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Comparison of Analytical and Experimental Performance of a Wind-Tunnel Diffuser Section

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COMPARISON OF ANALYTICAL AND EXPERIMENTAL PERFORMANCE OF A WIND-TUNNEL DIFFUSER SECTION

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SUMMARY

Wind Tunnel Diffuser performance is evaluated by comparing experimental data with analytical results predicted by an one-dimensional integration procedure with skin friction coefficient, a two-dimensional interactive boundary layer procedure for analyzing conical diffusers, and a two-dimensional, integral, compressible laminar and turbulent boundary layer code. Pressure, temperature, and velocity data for a 3.25° equivalent cone half-angle diffuser (37.3 in., 94.742 cm outlet diameter) was obtained from the one-tenth scale Altitude Wind Tunnel modeling program at the NASA Lewis Research Center. The comparison is performed at Mach numbers of 0.162 (Re-3.097×10^6), 0.326 (Re-6.2737×10^6), and 0.363 (Re-7.0129×10^6). The Reynolds numbers are all based on an inlet diffuser diameter of 32.4 in., 82.296 cm, and reasonable quantitative agreement was obtained between the experimental data and computational codes.

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INTRODUCTION

The use of experimental data to verify computational models is highly desirable in a research environment. Many computational models for analyzing diffuser sections have been developed at Lewis, however before these computational models can be used with confidence as design and analysis tools, they must be verified with experimental data. The modeling of the modified Altitude Wind Tunnel (AWT) at Lewis provided a unique opportunity to verify these computational models with experimental data. The proposed rehabilitation of the AWT required the use of these models to analyze the flow in the crossleg diffuser section designed for the tunnel. A schematic of the proposed tunnel and its capabilities are presented in figure 1 and and detailed descriptions of the tunnel can be found in references 1 to 3. The comparison of the experimental data gathered from the 0.1 scale AWT modeling program and analytical performance predicted by an one-dimensional integration procedure with skin friction coefficient, a two-dimensional interactive boundary layer procedure for analyzing flows in conical diffusers, and a two-dimensional, integral, compressible laminar and turbulent boundary layer code is presented in this paper.

NOMENCLATURE

Cp pressure recovery coefficient

M Mach number

R radius

Re Reynolds number

U velocity

X axial distance

δ^* displacement thickness

Subscripts

c centerline

i inlet

APPARATUS and PROCEDURE

Test Facility

The 0.1 scale test facility is described in detail in reference 4. A photograph and schematic of the facility are shown in figures 2 and 3 respectively. Room air enters the bellmouth and passed through a honeycomb flow straightener and two one-diameter-long (D = 82.296 cm) spool pieces before reaching the crossleg diffuser. The air was then turned by the corner vanes whereupon it flowed through the variable guide vane assembly and three spool pieces before exhausting through a choked nozzle-plate assembly to the central altitude exhauster system. The choked-plate assembly was used for flow control. It included a series of six removable plates plus one fixed plate arranged in the form of a converging nozzle. This assembly of plates provided seven specific flow rates between 35.38 and 81.65 kg/sec. The flow straightener was an aluminum honeycomb with a hexagonal cell pattern. The distance across the flats was 0.95 cm and the length was 7.08 cm. The crossleg diffuser was designed to connect corner 1 with corner 2, thus forming the high-speed crossleg of the wind tunnel.

INSTRUMENTATION

To determine the overall performance of the diffuser, diametrical and boundary layer rakes (fig. 4) for total pressure and temperature measurement were used at the diffuser upstream and downstream measurement stations (fig. 5). The diametrical rakes could be moved to four positions around the circumference (0°, 315°, 270°, and 225° clockwise looking downstream). Outer wall static pressure taps were located at 0°, 90°, 180°, and 270° looking downstream and the axial locations are shown in figure 6. All static and total pressure measurements were recorded on individual transducers which were calibrated just prior to each reading. The temperatures were determined from Chromel-constantan thermocouples using a floating-point temperature reference.

TEST PROCEDURE

For a given vane configuration, a particular choked plate was installed to set the desired airflow. The diffuser diametrical rake was positioned in the instrument ring either at 0° or 225° (clockwise looking downstream) and the boundary layer rake 90° from the diametrical rake at the upstream station. The downstream rake was then positioned at either 225° or 0° (opposite the upstream rake position) and the boundary layer rake was positioned at 90° to the diametrical rake. Data were recorded at this rake position, the facility was then shutdown and the boundary layer and diametrical rakes were manually indexed 45° to the next position. The flow point was then reestablished and data were then recorded at this position. This procedure was then repeated until data were recorded at the four boundary layer and diametrical rake positions. The upstream and downstream rakes were rotated in opposite directions to minimize the effect of the upstream wake on the downstream pressure measurement. In the data reduction program, the circumferential location of the boundary layer and diametrical rakes were matched. For the data presented herein, the measurements of all circumferential locations were averaged to obtain a value of total pressure at each radial position. The total pressure varied around the circumference of the diffuser and this can be attributed to the effect of the corner downstream of the diffuser on the flow upstream.

ANALYSIS

The computational models used in this analysis are described in references 5 to 7. An one-dimensional procedure with skin friction coefficients can be used to analyze subsonic or supersonic compressible flows in many arbitrary ducts. The two-dimensional interactive boundary layer procedure can be used for analyzing subsonic compressible flows in conical diffusers without centerbodies. A two-dimensional, integral, boundary layer code (BLAYER) can used to analyze compressible laminar or turbulent, subsonic or supersonic flows in ducts and turbomachinery. The diffuser geometry, static pressure distribution along the wall of the diffuser, inlet displacement thickness, inlet shape factor and reference conditions were used as input in the three computational models. The shape factor was obtained by plotting the velocity ratio versus the radial distance over the boundary layer thickness from the experimental data on log-log paper and and obtaining a power law exponent from the slope of these curves. This exponent was then used to determine the inlet shape factors. Also, both of the two-dimensional codes used in this analysis calculate along a normal to the surface for computation of the flowfields. Figure 7 shows a schematic of the coordinates used in the analysis of the diffuser.

RESULTS AND DISCUSSION

The results of this analysis are presented in figures 8 to 10. Figure 8 shows the plot of velocity ratio versus percent span of radius for the diffuser inlet and exit measurement stations. BLAYER and the two-dimensional analysis compare well with the experimental velocity profiles at the inlet, but at the exit both codes calculated slightly fuller profiles. Figure 9 shows the plot of pressure recovery coefficient versus axial distance from the diffuser inlet. The pressure recovery coefficients calculated from the one-and two-dimensional analysis compare favorably with those computed from the experimental data. The one-dimensional analysis compared slightly better, but both codes compare reasonably well. Figure 10 shows the plot of the displacement thickness versus axial distance from the diffuser entrance. Both BLAYER and the two-dimensional analysis calculated higher displacement thicknesses than those computed from the experimental data. Also, the effect of the transition from a straight duct to a conical duct creates a small separation in the flow at the diffuser inlet as shown in figure 9.

CONCLUSIONS

The computational codes used in this analysis compared well with experimental data. The two-dimensional analysis used compared slightly better than BLAYER in the comparison of the velocity profiles and displacement thicknesses. This can be attributed to the axisymmetric curvature correction used in the two-dimensional analysis, which BLAYER does not account for. The one-dimensional analysis used compared slightly better than the two-dimensional analysis, for the comparison of the pressure recovery coefficients, but this can be attributed to artificially matching the skin friction coefficient in this code with the experimental data. A skin friction coefficient computed from the Moody diagram or other appropriate source should be used for a fair comparison. Also, some disagreement in the computational codes with the data can be attributed to both of the two-dimensional codes calculating along a normal to the surface and the data was taken on a radial line.

REFERENCES

1. Abbott, J.A., et al.: Analytical and Physical Modeling Program for the NASA Lewis Research Center's Altitude Wind Tunnel (AWT). AIAA Paper 85-0379, Jan. 1985.

2. Chamberlin, R.: The Altitude Wind Tunnel (AWT) - A Unique Facility for Propulsion System and Adverse Weather Testing. AIAA Paper 85-0314, Jan. 1985.

3. Blaha, B.J.; and Shaw, R.J.: The Altitude Wind Tunnel : Its Role in Advanced Icing Research and Development. AIAA Paper 85-0090, Jan. 1985.

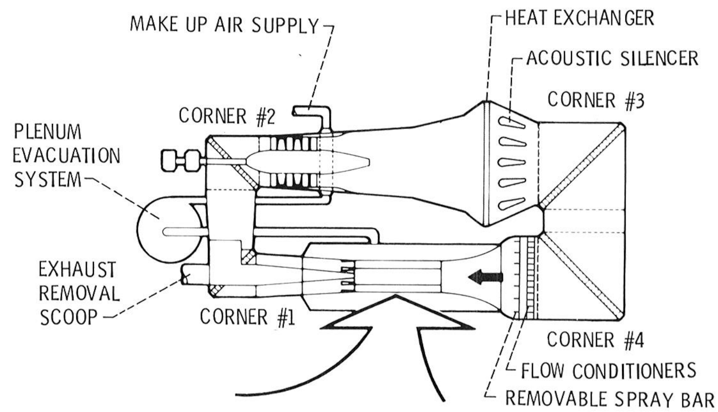
4. Boldman, D.R.; Moore, R.D.; and Shyne, R.J.: Experimental Evaluation of Two Turning Vane Designs for Fan Drive Corner of the 0.1- Scale Model of the NASA Lewis Research Center's Proposed Altitude Wind Tunnel. Proposed NASA TP, 1986.

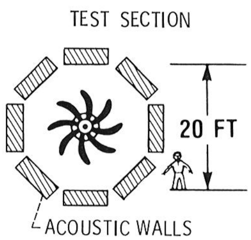
5. McFarland, E.R., Private Communication, May 1986.

6. Schumann, L.F., Private Communication, May 1986.

7. McNally, W.D.: Fortran Program for Calculating Compressible Laminar and Turbulent Boundary Layers in Arbitrary Pressure Gradients. NASA TN D-5681, 1970.

8. Schilicting, H.: Boundary - Layer Theory, 6th Ed., McGraw-Hill, 1968.





CAPABILITIES	
MACH NUMBER	0 TO 0.9 +
ALTITUDE	0 TO 55 000 FT +
TOTAL TEMPERATURE	-40° TO 60 °F
TEST SECTION ACOUSTIC LEVEL	120 dB (OASPL)

Figure 1. - Capabilities of the proposed rehabilitated Altitude Wind Tunnel (AWT).

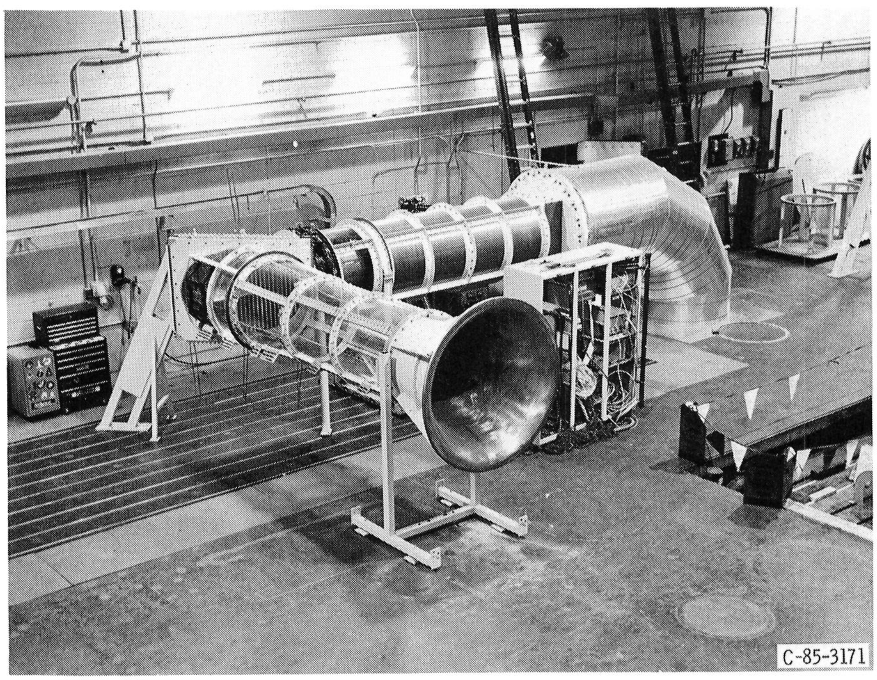


Figure 2. - Photograph of 0.1 scale AWT crossleg diffuser and corner 2 test facility.

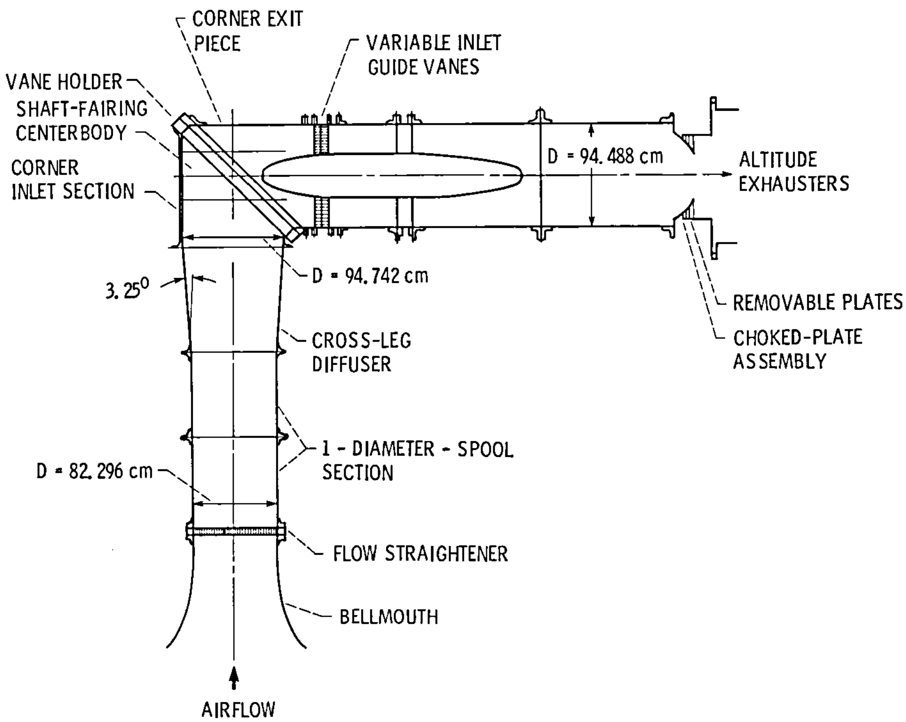
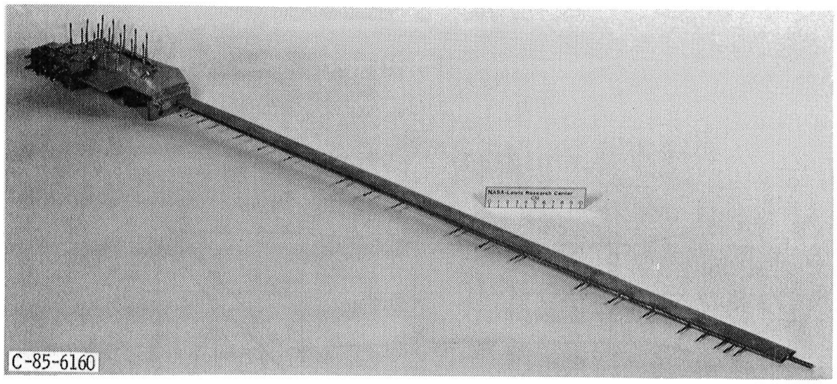
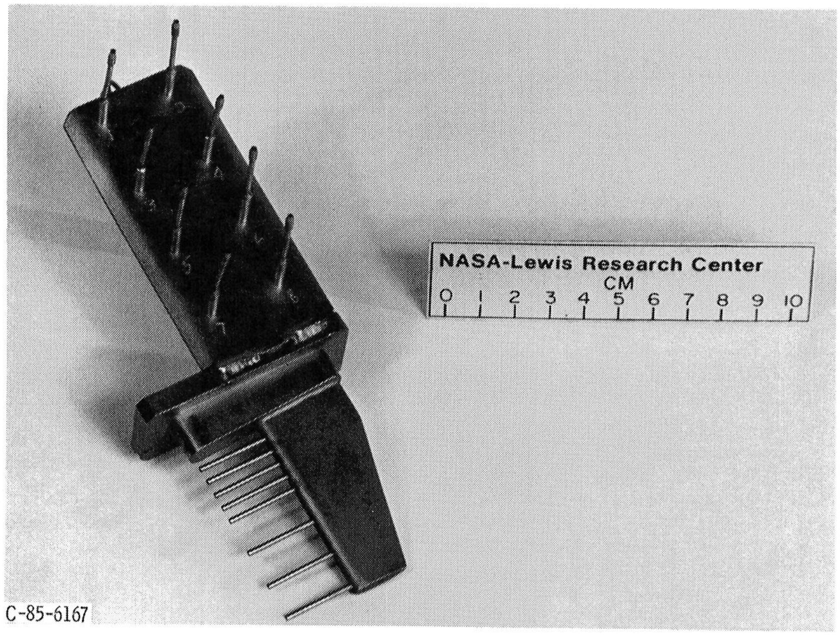


Figure 3. - Schematic of 0.1 scale AWT crosslog diffuser and corner 2 test facility.

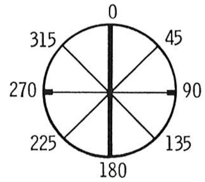


(a) Diametrical rake for total pressure and temperature.



(b) Boundary layer rake for total pressure.

Figure 4. - Instrumentation used in 0.1 scale AWT crossleg diffuser and corner 2 test program.



(LOOKING DOWNSTREAM) RAKES ROTATED TO FOUR CIRCUMFERENTIAL POSITIONS IN 45° INCREMENTS).

Figure 5. - Schematic of instrumentation location for 0.1 scale AWT corner 2 test program.

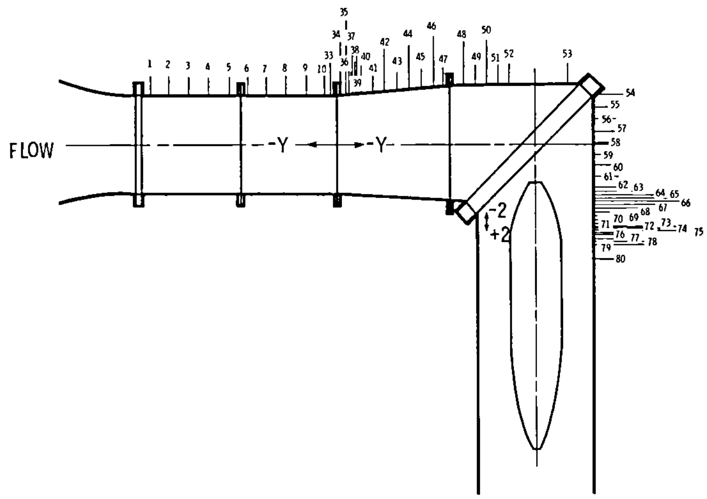


Figure 6. - Static pressure tap locations along wall of the 0.1 scale AWT corner 2 test facility.

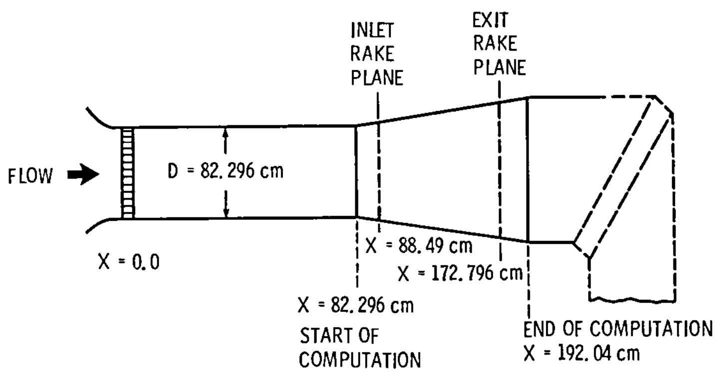
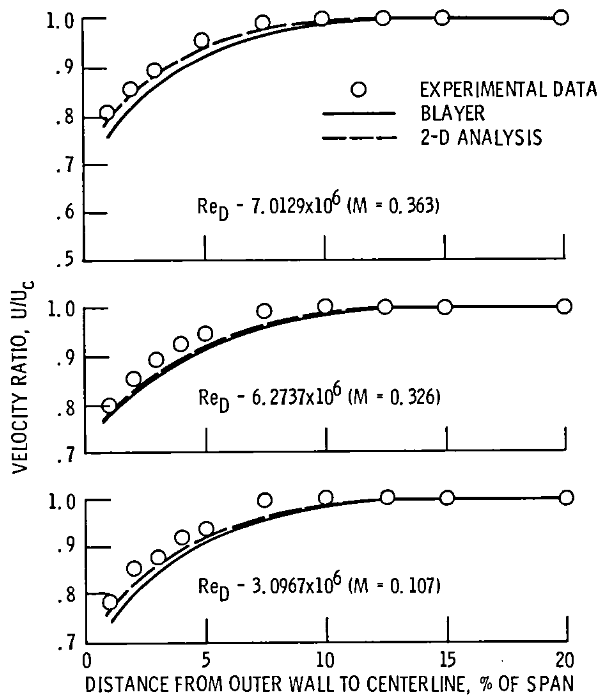
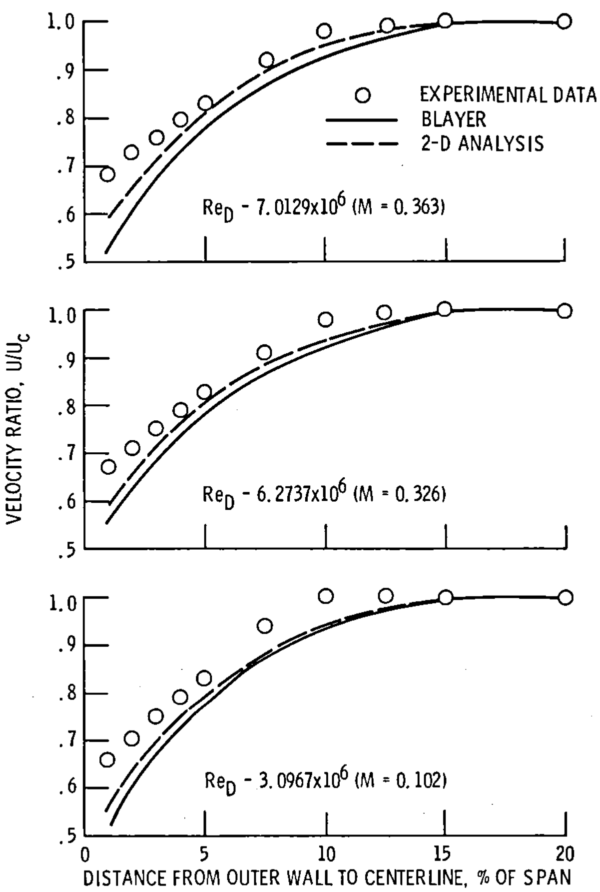


Figure 7. - Schematic of computational coordinates used in analysis of 0.1 scale AWT crossleg diffuser.



(a) Comparison at diffuser inlet.



(b) Comparison at diffuser exit.

Figure 8. - Comparison of analytical and experimental velocity ratios of 0.1 scale AWT crossing diffuser.

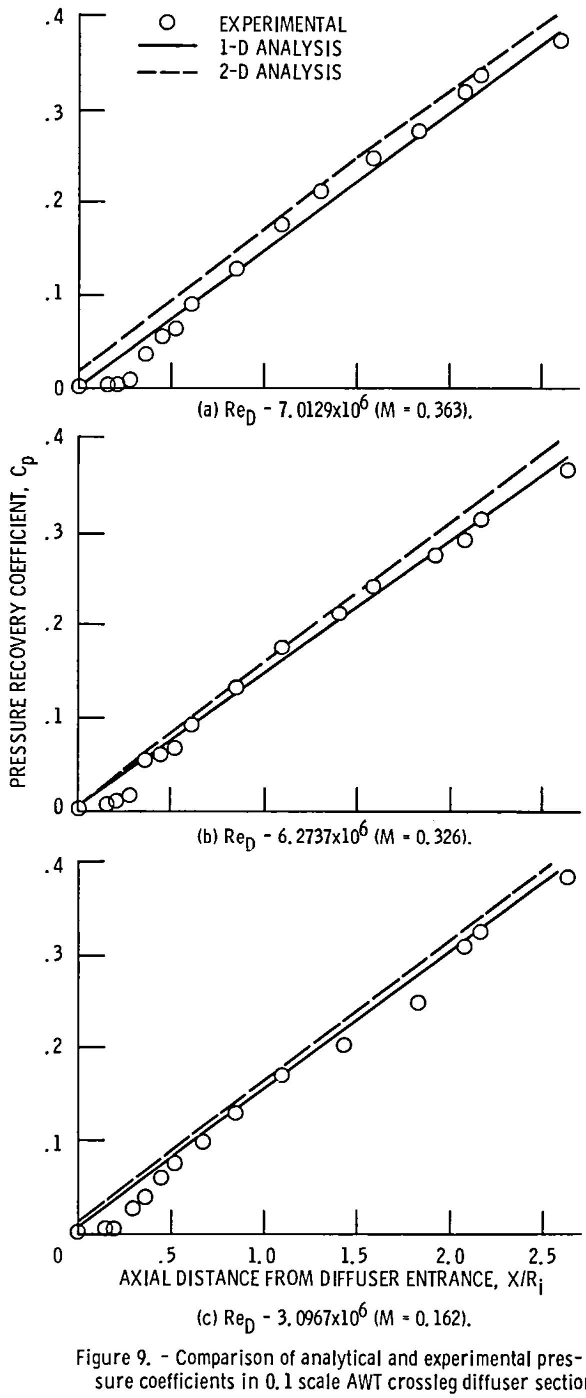


Figure 9. - Comparison of analytical and experimental pressure coefficients in 0.1 scale AWT crossleg diffuser section.

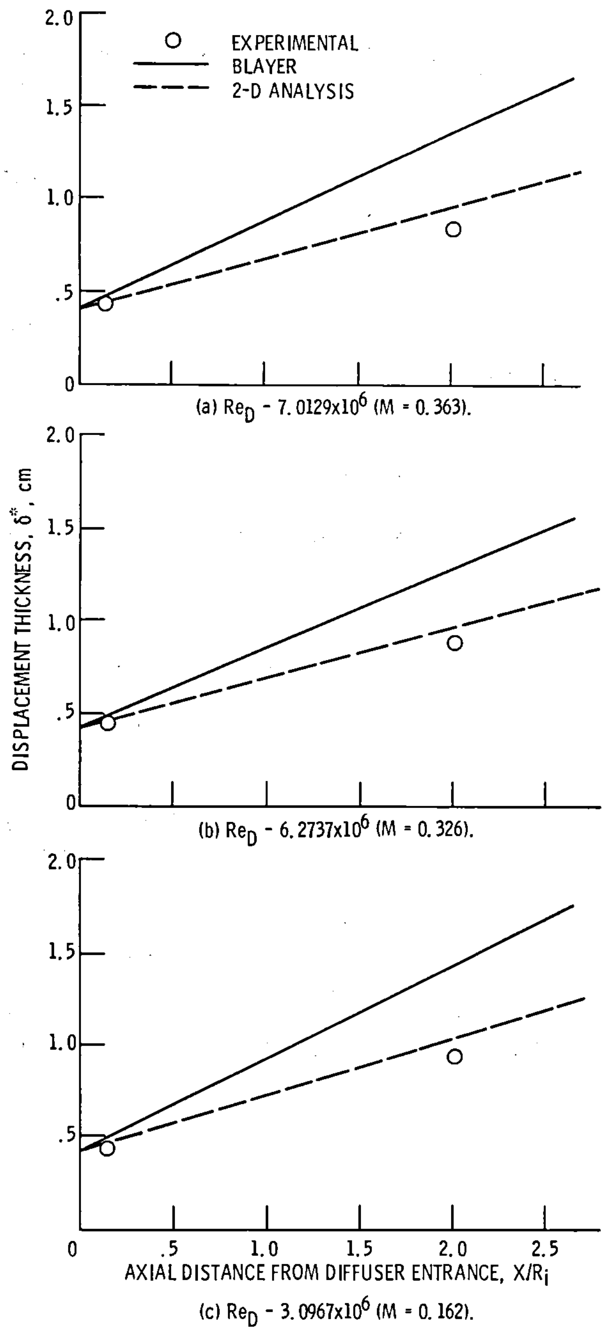


Figure 10. - Comparison of analytical and experimental displacement thicknesses in 0.1 scale AWT crossleg diffuser section.

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17. Key Words (Suggested by Author(s))
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