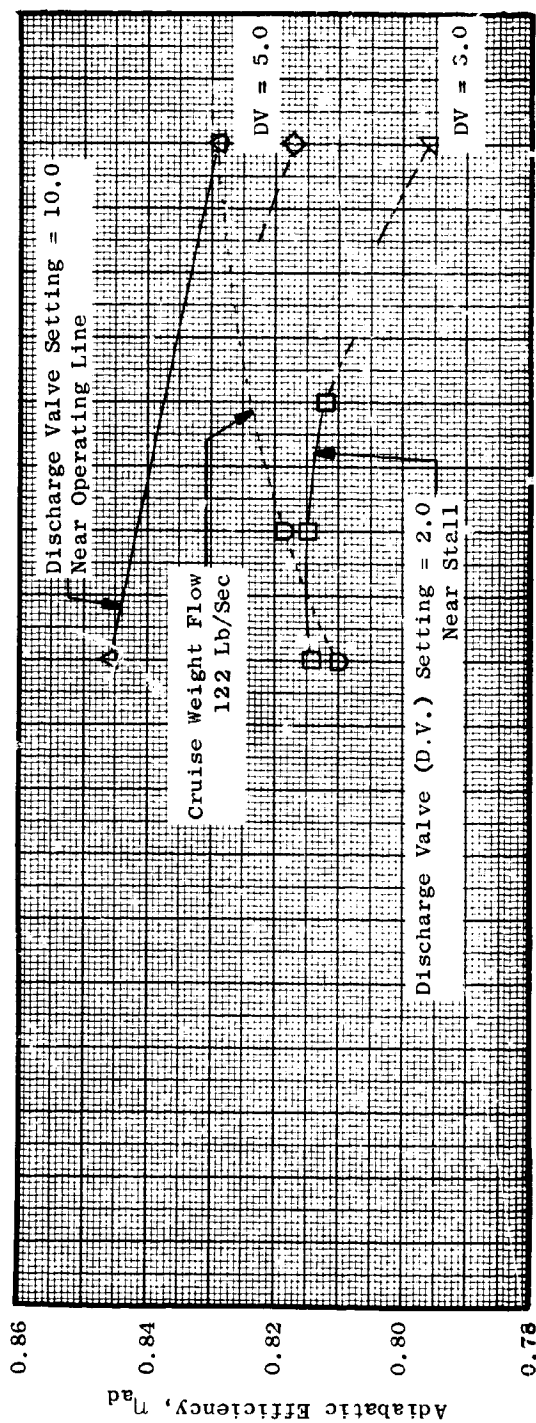
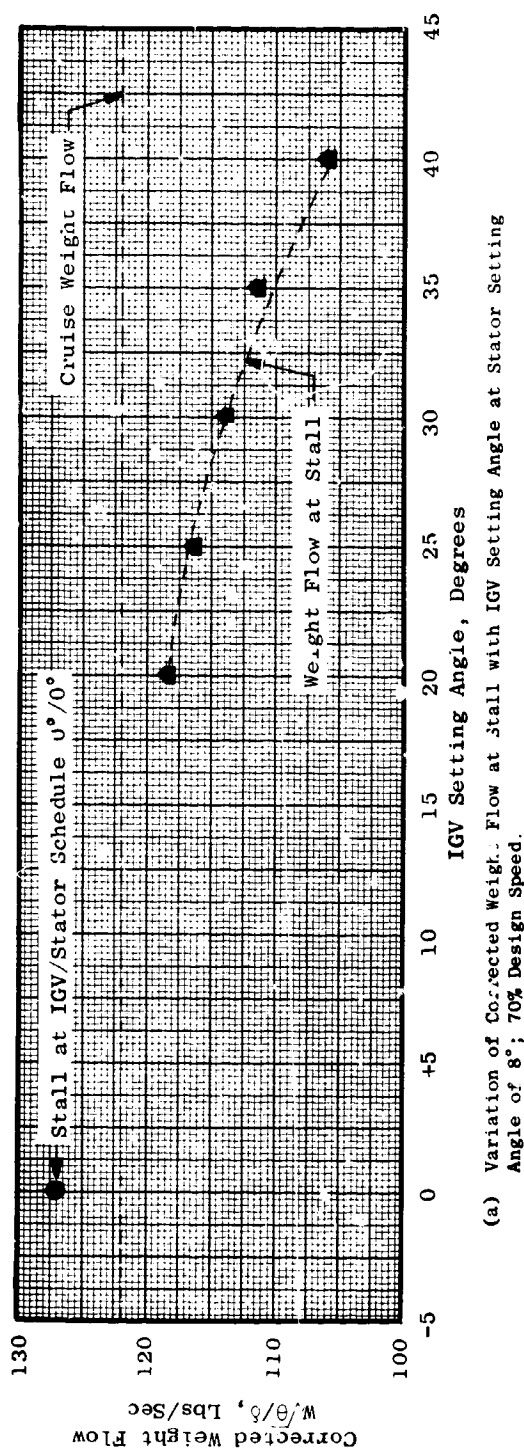


Figure 11. Relationship Between Flow Function and Meridional Mach Number - Used for Transferring Traverse Measurements to Blade Edges.

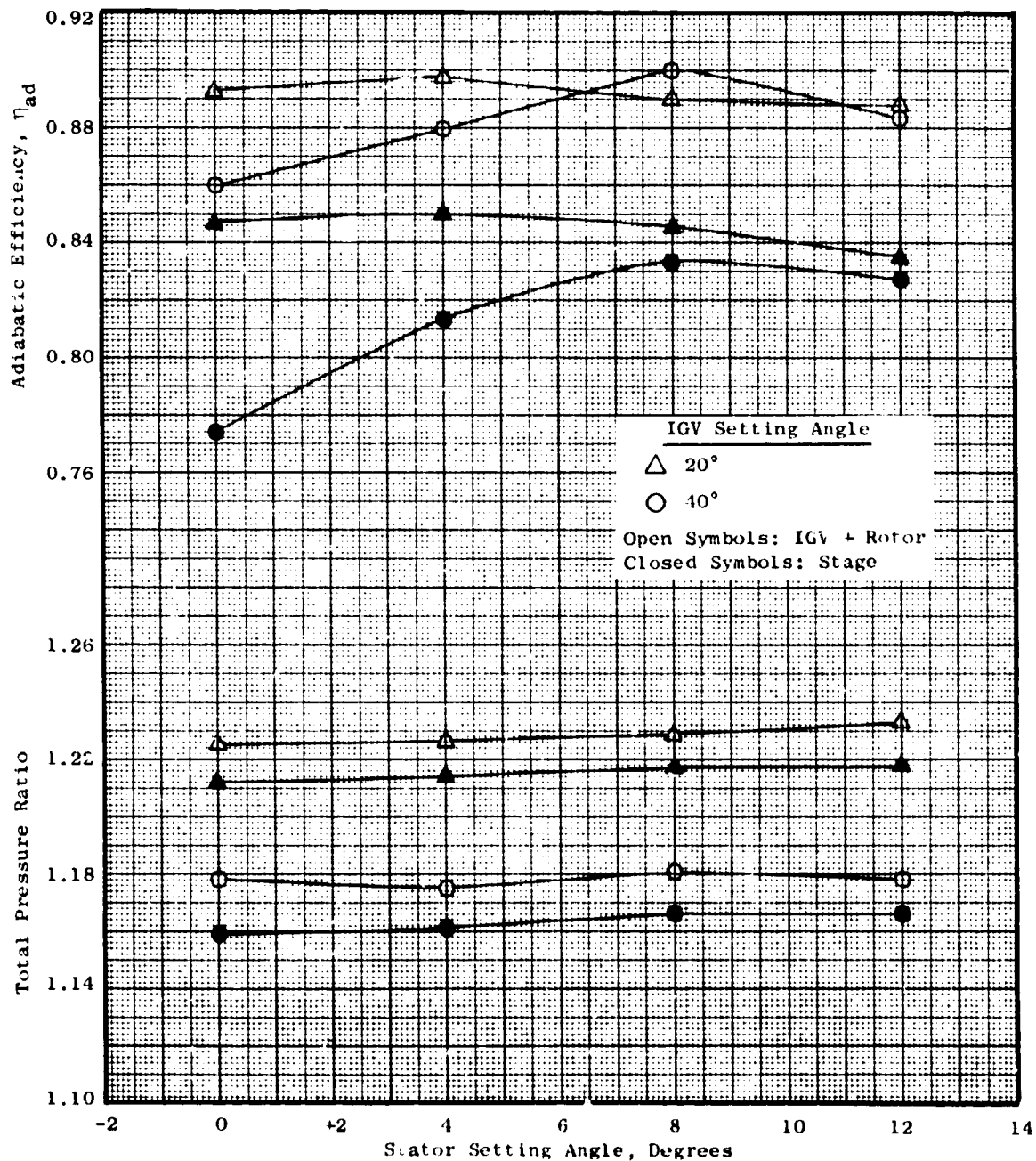


(b) Variation of Stage Adiabatic Efficiency with IGV Setting Angle at Stator Setting Angle of 8°; 70% Design Speed.



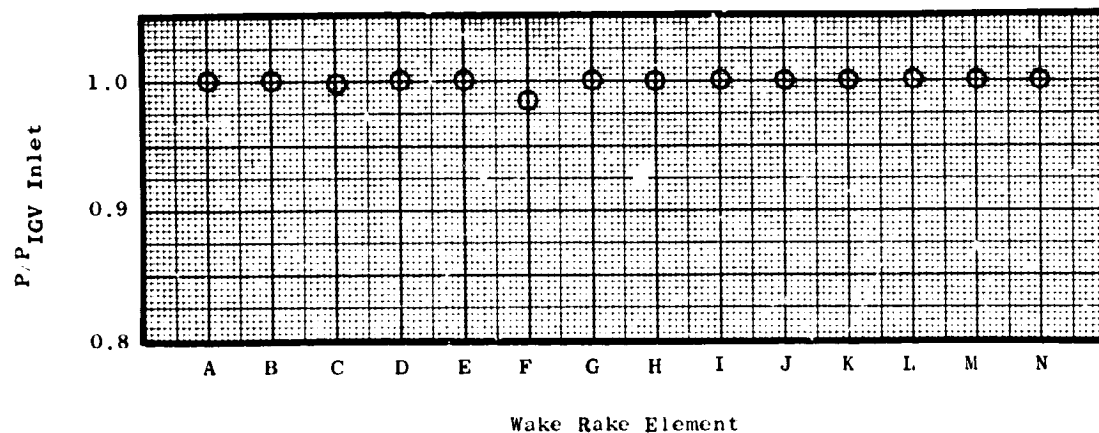
(a) Variation of Corrected Weight Flow at Stall with IGV Setting Angle at Stator Setting Angle of 8°; 70% Design Speed.

Figure 12. Selection of Off-Design IGV/Stator Schedules.

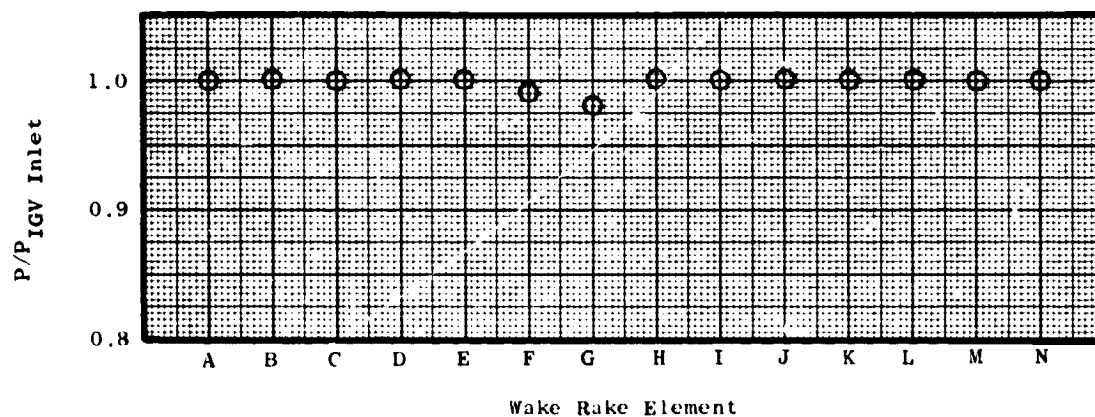


(c) Variation of Stage and IGV + Rotor Total Pressure Ratio and Efficiency with Stator Setting Angle at IGV Setting Angles of 20° and 40°; 70% Design Speed.

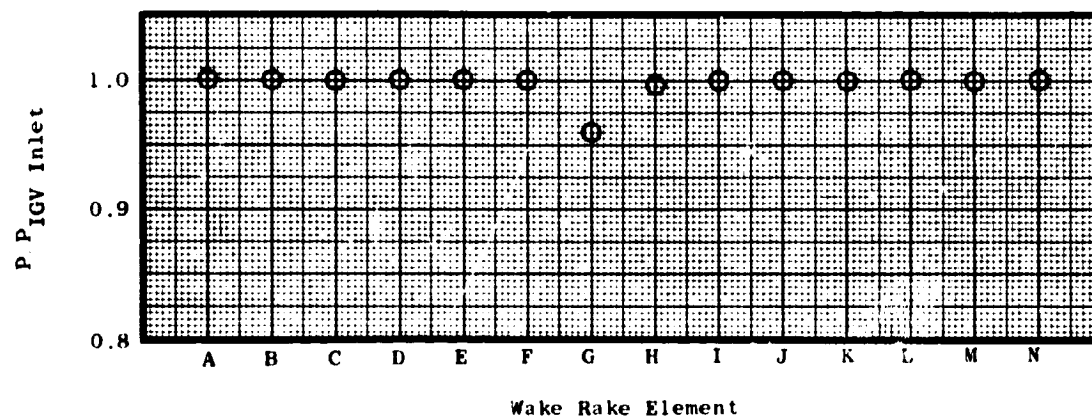
Figure 12. Selection of Off-Design IGV/Stator Schedules (Concluded)



(a) 50% Design Speed

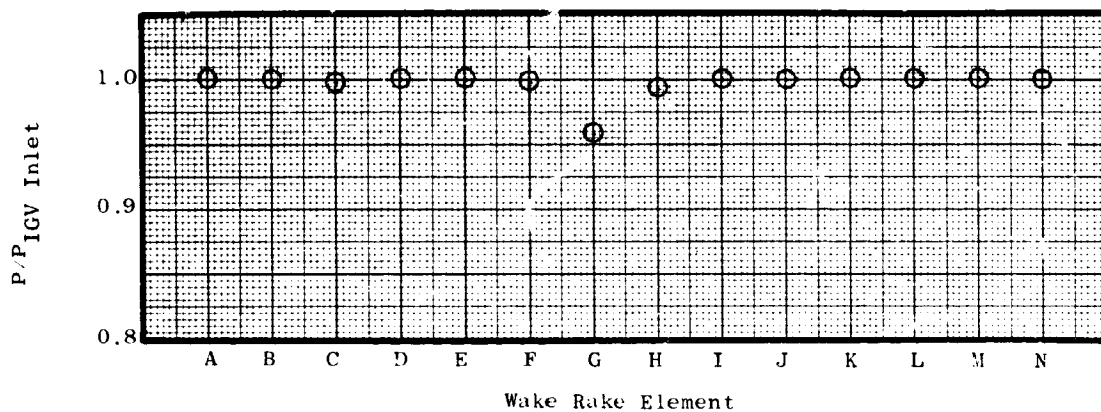


(b) 70% Design Speed

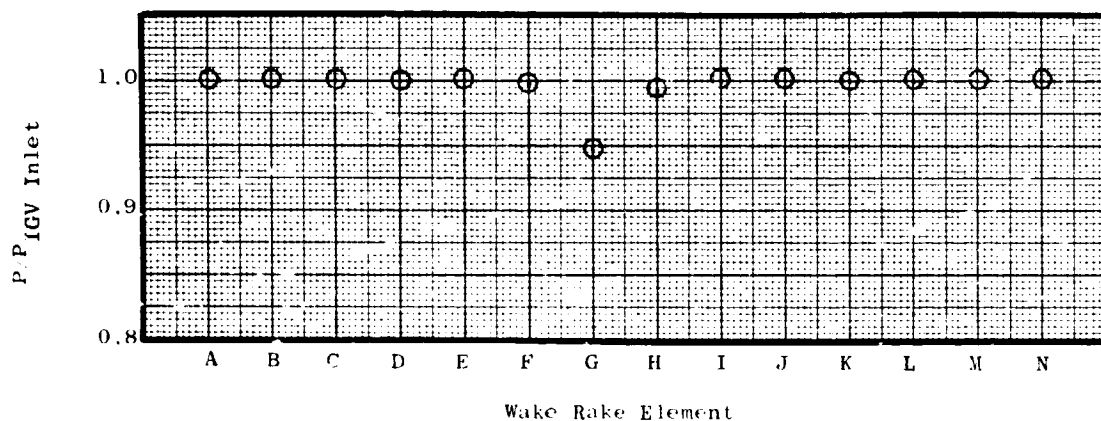


(c) 80% Design Speed

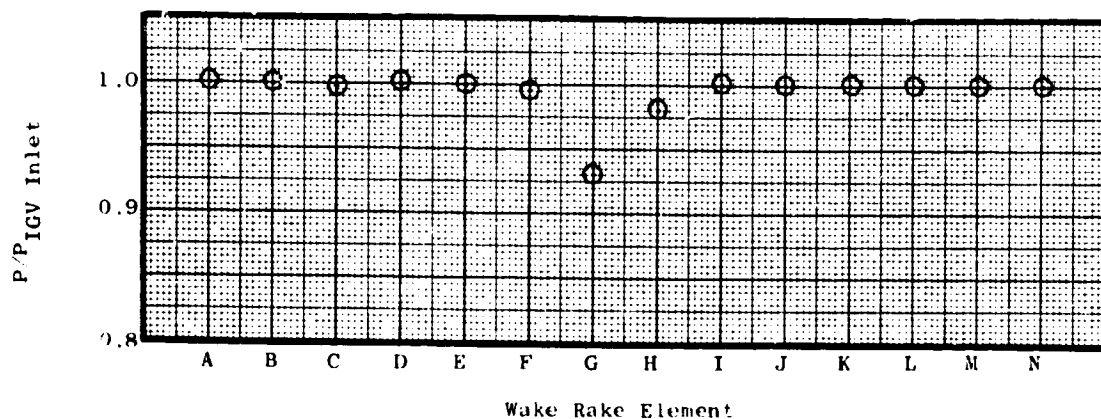
Figure 13. IGV Wake Profiles at 50% Immersion from Tip at IGV Setting Angle of 40° .



(d) 90% Design Speed

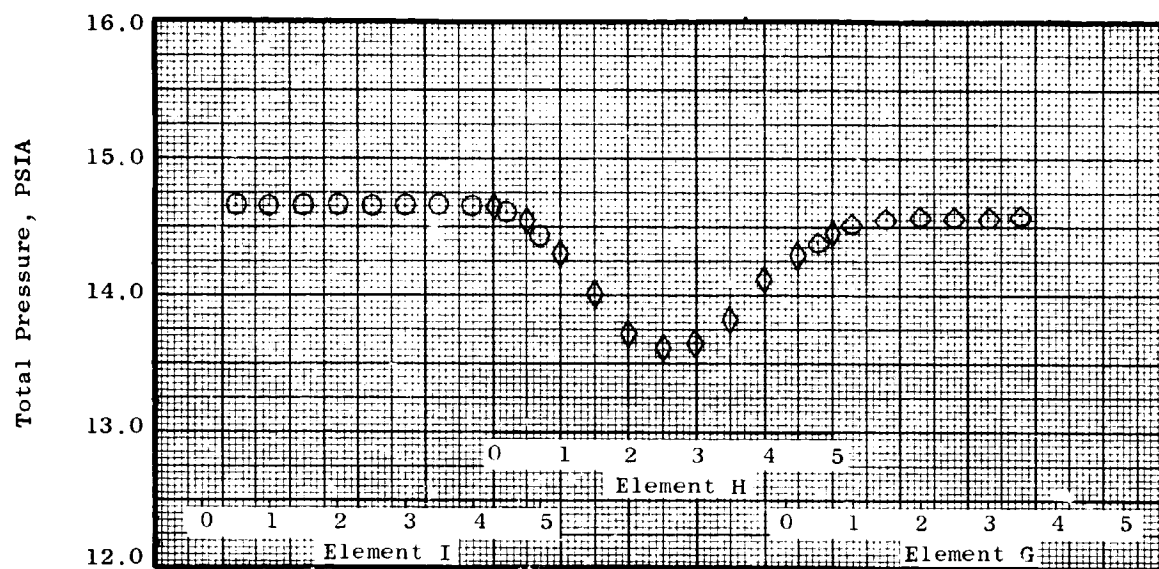


(e) 100% Design Speed



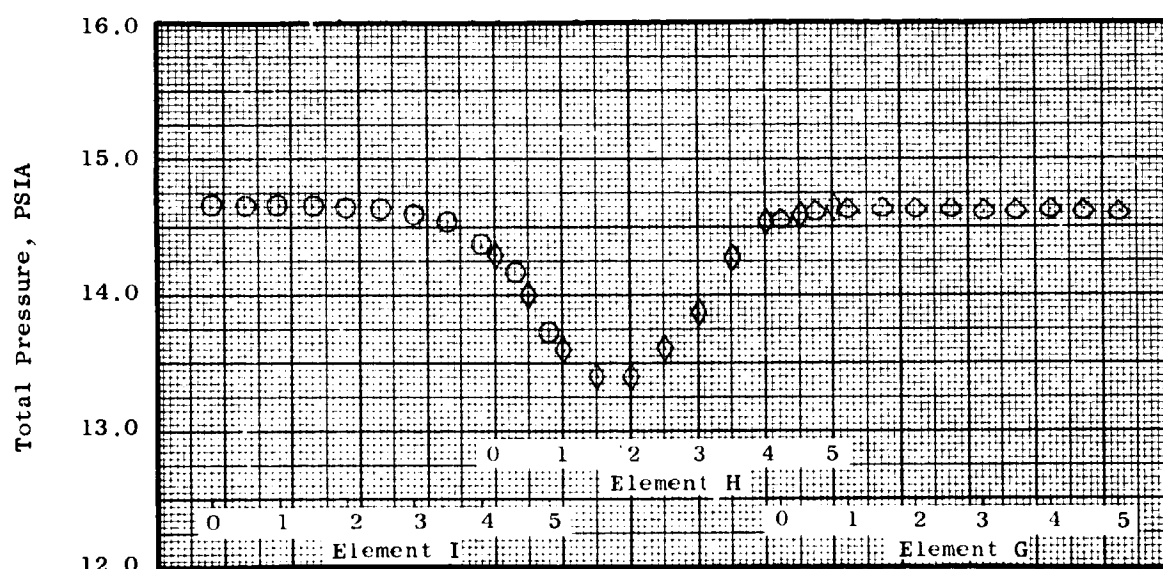
(f) 110% Design Speed

Figure 13. IGV Wake Profiles at 50% Immersion from Tip at IGV Setting Angle of 40° (Concluded).



IGV Setting Angle, Degrees

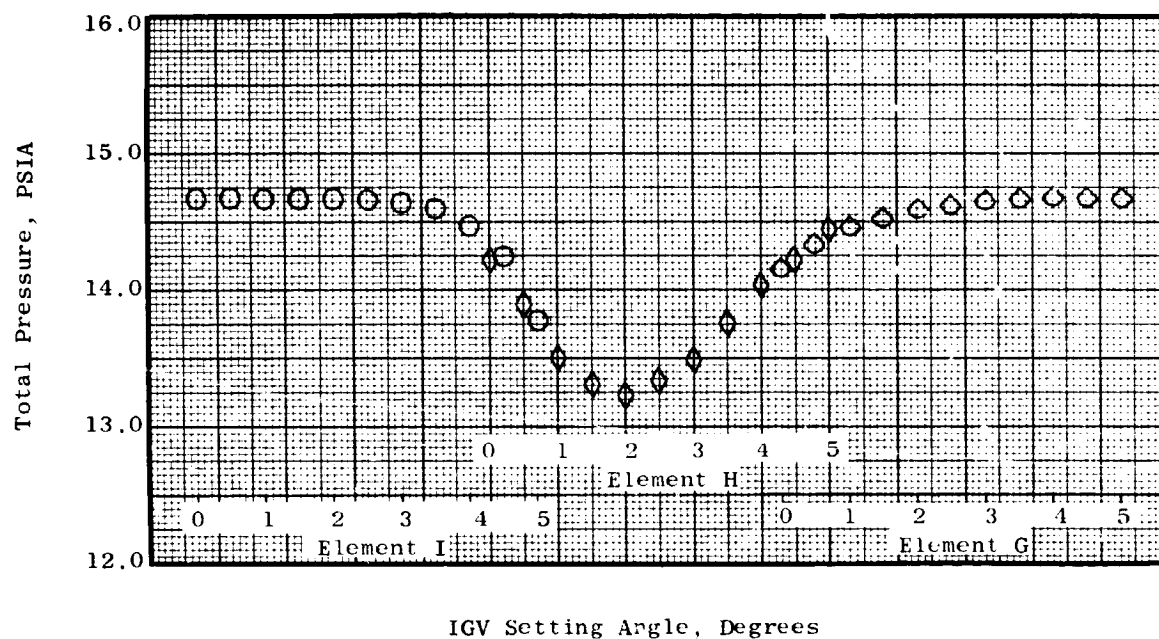
(a) 5% Immersion From Tip



IGV Setting Angle, Degrees

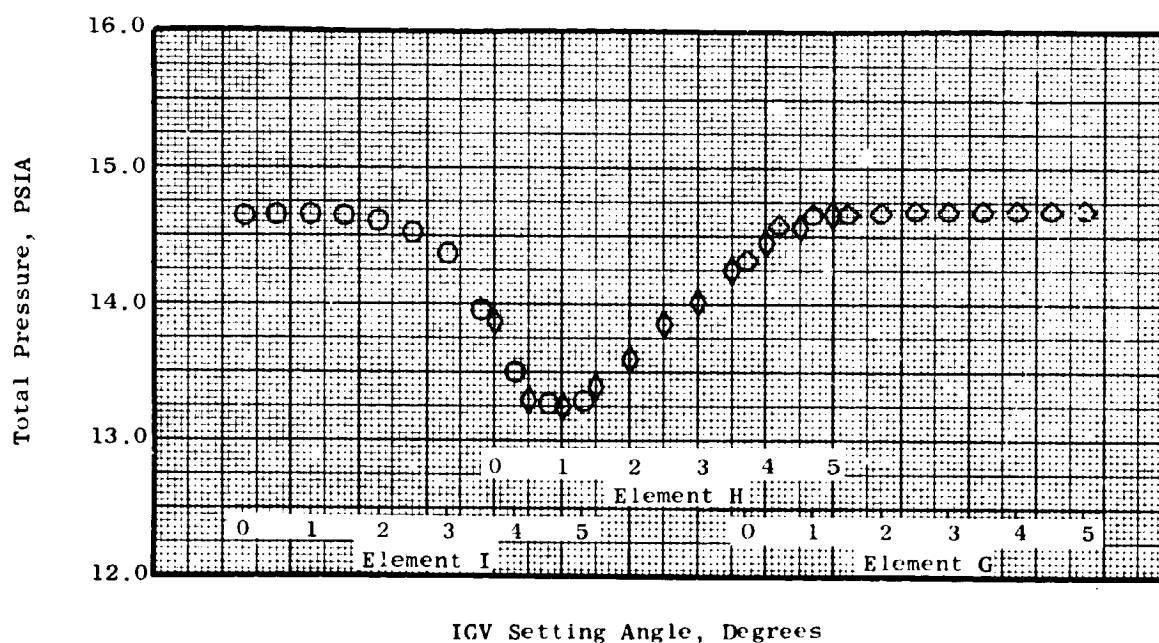
(b) 10% Immersion From Tip

Figure 14. IGV Wake Profiles at 100% Design Speed Obtained by Turning IGV from 0° to 5° in 0.5° Increments.



IGV Setting Angle, Degrees

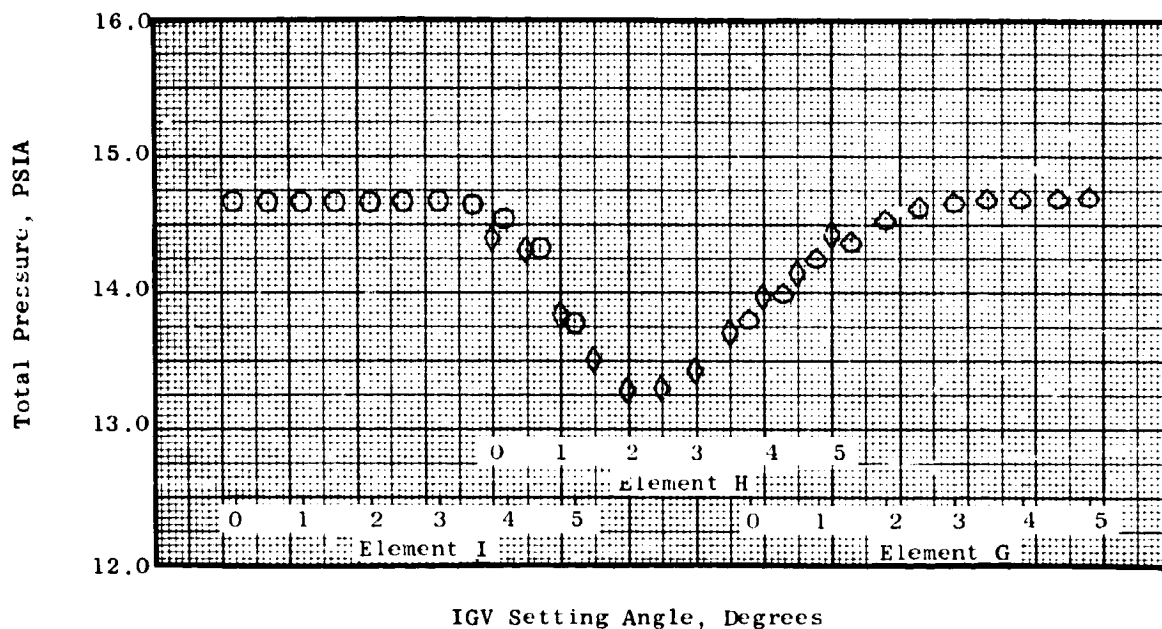
(c) 30% Immersion From Tip



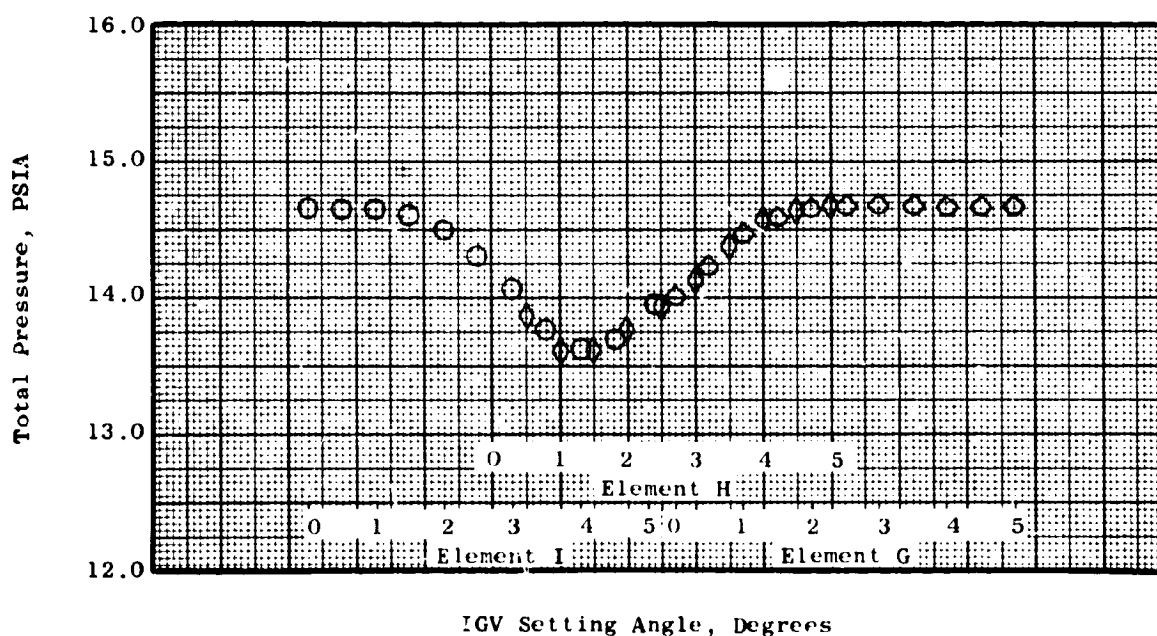
IGV Setting Angle, Degrees

(d) 50% Immersion From Tip

Figure 14. IGV Wake Profiles at 100% Design Speed Obtained by Turning IGV from 0° to 5° in 0.5° Increments (Continued).



(e) 70% Immersion From Tip



(f) 90% Immersion From Tip

Figure 14. IGV Wake Profiles at 100% Design Speed Obtained by Turning IGV from 0° to 5° in 0.5° Increments (Continued).

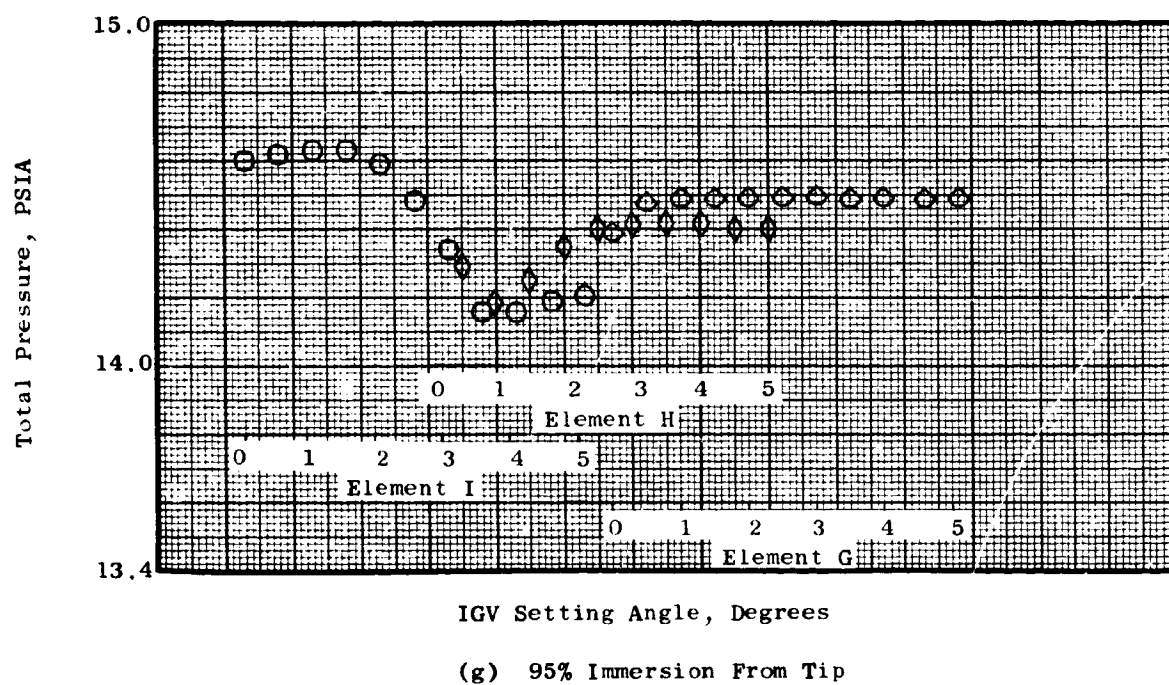


Figure 14. IGV Wake Profiles at 100% Design Speed Obtained by Turning IGV from 0° to 5° in 0.5° Increments (Concluded).

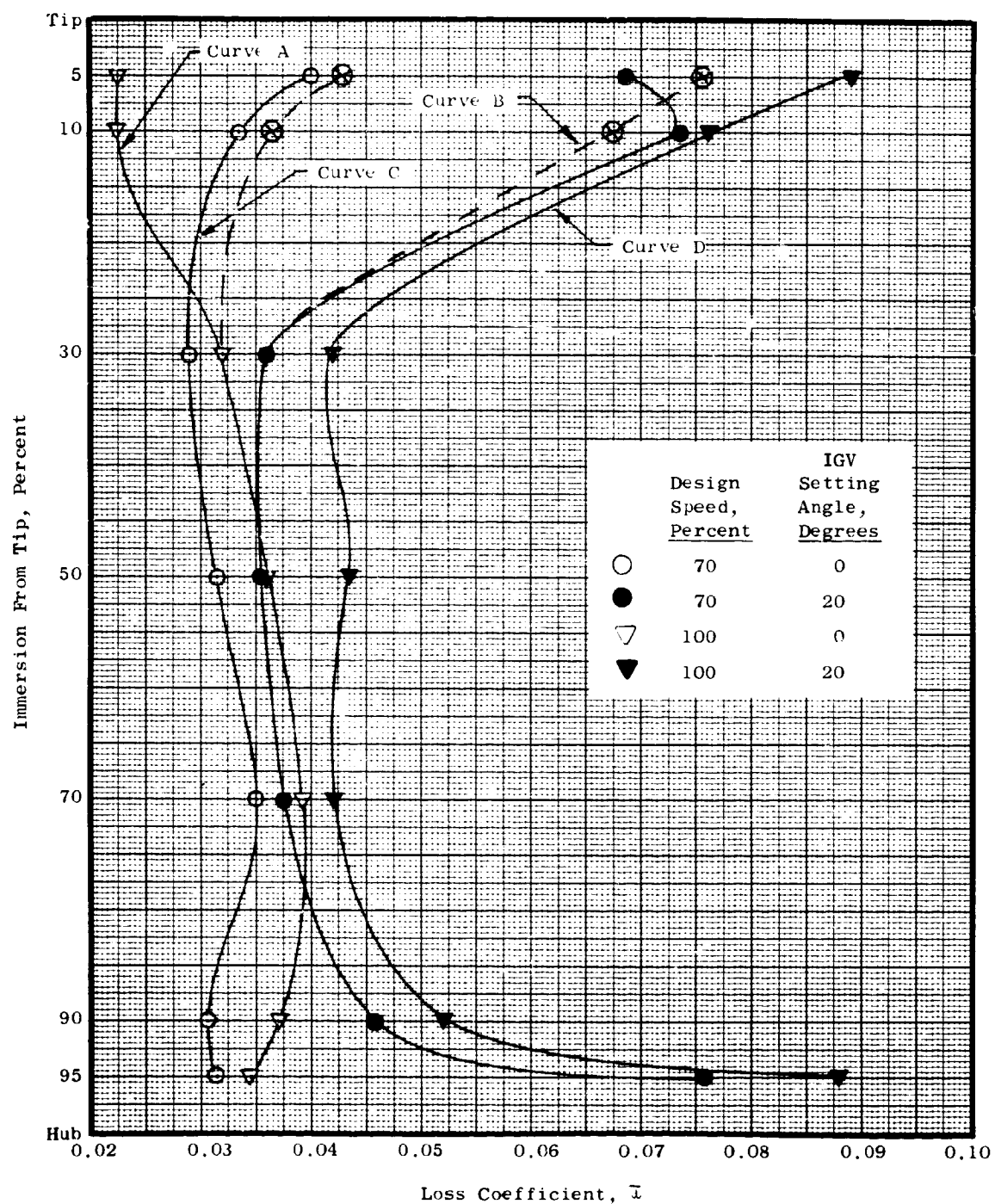


Figure 15. Radial Variation of IGV Total Pressure Loss Coefficient at 70% and 100% Design Speeds.

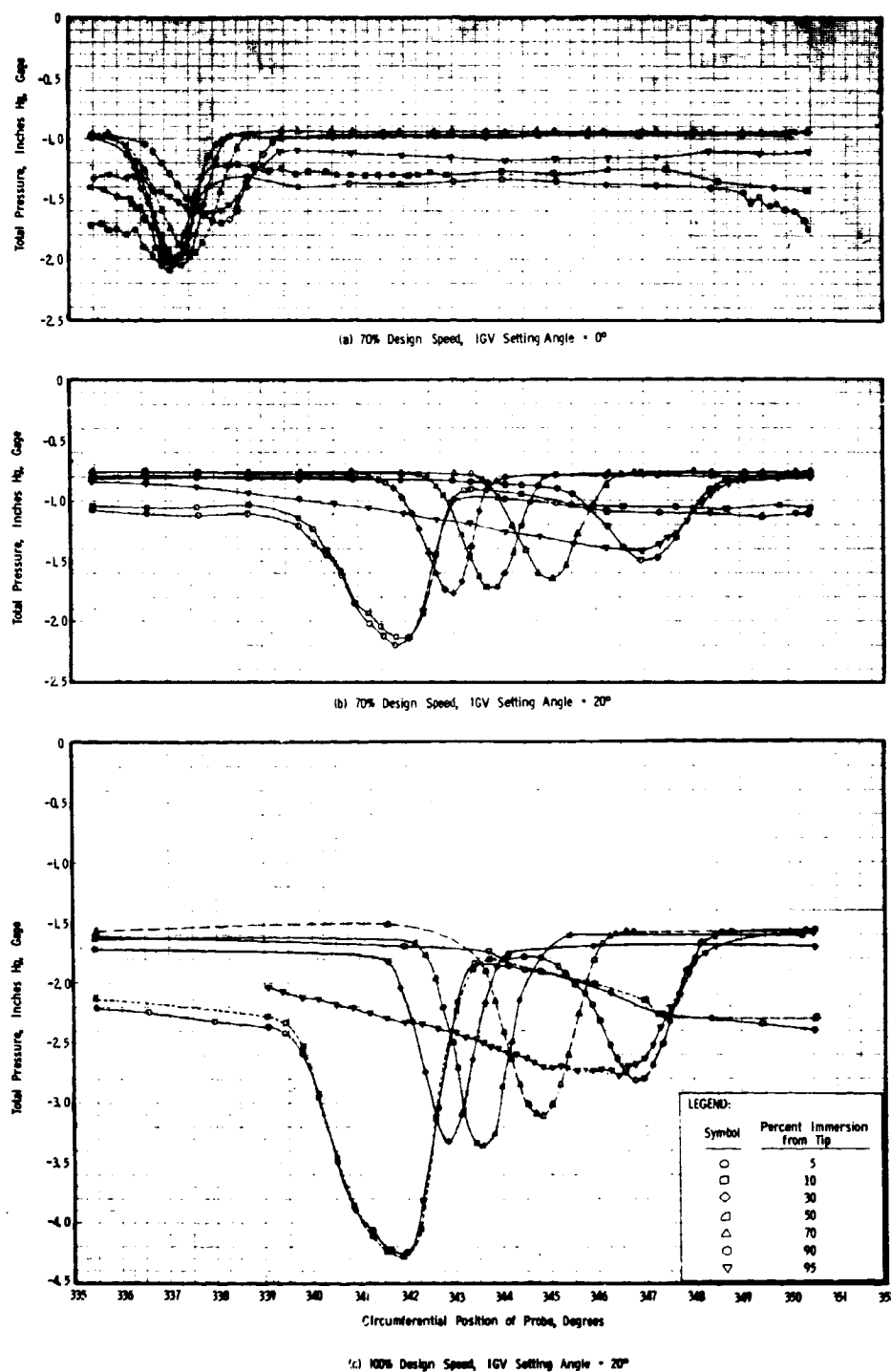


Figure 16. IGV Wake Profiles Obtained by Circumferentially Traversing a Combination Probe Across the Wake.

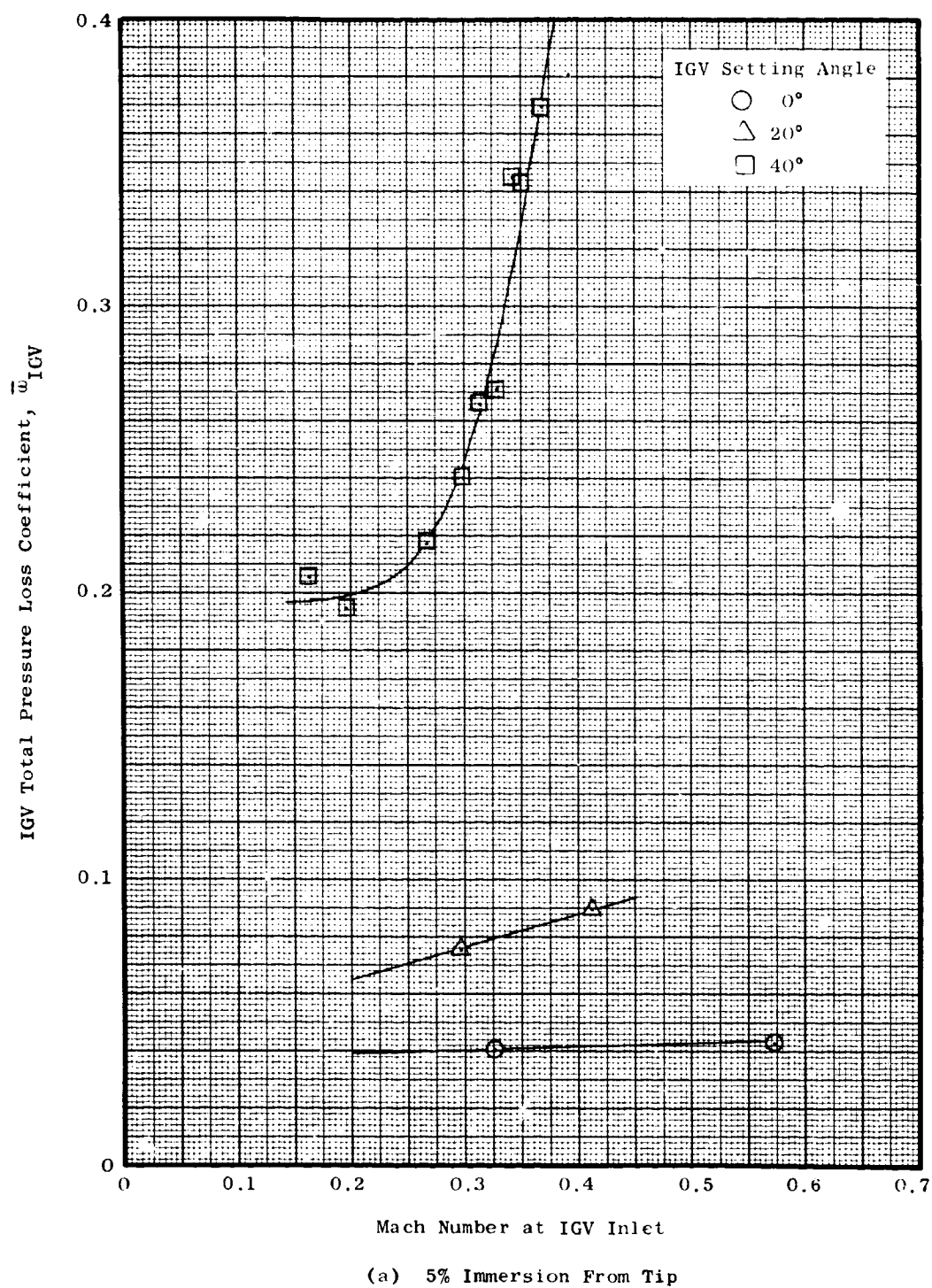
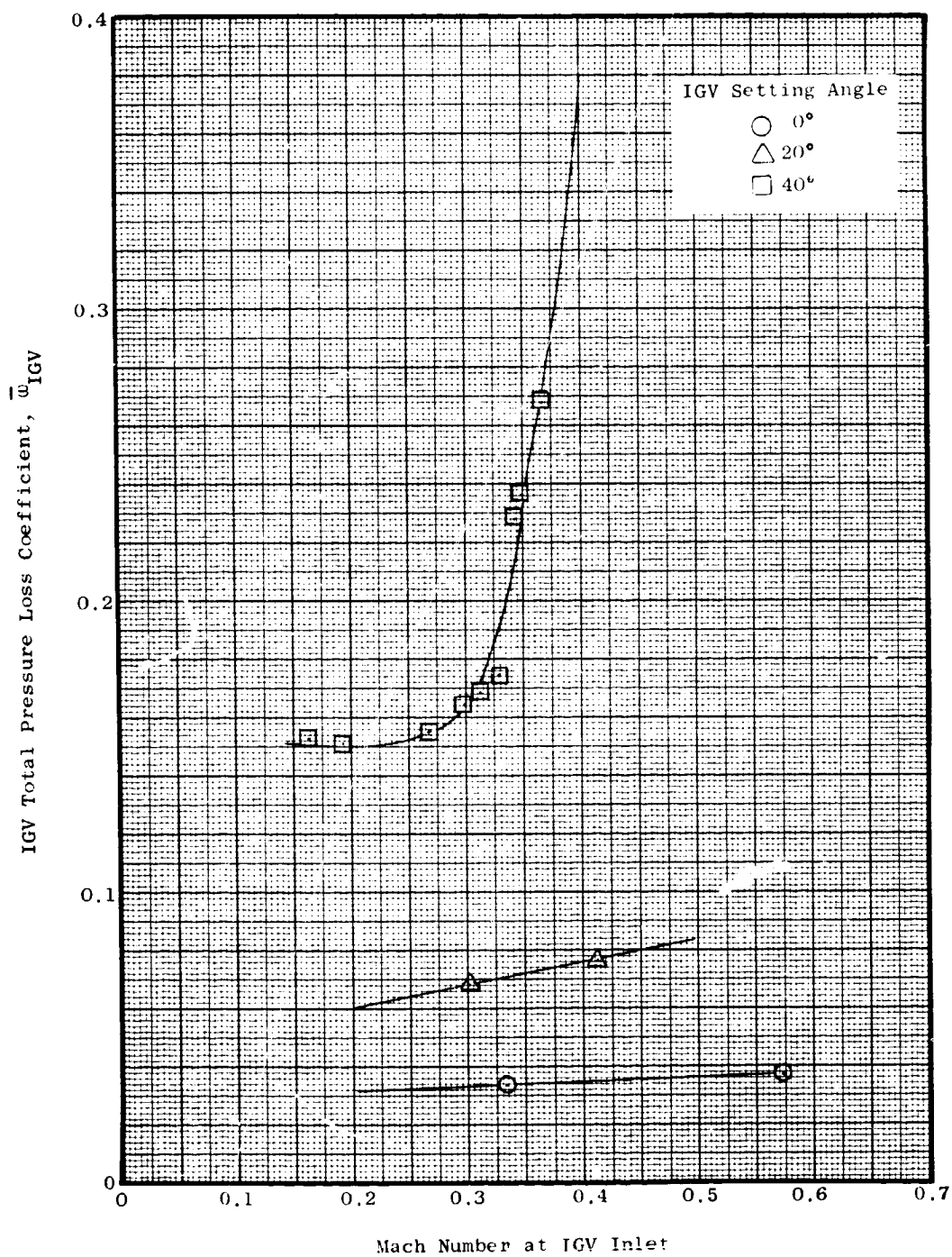
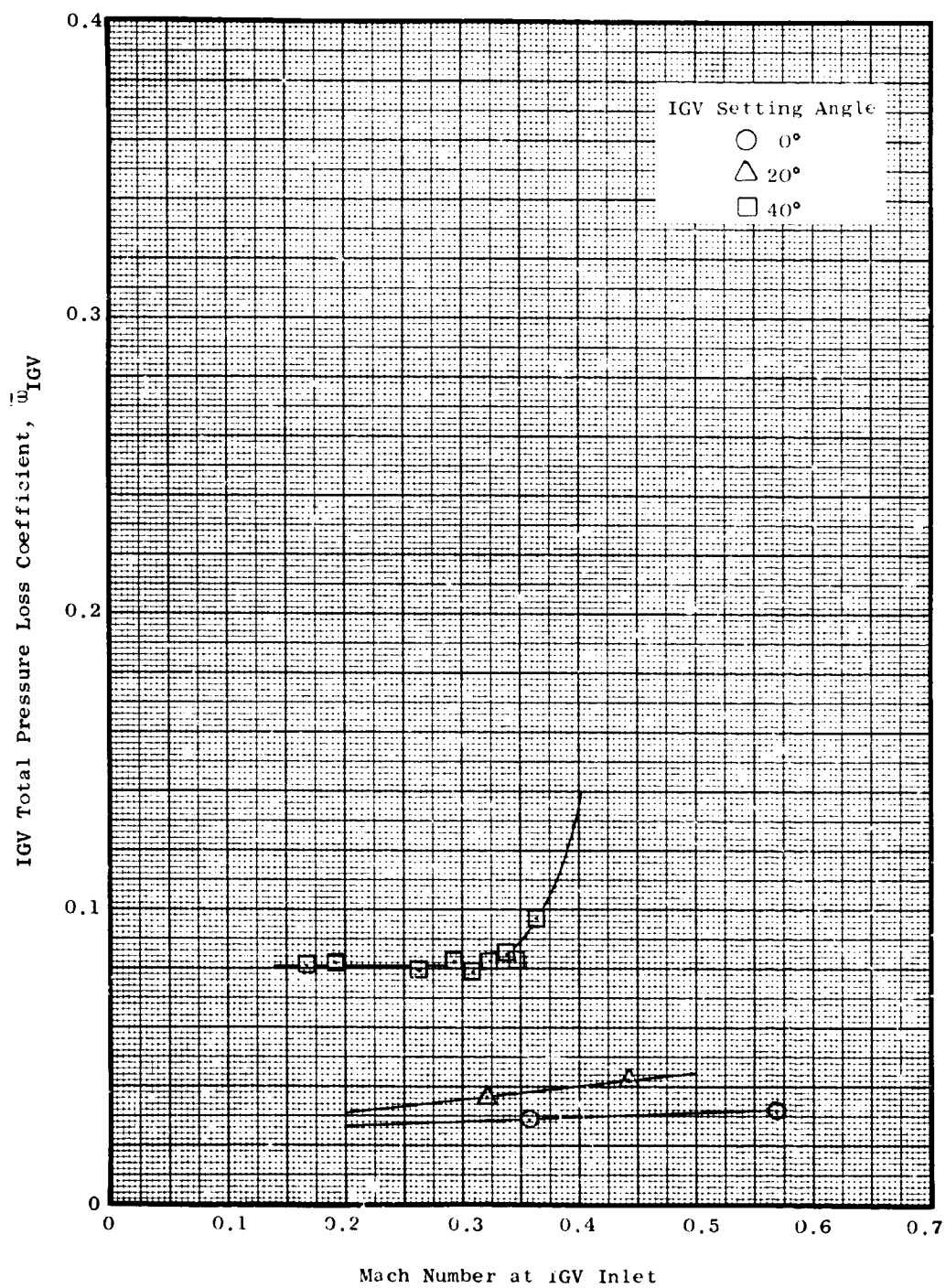


Figure 17. Variation of IGV Total Pressure Loss Coefficient with Mach Number.



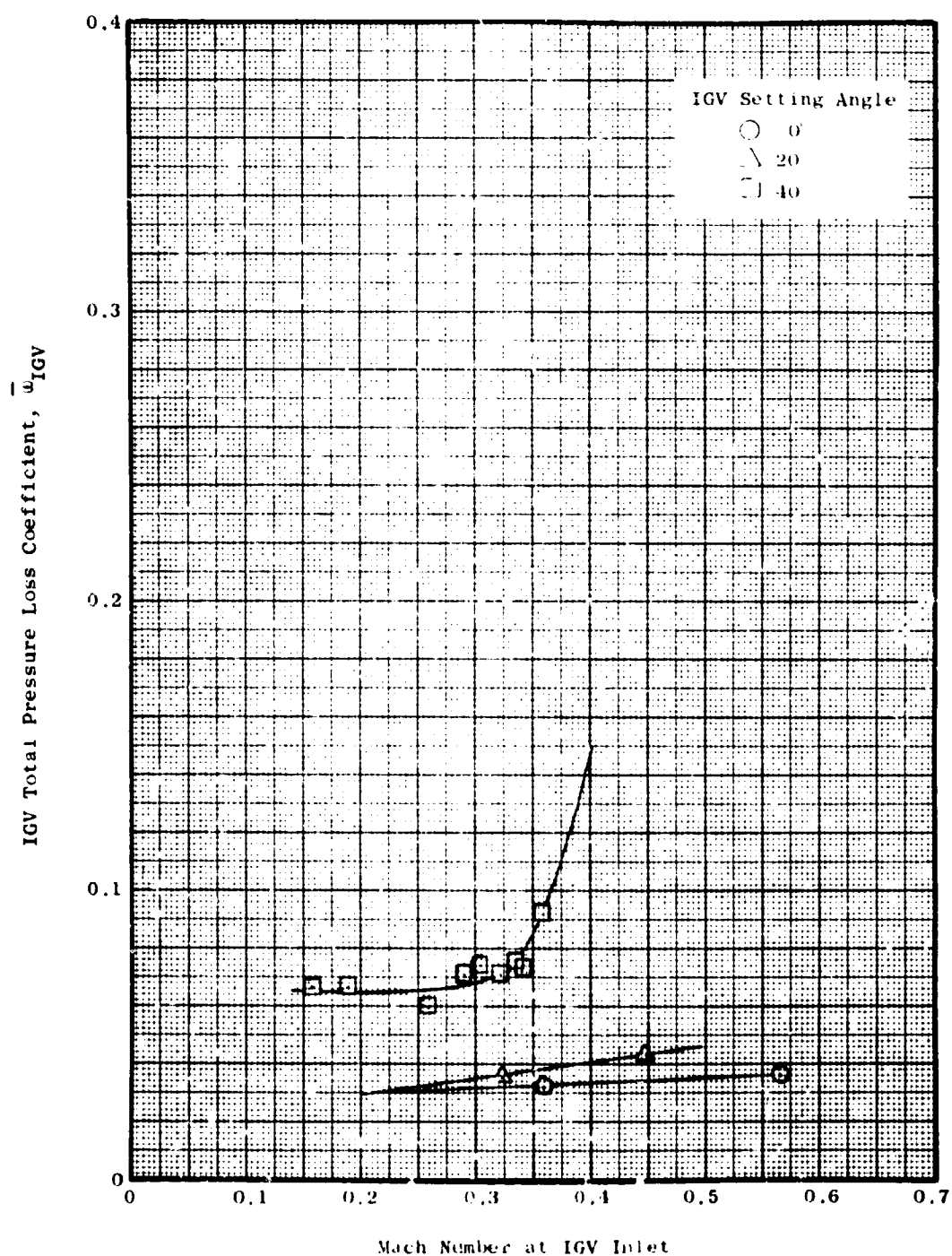
(b) 10% Immersion From Tip

Figure 17. Variation of IGV Total Pressure Loss Coefficient with Mach Number. (Continued).



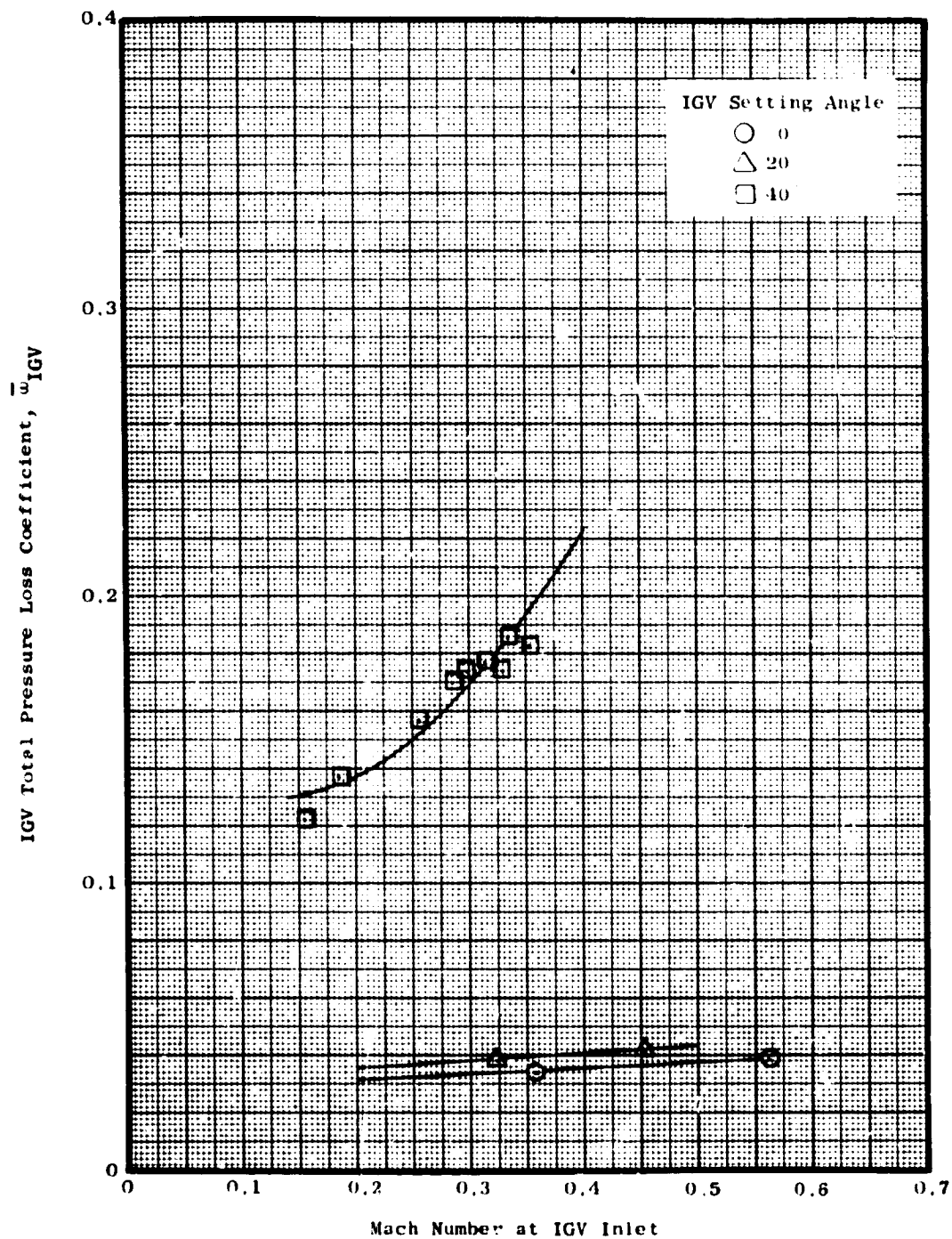
(c) 30% Immersion From Tip

Figure 17. Variation of IGVT Total Pressure Loss Coefficient with Mach Number. (Continued).



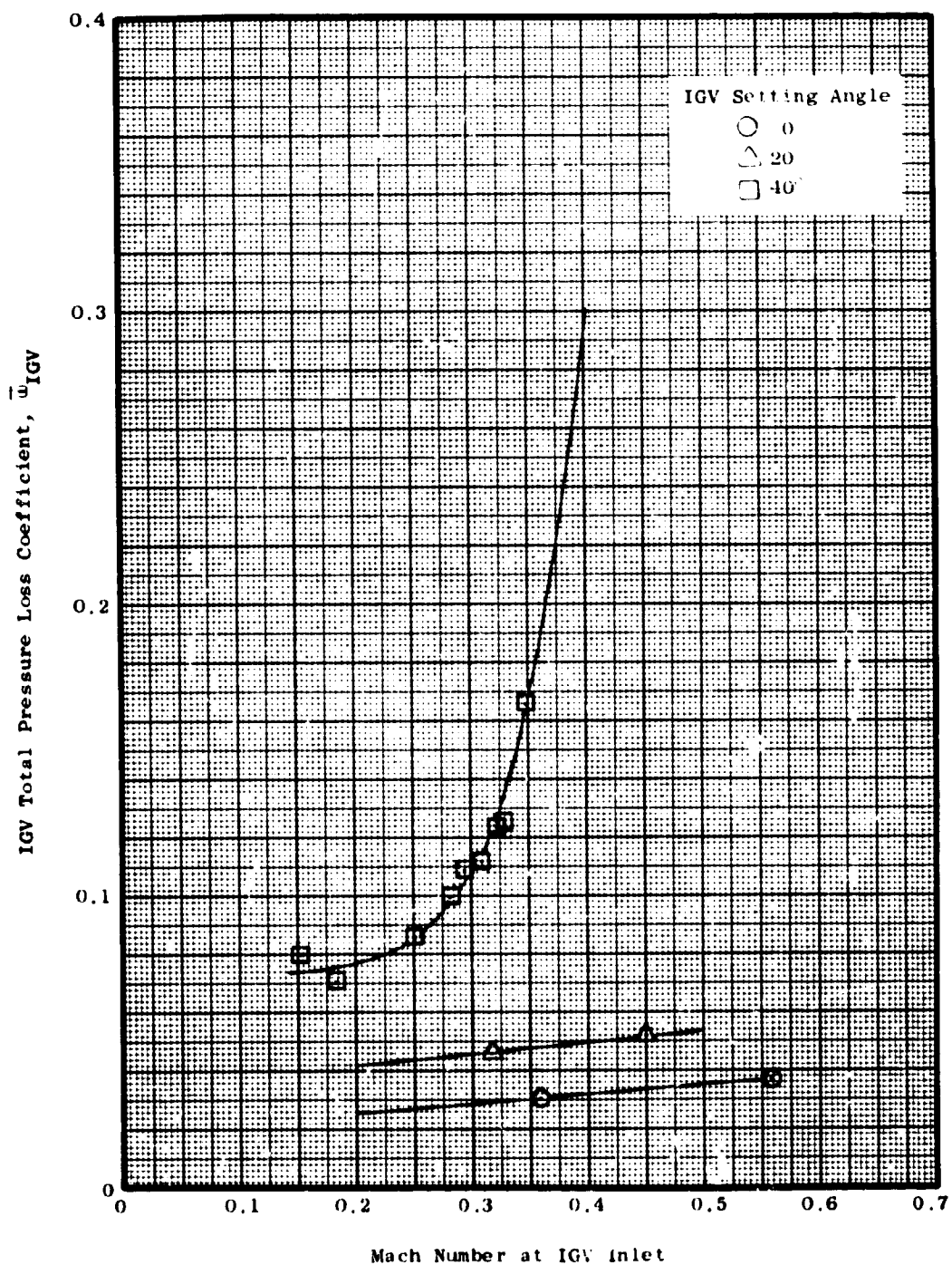
(d) 50% Immersion From Tip

Figure 17. Variation of IGW Total Pressure Loss Coefficient with Mach Number. (Continued).



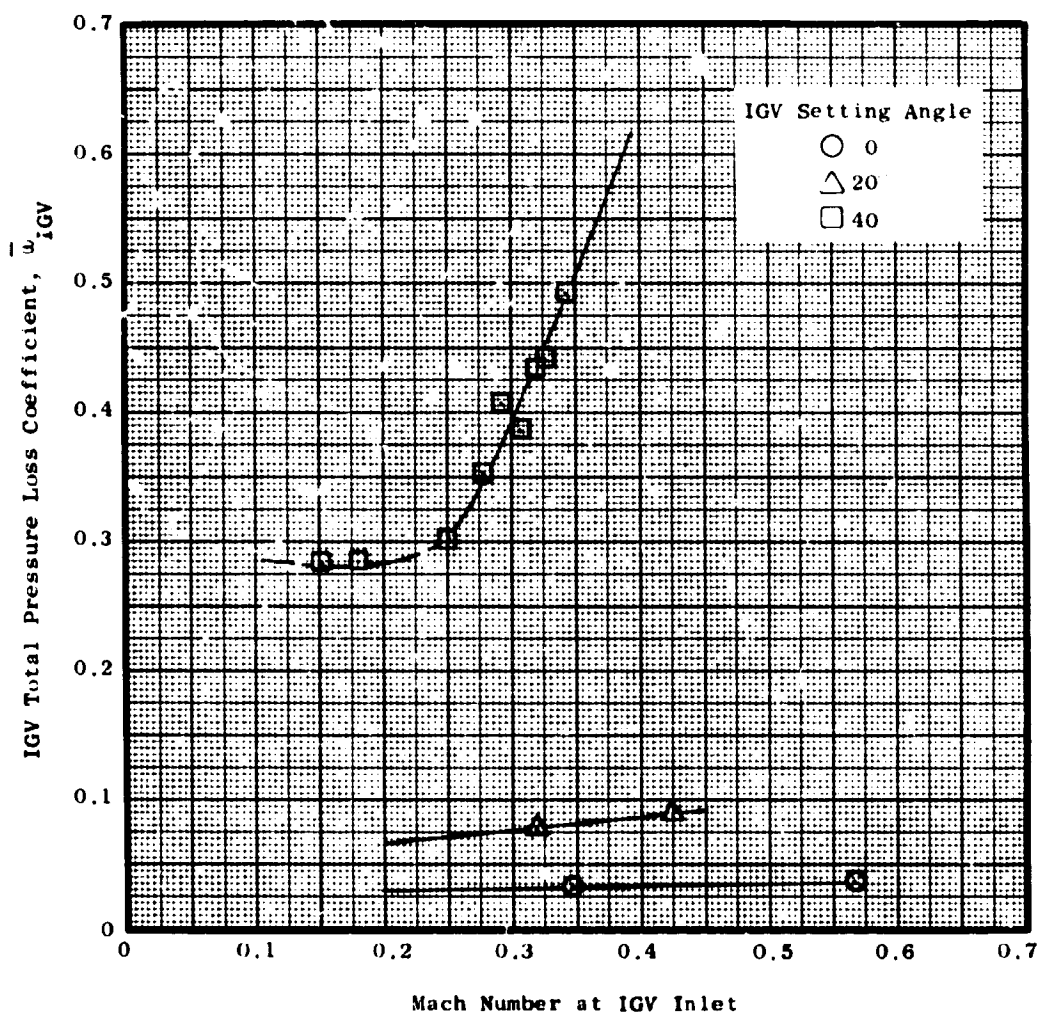
(e) 70% Immersion From Tip

Figure 17. Variation of IGW Total Pressure Loss Coefficient with Mach Number. (Continued).



(f) 90% Immersion From Tip

Figure 17. Variation of IGV Total Pressure Loss Coefficient with Mach Number. (Continued).



(g) 95% Immersion From Tip

Figure 17. Variation of IGV Total Pressure Loss Coefficient with Mach Number. (Concluded).

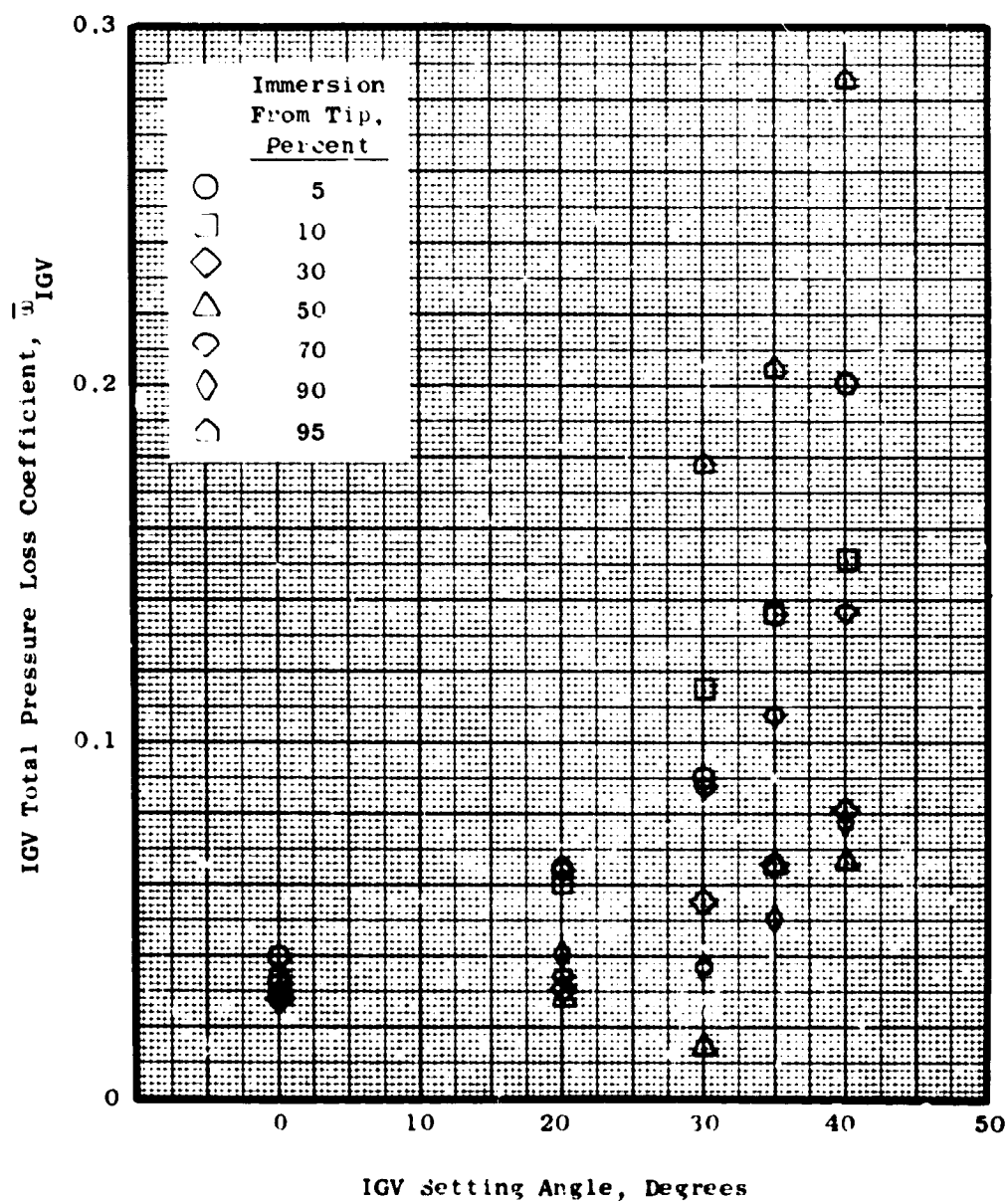


Figure 18. Variation of IGV Total Pressure Loss Coefficient with IGV Setting Angle; IGV Inlet Mach Number = 0.2.

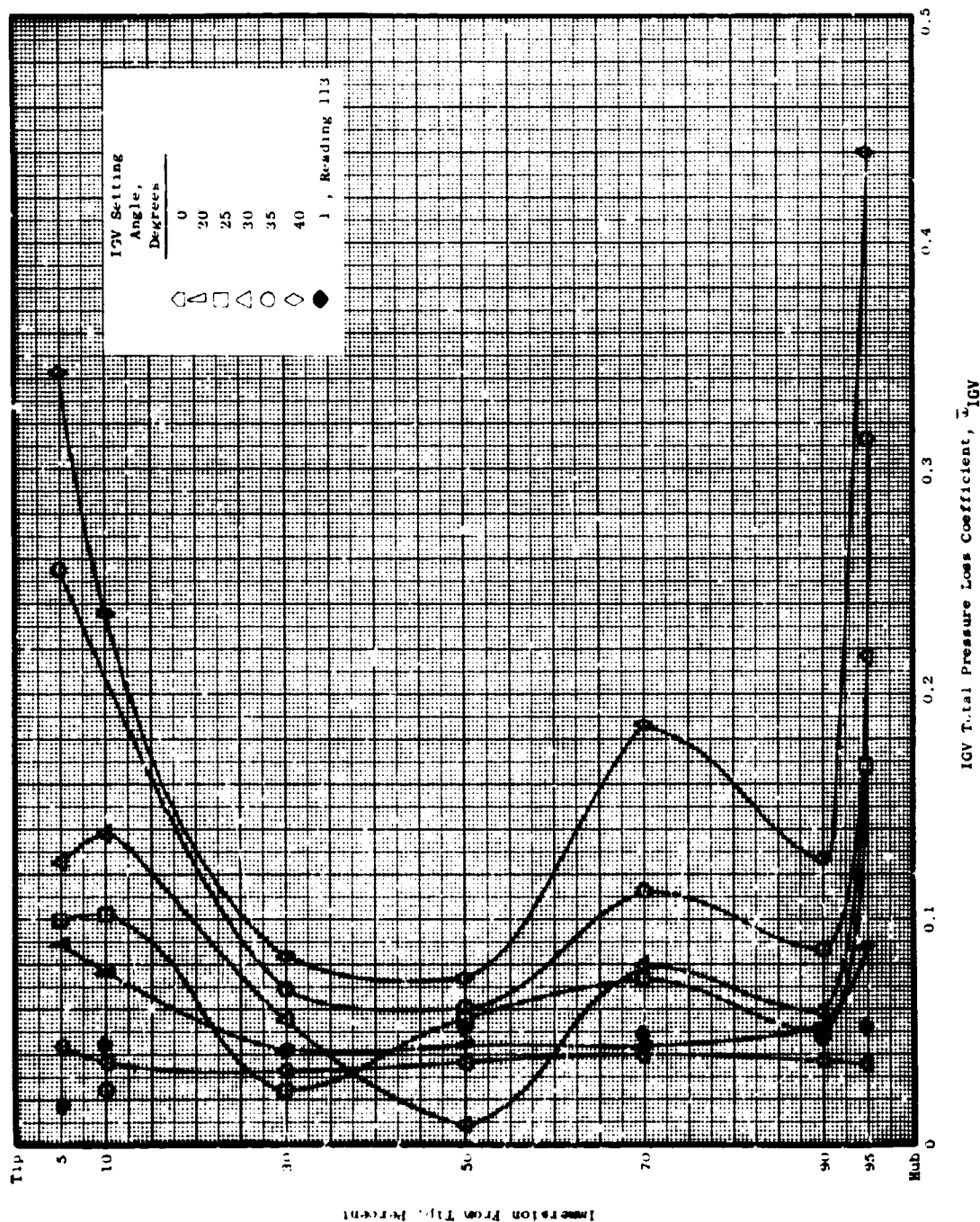


Figure 19. Radial Variation of IGV Total Pressure Loss Coefficient at 100% Design Speed at IGV Setting Angles of 0°, 1°, 20°, 25°, 30°, 35°, and 40°.

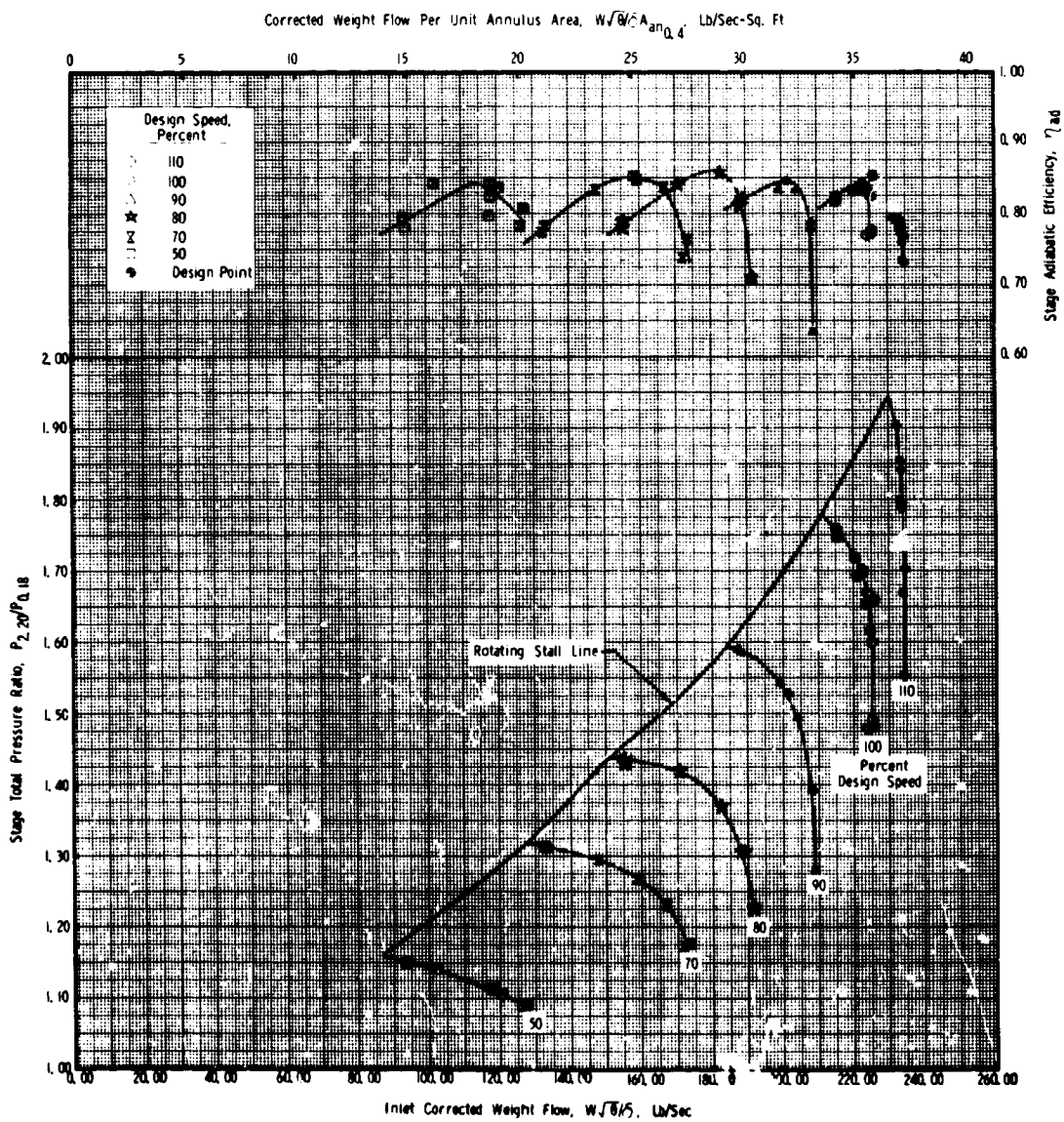


Figure 20. Stage Performance Map for IGV/Stator Schedule 0°/0°.

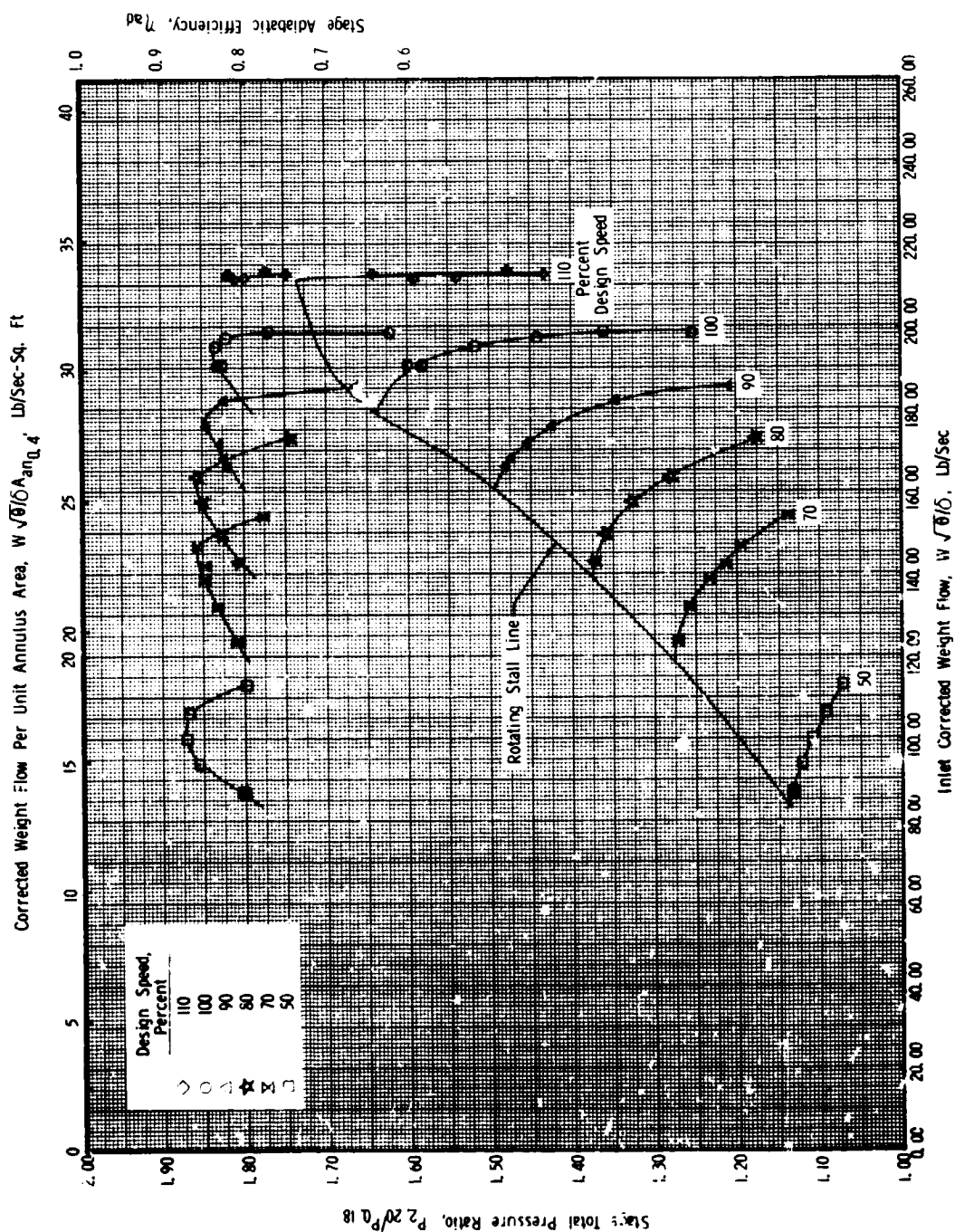


Figure 21. Stage Performance Map for IGV/Stator Schedule $20^\circ/4^\circ$.

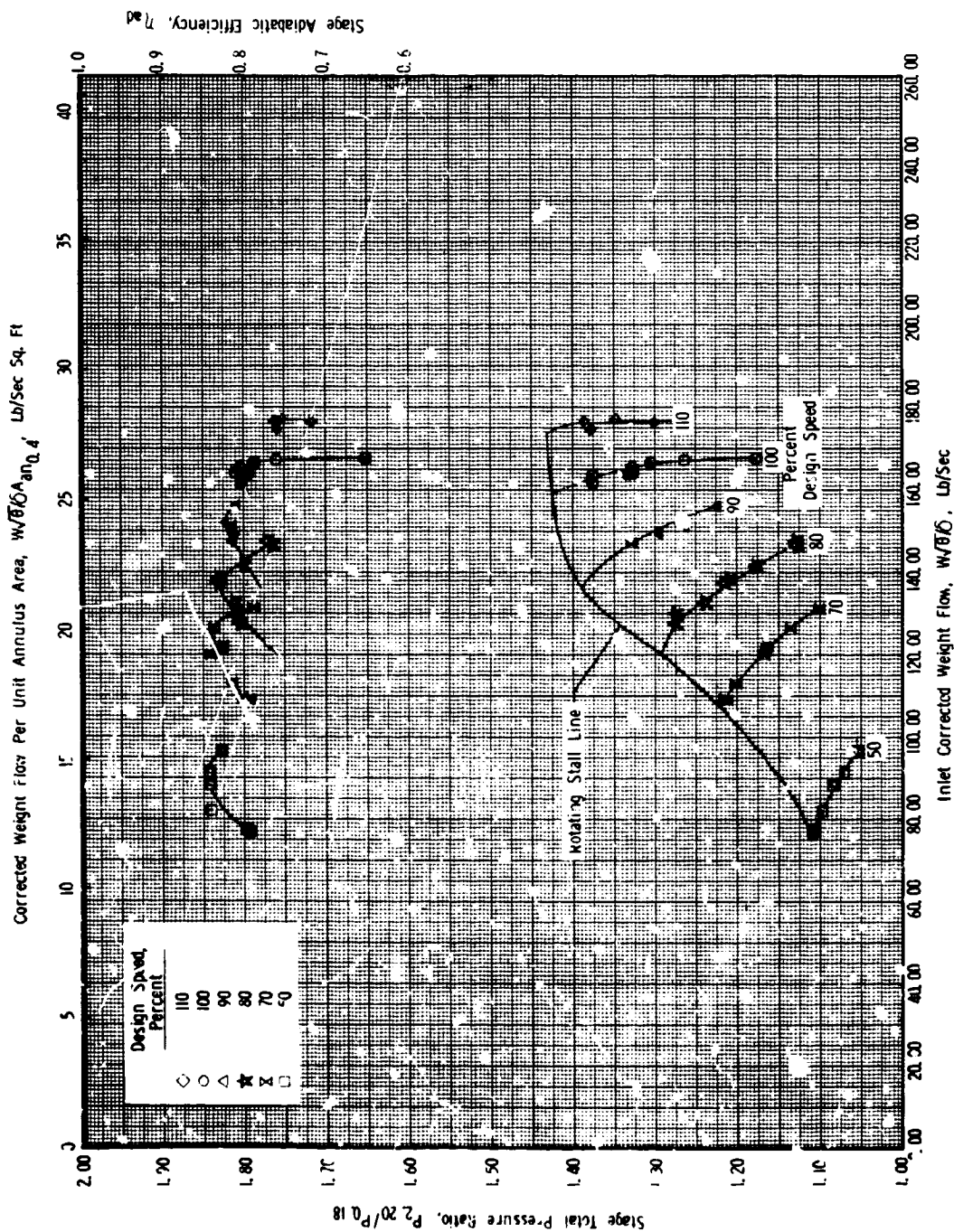


Figure 22. Stage Performance Map for IGV/Stator Schedule 40°/8°.

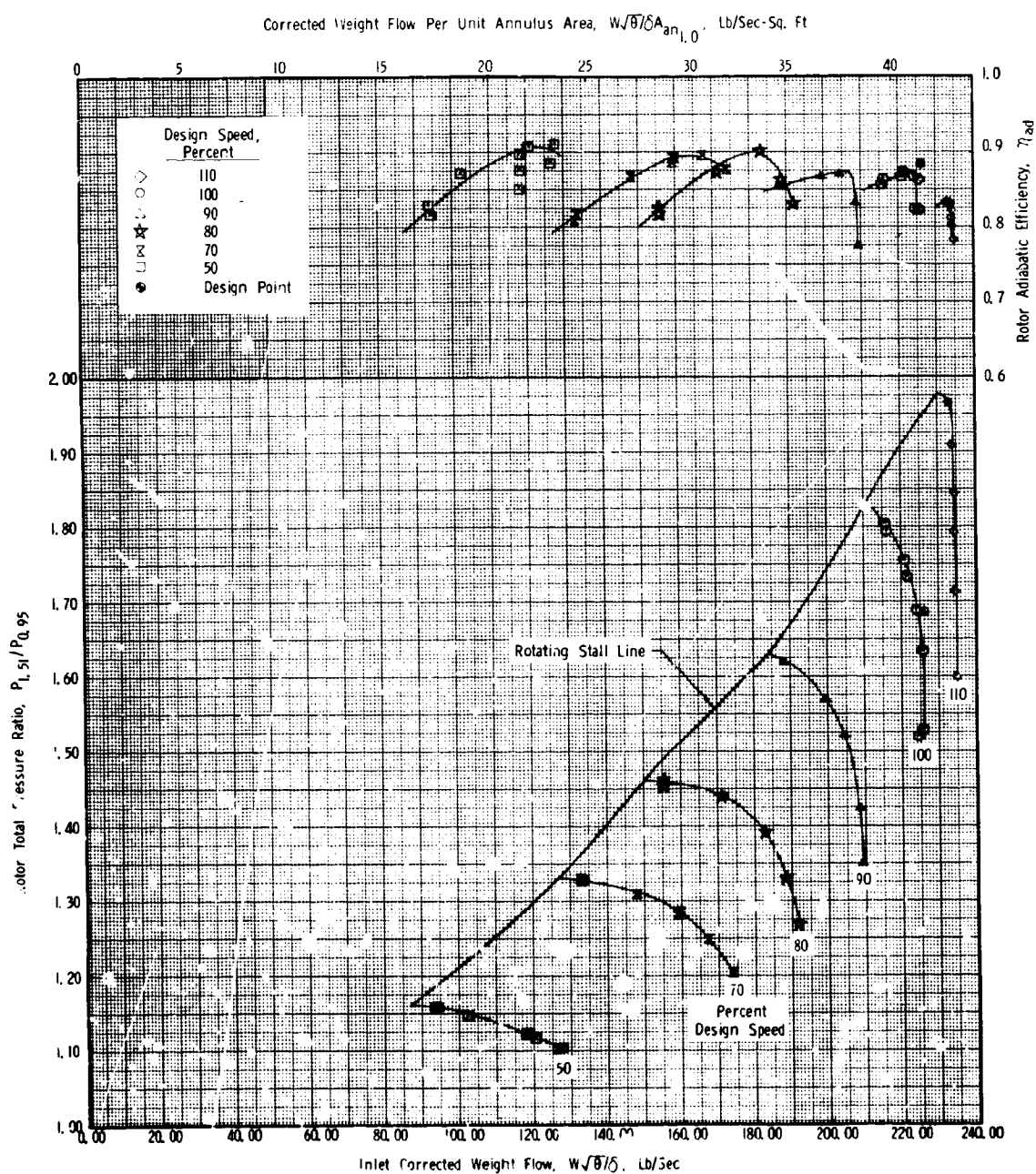


Figure 23. Rotor Performance Map for IGV/Stator Schedule 0°/0°.

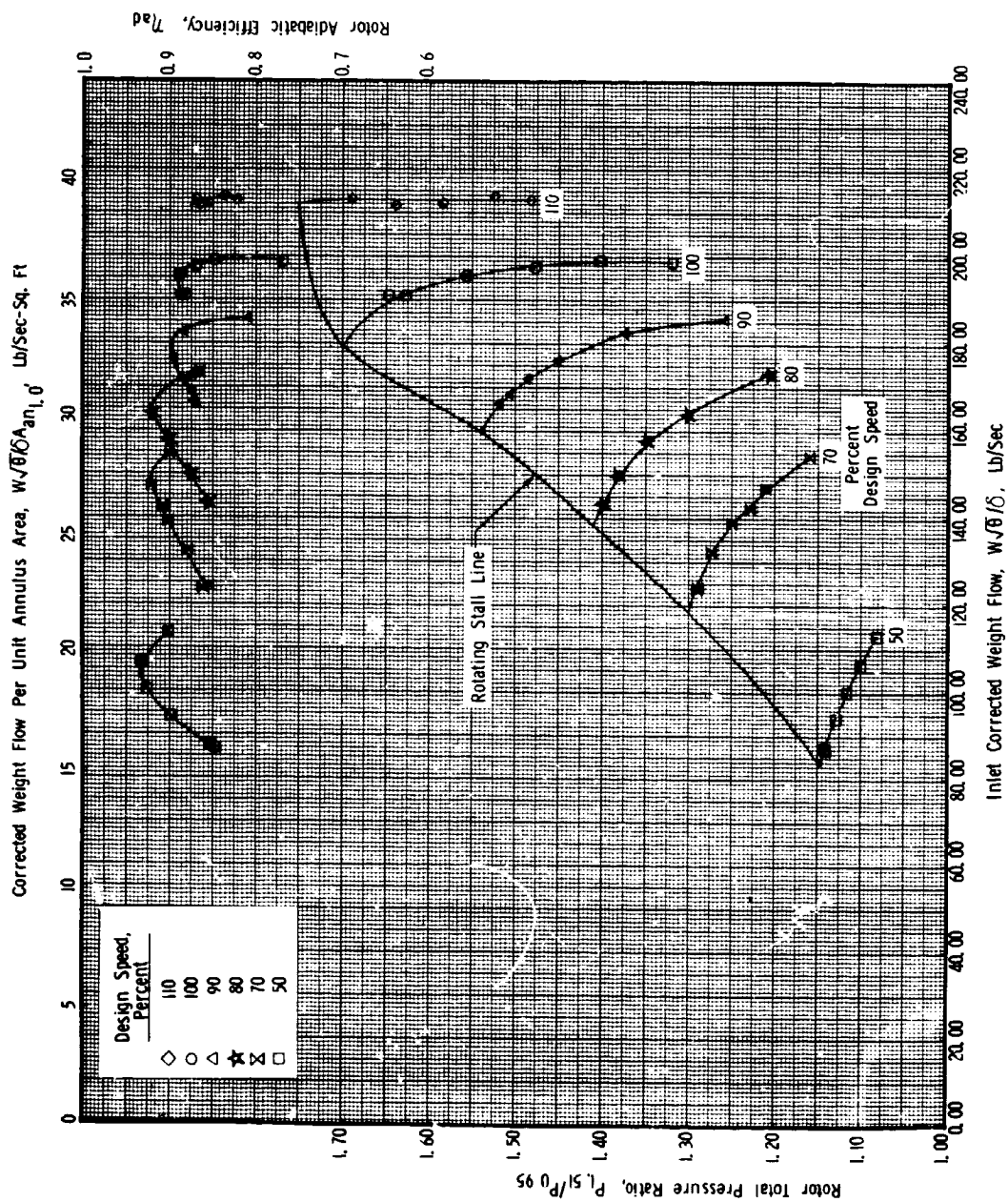


Figure 24. Rotor Performance Map for IGV/Stator Schedule 20°/4°.

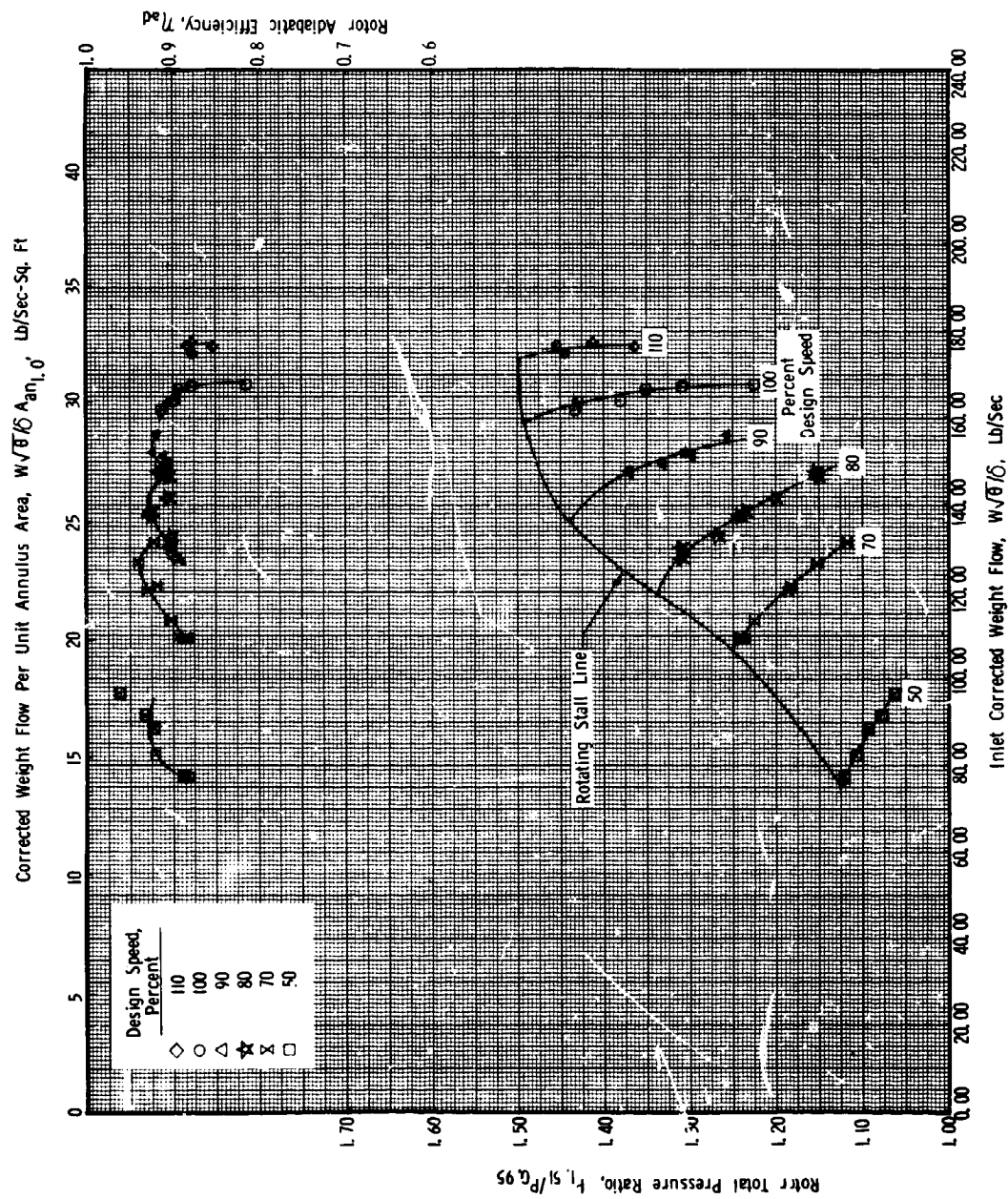


Figure 25. Rotor Performance Map for IGV/Stator Schedule 40°/8°.

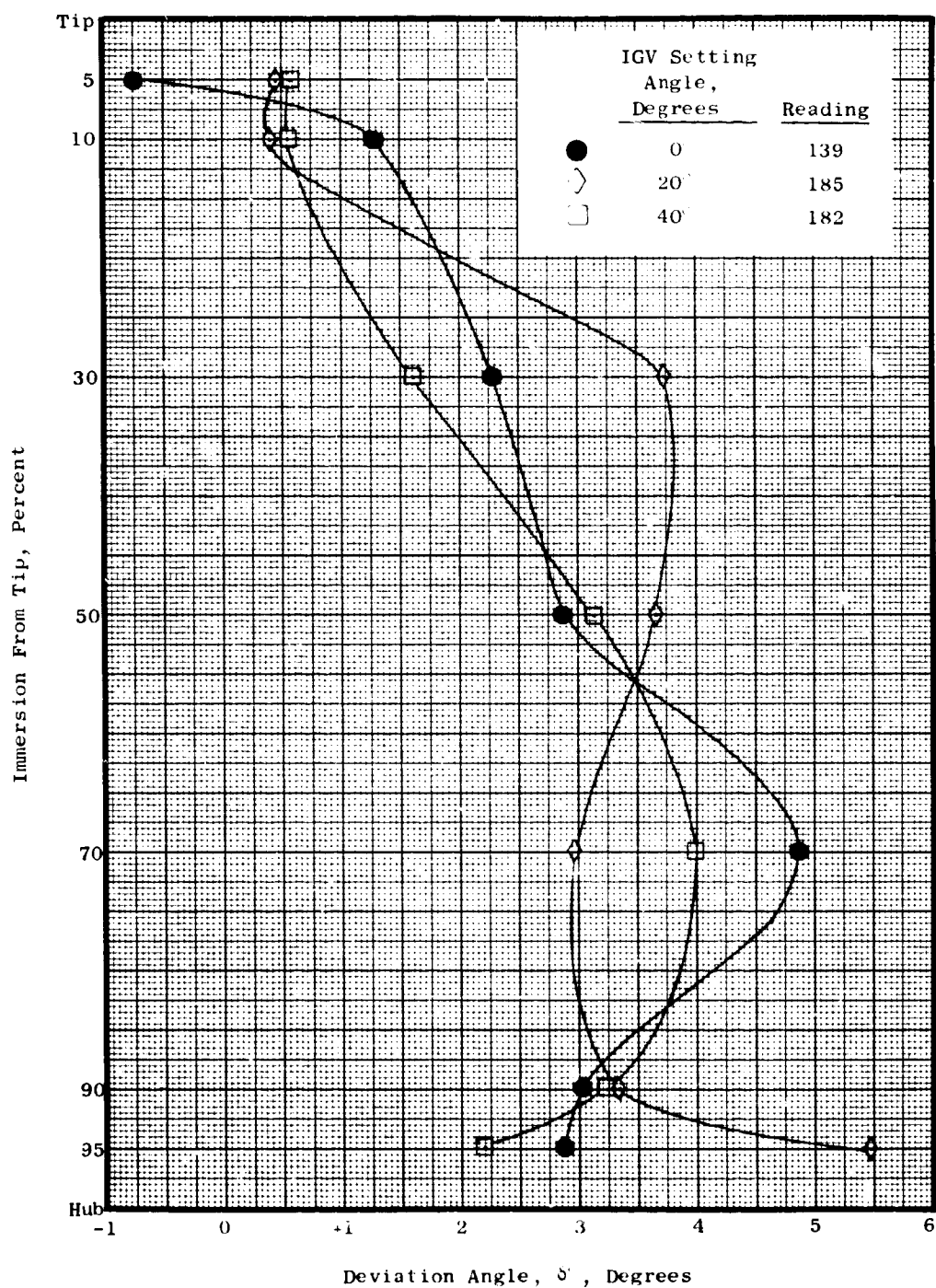


Figure 26. Radial Variation of IGV Deviation Angle at IGV Setting Angles of 0°, 20°, and 40°.

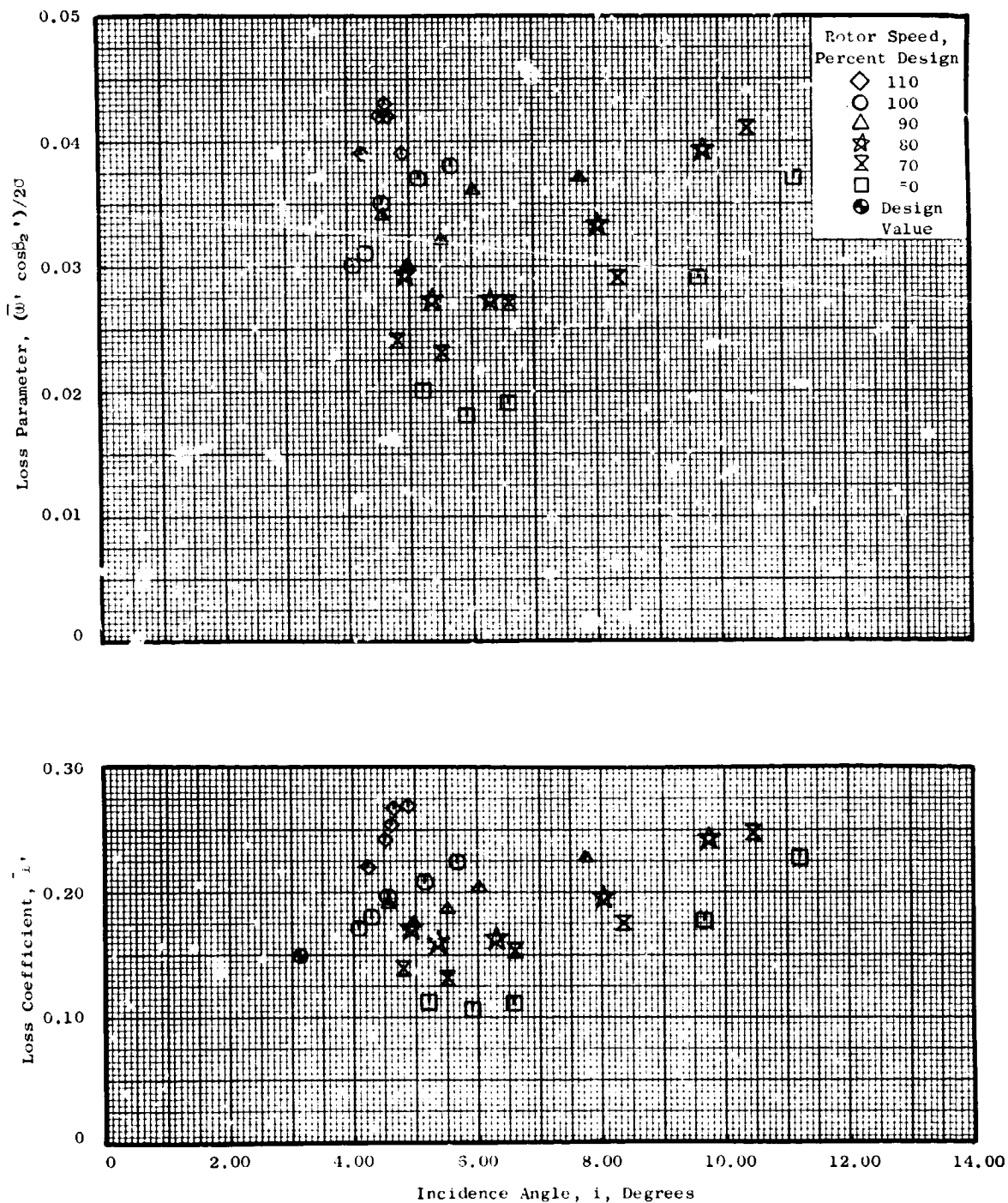


Figure 27 (a). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 5% Immersion from Tip.

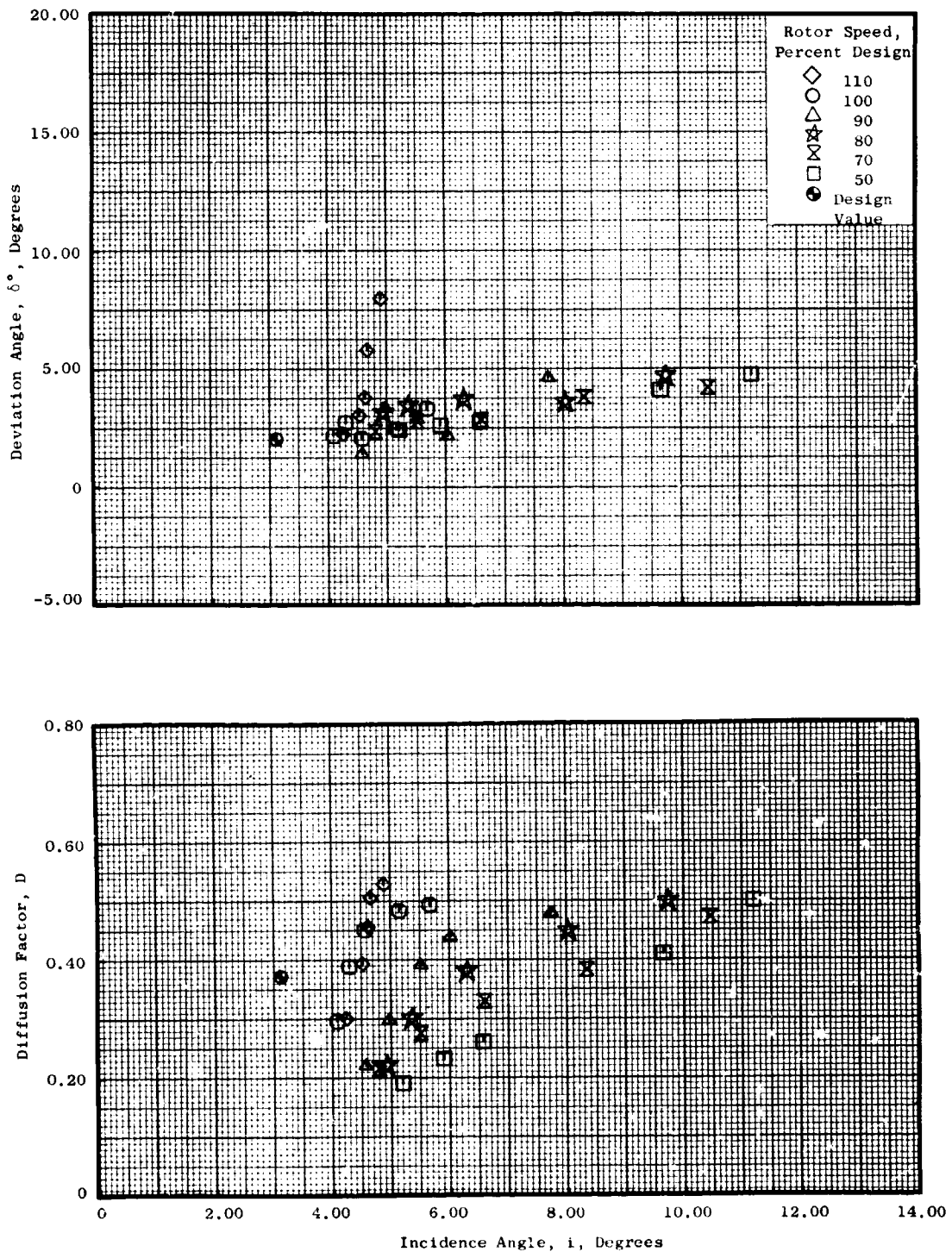


Figure 27 (a). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 5% Immersion from Tip (Concluded).

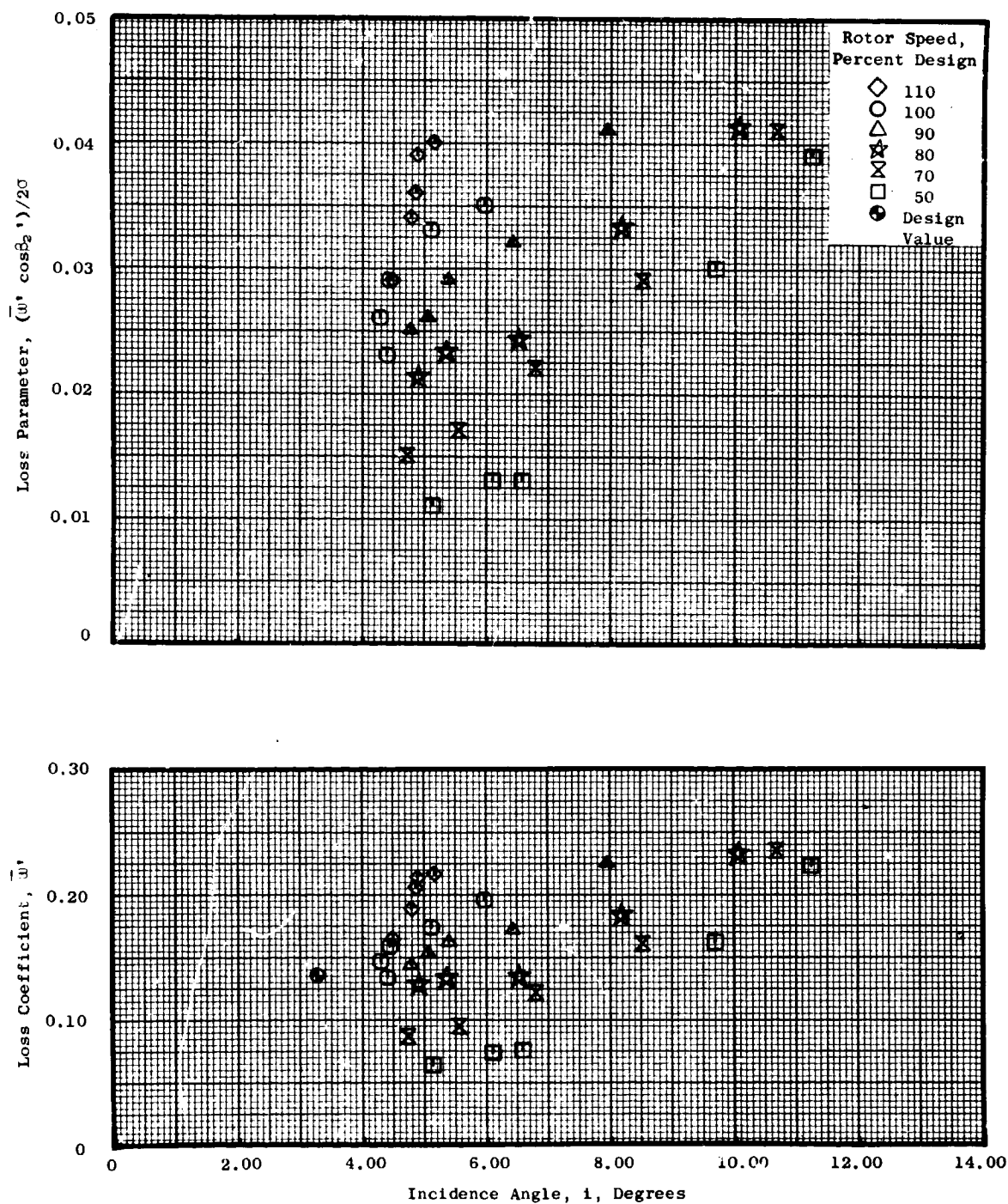


Figure 27 (b). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 10% Immersion from Tip.

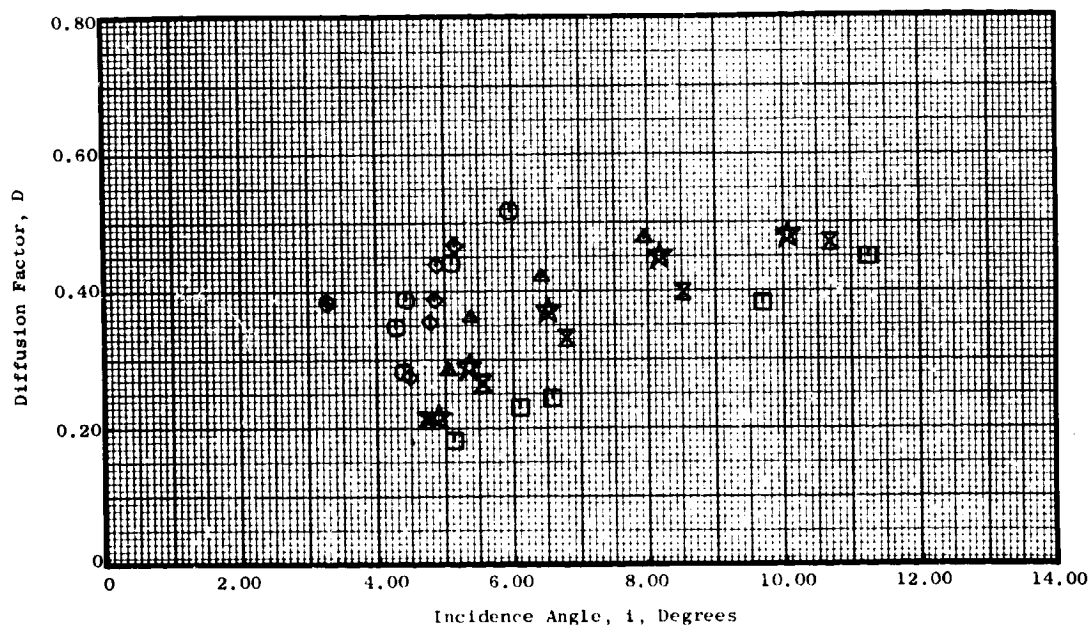
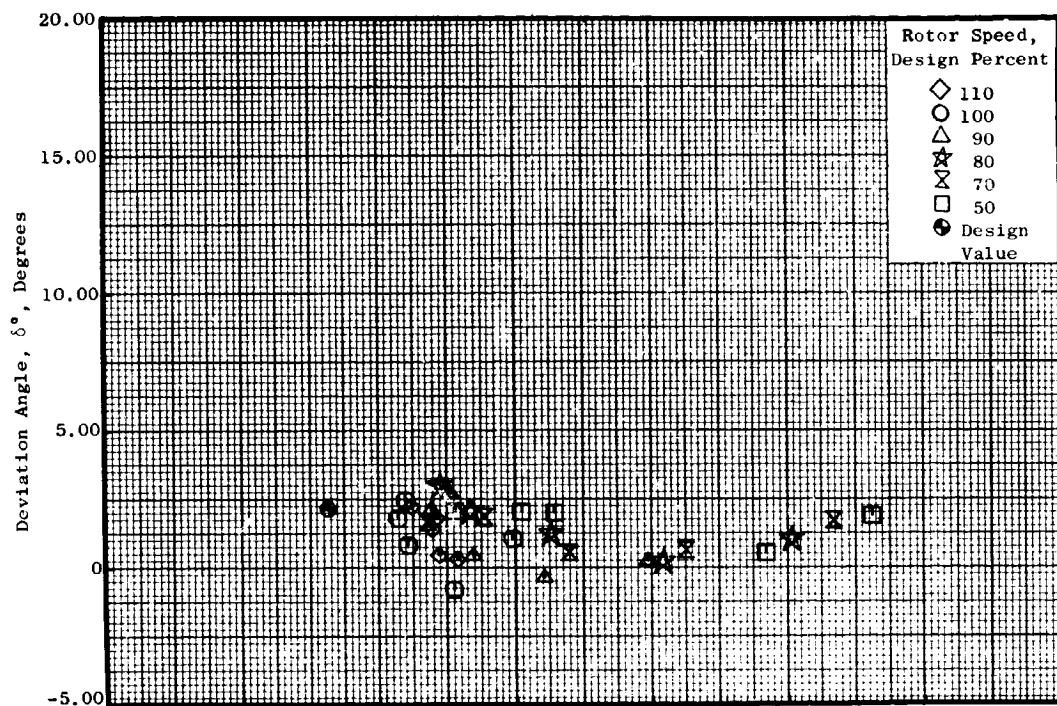


Figure 27 (L) Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 10% Immersion from Tip (Concluded).

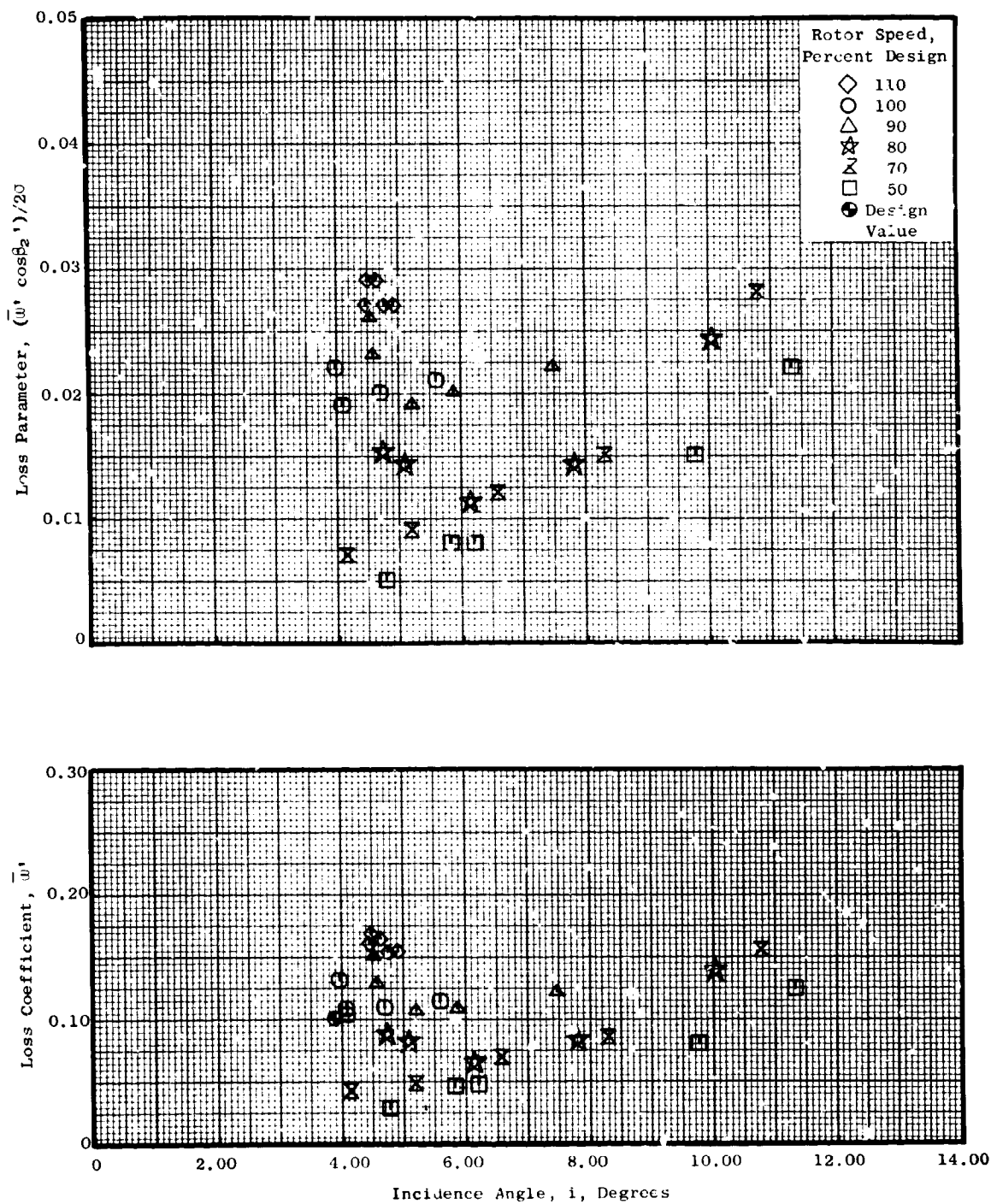


Figure 27 (c). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 30% Immersion from Tip.

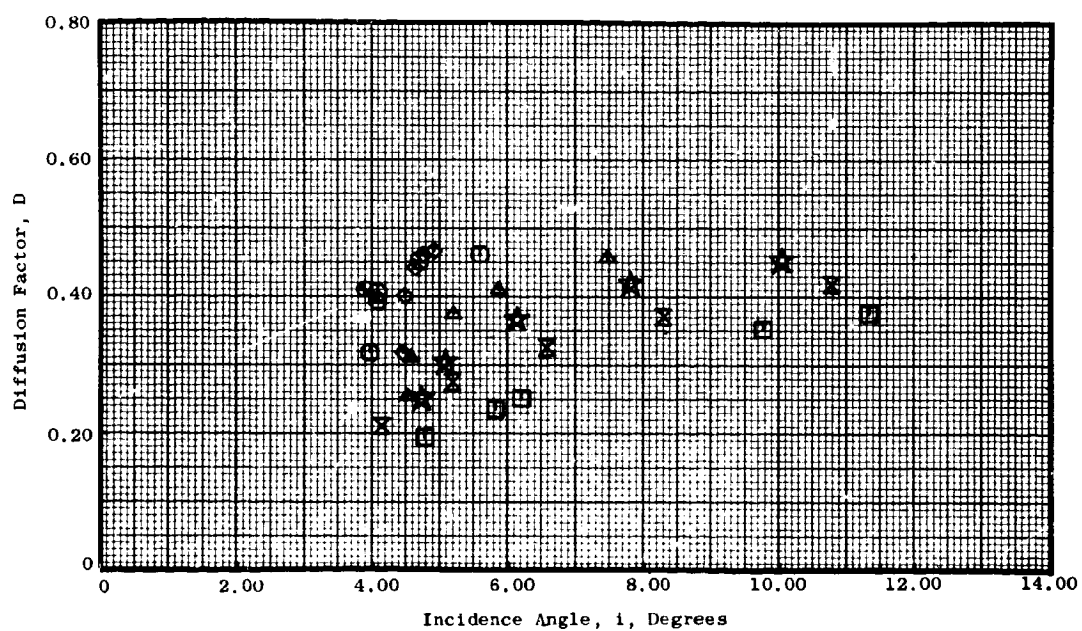
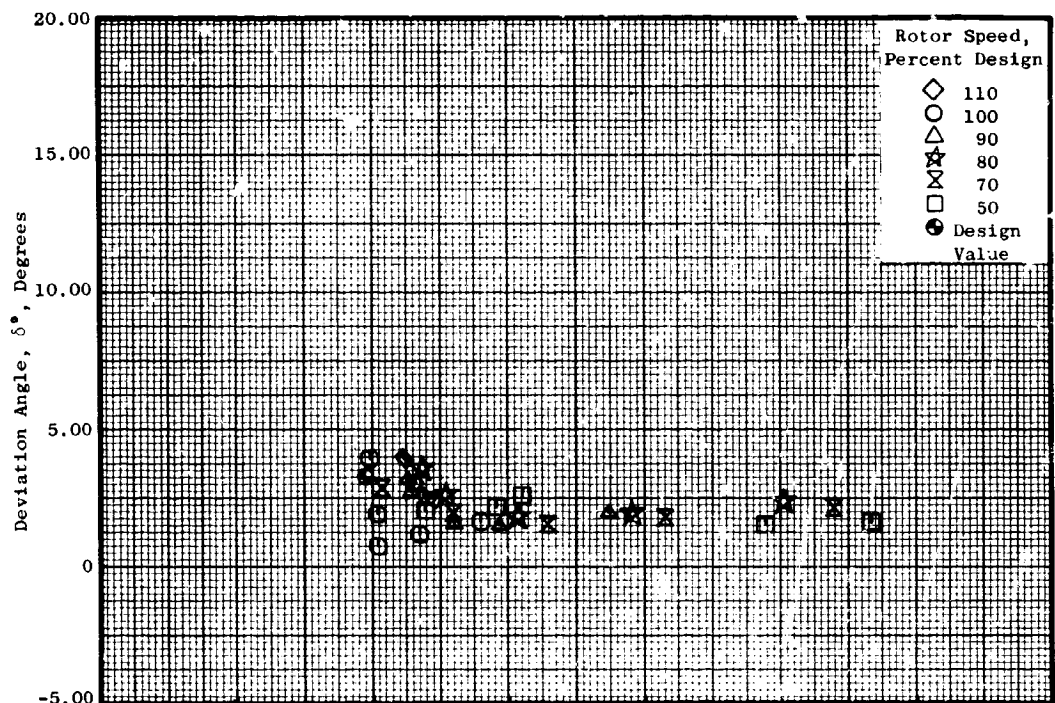


Figure 27 (c). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 30% Immersion from Tip (Concluded).

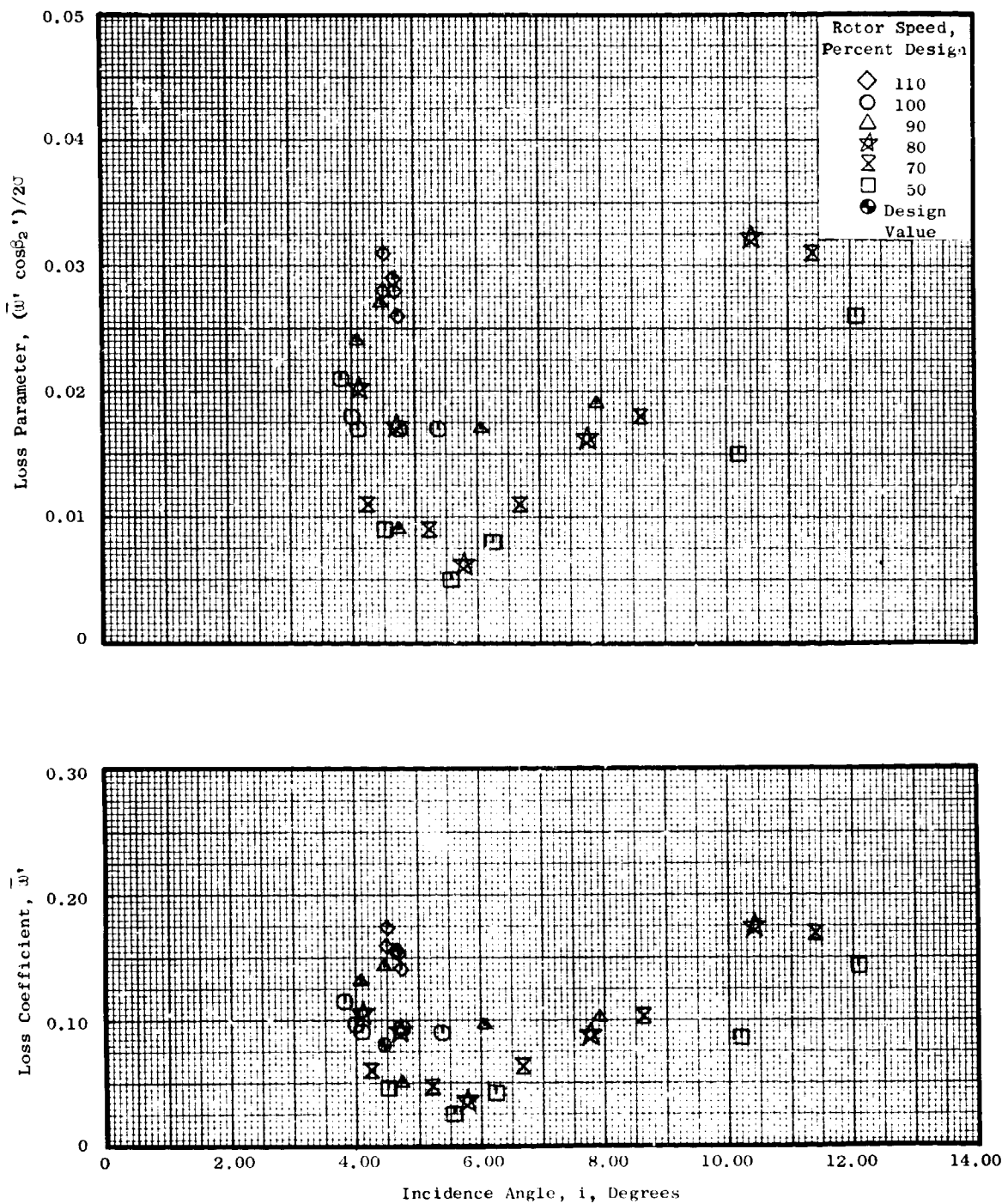


Figure 27 (d). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 50% Immersion from Tip.

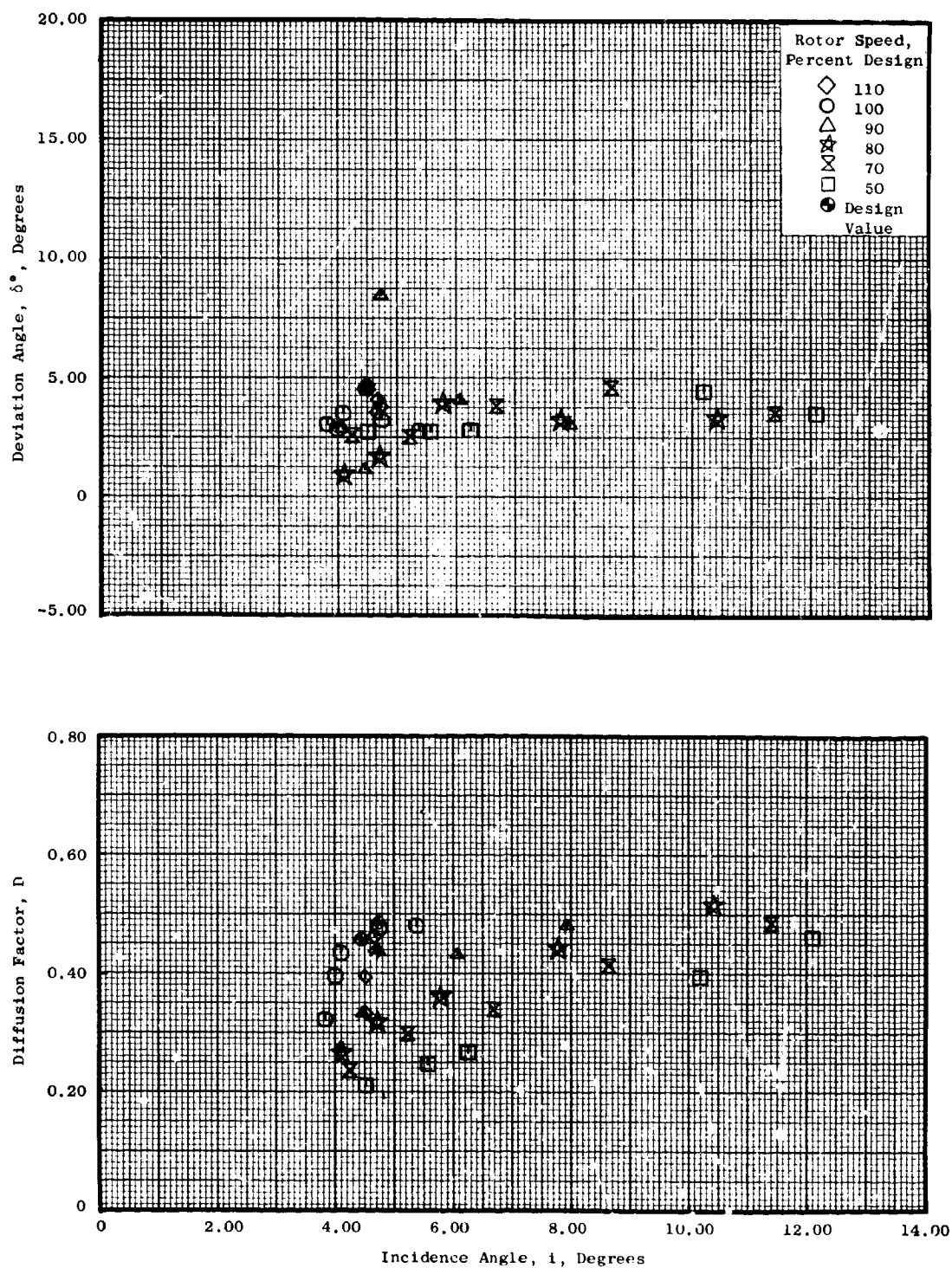


Figure 27 (d). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 50% Immersion from Tip (Concluded).

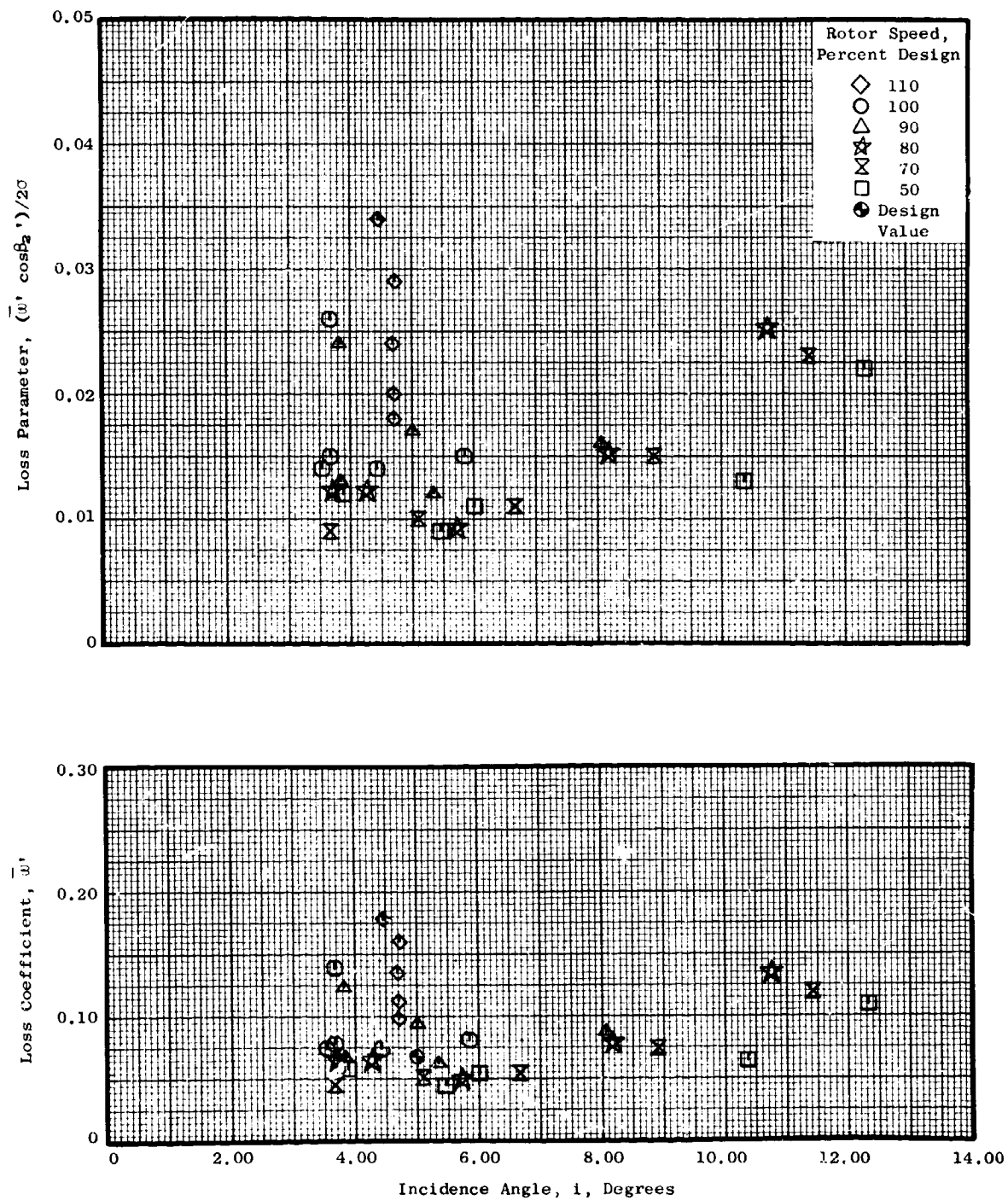


Figure 27 (e). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 70% Immersion from Tip.

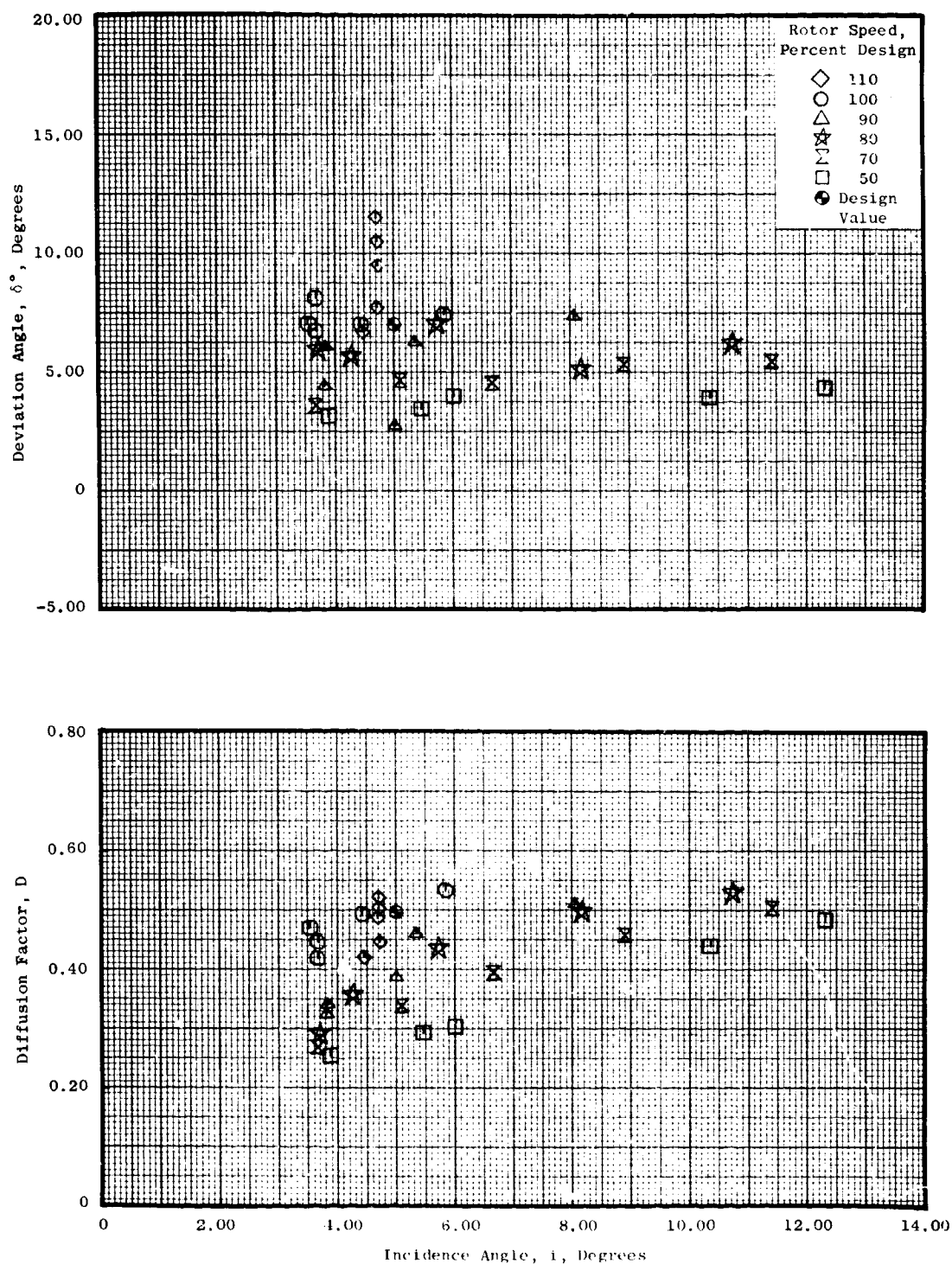


Figure 27 (e). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 70% Immersion from Tip (Concluded).

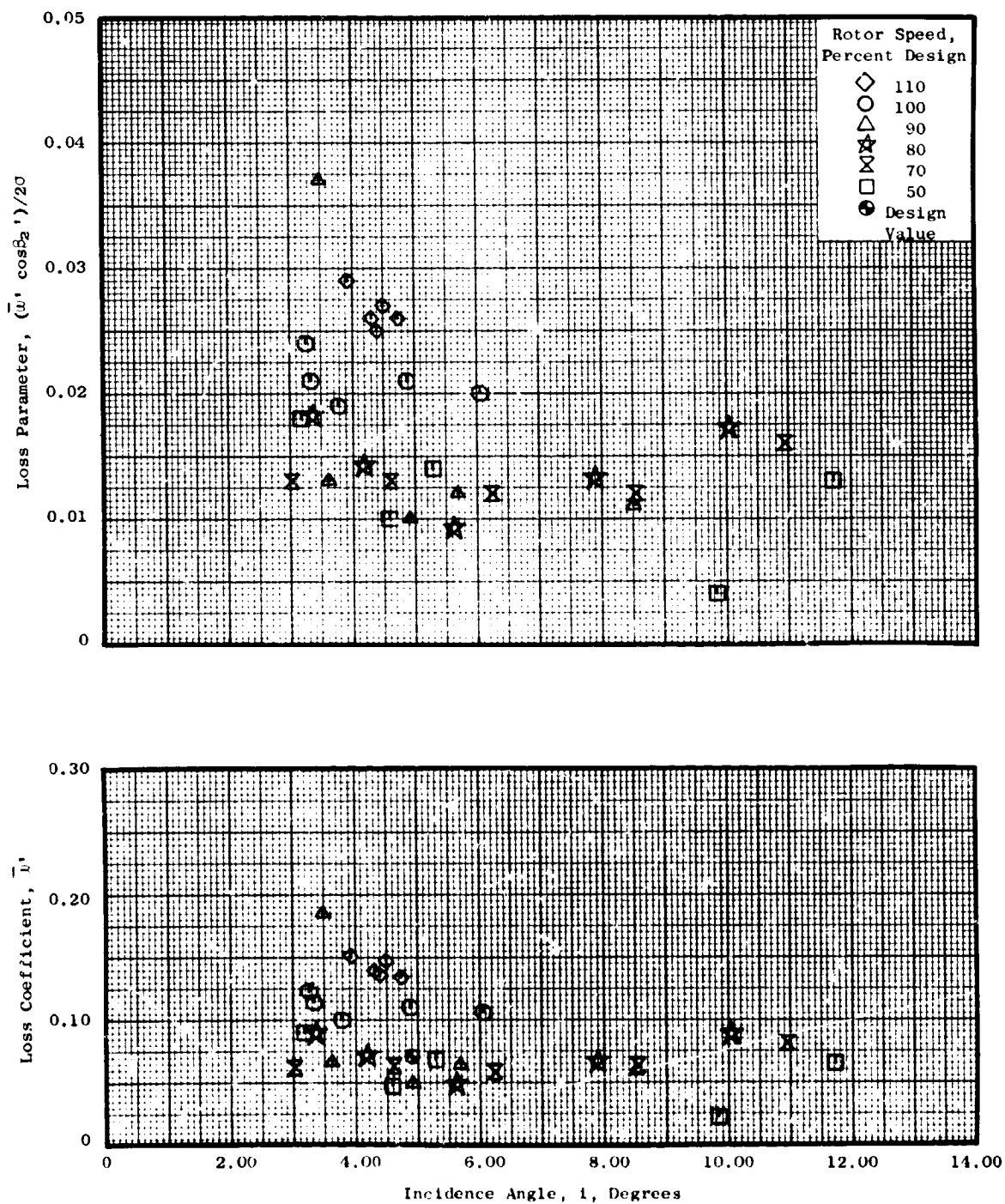


Figure 27 (f). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 90% Immersion from Tip.

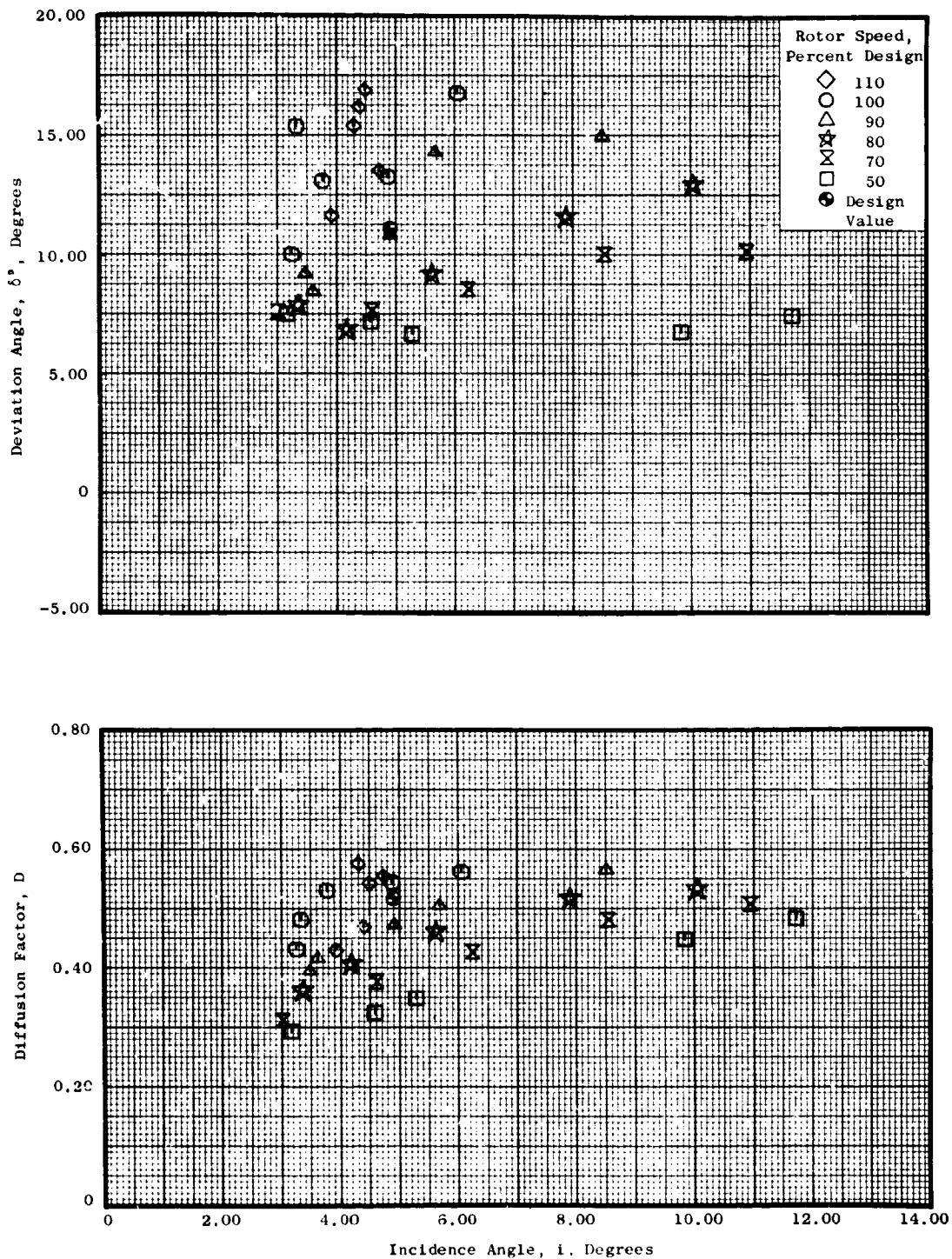


Figure 27 (f). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 90% Immersion from Tip (Concluded).

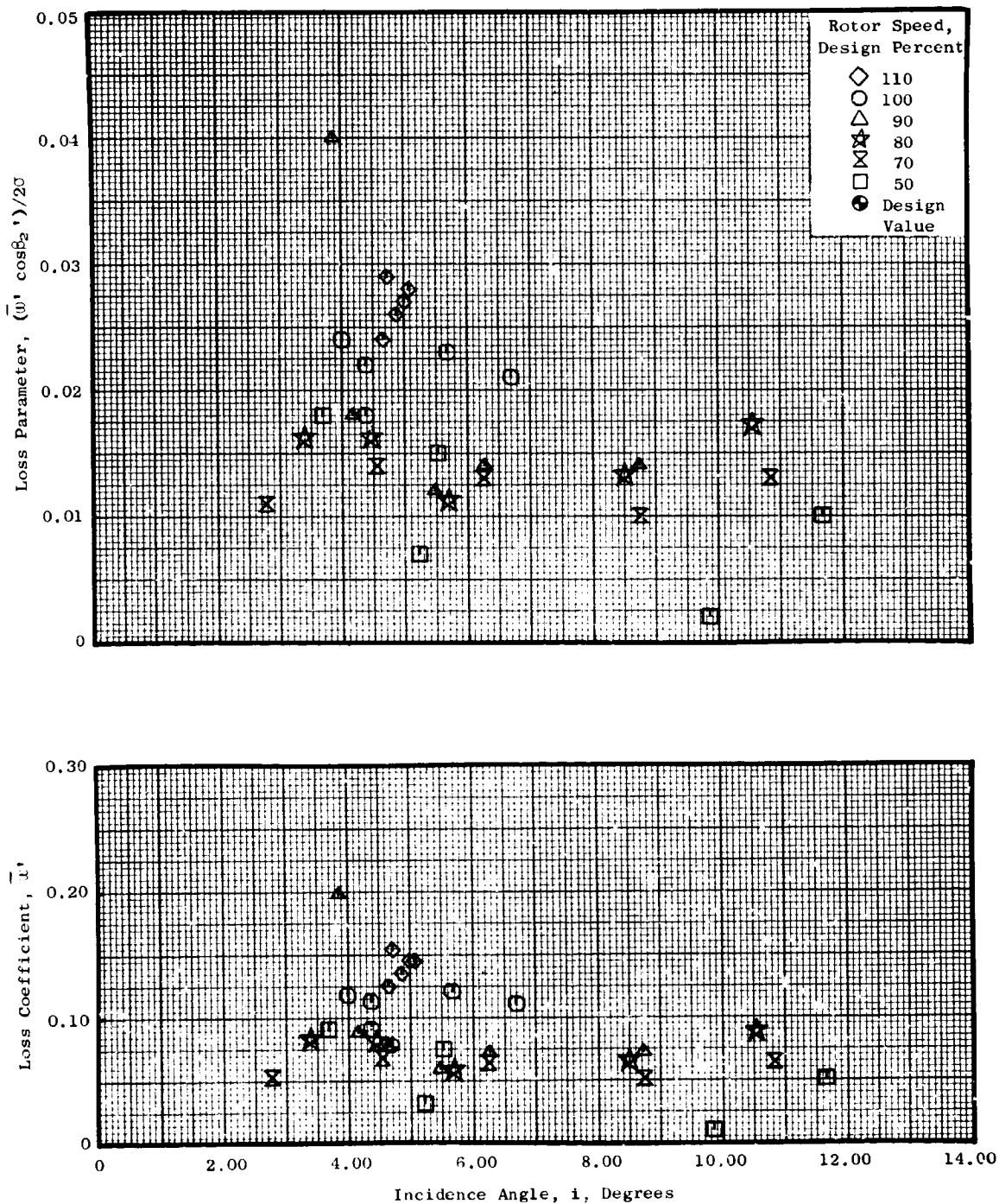


Figure 27 (g) Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 95% Immersion from Tip.

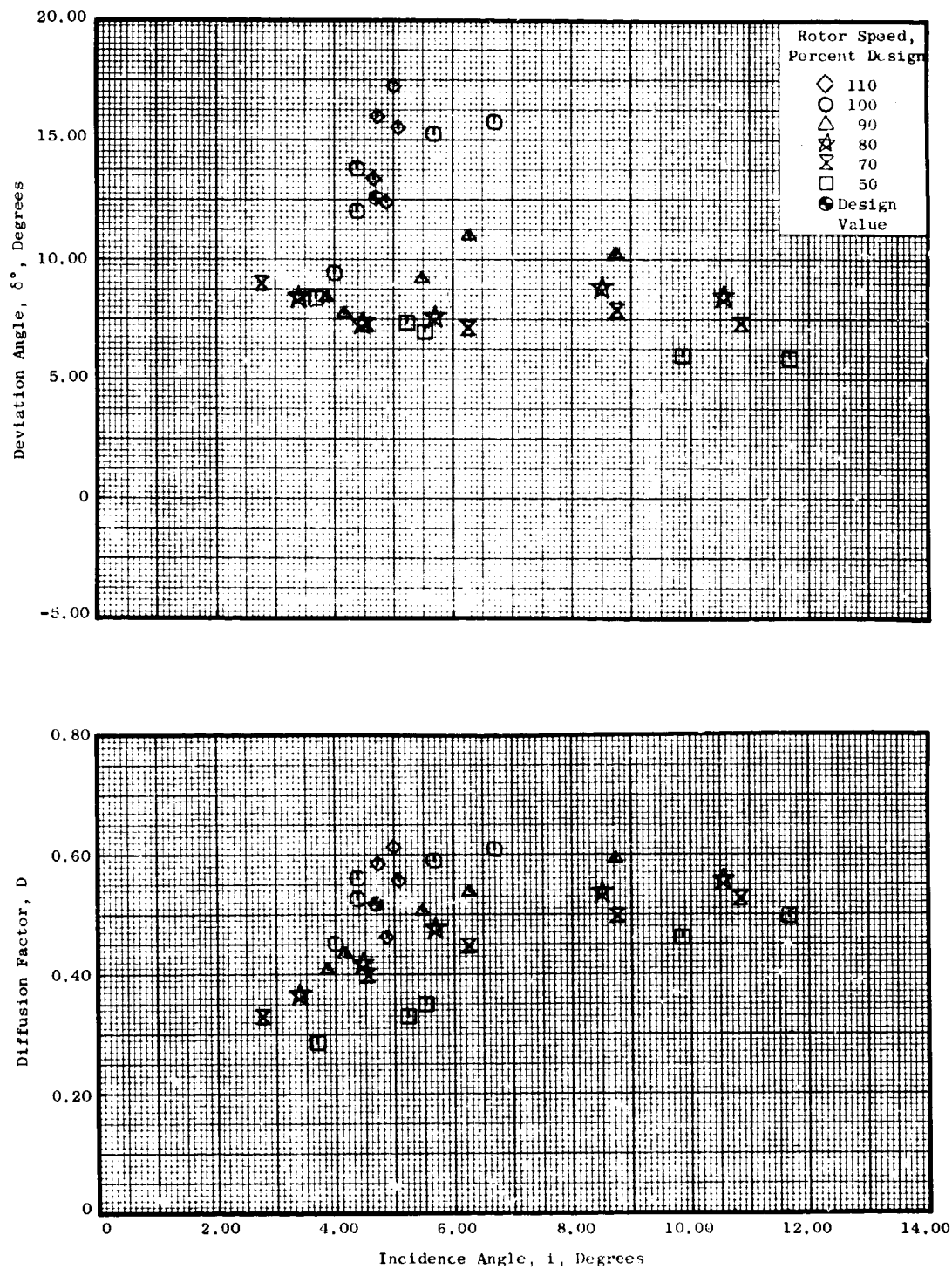


Figure 27 (g). Rotor Blade Element Data for IGV/Stator Schedule $0^\circ/0^\circ$, at 95% Immersion from Tip (Concluded).

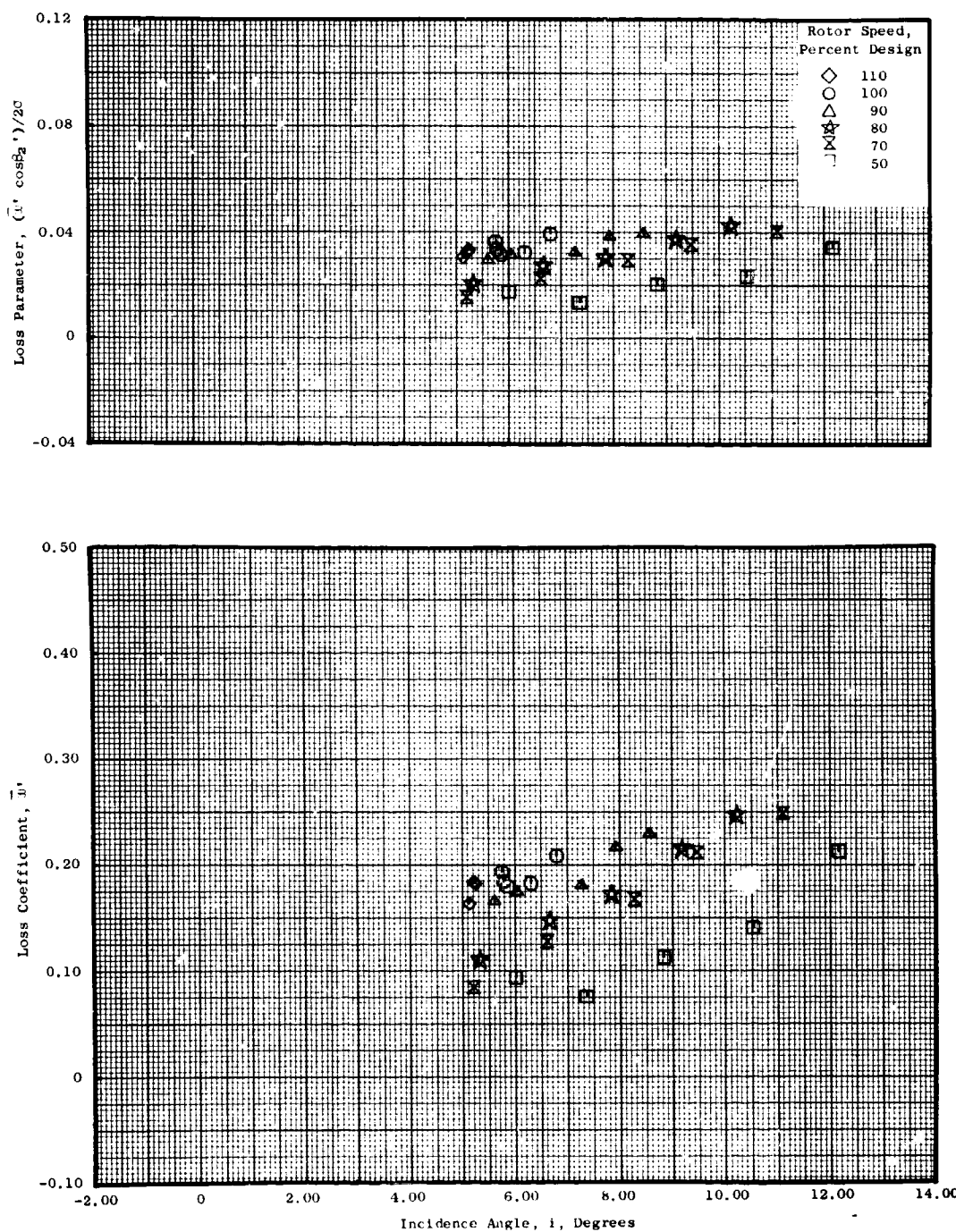


Figure 28 (a). Rotor Blade Element Data for IGV/Stator Schedule $26^\circ/4^\circ$ at 5% Immersion from Tip.

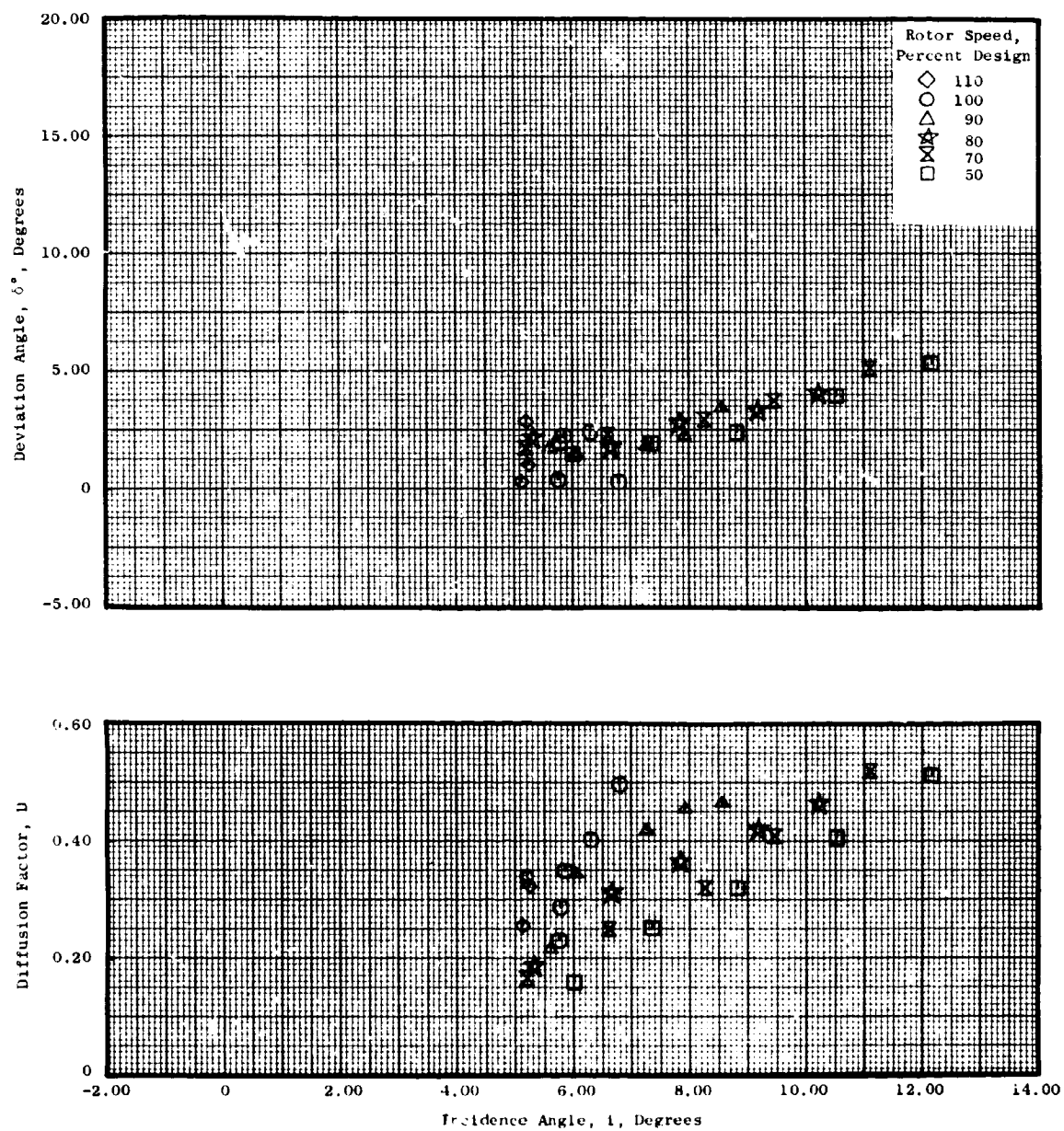


Figure 28 (a). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 5% Immersion from Tip (Concluded).

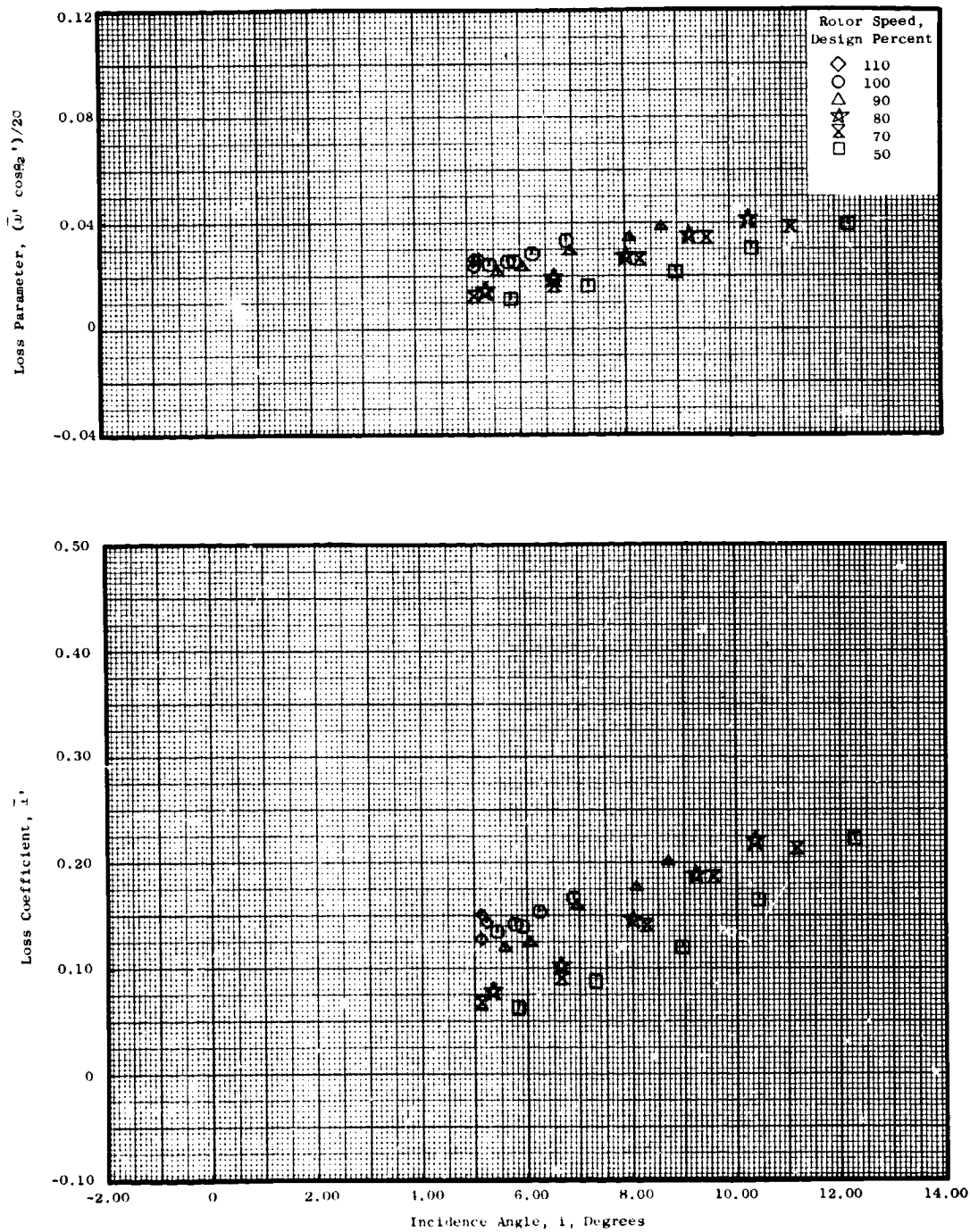


Figure 28 (b). Rotor Blade Element Data for IGV/Stator Schedule $20\frac{3}{4}^\circ$ at 10% Immersion from Tip.

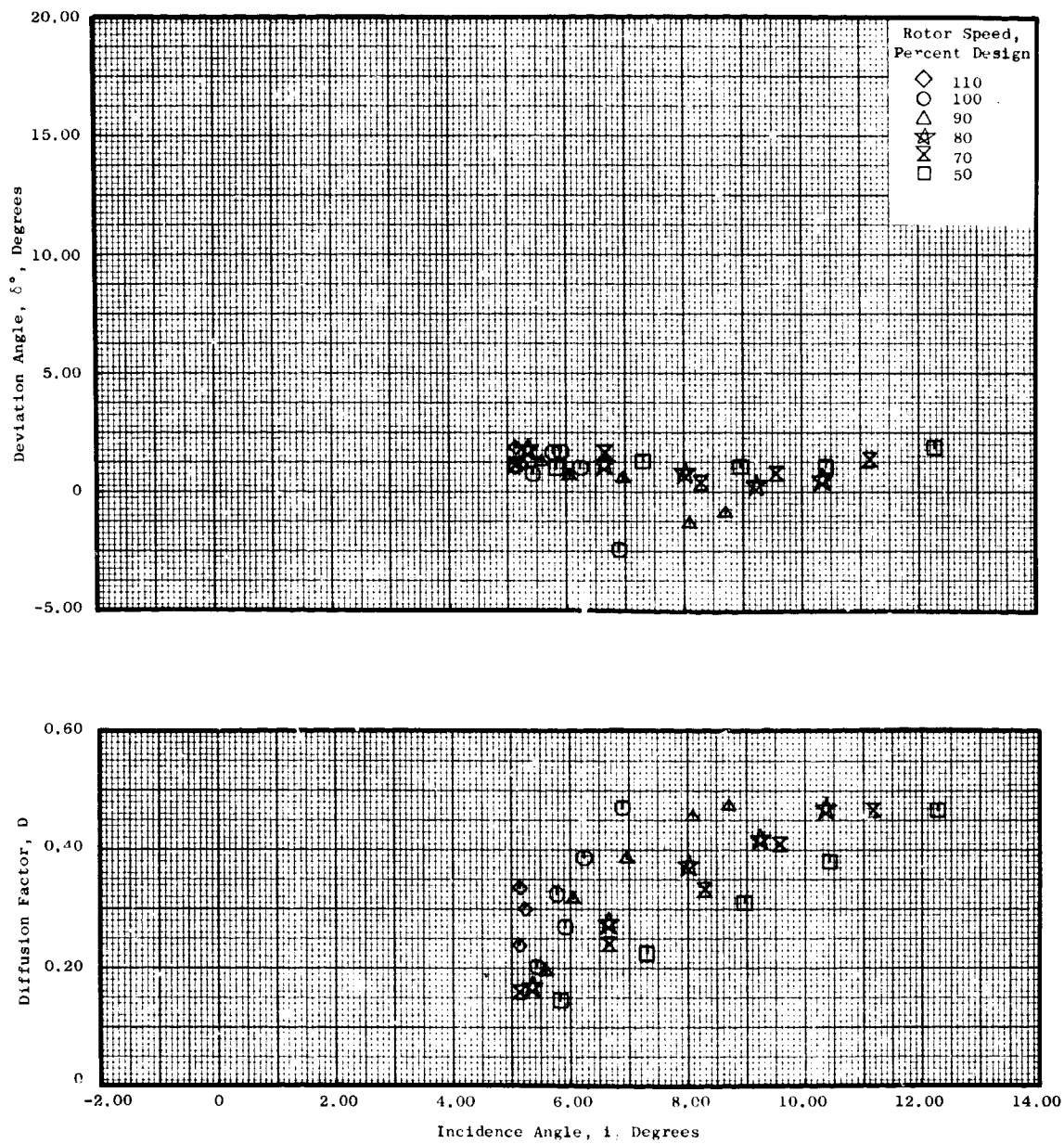


Figure 28 (b). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 10% Immersion from Tip (Concluded).

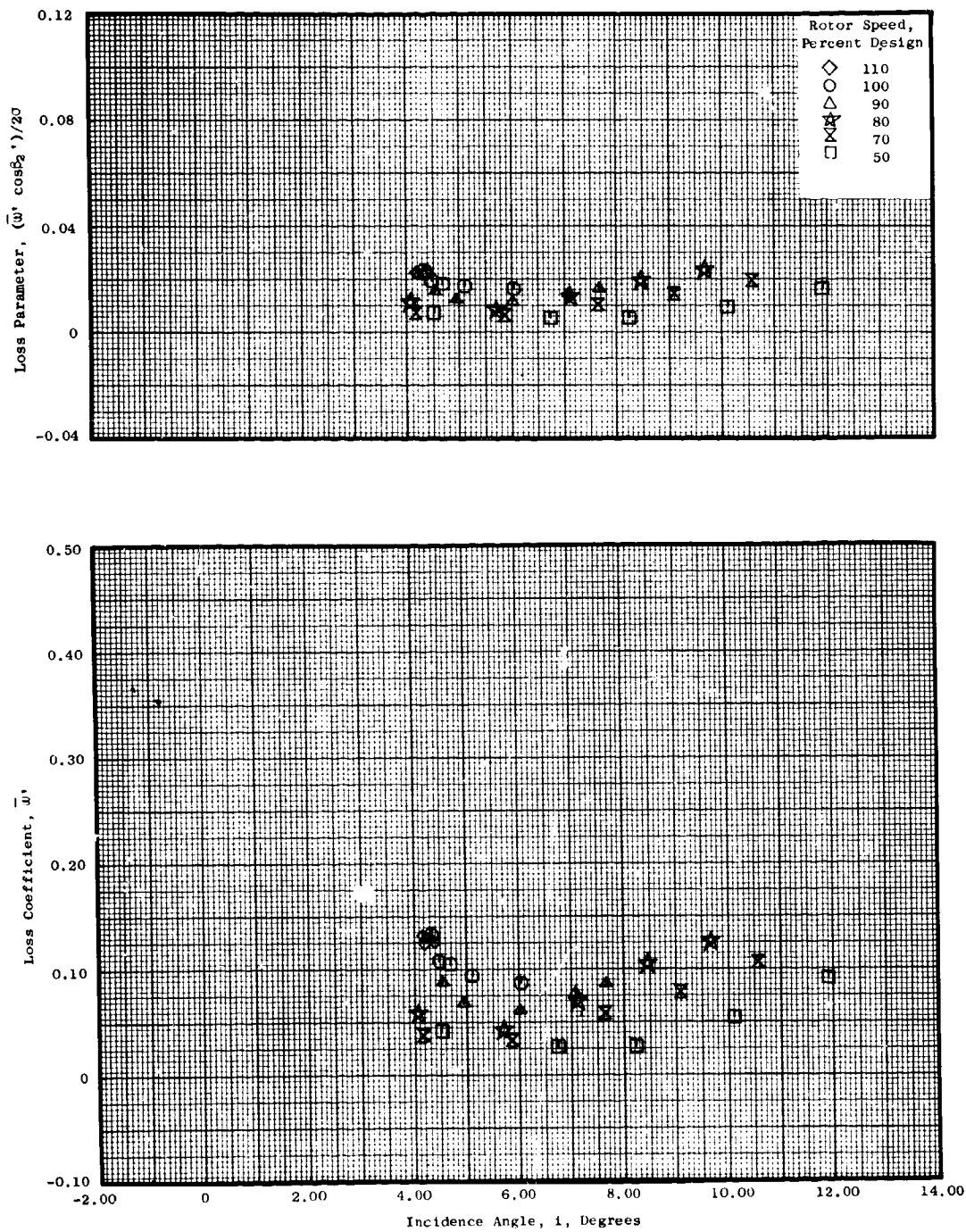


Figure 28 (c). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 30% Immersion from Tip.

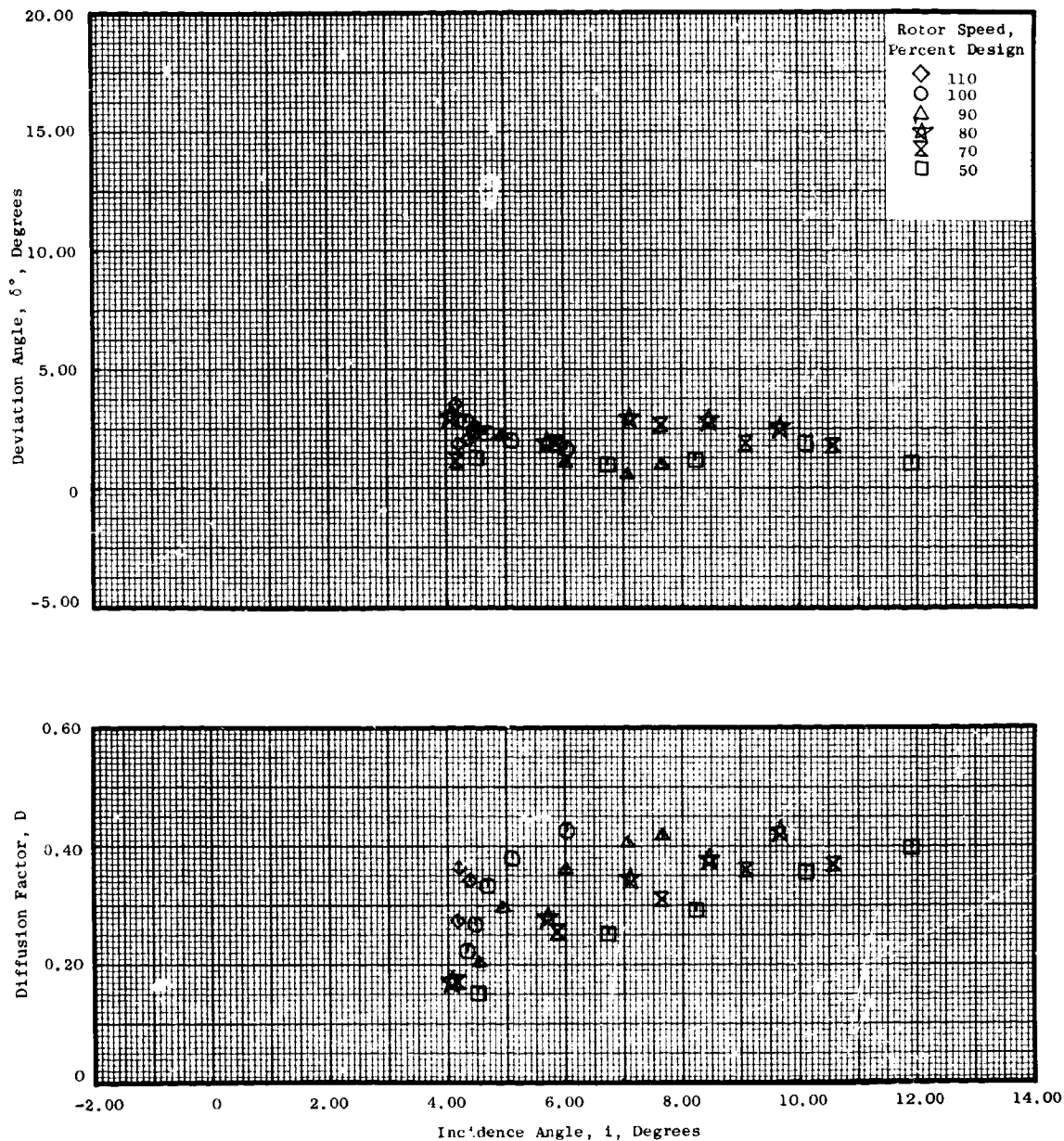


Figure 28 (c). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 30% Immersion from Tip (Concluded).

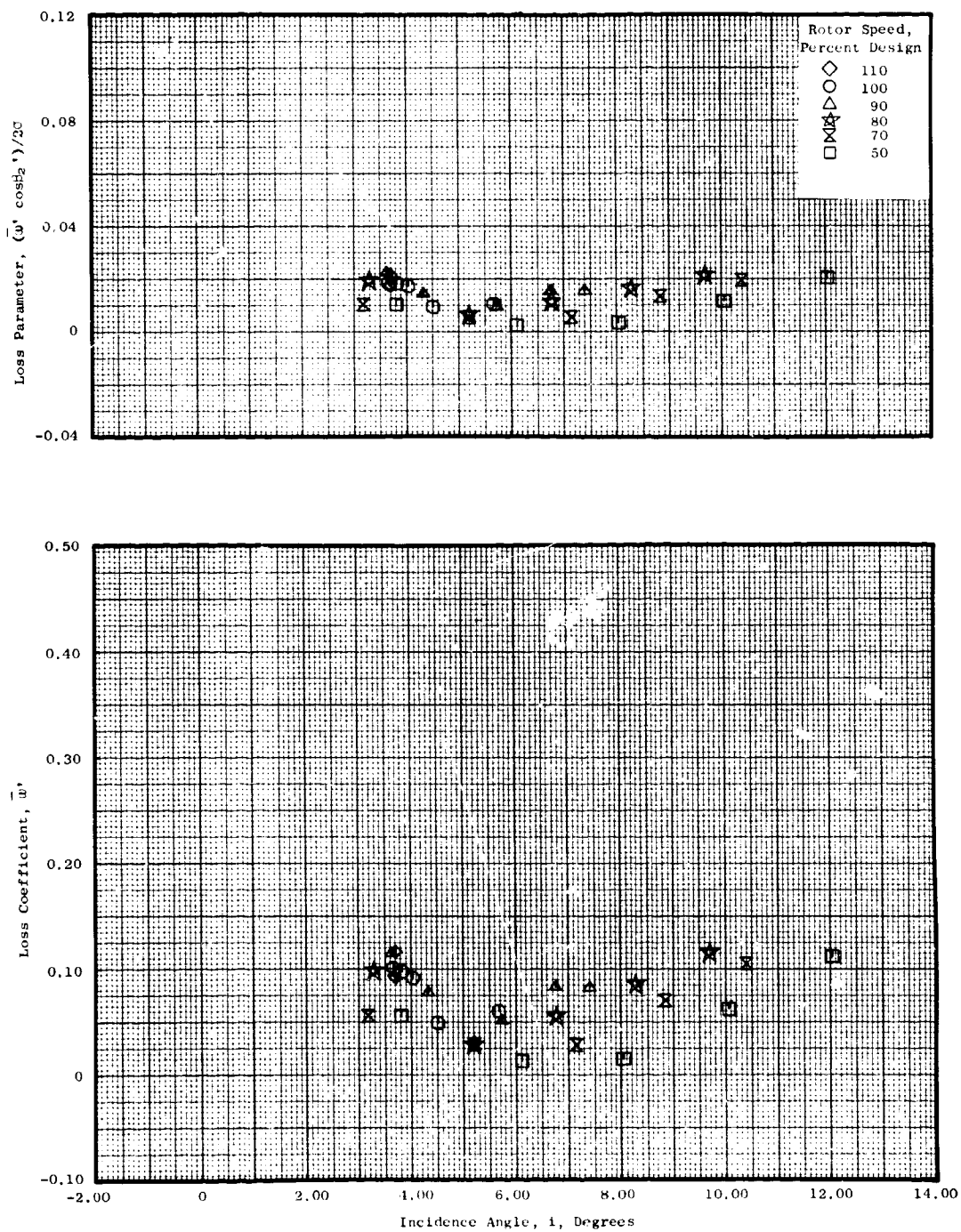


Figure 28 (d). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 50% Immersion from Tip.

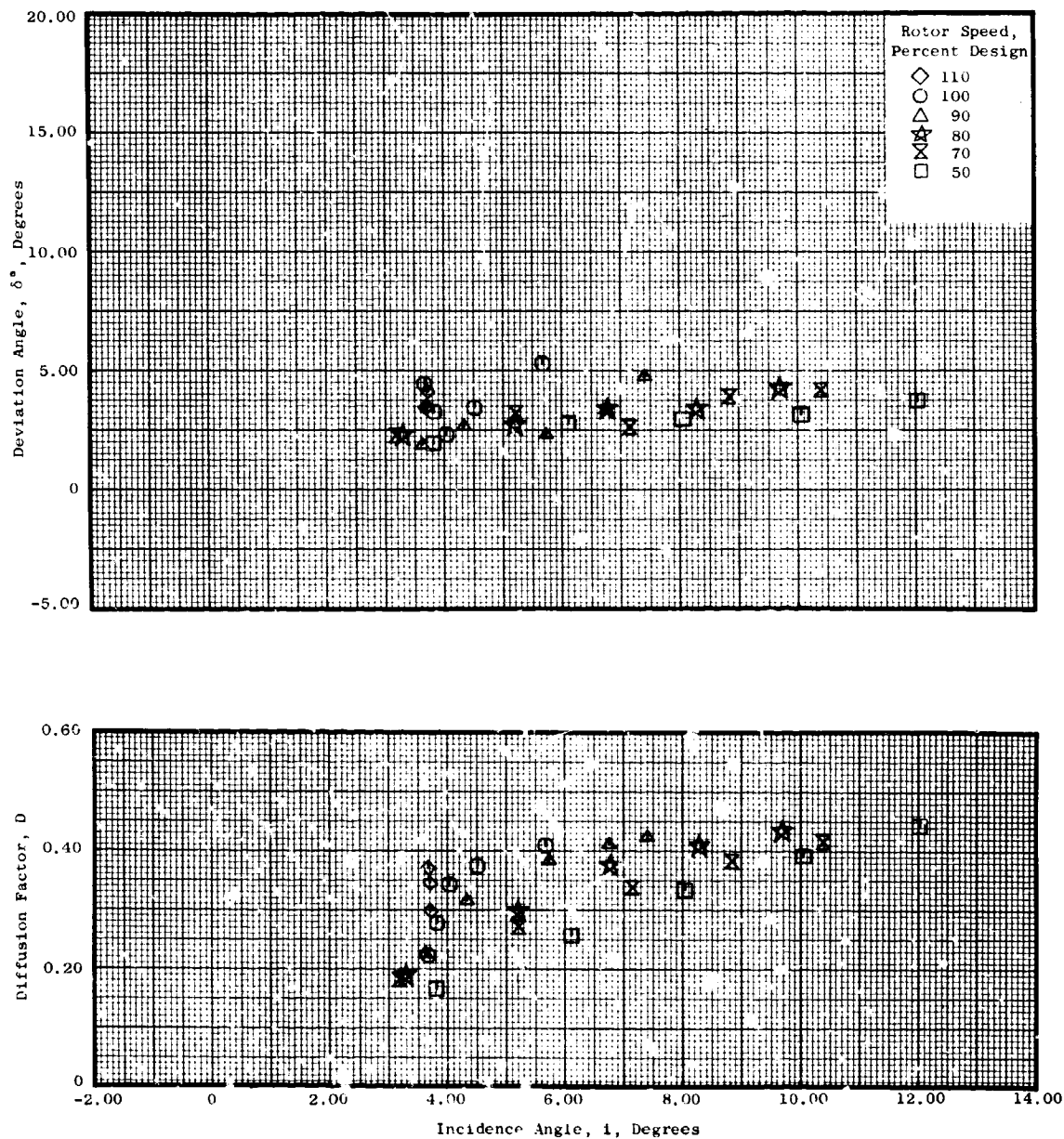


Figure 28 (d). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 50% Immersion from Tip (Concluded).

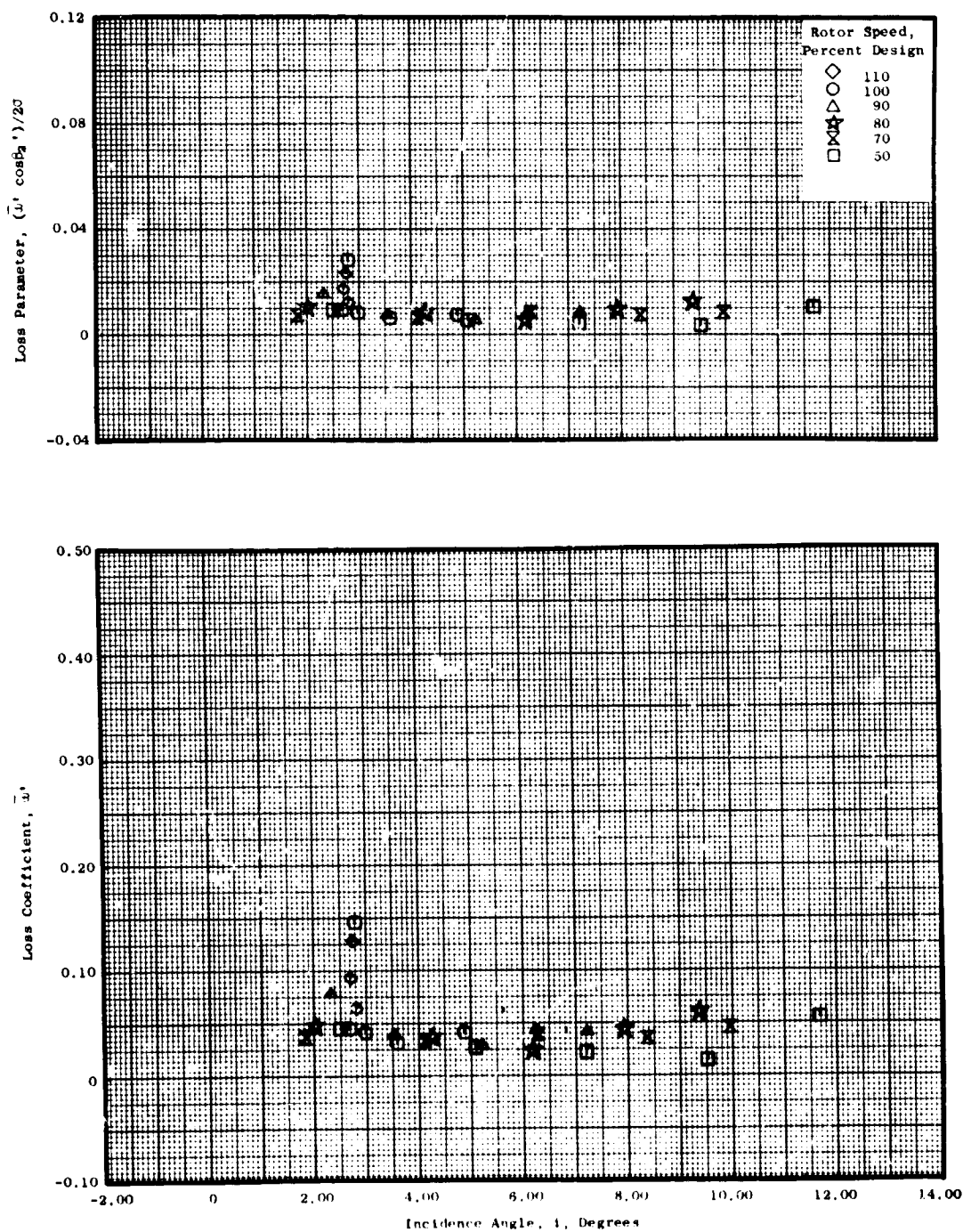


Figure 28 (c). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 70% Immersion from Tip.

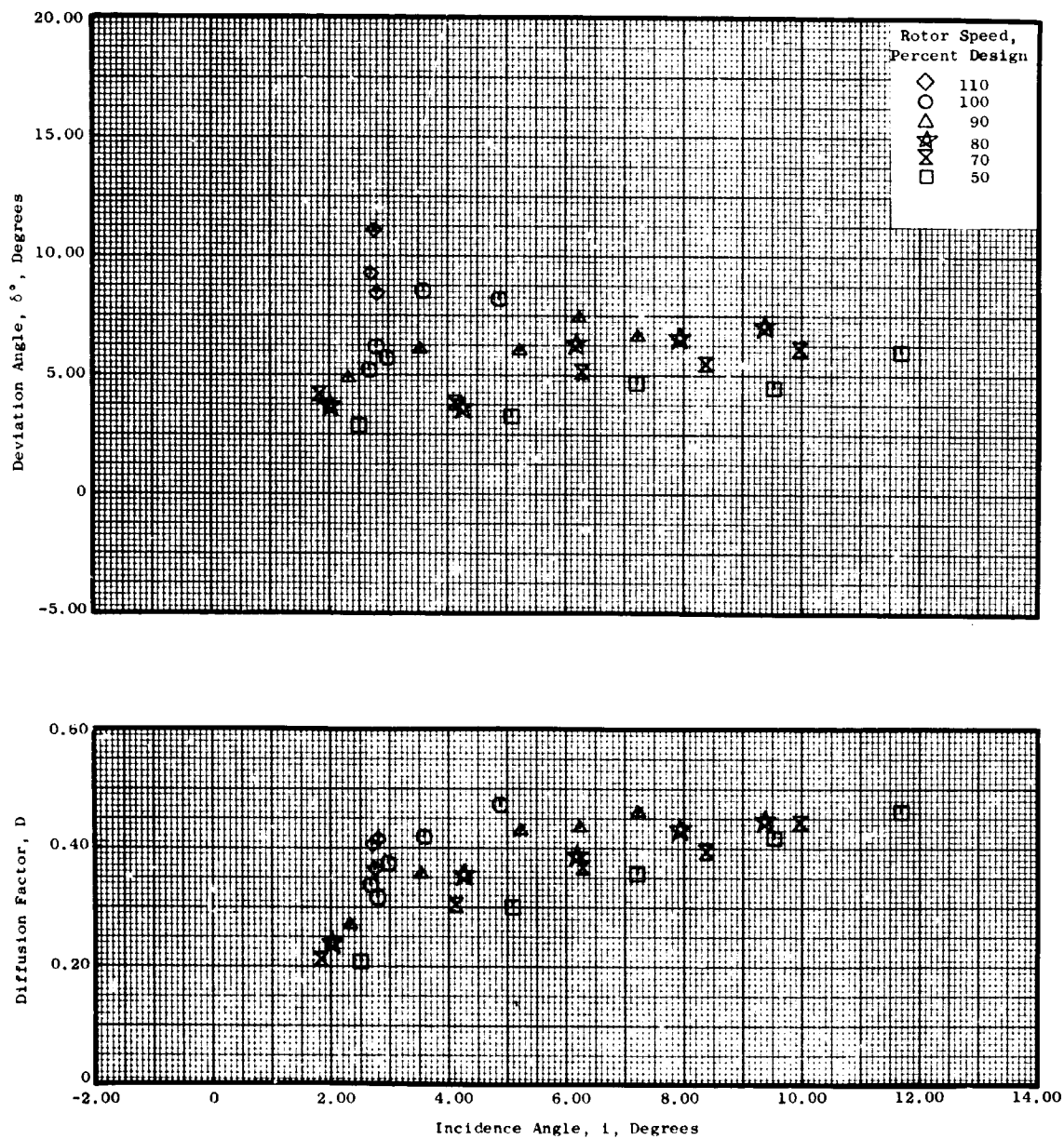


Figure 28 (e). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 70% Immersion from Tip (Concluded).

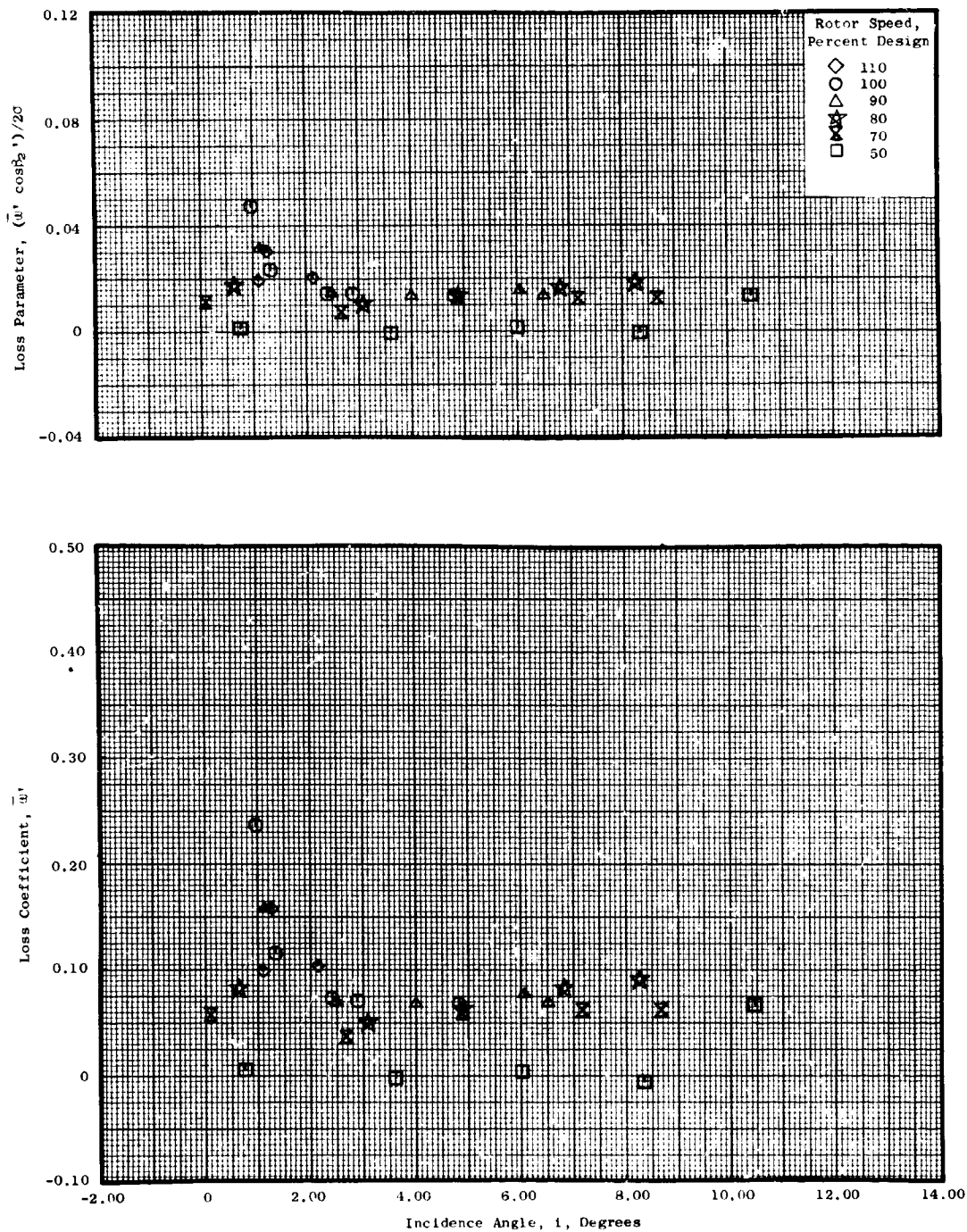


Figure 28 (f). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 90% Immersion from Tip.

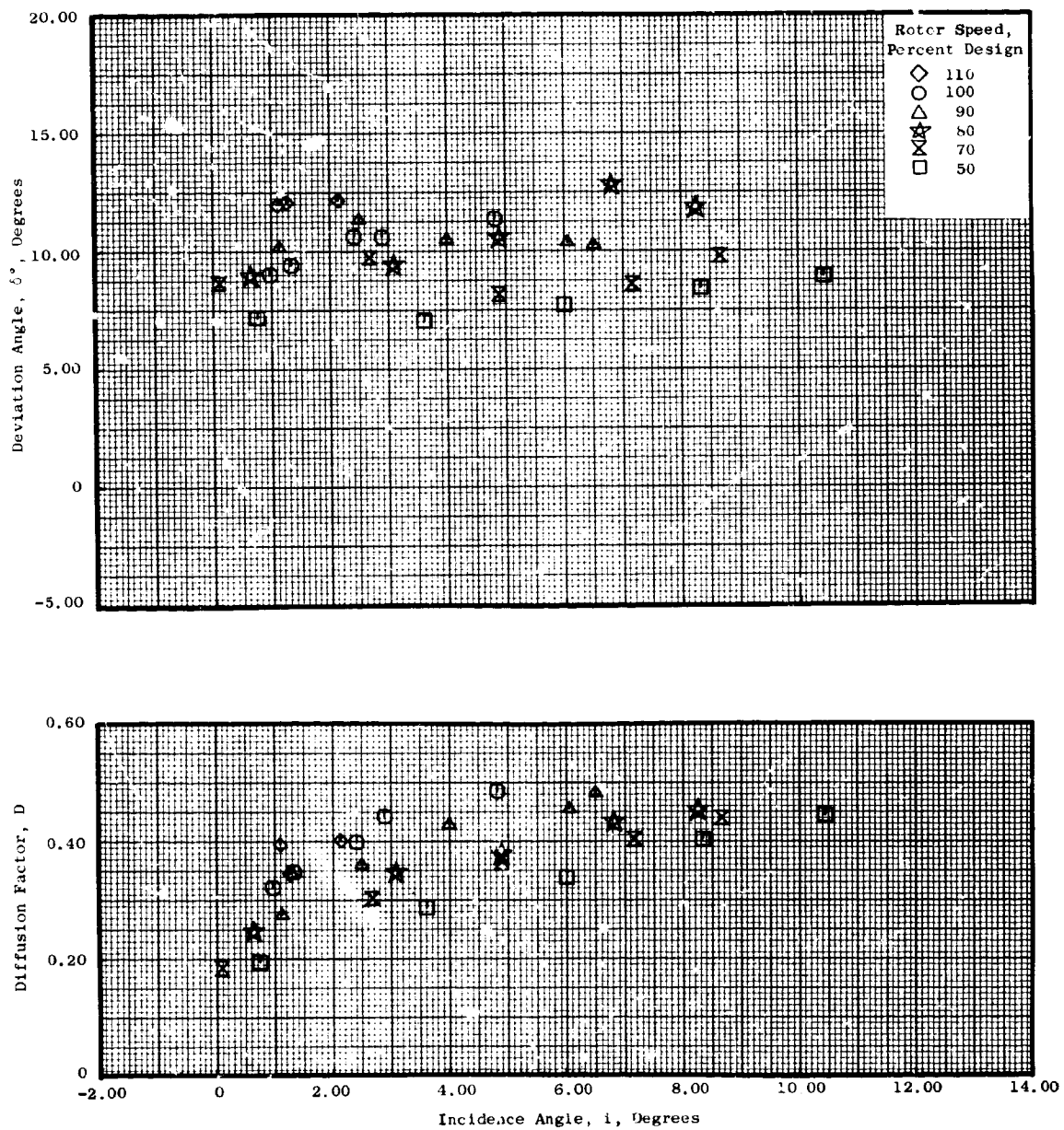


Figure 28 (f). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 90% Immersion from Tip (Concluded).

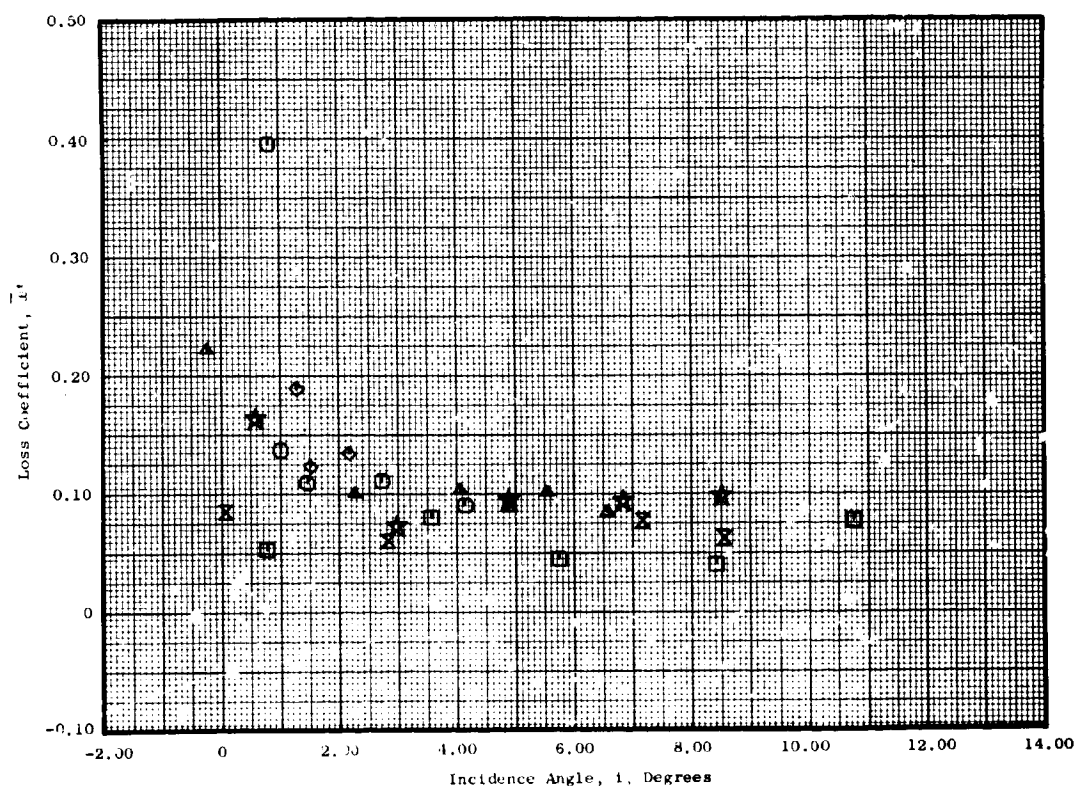
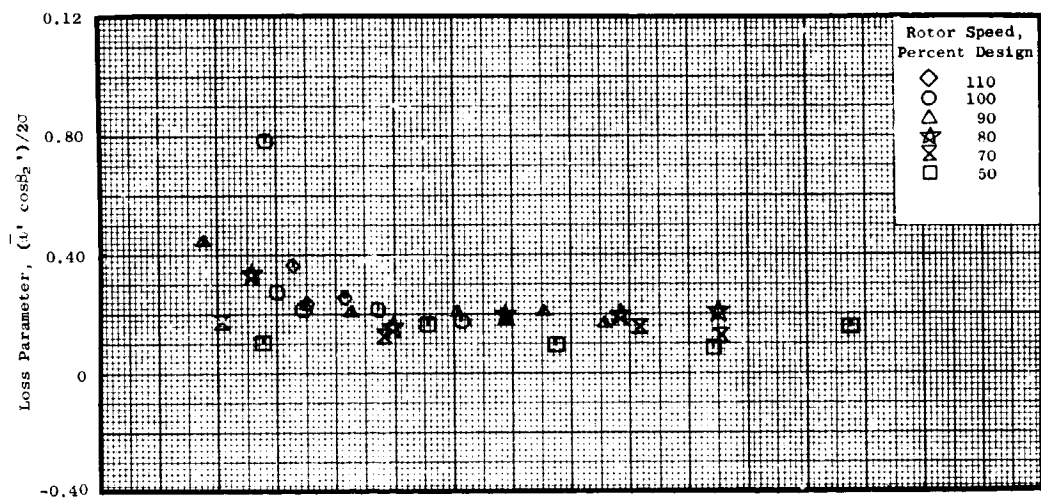


Figure 28 (g). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 95% Immersion from Tip.

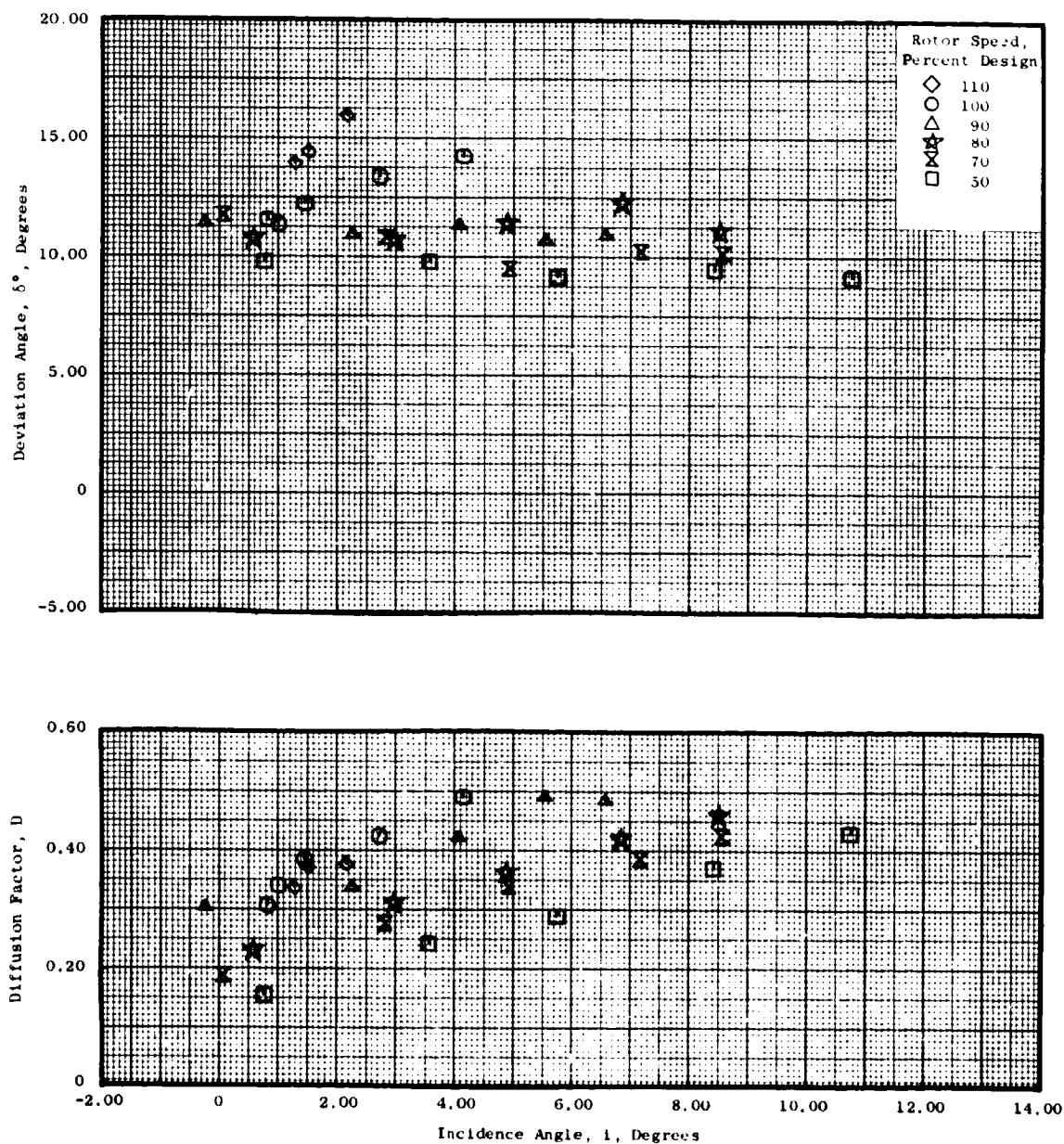


Figure 28 (g). Rotor Blade Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 95% Immersion from Tip (Concluded).

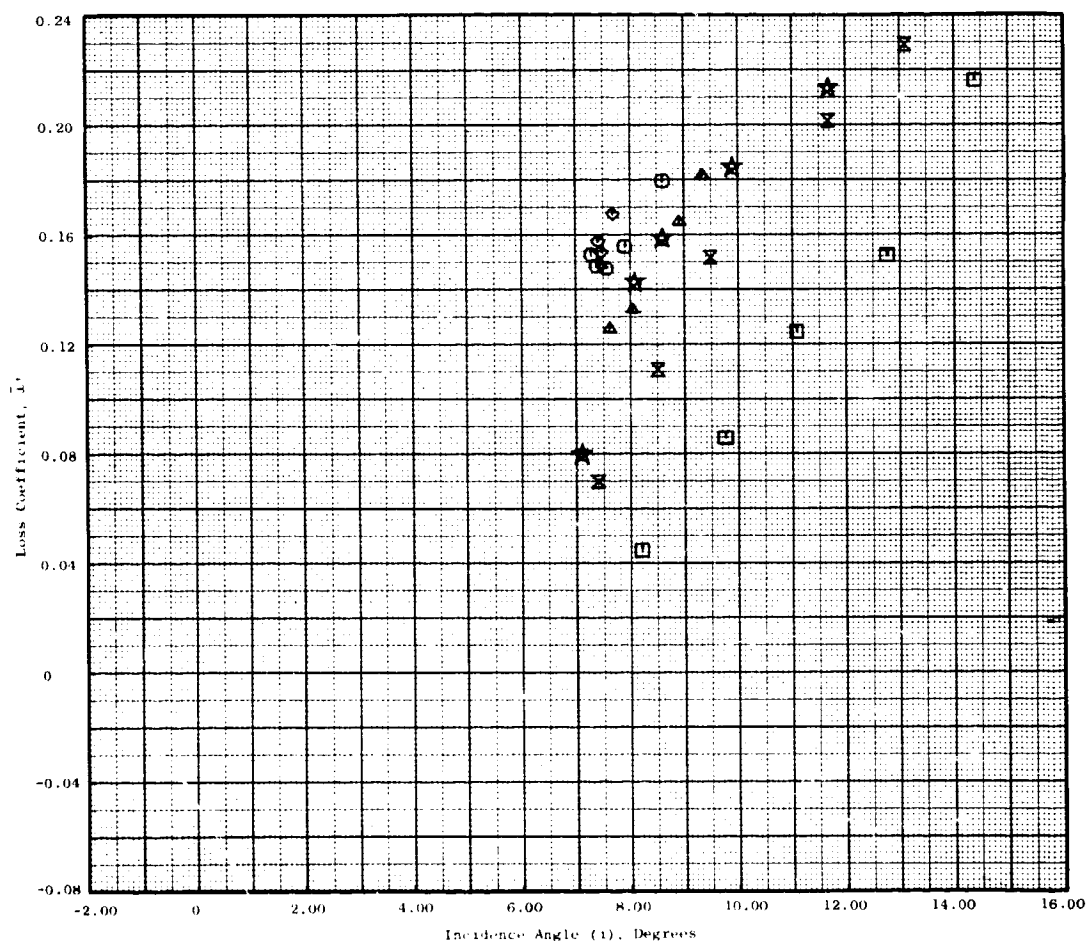
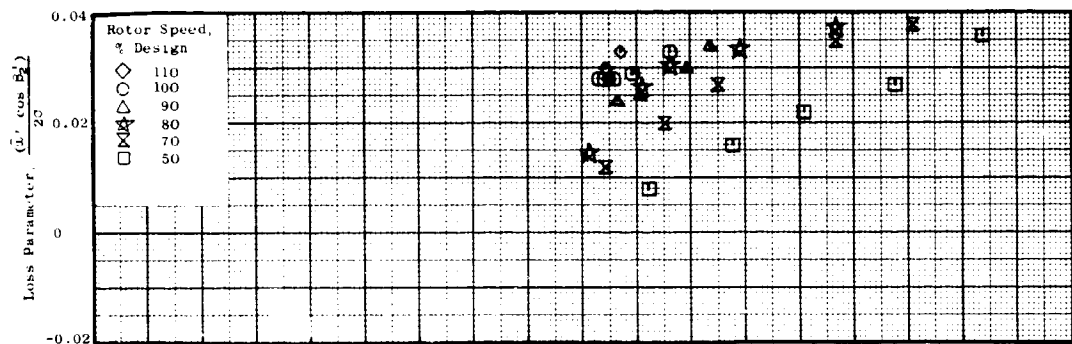


Figure 29(a). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 5% Immersion from Tip.

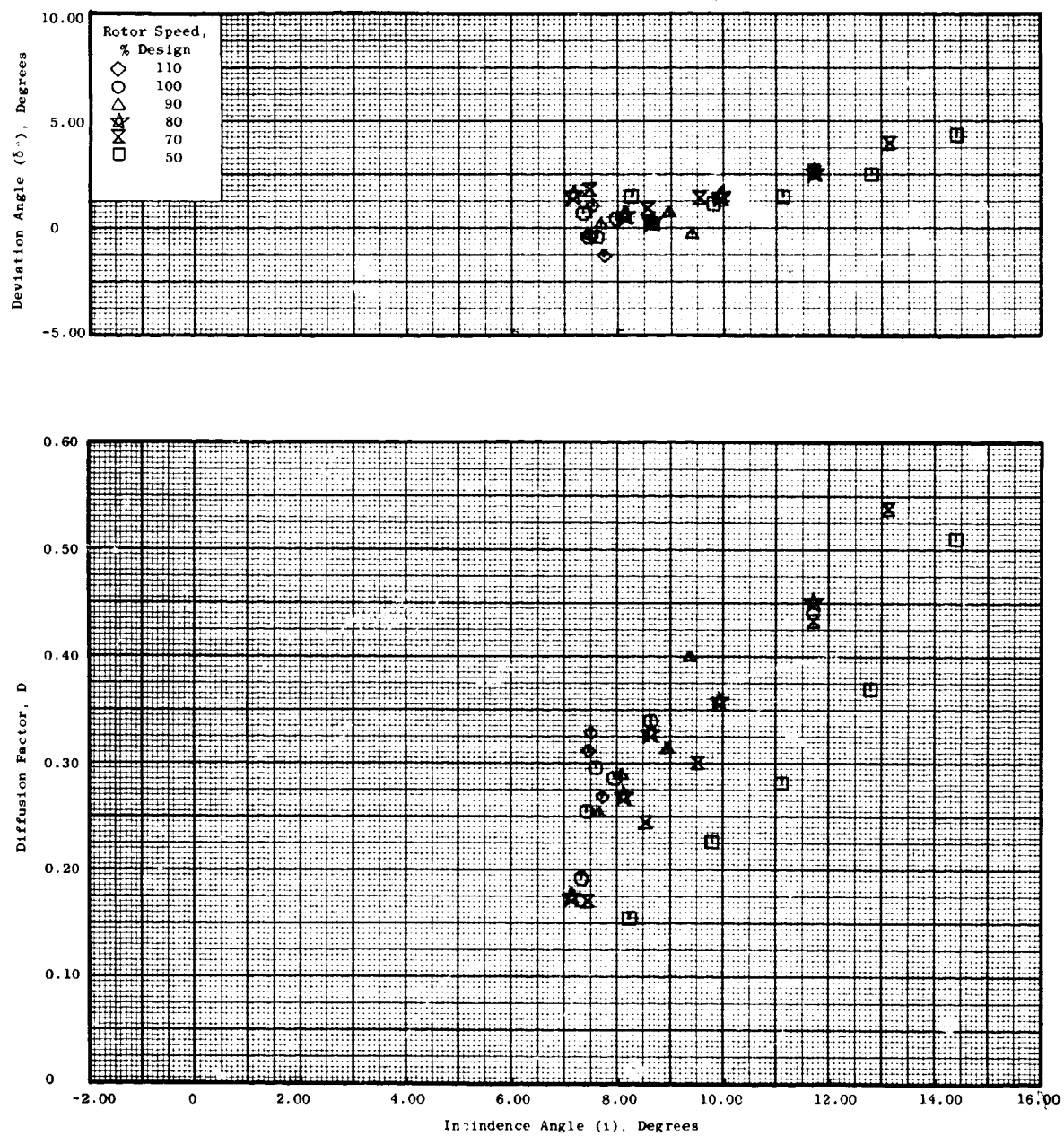


Figure 29 (a). Rotor Blade Element Data for IGV/Stator Schedule 40°/8° at 5% Immersion from Tip (Concluded).

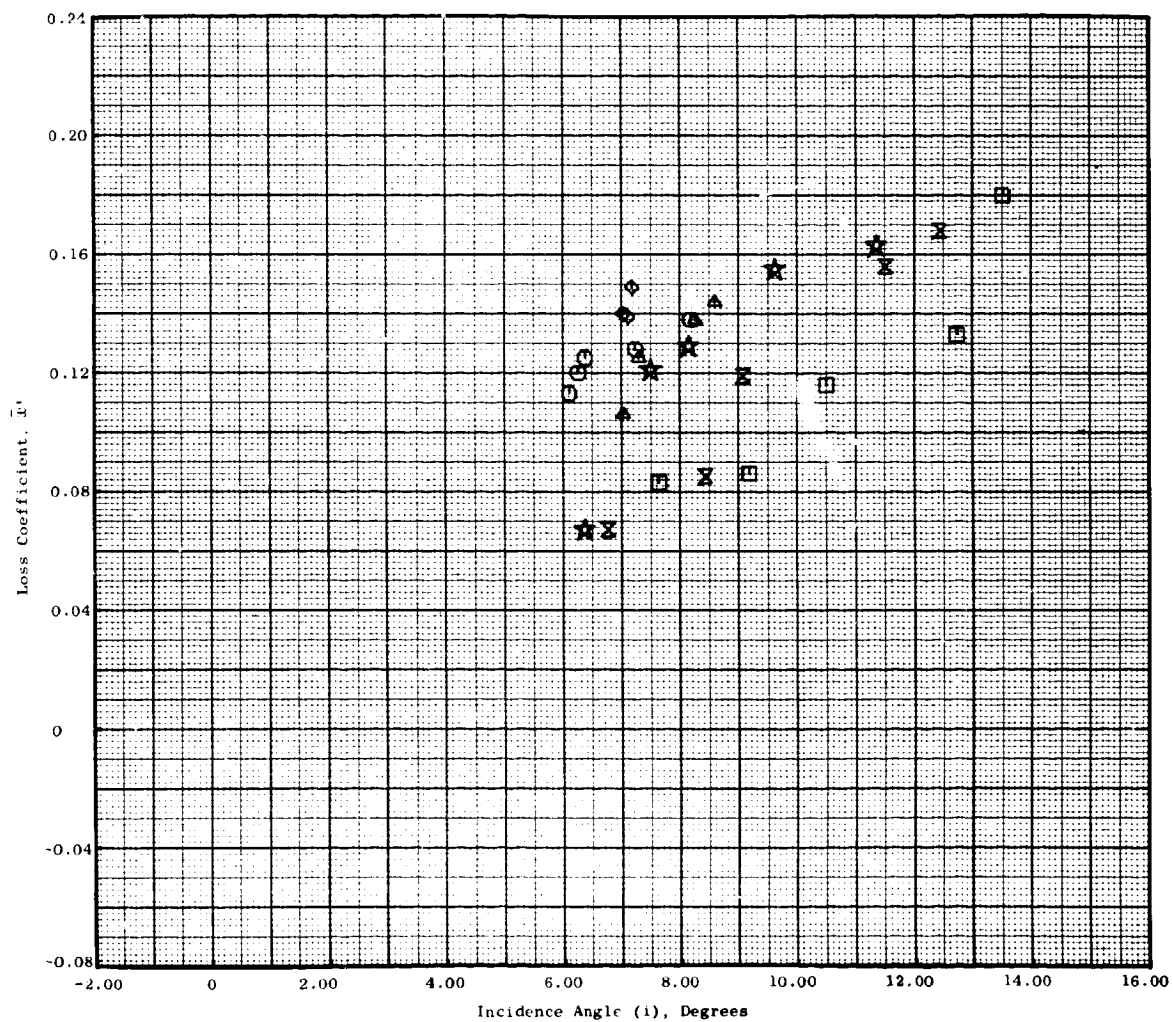
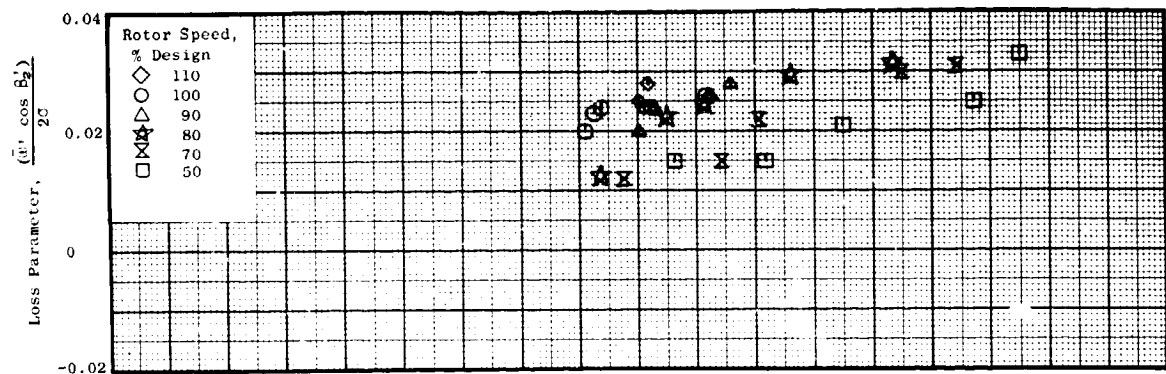


Figure 29(b). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 10% Immersion from Tip.

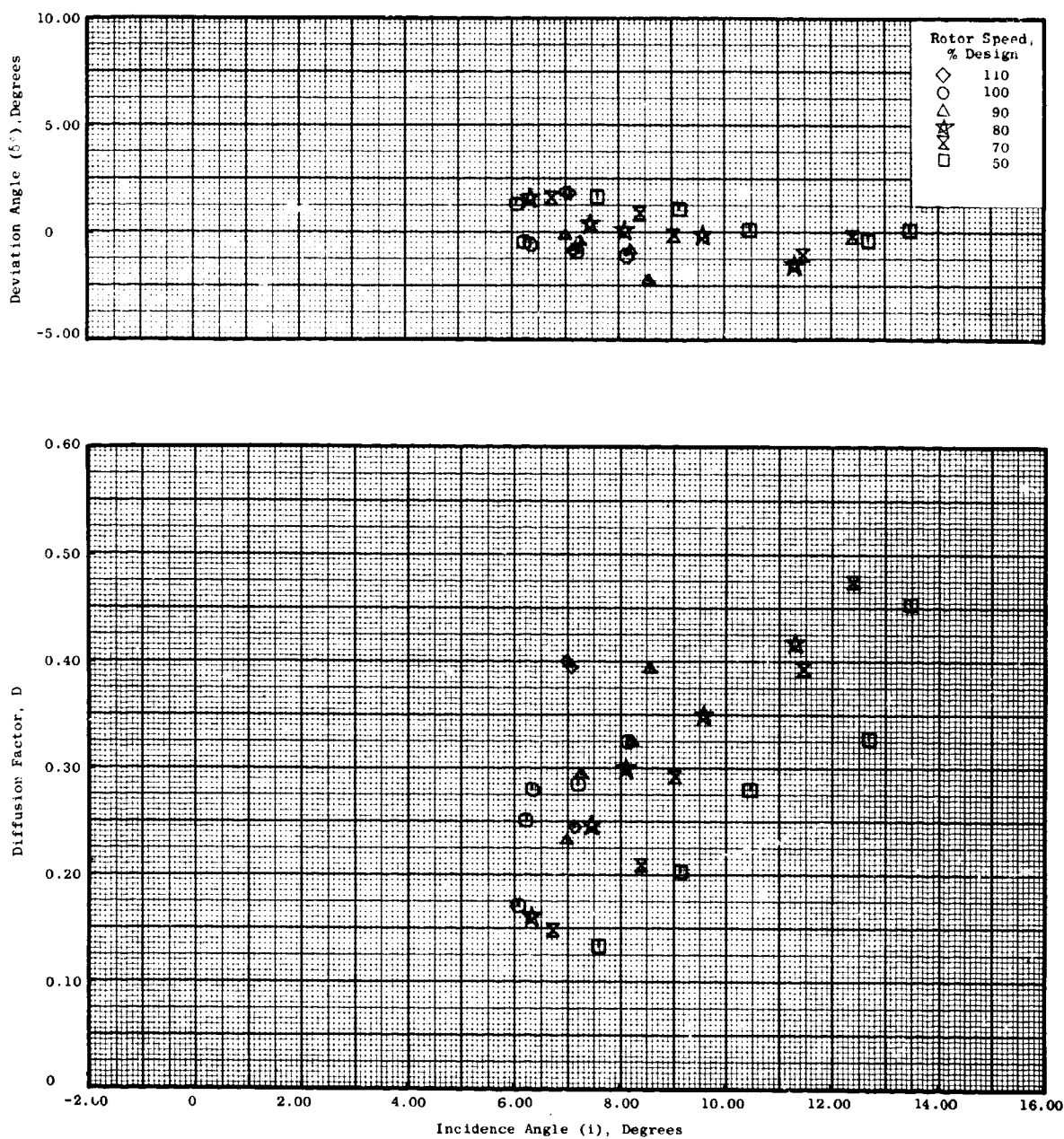


Figure 29 (b). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 10% Immersion from Tip (Concluded).

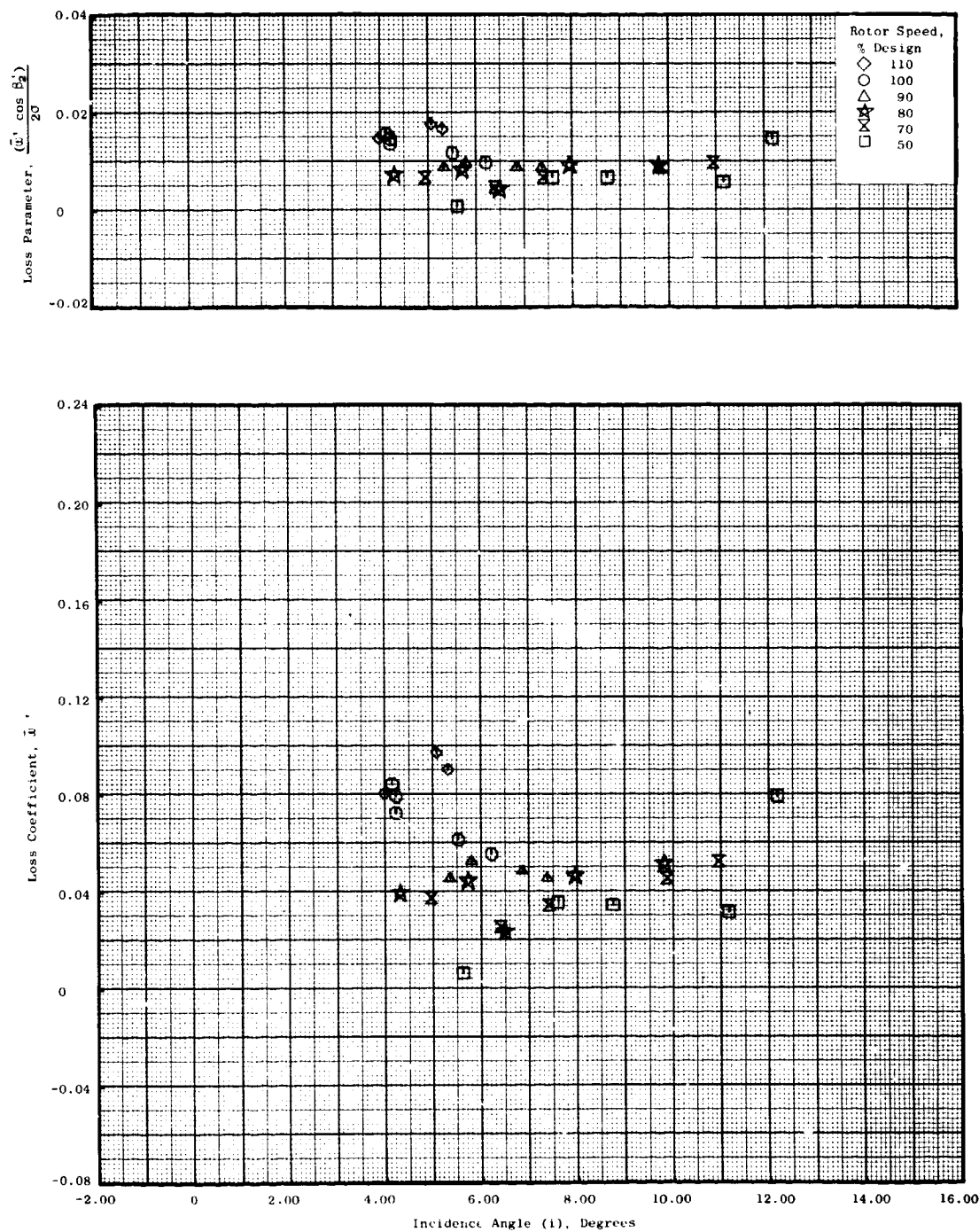


Figure 29(c). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 30% Immersion from Tip.

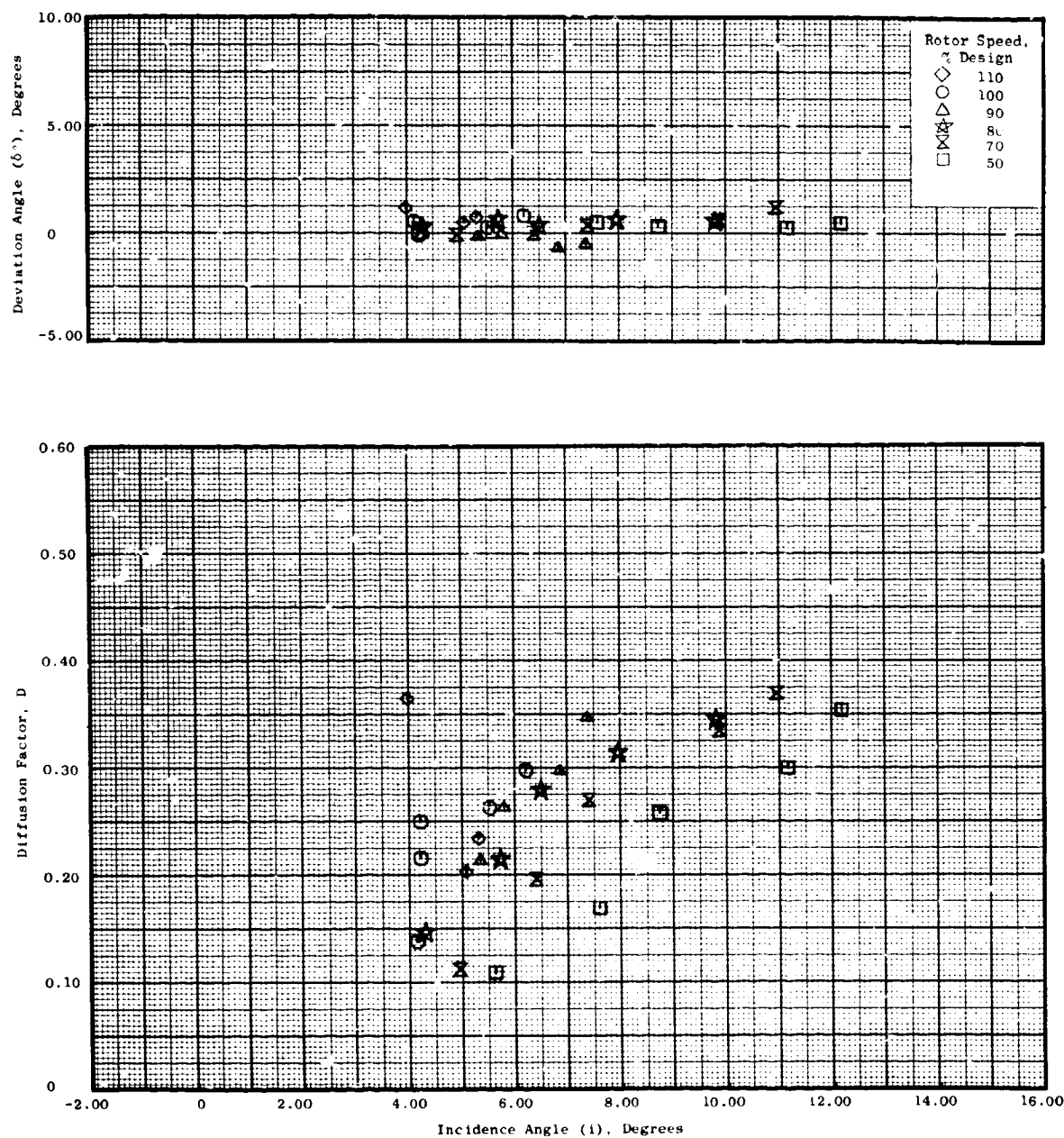


Figure 29 (c). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 30% Immersion from Tip (Concluded).

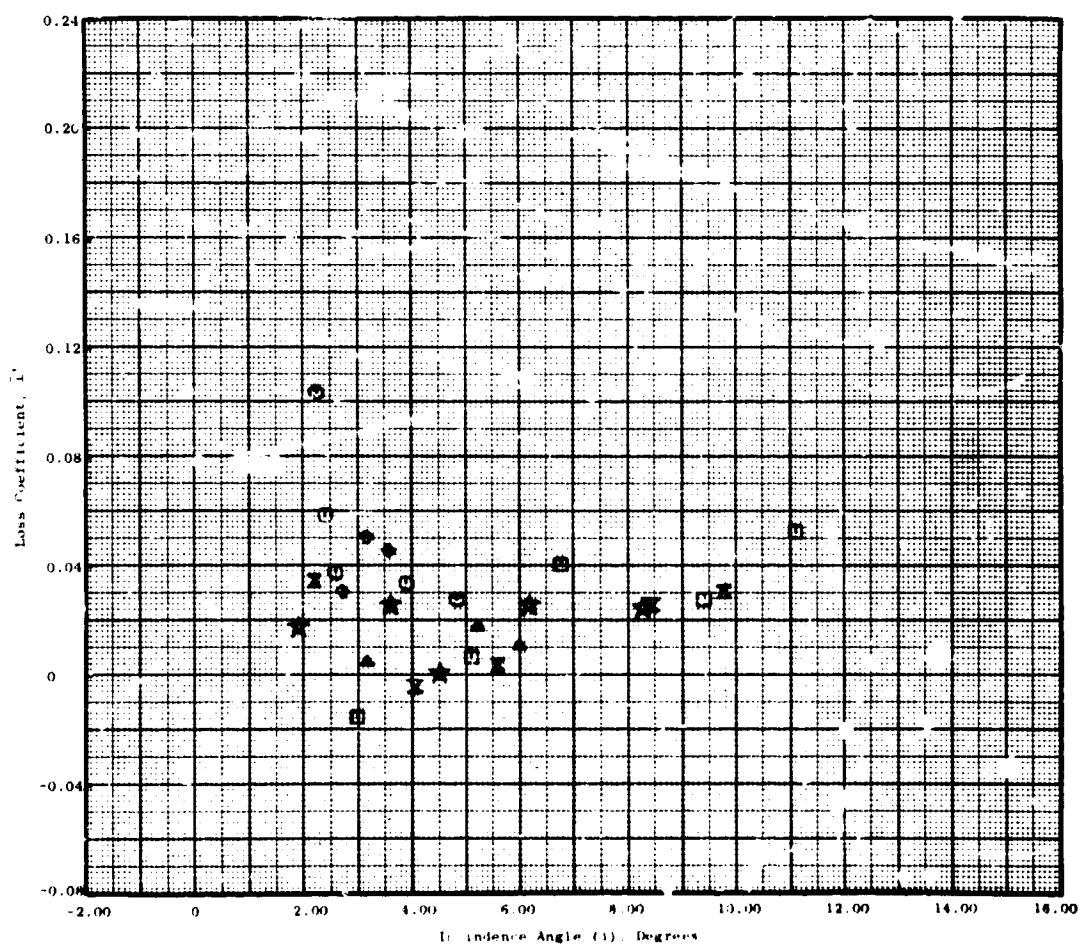
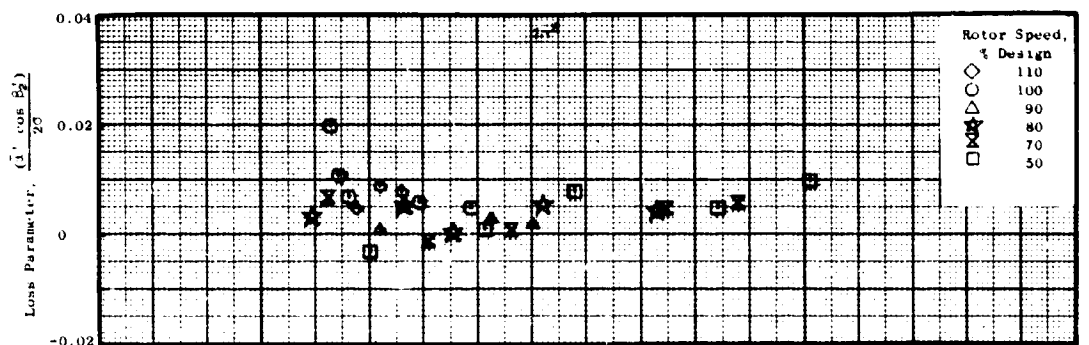


Figure 29(d). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 50% Immersion from Tip.

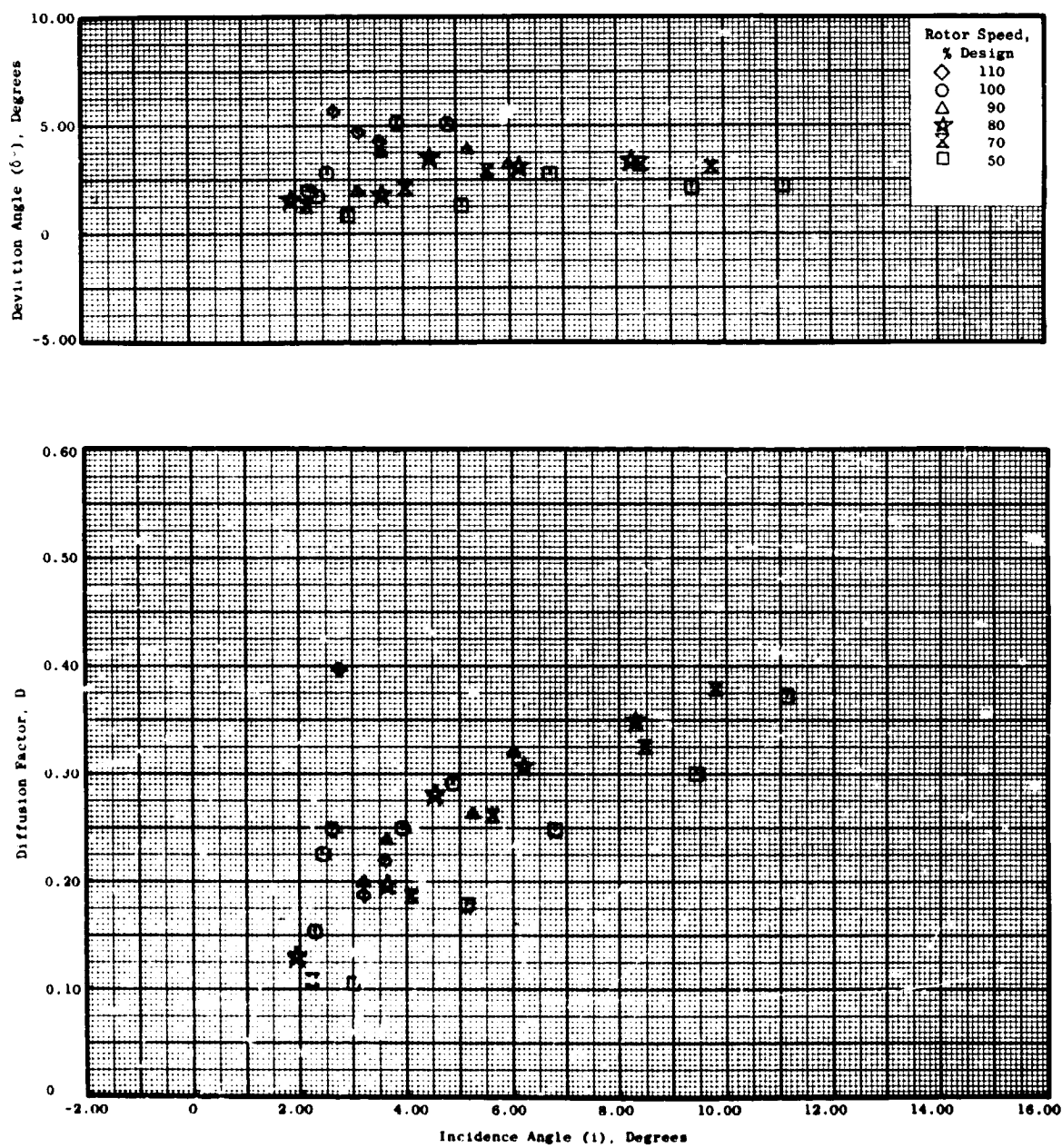


Figure 29 (d). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 50% Immersion from Tip (Concluded).

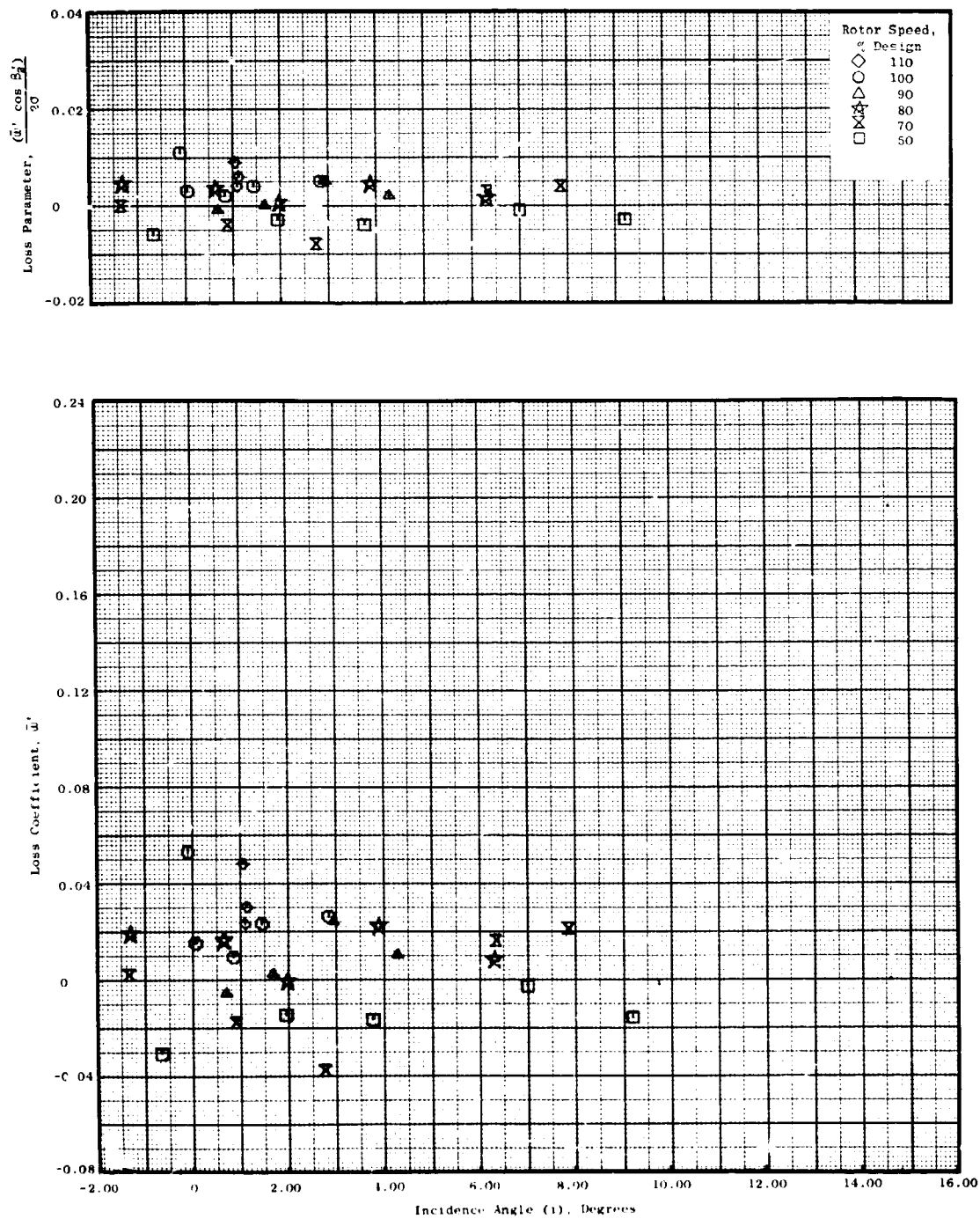


Figure 29(e). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 70% Immersion from Tip.

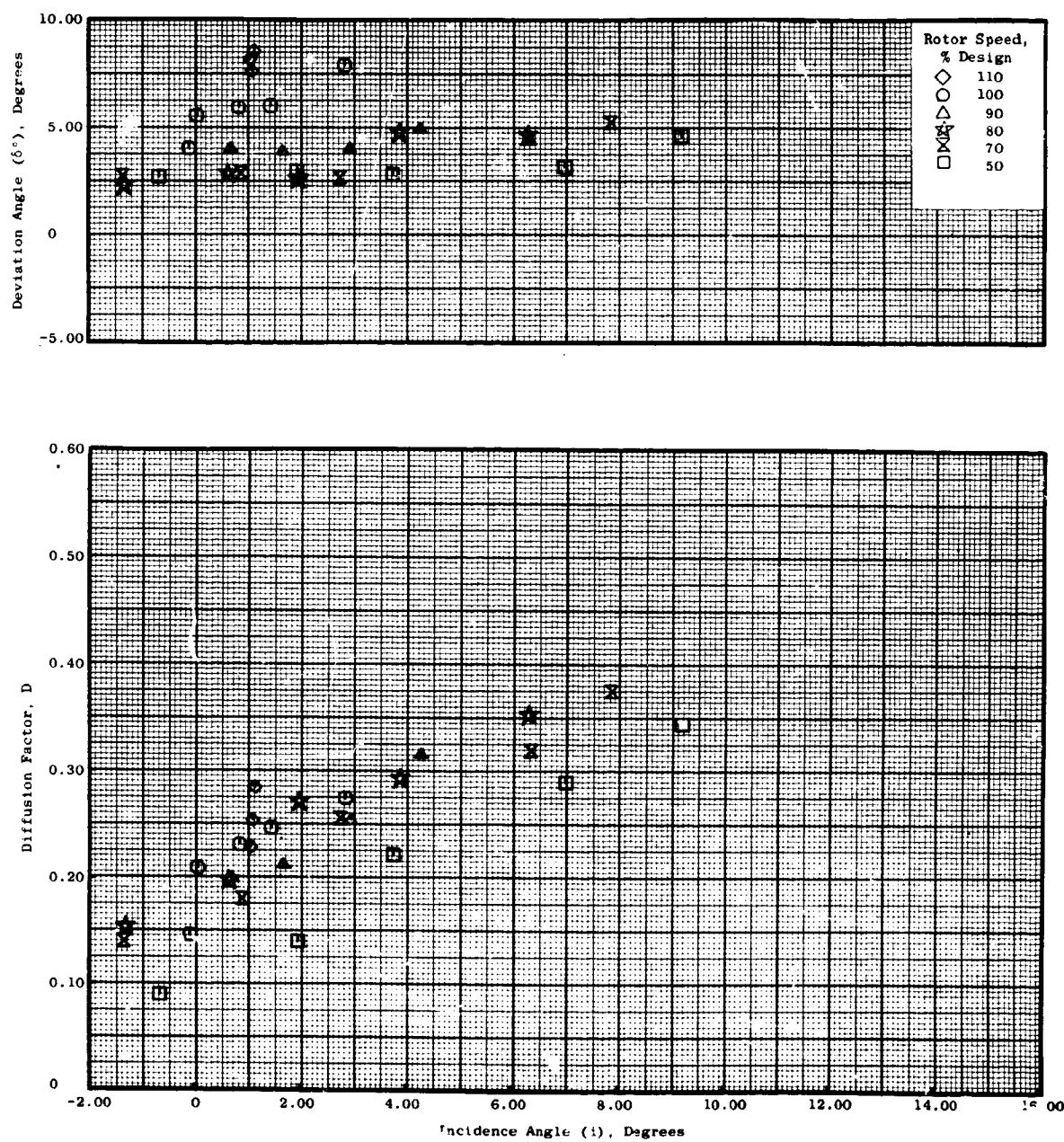


Figure 29 (e). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 70% Immersion from Tip (Concluded).

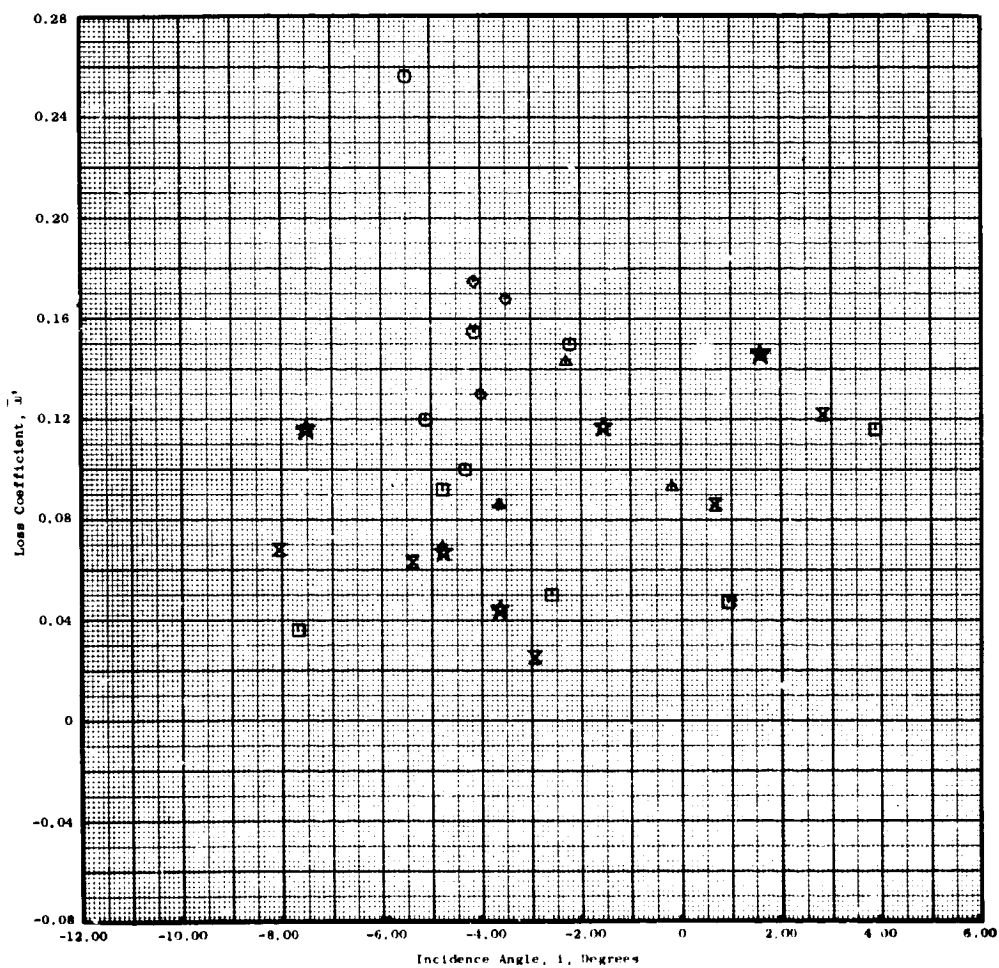
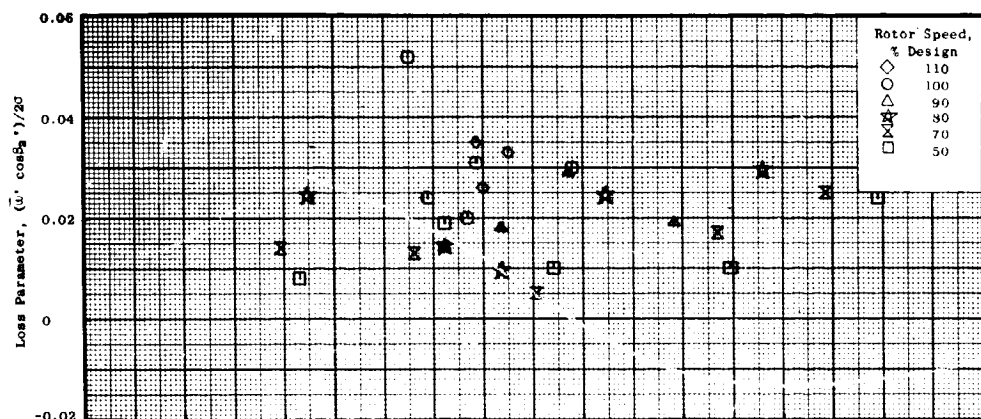


Figure 29 (f). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 90% Immersion from Tip.

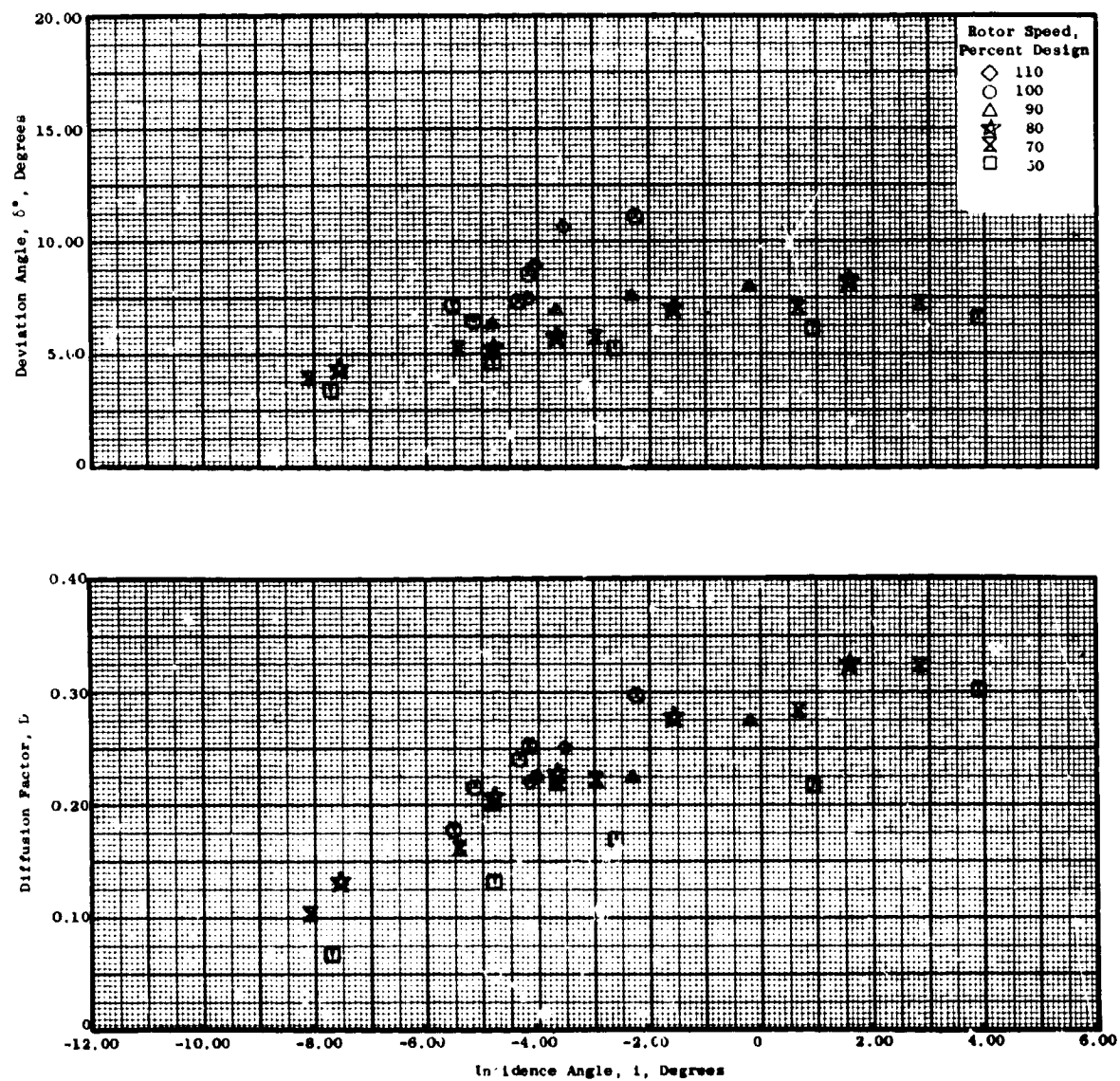


Figure 29 (f). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 90% Immersion from Tip (Concluded).

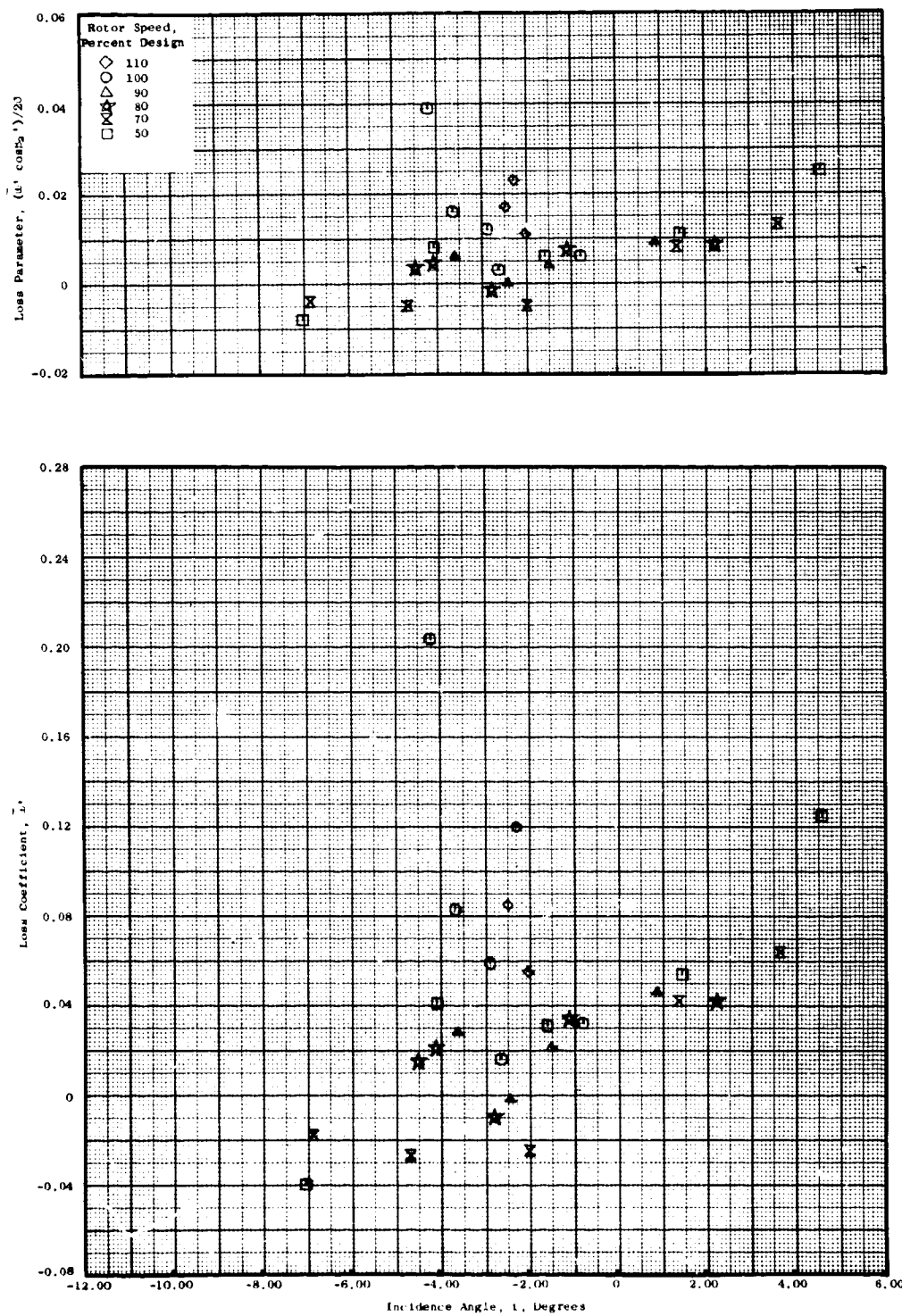


Figure 29 (g). Rotor Blade Element Data for IGV/Stator Schedule 40°/8° at 95% Immersion from Tip.

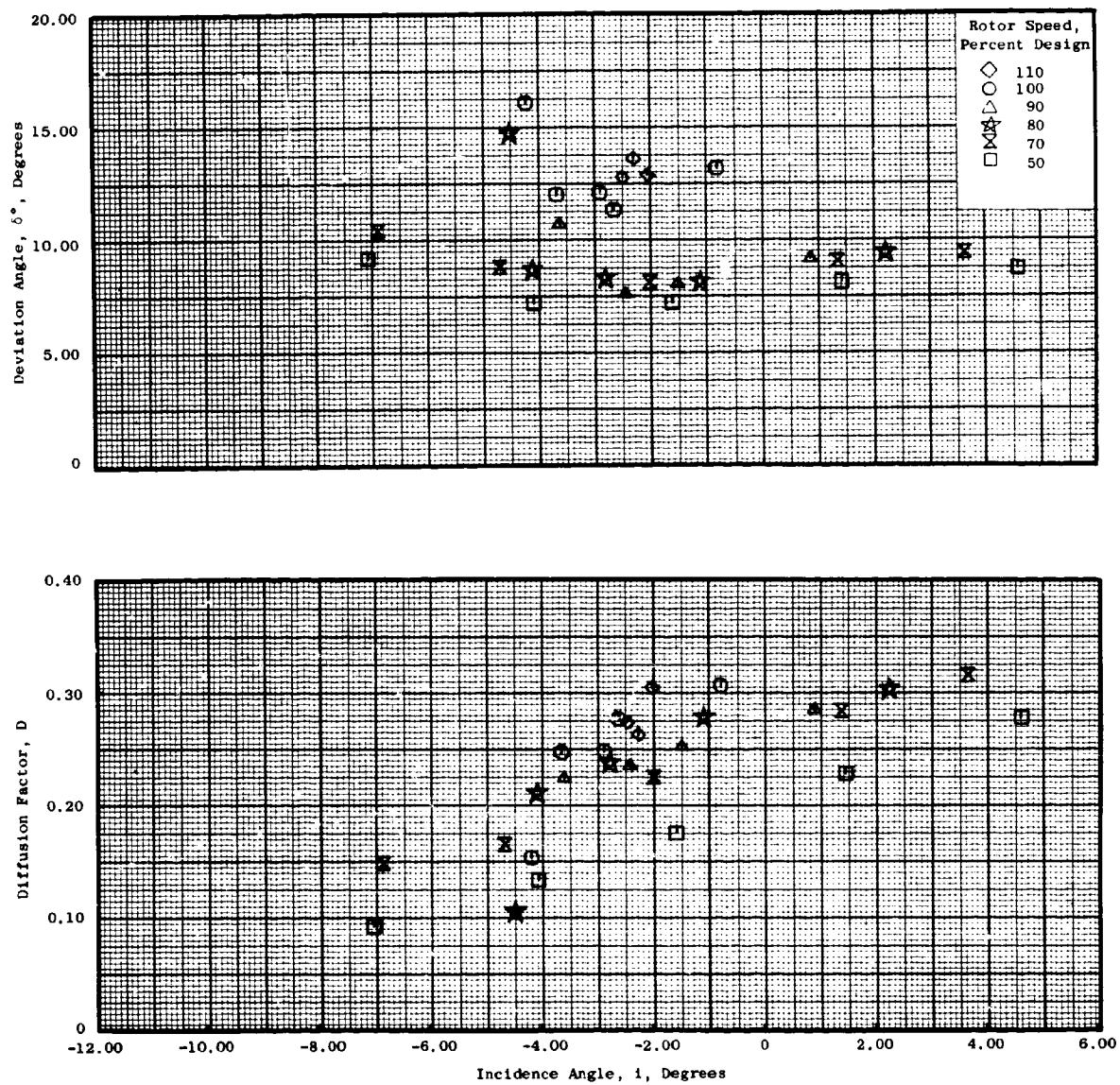


Figure 29 (g). Rotor Blade Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 95% Immersion from Tip (Concluded).

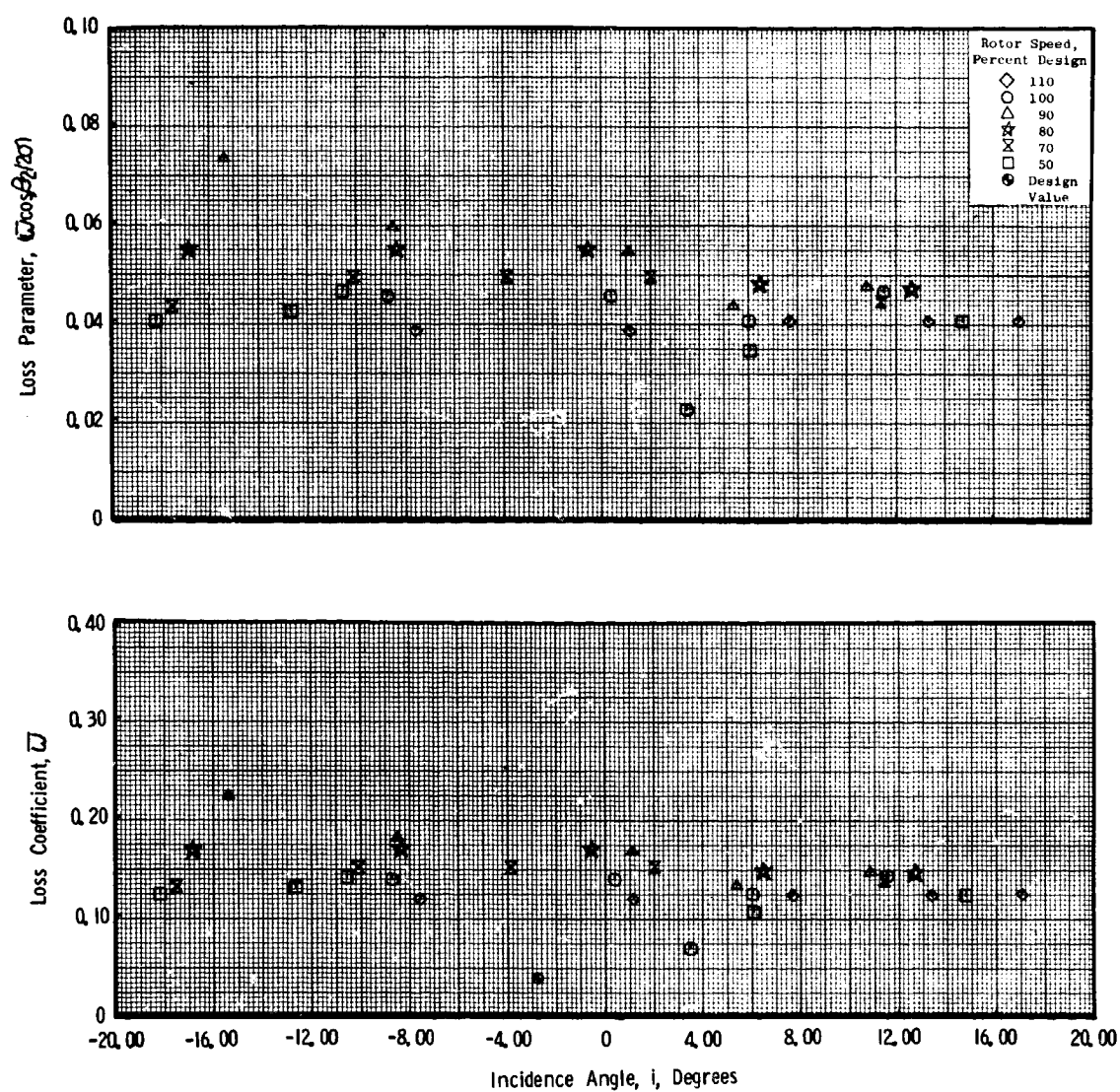


Figure 30(a). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 5% Immersion from Tip.

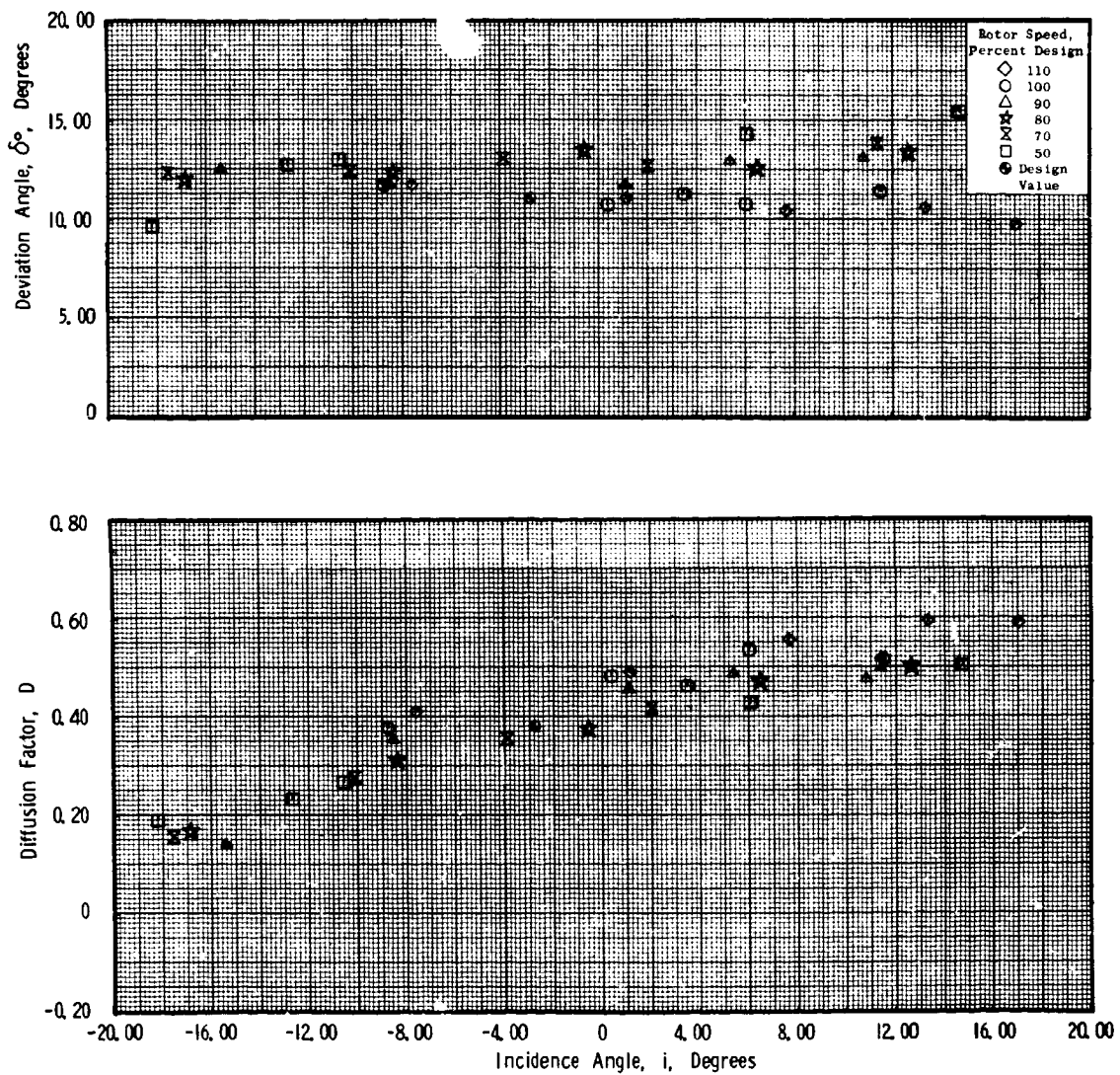


Figure 30(a). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 5% Immersion from Tip (Concluded).

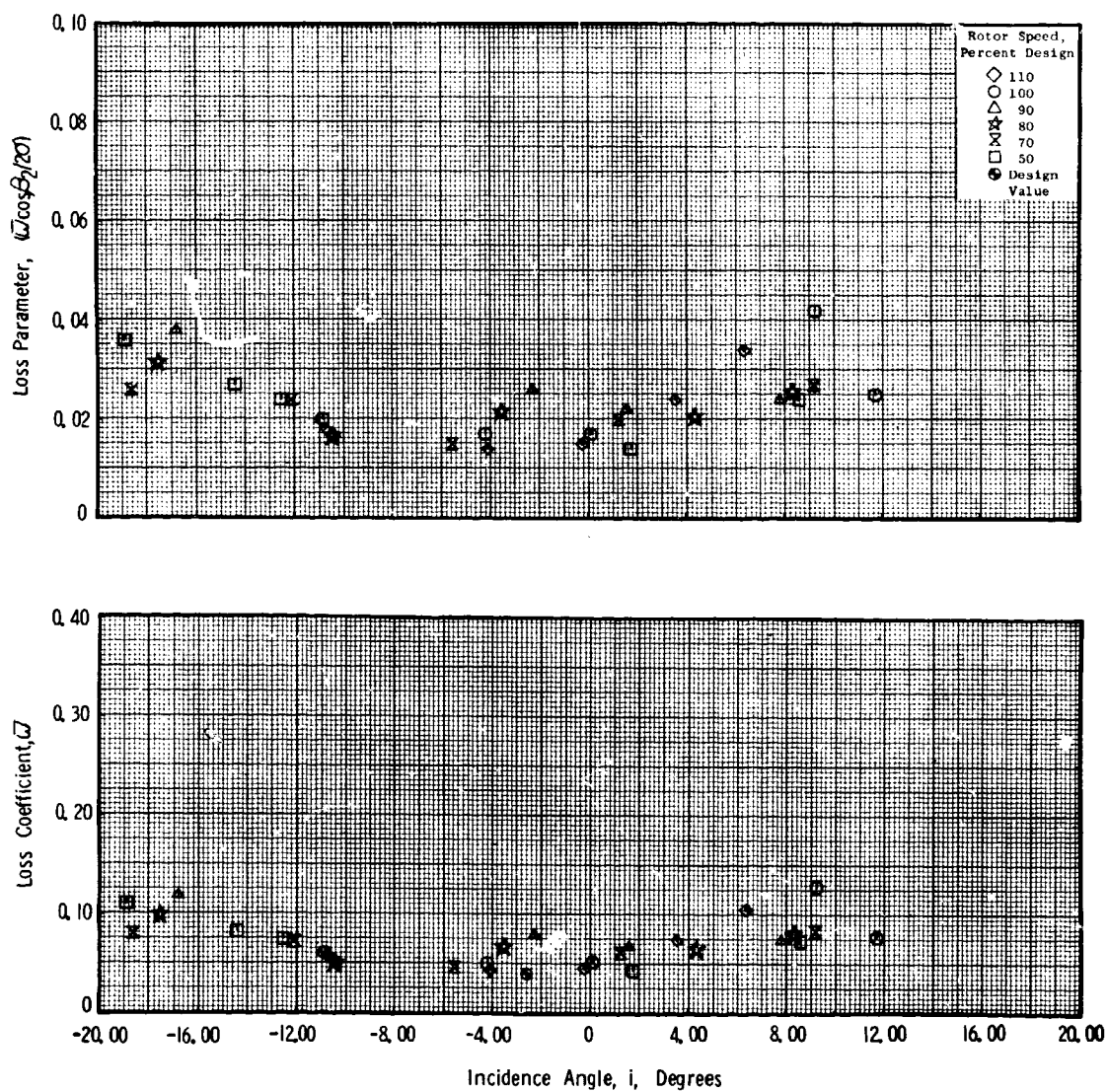


Figure 30(b). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 10% Immersion from Tip.

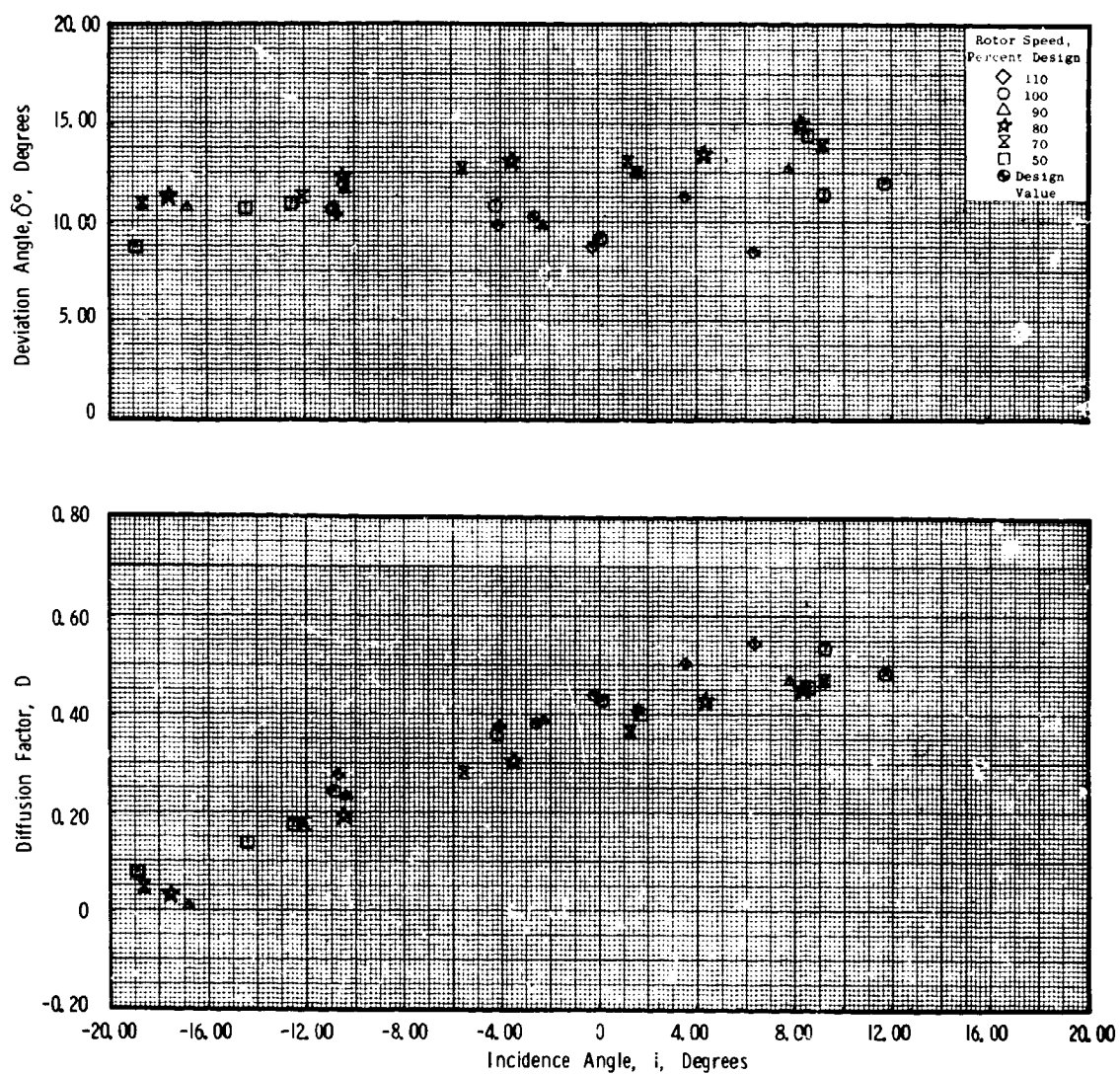


Figure 30(b). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 10% Immersion from Tip (Concluded).

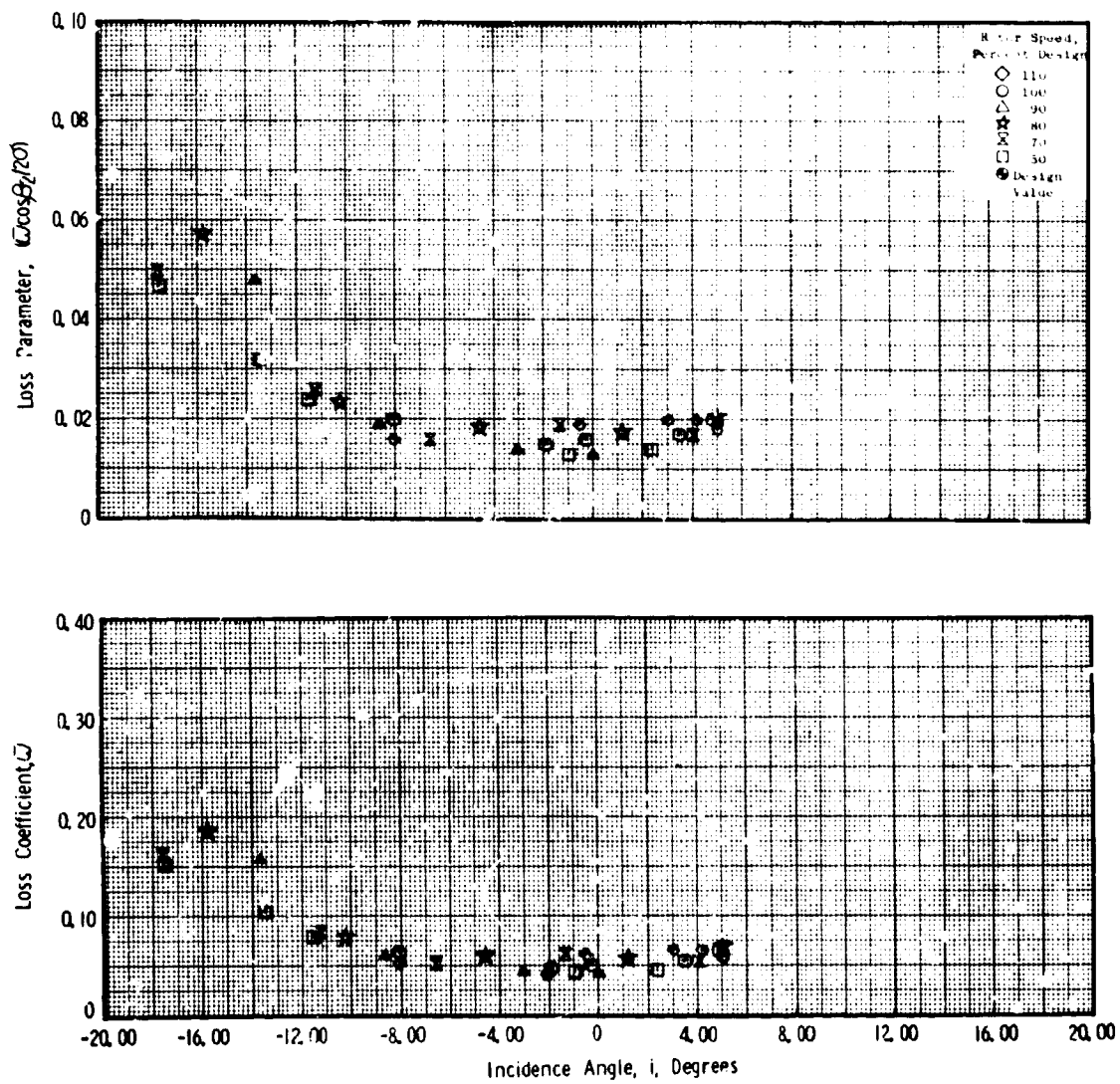


Figure 30(c). Stator Vane Element Data for IGV/Stator Schedule 0/0¹ at 30% Immersion from Tip.

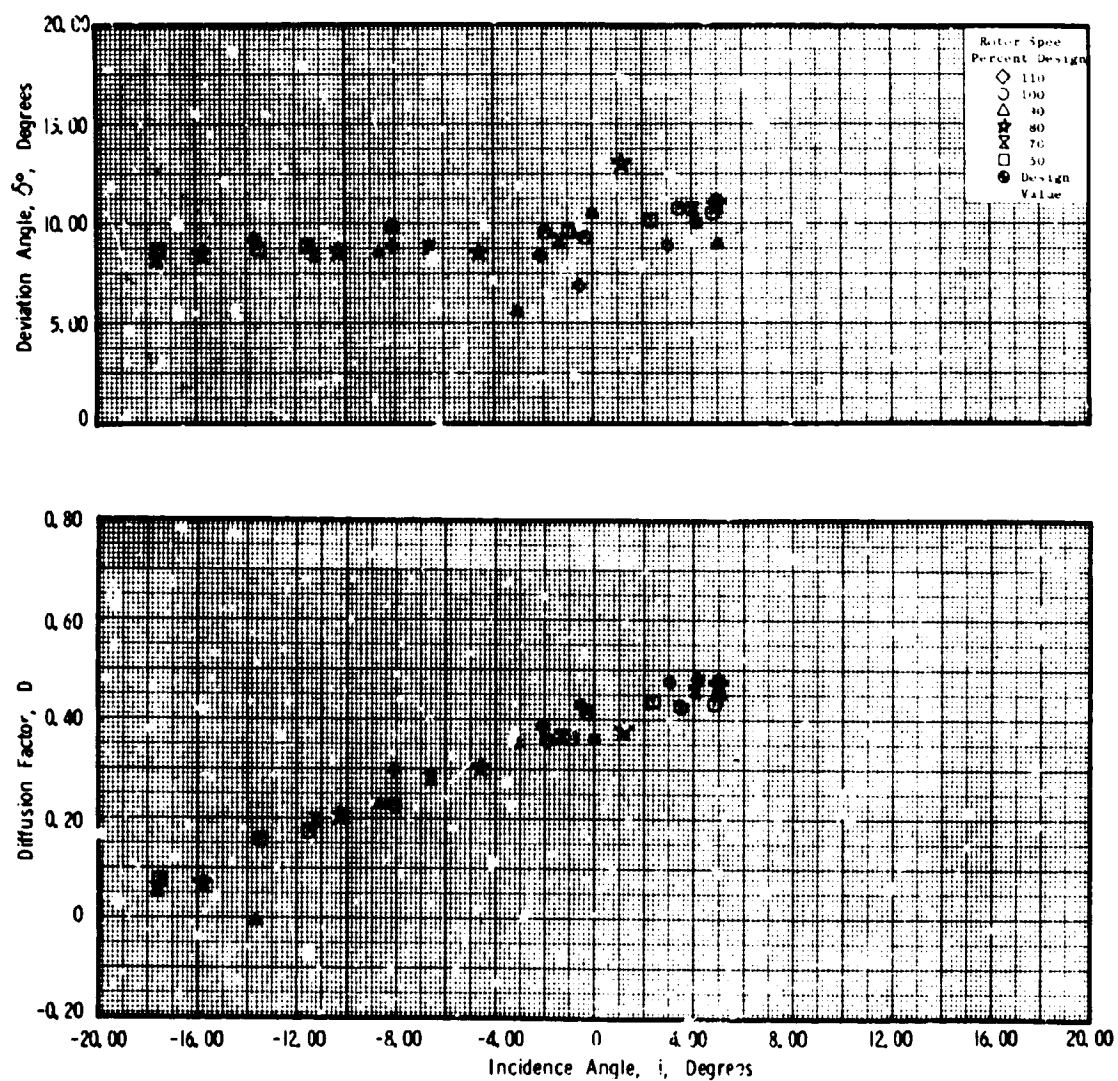


Figure 30(c). Stator Vane Element Data for IGV/Stator Schedule 0°/0° at 30% Immersion from Tip (Concluded).

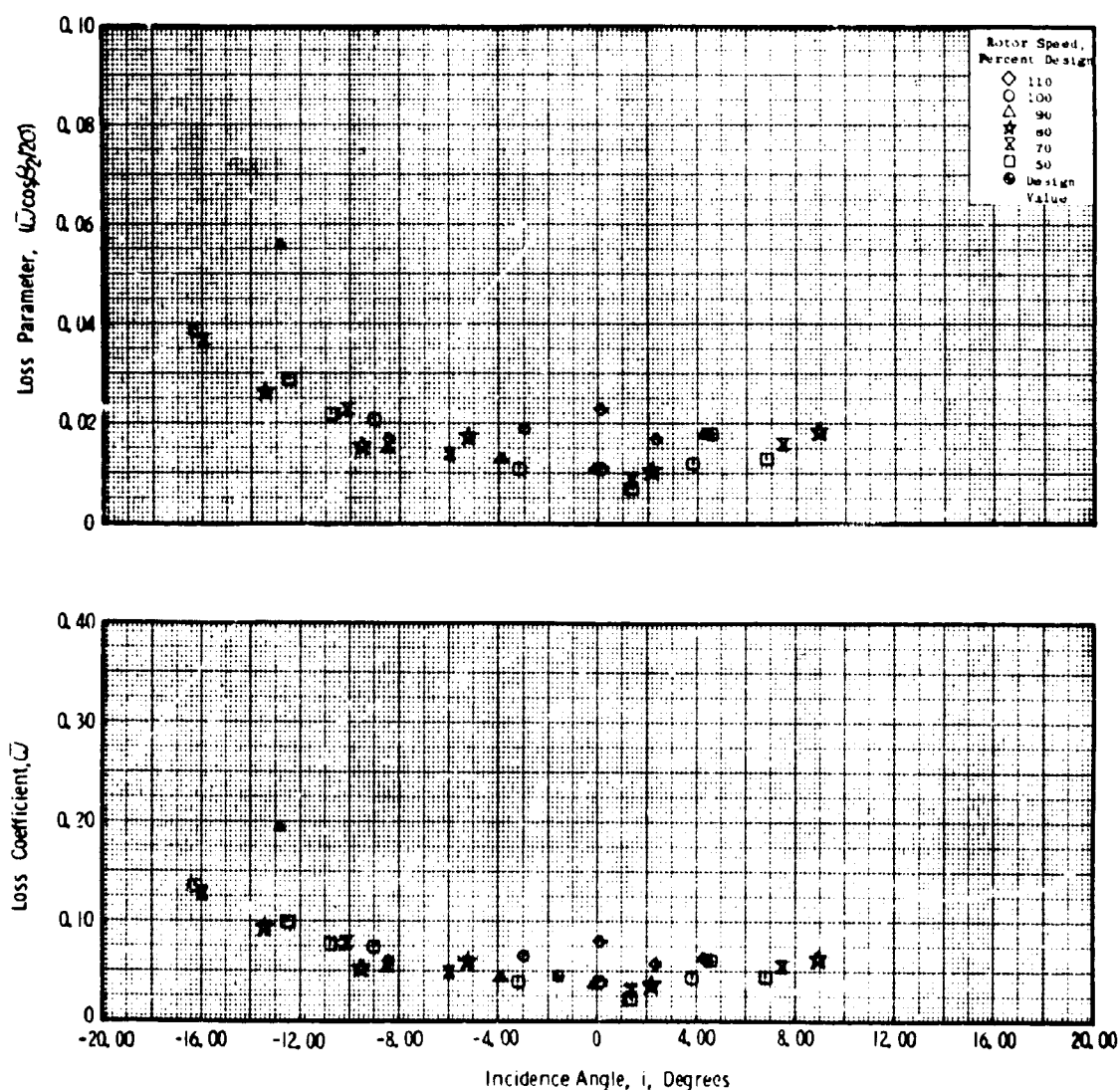


Figure 30(d). Stator Vane Element Data for IGV/Stator Schedule 0 / 0⁺ at 50% Immersion from Tip.

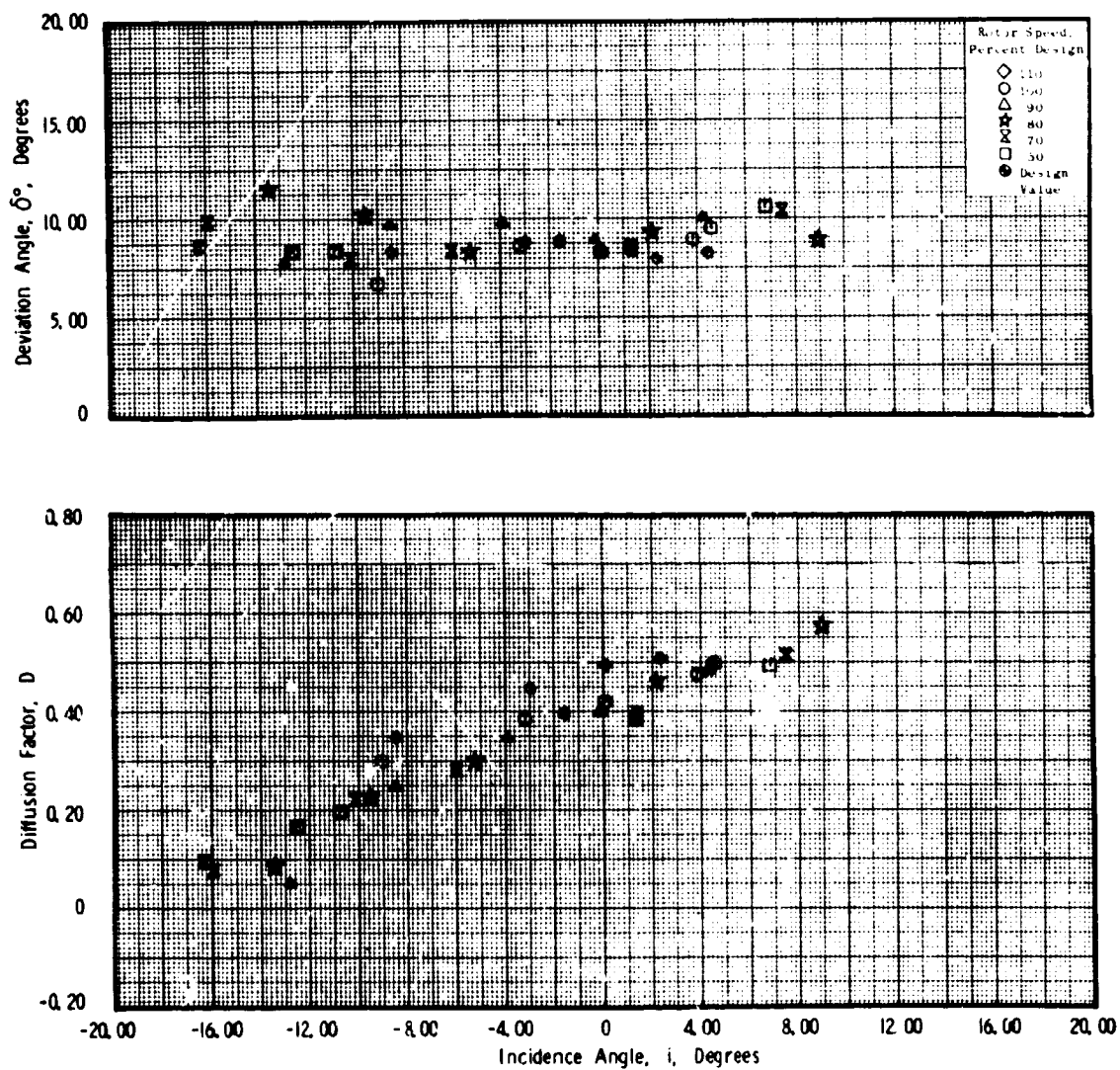


Figure 30(d). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 50% Immersion from Tip (Concluded).

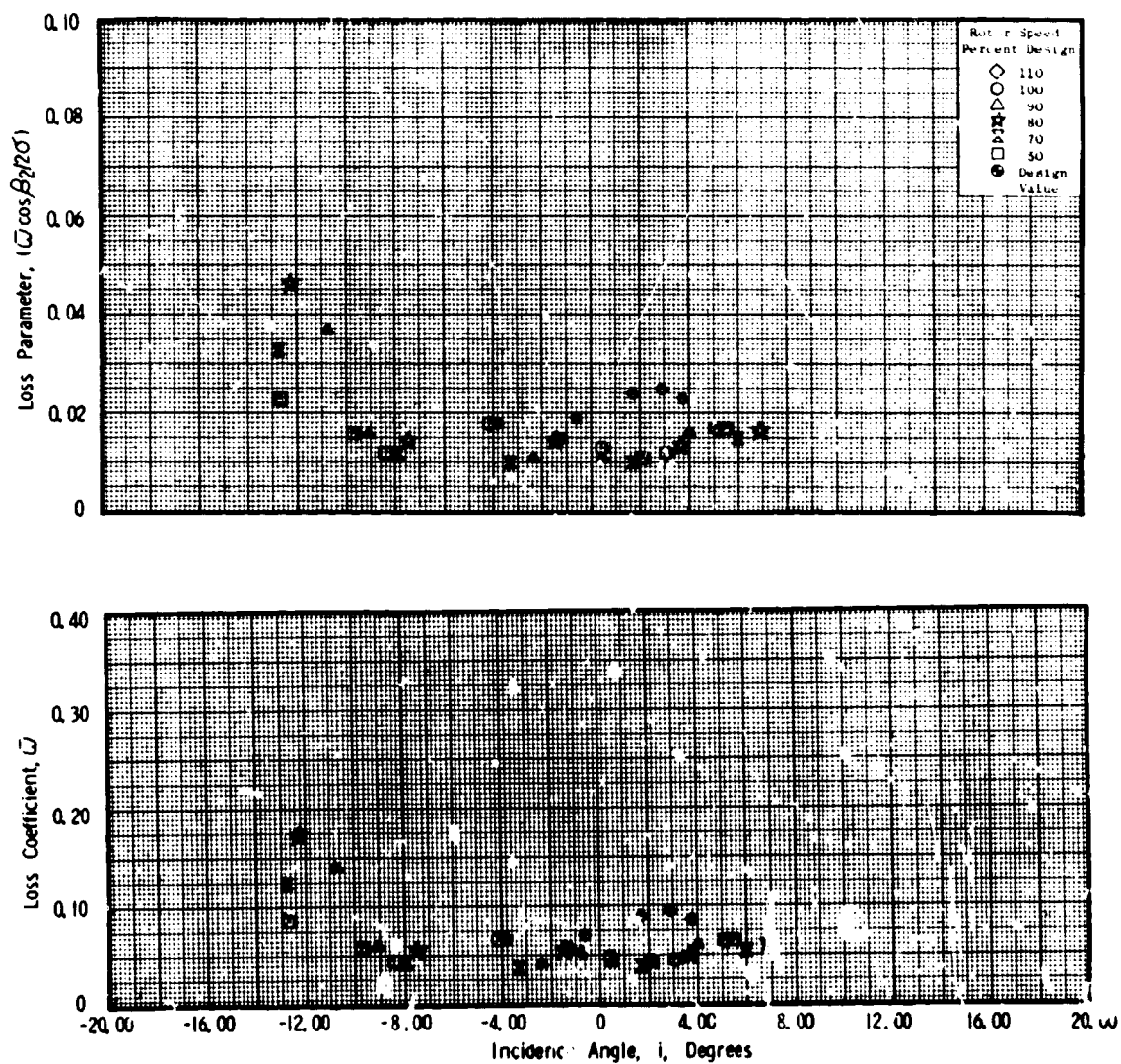


Figure 30(e). Stator Vane Element Data for IGV/Stator Schedule 0°/0° at 75% Immersion from Tip.

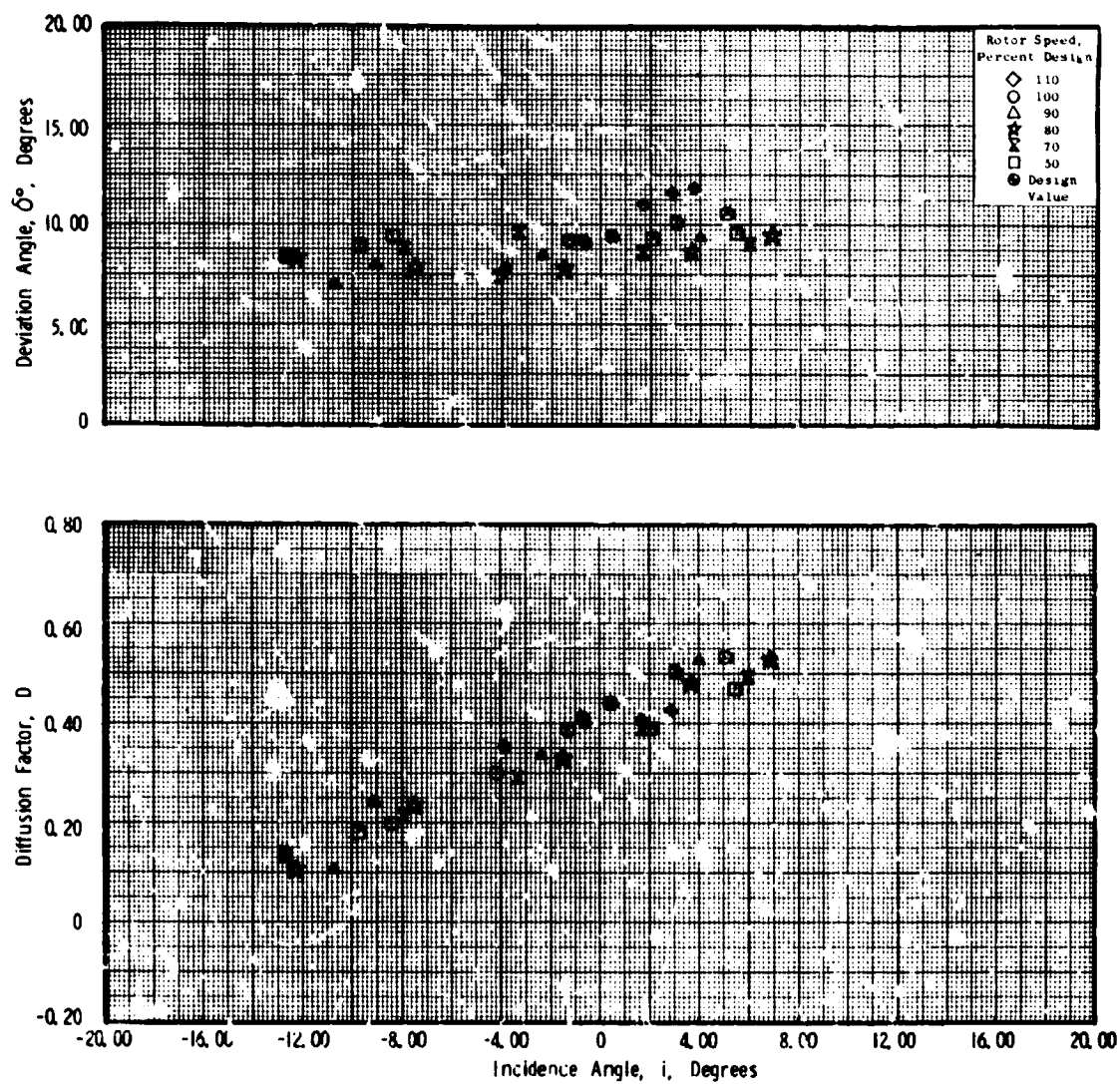


Figure 30(e). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 70% Immersion from Tip (Concluded).

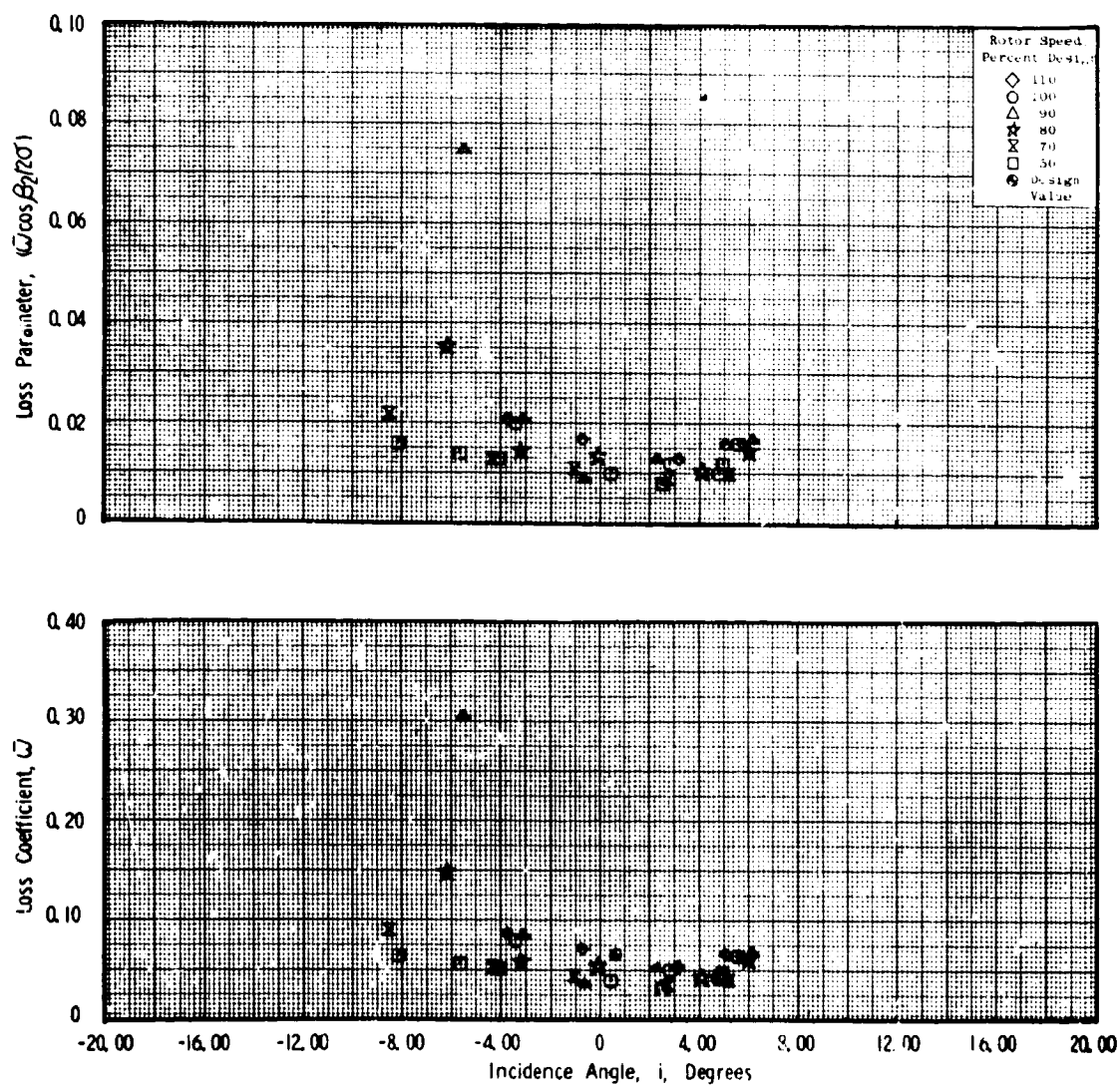


Figure 30(f). Stator Vane Element Data for IGV/Stator Schedule 0°/0° at 90% Immersion from Tip.

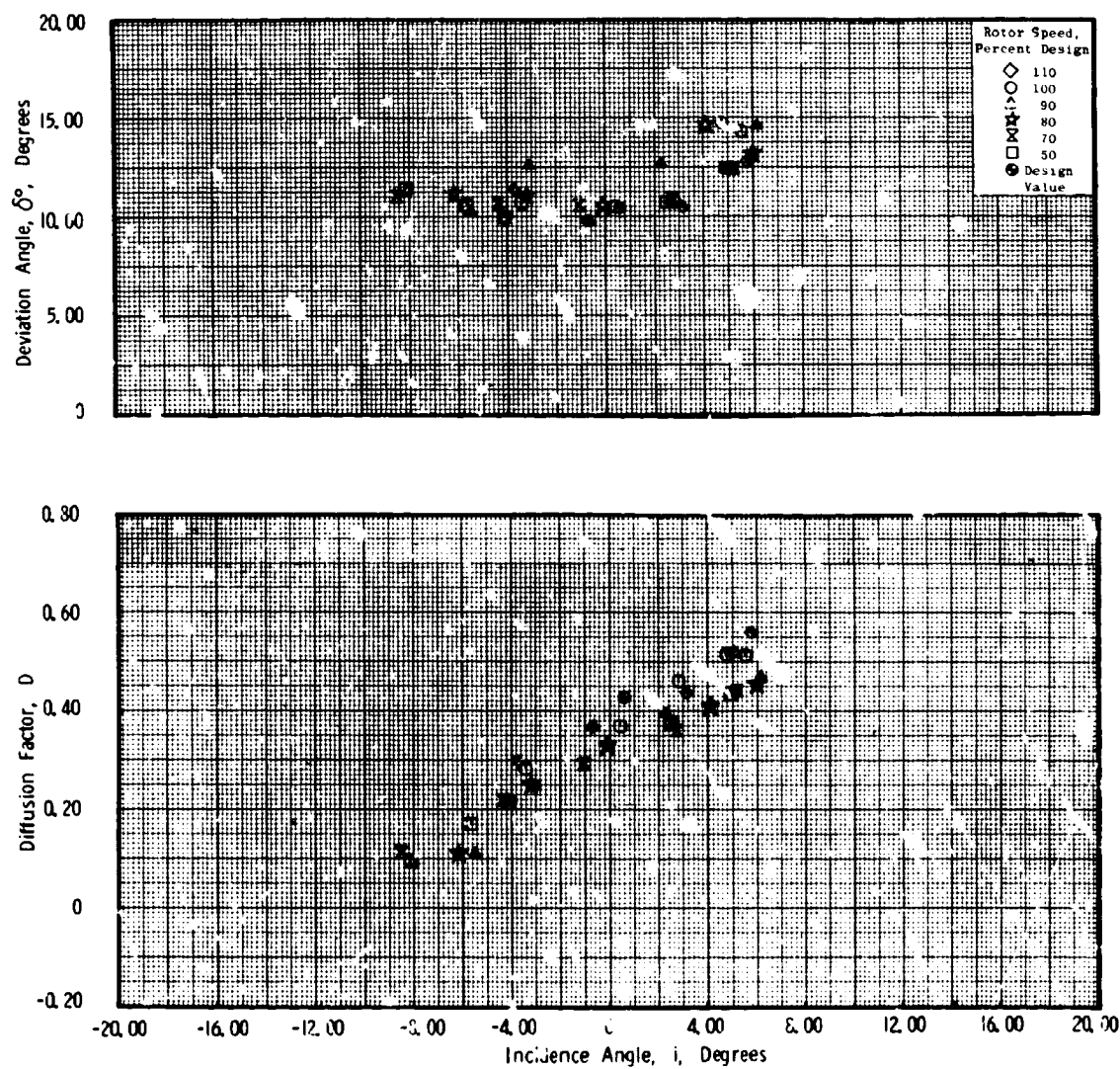


Figure 30(f). Stator Vane Element Data for IGV/Stator Schedule 0°/0° at 20% Immersion from Tip (C included).

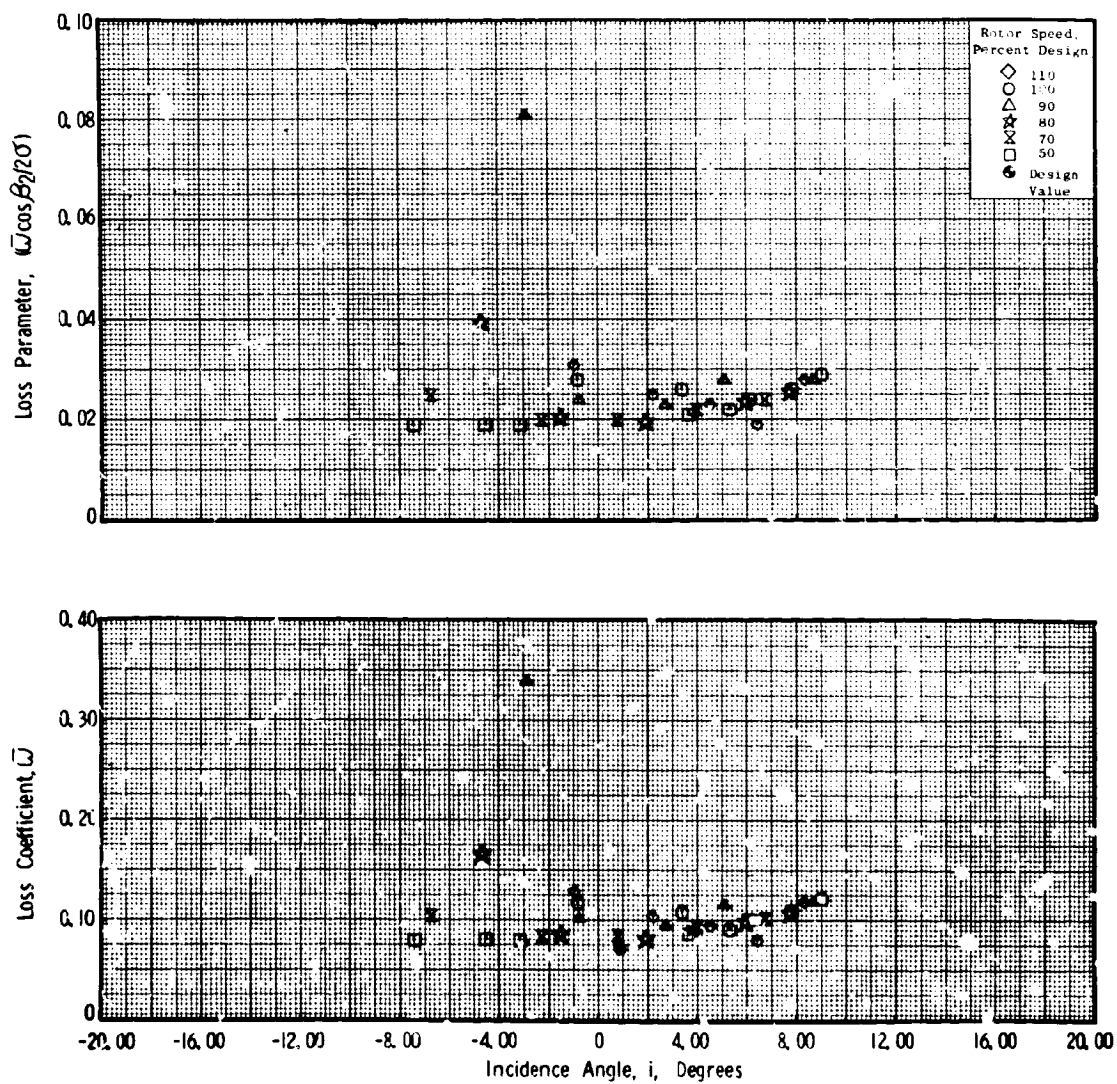


Figure 30(g). Stator Vane Element Data for IGV/Stator Schedule $0^\circ/0^\circ$ at 95% Immersion from Tip.

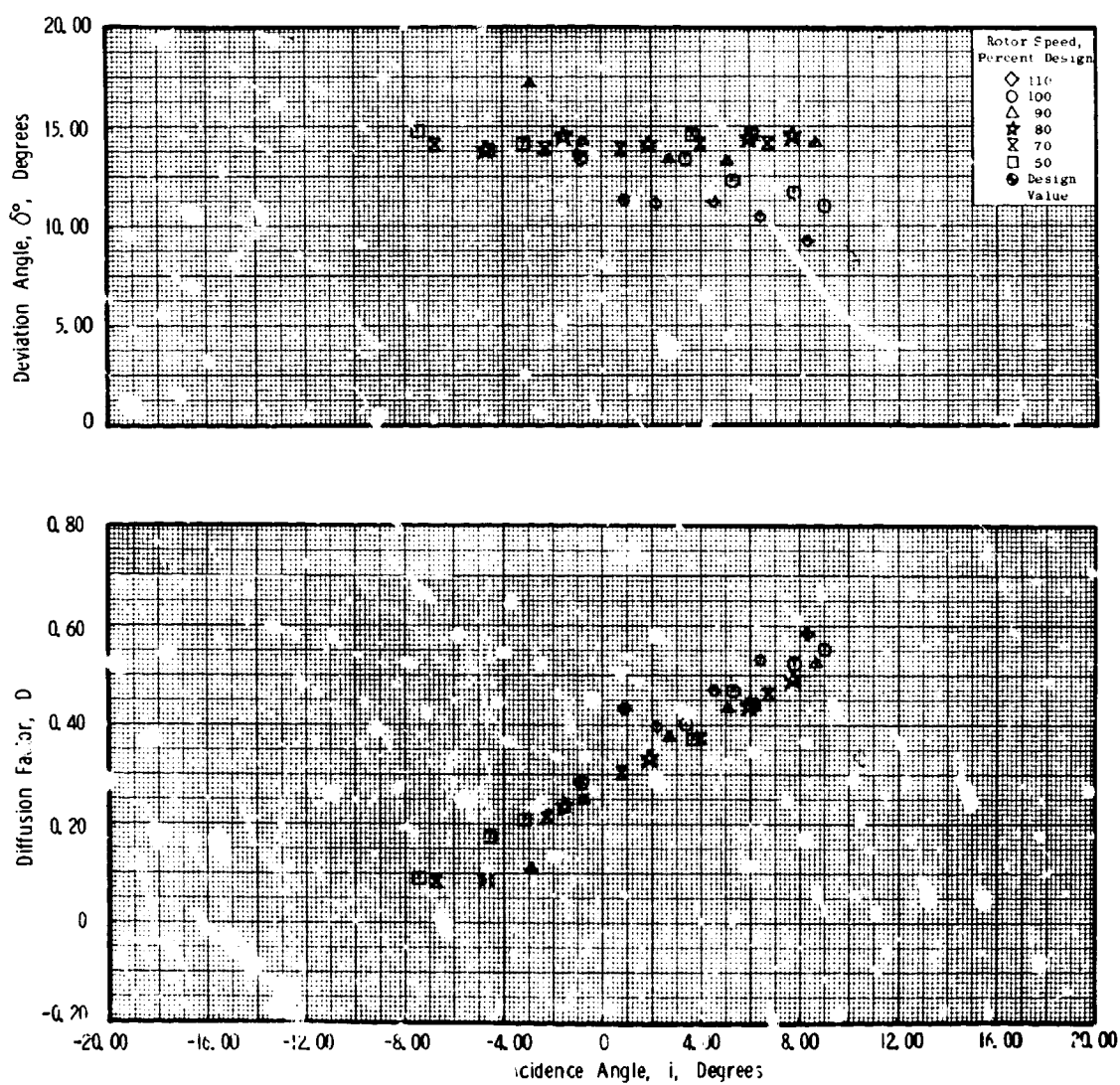


Figure 30(g) Stator Vane Element Data for IGV/Stator Schedule 0°/0° at 95% Immersion from Tip (Concluded).

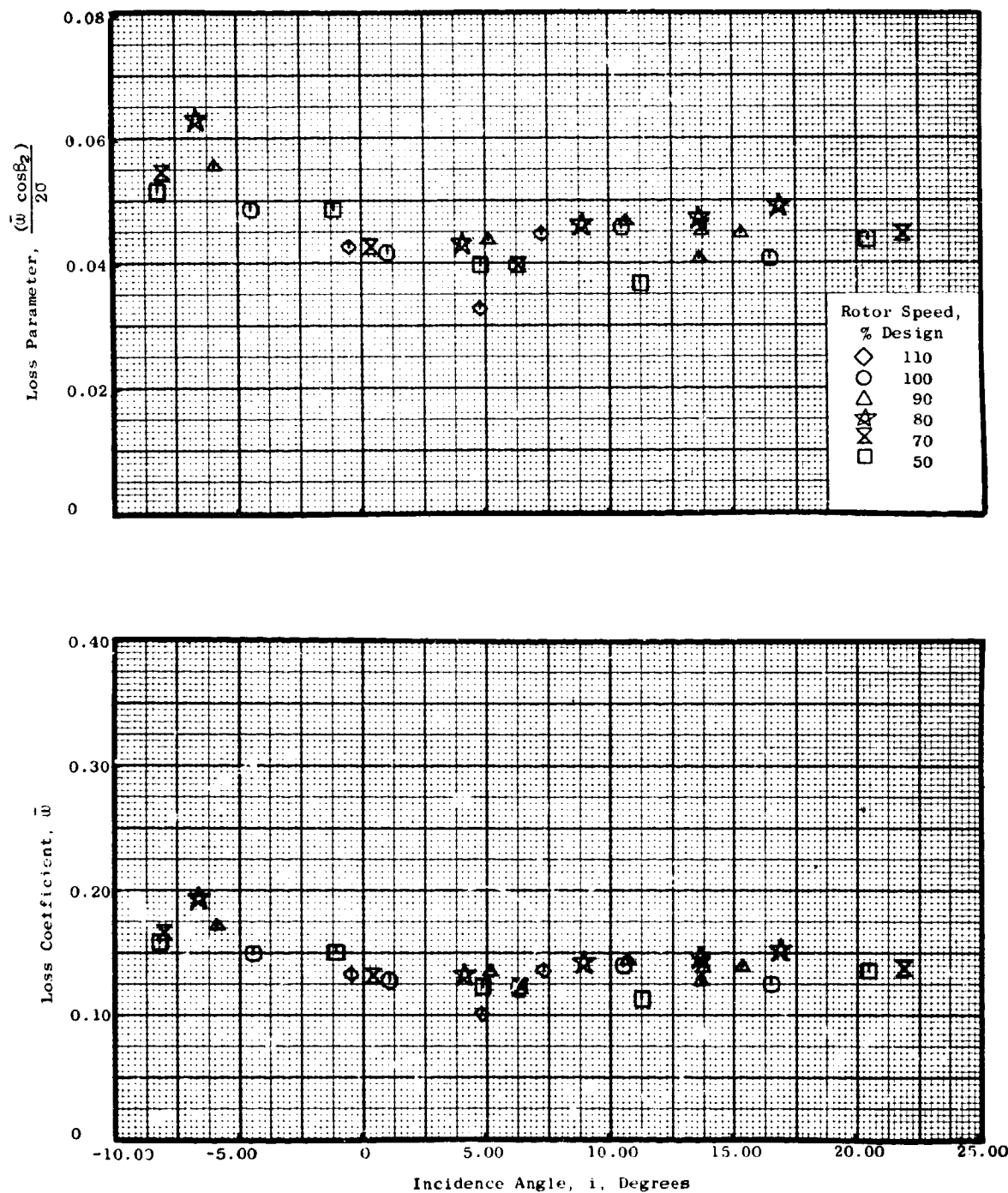


Figure 31(a). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 5% Immersion from Tip.

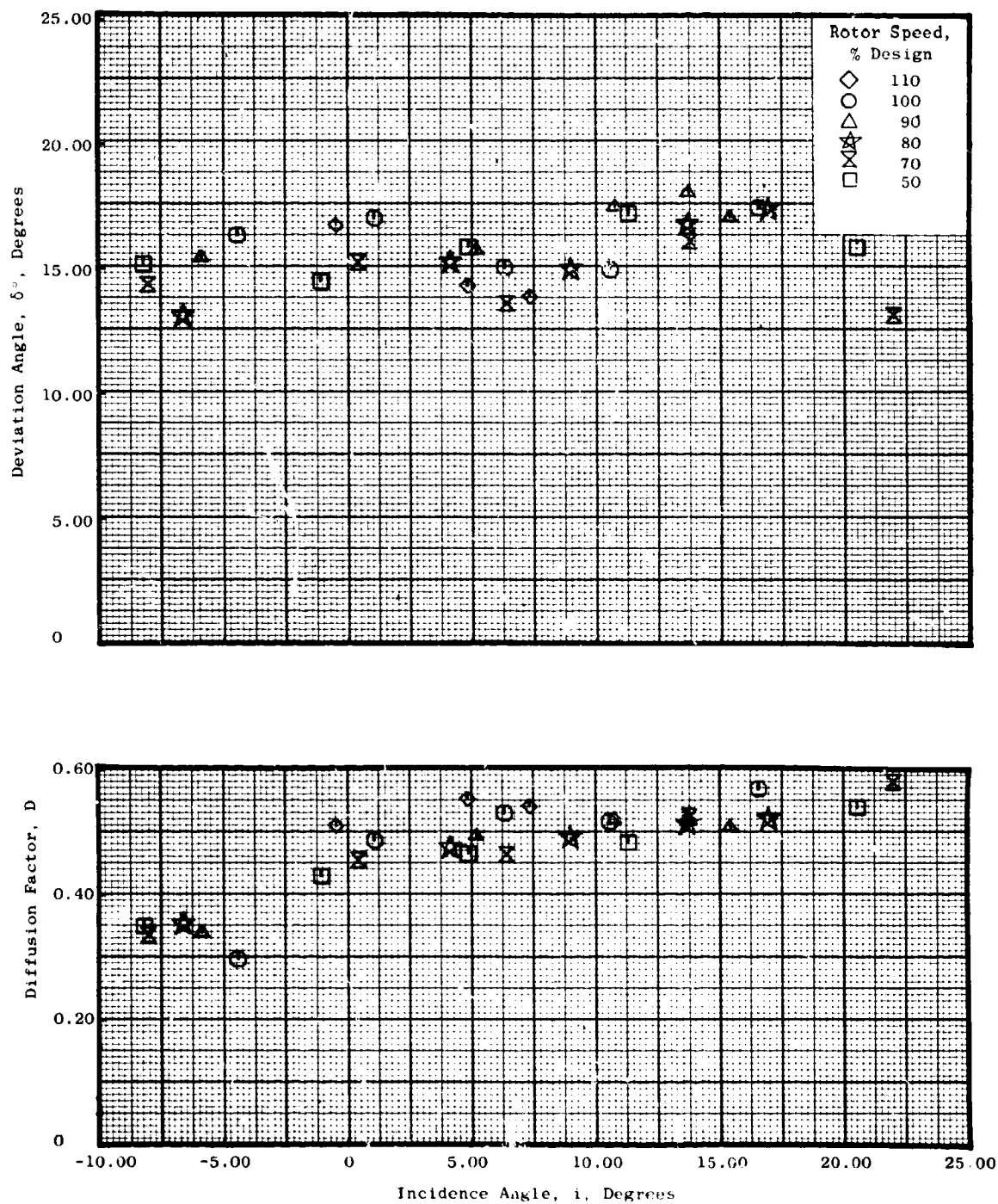


Figure 31(a). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 5% Immersion from Tip (Concluded).

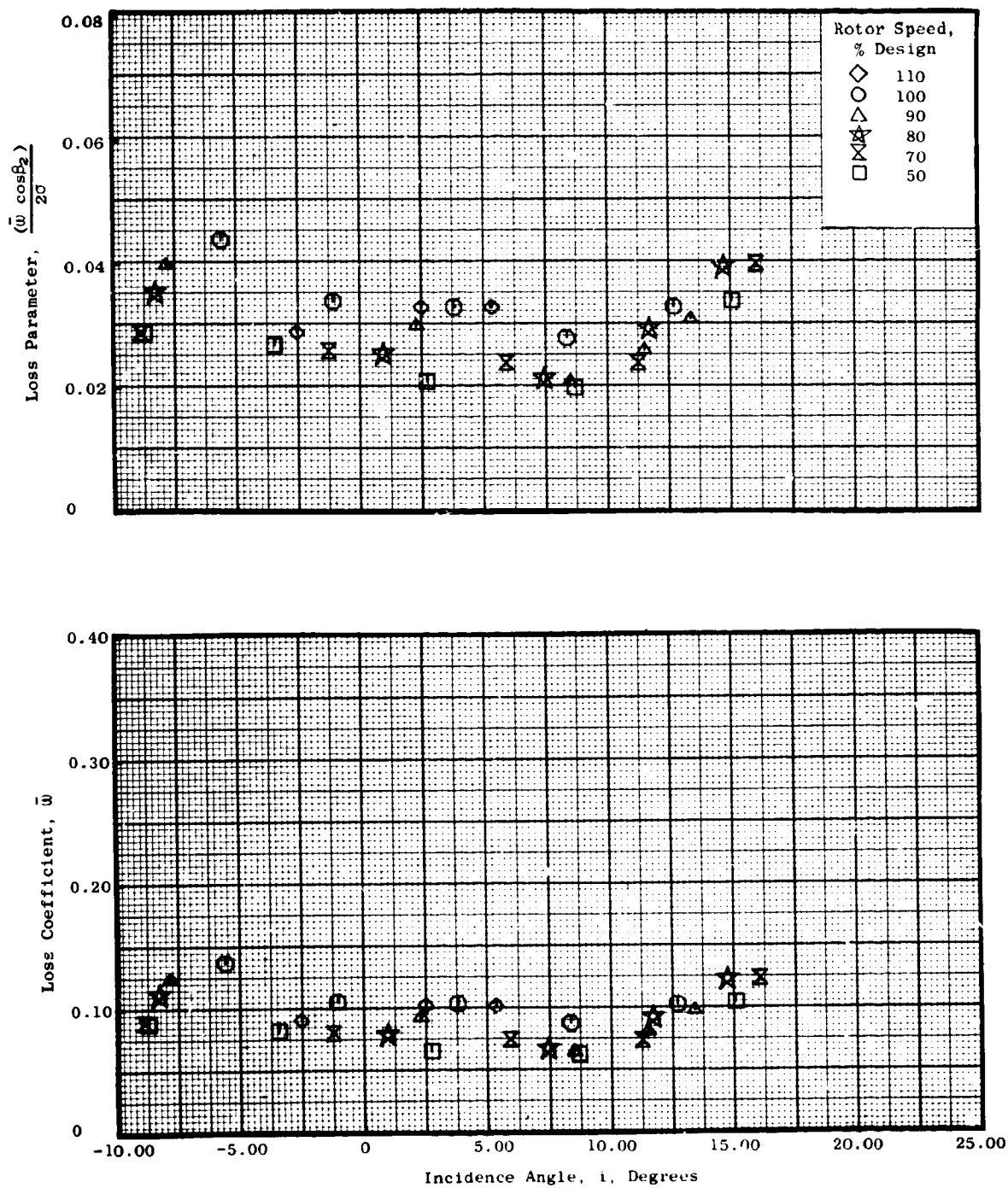


Figure 31(b). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 10% Immersion from Tip.

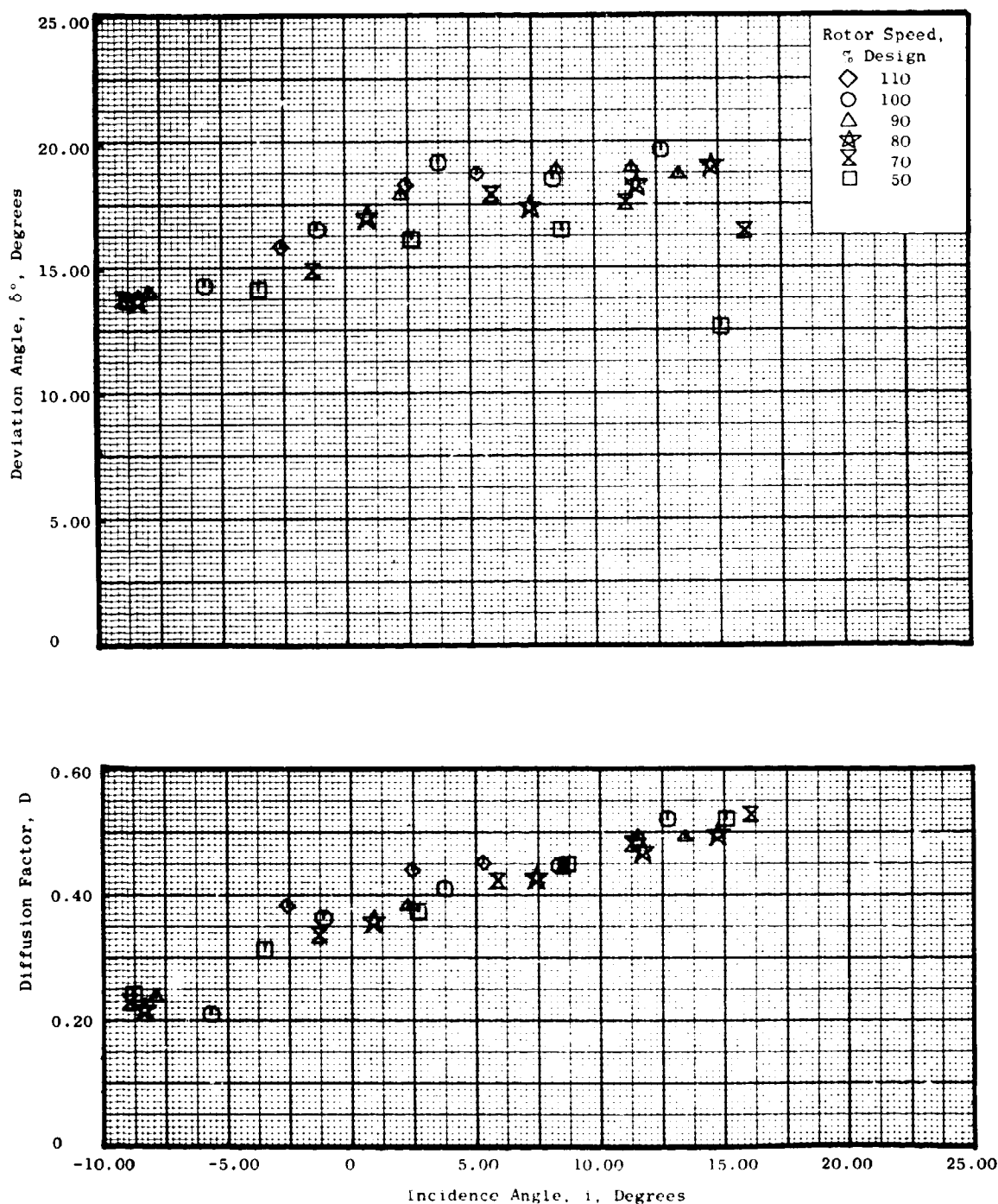


Figure 31(b). Stator Vane Element Data for IGV/Stator Schedule 20°/4° at 10% Immersion from Tip (Concluded).

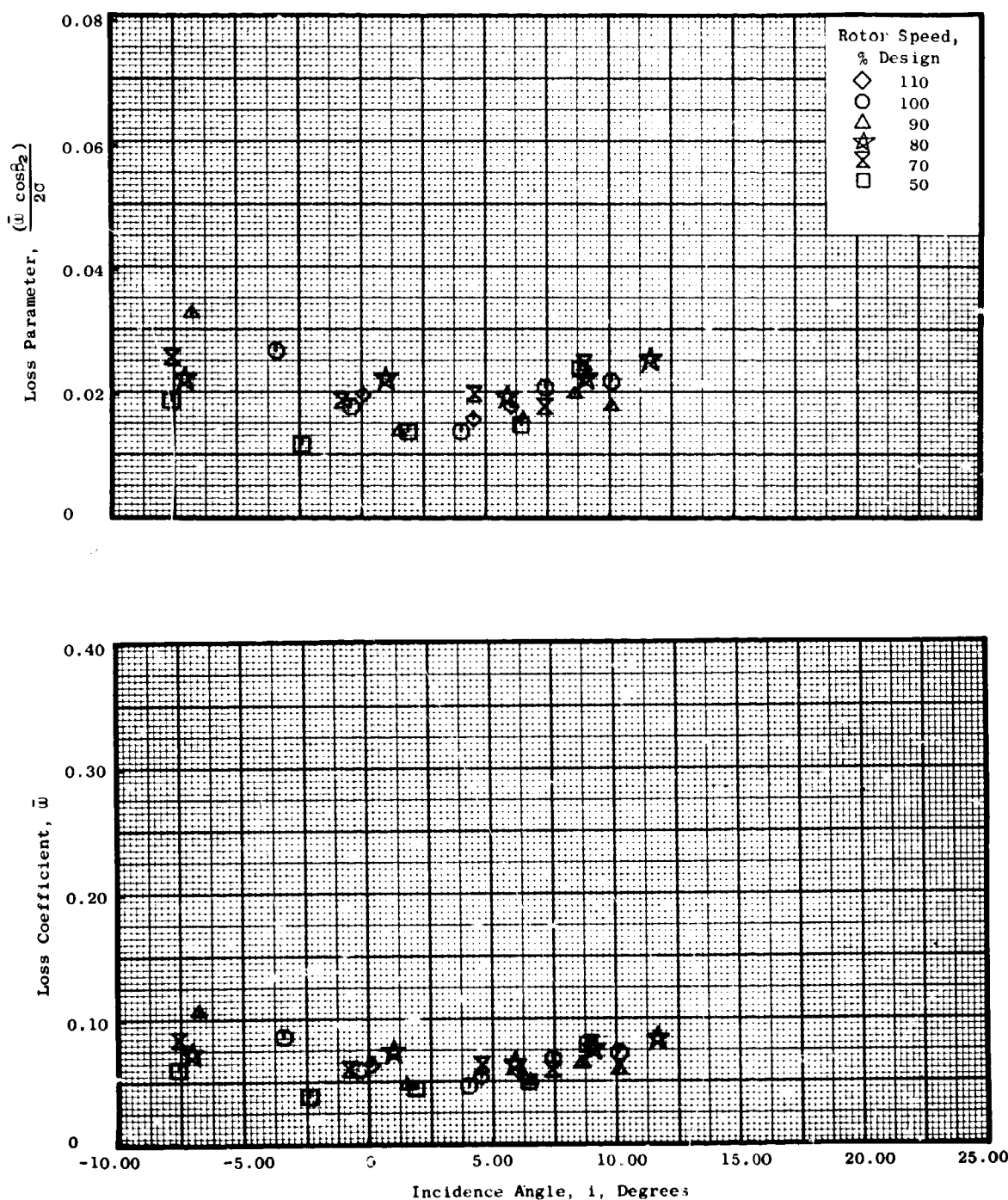


Figure 31(c). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 30% Immersion from Tip.

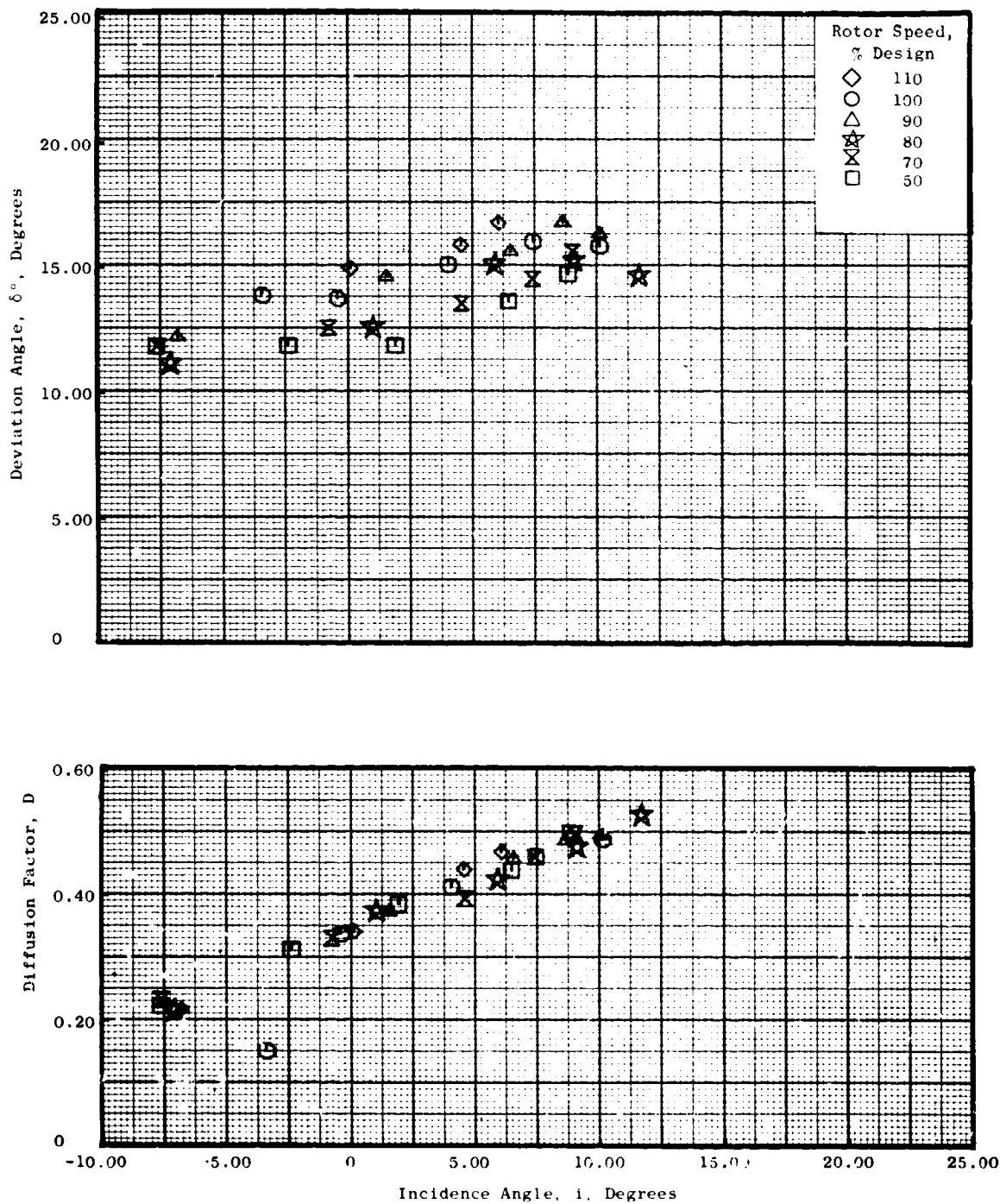


Figure 31(c). Stator Vane Element Data for IGV/Stator Schedule 20°/4° at 30° Immersion from Tip (Concluded).

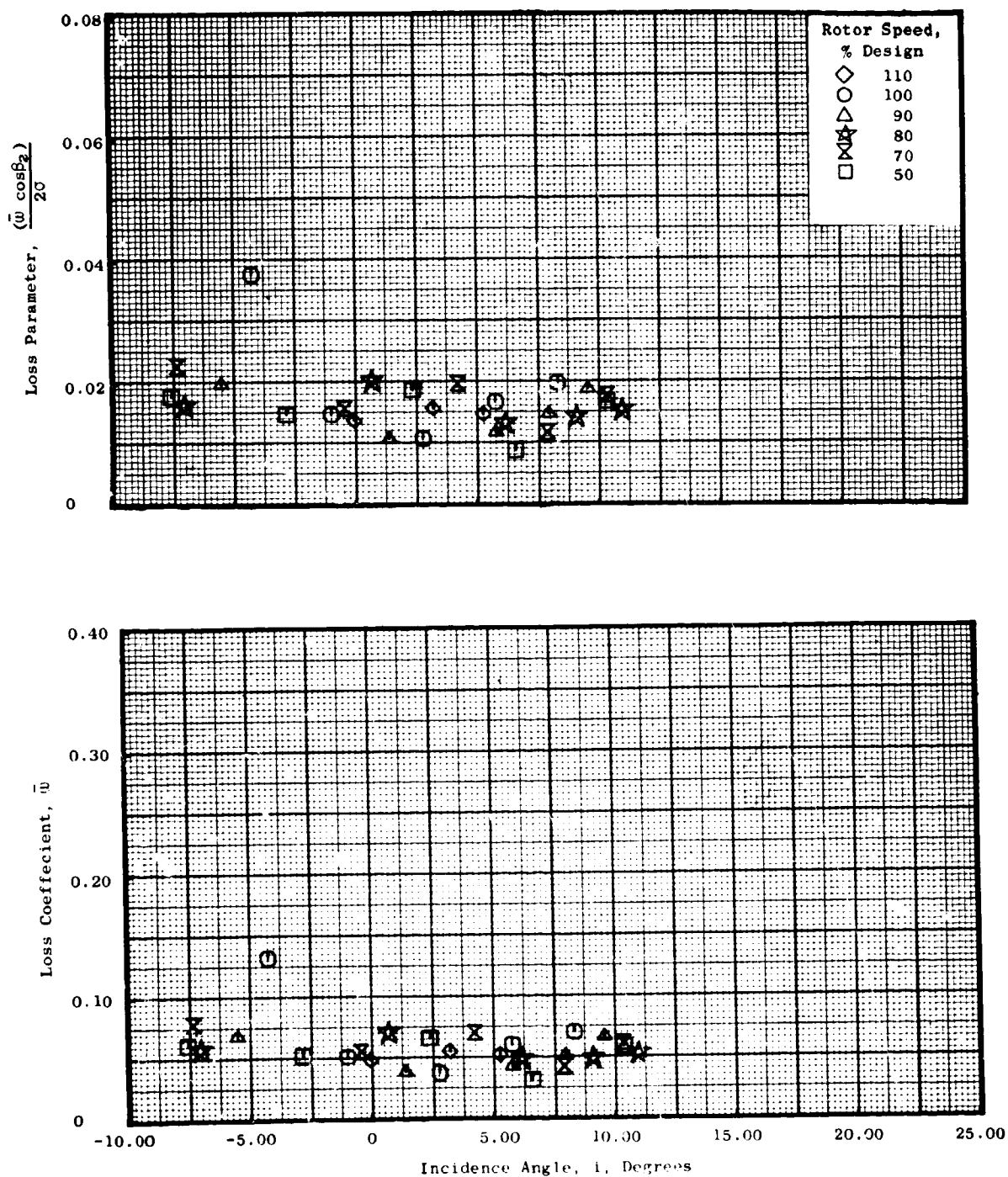


Figure 31(d). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 50% Immersion from Tip.

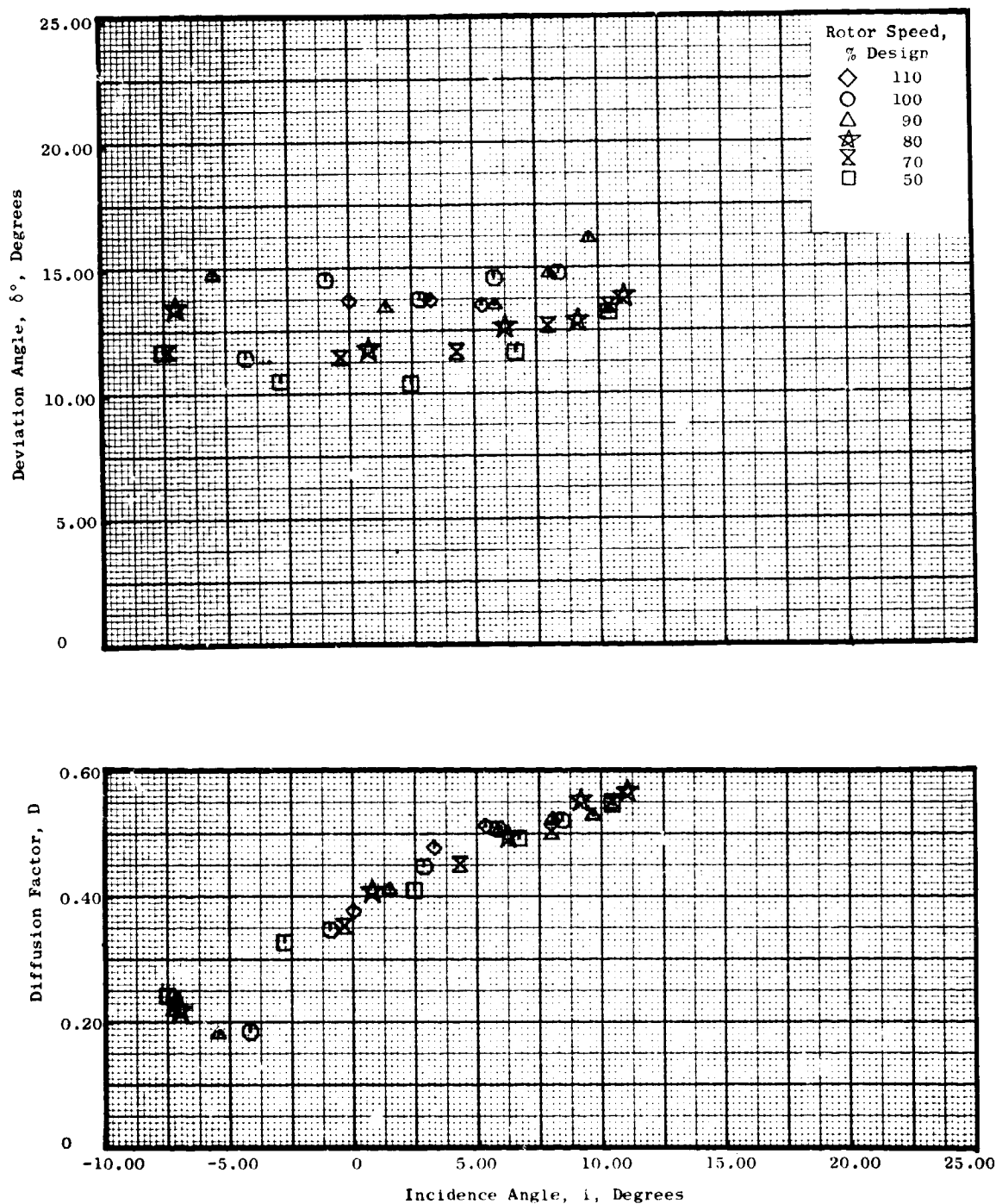


Figure 31(d). Stator Vane Element Data for IGV/Stator Schedule 20°/4° at 50% Immersion from Tip (Concluded).

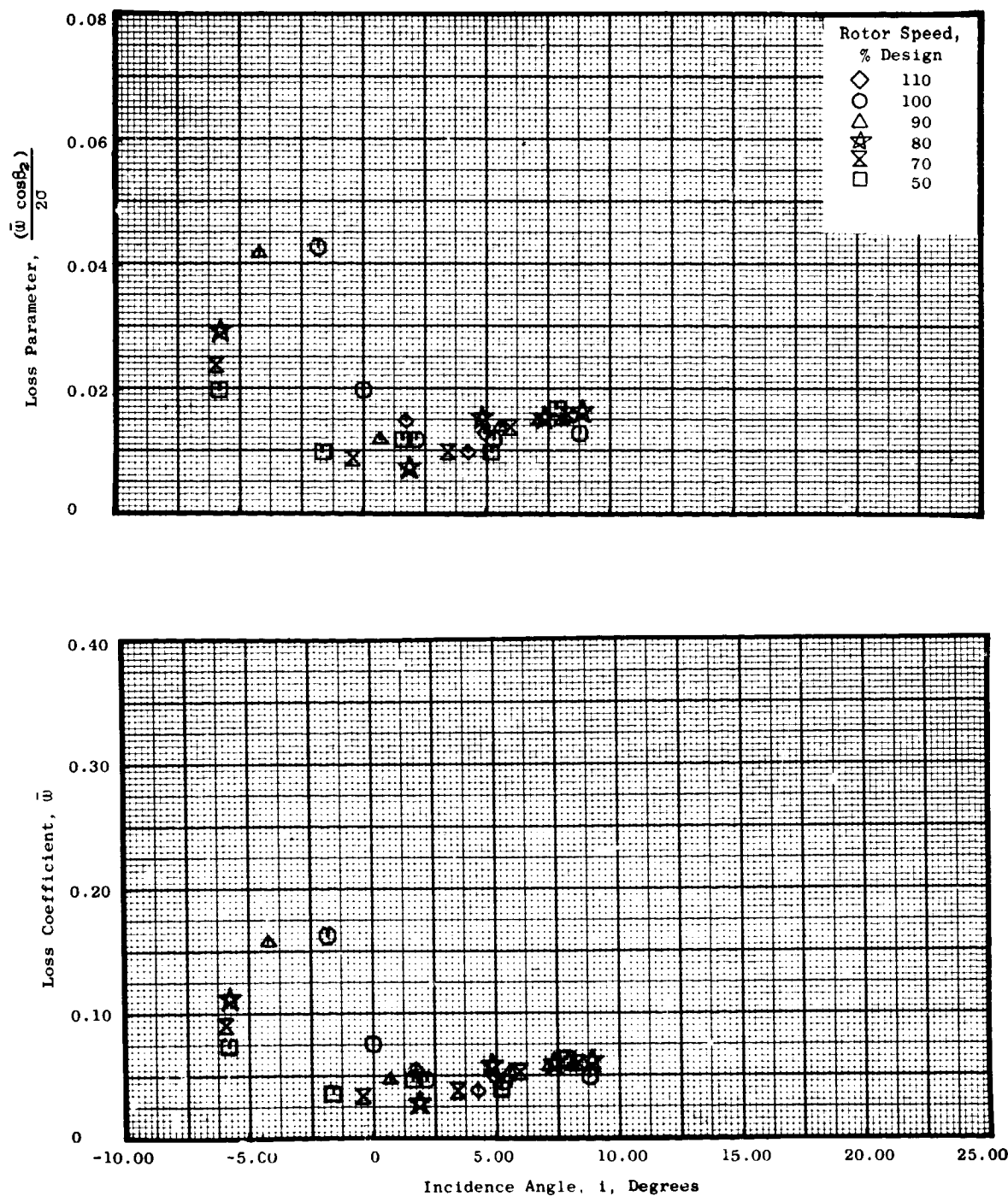


Figure 31(e). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 70% Immersion from Tip.

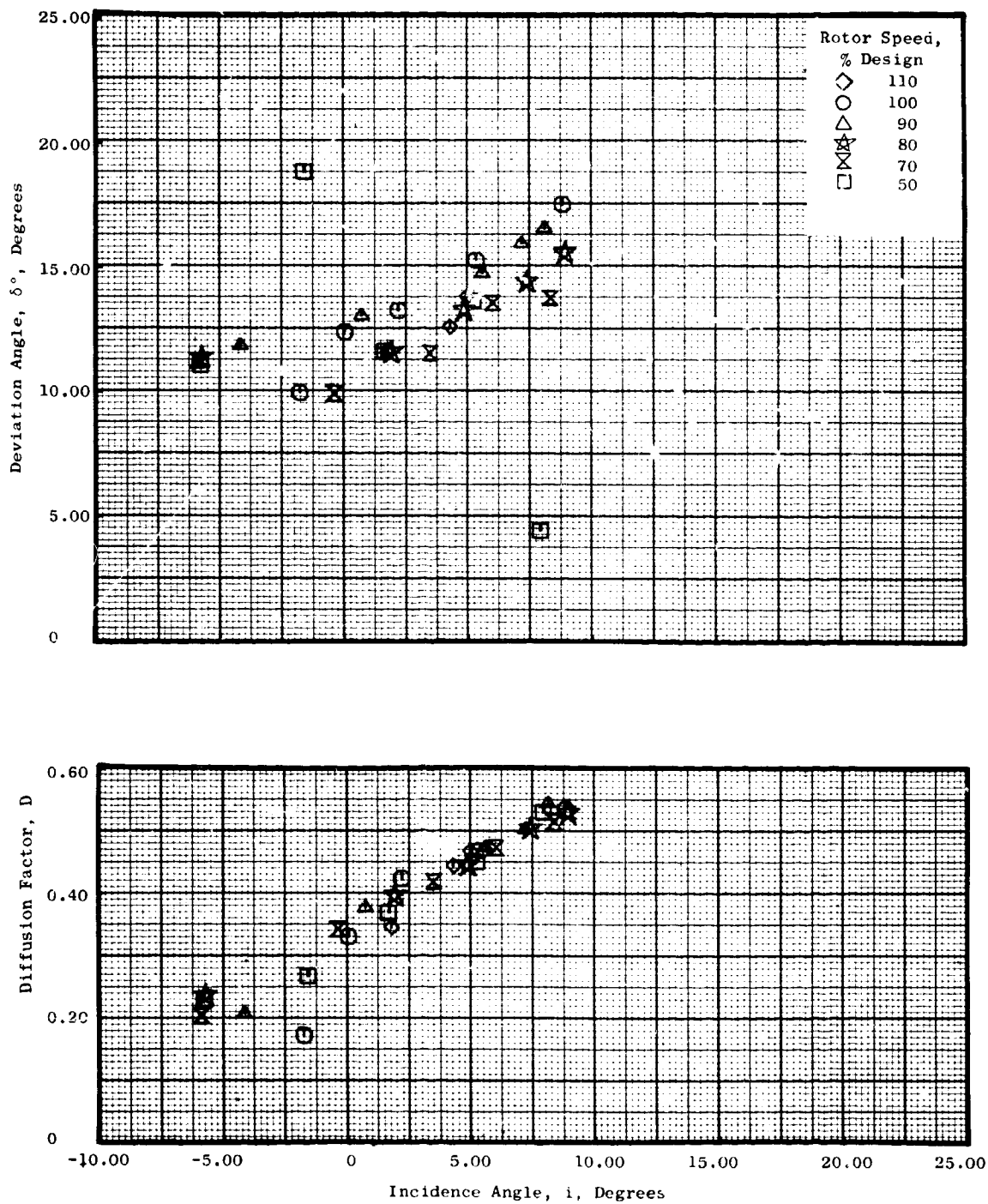


Figure 31(e). Stator Vane Element Data for IGV/Stator Schedule 20°/4° at 70% Immersion from Tip (Concluded).

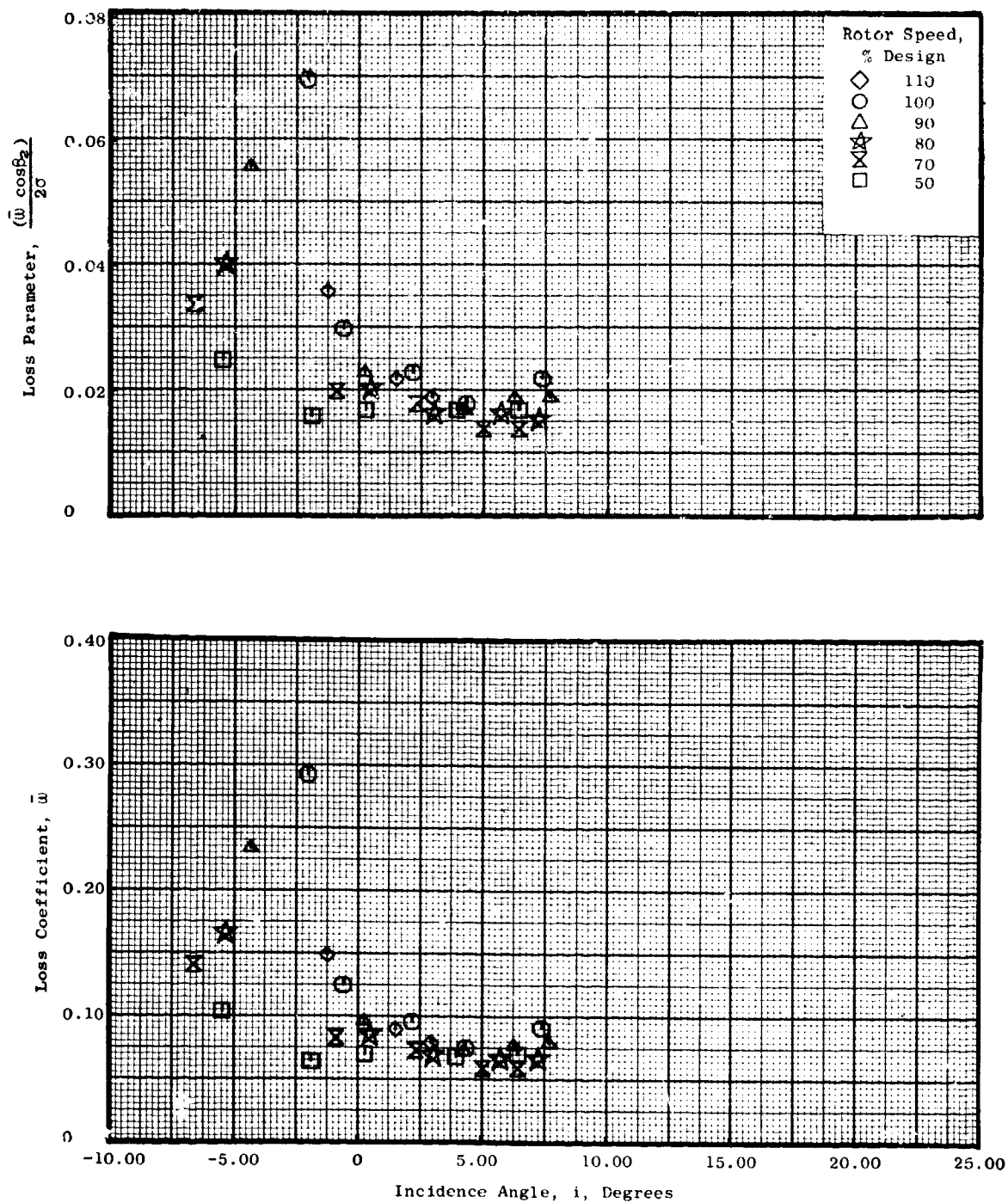


Figure 31(f). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 90% Immersion from Tip.

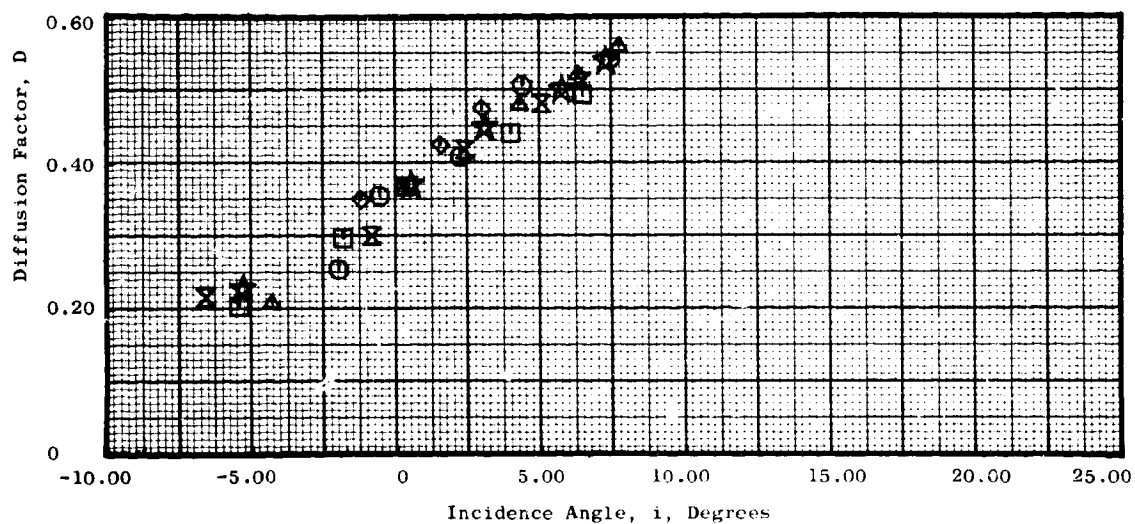
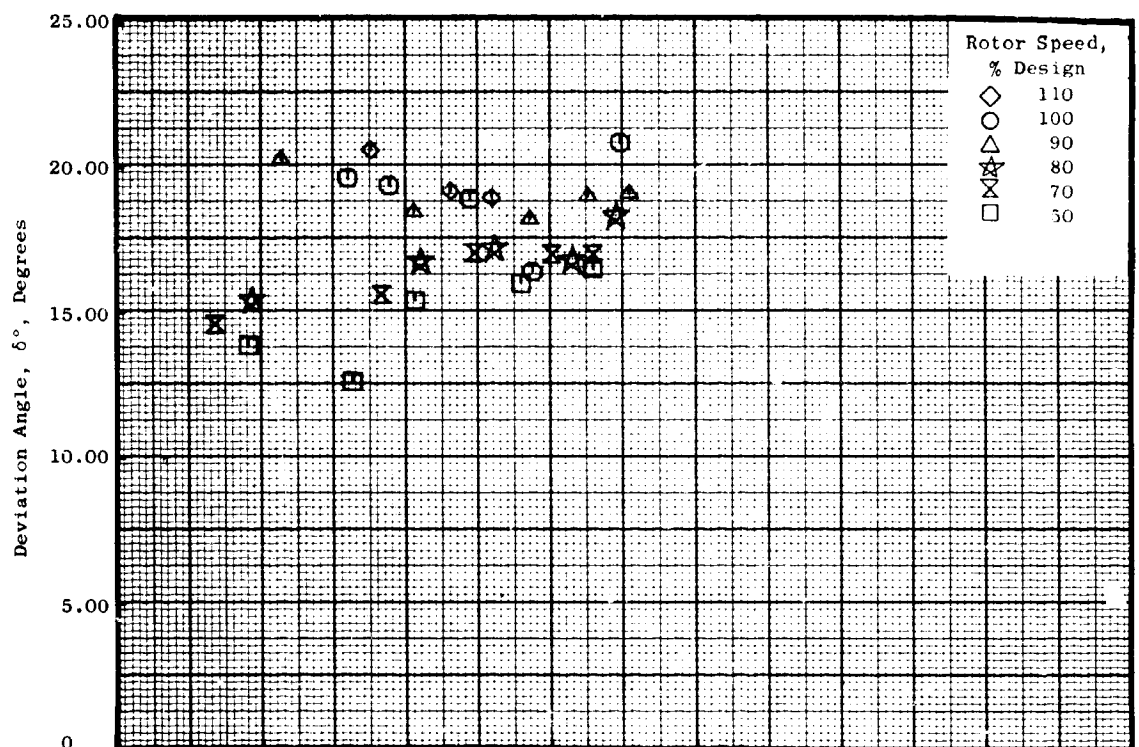


Figure 31(f). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 90% Immersion from Tip (Concluded).

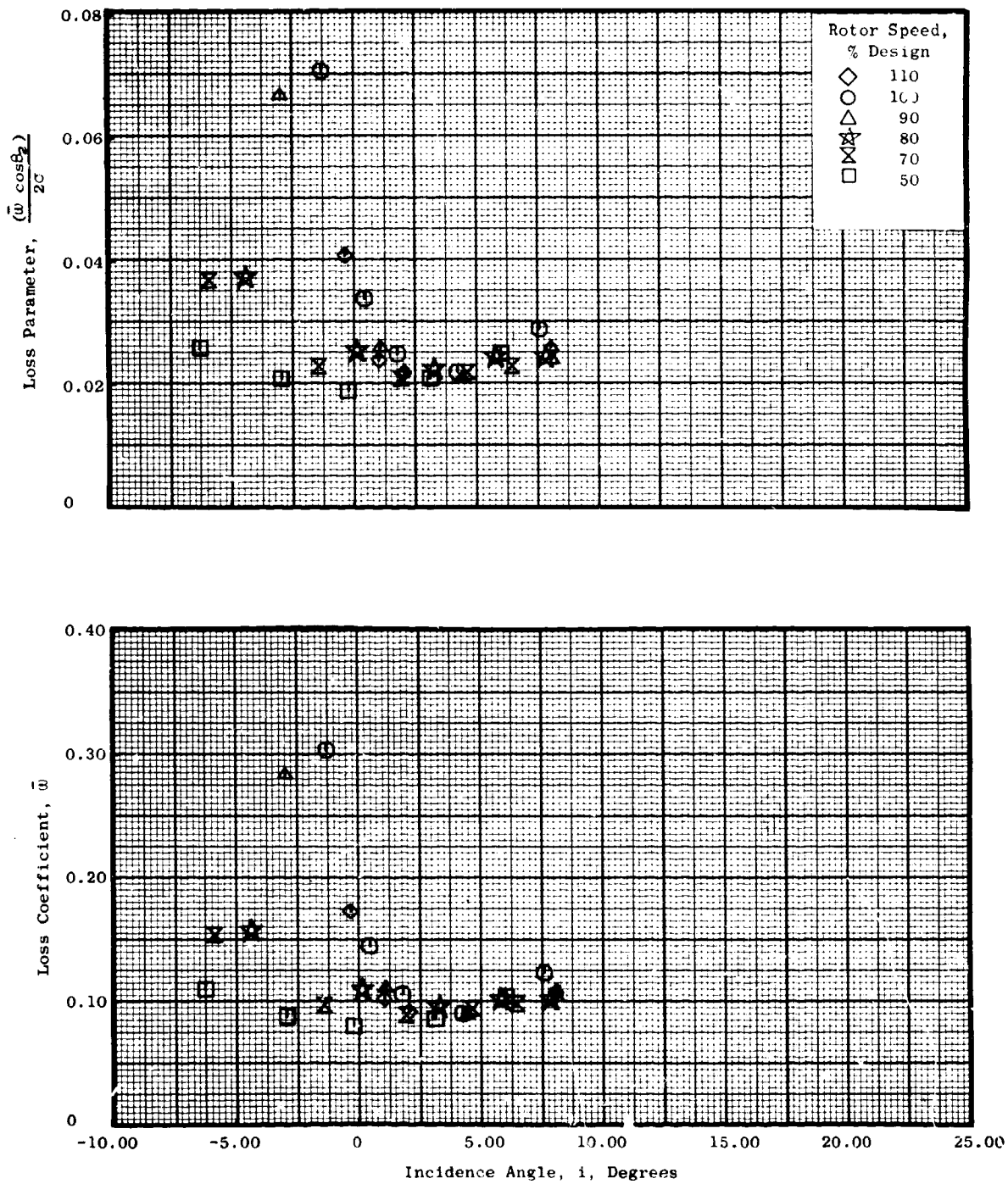


Figure 31(g). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 95% Immersion from Tip.

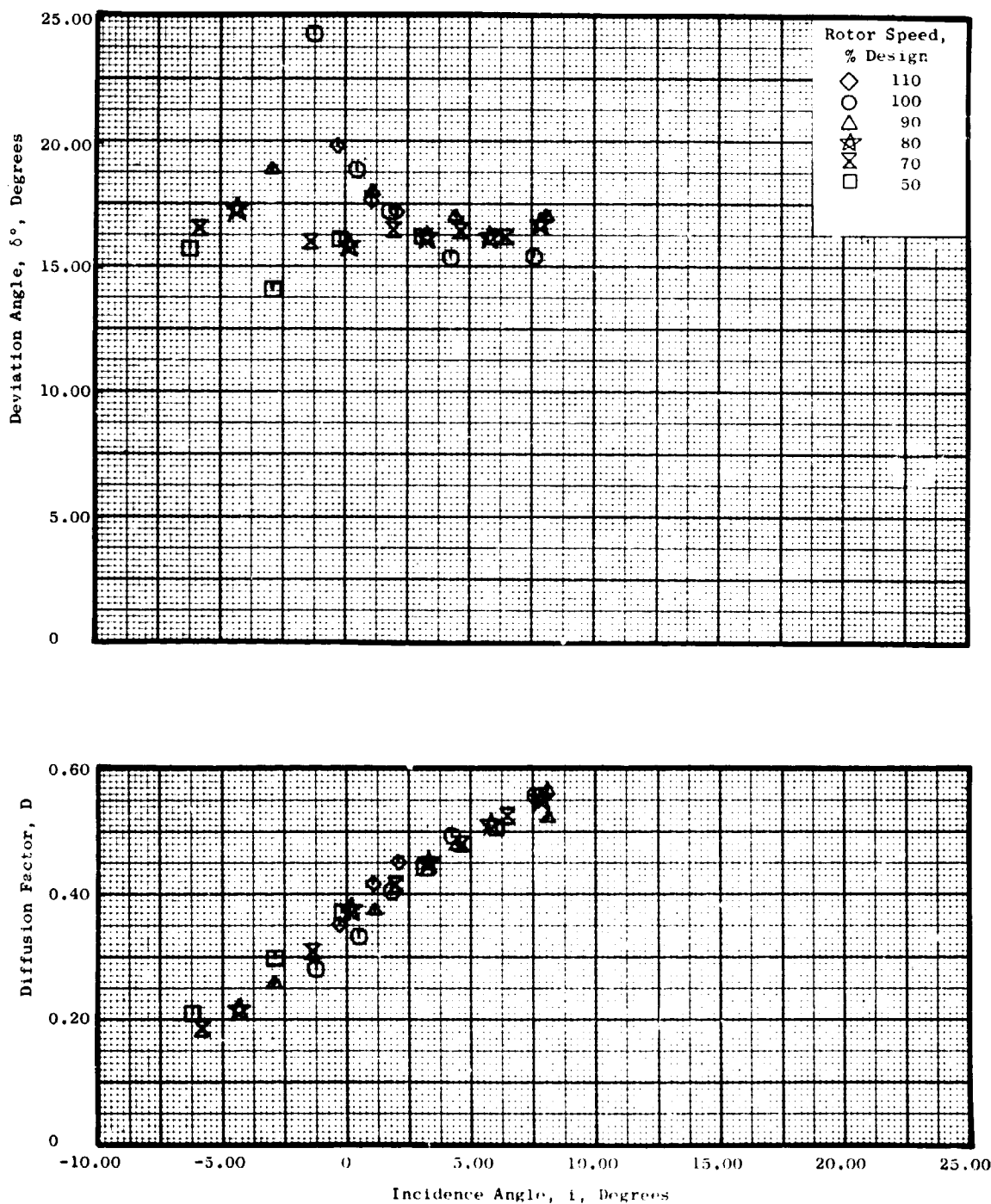


Figure 31(g). Stator Vane Element Data for IGV/Stator Schedule $20^\circ/4^\circ$ at 95% Immersion from Tip (Concluded).

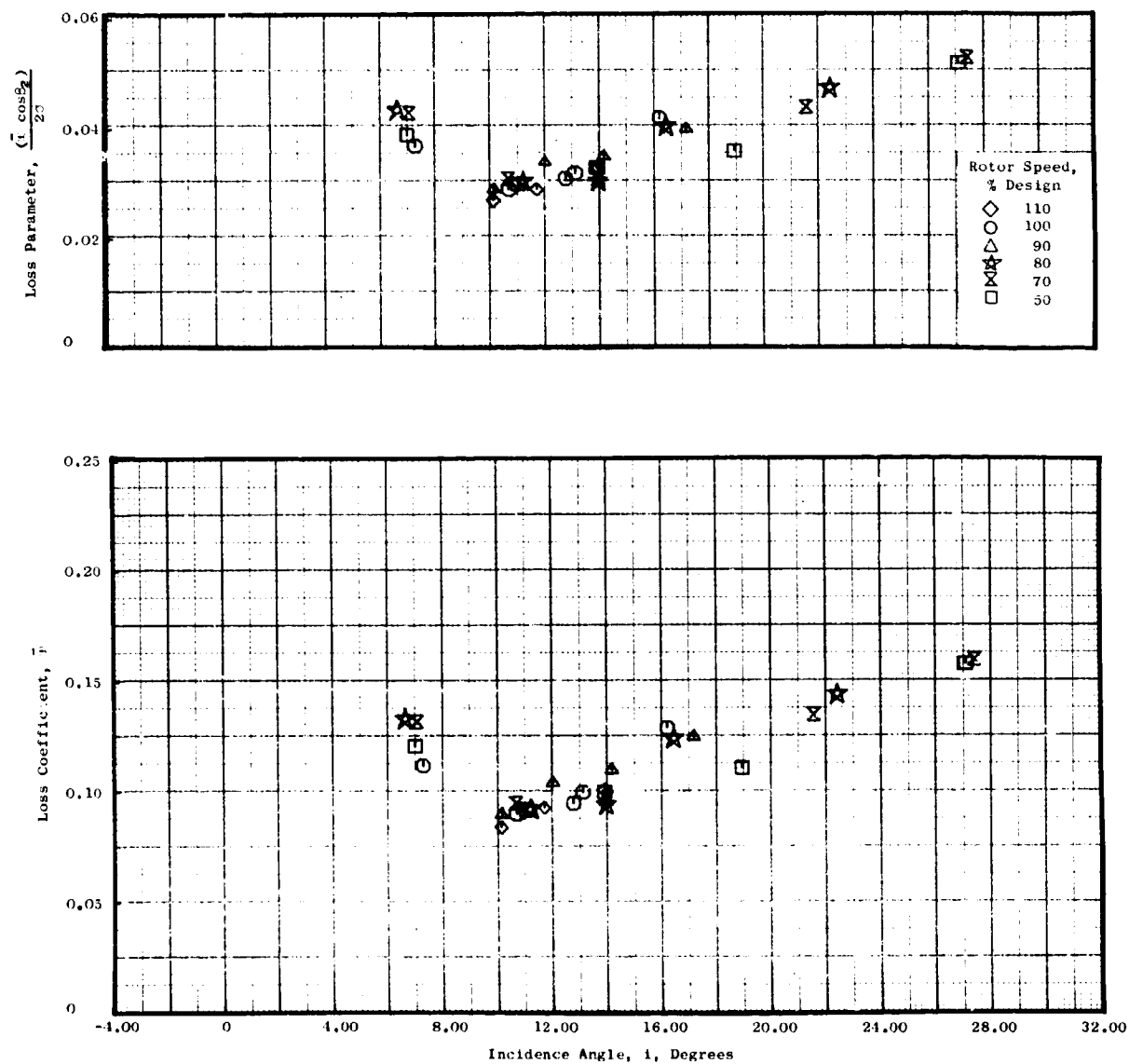


Figure 32(a). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 5% Immersion from Tip.

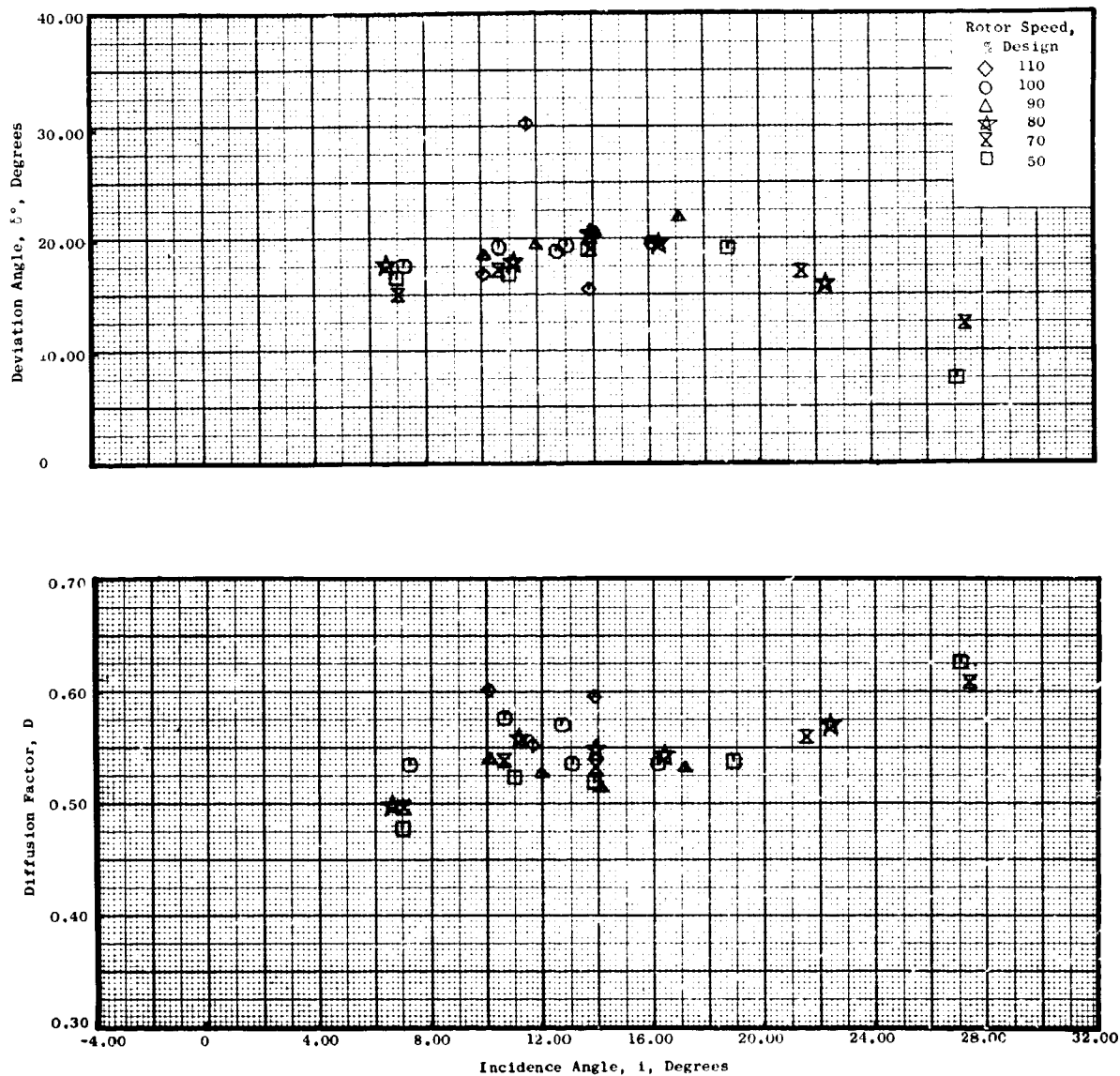


Figure 32(a). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 5% Immersion from Tip (Concluded).

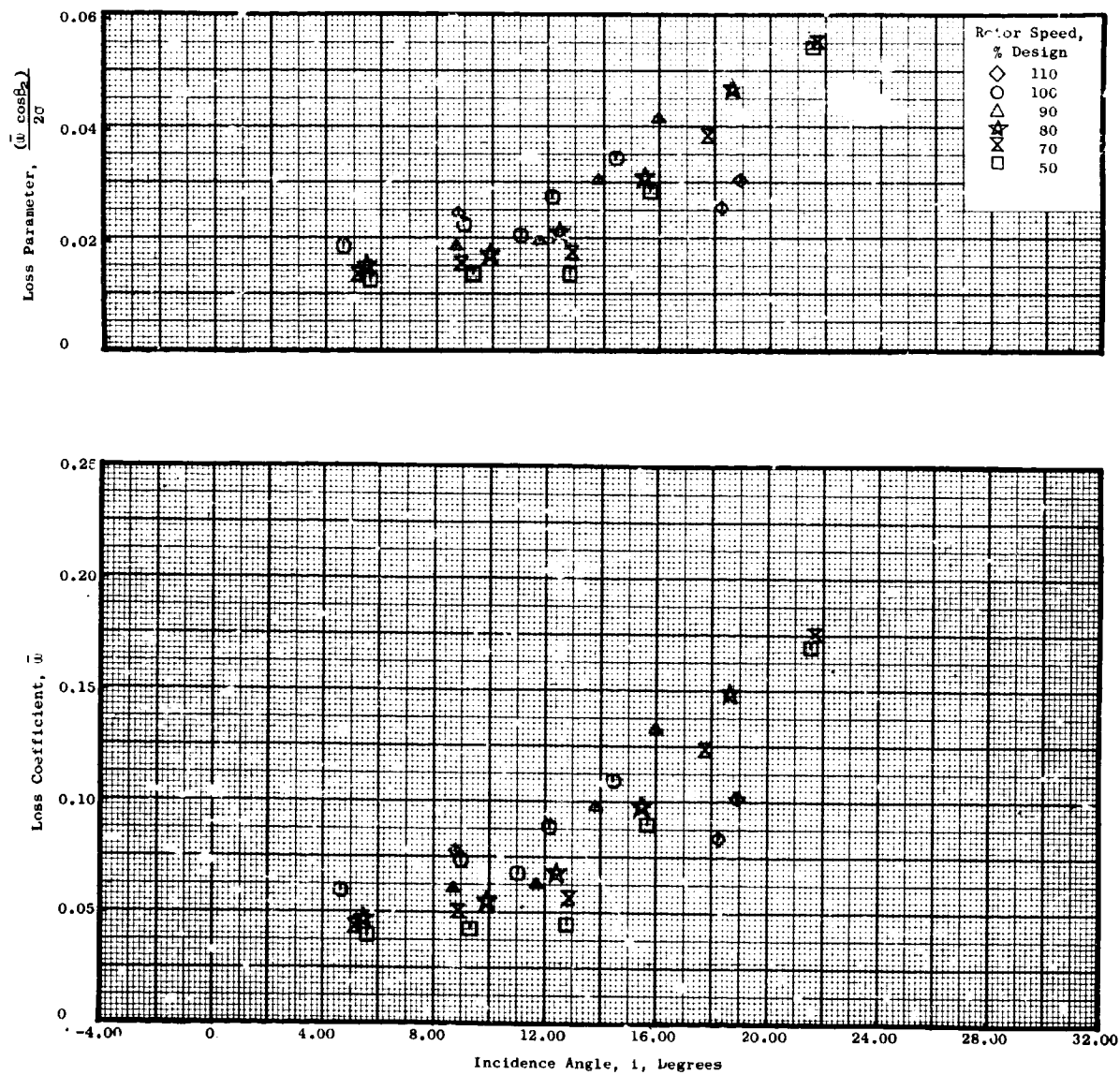


Figure 32(h). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 10% Immersion from Tip.

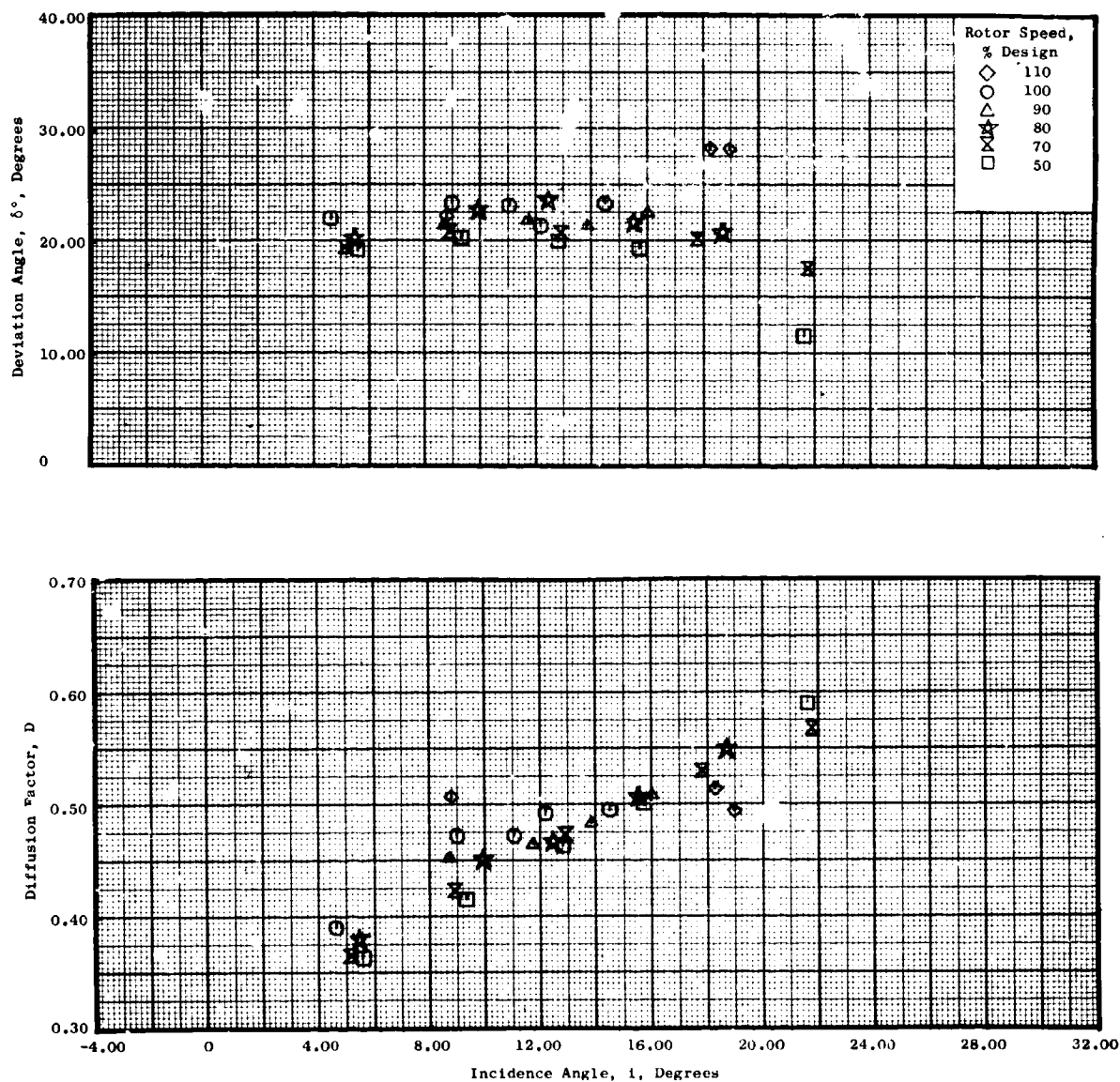


Figure 32(b). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 10% Immersion from Tip (Concluded).

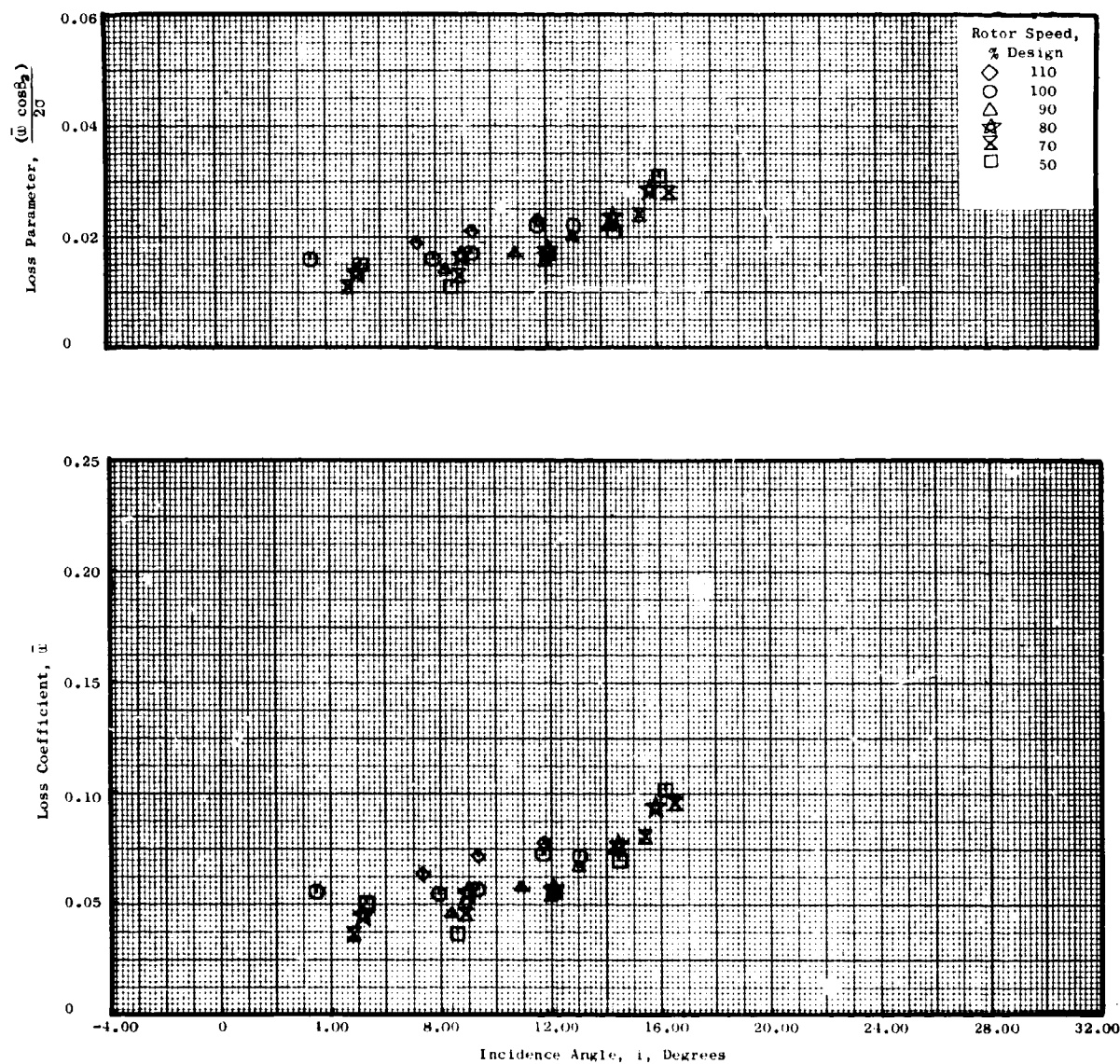


Figure 32(c). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 30° Immersion from Tip.

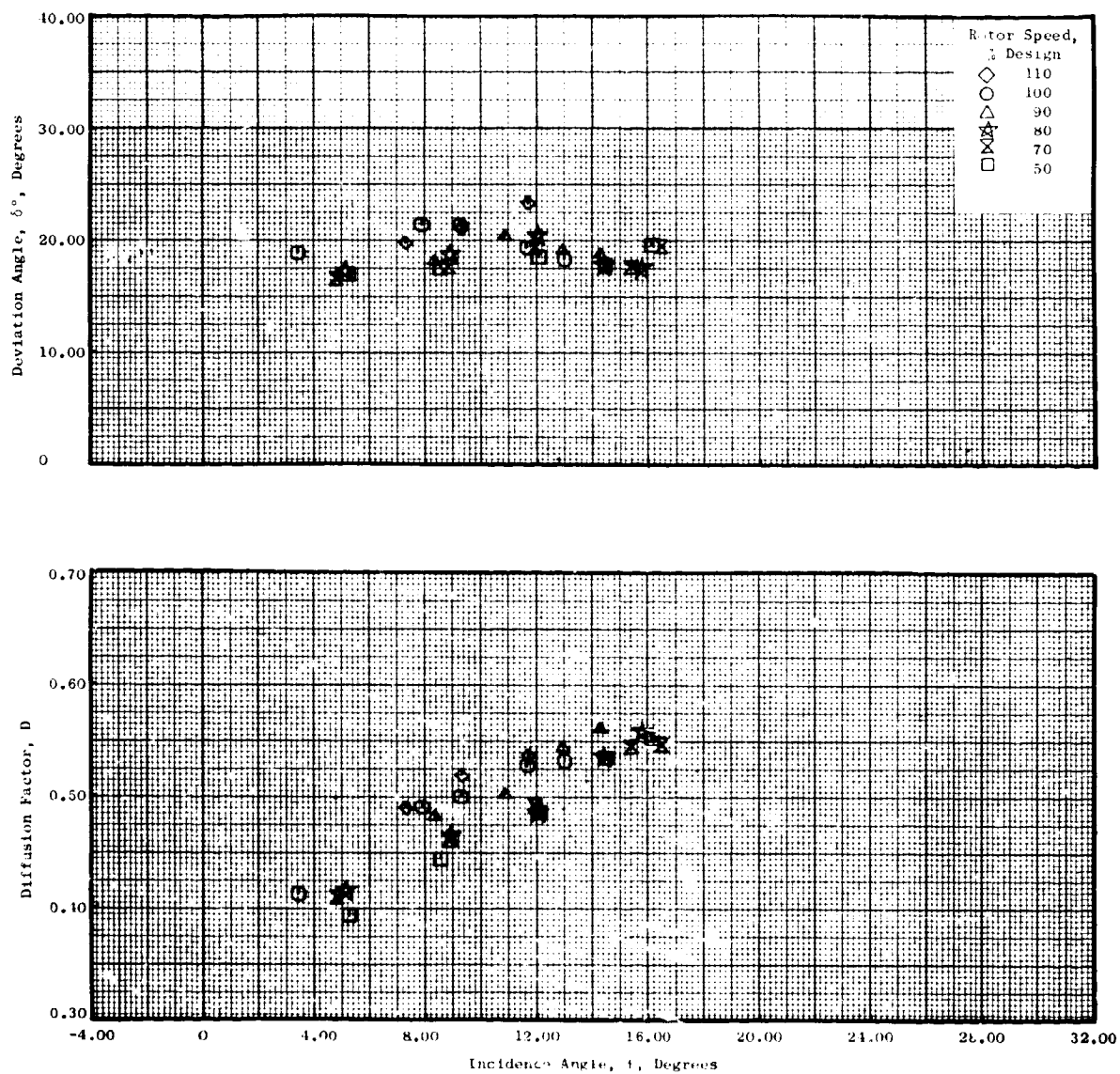


Figure 32(c). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 30% Immersion from Tip (Concluded).

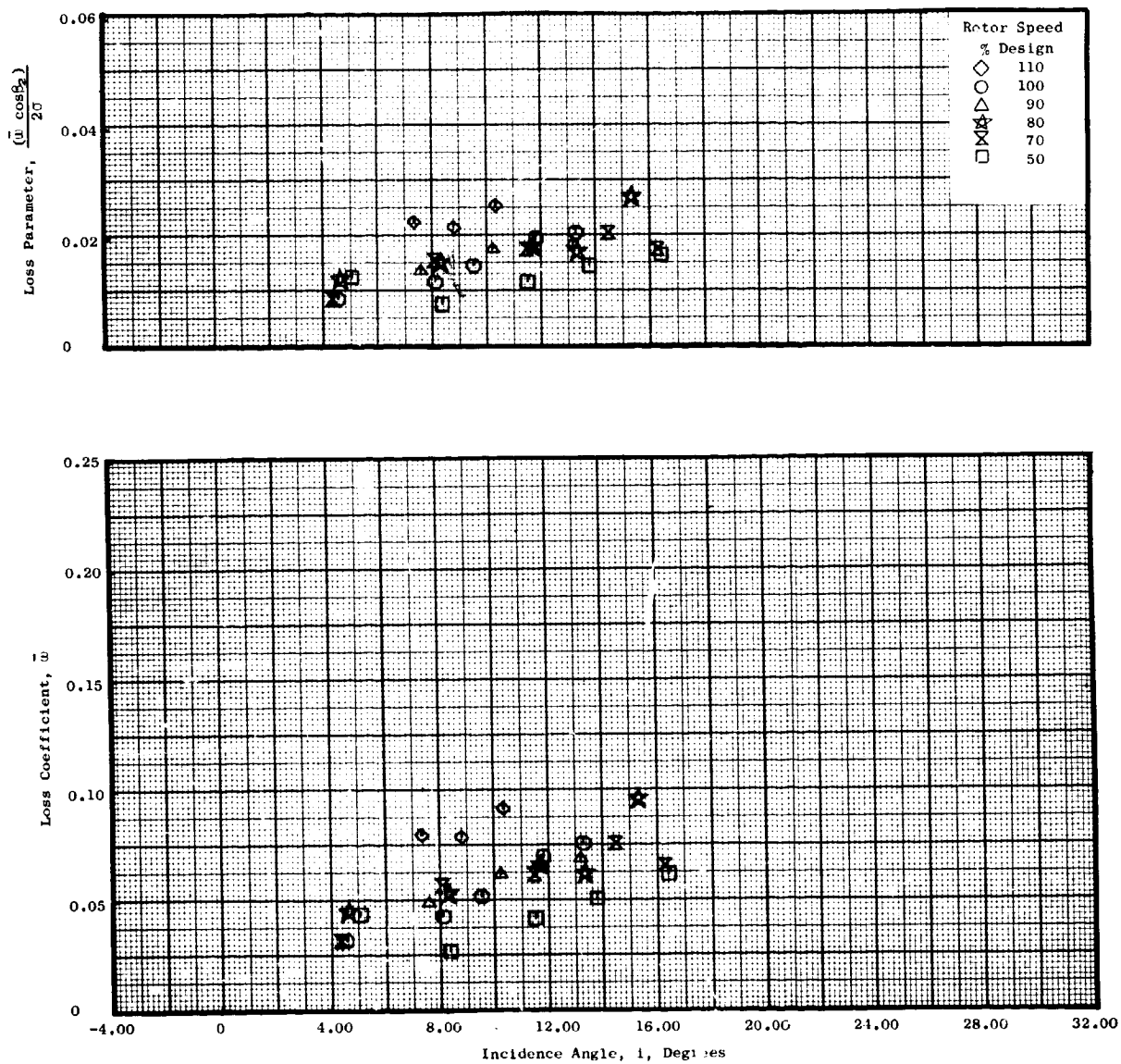


Figure 32(d). Stator Vane Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 50% Immersion from Tip.

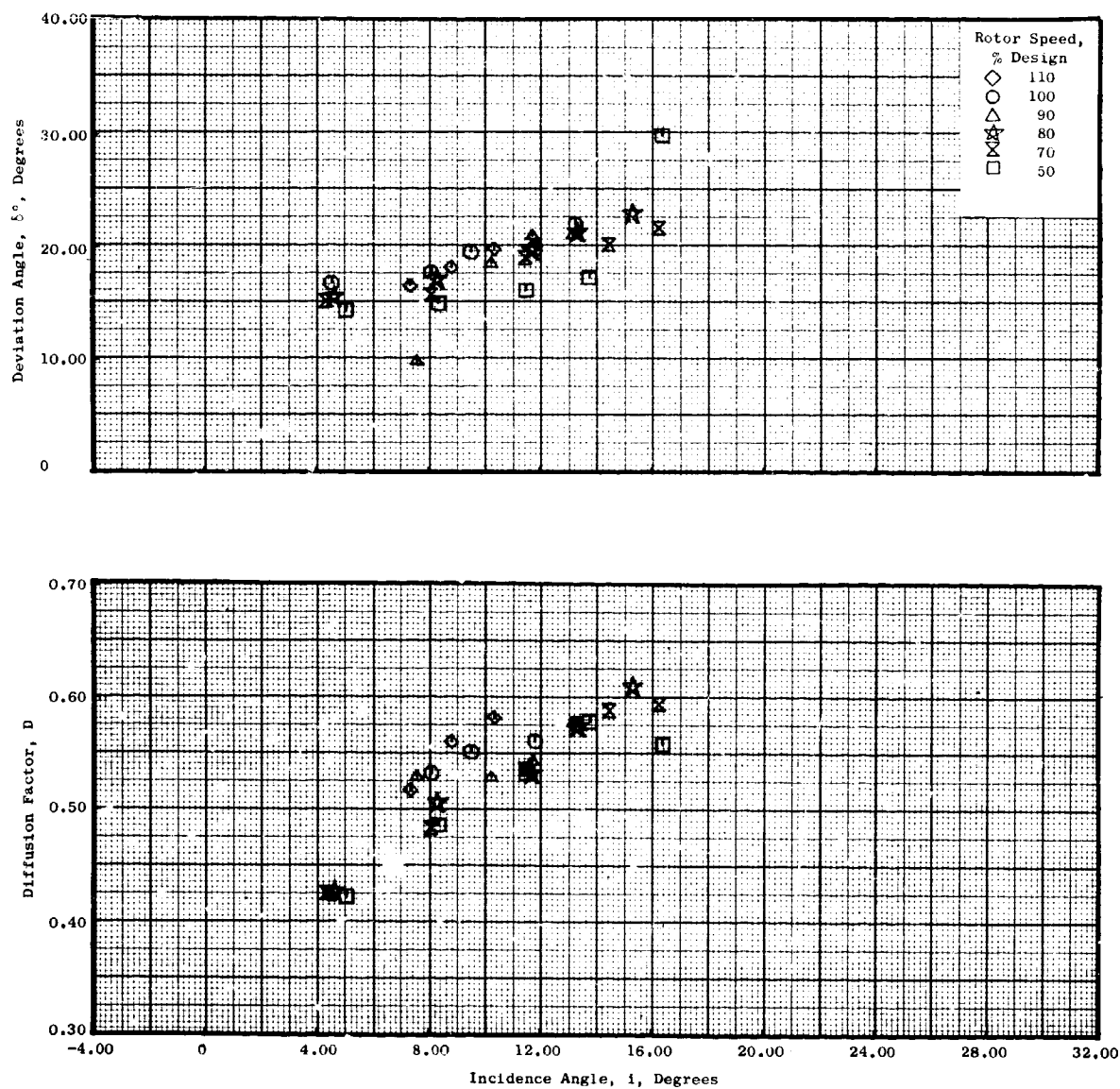


Figure 32(d). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 50% Immersion from Tip (Concluded).

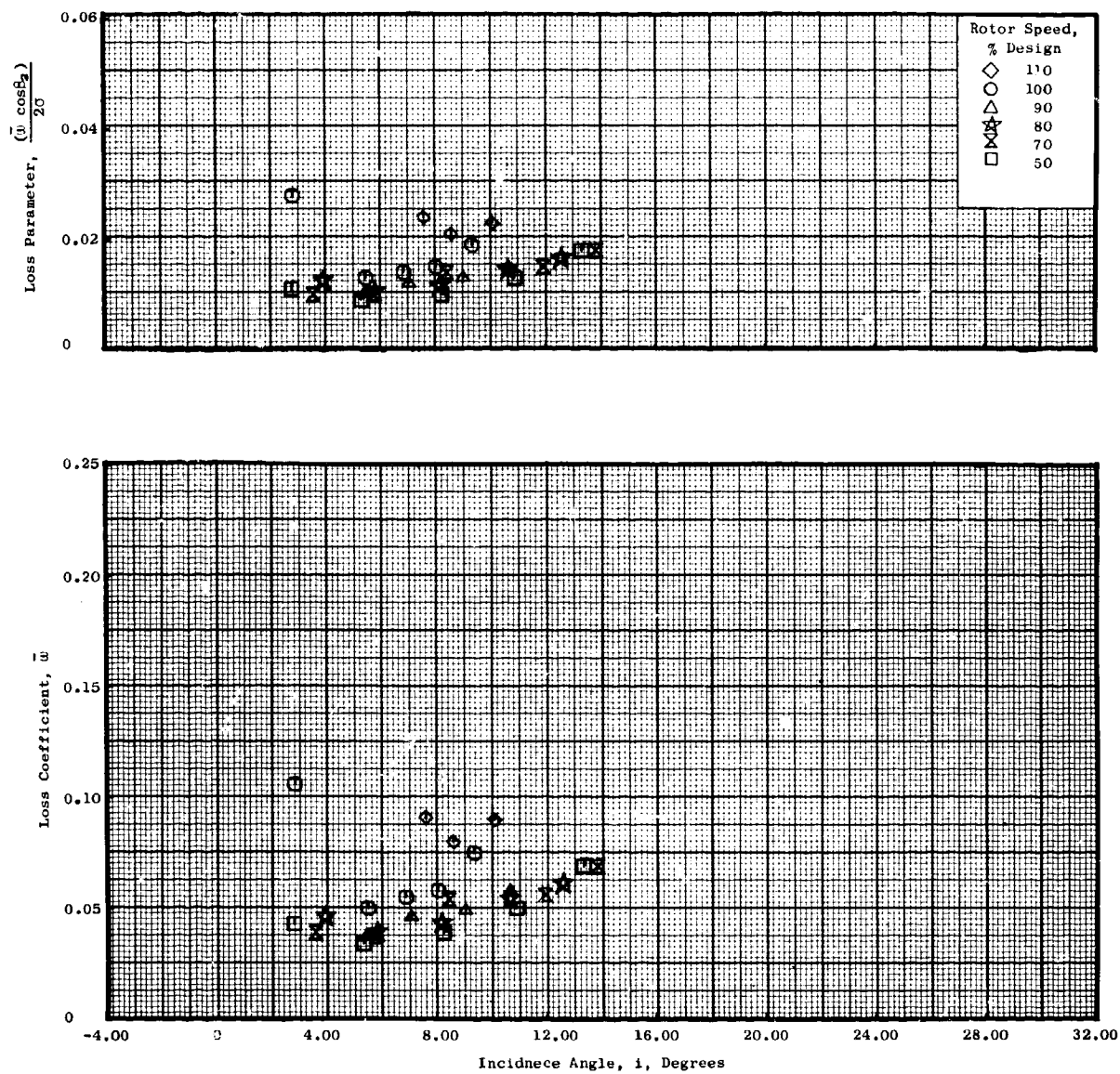


Figure 32(e). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 70% Immersion from Tip.

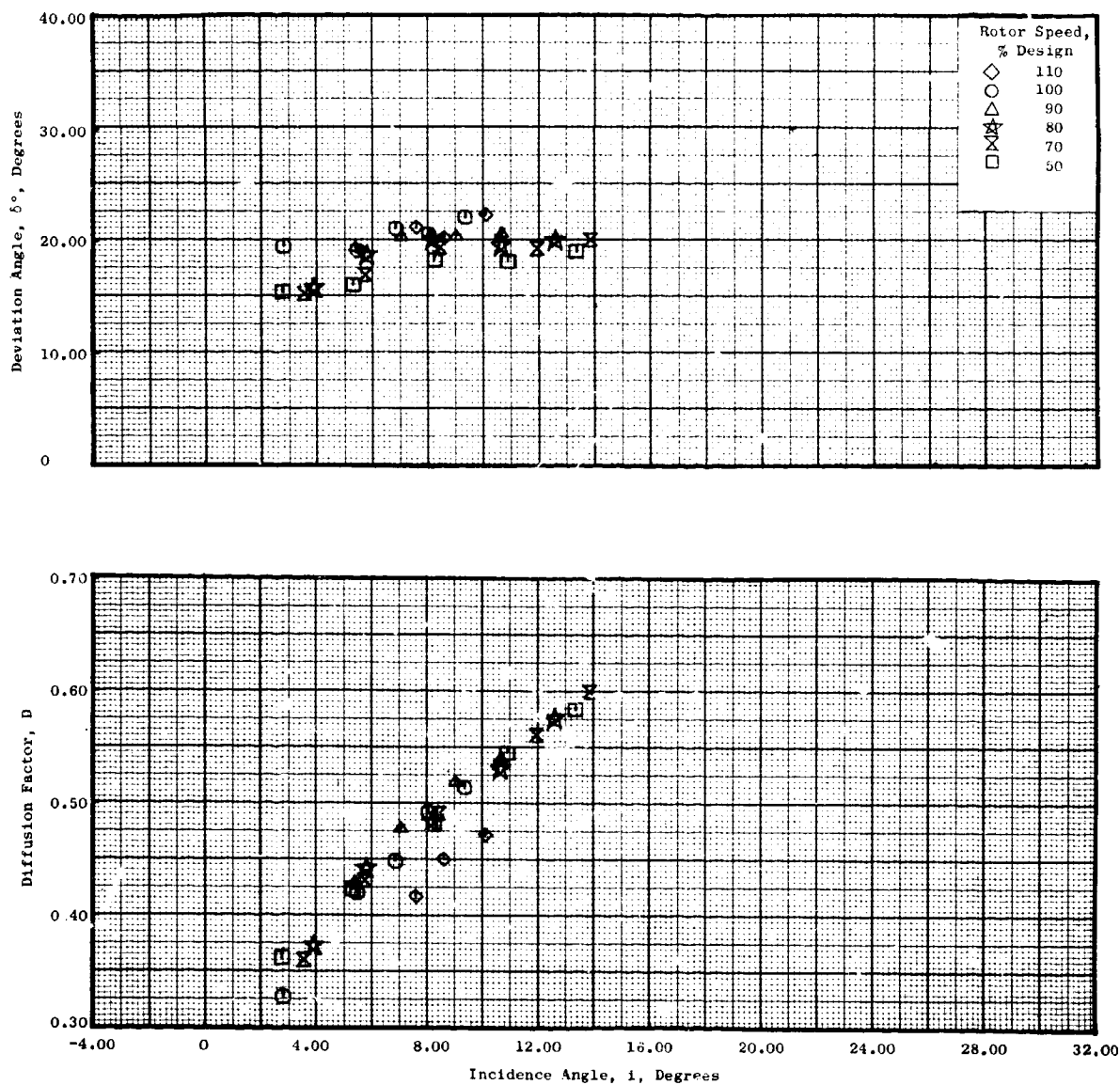


Figure 32(e). Stator Vane Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 70% Immersion from Tip (Concluded).

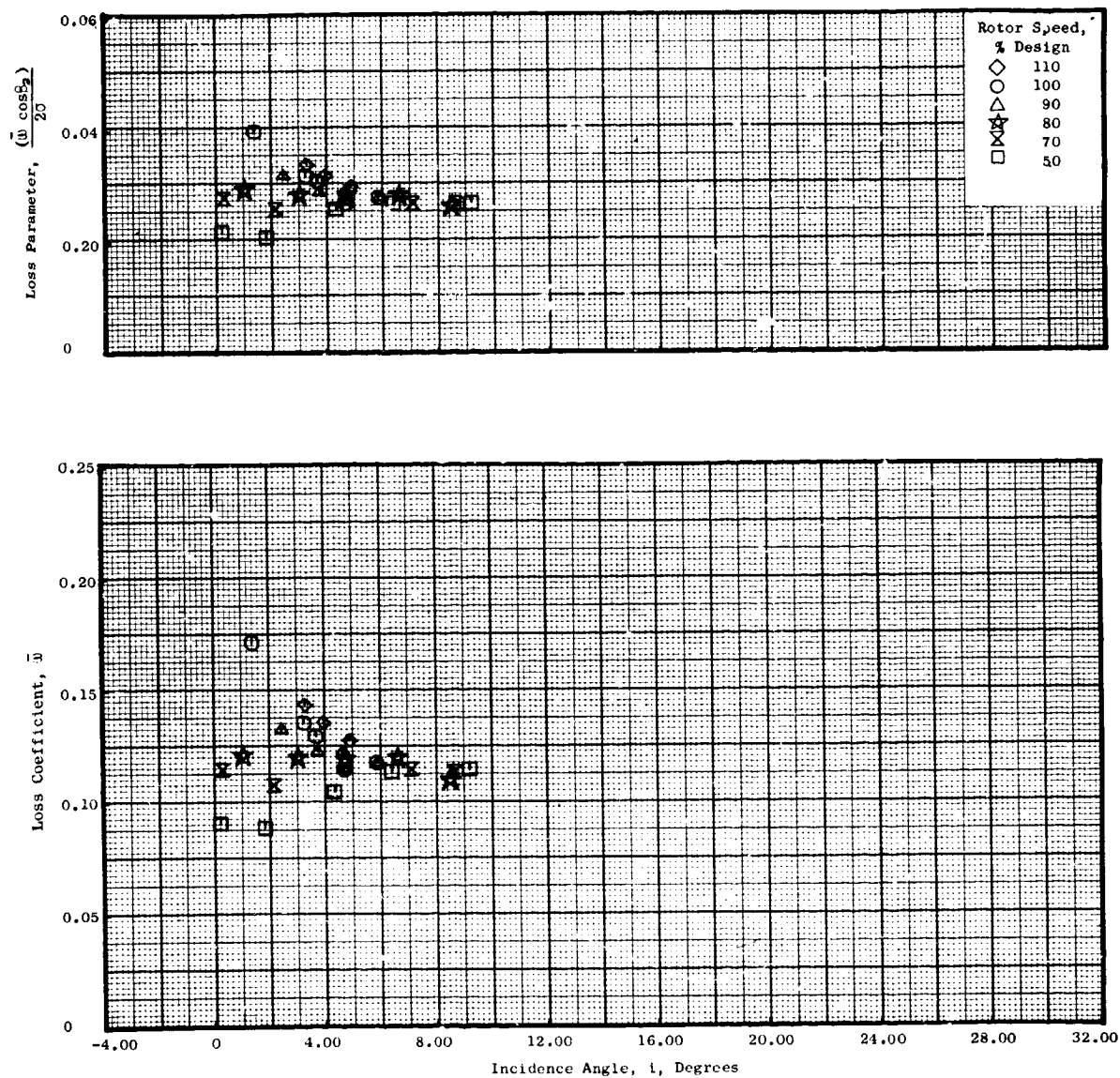


Figure 32(f). Stator Vane Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 90% Immersion from Tip.

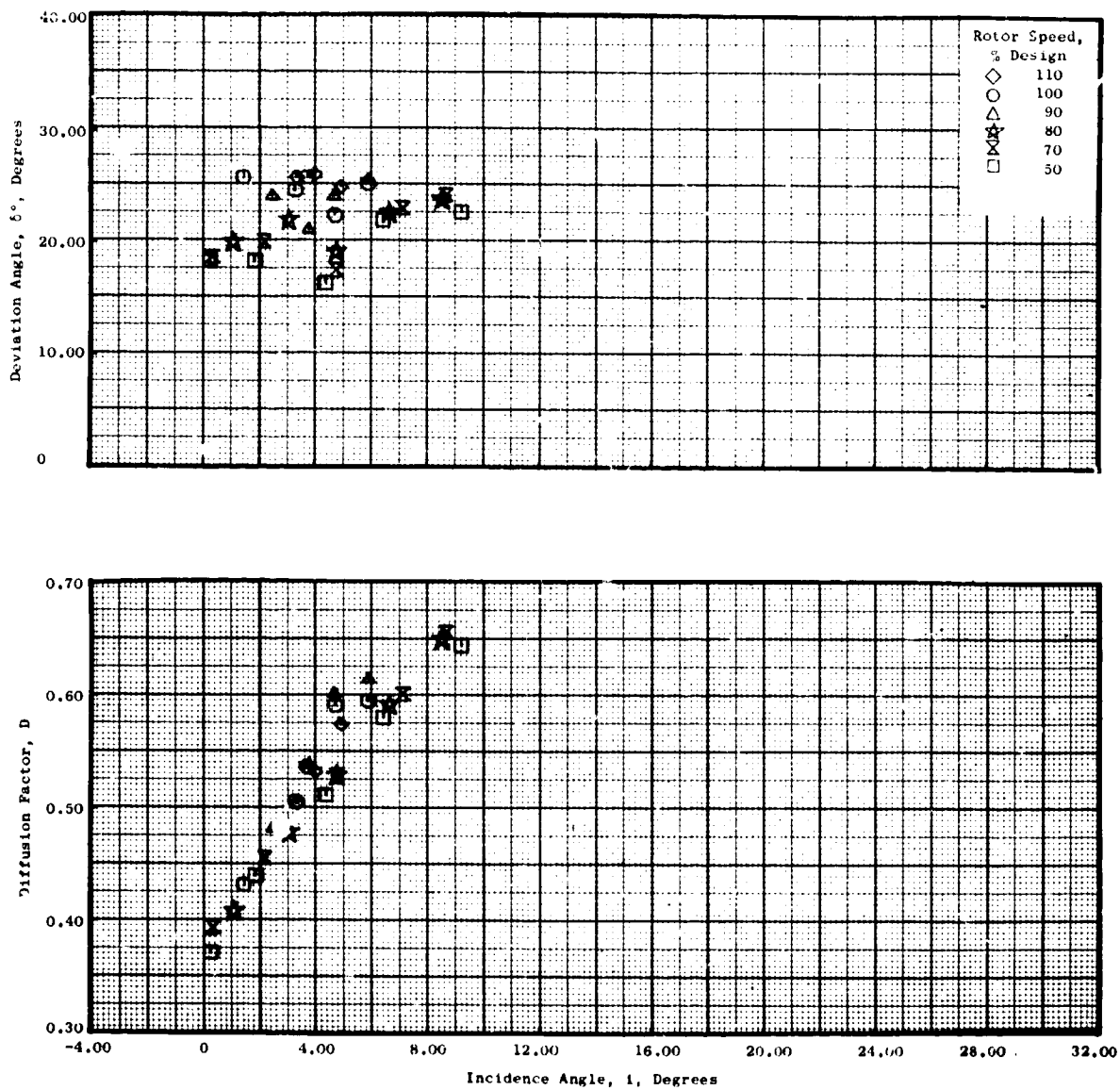


Figure 32(f). Stator Vane Element Data for IGV/Stator Schedule 40°/8° at 90% Immersion from Tip (Concluded).

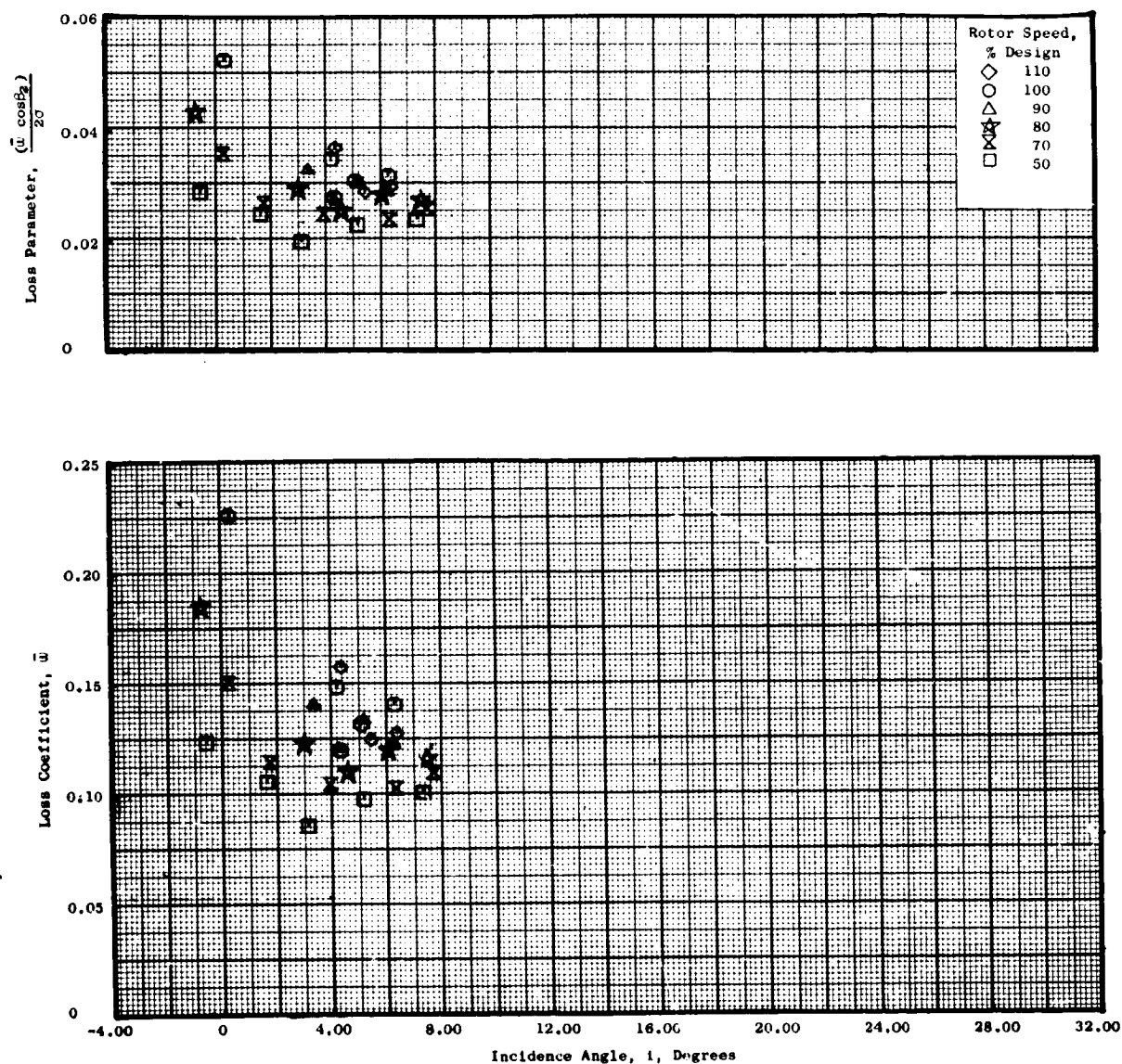


Figure 32(g). Stator Vane Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 95% Immersion from Tip.

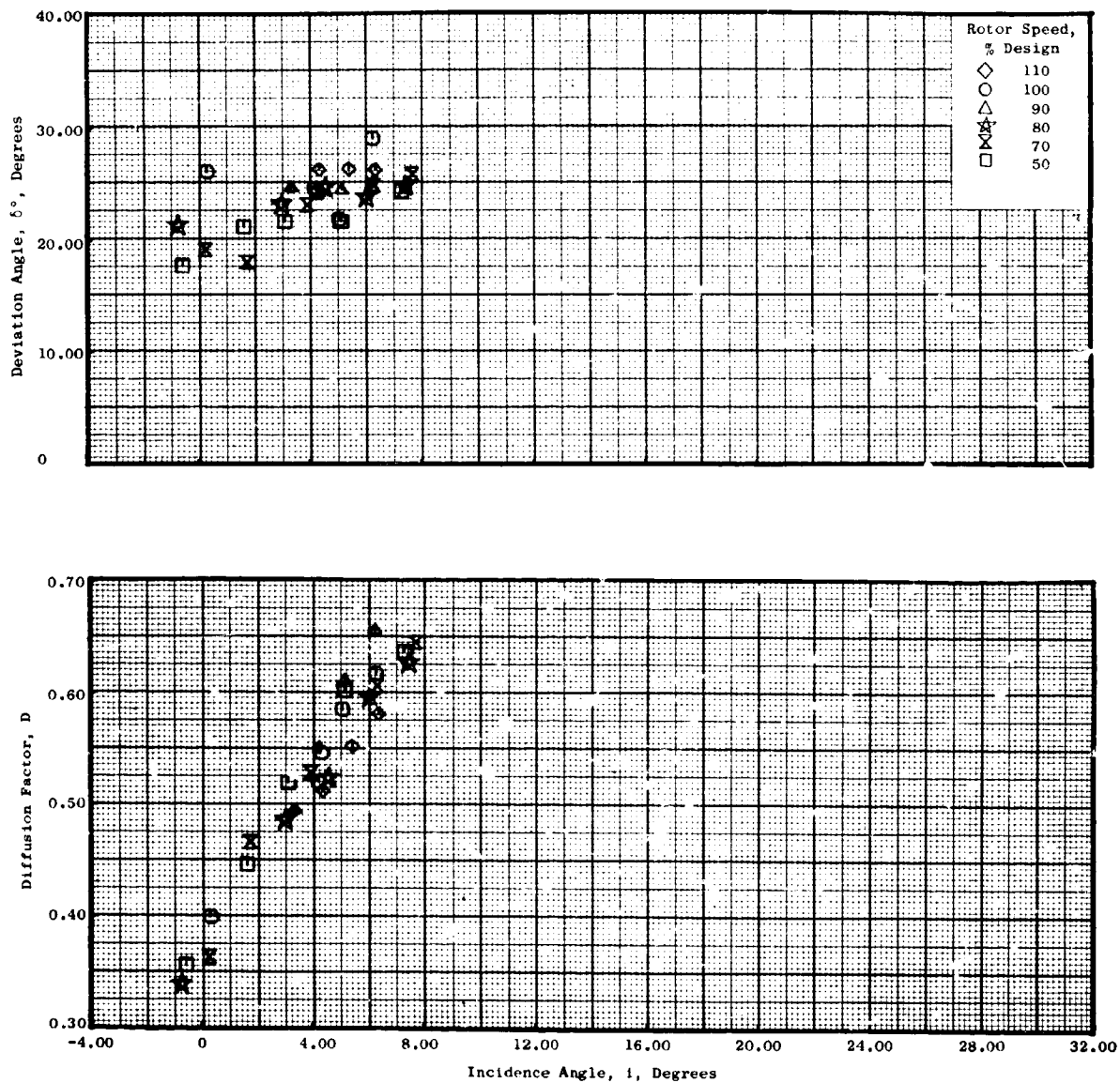
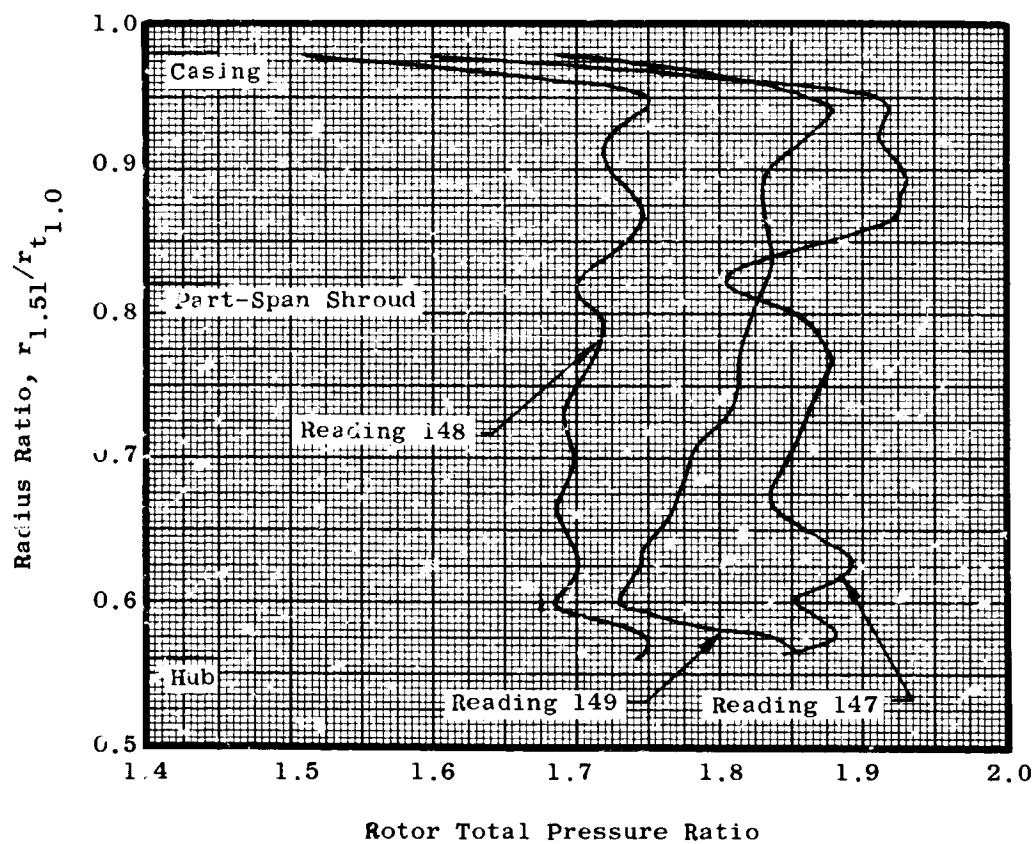
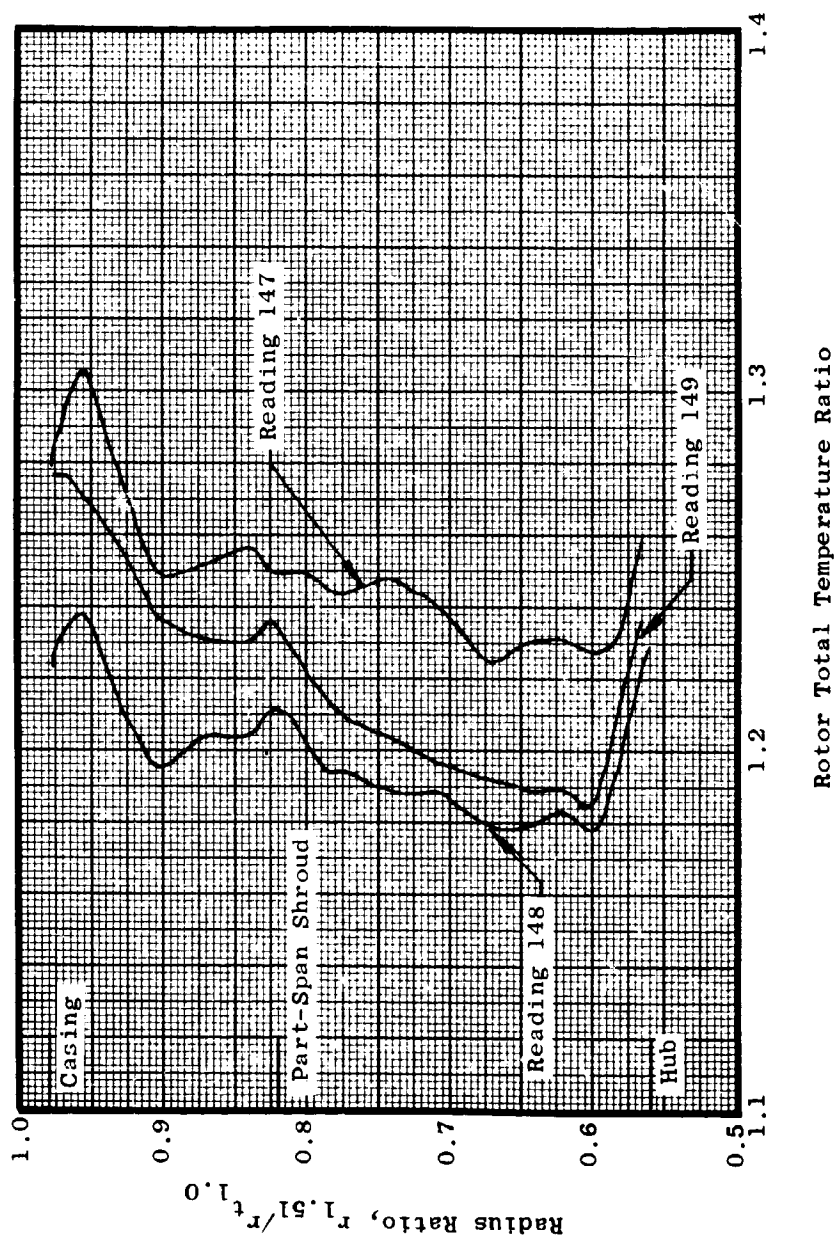


Figure 32(g). Stator Vane Element Data for IGV/Stator Schedule $40^\circ/8^\circ$ at 95% Immersion from Tip (Concluded).



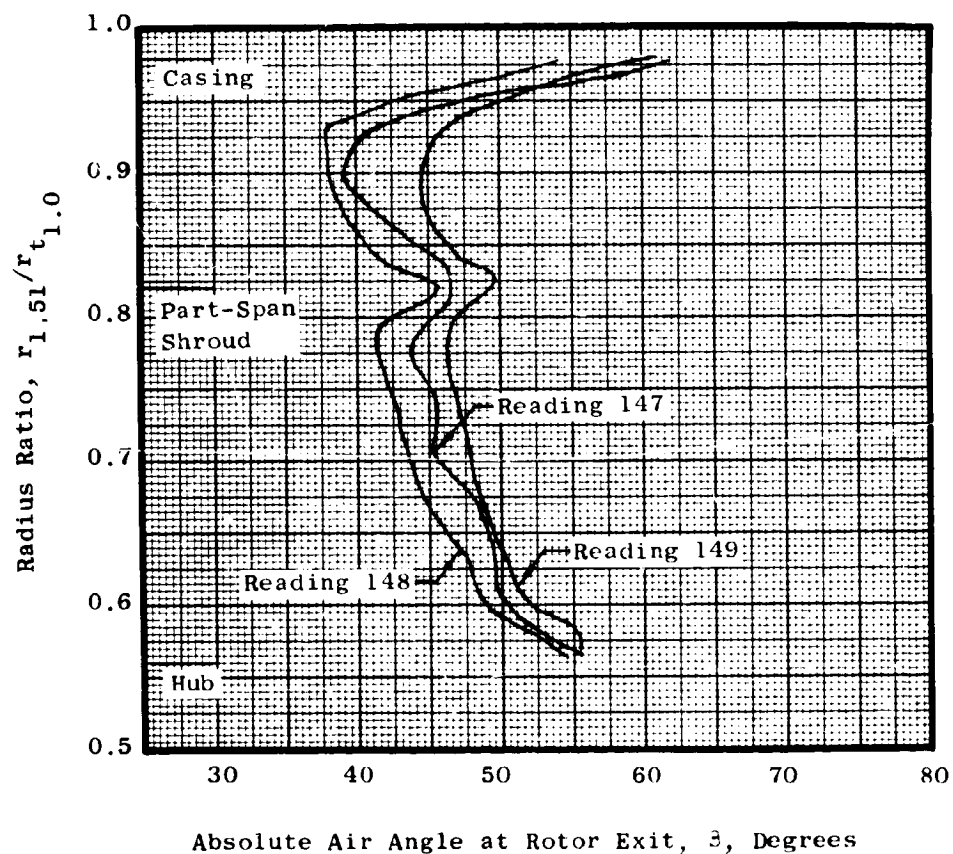
(a) Radial Variation of Rotor Total Pressure Ratio

Figure 33. Continuous Traverse Data at Rotor Exit Plane 1.51 for Readings 147 (110% Design Speed, Approximately on a Constant Throttle Line Through Design Point), 148 (100% Design Speed, Near Design Point), and 149 (100% Design Speed, Near Stall).



(b) Radial Variation of Rotor Total Temperature Ratio

Figure 33. Continuous Traverse Data at Rotor Exit Plane 1.51 for Readings 147 (110% Design Speed, Approximately on a Constant Throttle Line Through Design Point), 148 (100% Design Speed, Near Design Point), and 149 (100% Design Speed, Near Stall). (Continued).



(c) Radial Variation of Absolute Air Angle at Rotor Exit

Figure 33. Continuous Traverse Data at Rotor Exit Plane 1.51 for Readings 147 (110% Design Speed, Approximately on a Constant Throttle Line Through Design Point), 148 (100% Design Speed, Near Design Point), and 149 (100% Design Speed, Near Stall). (Concluded).