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EXPERIMENTAL STUDIES ON TAYLOR-GÖRTLER VORTICES

By

G. L. Goglia
Principal Investigator

and

S. M. Mangalam
Co-Principal Investigator

Final Report
For the period May 1, 1984 to February 28, 1985

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Research Grant NAG-1-353
J. Ray Dagenhart, Technical Monitor
TAD-Airfoil Aerodynmamics Branch

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Submitted by the
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Norfolk, Virginia 23508

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EXPERIMENTAL STUDIES ON TAYLOR-GÖRTLER VORTICES

By

G. L. Goglia[1] and S. M. Mangalam[2]

INTRODUCTION

Taylor-Görtler vortices arise in boundary layers along concave surfaces due to centrifugal effects. These counter-rotating streamwise vortices are one of three-known flow instabilities which lead to boundary-layer transition. Coupled with Tollmien-Schlichting waves and cross flow vortices, Taylor-Görtler vortices can trigger early transition to turbulence.

EXPERIMENT

A six-foot chord airfoil model (Fig. 1) was tested in the NASA Langley Low-Turbulence Pressure Tunnel (LTPT). Suction was used to insure attached laminar flow in the test region. The flow pattern was first visualized using a sublimating chemical technique. A fixed, essentially uniform, vortex spacing was observed in the concave zone (Fig. 2). An appreciable decrease in streak-contrast was observed in the accelerating flow region, indicating damping of Görtler vortices in this region, which was later confirmed by flow field measurements with laser velocimetry.

A specialized single axis, three-component laser velocimeter was used to study the flow field in the test region. Typical spanwise distributions of streamwise velocity component in the boundary layer are shown in Fig. 3 for various heights above the model surface. As in previous experiments, the vortex wavelength was preserved in the flow direction, but unlike

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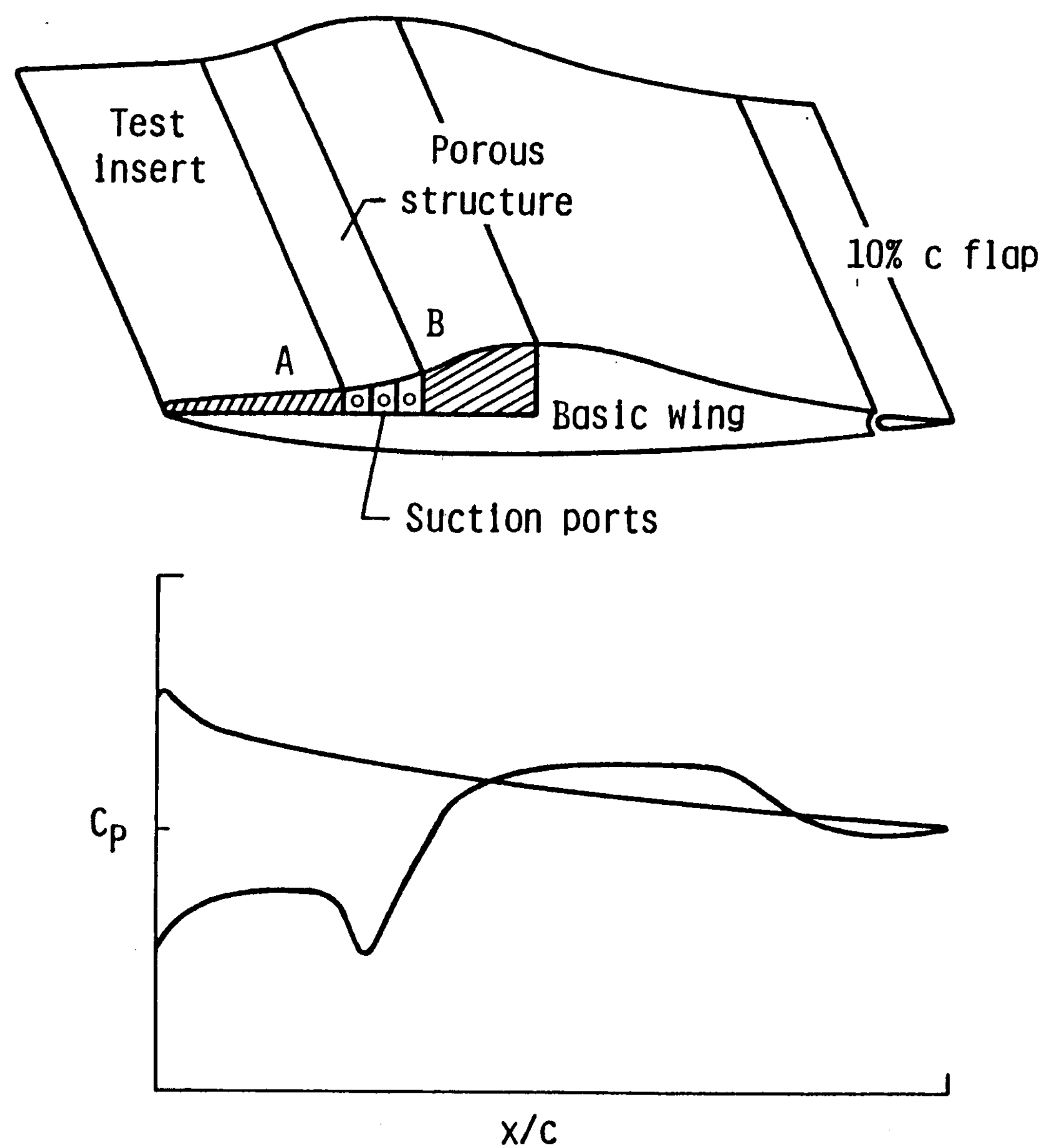
[2] Research Associate,

FIGURE 1. **MODEL SCHEMATIC DIAGRAM AND PRESSURE DISTRIBUTION**



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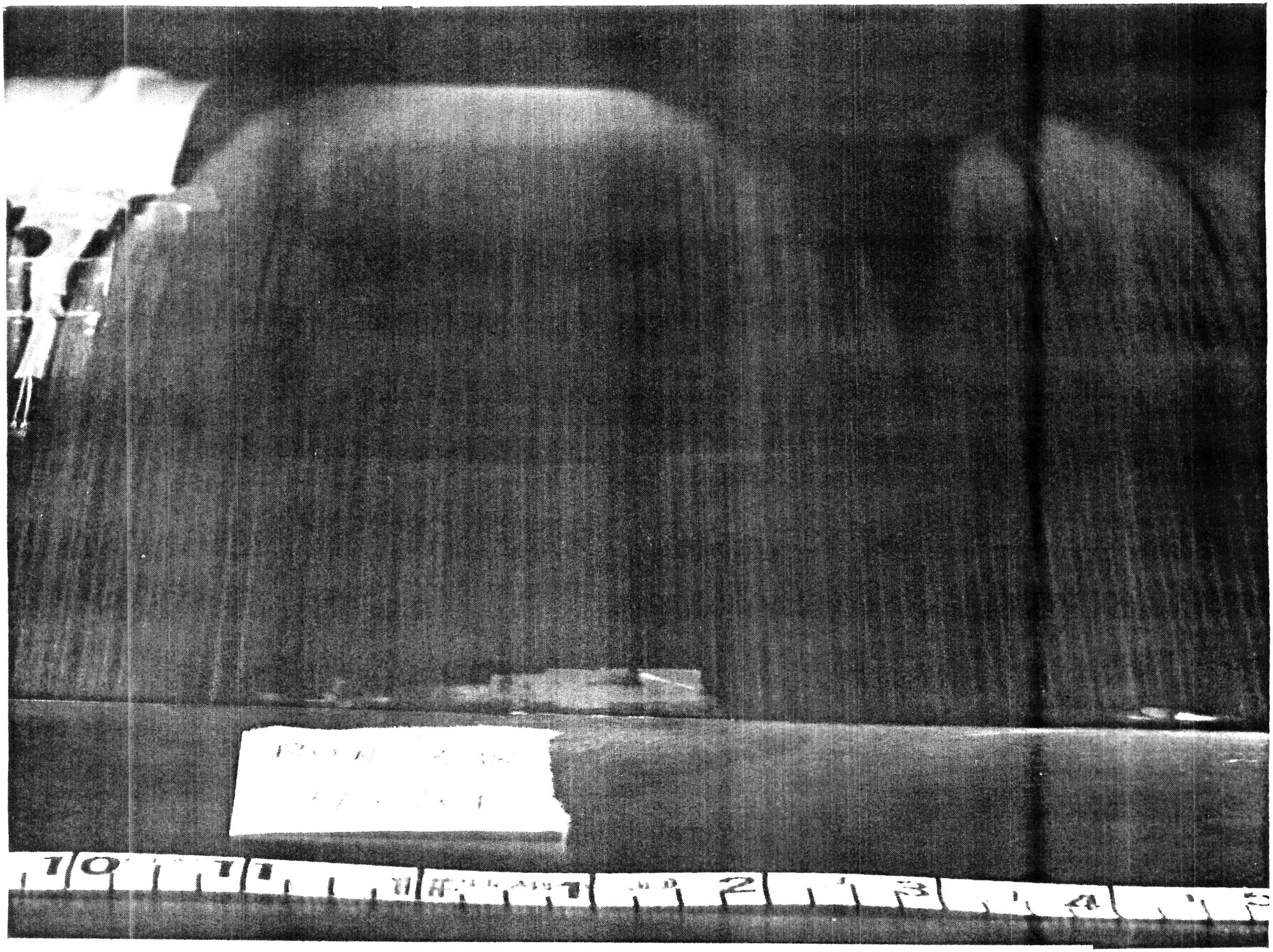


Figure 2. Taylor-Görtler Vortices (Flow Visualization using sublimating chemicals).

earlier experiments the wavelength varied appreciably with Görtler number and followed the trend predicted by linear stability theory. The variation of dimensional wavelength λ and the nondimensional wavelength parameter Λ are shown plotted in Figs. 4 and 5 where they are compared with available theoretical and experimental data.

CONCLUSIONS

1. A fixed, essentially uniform, vortex spacing was observed in the concave zone by both flow visualization and laser velocimeter measurements for each flow condition.
2. Both flow visualization and laser velocimeter measurements show a vortex wavelength which varied with Görtler number in accordance with linear stability theory.
3. A significant, abrupt decrease in streak contrast indicated vortex damping in the convex zone.
4. The velocity measurements showed both disturbance amplification in the concave zone and damping in the following convex zone.

SUMMARY OF ACCOMPLISHMENTS

1. The proposed experiment was successfully conducted.
   - (a) Taylor-Görtler vortices were visualized using sublimating chemicals instead of the smoke-wire technique, with very good results.
   - (b) It was possible to use advanced laser velocimetry instead of hot-wire anemometry to make flow field measurements. This entailed modifications of the airfoil model to accommodate laser optics. This objective was quickly and successfully accomplished. A dedicated computer system was used to record laser velocimeter data

Figure 3. **SPANWISE VARIATION OF STREAMWISE VELOCITY COMPONENT**

$X/C = 0.25 \quad G_M = 29.9 \quad R_C = 1.0 \times 10^6$

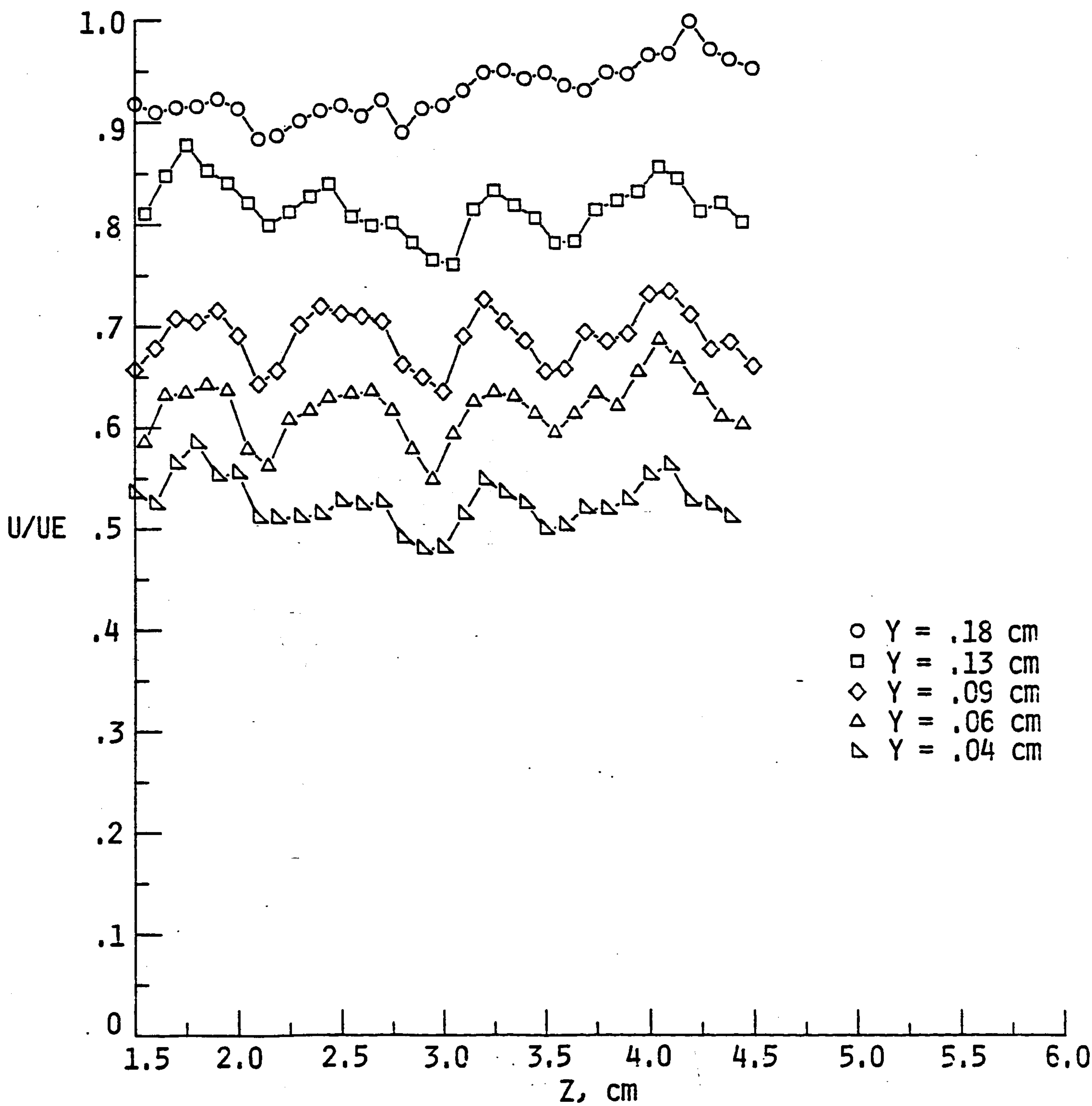
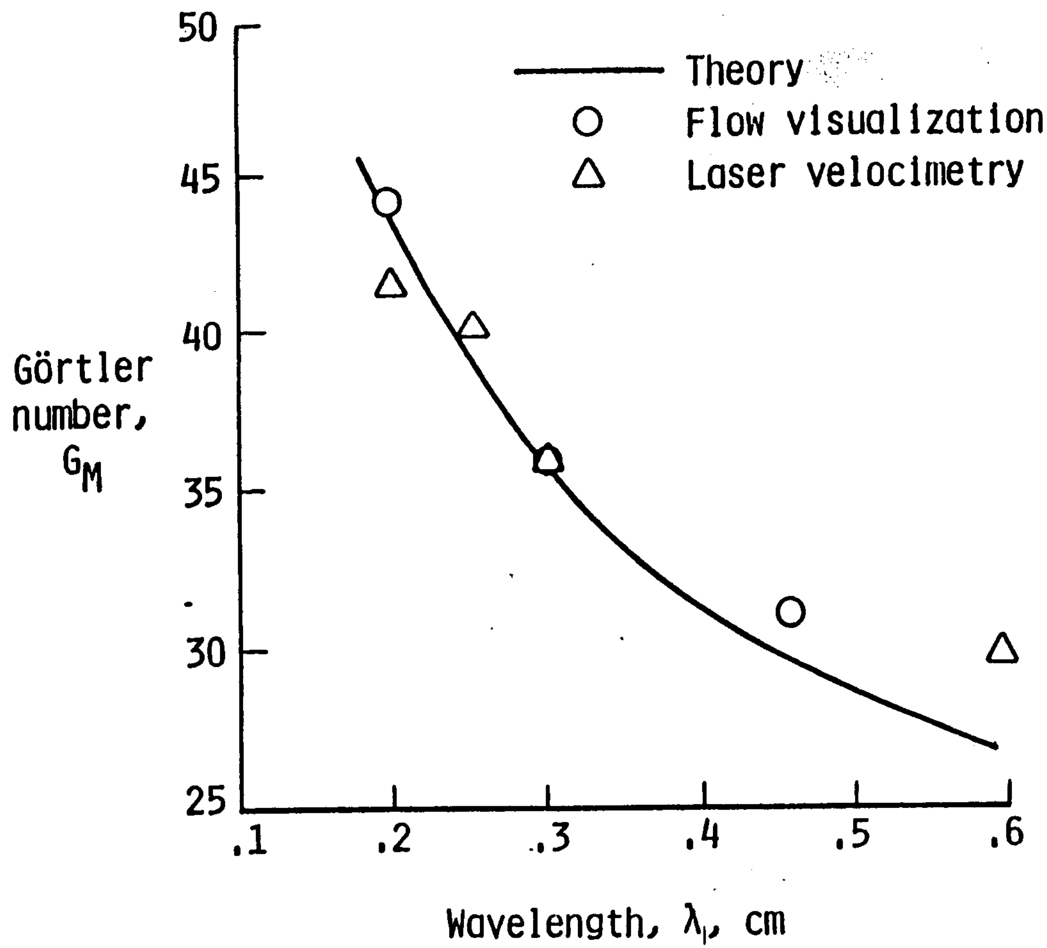


Figure 4. **VARIATION OF DIMENSIONAL WAVELENGTH WITH GÖRTLER NUMBER, COMPARISON WITH THEORY**



VARIATION OF NONDIMENSIONAL WAVELENGTH PARAMETER WITH GÖRTLER NUMBER, COMPARISON WITH THEORY AND OTHER EXPERIMENTS

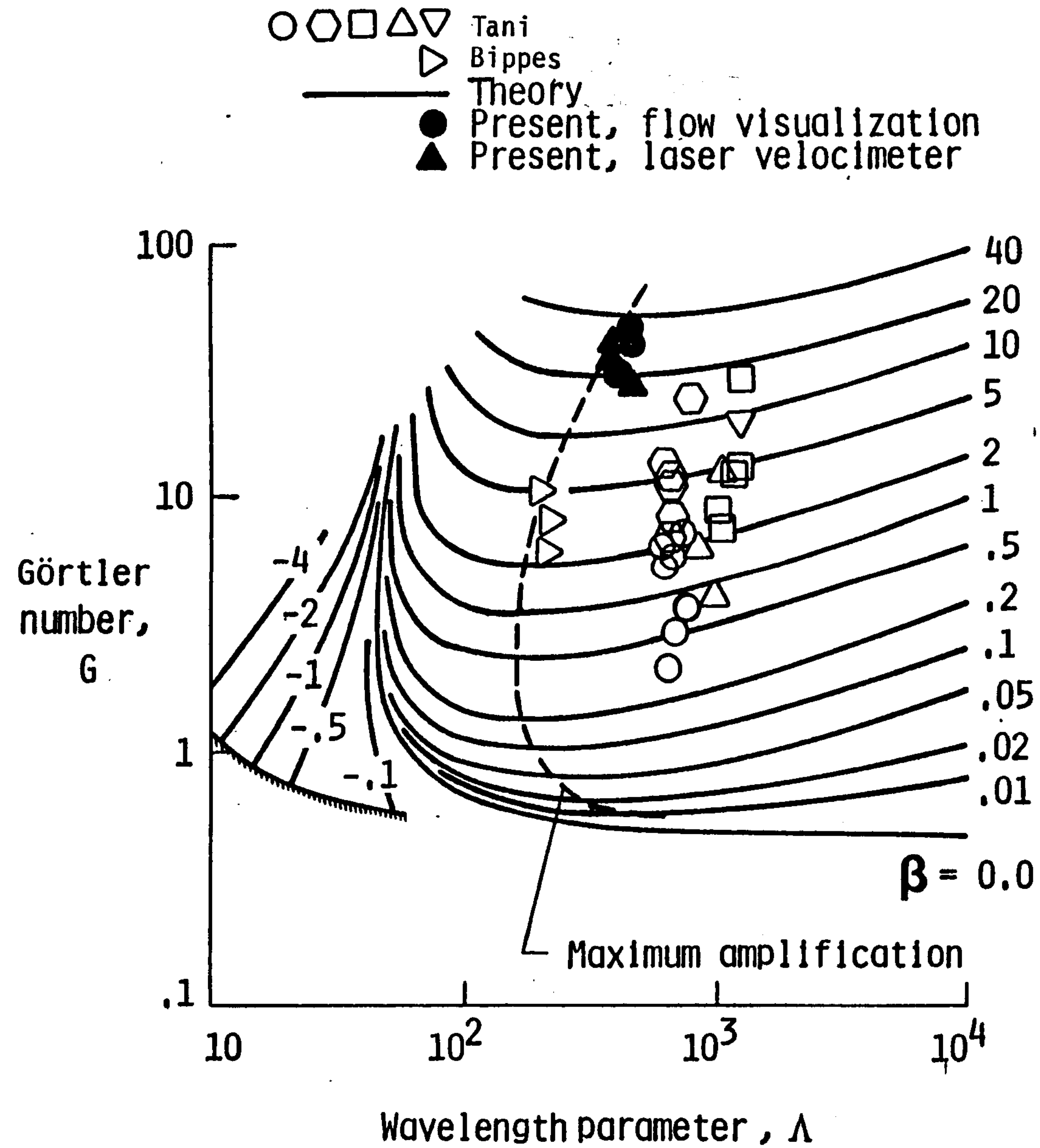


Figure 5

which were later used to compute boundary-layer and Taylor-Görtler vortex parameters. Measurements of all three velocity components by laser velocimetry greatly enhanced the value of the experiment.

2. Highlights and discussions on the experimental results were reported (see Appendix A).

   (a) NASA/Langley Monthly Highlights for May 1984.

   (b) NASA Research and Technology 1984 Annual Report of the Langley Research Center, NASA TM 86321.

   (c) AIAA-85-0491, "The Görtler Instability on an Airfoil," presented at AIAA 23rd Aerospace Sciences Meeting, Jan. 14-17, 1985, Reno, Nevada.

3. NASA/Langley recognized Görtler experiment with Group Achievement Award (see Appendix B) for "Experimentally demonstrating the theoretically-predicted correlation between Görtler number and vortex spacing on an airfoil in the Langley Research Center/Low-Turbulence Pressure Tunnel using advanced measurement techniques," Nov. 8, 1984.

APPENDIX A

HIGHLIGHTS AND DISCUSSIONS ON EXPERIMENTAL RESULTS

Taylor-Görtler Vortex Experiment

Taylor-Görtler (T-G) vortices arise in boundary layers along concave surfaces due to centrifugal effects. These streamwise vortices are one of three known principal sources of flow instability that lead to transition. Earlier investigations of these vortices were conducted in curved channels (internal flow) whereas the theory has been developed mainly for the Blasius-type boundary layer on a curved surface which is an external flow problem. The present experiment is the first of its kind to study the development of T-G vortices on an airfoil with a pressure gradient in the concave region.

A 6-foot chord experimental model is being tested in the Low-Turbulence Pressure Tunnel (LTPT) (see photograph 1). It has a concave region extending from $x/c = 0.175$ to $x/c = 0.275$. Attached laminar boundary-layer flow is insured by means of suction through a 4.5x30-inch perforated titanium panel in the compression portion of the concave region. The suction region is divided into three spanwise suction strips. The suction in each strip is independently controlled by its own needle valve. Tunnel flow parameters, model surface pressures, and suction flow rates are monitored, recorded, and processed by the LTPT data acquisition system. Four hot-film anemometers with oscilloscope displays and strip-chart recorder are used to monitor the boundary-layer flow quality. A five-beam laser velocimeter (LV) system is used to measure the three velocity components in the boundary layer. The flow is seeded with hydrocarbon particles for LV measurements by a particle generator which LTPT personnel redesigned for more efficient operation. LV data are recorded and processed by a dedicated computer system.

The T-G vortices were first visualized by coating the flat-black model surface with a white sublimating chemical coating followed by prolonged exposure to the flow. The streamwise vortices leave alternating light and dark streaks due to the differential shear stress pattern of the vortex layer (see photograph 2). Each pair of light and dark streaks together indicate one wavelength of the counter-rotating vortex layer.

Some previous experiments have shown that the wavelength is almost independent of free-stream velocity indicating that some portion of the experimental apparatus has probably "selected" the wavelength. In the present experiment, the wavelength clearly varies with free-stream velocity (i.e., with Reynolds number and Görtler number) as expected. The variation in wavelength falls within the theoretically predicted range.

Some preliminary LV measurements of the streamwise velocity component are shown in figures 1 and 2. Figure 1 shows the spanwise variation of the velocity at various heights above the model surface. The velocity variation along the span is shown in figure 2 at a given height above the model for several locations along the chord. Data acquisition is still in progress and much data analysis remains to be done.

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May 1984

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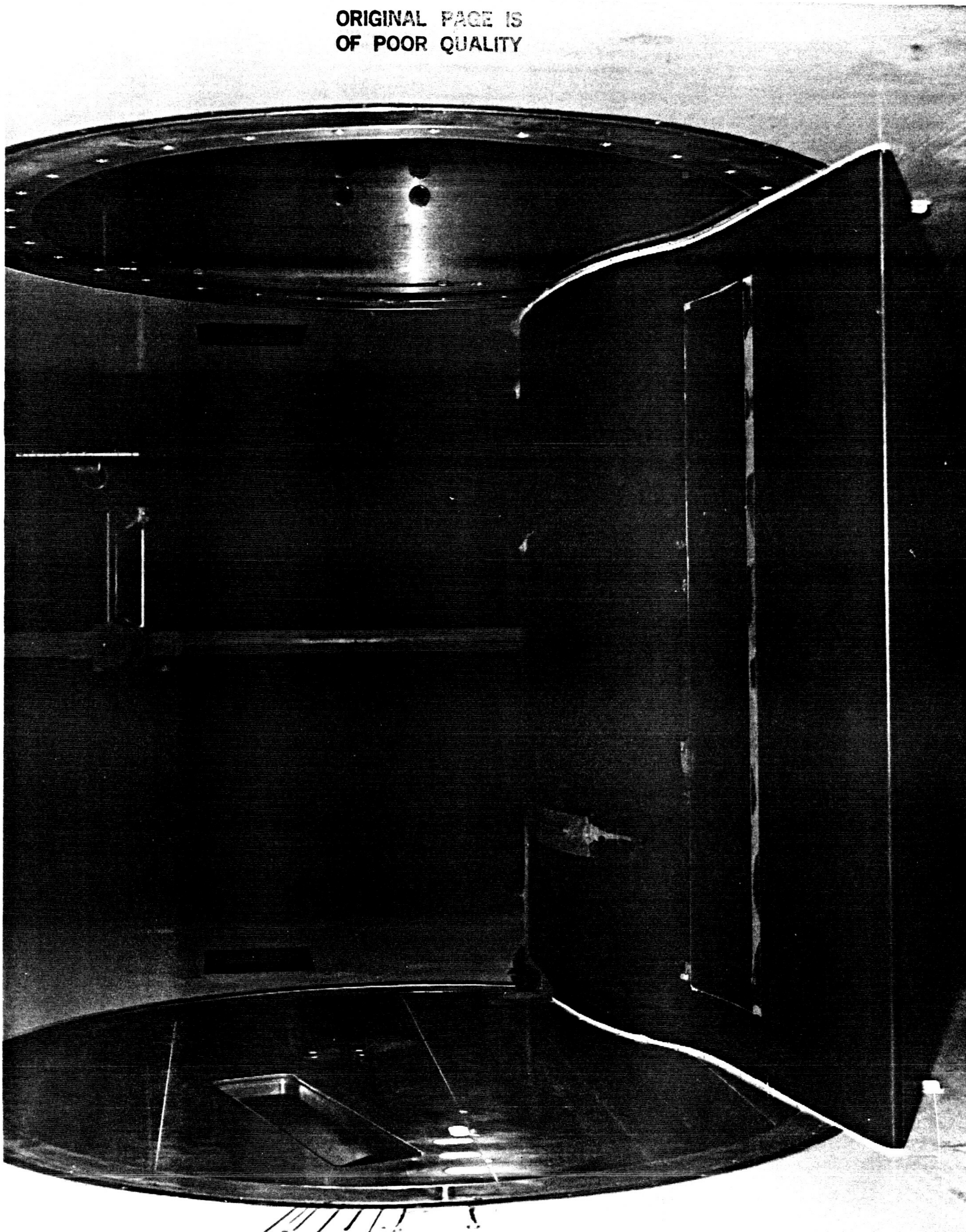

Photograph 1.

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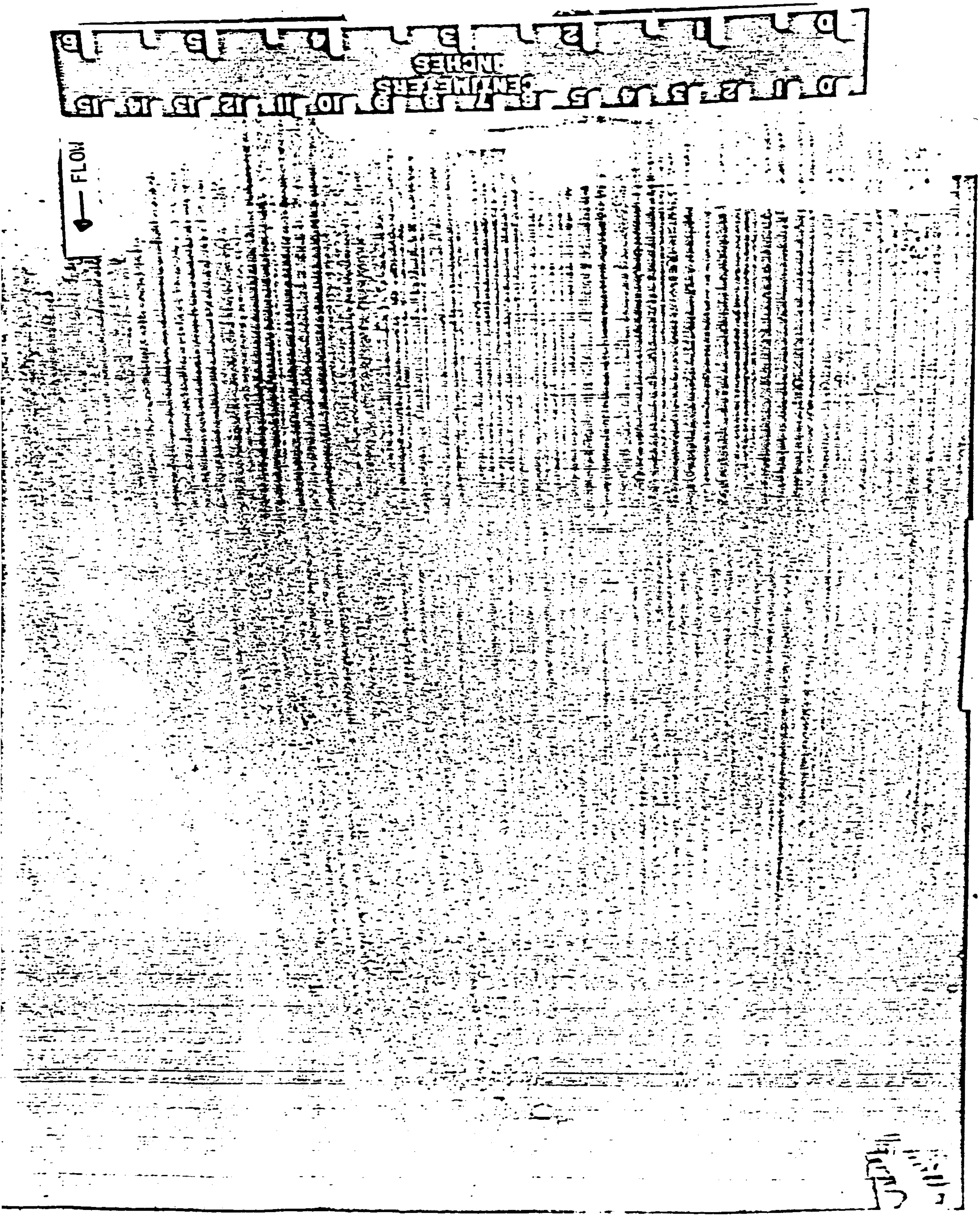


Photograph 2.

TAYLOR - GORTLER VORTEX EXPERIMENT

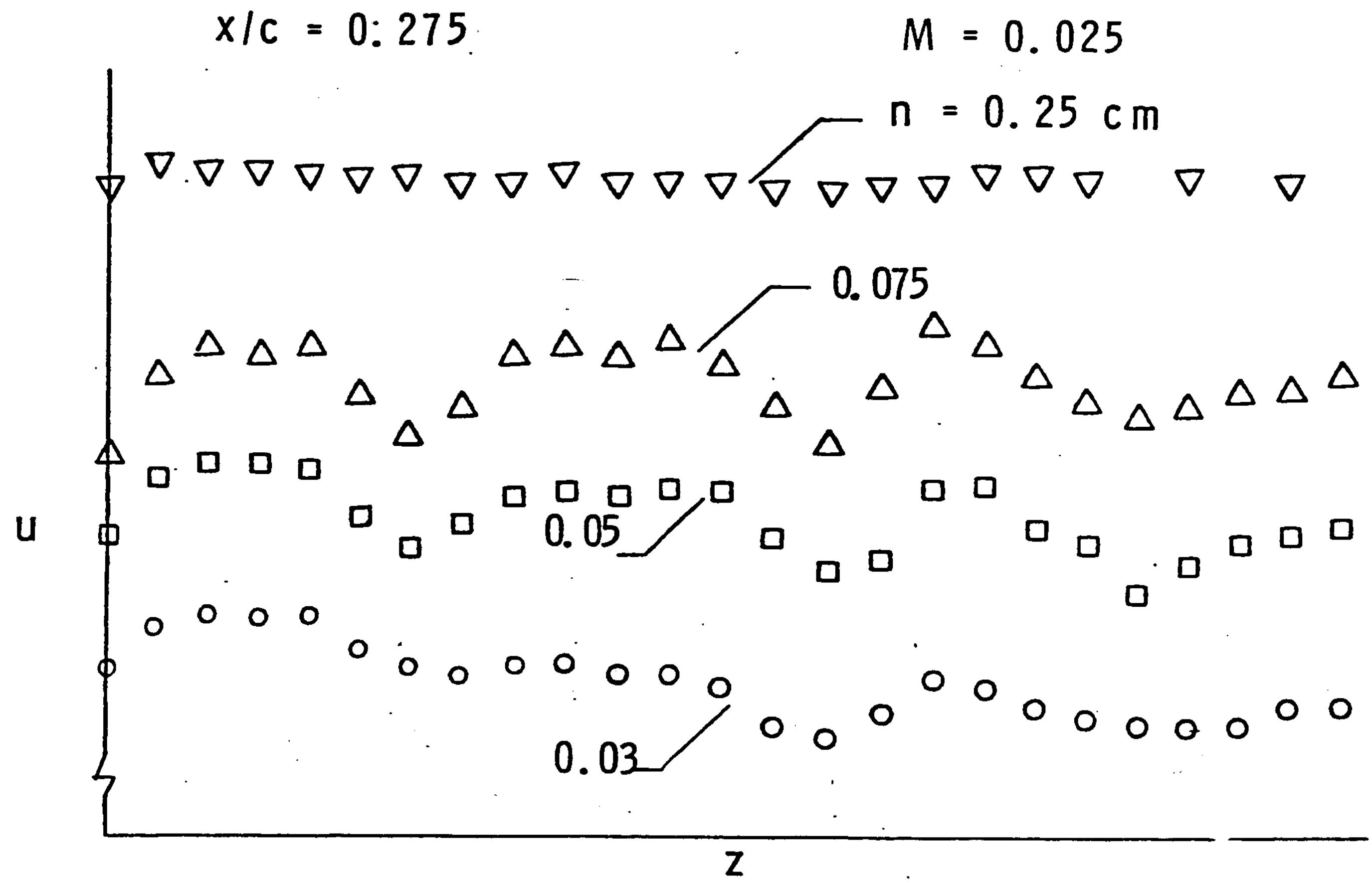


Figure 1:

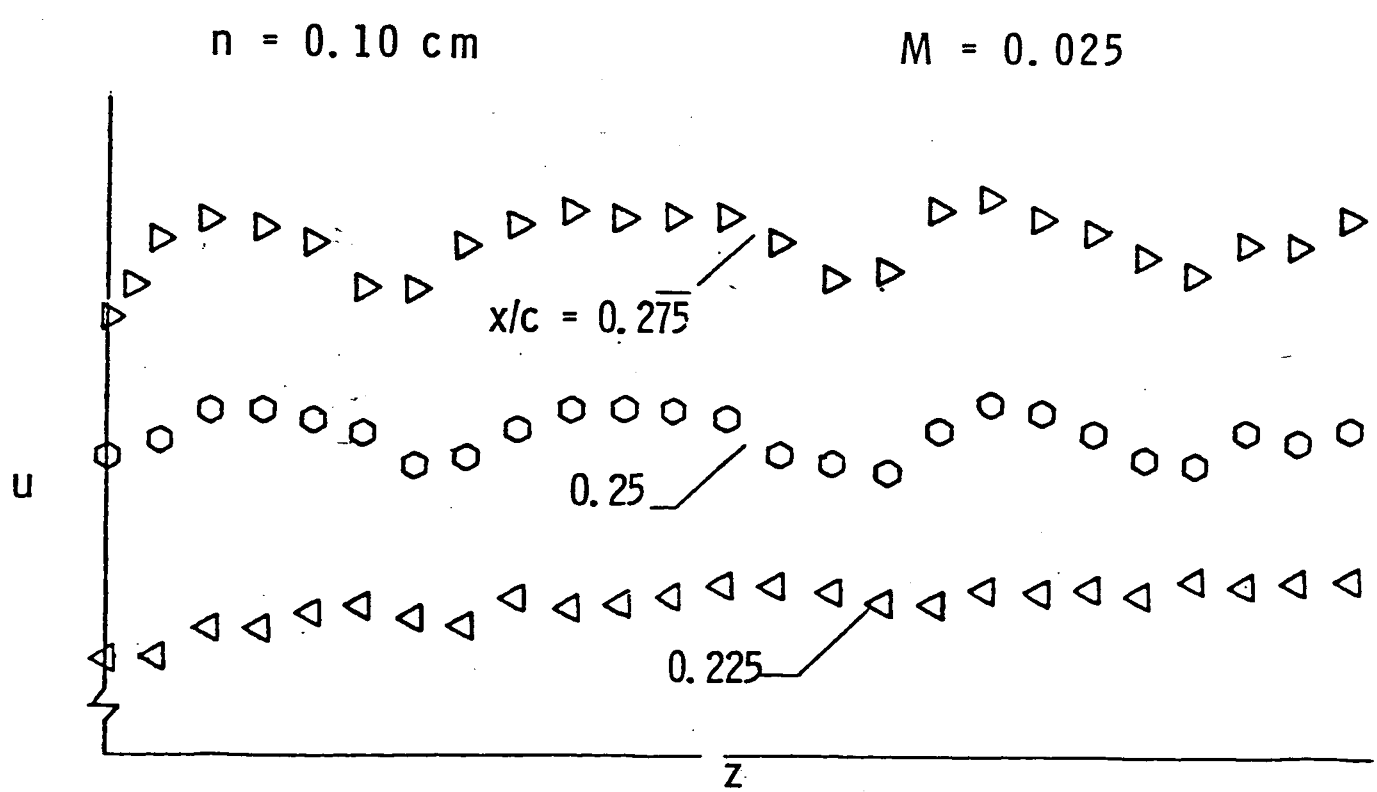


Figure 2.

GÖRTLER VORTEX EXPERIMENT

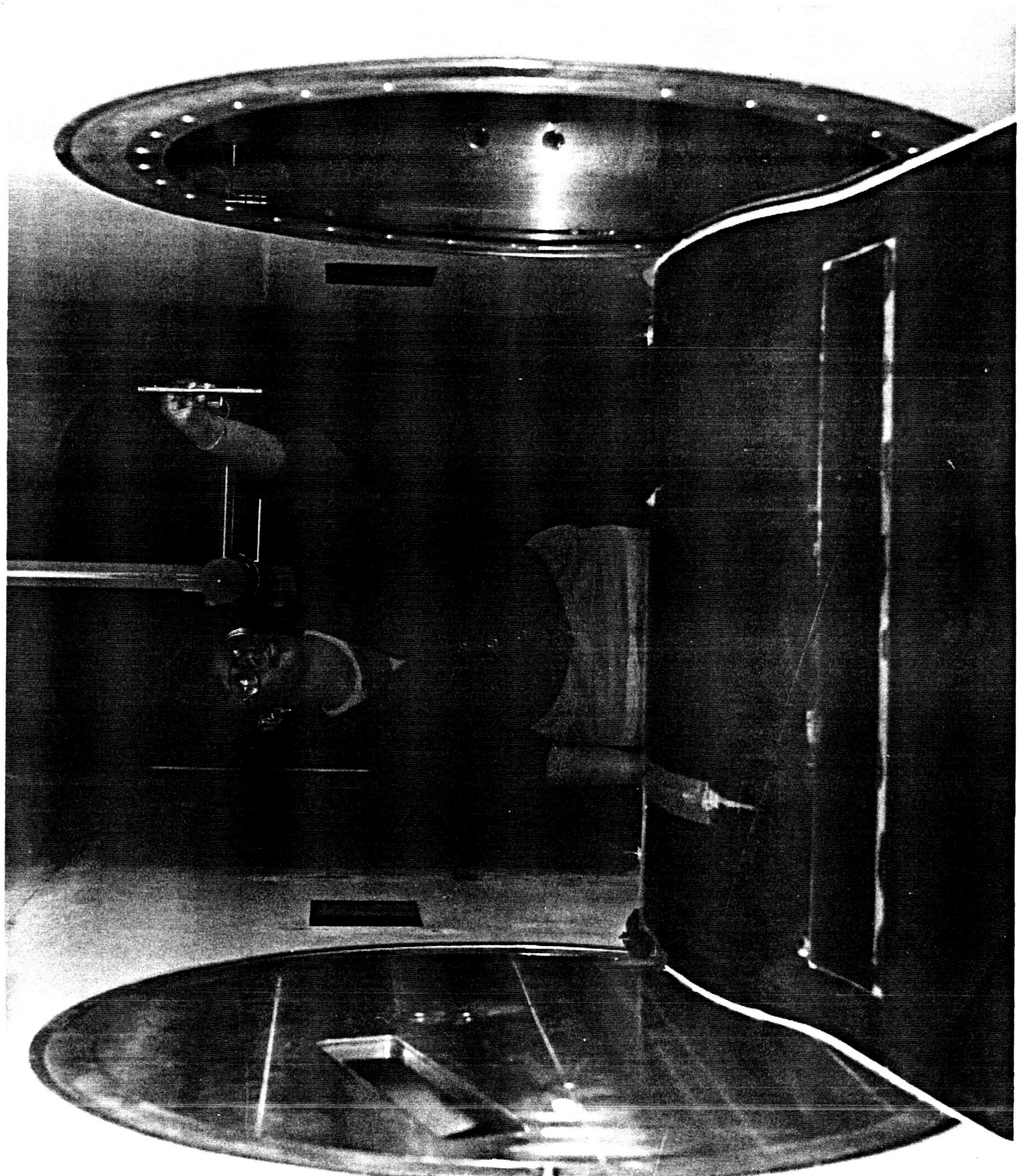
J. Ray Dagenhart and S. M. Mangalam (ODU) - Ext. 4514

RTR 307-03-01-03

Görtler vortices arise in boundary layers along concave surfaces due to centrifugal effects. These streamwise vortices are one of the three known principal sources of instability that lead to transition from laminar to turbulent flow. There are a number of flow situations where the fluid encounters concave curvature, e.g., the lower surface of an LFC supercritical wing. This experiment was the first of its kind to study the development of Görtler vortices on an airfoil with a pressure gradient.

A six-foot chord experimental model was tested in the Low-Turbulence Pressure Tunnel (LTPT) (See Photograph 1.). Görtler vortices were first visualized using sublimating chemicals. The streamwise vortices were observed as alternating light and dark streaks on the surface due to the differential shear stress pattern of the vortex layer. Each pair of light and dark streaks together indicate one wavelength of the counter-rotating streamwise vortex layer. A five-beam laser velocimeter was used to measure the three velocity components in the boundary layer and a dedicated computer system was used to record and process the data.

Theoretical studies of the Görtler instability have shown that the vortex amplification varies with free stream velocity (i.e., with Reynolds number and Görtler number). An experimental investigation would be expected to show a vortex spacing corresponding to the theoretically predicted maximum amplified wavelength. However, previous experiments which were conducted in curved channels with zero pressure gradient have not found this correlation. Indeed, the wavelength was found to be almost independent of free-stream velocity probably indicating that some portion of the test apparatus, such as turbulence damping screens, has "selected" the wavelength. In the present experiment, the Görtler number was varied by changing the free-stream velocity. The experimentally determined wavelength fell near the theoretically predicted maximum amplified wavelength and clearly varied with Görtler number as predicted. These expected results probably were obtained because of the excellent low-turbulence environment and the absence of the opposite channel wall in this experiment.



Photograph 1