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SECTION III

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WAKE EXPERIMENT

SELECTION OF AIRFOILS AND TEST CONFIGURATION

Detailed wake flow measurements were desired for a new fore-loaded supercritical design and a conventional aft-loaded multiple circular arc design. The supercritical airfoil design chosen was the fan exit guide vane mean section tested under a previous NASC contract (NASC NO0019-77-C-0546). The conventional airfoil was a design which was later tested

REPORT DOCUMENTATION	PAGE	READ INSTRUCTIONS
1. Report Number 47	2. Gove Accession No.	8. Recipient's Catalog Number
4. Title (and Sublittle) SUPERCRITICAL AIRFOIL TECHNOLO	GY_PROGRAM	5. Type of Beport & Period Covered Final Report,
Wake Experiments and Modeling for Fore- and Aft-Loaded Compressor Cascades	THI PULL	6. Performing, Org. Beport Number
7. Author(s)	FWA	8. Contract or Grant Number(s)
D. E. Hobbs A H. Wagner J. F. Dannenh	offer R. P./Dring	N00019-79-C-0229
9. Performing Organization Name and Address		10. Program Element, Project, Task Area
United Technologies Corporation Pratt & Whitney Aircraft Group Government Products Division		Work Unit Numbers
P.O. Box 2691, West Palm Beach, FL.	~	12 Basard Data
Department of the Navy	(II)	September 80
Navai Air Systems Command Washington, D.C. 20361 ATTN: Code A	AIR-310, AIR-954	13. Number of Pages 120
14. Monitoring Agency Name & Address (if different)	ram Controlling Office)	15. Security Class. (of this report) Unclassified
		15a. Declassification/Downgrading Schedu
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ACKNOWLEDGEMENTS

The principal experimental investigator was Mr. Joel H. Wagner. Mr. John Horan provided many helpful suggestions in the design of the cascade test section and also assisted in the analytical wake modeling study. The authors are especially indebted to Miss Diane Rodimon for her programming skills and data reduction and to Mr. David Potash for the cascade construction and data acquisition.

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SECTION I

INTRODUCTION

GENERAL

This report discusses the results of two compressor cascade airfoil wake experiments directed toward obtaining information necessary to model wakes in a compressor airfoil design system. The experiments include extensive measurements of the near and far wakes, trailing-edge boundary layers, and airfoil surface static pressures. The measured wake displacement surface and computed boundary layers were used in conjunction with a potential cascade flow solver to demonstrate the feasibility of modeling the viscous aspects of cascade flow. With this flow model and a generalized control volume mixing calculation, the computed uniform downstream flow angle and total pressure loss coefficient were shown to be consistent with the measurements downstream of the cascade.

BACKGROUND

Compressor Cascade Design Systems

Compressor airfoil sections of current production compressors and many advanced compressors are derived from related families of airfoils such as the NACA 65 series, the NACA 400 series, and the double circular arc series. Extensive plane cascade tests have been conducted on these families of cascade sections, and the performance of these cascades has been correlated as a function of their specific geometry, Mach number, and inlet air angle. The cascade correlations for exit air angle are formulated in terms of a "deviation angle" from some geometric reference angle such as the trailing-edge mean camber line angle. These correlations, modified to include actual compressor experience, are employed in current design systems that accurately predict the performance of compressors using standard series airfoil sections.

In the past 10 years, compressor cascade technology has advanced to the point where mathematically defined airfoils can be designed for given aerodynamic and structural requirements. These airfoils possess

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optimum surface pressure distributions and boundary layer characteristics, and offer aerodynamic performance superior to the standard airfoil sections currently in use. One very important example of this type of designed airfoil is the "supercritical" cascade airfoil.

Supercritical airfoils are transonic airfoils which operate with subsonic inlet and exit flow velocities and with embedded regions of supersonic flow adjacent to the airfoil surface. The term "supercritical" refers to the presence of velocities in the flowfield which are above the "critical", or sonic speed. Historically, progress in the design methods for transonic airfoils severely lagged methods used to design fully subsonic or supersonic airfoils. The lag results primarily from mathematical difficulties in solving the inviscid flow equations which model the transonic flow field. Without the fundamental ability to compute the velocities on the airfoil surface, the well-developed, low-speed isolated airfoil design techniques employing boundary layer viscous flow theory have been of no pratical value.

The early knowledge of airfoils in the transonic regime was derived from wind tunnel experiments on subsonic or supersonic designs. This type of experimentation provided an understanding that the aerodynamic deficiencies of these designs were caused by the strong normal shocks which terminated the embedded supersonic region. For isolated airfoils, this shock caused a rapid increase in drag and a reduction of lift as the approach Mach number increased through the high subsonic range. In cascades, this shock produced the analogous effects of increased total pressure loss and reduced flow turning. Typical features of this transonic flow field for a NACA 65 series cascade were shown in the schlieren photographs in the work of Dunavant et. al., (Reference 1).

In 1965, a resurgence of interest in developing improved supercritical design methods resulted from Whitcomb's now-famous supercritical isolated airfoil experiment at NASA Langley. Whitcomb's experimentally developed airfoil demonstrated the existence of shockless supercritical flowfields (Reference 2). The shockless feature made the flow entirely irrotational outside the boundary layer and wake and, thus, amenable to modeling with the potential equation.

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Subsequently, Garabedian, Korn, and Bauer (References 3, 4, and 5) of New York University developed a complex hodograph solution satisfying the two-dimensional potential equation for supercritical flows over is-By using this hodograph technique, an isolated semiolated airfoils. infinite displacement body containing the airfoil, plus boundary layer and wake displacement thickness, could be determined from a specified shockless surface velocity distribution. The final airfoil design program, including viscous boundary layer considerations necessary to extract the airfoil shape from the displacement body, was delivered to NASA in 1974, and has been used to design airfoils for a variety of applications. In the same year, Korn (Reference 6) developed a similar shockless supercritical cascade airfoil design system. In a cooperative program with Pratt & Whitney Aircraft (P&WA), a supercritical cascade was designed in 1974 by Korn, and tested in 1976 in the transonic cascade facility of the Deutsche Forschung and Versuchsanstalt fur Luft and Ramfahrt (DFVLR) in Cologne, West Germany. The results of these tests. reported by Stephens (Reference 7), substantiated the performance improvements predicted for this newly designed cascade airfoil.

During 1976 and 1977, these tests results provided the motivation for the development by P&WA of a new transonic cascade design procedure suitable for compressor application. This new design system incorporated a set of aerodynamic design point features for the airfoil surface Mach number distribution and boundary layer characteristics required to achieve efficient shockless cascade flow. A schematic of these features is shown in Figure 1. This new design system also reduced the cascade spacing restriction of the original Korn design method and introduced quasi three-dimensional effects necessary for compressor airfoil design. The new method permitted the selection of airfoil geometric characteristics which satisfied structural and foreign object damage resistance requirements. The design system was based on an analysis method developed by Ives and Liutermoza (References 8 and 9).

The advantages of a pratical supercritical airfoil were then demonstrated experimentally in the DFVLR cascade facility under Naval Air Systems Command (NASC) Contract NO0019-77-C-0546. These results are reported by Stephens and Hobbs (Reference 10). Based on these results

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and further P&WA tests, an airfoil design system is currently under development which is intended to have general applicability beyond the range of available experimental results.







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SECTION II

DESIGN SYSTEM DEVELOPMENT

PREDICTION OF TURNING AND PROFILE LOSS

An accurate prediction of flow turning angle is necessary in compressor designs to ensure that the required rotor and stator pressure ratios are obtained, and that the optimum incidence is provided to the successive rows of airfoils. The supercritical airfoil data acquired to date have indicated that the turning angle and the profile total pressure loss of designed airfoil cascades are not predicted accurately by data correlations currently employed for standard airfoil series. This appears to be due to the attached boundary layer behavior which is a specific design requirement for these new airfoils. Also, because of the many geometric degrees of freedom, it is difficult to pursue a geometrically based cascade correlation to develop a deviation and loss system for designed airfoils. For designed airfoils, the correlation approach would require a large number of tests and become excessively expensive.

The approach to this design problem, which currently seems most cost effective and technically promising under the circumstances of attached boundary layers, is an analytical prediction which includes an accurate wake model and a control volume mixing calculation. The mixing calculation would be similar to the well-known method of Stewart (Reference 11), or would be generalized to use variable aerodynamic conditions on the airfoil trailing-edge boundary of the control volume. The choice of mixing calculations depends on the amount of flow nonuniformity in the cascade exit plane. The conditions would be taken from the inviscid analysis of the flow, coupled with adjustments for the viscous boundary layer and wake. The approach is similar to that proposed by Hansen, Serovy, and Sockol (Reference 12). The current problem with this approach centers on the modeling of wakes of relatively thick, blunt trailing edges of typical compressor airfoils.

Mathematical techniques for design and analysis are now available that closely model the aerodynamics of cascades, except in the immediate region of the thick, blunt trailing edge. In this region, current inviscid cascade flow calculations are inadequate, even with boundary

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layer adjustments to the airfoil surface because they do not model the airfoil wake. The wake modeling deficiency presents two major problems, as discussed in the following paragraphs.

The first problem arises because surface velocity distribution cannot be computed accurately without accounting for viscous effects. When the wake is not modeled, a stagnation point not existing in the real viscous flow is computed on the airfoil surface at the trailing edge which affects the pressure distribution over the last 10 to 15 percent of the airfoil surface. The effect is shown in Figure 2 by comparing data with a calculation for the NASC supercritical airfoil from Reference 10. The methods currently used to correct these inaccuracies in the trailing edge flow are based on past experience with standard series airfoils. These methods lack the sound physical basis that would permit their general use for designed airfoils. Subsequently, if the velocity distribution is not corrected properly, errors in the calculated boundary layer may result, possibly masking separation prior to the trailing edge. Perhaps, more importantly, the errors in the trailing-edge region also make it difficult to apply a viscous trailing-edge condition to determine the downstream flow angle. A recent discussion of this problem is provided by Klein (Reference 13).

The second problem involves inaccuracies throughout the entire trailing-edge region. The large velocity variations at the airfoil trailing edge create an artificial disturbance which may propagate across the entire pitch. This leads to errors in the calculation of the downstream flow properties when wake mixing calcultions are used.

Since a mixing calculation can be used for the accurate prediction of the far downstream cascade total pressure loss and gas angle for designed airfoils, the current approach is to provide the mixing calculation with the correct trailing-edge flow properties in the boundary layer and free stream. The problem can be solved through a physically based model of the cascade wake which can be used in conjunction with inviscid cascade and boundary layer calculations.

Unfortunately, very little detailed aerodynamic data exists to guide the development of such a wake model for cascades of airfoils with thick, blunt trailing edges. The present work is intended to fill this need and, hopefully, suggest the type of modeling which would be

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adequate to achieve the design goal to predicting turning and loss. The goal of this experiment is to measure the wake flow of an airfoil operating in a periodic, two-dimensional cascade flow. Specifically, it is desired to determine the local time-mean velocities in the wake so that the trajectory of the wake centerline and wake parameters can be computed. To make use of this wake information in developing the design methods, the aerodynamic conditions far upstream and downstream of the cascade, static pressures on the airfoil surface, and the boundary layers at the airfoil trailing edge are also required.

The succeeding sections of this report discuss the cascade wake experiment and the application of the results to wake modeling.



FIGURE 2 COMPARISON OF TEST AND ANALYTICAL SURFACE MACH NO. DISTRIBUTION

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SECTION III

WAKE EXPERIMENT

SELECTION OF AIRFOILS AND TEST CONFIGURATION

Detailed wake flow measurements were desired for a new fore-loaded supercritical design and a conventional aft-loaded multiple circular arc design. The supercritical airfoil design chosen was the fan exit guide vane mean section tested under a previous NASC contract (NASC NO0019-77-C-0546). The conventional airfoil was a design which was later tested for comparison with the supercritical design. These two cascades are shown in Figures 3 and 4. Significant differences in these designs include the shape of the suction surface static pressure distributions, the thickness of the airfoil leading and trailing edges, and the pitch to chord ratio. The cascade geometry is listed in Table 1.

Required near and far wake flow measurements include velocities, pressures, turbulence levels, and flow angles. To achieve acceptable measurement accuracy near the airfoil trailing edge with reasonably reliable probes, a large-scale, low-speed experiment was required. The scale-speed combination was chosen to retain dynamic similitude in the wake by holding the airfoil chord Reynolds number within the correct range. Also, to achieve the desired high-speed static pressure coefficient distribution shape on the airfoil surface at a low Mach number, the upstream flow angle of the airfoil was altered so that the cascades operated at -5° incidence, relative to the original high-speed design conditions. The resulting distributions are shown in Figure 5. Both of the airfoils tested in this experiment have undergone extensive highspeed testing in the DFVLR transonic cascade tunnel. The results of these experiments show no significant change in cascade performance with inlet Mach numbers below a value of 0.70, except near the cascade choking condition at -10° of incidence.

Another important consideration in the design of this experiment was the requirement for a two-dimensional flow. This was achieved by measuring on the cascade centerline and controlling the endwall boundary layer flows sufficiently to achieve an overall midspan axial velocitydensity ratio near 1.0. Reducing the axial velocity ratio from the design value of 1.15 to 1.0 increased the cascade loading

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TABLE I. CASCADE GEOMETRY AND TEST CONDITIONS

Cascade Geometry	Build I	Build II
Pitch/Chord Aspect Ratio (Span/Chord) Pitch Axial Chord Chord Trailing edge diameter	0.70 1.525 142.24mm (5.600 inches) 195.58mm (7.700 inches) 203.20mm (8.000 inches) 3.6068mm (0.142 inches)	0.60 1.307 142.24mm (5.600 inches) 221.64mm (8.726 inches) 237.11mm (9.335 inches) 1.3208mm (0.052 inches)
Test Conditions	Build I	Build II
Inlet Flow Angle (degrees from tangential)	52	50.5
Exit Flow Angle (degrees from tangential)	87.1	87.1
Flow Turning (degrees)	35.1	36.6
Inlet Mach Number Exit Mach Number AVDR Profile Loss (ω) Reynolds Number	0.1132 0.0912 1.023 0.017 4.78 (10 ⁵)	0.1162 0.0928 1.037 0.0175 5.88 (10 ⁵)

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FIGURE 5 COMPRESSIBLE PRESSURE DISTRIBUTION - CP vs X/BX

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and countered the decrease in loading resulting from the -5° incidence change. The approximately axial cascade outlet flow angle was also optimum for eliminating the effect of any remaining local axial velocity ratio variations on the mean flow angle in the flow downstream of the trailing edge.

TEST FACILITY

The facility used for these experiments was the United Technologies Research Center's Large-Scale Cascade (LSC). The cascade tunnel, as shown in Figure 6, is an open-loop type, receiving and exhausting air within a single test cell. The upstream air supply section consists of a double inlet, double-width fan, a perforated plate, honeycomb and screens, and an adjustable contraction. The test section attaches to the contraction and holds the cascade of seven airfoils with a 310 mm (12.2 in.) span.

The fan is a radial flow, squirrel cage design, belt-driven with a 37.3 kw (50 hp) electric motor. Flowrate is controlled by simultaneously adjusting two vortex valves located at the fan inlets. The fan is capable of producing a flow of 450 kliters/min. (16,000 cfm) with a 21 mm Hg (11 in. of water) pressure rise and 750 kliters/min (26,500 cfm) at no pressure rise. For typical cascades, this gives a maximum inlet test section velocity of approximately 43 m/sec (140 ft/sec), or a typical Reynolds number range of about 5.0 x 10^5 to 1.0 x 10^6 .

Perforated plate, honeycomb, and screen were carefully selected to obtain a minimum amount of total pressure distortion at the test section inlet. Screens were selected to minimize distortion due to screen nonuniformity and maximize flow distortion attenuation. Inlet distortion was less than +1% of the inlet dynamic head (Qo).

As shown in Figure 6, the test section is mounted on rollers and is easily attached or removed from the contraction of the upstream section. The endwall disks rest on rollers to allow changing the cascade setting angle. For this test, the airfoils were attached to both endwalls, one metal and the other clear plexiglass. A view of the cascade through the plexiglass wall is shown in Figure 7.

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FIGURE 7 LARGE-SCALE CASCADE TEST SECTION





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Two suction systems and movable tailboards were used to obtain twodimensional, periodic flow in the cascade test section. The locations of the various controls are shown schematically in Figure 8.

The endwall boundry layer scoops are located upstream of the cascade to remove the boundary layer on the endwalls as shown in Figure 9. The upper and lower bleeds were used to remove the boundary layers formed on the ceiling and floor of the cascade inlet section. A second suction system was used to remove the corner endwall secondary flow on the suction side of each airfoil. These corner flow control slots are shown in Figure 10. The effectiveness of corner slots in eliminating cascade secondary flow is shown by Peacock (Reference 14). The final adjustment for controlling the periodicity of cascade flow was the system of tailboards shown in Figures 7 and 8. All four tailbords are independently adjustable.

INSTRUMENTATION

Measurements were made of total and static pressure, velocity, turbulence, temperature, as well as pitch and yaw flow angles. Pressure was measured with either a miniature Kiel probe, a five-hole combination probe, or surface static taps. Velocity was measured with a singleelement hot-film probe. Kiel and five-hole combination probes were used for the far wake traverses, whereas only a single-element hot-film probe was used in the near wake. All the probes used are shown in Figure 11 with a cross section of the trailing edges of Build 1 and Build 2 shown for comparison. Temperature was measured with a chromel-alumel thermocouple or a mercury thermometer.

The Kiel probe was used to measure the total pressure downstream of the cascade. The Kiel is a standard United Sensor miniature, 1.5 mm (0.060 in.) in diameter, probe supported in a 6.3 mm (0.25 in.) stainless steel tube. The Kiel acceptance angle was found to be $\pm 45^{\circ}$.

The five-hole probe is a standard United Sensor probe with five pressure taps on an ogival tip of 2.4 mm (0.093 in. diameter). With calibration curves, it is possible to determine total and static pressure, as well as yaw and pitch angles.



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FIGURE 8 SCHEMATIC OF TEST SECTION

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The hot-film probe used to measure flow velocity and turbulence is a single-element type with a 0.025 mm (0.001 in.) diameter sensing portion. The sensing element is supported on 6.3 mm (0.25 in) long needles which are attached to a 100 mm (4 in.), 1.5mm (0.060 in.) diameter tube. A special probe holder, shown in Figure 11, was designed to allow probe tip axial locations other than the mechanical probe slider positions in the endwall.

All the airfoils used in the investigation were instrumented with static pressure taps, primarily at midspan. The center airfoils were more heavily instrumented than the surrounding airfoils with a concentration of taps near the trailing edge and eight taps located spanwise at two-chord locations. The instrumented airfoils can be seen in Figure 9.

MEASUREMENT LOCATIONS

Seven airfoils were used in each cascade, numbered as shown in Figure 8. The coordinate system used to locate the measurements for both builds originated at the trailing edge along the mean camber line of the center airfoil. The positive x-direction is in the direction of flow normal to the cascade plane, while the positive y-direction is parallel to the cascade plane and pointing away from the pressure slide of the airfoil surface. Angles are measured counterclockwise from the x-axis. See Figure 8.

The probe traverse system, mounted on the metal endwall, consists of a motor-driven worm gear on a threaded rod attached to a precision traverse table. The probe traverse table moves parallel to the cascade trailing-edge plane, i.e., in the y-direction. The platform has probe traverse mounting slots directly corresponding to sliding bars in the metal endwall. A partial view of these bars can be seen in Figure 10. There are five probe traverse locations downstream of the blade and one upstream, as shown in Figure 8. Axial placement of the Kiel and fivehole probes was limited to the fixed axial traverse locations, while the hot-film probe could be placed at any axial location desired. The same axial traverse locations and the type of probe used. Table 2 also includes estimates of the probe location accuracy.





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FIGURE 11 TRAVERSE PROBES

TABLE	2.	PROBE	MEASUREMEN	T LOCATIONS	AND	ESTIMATED
		PROBE	PLACEMENT	ACCURACIES		

X (mm) X (in.) X/ TED KIEL FIVE-HOLE HOT-FILM Build II Build I X -241.0 ~9.50 -1.76 -4.81 - 6.4 -0.25 X -0.031 -0.22 -0.60 X - 0.8 0.22 0.60 0.031 X 0.8 2.4 0.094 0.66 1.81 X 4.0 3.00 0.156 1.10 X 6.4 0.25 1.76 4.81 X 12.7 0.50 3.52 6.92 Х 25.4 1.00 7.04 19.23 X 50.8 2.00 38.46 X 3.00 X 76.2 X 127.0 5.00 X X 228.6 9.00 X X * BUILD I only

** Build II only

Measurement Locations

Estimated Probe Placement Accuracies

Probe Position

X-Direction

 Five-hole and Kiel
 ±1.27 mm (±.050 in.)

 Hot-Film
 ±0.38 mm (±.015 in.)

Y-Direction

Relative	<u>+.02 mm (+.001 in.)</u>
Absolute	<u>+.84 mm (+.030 in.)</u>
Angles	<u>+.5 degrees 22</u>

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DATA ACQUISITION

The basic data acquisition system is comprised of probe traversing controls, transducers, water manometers, and the Colog recording system. Anemometry and spectrum equipment and various digital voltmeters were used for hot-film measurements. All probe traversing and rotation was controlled from the control room. Probe position was determined with a calibrated linear potentiometer.

Pressure measurements were made either with the Scanivalve/Colog system or read manually on water manometer boards. The Scanivalve is a forty-eight port model incorporating a 45 mm Hg (24 in. H₂O) Druck transducer. The first eight ports were dedicated to measuring four calibration pressures from the transducer calibration system. The remaining port assignments were either probe pressures or airfoil surface The transducer calibration system is a secondary static pressures. standard system consisting of four water columns calibrated with a Meriam micromanometer. When the Colog system is activated, the Scanivalve is automatically stepped every 4 sec. The signal is smoothed with a low frequency filter for 3 sec and read during the fourth. The data is converted into a digital signal and stored in Colog memory. After all the ports are sampled, the data is punched on paper tape and processed later on a Univac 1110 computer.

The hot-film velocity acquisition system consists of a TSI 1050 anemometer, 1052 linearizer, and a 1047 averaging circuit. Linearized anemometer voltages were read with Kiethly model 177 and Hewlett Packard 3466A digital voltmeters with dc and true rms capabilities. Linearized anemometer output was also input to a Spectral Dynamics model SD340 spectrum analyzer capable of analyzing frequencies up to 20 kHz.

The estimated accuracy of the data acquisition system for pressure measurements is $\pm 1\%$ of the upstream reference dynamic head, Qo. The estimated accuracy for velocities is $\pm 2\%$ of the local velocity.

DATA REDUCTION

A computer program was developed to reduce and plot the data for comparison with analytical results and with other data.

The reduction program, used for all the probe traverse data, accepts raw Kiel, five-hole, and hot-film data and reduces it to engineering units. Mass averaging was done over one pitch, while wake integral parameters were found by integrating only the wake data, as shown in the data tables (between the asterisks). The wake edge was defined as the location of the velocity deficit, which was 99% of the nearest free stream level.

Because the cascade tunnel cannot be operated at a strictly constant temperature, the hot-film probe was operated at a fixed operating resistance, or essentially a fixed sensor temperature. The aneometer output was linearized to simplify the determination of turbulence and velocity. The reduction of the hot-film velocity data was performed with a simple temperature correction for the small variations of temperature in the rig, as suggested by the TSI General System Information Manual (Reference 15).

SECTION IV

EXPERIMENTAL RESULTS

The results of this experimental investigation are divided into four sections: (1) cascade test conditions, (2) far wake Kiel and fivehole total pressure and velocity measurements, (3) boundary layers and near wake hot-film velocity measurements, and (4) wake similarity fits, mass averaged and integrated wake parameters, and wake centerline location. All data are tabulated in the Appendix.

CASCADE TEST CONDITIONS

The measurements of cascade two-dimensionality, periodicity, and inlet uniformity confirmed that the desired aerodynamic cascade conditions were achieved for the wake experiment. Surface pressure distributions and boundary layer behavior of both airfoils provided airfoil trailing-edge conditions similar to the viscous trailing-edge flow at high speed. Cascade test conditions are listed in Table 1.

Two-Dimensionality and Periodicity

Flow visualization and airfoil surface static pressures were used to determine the extent of two-dimensionality and periodicity. Figures 12 and 13 show the cascade test section for each build with yarn tufts installed. The pictures with and without corner suction show the effectiveness of the corner flow slots in preventing endwall boundary layers from flowing toward the cascade midspan on the airfoil suction side. Note the tufts point inward with no suction and straight backward with suction. The tufts also indicated that the Build II configuration had less stable suction side boundary layer which occasionally separated at about 75% chord. Another method of flow visualization used was ammonia gas injected on airfoil and endwall surfaces covered with Ozalid paper. The ammonia traces show the surface flows in Build I to be twodimensional over essentially the full span, while Build II was two-dimensional over the center 40% of the airfoil span.

The two-dimensionality of the midspan flow is shown in Figure 14 by a comparison of the measured airfoil surface pressures with the two-dimensional analysis of Caspar (Reference 16) using the aerodynamic

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FIGURE 12 TUFT FLOW VISUALIZATION - BUILD I



Corner Flow Suction Off



Corner Flow Suction On

FIGURE 13 TUFT FLOW VISUALIZATION - BUILD II



conditions in Table 1. Excellent cascade periodicity is shown for both builds in Figure 14 for the central three cascade passages by the close agreement of airfoil surface static pressures.

Build I static pressures did not vary with span. Build II spanwise static pressure data displayed weak spanwise gradients due to the secondary flow phenomena seen by the tufts and ammonia traces near the quarter span locations. The center airfoil static pressures are tabulated in Table 3 in terms of pressure coefficient, Cps, versus chord location.

Excellent periodicity was also shown for the wakes of the center three airfoils by the far downstream, midspan measurements. Traverses for both Builds I and II showned the center three blades to have nearly identical, periodic wakes. Downstream distortion of static pressure and flow angle were minimal. Pressures measured between wakes far downstream varied by less than 1% of the inlet referenced dynamic head, Qo.

Upstream Uniformity

The two builds had acceptable inlet uniformity for total pressure, static pressure, and flow angle. Upstream five-hole probe measurements were made to check inlet uniformity. Sparse traverse locations at approximately 0.15 axial chords upstream of the leading edge were selected over the entire inlet in the y-direction. For both builds the inlet total pressure distortion was less than +1% of inlet Qo, while static pressure results showed a $\pm 5\%$ variation in inlet static pressure with a 5 to 7% decrease in the mass average static pressure from the reference probe located further upstream. The variation in static pressure was primarily caused by blade-to-blade potential flow variations since the axial location of the measurements was close to the leading edge. The decrease in the mass averaged static pressure is caused by a streamtube contraction, due to insufficient removal of flow through the boundary layer scoops and, possibly, the corner slots. Upstream yaw angle nonuniformity was $+1^{\circ}$ and $+1.5^{\circ}$ for Builds I and II respectively. There was a 2° difference in the measured mass average inlet yaw angle between the two builds.





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FIGURE 14 AIRFOIL SURFACE STATIC PRESSURES - BUILD | AND || Blade Static Pressures

TABLE 3. TABULATION OF BLADE STATIC PRESSURE DATA

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BUILD 1

SUCTION	SIDE DATA	PRESSURE	SIDE DATA
x	CPS	X	CPS
. 404	~. 589	• 403	.099
1.192	782	1.196	.244
2.407	718	2, 397	•405
3.597	~. 552	3. 589	• 511
4.813	167	4.800	.493
5.602	.011	5, 987	• 466
6.055	•073	6.398	• 437
6.375	.125	6. 784	.405
6.797	.182	7.196	• 376
7.197	•219	7. 592	• 327
7.597	.243	7,905	• 252
7.942	• 255	7.952	• 270
7.980	• 268	7.991	.271

BUILD II

SUCTION	SIDE DATA	PRESSURE SIDE	DATA
х	CPS	X CP	s
• 430	189	• 524 • 10 ¹	9
1.318	261	1.441 .13	1
2.867	407	2.828 .22	9
4.266	603	4.235 .42	1
5.763	490	5.661 .48	2
6.682	411	7.072 .50	1
7.154	279	7• 540 • 49	0
7.381	211	7.991 .494	4
8.048	080	8.485 .46	3
8.481	• 036	8.888 .43	2
8.870	.169	9.258 .30	7
9.270	• 306	9.288 .30	2
9.322	.316	9.340 .32	6

1. These dimensions are in inches

2. X is true chord dimension from leading edge.

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Low Speed-High Speed Flow Similarity

Overall cascade test conditions are listed for Builds I and II in For comparison, the relevant high-speed data for the super-Table 1. critical design can be found in the data summary of Reference 10, test The profile loss of the low-speed test follows the points 30-32. smooth, nearly constant trend with inlet Mach number established by the DFVLR high-speed results for Mach numbers between 0.43 and 0.70. Flow turning in the low-speed test was lower than the high-speed test. This is primarily due to the approximately 10% lower AVDR of the low-speed test. The low-high speed performance comparison for the Build II cascade Low-speed pressure distributions were also similar in was similar. shape to the desired high-speed distributions. The Build I fore-loaded suction side distribution peaked at approxmately 20% axial chord, while Build II aft-loaded pressure distribution peaked at approximately 50% axial chord. The combination of similar surface pressure distributions and Reynolds numbers implies that the trailing-edge boundary layers will also be similar to the high-speed counterparts. This is partially confirmed by the similar profile losses. Thus, it can be concluded in this instance that the low-speed test can be used to model the viscous effects present in shockless high-speed cascade flow.

FAR WAKES

Far downstream Kiel and five-hole traverse results are shown in Figures 15 through 18. Results are presented in terms of pressure coefficients and nondimensional velocity ratios. Downstream static pressure varied by less than 1% of inlet Qo and is not plotted here. Angles are also not shown because of the excellent exit flow uniformity. The five-hole probe did indicate yaw angle variations due to the shear flow in the wakes. These apparent yaw angle variations are probably not actually present in the flow. Kiel total pressure results (Figures 15 and 16) compare closely to the five-hole total pressure data (Figure 17 and 18).

The five-hole results in Figures 17 and 18 for the two builds show several phenomena. Both builds produced a gradual decrease in wake depth and increase in wake width with increasing distance downstream. At a fixed axial location, the Build II wake is more attenuated than



FIGURE 15 KIEL TOTAL PRESSURE RESULTS - BUILD I

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FIGURE 16 KIEL TOTAL PRESSURE RESULTS - BUILD II





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the Build I wake. This is evidenced by shallower wake depths. The angle of the wake minimum velocity trajectory for Build I was approximately one degree higher than the measured exit air angle. For Build II, the wake trajectory was at an angle slightly more than two degrees.

BOUNDARY LAYERS AND NEAR WAKES

Boundary layers from both builds measured at the X = -6.35 mm (0.25 in.) position are presented in Figures 19 and 20. Both pressure and suction side profiles are shown. Curves plotted in U⁺ and Y⁺ coordinates are from a Scharnhorst et. al., (Reference 18) three parameter boundary layer fit. Two general observations can be made. The pressure surface universal profiles have favorable pressure gradient profile shapes (see Figure 14), while the suction side data shows large adverse pressure gradient shapes. The boundary layer thickness on the pressure side of Build II is twice as large as that on the Build I airfoil. Further comparisons will be made with the integrated data results in the following section.

Boundary layer and mean velocity defect profile results in the near wake are shown in Figures 21 and 22. Again, Build I profiles show much more wake shifting in the y-direction than Build II. The Build I traverse data shows a region of nearly constant low velocity in the very near wake at X/BX locations of 0.004, 0.012, and 0.020. This low velocity region increases in apparent velocity with increasing X/BX which seems to rule out steady reversed flow as its cause. The Build II wakes do not show such a low velocity region. For Build I, these first three traverses (X/BX = 0.004, 0.012, and 0.020) were made within a distance 1.25 trailing-edge diameters aft of the airfoil. For Build II, however, only one traverse was made within this relative distance. This was due to the much thinner trailing-edge diameter of Build II. The fact that the low velocity region observed in the near wake of Build I was not observed in Build II at a corresponding relative distance aft of the airfoil (X/TED) suggest that the ratio of the trailing-edge diameter to total boundary layer size may play a role in determining the nature of the near wake.



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Boundary Layer and Near Wake Velocity Profiles

FIGURE 21 BOUNDARY LAYER AND NEAR WAKE VELOCITY PROFILE - BUILDS I AND II

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Build II



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FIGURE 22 BOUNDARY LAYER AND NEAR WAKE HOT-FILM VELOCITY DEFICIT --- BUILDS I AND II

The near wakes of the two builds are different near the trailing edge, but do look very similar further downstream (by X/BX = 0.032). The near wakes of both builds strongly resemble the airfoil boundary layers just upstream of their trailing edges. This leads to stronger velocity gradients on the pressure sides of the wakes near the trailing edge than on the suction sides.

The far downstream wake profile shapes presented are similar to the profile shapes presented by Raj and Lakshminarayana (Reference 19) and also Lakshminarayana and Davino (Reference 20). However, the data shown in Reference 19 at the trailing-edge traverse location does not look like the Build I data at X/BX = 0.004, although it is similar to, though not quite as deep as, the Build II data at X/BX = 0.0036.

TURBULENCE AND WAKE SHEDDING FREQUENCY

Turbulence intensity in Figures 23 and 24 was derived from measured linearized anemometer voltages. Turbulence intensity in this report is defined as the linearized voltage divided by the local time averaged linearized voltage. Both Builds I and II have turbulence intensities exceeding 40% in the near wake. The inner wake region of Build I near the trailing edge (X/BX = 0.004, 0.012, 0.020) has a local minimum in turbulence intensity. This effect was also observed by Lakshminarayana and Davino (Reference 20) who explained this phenomenon as zero turbulence intensities near the surface in the boundary layer profiles "being transformed into a free shear layer" as the flow passes the trailing edge. The Build II data presented here does not support this statement. Even though the closest turbulence intensity profiles in the wake resemble the boundary layer turbulence intensity profiles, only Build I has this decrease in the inner wake.

Caution must be exercised when interpreting turbulence intensities. In the large shear flow gradients at the edge of the wake, the probe remained fixed in space, while a small amount of wake flutter (i.e., Karman vortex strut) produced large variations in velocity and, thus, high readings. If a Lagrangian technique could be used (i.e., the probe follows the fluctuating wake), lower turbulence intensities would be measured because the probe would be in the same location relative to the wake and would not oscillate between high and low velocity regions.



Turbulence Intensity Profiles Build I

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Turbulence Intensity Profiles Build II



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Build II

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FIGURE 24 NEAR WAKE HOT-FILM LOCAL TURBULENCE INTENSITY - BUILDS I AND II

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The amount of time the probe spends in the turbulent wake compared to the time in the laminar outer wake can be referred to as an intermittency factor. This intermittency effect, explained by Lin (Reference 21) was evident on an oscilloscope during data acquisition.

Turbulence spectra were acquired at selected locations to determine the shedding frequency of the trailing edge Karman vortices. Approximate shedding fequencies were determined from the Strouhal number of a circular cylinder and defined using the trailing-edge diameter (TED) as the characteristic length and the free stream velocity (FSV), as follows. FSV is defined in Figure 25.

> $S = \frac{\text{TED}(f)}{\text{FSV}} = 0.21$ f_{BUILD I} = 1775 Hz f_{BUILD II} = 4850 Hz

Two typical plots are shown in Figure 26 for Builds I and II. Both were recorded near the trailing edge on the pressure side of the wake. The Build I spectrum indicates an increase in turbulence level caused by vortex shedding for frequencies between 1500 and 2200 Hz. The vortex shedding in Build I was most prominent in the two traverses made downstream of the low velocity region near trailing edge (X/BX = 0.032, 0.065). The Build II turbulence spectra does not indicate that the Karman vortex shedding was occurring.

Vortex shedding has been measured in the wakes of a high-speed turbine plane cascades with thick trailing edges by Lawaczeck (Reference 22), Heinemann (Reference 23), and by Sieverding (Reference 24). The results of the current experiment for Build I are similar. It may be conjectured that the lack of a predominant shedding frequency in Build II is due to the small size of the trailing edge relative to the boundary layer.

WAKE VELOCITY PROFILE SIMILARITY AND INTEGRAL PARAMETERS

Wake velocity shape similarity profiles for the five-hole probe and hot-film traverses are shown in Figures 27 and 28. The profiles

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FIGURE 25 WAKE NOMENCLATURE



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FIGURE 26 FREQUENCY SPECTRUM PROFILES - BUILDS 1 AND 11 Frequency Spectrum Profiles



FIGURE 27 UNIVERSAL WAKE PROFILE (FIVE-HOLE PROB**E I**



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Universal Wake Profile (Hot-Film) Build I

FIGURE 28

UNIVERSAL WAKE PROFILES (HOT-FILM PROBE





Universal Wake Profile (Hot-Film)

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were normalized by the wake half-width. The fit used in Reference 20 $(e^{-n^2 \ln 2})$ is excellent for the far downstream traverses (i.e., X/BX > 0.057). As expected, however, the near wake traverses do not fit this universal wake shape.

Wake parameter mass averages performed over a cascade pitch did not indicate any appreciable changes in total pressure loss, static pressure, normalized velocity, or turbulence intensity versus downstream distance.

Wake parameters, including wake half-width (δ_{HW}). displacement thickness (δ *), momentum thickness (θ), shape factor (δ */ θ), and wake minimum time average normalized velocity (V_{CL}/FSV) are plotted versus X/BX in Figure 29. Data from the five-hole, Kiel, and hot-film traverses are presented. Velocities from the Kiel results were calculated assuming an atmospheric static pressure. This assumption was justified by the five-hole data.

Both builds have similar wake half-widths near the trailing edge. The build II width increases slightly more rapidly with increasing distance from the trailing edge. If the boundary layer thickness halfwidths are summed with the trailing-edge diameter, the result will form a continuous line instead of having a step at X/BX = 0.

The Build I displacement thickness in the very near wake is substantially larger than for Build II, due to the low momentum region which acts like an extension of the airfoil's larger trailing edge. Even though Build I has a larger displacement thickness at the trailing edge, both builds are similar at the far downstream positions, asymptatic to almost the same value of $\delta */PITCH = 0.01$. Again, if the trailing-edge diameter is added to the boundary layer displacement thickness data, a more continuous function is formed.

The normalized momentum thickness plots for both builds are similar in shape and magnitude. Build II has slightly larger thicknesses in the near wake, but both builds have similar values far downstream.

Shape factor $\delta */\theta$ data for both builds reflect the displacement and momentum thickness data and the decay of the velocity defect. As expected, the value of shape factor decays asymptotically to 1.0 as the wakes mix out.

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FIGURE 29 BOUNDARY LAYER AND WAKE INTEGRAL PAR

Boundary Layer and Wake Integral Parameters

Build I



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FIGURE 29 NTEGRAL PARAMETERS - BUILDS I AND II

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Boundary Layer and Wake Integral Parameters Build II Hot-Film Kiel Five Hole Δ Theoretical Boundary Layer Calculation Pressure Side Ρ Suction Side s Data Fit 0.10 **MW/PITCH** EQN 1 a1 = 0.0246 b1 = 40 m1 = 0.369 0.05 0 0.04 0.03 8"/PITCH o^{os} 0.02 EQN 2 0.0 $a_2 = 0.682 \ b_2 = 5 \ m_2 = -0.615$ ЮР ſ 0.02 00 0 0/PITCH oó s 0.01 **О**О Р 0 3.0 θ/•δ 2.0 a3 = 0.567 b3 = 40 m3 = -0.464 EQN 3 1.0 1.0 EQN 4 Ū_{CL}/FSV 0 $a_4 = 0.997 b_4 = 40 m_4 = -0.542$ 0.5 É 0 -0.2 0.2 0.4 0.8 0 0.6 1.0 1.2 X/BX FD 201766 600707

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The minimum wake velocity data for Build I, in contrast to the Build II data, shows an apparent shifting of the plotted data in the positive x-direction. The apparent trailing edge has been shifted downstream due to the recirculation region. Also, the Build II data are slightly higher than Build I, indicating Build II wakes mix faster than Build I.

It is believed that the more rapid mixing of the Build II wake is due primarily to the airfoil's thinner trailing-edge diameter. This difference in wake behavior is not a result of the airfoil boundary layers, since they are very similar on an integral thickness basis for the two airfoils. In fact, the total boundary layer momentum thickness (pressure and suction) at the airfoil trailing edge (and even the momentum thickness to chord ratio) is slightly larger for Build II than for Build I. Had the airfoil trailing-edge diameters been the same, one would have expected the Build II wake defect to mix out more slowly. The fact that the opposite occurred must be attributed to the thinner Build II trailing edge.

The computed boundary layer results from Reference 17 generally agree well with measured data. The suction side prediction for Build II did not reach the trailing edge. The calculations were begun as laminar flow from the leading edge. When the skin friction went to zero, the calculation was "tripped" to turbulent flow, holding the boundary layer momentum thickness constant through transition. The suction side calculation predicted separation at the 90% axial chord location for Build II. The trip locations are tabulated as follows:

Boundary Layer Transition Location (X/BX)

	Build I	Build II
Suction Side	0.28	0.56
Pressure Side	0.15	0.24

Each set of wake parameter data was fit to equations listed below. The forms of these equations were derived from those presented in References 19 and 20. The exponents determined for wake centerline velocity and, to a lesser extent, wake width decay rate agree with exact solutions presented in Schlichting (Reference 25) for an isolated twodimensional wake.

$$\delta_{HW}^{PITCH} = a_1 (b_1 (X/BX) + 1)^{m_1}$$
 (1)

$$1 - \frac{0.01}{(\delta^*/\text{PITCH})} = a_2(b_2(X/BX) + 1)^{m_2}$$
(2)

$$1 - \frac{1}{\delta^*/\theta} = a_3 (b_3 (X/BX) + 1)^{m_3}$$
 (3)

$$1 - \frac{V_0}{FSV} = a_4 (b_4 (X/BX) + 1)^{m_4}$$
(4)

 θ /PITCH was determined from the $\delta */\theta$ and $\delta */PITCH$ fit calculations. Shown in Figure 29 are the fitted curves and the associated constants. When comparing the fit results, it is valuable to realize the constant (a) is an initial value term at X/BX=0, and the exponent (m) and constant (b) are related to decay rate. The value of b was chosen and the other constants determined by a least squares fit. The constant (a) can be approximated from the boundary layer prediction calculations to give acceptable results.

The location of the wake centerline and displacement surface is of particular interest when wake modeling is considered. The location of the far wake was well-defined by these experiments. The far wakes are convected at the mean flow angle which remains nearly constant. The near wake centerline was less well-defined due to the smaller scale in this region relative to the trailing edge. There is considerable scatter, especially in Build II, in the locations of the near wake centerline. Build I had the additional complexity of the wide low-velocity region. An estimate of the locus of wake centerline points is shown in Figures 30 and 31. Adding the boundary layer and wake displacement thickness onto this line provides a continouous displacement body, also shown in Figures 30 and 31. The most notable characteristic of these displacement surfaces in the near wake is the curvature on the pressure side. These displacement surfaces will be used in conjunction with an inviscid analysis and validity of this model will be discussed in the next section.



FIGURE 30 WAKE LOCATION - BUILD I

★ Hot Film Probe Wake Center Line ⊙ Kiel Probe Wake Center Line

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SECTION V

ANALYTICAL WAKE MODELS

The major objective of the analytical phases of this program was to model the viscous flow in both the near- and far-wake regions in an inviscid cascade flow calculation. The most efficient cascade flow calculations for transonic flow use the potential flow model. Both Ives (Reference 9) and Caspar (Reference 16) offer computations of this type. Modeling viscous effects and retaining the potential flow model require adjusting the streamlines around the actual body to create a new displacement surface containing the viscous flow blockage and curvature effects. This streamline adjustment can be accomplished by either of two equally accurate methods. First, a non-zero velocity (airfoil surface blowing) boundary conditions may be imposed on the potential solution or, second, a new displacement body may be used with the usual zero normal-velocity boundary conditions. For this study, the second approach was taken.

WAKE MODELS

Two cases were studied for Build I: the first using the experimentally measured wake displacement surface location and a second using a wake displacement surface constructed with some of the experimental information and supplemented with a free shear layer calculation. For both cases, the imposed upstream and downstream conditions were derived from the test data. Upstream conditions were determined from an integration of the five-hole probe traverse data; the downstream angle was taken to be determined by the far wake trajectory.

In the first approach, a displacement body was constructed which had the shape of the combination of the airfoil shape, the computed blade boundary layer, and the measured wake displacement thickness. This body is shown in Figure 32. The pressure distribution for this displacement body was calculated using Caspar, and is plotted in Figure 32. The plot indicates that there is a considerable amount of loading in the wake region, as shown by the shaded area at the trailing edge. This large loading results from the near wake curvature, immediately aft of the trailing edge. It is possible that either the wake displacement surface, as defined by the absolute y-coordinate, is not correct in the

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FIGURE 32 MEASURED DATA WAKE MODEL AND PRESSURE DISTRIBUTION

near wake or the model is inadequate. More accurate near wake measurements would be required to resolve this.

In the second approach, an initial displacement body was first constructed which was the combination of the blade shape, the stagnation streamline calculated by analyzing the blade alone, and a cusp-shaped base region which was added symmetrically to the stagnation streamline immediately aft of the blade trailing edge. The resulting body and the computed pressure distribution for this case are shown in Figure 33. This figure indicates that there is nearly no loading in the wake region.

This pressure distribution was then used with very fast integral boundary/shear layer calculation to compute displacement thicknesses. These thicknesses were added to the initial body to construct the final displacement body. The laminar calculation is based upon the method of Gruschwitz (Reference 25); the turbulent solution is the lag-entrainment method of Green, et. al., (Reference 26). The computed results for the displacement and momentum thicknesses, both normalized by cascade pitch. are plotted in Figures 34 and 35, along with the experimentally measured values. As can be seen, there is good agreement both before the trailing edge (X/BX < 0) and in the far wake region (X/BX>0.1). There is some disagreement, however, between the measured and predicted variations in the near wake region. The final body and pressure distributions are shown in Figure 36 compared with the measured static pressure data.

PROFILE LOSS

Using the wake integral parameters, the mixed out profile loss was then calculated using the control volume calculation of Stewart (Reference 11). The aerodynamic conditions at various axial chord loctions downstream of the actual airfoil were used. In each case, the computed profile loss (ω_2) was 0.017. This is in agreement with the experimentally measured value for the Kiel proble. Angle changes due to mixing for this axial exit angle case are negligible.





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FIGURE 33 CONTRUCTED INITIAL WAKE MODEL AND PRESSURE DISTRIBUTION



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FIGURE 36 CONTRUCTED FINAL WAKE MODEL AND PRESSURE DISTRIBUTION

FLOW TURNING

As is well known, a potential flow solution about a body is unique only if the circulation is specified. For cascade flows with specified upstream conditions, this implies the imposition of either the downstream conditions or a local trailing-edge condition. As mentioned before, this is more fully discussed in the review by Klein (Reference 13). The local trailing-edge condition which has the most experimental verification is that the static pressures are equal on the suction and pressure sides at the trailing edge prior to separation. The data taken for Builds I and II confirm this equal pressure condition, as shown in Figure 14 and Table 3. It must be emphasized that this is a viscous flow condition. With large, rounded trailing edges, this condition has not been reliably implemented to predict flow turning because the computed inviscid flow is a very inaccurate representation of the true trailing-edge viscous flow. The improvements in accuracy at the trailing edge in the inviscid calculations which include a wake model should improve the accuracy of these turning calculations. More work is required to verify this.

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SECTION VI

CONCLUSIONS

- The desired aerodynamic conditions were achieved for the wake experiment. Excellent cascade flow periodicity and twodimensionality were achieved for both builds. Surface pressure distributions and boundary layer behavior of both airfoils provided the desired airfoil trailing-edge conditions for the wake experiments.
- Profile losses and flow turning computed from far downstream traverses agree well with the high-speed data taken in the DFVLR tunnel. Thus, the low-speed test can be used to model the viscous effects present in shockless high-speed flow.
- Far wake velocity profiles were found to satisfy a universal wake function. Although trailing-edge conditions for each of the airfoils were quite different, the far wakes are very much alike. The cascade airfoil far wake velocity profiles develop in a way similar to those of isolated airfoils.
- Near wake velocity profiles look similar to their respective boundary layer velocity profiles. Therefore, a universal wake function was not found for the near wake velocities.
- Von Karman vortex shedding was found to occur in the near wake of the Build I airfoil, but not for the Build II airfoil. The Strouhal number was approximately 0.21. The reason for this difference may be related to the small size of the Build II trailing-edge relative to the boundary layer.
- The wake flow was highly turbulent with a wide band of frequencies present for both builds. The shedding frequency was not a dominant feature of the flow and appears not to effect the mean velocity profiles in the far wake.
- The viscous flow effects in cascade wakes can be approximately modeled in potential flow calculations with a displacement body. More accurate experimental information is required to gain confidence in the details of the near wake model.
- The use of a wake model eliminates the trailing edge stagnation point in the inviscid calculation and resulted in a considerably more realistic flow in the trailing edge plane. Losses and angles consistent with measured data were computed with a wake mixing calculation.
- The use of a wake model should improve the accuracy of flow turning predictions based on a local trailing edge pressure condition.

APPENDIX

TABLES OF EXPERIMENTAL RESULTS

Tables 4 through 11 detail the data generated in this experimental investigation to analytically model the viscous wake in an inviscid potential flow calculation.

TABLE 4. TABULATION OF FIVE-HOLE TRAVERSE DATA

BUILD I

X/BX = 0.390

Pt	Y/PITCH	CPT	CPS	YAW	PHI	VEL/FSV
1	5750	001	.330	3.383	-1.639	1.003
2	4857	.002	. 330	3.295	-1.799	1.005
3	3964	.002	.331	3.291	-1.708	1.005
4	3518	.001	.333	3.193	-1.633	1.001
5	3071	.000	.329	3.032	-2.101	1.003
6	2714	003	.331	3.008	-1.735	1.000
7	2357	003	• 332	3.010	-1.787	. 998
8	2000	001	.333	3.013	-1.837	.999
9	1643	001	.330	3.126	-2.088	1.001
10	1464	009	• 333	3.104	-1.777	• 997
11	1286	002	• 333	3.009	-1.761	.997
12	1107	001	•333	2.816	-1.673	. 999
**						
13	1018	008	• 331	2.815	-1.664	. 995
14	0929	023	• 330	2.342	-1.677	• 985
15	0839	059	.333	2 . 9 10	-1.663	•954
16	0750	110	.334	2.251	-1.760	.913
17	0661	171	• 336	2.355	-1.918	.859
18	0571	230	.337	2.372	-2.129	• 805
19	-• 0482	267	.336	2.751	-2.138	.771
20	0393	281	.335	2.841	-2.077	.757
21	0304	268	• 335	3.385	-1.703	•771
22	0214	228	.336	3.385	-1.702	.809
23	0125	177	.331	3.663	-1.277	.859
24	0036	115	.331	3.665	-1.142	.912
25	.0054	063	.328	3.763	986	•954
26	.0143	028	.329	3.765	935	•981
27	.0232	-• 008	• 330	3.667	-1.053	• 997
**					• • •	
28	.0321	002	.331	3.385	969	• 998
29	.0500	002	.331	3.382	-1.089	• 998
30	•0679	001	.331	3.384	-1.016	• 999
31	.1036	002	• 333	3.382	-1.072	.997
32	.1393	003	.331	3.385	959	• 998
33	.1839	006	.330	3.384	992	.997
34	.2286	-• 008	.327	3.387	893	• 998
35	•3179	006	• 329	3.380	-1.189	.99/
36	•4071	005	.329	3.378	-1.443	• 999
37	• 5857	002	.329	3.284	-1.496	1.001
48	. 6 / 50			4.745	-1./41	1. ((()))

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TABLE 4.TABULATION OF FIVE-HOLE TRAVERSE DATA
(Con't)

BUILD I

X/BX = 0.649

Pt	Y/PITCH	CPT	CPS	YAW	PHI	VEL/FSV
1	5750	002	.334	2.725	-1.756	1.001
2	4857	.001	.334	2.724	-1.738	1.002
3	3964	.002	.333	2.529	-1.600	1.003
4	3518	.000	.334	2.534	-1.720	1.000
5	2893	003	.336	2.530	-1.636	.998
6	2536	002	.333	2.535	-1.741	.999
7	2179	003	.334	2.531	-1.665	.998
8	2000	002	.335	2.531	-1.663	.998
9	1821	004	.333	2.534	-1.719	.998
10	1643	002	.335	2.531	-1.655	.997
11	1464	003	.332	2.439	-1.716	.998
12	1286	004	.332	2.434	-1.586	.998
**						
13	1196	013	.333	2.436	-1.652	.990
14	1107	033	.331	2.246	-1.633	.975
15	1018	062	.331	2.060	-1.710	.953
16	0929	102	• 332	2.063	-1.778	.921
17	0839	144	.333	2.062	-1.763	•885
18	0750	182	•334	2.066	-1.842	.851
19	0661	212	• 333	2.064	-1.805	.825
20	0571	229	• 334	2.633	-1.811	. 809
21	0482	232	.332	2.626	-1.672	• 808
22	0304	182	.331	2.810	-1.379	•855
23	0214	141	• 330	3.000	-1.269	.89 0
24	0125	097	.331	3.002	-1.144	•927
25	0036	-,058	.330	3.003	-1.112	• 958
26	.0143	013	• 334	2.814	-1.079	• 993
**						
27	.0321	002	.330	2.813	-1.106	1.000
28	•0500	001	.335	2.814	-1.066	1.000
29	.0679	•001	.332	2.814	-1.083	1.001
30	.0857	004	.330	2.814	-1.061	•998
31	.1036	001	.330	2.816	-1.007	1.000
32	.1393	004	.328	2.817	980	•999
33	.1839	005	• 330	3.008	915	• 998
34	•2286	007	.330	2.818	929	•996
35	.3179	006	• 329	2.717	-1.188	• 998
36	.4071	004	.329	2.715	-1.327	•999
37	• 4964	002	.329	2.716	-1.253	1.001
38	• 5857	004	.329	2.715	-1.418	.999
39	. 6750	003	• 330	2.726	-1.779	• 999

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TABLE 4. TABULATION OF FIVE-HOLE TRAVERSE DATA

COMPANY + ACL 10

(Con't)

BUILD I

X/BX = 1.169

Pt	Y/PITCH	CPT	CPS	YAW	PHI	VEL/FSV
1	-1.2893	-• 006	.328	3.000	-1 284	1 000
2	-1.2891	001	.330	3,095	-1 220	1.000
3	-1.2357	003	.332	3,003	-1.230	1.004
4	-1.1464	055	. 327	2.624	-1 103	1.000
5	-1.0929	-, 175	.331	2.621	-1.102	• 964
6	-1.0393	086	. 331	3.370	-1.314	• 861
7	9679	003	.330	2, 905	-1.23/	• 936
8	8607	.006	.331	2.905	$-1 \cdot 2/1$	1.001
9	7536	.000	. 329	2,715	-1.220	1.005
10	5929	.000	.329	2.822	-1.339	1.001
11	3964	• 002	. 331	2.717	-1.5(0	1.003
12	3250	003	.330	2.718	-1.500	1.003
13	2357	004	. 331	2.720	-1.582	1.001
**				2.720	-1.044	• 999
14	1643	015	. 329	2. 532	-1 600	
15	1286	091	.328	2.535	-1.749	• 991
16	0750	-,172	.328	2,811	-1.517	•933
17	0214	052	.328	2.908	-1.120	• 865
18	• 0500	004	.325	2,816	-1.120	• 965
**						1.002
19	.1750	007	.327	2,913	- 020	000
20	• 3179	008	. 327	3,000	-1 225	• 999
21	• 39 50	004	.329	2. 526	-1.230	• 999
22	•5143	006	. 326	2.715	-1.400	1.000
23	•6750	006	.327	2.722	-1.707	1.000
24	• 7464	005	. 325	2.710	-1.617	.999
25	•8714	022	. 326	2.528	-1.01/	1.001
26	• 9250	183	.326	2,528	-1+ 330	• 989
27	• 9786	064	.325	2.530	-1.000	• 855
28	• 9964	026	. 323	2.624	-1.007	• 957
2 9	1.1036	003	.329	2.717	-1.167	• 987
30	1.2107	001	. 324	2.716	-1.01	1.004
				60/10	-1.712	1.005

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TABLE 4. TABULATION OF FIVE-HOLE TRAVERSE DATA

(Con't)

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and a state

BUILD I

X/BX = -1.260

Ρt	Y/PITCH	CPT	CPS	YAW	PHI	VEL/FSV
1	-2.9 00	004	069	38.326	-, 893	1,000
2	-1.700	006	060	38.274	986	.995
3	-0.580	005	-• 055	36 . 9 47	754	.991
4	0. 580	006	034	38.881	749	.982
5	1.700	004	025	37.344	850	.978
6	2.900	001	099	38.408	267	1.014

TABLE 5. TABULATION OF KIEL TRAVERSE DATA

BUILD I

X/BX = 0.065

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 X/BX = 0.130

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PT	Y/PITCH	CPT	PT	Y/PITCH	CPT
1	5750	.003	1	5750	01 3
2	4857	.005	2	4857	006
3	3964	.013	3	4411	013
4	3071	•003	- 4	3964	005
5	2179	•000	5	3518	006
6	1286	 001	6	3071	005
7	1107	001	7	2179	003
8	0929	•002	8	1732	005
**			9	1464	005
9	0839	•001	10	1286	004
10	0750	004	11	1107	002
11	0661	019	**		
12	0571	073	12	0929	001
13	0482	166	13	0750	011
14	0393	248	14	0661	049
15	0357	291	15	0571	139
16	0321	325	16	0482	222
17	0286	361	17	0393	317
18	0250	404	18	0304	383
19	0214	441	19	0214	401
20	0179	463	20	0125	291
21	0143	464	21	0036	189
22	0107	438	22	.0054	094
23	0071	368	23	.0143	045
24	0036	310	24	.0321	013
25	.0000	231	**		
26	.0036	173	25	.0500	.003
27	.0071	115	26	.0857	.000
28	.0107	-• 089	27	.1393	003
29	.0143	069	28	.2286	006
30	.0321	008	29	• 2732	005
**			30	.3179	004
31	.0500	.001	31	• 3625	007
32	.0946	•001	32	.4071	006
33	.1393	•003	33	• 4964	006
34	.2286	•000	34	• 5411	• 000
35	.3179	003	35	• 5857	•006
36	.4071	003	36	•6304	002
37	.4964	003	37	.6750	005
38	• 5857	001			
39	.6750	001			

TABLE 5. TABULATION OF KIEL TRAVERSE DATA

(Con't)

BUILD I

X/BX = 0.260

X/BX = 0.390

PT	Y/PITCH	CPT	PT	Y/PITCH	CPT
1	- 5750	001	,	- 5750	- 001
2	4857	•004	2	~. 4857	-,002
3	4411	.001	3	3964	•010
4	3964	001	4	3518	•004
5	-, 3518	•006	5	2714	•003
6	3071	• 000	6	2357	•000
7	- 2179	006	7	~ 2000	- 002
8	1732	• 000	8	- 1643	- 002
9	1464	002	9	- 1464	- 005
10	1286	002	**	• 1 - 0 -	~•005
**			10	1107	010
11	110/	009	11	0929	026
12	0929	007	12	0839	070
13	0750	059	13	0750	130
14	0661	-• 137	14	0661	189
15	05/1	210	15	0571	240
10	0482	-• 276	16	0482	270
10	0393	314	17	0393	276
10	- 0304	312	18	0304	251
20	-0.0214	268	19	0214	200
20	- 0026	-• 18/	20	0125	137
22	0036	-•116	21	~.0036	079
22	0034	054	22	•0054	036
23	•0143	015	23	.0143	014
24	•0321	003	**		
25	0500	001	24	•0232	002
26	.0670	• 001	25	.0321	001
27	0857	001	26	.0500	001
28	.1393	•002	27	•067 9	001
29	. 1839	- 007	28	•10 36	• 000
30	. 2286	007	29	•1393	002
31	. 2732	- 006	30	•1839	004
32	. 3179	- 007	31	• 2286	004
33	. 3625	007	32	.3179	007
34	. 4071	009	33	.4071	005
35	.4518	000	34	• 4964	• 000
36	. 4964	-003	35	• 5857	003
37	. 5857	- 005 - 005	36	•6750	003
38	.6750	003			
		• • • • • •			

TABLE 5. TABULATION OF KIEL TRAVERSE DATA

(Con't)

BUILD I

X/BX = 0.649

X/BX = 1.169

*.

PT	Y/PITCH	CPT	PT Y/PITCH	CPT
1	5750	•000	1 4857	.002
2	4857	.001	2 3964	.002
3	3964	.001	3 3071	002
4	3071	•001	4 2179	.000
5	2714	.000	5 2000	004
6	2357	001	**	
7	2000	001	6 1821	007
8	1643	001	71643	020
9	1464	002	8 1464	052
**			9 -, 1286	104
10	1286	010	10 1107	150
11	1107	044	111018	165
12	1018	076	12 0929	175
13	0929	122	130839	176
14	0839	-,160	140750	171
15	0750	192	150661	152
16	0661	218	16 0571	131
17	0571	229	170482	105
18	0482	221	18 0393	081
19	0393	198	190304	055
20	0304	157	20 0214	035
21	0214	119	210036	012
22	0125	078	**	
23	0036	044	.0143	003
24	.0143	008	23 .0321	001
**			24 .0500	001
25	.0321	002	25 .0679	~ .003
26	.0500	.000	26 .0857	001
27	.0679	001	27 .1393	005
28	.1036	.001	28 .2286	005
29	.2286	004	29 .3179	009
30	.3179	005	30 .4071	005
31	.4071	004	31 .4964	006
32	.4964	005	32 .5857	005
33	. 5857	004	33 . 6750	001
34	.6750	004		

BUILD I

X/BX = -0.032

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SUCTION SIDE

Marthowle

PT	Y/PITCH	TI	V/FSV
1	3359	•002	• 988
2	2466	.002	• 988
3	2020	.002	• 99 0
4	1573	• 002	• 991
5	 1127	• 002	• 99 4
6	1038	• 002	• 993
7	0948	• 002	• 993
8	0859	.002	• 995
9	0770	• 005	• 997
10	0680	•005	1.000
11	0636	.007	1.000
12	0591	.011	• 998
**			
13	0546	.023	• 995
14	0502	.043	• 9 67
15	0466	.063	•933
16	0430	•07 9	• 889
17	0395	• 0 9 2	• 8 40
18	0359	.105	.791
19	0323	.117	• 734
20	0288	.126	.681
21	0252	.138	•622
22	0234	.142	• 595
23	0216	.145	• 567
24	0198	.148	• 536
25	0180	.151	• 510
26	0163	.159	.483
27	0154	.176	• 448
28	0145	.200	.401
29	0136	.241	• 279
30	0127	.000	.000

(Con't)

BUILD I

X/BX = -0.032

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PRESSURE SIDE

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PT	Y/PITCH	TI	V/FSV
1	.0127	.000	.000
2	.0130	.144	. 390
3	.0132	.164	•437
4	.0148	.104	•727
5	.0157	.081	.793
6	.0166	.069	.832
7.	.0175	.068	.838
8	.0184	.062	• 857
9	.0202	.055	.880
10	• 0220	• 053	• 894
11	•0237	.047	.91 0
12	• 0255	• 045	•921
13	.0273	• 042	• 934
14	•0291	.039	• 942
15	•0327	• 036	•957
16	.0363	.031	.972
17	•0 398	• 024	• 987
18	. 04 3 4	•018	•992
**			
19	•0470	•013	1.000
20	• 0648	• 003	• 999
21	•0827	• 002	.995
22	.1005	• 002	• 990
23	.1452	• 002	• 985
24	.1898	.002	• 984
25	.2791	• 004	• 987
26	• 3684	• 004	• 996

(Con't)

BUILD I

X/BX = -0.004

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SUCTION SIDE

PT	Y/PITCH	TI	V/FSV
1	5000	• 002	• 983
2	3964	.002	• 986
3	3071	.002	. 989
4	2179	.002	.992
5	1286	• 002	.999
6	1107	.002	. 998
7	0929	.003	1.000
8	0839	.003	1.000
9	0750	.005	1.000
**			
10	0661	.011	1,000
11	0571	.038	• 980
12	0482	•076	. 894
13	0393	.108	.778
14	0357	.118	.719
15	0321	.131	.675
16	0286	.139	.625
17	0250	.148	• 581
18	0214	.157	. 526
19	0196	.164	.501
20	0179	•178	• 462
21	0161	.230	. 393
22	0143	• 380	.254
23	0134	.498	.152
24	~ •0125	•436	.052
25	0116	.327	.043
26	0107	.208	.036
27	0104	.000	.000
**			5000

(Con't)

BUILD I

X/BX = -0.004

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PRESSURE SIDE

PT	Y/PITCH	TI	V/FSV
**			
1	.0086	.000	•000
2	.0089	.191	•035
3	.0093	.295	•068
4	.0098	.361	.151
5	.0102	• 254	.357
6	.0107	.136	•666
7	.0116	.100	.771
8	.0125	.093	• 804
9	.0143	•072	•859
10	.0179	• 054	• 903
11	.0232	.045	.929
12	.0268	• 040	.951
13	.0321	•034	•968
14	.0411	• 020	• 992
**			
15	.0500	• 008	1.000
16	.0946	.002	• 984
17	.1393	• 002	.981
18	.2286	• 002	• 978
19	.3179	.002	• 982
20	• 5000	• 002	1.000

(Con't)

BUILD I

X/BX = 0.004

PT	Y/PITCH	TI	V/FSV
1	-, 3964	.002	• 99 0
2	3071	.002	. 99 5
3	2179	• 002	• 995
4	1286	• 002	•992
5	1107	.002	• 992
6	0929	.003	• 995
7	0834	.004	• 994
8	0750	• 007	.997
**			
9	0661	.021	.99 2
10	~ •0571	.061	• 936
11	0482	• 0 97	•827
12	0393	•126	•700
13	0357	.136	•653
14	0321	•146	• 598
15	0286	.153	.552
16	0250	•163	• 503
17	0214	.261	.389
18	0196	• 382	• 256
19	0179	• 474	•144
20	0161	.358	•077
21	0143	.348	.069
22	0125	• 357	• 07 0
23	0107	.364	.070
24	0089	• 387	•066
25	0071	• 422	.062
26	0054	• 470	•063
27	0036	• 483	•064
28	0016	• 481	•063
29	•0000	• 496	.056
30	.0018	• 434	.076
31	•00 36	. 221	• 526
32	•0054	.103	•776
33	.0071	.072	•846
34	•0089	•061	•878
35	•0143	• 048	.921
36	.0232	• 036	• 9 62
37	•0321	•024	.991
38	.0411	• 009	1.002
**	0500	005	000
39	• 0500	• 005	• 999

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(Con't)

BUILD I

X/BX = 0.004

PT	Y/PITCH	TI	V/FSV
40	.0946	•003	• 987
41	.1393	.003	• 982
42	.2286	.003	.981
43	.3179	.003	.982

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(Con¹t)

BUILD I

X/BX = 0.012

PT	Y/PITCH	TI	V/FSV
1	5000	• 002	1.002
2	3964	.002	1.022
3	3071	.002	1.024
4	2179	.002	1.071
5	2179	.002	1.017
6	1286	.002	1.017
**			
7	1107	.002	1.008
8	0929	.003	1.005
9	0839	.004	1.006
10	0750	• 007	1.005
11	0661	.014	1.002
12	0571	•042	.977
13	0482	•07 9	.884
14	0393	.109	.767
15	~.0357	.123	.715
16	0321	.133	.669
17	0304	.137	.657
18	0286	.145	.622
19	0268	•153	. 597
20	0250	.154	• 575
21	0232	.160	. 543
22	0214	•171	.521
23	0196	.199	.478
24	0179	.256	.414
25	0161	.302	.349
26	0143	.373	• 260
27	0125	.418	.203
28	0107	.429	.128
29	0089	.403	.110
30	 0071	.412	.118
31	0054	• 378	.136
32	0036	• 371	.146
33	0018	. 323	.161
34	•0000	• 331	.149
35	•0018	• 335	.141
36	.0036	•403	.177
37	• 0054	• 300	. 449
38	•0071	•150	•723
77	.0089	.083	.829
40	•0143	• 060	• 883

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(Con¹t)

BUILD I

X/BX = 0.012

PT	Y/PITCH	TI	V/FSV
41	.0232	•046	.928
42	.0321	.035	.965
43	.0411	.018	.987
**			
44	.0500	.007	•99 2
45	.0946	.002	.984
46	.1393	.002	.979
47	.2286	.002	.973
48	.3179	.002	.981
49	.5000	•002	.995

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History and

(Con't)

BUILD I

X/BX = 0.020

PT	Y/PITCH	TI	V/FSV
1	5000	.002	1.008
2	3964	.002	1.016
3	3071	.002	1.018
4	2179	• 002	1.019
5	1286	.002	1.018
6	0929	•003	1.013
7	0750	•007	1.013
**			
8	0661	.016	1.009
9	0571	• 050	• 96 8
10	0482	•089	.862
11	0393	.120	•738
12	 0357	.134	•681
13	0321	•147	.624
14	0304	•151	• 609
15	0286	.159	• 577
16	0268	• 166	• 549
17	0250	.172	• 533
18	0232	• 186	•497
19	0214	• 224	.453
20	0196	• 245	• 422
21	0179	.301	•355
22	0161	• 367	.291
23	0143	•432	•216
24	0125	• 420	.181
25	0107	.364	.162
26	 00 89	• 318	•172
27	0071	.295	•186
28	0054	• 288	.190
29	0036	.288	.189
30	0018	.314	.187
31	• 0000	.361	• 228
32	.0018	.327	• 380
33	• 0036	• 220	.591
34	• 0054	.161	•709
35	.0071	.095	.809
36	.0089	•074	•838
37	•0143	• 053	• 884
38	•0232	•040	•927
39	•0321	.027	• 961
40	.0411	.012	• 9 81

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(Con't)

Constant of the last of the

BUILD I

X/BX = 0.020

РT	Y/PITCH	TI	V/FSV
**			
41	.0500	.005	.983
42	.0679	.004	• 9 81
43	.0768	•004	.981
44	.0946	.004	. 98 0
45	.1393	.003	•975
46	.2286	.002	•972
47	.3179	.002	.975
48	. 5000	.002	.987

(Con't)

BUILD I

X/BX = 0.032

PT	Y/PITCH	TI	V/FSV
1	3964	.003	1.014
2	3071	.003	1.015
3	2179	.003	1.015
4	1286	.003	1.008
5	1107	.003	1.008
6	0929	.005	1.002
7	0839	•007	1.001
**			
8	 0750	.015	• 998
9	0661	.048	• 961
10	0571	•086	• 864
11	0482	.127	•725
12	0357	. 179	• 537
13	0321	.217	•478
14	0286	.261	• 405
15	0250	. 339	.332
16	0214	.452	.230
17	0179	• 442	.182
18	0143	.428	.208
19	0107	.387	• 302
20	0071	.252	• 541
21	0036	.198	• 666
22	.0054	.057	.893
23	•0143	.040	.939
24	.0232	.024	.973
25	.0321	.011	• 988
**			
26	.0411	.006	• 993
27	.0500	.005	• 991
28	•0946	.004	• 989
29	.1393	.004	.981
3 0	.2286	.003	• 982
31	.3179	.003	• 9 85

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(Con't)

BUILD I

X/BX = 0.065

ΡT	Y/PITCH	TI	V/FSV
1	- 3964	003	1 014
2	- 3071	•003	1.014
2	- 2179	.003	1.015
4	- 1286	•003	1.003
7 5	- 1107	.004	• • • • • • • • • • • • • • • • • • • •
6	- 0929	005	• 595
**	.0525	•000	• 309
7	0839	.010	987
8	- 0750	•010	• 907 078
a a	- 0661	060	• 57 O 0 2 Q
10	- 0571	.096	. 827
11	0482	.136	. 695
12	0393	. 191	. 556
13	0357	. 215	. 495
14	0321	. 244	.453
15	0286	.252	.405
16	0250	. 243	. 392
17	0214	.239	.409
18	0179	,228	.473
19	0143	. 204	. 548
20	0107	.184	.637
21	0071	.145	.739
22	0036	.130	.787
23	.0071	.054	.918
24	.0143	.033	.959
25	.0232	.020	• 9 85
26	.0321	.011	.993
27	.0411	•009	• 998
**			
28	.0500	.008	1.000
29	•0 9 46	.008	1.008
30	.1393	.008	1.008
31	.2286	•008	1.007
32	.3179	.008	1.012

(Con't)

BUILD I

X/BX = 0.130

PT	Y/PITCH	TI	V/FSV
1	3964	. 002	1 010
2	3518	.003	1.010
3	3071	.003	1.012
4	2625	.003	1.010
5	2179	.003	1 003
6	1732	.003	1,000
7	1464	.003	1.000
8	1286	.003	• 7 7 7
9	1107	.003	• 990 005
10	0929	.005	. 995
**			• 550
11	-,0750	.019	. 994
12	0661	.054	. 958
13	0571	.096	. 868
14	0482	.132	. 754
15	-,0393	.157	.643
16	0304	.191	• 562
17	0214	.153	.571
18	0125	.151	• 670
19	0036	.119	.814
20	.0054	.079	.913
21	.0143	.043	.971
22	.0321	.011	.998
**			
23	•0500	• 004	.994
24	•067 9	.003	. 998
25	•0857	•003	1.000
26	•1393	.003	1.000
27	. 1839	.003	1.000
28	• 2286	.003	1.003
29	.2732	.002	1.008
30	.3179	.002	1.007

BUILD II

X/BX = 0.344

PT	Y/PITCH	СРТ	CPS	YAW	PHI	V/FSV
1	5795	.000	• 314	3.174	-1.858	1.003
2	4902	.002	.312	3.177	-2.008	1.004
3	4009	.003	.315	2.986	-1.909	1.004
4	-• 3562	.004	.315	2.985	-1.897	1.007
5	3116	.003	.315	2.986	-1.928	1.005
6	 2759	.005	.318	2.794	-1.776	1.004
7	2402	.005	.316	2.794	-1.807	1.004
8	2045	• 006	.319	2.607	-1.903	1.003
9	1688	•008	.319	2.417	-1.863	1.004
10	1330	.009	.321	2.035	-1.648	1.003
11	1152	.010	.320	2.034	-1.527	1.004
**						
12	0884	.006	.322	1.847	-1.260	1.001
13	0795	004	.320	1.470	-1.145	• 993
14	0705	028	.319	1.470	-1.153	•977
15	0616	063	.320	1.282	-1.089	•950
16	0527	101	.325	1.281	-1.138	.913
17	0438	154	.323	1.088	-1.476	•874
18	0348	196	• 324	1.088	-1.586	•837
19	0259	232	.325	1.280	-1.842	•804
20	0170	251	.326	1.282	-1.947	•787
21	0080	257	.329	1.848	-1.819	.781
22	.0009	225	.323	1.848	-1.820	.811
23	•0098	184	.323	2.225	-1.733	•848
24	.0188	125	.320	2.224	-1.472	•900
25	.02//	069	.320	2.417	-1.159	• 943
26	.0366	034	.319	2.418	-1.062	•970
2/	•0455	012	• 320	2.418	-1.089	• 987
**	0(0)					
28	.0634	.003	• 321	2.420	-1.008	• 997
29	.0991	.004	• 322	2.608	-1.038	• 997
30	.1348	.003	.323	2./9/	-1.075	• 996
31	.1/95	.002	• 323	3.176	-1.088	• 995
32	• 2241	003	.319	3.178	941	• 994
27	• 31 34	•002	• 322	3.334	-1.090	• 998
34	•4027	001	. 318	3.554	-1.093	• 996
32 22	•492U	•003	• 320	3.333	-1.183	• 998
0C 72	• JØ1 J 6705	.007	• 32 3	J. 221	-1.301	• 998
21	•0/UD	.007	• 322	3.220	-1.203	• 999

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BUILD II

X/BX = 0.573

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PT	Y/PITCH	CPT	CPS	YAW	PHI	V/FSV
1	5795	.001	.317	3.171	-1.634	1.002
2	4902	.000	.317	3.172	-1.725	1.001
3	4009	.005	.319	3.361	-1.676	1.002
4	3116	.002	.318	3.171	-1.619	1.000
5	2223	•00 9	.321	2.792	-1.448	1.003
6	1866	.007	.321	2.793	-1.395	1.003
7	 150 9	•00 9	.321	2.415	-1.311	1.003
8	1330	.010	.322	2.415	-1.270	1.002
9	1152	.009	.320	2.038	-1.132	1.003
**						
10	0973	.002	.321	2.039	-1.105	. 998
11	- •0795	034	.319	1.662	986	.973
12	0705	063	.319	1.662	-1.017	•950
13	0616	093	.321	1.662	-1.032	.926
14	0527	127	• 322	1.470	-1.125	•897
15	0438	158	.323	1.468	-1.248	•870
16	0348	182	• 325	1.467	-1.338	•848
17	0259	202	.323	1.466	-1.449	•832
18	0170	208	• 324	1.846	-1.383	•826
19	0080	208	.323	1.845	-1.507	.826
20	• 000 9	19 0	.322	1.845	-1.550	• 844
21	•0098	162	.321	2.224	-1.609	• 868
22	•0188	124	.321	2.413	-1.492	• 900
23	•0277	085	.318	2.415	-1.314	.932
24	• 04 55	022	.318	2.418	-1.096	• 980
25	•0634	001	•319	2.419	-1.047	.997
**	0010	001	200	o () o	1 000	007
26	.0813	.004	. 320	2.418	-1.099	.997
21	.0991	.003	• 321	2.797	-1.091	• 996
28	•1348	.002	• 320	2.798	-1.041	• 995
29	•1705	.002	• 322	2.988	900	• 775
30	• 2241	.003	• 322	3.1/8	- 900	• 996
21	• 31 34	•001	• 322	3.300 2.7/5	939	. 994
32	•492U	•004 005	+ 323	3.743		• 775
35	• JÖIJ 6705	.005	• 324	3.743	-1.118	• 994
54	•0/05	•009	• 343	3.741	−1• 2/1	• 770

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TABLE 7. TABULATION OF FIVE-HOLE TRAVERSE DATA

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BUILD II

X/BX = 1.031

PT	Y/PITCH	CPT	CPS	YAW	PHI	V/FSV
1	-1.2937	•000	.312	2.984	-1.241	1.003
2	-1.2045	002	.314	2.604	-1.312	1.001
3	-1.1330	002	.313	2.036	-1.336	1.000
4	-1.0973	021	.311	1.658	-1.271	. 988
5	-1.0616	085	.311	1.471	-1.100	.939
6	-1.0437	124	.314	1.472	-1.045	.906
7	-1.0259	153	.315	1.663	977	.822
8	-1.0080	159	.314	2.045	772	.877
9	9902	134	.313	2.237	443	.897
10	~ • 9545	044	.312	2.614	252	.969
11	9187	.004	.314	2.426	563	1.002
12	8473	005	.313	2.797	-1.053	• 996
13	7580	004	.313	3.173	-1.222	.996
14	6687	.001	•317	3.172	-1.355	.998
15	5795	002	.315	3.361	-1.416	.996
16	4902	.001	.315	3.361	-1.339	.999
17	4009	.003	.317	3.171	-1.404	.999
18	3116	.008	.319	3.173	-1.258	1.001
19	2223	.007	.318	2.797	-1.089	1.002
**						
20	1509	•004	.317	2.422	864	.999
21	1152	016	.318	2.235	732	• 983
22	0795	087	.319	2.045	782	• 928
23	0616	128	.318	2.043	 9 05	•897
24	0438	154	.321	2.044	823	.874
25	0259	163	.319	2.040	-1.035	•868
26	0080	144	.317	2.420	993	•885
27	•0098	106	.315	2.797	-1.072	.917
28	.0277	055	.314	2.800	938	.958
29	•0634	.000	.316	2.992	740	• 998
**						
30	.0991	.005	.319	3.182	717	• 999
31	•1884	•003	.318	3.373	593	•997
32	•2777	•002	.319	3.373	 572	•997
33	.3670	.003	.320	3.751	605	•997
34	• 4563	•005	.321	3.751	667	• 998
35	• 54 5 5	.005	.319	3.939	751	•998
36	•6348	•007	.322	3.937	-,877	• 998
37	.7241	•007	.322	3.938	846	•998
38	•7777	•004	.322	3.938	807	•997
39	. 81 34	016	.320	3.748	841	•983
40	.8491	067	.319	3.557	944	•944
41	. 8670	102	.320	3.748	839	.916
42	•8848	133	.321	3.748	842	• 891



BUILD II

X/BX = 1.031

PT	Y/PITCH	CPT	CPS	YAW	PHI	V/FSV
43	• 9027	155	. 320	3.750	728	.873
44	.9205	161	.321	4.130	573	•867
45	. 9562	124	.322	4.130	551	•897
46	.9920	046	.323	4.319	320	• 954
47	1.0277	007	.321	3.937	114	• 988
48	1,1170	.006	.324	3.938	127	. 996
49	1.2063	.008	.323	3.937	082	•997

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BUILD II

X/BX = 1.229

PT	Y/PITCH	CPT	CPS	YAW	PHI	V/FSV
1	-2.900	004	125	39.397	667	1.000
2	-2.200	002	011	38.593	948	.949
3	-1.500	009	121	39.996	777	.995
4	-0.700	.001	045	38 . 8 98	629	.964
5	0.000	001	100	40.898	621	.989
6	0.700	•004	083	40.198	363	• 982
7	1.500	.002	033	41.898	340	.959
8	2.200	.007	101	40.098	363	.99 0
9	2 .9 00	.008	015	41 .39 5	113	•951

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TABLE 8. TABULATION OF KIEL TRAVERSE DATA

BUILD II

X/BX = 0.229

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X/BX = 0.344

PT	Y/PITCH	CPT	PT	Y/PITCH	CPT
1	5795	003	1	5795	006
2	5348	002	2	4902	003
3	4902	001	3	4009	004
4	4455	.000	4	3116	002
5	4009	.000	5	2402	.001
6	3562	001	6	1688	.002
7	3116	.001	7	1330	.003
8	2670	.000	8	0973	.003
9	2223	.000	**		
10	1688	.003	9	0884	005
11	1330	.007	10	0795	020
12	1152	.006	11	-, 0705	053
13	0973	.006	12	0616	101
14	0884	.004	13	0527	157
**			14	0438	204
15	0795	.000	15	0348	244
16	0705	023	16	- •0259	268
17	0616	072	17	0170	268
18	0527	131	18	0080	246
19	0438	204	19	.0009	194
20	0348	265	20	.0098	144
21	 0259	303	21	.0188	086
22	0170	319	22	.0277	040
23	0080	292	23	.0366	015
24	.0009	225	24	•0455	004
25	.0098	144	**		
26	.0188	~.080	25	.0634	.003
27	.0277	037	26	.0991	.013
28	.0366	012	27	.1348	.002
29	.0455	005	28	.2241	.004
**			29	.3134	.002
30	.0634	• 002	30	•4027	• 002
31	.0991	.005	31	.4920	.006
32	.1348	002	32	.5813	.006
33	.1795	.002	33	.6705	.013
34	.2241	.003			
35	.3134	• 004			
36	.358 0	• 004			
37	•4027	.005			
38	.4473	.003			
39	.49 20	•005			
40	• 5366	.005			
41	.5813	• 004			
42	.6705	•006			

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TABLE 8. TABULATION OF KIEL TRAVERSE DATA

BUILD II

X/BX = 0.573

X/BX = 1.031

PT	Y/PITCH	CPT	PT	Y/PITCH	CPT
1	5795	.000	1	-1.2937	004
2	 49 02	.001	2	-1.2045	•005
3	4009	001	3	-1.1330	004
4	3116	•002	4	-1.0973	039
5	2223	.003	5	-1.0616	111
6	1866	.003	6	-1.0437	147
7	1509	.000	7	-1.0259	169
8	1330	.007	8	-1.0080	164
**			9	9902	132
9	1152	.004	10	-• 9545	042
10	0973	011	11	9187	002
11	0795	055	12	8473	002
12	0705	09 0	13	7580	.001
13	0616	119	14	6687	.001
14	0527	154	15	5795	001
15	0438	180	16	4902	•001
16	0348	203	17	4009	001
17	0259	217	18	3116	.005
18	0170	223	19	2223	•001
19	0080	210	**		
20	.0098	161	20	1509	.003
21	.0188	123	21	1152	028
22	.0277	086	22	0795	099
23	.0455	025	23	0616	133
24	.0634	.002	24	0438	150
**			25	 0259	142
25	.0991	•005	26	0080	108
26	.1705	•003	27	• 0098	064
27	.2241	.002	28	.0277	026
28	.3134	.001	29	• 0634	•001
29	•4027	• 004	**		
30	.49 20	.003	30	•0991	•001
31	.5813	.004	31	.1884	.001
32	.6705	.003	32	•2777	.001
			33	.3670	.004
			34	• 4563	•004
			35	.5455	.005

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37 38

39

40

41

42

.6348

.7241

.7777

.8134

.8491

.8670

.8848

.008

.005

.002

-.013

-.063

-.093

-.127

TABLE 8. TABULATION OF KIEL TRAVERSE DATA

BUILD II

X/BX = 1.031

PT	Y/PITCH	CPT
43	• 9 027	156
44	•9205	164
45	• 9562	-,129
46	.9920	058
47	1.0277	008
48	1,1170	.010
49	1.2063	.010

BUILD II

X/BX =	-0.0287
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SUCTION SIDE

PT	Y/PITCH	TI	V/FSV
1	-• 5564	• 004	. 983
2	4671	• 004	. 985
3	3779	.007	. 988
4	2886	.004	.993
5	1993	.004	1.007
**			
6	1636	.005	1.000
7	1279	.005	.977
8	0921	•006	.975
9	0832	• 007	.973
10	0743	.010	.983
11	0654	.016	.981
12	0564	.031	.968
13	0475	.062	.926
14	0386	.092	.861
15	0296	.115	•762
16	0252	.121	.725
17	0207	.128	•668
18	0171	.135	•62 0
19	0145	.145	• 580
20	0127	•153	• 555
21	0109	.161	•522
22	0091	.169	•490
23	0073	.183	•451
24	0064	.194	.427
25	0055	.210	.390
26	0046	•000	•000
**			

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BUILD II

X/BX = -0.0287		PRESSURE SIDE		
PT	Y/PITCH	TI	V/FSV	
**				
1	.0046	•000	•000	
2	•0050	• 289	• 398	
3	.0055	.124	• 564	
4	.0059	.103	.708	
5	.0064	.092	•749	
6	.0104	.065	.8 40	
7	.0202	.054	.899	
8	.0345	•043	• 948	
9	.0514	.026	•98 5	
10	.0675	.012	1.000	
**				
11	.0854	• 008	1.000	
12	.1121	.007	1 .0 04	
13	.1479	• 006	1.009	
14	.1836	• 006	1.013	
15	.2193	.005	1.020	
16	.3086	.004	1.032	
17	.3979	.004	1.047	
18	.4871	.003	1.061	
19	. 5764	.004	1.079	

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BUILD II

X/BX = -0.0036		SUCTION SIDE		
PT	Y/PITCH	TI	V/FSV	
1	5511	•003	.982	
2	4618	.003	.989	
3	3725	• 003	• 994	
4	2832	•004	• 99 5	
5	1939	•005	1.007	
6	1582	.005	1.000	
**				
7	1225	• 006	• 996	
8	0868	.010	.989	
9	0689	.007	.976	
10	0511	•075	•907	
11	0421	.107	• 840	
12	0332	.131	•742	
13	0243	.159	.626	
14	0154	.216	•470	
15	0136	• 230	• 436	
16	0118	• 243	.412	
17	0100	.261	.372	
18	0091	.279	.341	
19	0082	• 285	.329	
20	0073	.319	.293	
21	0064	.333	•275	
22	0055	• 381	.225	
23	0046	•000	.000	
**				

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BUILD II

X/BX = -0.0036		PRESSURE SIDE		
PT	Y/PITCH	TI	V/FSV	
**				
1	.0046	.000	• 000	
2	.0055	• 098	.736	
3	•0064	.077	.817	
4	.0073	.071	.836	
5	.0091	•065	• 860	
6	.0109	• 062	.879	
7	.0127	.059	. 89 0	
8	.0145	.057	• 901	
9	.0180	.055	.915	
10	.0216	.051	• 932	
11	.0305	• 044	• 958	
12	.0 39 5	•036	•977	
13	•0573	•018	1.000	
**				
14	.0752	.01 0	.993	
15	•0 93 0	•009	• 990	
16	.1287	.007	.992	
17	.1645	•007	.992	
18	.2002	• 006	1.000	
19	.289 5	•005	1.003	
20	.3788	•005	1.020	
21	•4680	•004	1.036	
22	.5573	•004	1.057	

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BUILD II

X/BX = 0.0036

PT	Y/PITCH	TI	V/FSV
1	- 5723	- 006	1.037
2	4830	.007	1.040
ร้	- 3937	. 008	1.045
4	3045	.009	1.046
5	2152	.010	1.049
**	• 2 1 52	•••••	1.049
6	-,1259	.014	1.032
7	0902	.018	1.015
8	0723	.025	1.000
9	0545	.058	. 941
10	0455	.087	.865
11	0366	.121	.764
12	0277	.183	.638
13	0188	• 224	.486
14	0143	.265	.402
15	0098	. 325	.323
16	0054	.483	.189
17	0009	.421	.081
18	• 0014	.371	.089
19	.0025	• 300	.256
20	•0036	.135	.607
21	•0059	•070	•814
22	•0080	•074	.848
23	.0125	•054	.875
24	•0170	.050	.893
25	•0259	•044	.921
26	.0348	.038	•952
27	•0438	•031	• 969
28	•0527	.023	• 98 0
**			
29	•0705	.012	• 986
3 0	.1063	•009	• 9 85
31	.1420	• 008	• 991
32	•1777	•008	• 9 89
33	• 2313	.007	• 994
34	• 3205	.007	1.003
35	• 4098	• 005	1.013
36	• 4991	• 005	1.025
37	• 5884	.005	1.038

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BUILD II

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X/BX = 0.011

PT	Y/PITCH	TI	V/FSV
1	- 5762	006	1.017
2	4870	.007	1.022
2	3977	.008	1.020
, ,	• 3084	.000	1.03/
4 5	- 2101	•010	1 031
6	- 1/77	.011	1.021
**	-• 1 4 / /	•012	1.021
7	1120	. 014	1.019
8	0763	.022	1.006
ğ	0584	.050	.952
10	0495	.074	. 888
11	0405	.103	. 800
12	0316	.130	.697
13	0227	.173	. 568
14	0182	.209	.495
15	0137	.254	.413
16	0093	.322	.330
17	0048	. 404	.236
18	0004	.371	.202
19	.0020	.255	.415
20	.0041	.133	.691
21	.0086	.061	.833
22	.0130	.054	.865
23	.0175	.051	.883
24	.0220	•047	.9 04
25	.0264	.045	.915
26	•0309	.041	.9 38
27	•0354	.038	.951
28	.0398	.034	.958
29	•0488	.025	.975
30	•0577	.016	• 9 84
**			
31	•0666	•012	• 988
32	•0755	.011	•9 88
33	•0845	•010	• 989
34	.1023	.010	• 986
35	.138 0	.009	• 986
36	•1738	.008	• 9 86
37	•2273	.007	1.000
38	•3166	• 007	1.009
39	.4059	• 006	1.018
40	•4952	•005	1.032
41	• 5845	• 005	1.041

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BUILD II

X/BX = 0.018

PT	Y/PITCH	TI	V/FSV
1	5798	. 009	1 015
2	4905	.005	1.025
3	4012	.006	1.030
4	3120	.007	1.036
5	2227	.008	1.036
6	1512	.010	1.028
**			
7	1155	.010	1.019
8	0798	.016	1.001
9	0620	.039	.967
10	0530	.065	.911
11	0441	•088	.834
12	0352	.110	.736
13	0263	.146	•628
14	0218	.159	•567
15	0173	•192	•496
16	0129	.2 52	•420
17	0084	• 295	. 349
18	0039	.337	.261
19	0018	.253	.331
20	• 0005	.218	•432
21	•0050	•105	•744
22	.0095	•060	•834
23	.0139	• 054	•86 0
24	•0184	•052	•883
25	•0229	• 046	• 9 01
26	•0273	• 044	•918
27	•0318	• 041	• 929
28	•0363	• 038	•942
29	.0452	•030	• 963
30	•0541	•019	•978
21	0(20		
22	•0030	•013	• 983
32	•0720	•011	• 984
37	• 0809	• 009	•985
35	•0987	•008	• 985
36	•1343 1702	•007	• 984
37	• 1/02	•007	• 986
38	• 2230	•007	• 993
30	• 21 20	• 006	1.002
40	• 4023	• 005	1.011
40	++710 5800	•005	1.021
T 4	• 3007	•005	1.033

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BUILD II

X/BX = 0.029

PT	Y/PITCH	TI	V/FSV
1	5846	• 005	1.006
2	4954	•005	1.013
3	4061	.005	1.020
4	3168	.007	1.021
5	2275	.007	1.030
**			
6	1561	• 009	1.019
7	1204	011	1.007
8	0846	.013	.991
9	0668	•024	.973
10	0579	• 042	.9 40
11	0489	•074	•864
12	0400	.105	.773
13	0311	.138	•657
14	0266	.176	• 588
15	0221	.218	• 524
16	0177	• 244	•460
17	0132	.281	• 398
18	0088	.284	.341
19	0043	• 223	.376
20	.0002	.180	• 574
21	•0046	• 094	•785
22	.0091	•059	•852
23	.0136	• 052	.874
24	•0225	.047	.918
25	• 027 0	•044	.933
26	• 0404	•033	•967
27	• 0493	•023	• 980
28	•0582	•015	• 989
**			
2 9	.0671	•010	•990
30	.0761	•007	• 992
31	.0939	•007	• 990
32	•1296	•007	•992
33	•1654	•007	• 996
34	.2189	•006	1.002
35	.3082	.006	1.008
36	.3975	•006	1.016
37	• 4868	•005	1.027
38	• 5761	•005	1.039

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BUILD II

X/BX = 0.057

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No. of the local distance of the local dista

PT	Y/PITCH	TI	V/FSV
I	5795	.003	1.007
2	4902	.003	1.013
3	4009	.003	1.017
4	3116	.004	1.016
5	2223	.005	1.015
6	1509	.006	1.011
7	1330	.007	1.010
8	1152	.007	1.006
**			
9	0884	.009	1.002
10	~.0795	.010	.999
11	~. 0705	.011	• 996
12	0616	.014	•990
13	0527	.028	•977
14	0438	•054	.929
15	0348	.091	•846
16	0304	.101	.799
17	 025 9	.119	.746
18	0214	.148	•687
19	0170	.167	.683
20	0125	.193	• 567
21	0080	.203	.518
22	0036	.188	.481
23	•0009	.191	.473
24	• 0054	.132	• 536
25	• 0098	.128	•635
26	.0143	.103	•767
27	•0188	•071	•846
28	.0277	,041	.913
29	.0366	•034	.937
30	•0455	•028	•961
31	.0634	.012	•986
**			
32	.0813	•006	• 992
33	•1170	•004	•994
34	.1348	.004	• 993
35	• 2241	•003	.994
36	.3134	.003	1.000
37	•4027	.002	1.005
38	• 4920	.003	1.013
39	•5813	.003	1.018
40	•6705	•003	1.021

BUILD II

X/BX = 0.115

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PT	Y/PITCH	TI	V/FSV
1	-, 5973	.003	1.016
2	5080	.003	1.018
3	-,4188	.004	1.019
4	-, 3295	.005	1.019
5	2402	.005	1.020
6	-, 1687	.007	1.015
**			
7	-,1330	•007	1.009
8	1152	•007	1.003
9	0973	•008	.995
10	0884	•008	.990
11	0795	.010	• 988
12	0705	•015	•982
13	0616	.024	•966
14	0527	•047	•938
15	0438	.071	.881
16	0393	•084	•856
17	~.0348	.102	.816
18	0304	•114	•772
19	-,0259	.125	.734
20	0214	.136	.693
21	0170	.138	•653
22	0125	.136	•625
23	0080	.127	• 609
24	0036	.122	•614
25	.0009	•129	•644
26	•0054	.130	•697
27	.0098	•119	•757
28	.0143	•099	.819
29	.0188	•075	•865
30	.0277	•049	•915
31	.0366	• 040	•941
32	•0455	.031	• 9 65
33	•0545	•022	•978
34	•0634	.013	•986
**		• • ·	
35	.0723	•008	•990
36	.0812	•005	• 992
37	.0991	.004	•991
38	.1170	•004	• 991
39	.1527	•004	•991
40	• 2062	•003	•992

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BUILD II

X/BX = 0.115

PT	Y/PITCH	TI	V/FSV
41	• 2955	.003	• 998
42	• 3848	.003	1.002
43	.4741	•003	1.008
44	• 5634	.003	1.015

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BUILD II

X/BX = 0.229

PT	Y/PITCH	TI	V/FSV
1	- 5795	. 004	1.010
2	4902	.004	1.007
วิ	4009	. 004	1.007
4	3116	.004	1.007
5	2223	.005	1.005
6	- 1688	.005	1.006
7	1330	.006	1.005
8	-, 1152	.007	1.002
ğ	0973	.008	1.001
10	0884	.010	1.002
iĭ	0795	.014	1.003
**			
12	0705	.027	1.000
13	0616	•052	•976
14	0527	•077	•933
15	0438	,103	•877
16	0393	,112	•842
17	0348	.118	.810
18	0304	.123	.785
19	0259	.126	•756
20	0214	.123	•728
21	0170	.120	•708
22	0125	•114	•694
23	0080	. 109	• 690
24	0036	.108	•697
25	•000 9	.114	.714
26	•0054	.112	.741
27	.0098	.113	•774
28	.0188	•0 9 4	• 856
29	.0277	•068	•918
30	•0366	•045	• 956
31	.0455	•02 9	•976
32	•0634	.011	• 993
**			
33	.0813	• 006	.993
34	•0991	.005	• 991
35	.1348	•004	• 989
36	•1795	• 005	• 989
37	.2241	• 004	•990
38	.3134	• 004	•991
39	• 4027	.004	•994
40	•4 9 20	• 004	• 996
41	•5813	.004	• 998
42	.6705	.003	• 997

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A DESCRIPTION OF THE OWNER OF THE

والقلاب ومحقا متكمه مديد والمعاد ومعالم والمنام والمتحافظ والمتحافظ والمتحاف والمحمد والمحمد والمحمد والمحمد والمحمد

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TABLE 10. WAKE AND BOUNDARY LAYER INTEGRAL PARAMETERS

X/BX	HW/PITCH	δ*/PITCH	θ /PITCH	δ*/θ	Vo/FSV
Hot-Film					
110 C - L I TU	•				
032 (s	.00469	.01116	.00663	1.684	
032 (P	.00088	.00310	.00229	1.355	
032 (s	.00557	.01426	.00892		
032 (*	•) •03092	.03961			
004 (s	.00925	.01582	.00777	2.037	
004 (P	• 00186	.00391	.00219	1.783	
004 (5	6+P) .01111	.01973	.00996		
004 (*	•) •03210	.04062			
.004 (S	.01150	.01523	.00787	1,936	
.004 (F	.00187	.00369	.00238	1.550	
.004 (S	(+P) .01337	.01892	.01025	1.846	
.004 (*	•) •03043	.03565	.01131	3.151	.056
.012 (5	.01365	.01617	.00867	1.865	
.012 (E	2) .00610	.00751	.00339	2.216	
.012 (5	(+P) .01976	.02368	.01206	1,963	
.012 (*	•) •02995	.03297	.01332	2.475	.141
020 /5	c) 016 9 6	.01620	- 00860	1, 885	
.020 (3) .0053 9	- 00688	.00383	1.798	
.020 (1	(+P) .02234	.02308	.01242	1.858	
.020 (*	•) •03228	.03184	.01398	2.279	.162
032 (9	s) 02143	. 01897	. 00923	2.055	
.032 (3	(0214)	.01197	.00529	2.262	
.032 (5	S+P) .03358	.03094	.01452	2.130	1.82
065 (9		01/62	.00845	1.729	
-005 (a	02331	01186	.00714	1.661	
.065 (9	S+P) .03966	.02648	.01560	1.698	.392
120 /6	••••••	00802	00626	1 426	
120 (2) •02000) •0277	01160	00757	1.506	
130 (1	() •U24//	•01140	01382	1 470	562
•120 (5	o⊤rj •U44/0	• 02032	• UI JOZ	1.4/0	• 204

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BUILD I

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BUILD I				
HW/PITCH	δ */PITCH	θ /PITCH	δ*/θ	Vo/FSV
.03594	.01991	.01349	1.476	. 504
.04650	.01731	.01294	1.338	.624
.05276	.01609	.01265	1.272	.705
•05909	.01506	.01230	1.224	.750
.07107	.01461	.01248	1.171	.796
•09042	.01400	.01246	1.124	.850
•06022	.01497	•01230	1.216	.757
•07072	.01378	.01184	1.164	.808
•08955	.01176	.01077	1.092	.855
	HW/PITCH .03594 .04650 .05276 .05909 .07107 .09042 .06022 .07072 .08955	BUILD HW/PITCH δ*/PITCH .03594 .01991 .04650 .01731 .05276 .01609 .05909 .01506 .07107 .01461 .09042 .01400 .06022 .01497 .07072 .01378 .08955 .01176	BUILD I HW/PITCH δ*/PITCH θ/PITCH .03594 .01991 .01349 .04650 .01731 .01294 .05276 .01609 .01265 .05909 .01506 .01230 .07107 .01461 .01248 .09042 .01400 .01246 .06022 .01497 .01230 .07072 .01378 .01184 .08955 .01176 .01077	BUILD I HW/PITCH δ*/PITCH θ/PITCH δ*/θ .03594 .01991 .01349 1.476 .04650 .01731 .01294 1.338 .05276 .01609 .01265 1.272 .05909 .01506 .01230 1.224 .07107 .01461 .01248 1.171 .09042 .01400 .01246 1.124 .06022 .01497 .01230 1.216 .07072 .01378 .01184 1.164 .08955 .01176 .01077 1.092

TABLE 10. WAKE AND BOUNDARY LAYER INTEGRAL PARAMETERS

Notes:

And a state in the best of the second

S = Suction surface boundary layer
P = Pressure surface boundary layer
(*) = Sum of boundary layers + (airfoil thickness or constant velocity
 region)
(?) = Data of questionable accuracy due to probe size
BX = 195.707mm (7.705 in.)
Pitch = 142.240mm (5.6 in.)
TED = 3.6068 mm (0.142 in.)

TABLE 11. WAKE AND BOUNDARY LAYER IN DEGRAL PARAMETERS

BUILD II

and the second second discrete second second second second

X/BX	δ HW/PITC H	$\delta * / PITCH$	θ/PITCH	δ*/θ	Vo/FSV
Hot-Film					
029 (S)	.00504	.01514	.01029	1.471	
029 (P)	.00061	.00460	.00369	1.246	
029 (S+I	P) .00565	.01974	.01398		
029 (*)	.01494	•02 9 03			
0036 (S)	.01242	.01803	.01020	1.768	
0036 (P)	.00061	.00331	.00263	1.261	
0036 (S-	+P) .01303	.02113	.01283		
0036 (*)	•02230	•03042			
.0036 (S	.02106	.02279	.01081	2.108	
.0036 (P)	•00426	.00744	.00372	2.002	
.0036 (S-	+P) .02532	.03023	.01453	2.081	.081
.011 (S)	•02462	.02220	.01096	2.024	
.011 (P)	.00377	•00663	.00449	1.474	
.011 (S+1	P) .02839	•02882	.01546	1.865	• 202
.018 (S)	.02255	.01968	.01129	1.743	
.018 (P)	.00731	• 0 086 4	.00540	1.602	
.018 (S+F	•02986	.02833	.01669	1.698	.262
.029 (S)	.02335	•01774	.01070	1.659	
.029 (P)	•010 98	.01003	.00604	1.659	
.029 (S+I	.03432	.02777	•01674	1.659	.341
.057 (S)	.02607	.01508	.00966	1.561	
.057 (P)	.01236	.00859	• 00594	1.446	
.057 (S+I	P) .03843	.02367	.01560	1.517	.473
. 115	.02562	.01198	.00909	1.317	
.115	.02127	.00986	.00726	1.357	
.115	• 04689	.02184	.01636	1.335	.609
.229	.03169	•00998	.00774	1.290	
.229	.02562	.00845	.00658	1.283	
.229	.05731	.01843	.01432	1.287	.69 0

X/BX	HW/PITCH	δ*/PITCH	θ /PITCH	δ*/θ	Vo/FSV
Kiel					
•229 •344 •573 1•031	.05506 .06613 .08360 .09600	.01650 .01575 .01588 .01217	.01313 .01371 .01371 .01111	1.256 1.209 1.158 1.096	.713 .765 .813 .877
Five Hole					
.344 .573 1.031	.06473 .08001 .10010	.01454 .01418 .01351	.01223 .01234 .01223	1.188 1.149 1.105	.781 .826 .867

TABLE 11. WAKE AND BOUNDARY LAYER INTEGRAL PARAMETERS

BUILD II

Notes:

No. of Lot of Lo

(S)	=	Suction side boundary layer
(P)	=	Pressure side boundry layer
(*)	×	Sum of boundary layers + TED
BX	=	221.539mm (8.722 in.)
Pitch	=	142.240mm (5.60 in.)
TED	=	1.3208mm (0.052 in.)

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LIST OF SYMBOLS

AVDR	Axial velocity density ratio = streamtube inlet height/exit height, H_1/H_2
a,b,m	Constants in data fit equations
BX	Airfoil axial chord
C	Airfoil chord
c _f	Skin friction coefficient
C _{PS}	Static pressure coefficient = $P-P_{SO}/Q_0$
C _{PT}	Total pressure coefficient = $P-P_{TO}/Q_0$
dB	Decibels = 20 LOG ($E/VREF$)
f	Frequency Hz (1/sec)
FSV	Free stream velocity
Е	Linearizer voltage
н	Spanwise streamtube height
M	Mach number
Р	Pressure
рітсн,	Caseade pitch
q	Local dynamic head, $P_T - P_S$
QO	Inlet dynamic head = $P_{TO} - P_{SO}$
Re	Reynolds number = $\frac{VoC}{v}$
S	Strouhal number = $\frac{\text{TED}(f)}{\text{FSV}}$
TED	Trailing edge diameter
TI	Turbulence intensity
υ +	Velocity to friction velocity ratio
U	Friction velocity = <u>wall shear stress</u> density
v	Velocity

v _D	Velocity deficit = $\frac{FSV - V}{FSV}$
VREF	Reference voltage
X	Axial coordinate, defined in text
у	Pitchwise coordinate, defined in text
Y +	Nondimensional pitchwise distance = $\underline{Y \cdot U^+}$
a _{CD}	chord angle
β	Cascade flow angle
δ	Boundary layer or wake thickness parameter
δ*	Displacement thickness
	Spanwise flow angle (degrees)
THETA, YAW	Yaw angle (degrees) defined in text
	Momentum thickness
θ	Normalized pitchwise distance = Y / δ_{HW}
η	Kinematic viscosity
ν	Cascade loss coefficient,
ω	
Subscripts	Wake center line
CL	Half width (see wake nomenclature)
HW	Upstream cascade reference position or
0	Upstream of cascade
1	Downstream of cascade
2	Static
S	Total
Т	

Superscripts

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Time average.

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