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WATER-TABLE TESTS OF PROPOSED HEAT-TRANSFER TUNNELS FOR SMALL TURBINE VANES

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16. Abstract

Water-table flow tests were conducted for proposed heat-transfer tunnels which were designed to provide uniform flow into their respective test sections of a single core engine turbine vane and a full annular ring of helicopter turbine vanes. Water-table tests were also performed for the single-vane test section of the core engine tunnel. The flow in the heat-transfer tunnels was shown to be acceptable.

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WATER-TABLE TESTS OF PROPOSED HEAT-TRANSFER TUNNELS FOR SMALL TURBINE VANES

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SUMMARY

Water-table flow tests were conducted for proposed heat-transfer tunnels which were designed to provide uniform flow to their respective test sections of a single core engine turbine vane and a full annular ring of turbine vanes for an Army helicopter engine. Water-table tests were also performed for the single-vane test section of the core engine tunnel.

The three-dimensional flow through the tunnel configurations was simulated two dimensionally and at twice full size by modeling a slice through the cylindrical tunnel cross sections. The tunnels were simulated from the burner outlet to the inlet of the corresponding test sections. The single-vane test section of the core engine tunnel was modeled full scale. The flow in the heat-transfer tunnel configurations was shown to be acceptable for use in planned heat-transfer tests.

INTRODUCTION

Water-table flow tests were conducted for proposed heat-transfer tunnels which were designed to accommodate a core engine single-vane test section and a test section consisting of an annular ring of turbine vanes for an Army helicopter engine. Water-table tests were also performed for the single-vane test section of the core engine tunnel. The overall tunnel configurations were designed to give good flow paths into their respective test sections.

The heat-transfer tunnels will be used for high-temperature and high-pressure tests of core engine and helicopter vanes incorporating advanced cooling schemes. To obtain meaningful test results, it is important that the flow patterns into the test sections be as similar as possible to those experienced in actual engine operation. Large variations or discrepancies in the test-section flow patterns could give heat-transfer test results which, if incorporated into final engine designs, could seriously impair the performance of those designs.

In the investigation described in this report, the three-dimensional flow through the tunnel configurations was modeled twice full size by simulating a slice through the cylindrical tunnel cross sections. Dye was injected at the tunnel entrances and just upstream of the single-vane test section of the core engine tunnel. Photographs of the resulting flow patterns were obtained and analyzed qualitatively. Design modifications were made as the tests progressed to provide straight flow into both test sections and to ensure that the streamlines around the core engine stator vane were acceptable for the planned heat-transfer tests.

APPARATUS

Water-Table Description

An overall view of the water table which was used to determine the flow patterns in the heat-transfer tunnel configurations is shown in figure 1(a). The rake and hypodermic needles that were used to inject dye into the water stream are shown in figure 1(b).

The water table measures 226 by 122 centimeters (89 by 48 in.) and is illuminated from below through a glass plate which forms the bottom of the table. A camera is mounted from a truss network above and records the streamline patterns in the flow model. An electric motor continually recirculates filtered water. The depth of the water can be set from 0 to 11.4 centimeters (0 to 4.5 in.), and the flow rate can be varied from 13.2×10^3 to 114×10^3 cubic centimeters per minute (3.5 to 30 gal/min).

Basic Tunnel Configuration

The starting-point configuration for both tunnels is shown schematically in figure 2 by the solid lines. The labeled components of this configuration are those items which were known to be needed. They are the burner outlet, bluff body, settling chamber, and test-section inlet. The purpose of the settling chamber is to allow thorough mixing of the gas stream and thus give a uniform flow temperature profile into the test section. The bluff body is used to prevent direct radiation from the burner to the test vane or ring of vanes. This allows accurate heat-transfer measurements to be made without recourse to large radiation corrections. The dashed lines show the helicopter engine test section inlet and the triangular ring which, in the course of the flow tests, was found to be necessary to properly direct the flow to the test-section inlet.

PROCEDURES

The heat-transfer tunnel configurations were developed to provide thorough gas mixing and to eliminate combustor radiation at the test sections. It was also desired to develop configurations which would guide the flow into the inlet of the corresponding test sections without undue scrubbing of the side walls. The actual tunnel configurations upstream of the test section are cylindrical in shape, but the geometries were developed by taking a two-dimensional slice through the cross sections. Also, these portions of the tunnels were modeled twice full size. The heat-transfer tunnel models were fabricated from sections of urethane foam and clear plastic. A full-scale single-vane test section of the core engine tunnel, including the inlet section, was fabricated from clear plastic. The flows through the tunnels and the single-vane test section were visualized by injecting dye upstream (through hypodermic needles and a rake, respectively) and photographing the streaks that formed as the water flowed through the models.

RESULTS AND DISCUSSION

Water-table flow tests are often used to model two-dimensional, isentropic, compressible flow of air in which no body forces, friction, or turbulence is assumed to be present. For a complete analogy, geometric similarity and equivalence in specific-heat ratio γ and Mach number must exist between the real case and the modeled flow. Not all these equivalences can be satisfied in flow modeling using water-table tests.

The specific-heat ratios of air and water are not equal ($\gamma = 2.0$ for water, $\gamma < 1.4$ for air at elevated temperatures), but the error introduced by this discrepancy is small and unavoidable when modeling an air phenomena in water. Most importantly, however, the flow Mach number M through the heat-transfer tunnel test rig is so low ($M = 0.05$ at the burner outlet, 0.014 over the bluff body, and 0.21 at the core engine test-section inlet) that the flow can be considered incompressible. This negates the Mach number equivalence in favor of geometric similarity. The main thrust of this investigation was thus directed at correctly modeling the sudden area changes (and thus the resulting decelerations and accelerations) which the gas stream experiences in traversing the tunnel test rig from the burner outlet to the test-section inlet.

Core Engine Single-Vane Tunnel

The tunnel configuration for the core engine single-vane test section was developed first. The tunnel components are the same as those assumed for the basic tunnel configuration, except that it was necessary to add a triangular ring around the periphery of the settling chamber. This ring directs the flow towards the test-section inlet and keeps the flow from attaching to the side walls. If the triangular ring cross section was too small, the flow impinged on the back wall, just to the side of the test-section inlet, and in extreme cases the flow reattached itself to the side walls.

Various shapes of bluff bodies were investigated (see fig. 3). The curvature on the front of the bluff body had no significant effect on the flow downstream. The depth of the bluff body in the axial direction was dictated by the need to get the internal cooling configuration into the bluff body. Figure 4 shows the final geometry of the core engine vane tunnel. The tunnel is 31.8 centimeters (12.4 in.) in length and has a diameter of 30.5 centimeters (12.0 in.). The back face of the triangular ring is located 21.6 centimeters (8.5 in.) from the burner outlet face, and its height is 4.45 centimeters (1.75 in.). The bluff body has an outside diameter of 17.8 centimeters (7.0 in.), and its back is cut off perpendicular to the axial flow direction. The bluff body is supported by two radial struts. These struts were not modeled in the two-dimensional water-table tests. They are indicated by dashed lines in figure 4. The struts serve the dual purpose of supporting the bluff body and carrying the cooling water for the internal cooling passages to and from the bluff body.

Typical test streak patterns for the final tunnel configuration are shown in figure 5. Note that the extraneous dark lines and spots in these photographs are caused by the rubber suction cups and supporting braces upon which the water table rests, as well as by the overhead truss structure for the camera. It can be seen from these photographs that the final tunnel configuration should provide the flow uniformity required at the inlet to the single-vane test section.

The core engine single-vane test section was developed separately from the heat-transfer tunnel geometry. The development model was full size and is shown in figure 6. The flow tests for the single-vane test section were performed with the whole test section submerged in the water. As such, these tests were performed in a "water tunnel" rather than a "water table" configuration. The vane is designed for the first stage of a core engine high-pressure turbine. The core turbine is expected to operate at temperatures and pressures up to 2480 K (4000° F) and 3.10×10^{6} newtons per square meter (450 psia), respectively. The turbine has an outside diameter of 25.4 centimeters (10.0 in.) and uses 36 vanes in the first stage stator ring. The first stage vane, which is modeled in this test section, has a span of 3.81 centimeters (1.50 in.) and a chord of 5.552 centimeter (2.186 in.) and has no twist or taper. A cross section of its profile is shown in figure 7.

The geometry of the test section was derived by considering the flow path between two adjacent vanes, separated by a distance of the mean pitch. A sketch of the test-section configuration is shown in figure 8. The side walls represent the suction and pressure sides of the adjacent vanes. The vane was placed approximately two chord lengths behind the bellmouth inlet. This was considered sufficient distance to give straight flow at the vane leading edge. Photographs of typical streamlines (fig. 9) show good flow characteristics into the inlet and over the vane. For each of these pictures, the rake was positioned so that the dye streaks were at roughly the half way point on the vane span. The grid pattern observable in these pictures was achieved by placing a plastic sheet with grid lines below the test section. This allowed easy determination of the relative straightness of the inlet streamlines.

The approximate nature of the water-table flow tests prompted a more detailed examination of the flow behavior in the single-vane test section. The flow over the vane was tested at ambient conditions in air. The results of the investigation are reported in reference 1. The investigation confirmed the findings of the water-table tests. That is, the flow behavior over the test vane is acceptable and adequate for use in the planned heat-transfer tests.

Helicopter Engine Stator Ring Tunnel

The heat-transfer tunnel for the full stator ring test section was developed in a manner analogous to, and starting with, the single-vane cascade heat-transfer tunnel configuration. The overall tunnel dimensions are the same: length, 31.8 centimeters (12.5 in.); diameter, 30.5 centimeters (12.0 in.). The major change was the relocation and reduction in size of the triangular ring. The back face of the triangular ring is located 22.23 centimeters (8.75 in.) from the burner outlet face, and its height is 1.91 centimeters (0.75 in.). The bluff body for the full stator ring test section is supported by three radial struts, as well as by a rear extension which extends to the plane of the test-section inlet. As for the core engine single-vane tunnel, the radial struts were not modeled in the water-table tests. They are indicated by dashed lines in figure 10, which shows the final tunnel and bluff body configuration. Typical test streak patterns for this tunnel geometry are shown in figure 11. From these photographs it appears that the final tunnel geometry will be adequate to provide uniform flow into the full stator ring test section.

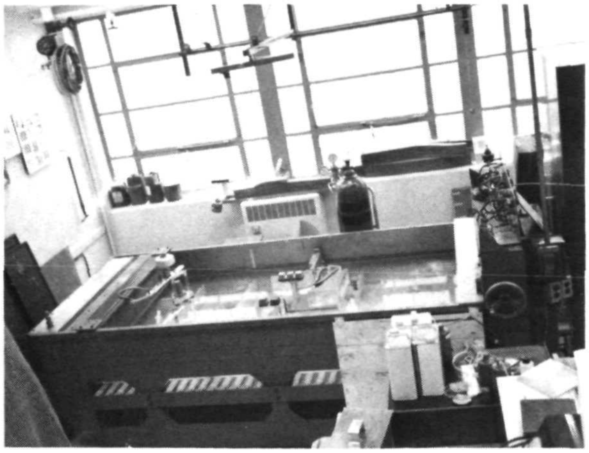
CONCLUDING REMARKS

The water-table flow tests described in this report have shown the heat-transfer tunnels to have acceptable flow patterns for both the core engine single-vane test section and the full stator ring test section. Furthermore, the core engine single-vane test section has been shown to have excellent streamlines, both at the inlet and over the test vane itself. It must be realized, however, that water-table flow tests are not an absolute measure of subsonic flow behavior. The water-table test results can thus be used only qualitatively to point out the general flow behavior.

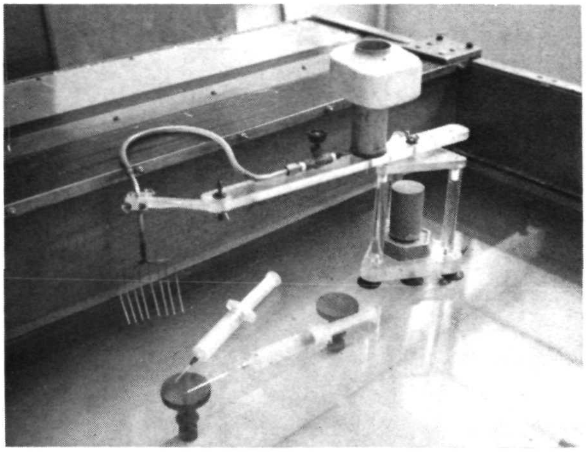
Lewis Research Center,
National Aeronautics and Space Administration,
and
U. S. Army Air Mobility R&D Laboratory,
Cleveland, Ohio, March 11, 1974,
501-24.

REFERENCE

1. Stabe, Roy G.; and Kline, John F.: Aerodynamic Performance of a Core-Engine Turbine Stator Vane Tested in a Two-Dimensional Cascade of 10 Vanes and in a Single Vane Tunnel, NASA TM X-2766, 1973.



(a) Overall view.



(b) Rake and hypodermic needles used to inject dye into water flow.

Figure 1. - Water table.

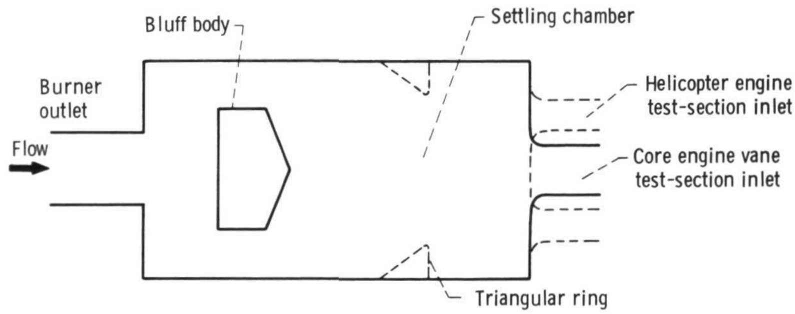
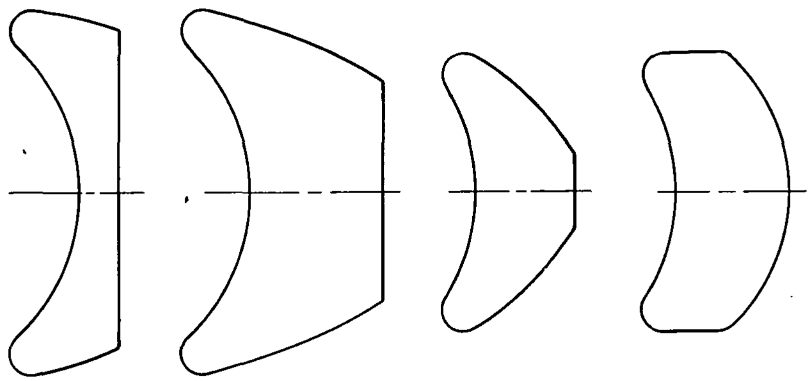


Figure 2. - Starting-point tunnel configuration.



(a) First configuration.

(b) Second configuration.

(c) Third configuration.

(d) Fourth configuration.

Figure 3. - Shapes of bluff bodies investigated.

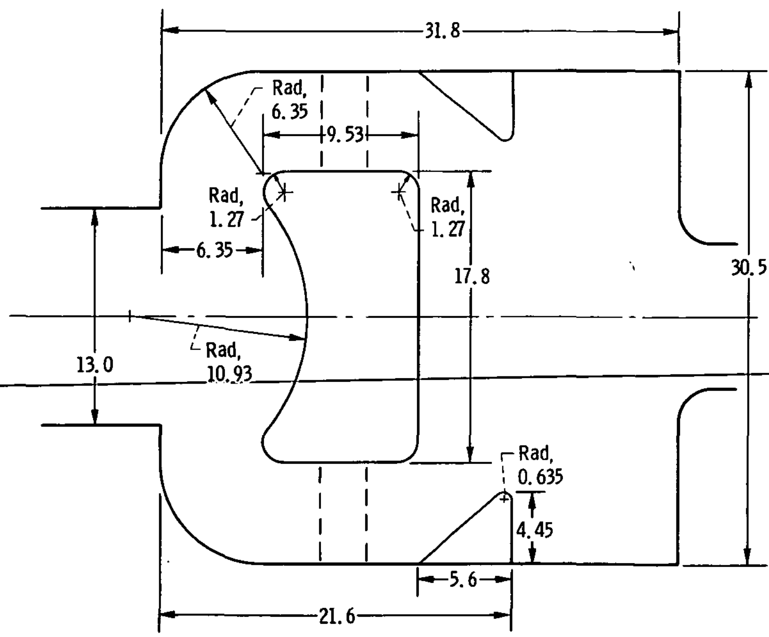
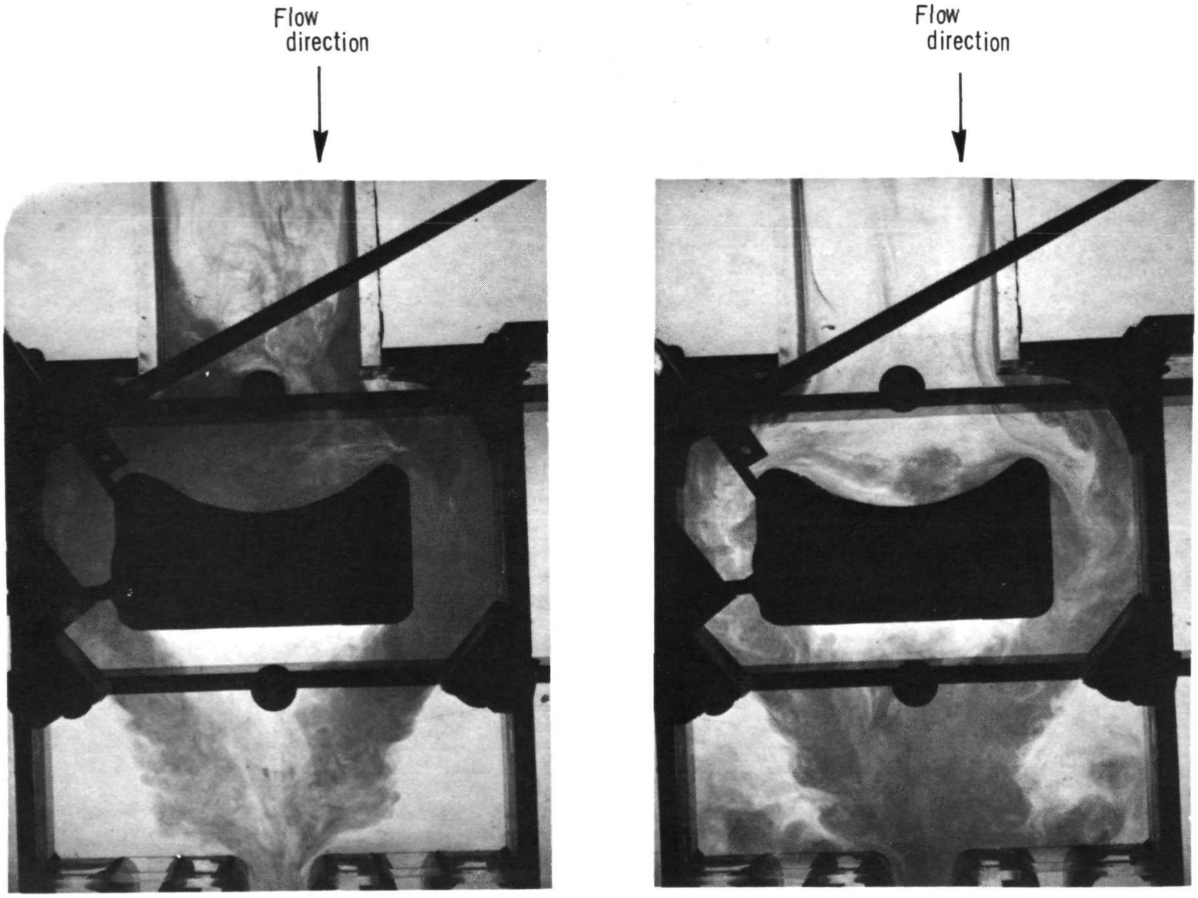


Figure 4. - Final heat-transfer tunnel geometry for core engine single-vane test section. (Dimensions in centimeters.)



(a) Streak pattern shortly after dye injection at burner outlet.

(b) Streak pattern after most of dye had traversed tunnel configuration.

Figure 5. - Streak patterns for core engine single-vane tunnel configuration.

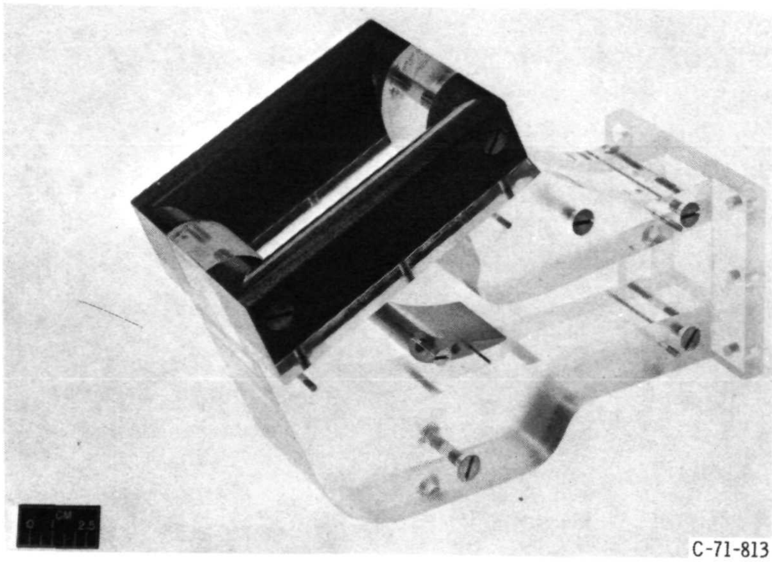
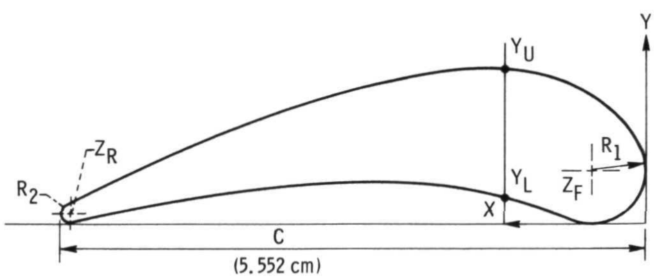


Figure 6. - Core engine vane cascade test-section model.



Point Z_F		Point Z_R		Leading edge radius, R_1/C	Trailing edge radius, R_2/C
X/C	Y/C	X/C	Y/C		
0.0915	0.0915	0.9840	0.0160	0.0915	0.0160

X/C	Y_L/C	Y_U/C
0	0.091	0.091
.023	.031	.153
.046	.012	.181
.069	.003	.202
.091	0	.219
.114	.003	.232
.137	.011	.242
.160	.022	.251
.183	.030	.257
.206	.037	.262
.229	.043	.264
.252	.048	.265
.274	.053	.266
.320	.059	.263
.366	.065	.258

X/C	Y_L/C	Y_U/C
0.412	0.068	0.249
.457	.069	.238
.503	.069	.226
.549	.067	.214
.595	.064	.200
.640	.059	.186
.686	.054	.170
.732	.047	.153
.777	.040	.134
.823	.032	.115
.869	.024	.093
.915	.015	.070
.961	.005	.047
1.000	.016	.016

Figure 7. - Core engine vane and coordinates.

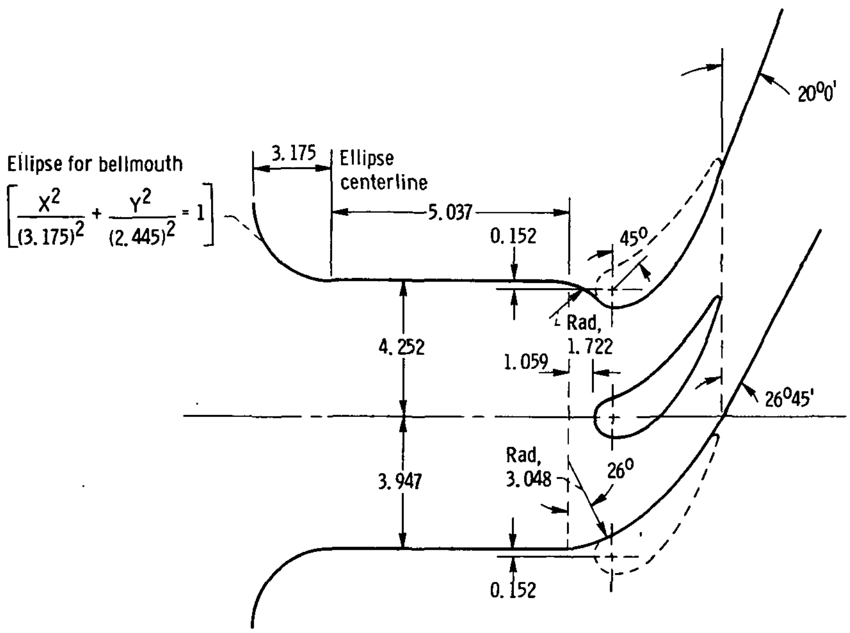
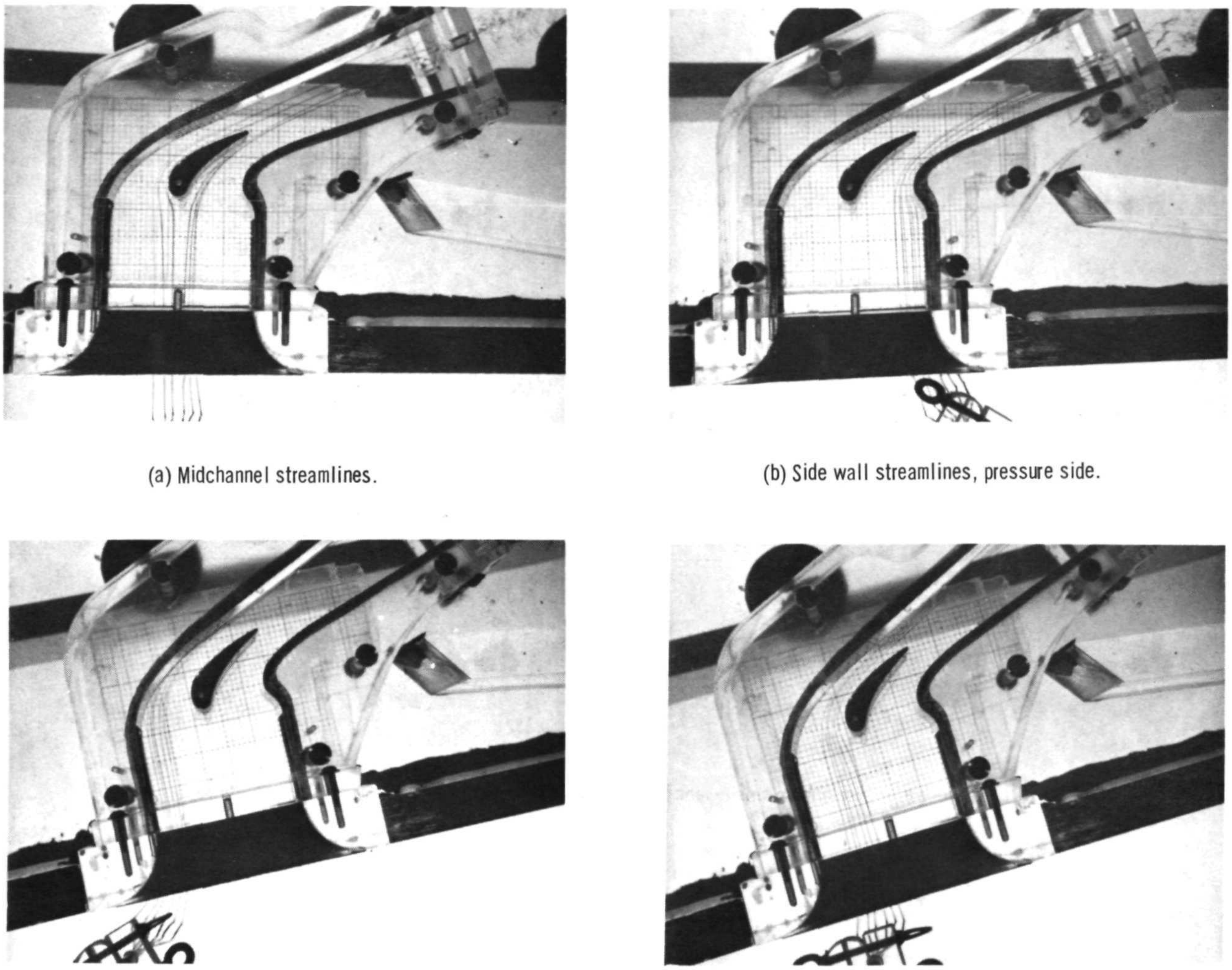


Figure 8. - Core engine single-vane test section geometry. (Dimensions in centimeters.)



(a) Midchannel streamlines.

(b) Side wall streamlines, pressure side.

(c) Side wall streamlines, suction side.

(d) Test vane streamlines, suction side.

Figure 9. - Streamline patterns for core engine one-vane test section.

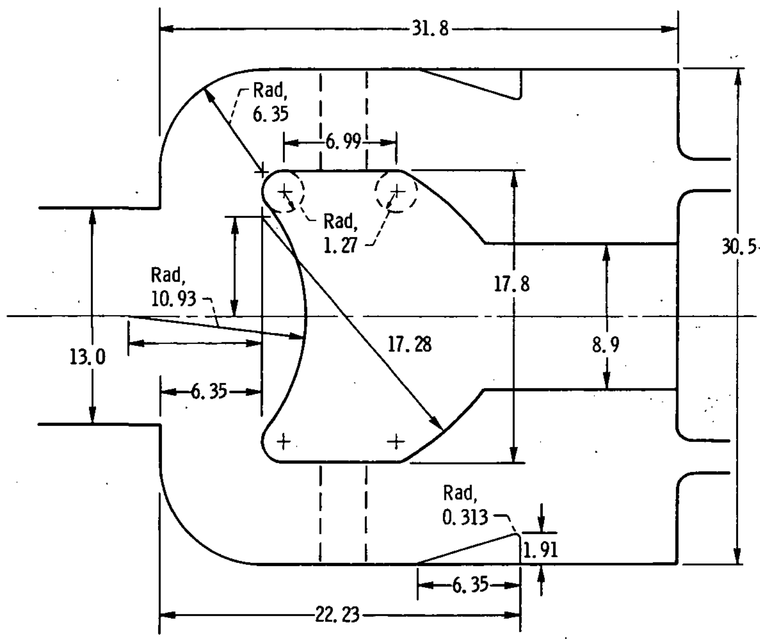
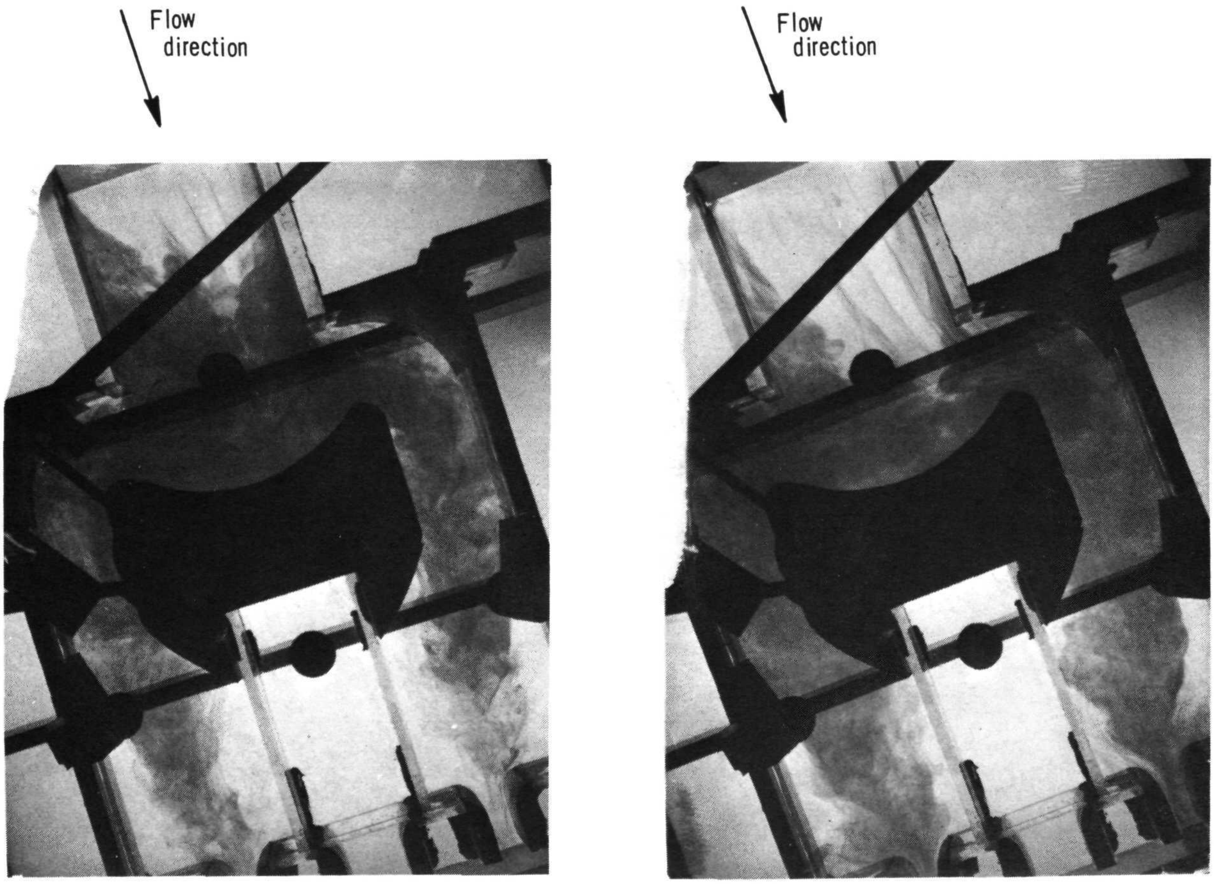


Figure 10. - Final heat-transfer tunnel geometry for full stator ring test section. (Dimensions in centimeters.)



(a) Streak pattern shortly after dye injection at burner outlet.

(b) Streak pattern shortly after dye had traversed inlet section.

Figure 11. - Streak patterns for full stator ring tunnel configuration.

NASA-Langley, 1974 E-7870

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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