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A PHYSICAL DESCRIPTION OF A VARIABLE-MACH-NUMBER 4- BY 4-INCH PILOT CORNER NOZZLE

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A PHYSICAL DESCRIPTION OF A VARIABLE-MACH-NUMBER 4- BY 4-INCH PILOT CORNER NOZZLE

I. INTRODUCTION

In April, 1951, the University of Michigan's Supersonic Wind Tunnel started an experimental evaluation of a variable-Mach-number model corner nozzle. The project is sponsored by the Air Force under Contract AF 33(038)-23070. The central objective of this evaluation program is to determine a matched set of fixed nozzle contours such that a simple translation (or at most, a translation plus a rotation) of one contour relative to the other will produce a change in Mach number between M = 1.4 and M = 4.0. At the same time, certain conditions of uniformity in the flow must be met.

Since theory can give only approximate contours for a real gas (i.e., contours including effects of viscosity), this pilot model has many controls and adjustments on contour that a developed nozzle will not require. The design, construction, and installation of the equipment required for this work was completed in June, 1953, and follows the aerodynamic requirements given by Murphy and Buning.[1] The initial operation of this model nozzle has been highly successful and the detailed aerodynamic evaluation is now in progress.

This report has been prepared at this time to describe briefly the physical components of this model nozzle and how it has been connected with the existing wind-tunnel facilities. Only the overall design philosophy and criteria will be mentioned as well as some of the unusual details of construction.

II. DESCRIPTION OF CHANNEL CIRCUIT

The corner-nozzle channel was designed to utilize the existing circuit established in connection with the 8- by 13-inch channel. A complete description of that facility is given in an external memorandum by Garby and Nelson[2].

Briefly stated, it is of the intermittent-flow blowdown type in which air is caused to flow from atmospheric pressure down to an evacuated tank. The principal components of the circuit are shown in the line diagram of Fig. 1. As shown, the 4- by 4-inch nozzle now parallels the installation of the 8- by 13-inch channel between the air storage and vacuum tanks. The 4- by 4-inch channel is composed of a number of sections, each having a different function, arranged one following another along the flow path between the air storage and vacuum tanks. These are, in order of their axial displacement (see Fig. 2),

(a) the entrance ducting, turbulence screens, and converging section followed by a slide-plate valve;

(b) the pilot corner-nozzle test section;

(c) the adjustable supersonic diffuser section;

(d) the fixed subsonic diffuser section; and

(e) the butterfly tunnel operation valve, slide-plate safety valve, and exit ducting.

In the following paragraphs, the channel sections (a, c, and d) and (e) are discussed briefly, since they are of only minor importance, while the discussion of section (b) is deferred to the next part of this report.

A. Entrance Ducting and Converging Section

This section of the channel leads the inflowing air from the air storage tank into the nozzle test section. It is composed of the four parts previously mentioned. The ducting has a 2-foot-square cross section, is 8 feet long, and is made from light welded sheet metal. A set of three turbulence screens (No. 30 copper mesh) at 8-inch centers follows the duct. Immediately following this is the converging section. It is 3 feet long, the entrance is 2 feet square, and the exit is 4 by 12 inches. This section is welded sheet steel and its function is to accelerate the air with a nearly uniform pressure gradient from the duct velocity to the nozzle-entrance velocity.

Between the converging section exit and the nozzle test-section entrance a slide cut-off valve has been placed. This valve, manually operated and sealed by pressure tubes, makes it possible to seal the forward entrance of the nozzle test section. The overall length of these units from air storage tanks to nozzle test-section entrance is 13 feet.

B. Diffuser Sections and Exit Ducting

This section of the channel has five distinct parts: the adjustable supersonic diffuser immediately following the test section, the fixed transition

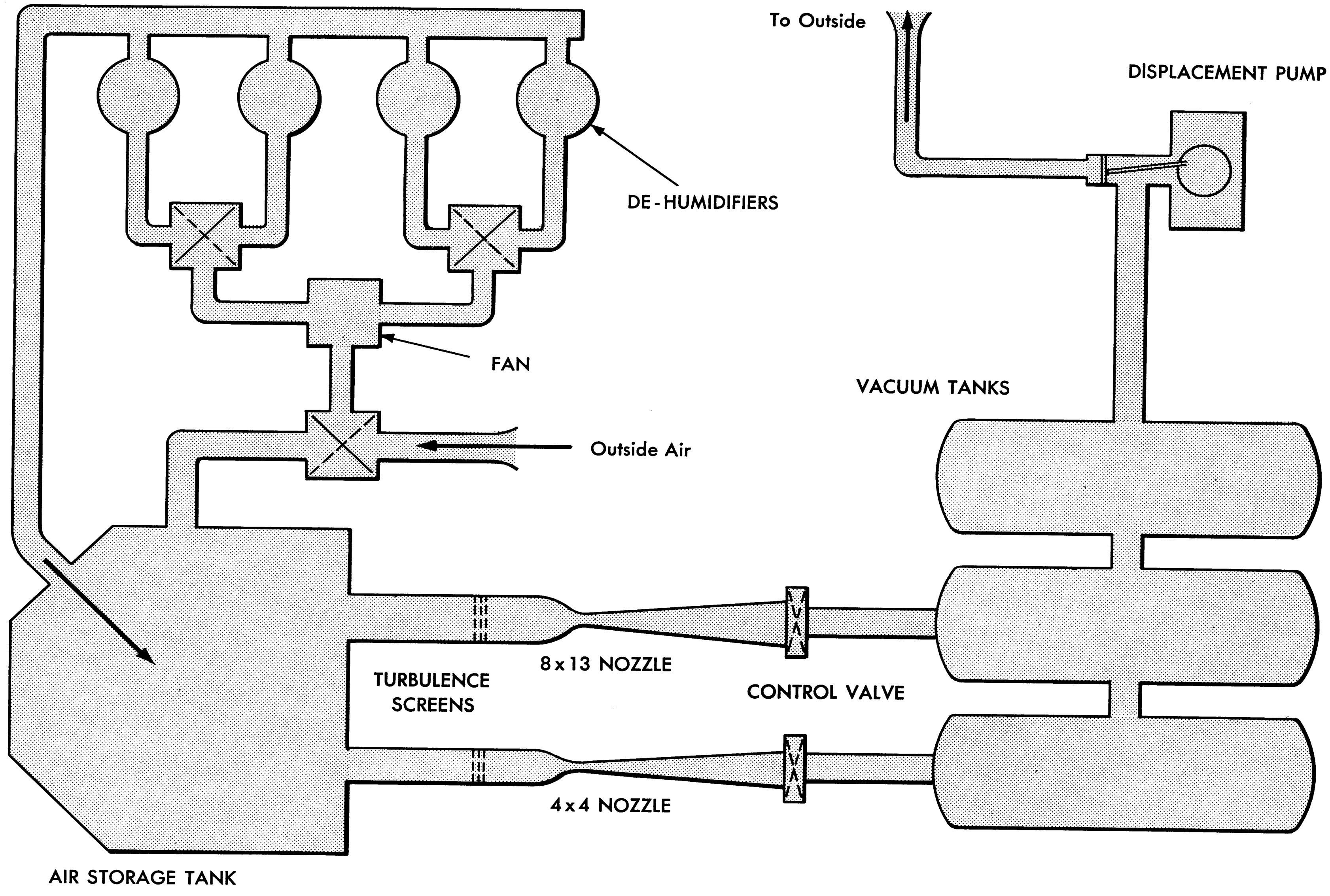

FIG. 1 LINE DIAGRAM OF TUNNEL CIRCUIT

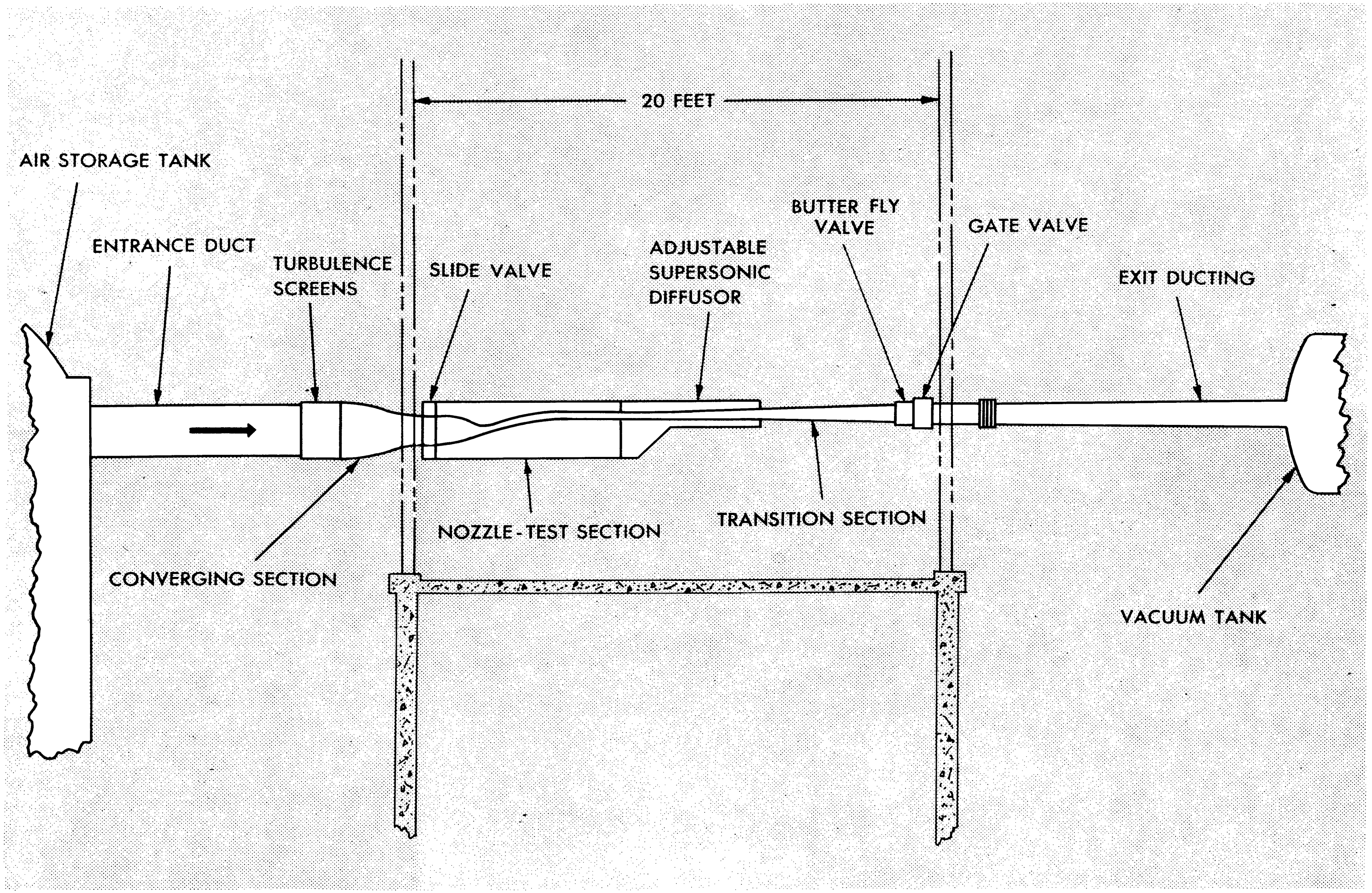

FIG. 2 DIAGRAM OF 4" x 4" PILOT CORNER NOZZLE CHANNEL

section, followed by the butterfly valve, a gate valve, and exit ducting between this valve and the vacuum tanks.

The supersonic diffuser (see Fig. 3) has an external case, 5 by 26 inches at the forward end and 64 inches long, made from 1/2-inch welded steel plates that have been bolted together after having been machined on the mating and aerodynamic surfaces to a close-tolerance finish. The sidewalls of the case form the sidewalls of the aerodynamic channel. Internal to the case are movable top and bottom plates hinged at approximately the mid-position (i.e., 27 inches from the upstream end). A screw mechanism in the case moves the top plates at this mid-hinge position in such a way as to form a shallow vee. This arrangement, with the flat bottom plates, makes an adjustable throat that may be set for optimum diffuser efficiency. In addition to these motions, the forward ends of the top and bottom plates are attached to the downstream ends of the test-section plates and must follow the motions introduced by their adjustments. The nature of these motions is such as to require the forward end of the top plate to move through a vertical adjustment of approximately 3/4 inch and a horizontal adjustment of at most 1/4 inch. The bottom plate has the 3/4-inch vertical adjustment, and is capable of a 14-inch axial translation. With these adjustments, the forward opening may be as little as 4 by 4 inches and as much as 4 by 5-1/2 inches, while the downstream opening is constant at 4 by 5 inches.

The fixed transition section (see Fig. 5) is an all-welded steel construction. The mating surfaces are machined. The forward opening is 4 by 5 inches, which then blends through the length of 61 inches into an 8-inch-diameter exit opening. The next component is an 8-inch-diameter butterfly valve which can be operated both manually and by pneumatic remote control. Following this is an 8-inch-diameter Jenkins gate valve which in turn leads into an exit ducting. This ducting, some 50 feet in length, is a heavy-gage welded-steel 12-inch-diameter pipe and connects the channel with the vacuum tanks.

III. NOZZLE TEST SECTION

The design and construction of the corner nozzle was subcontracted to the Wind Tunnel Instrument Company of Cambridge, Massachusetts, in October, 1951. Preceding this subcontractual agreement was a series of conferences which led to "Specifications for Design and Construction of a Corner Nozzle" (see Appendix A). In general, the specifications required certain mechanical features and arrangements. The specifications also covered tolerances on aerodynamic contour, surface finish, and rigidity. In the final design, all of them have been achieved in a most satisfactory manner.

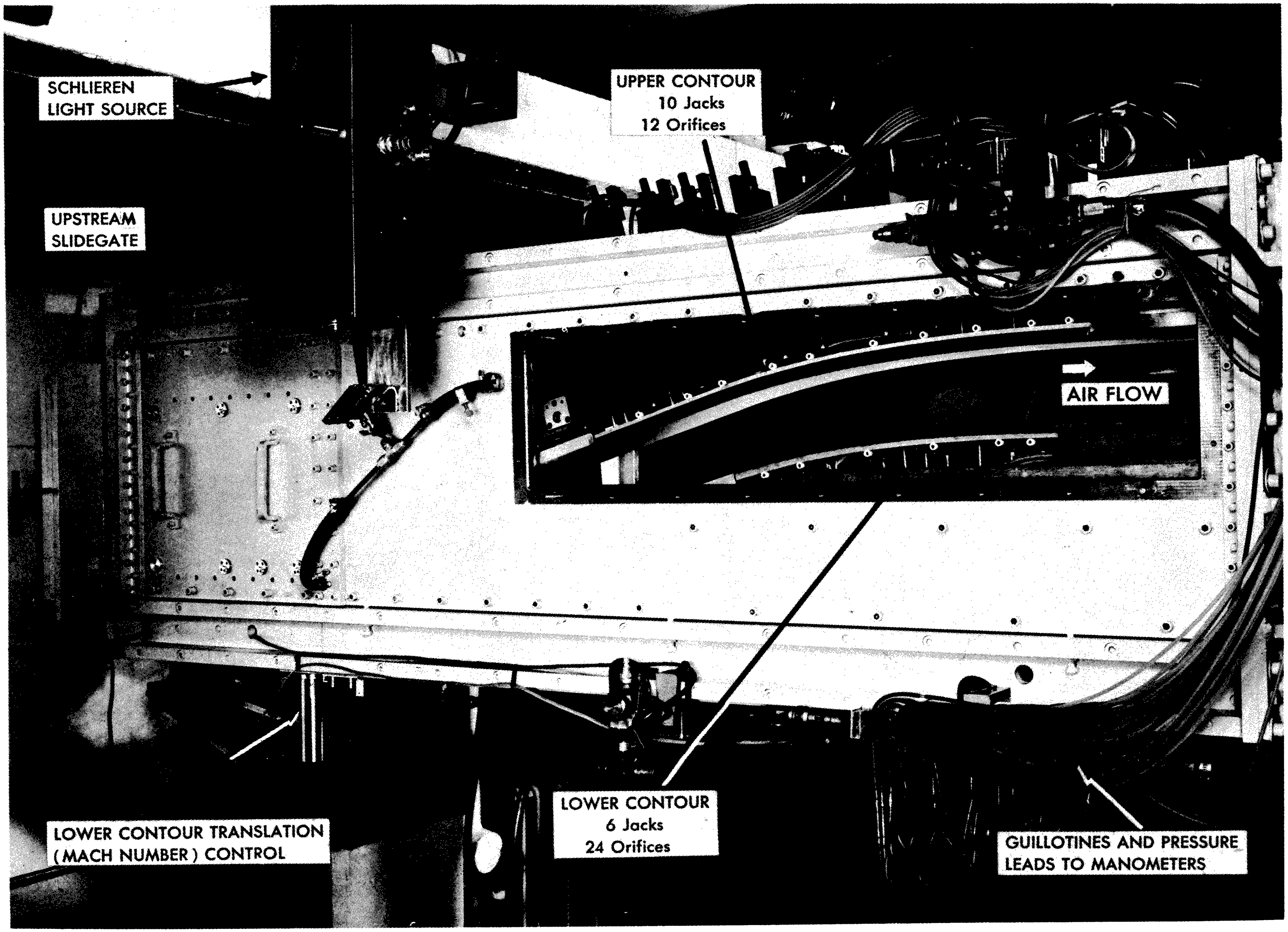

FIG. 3 CORNER NOZZLE IN MACH 1.4 POSITION

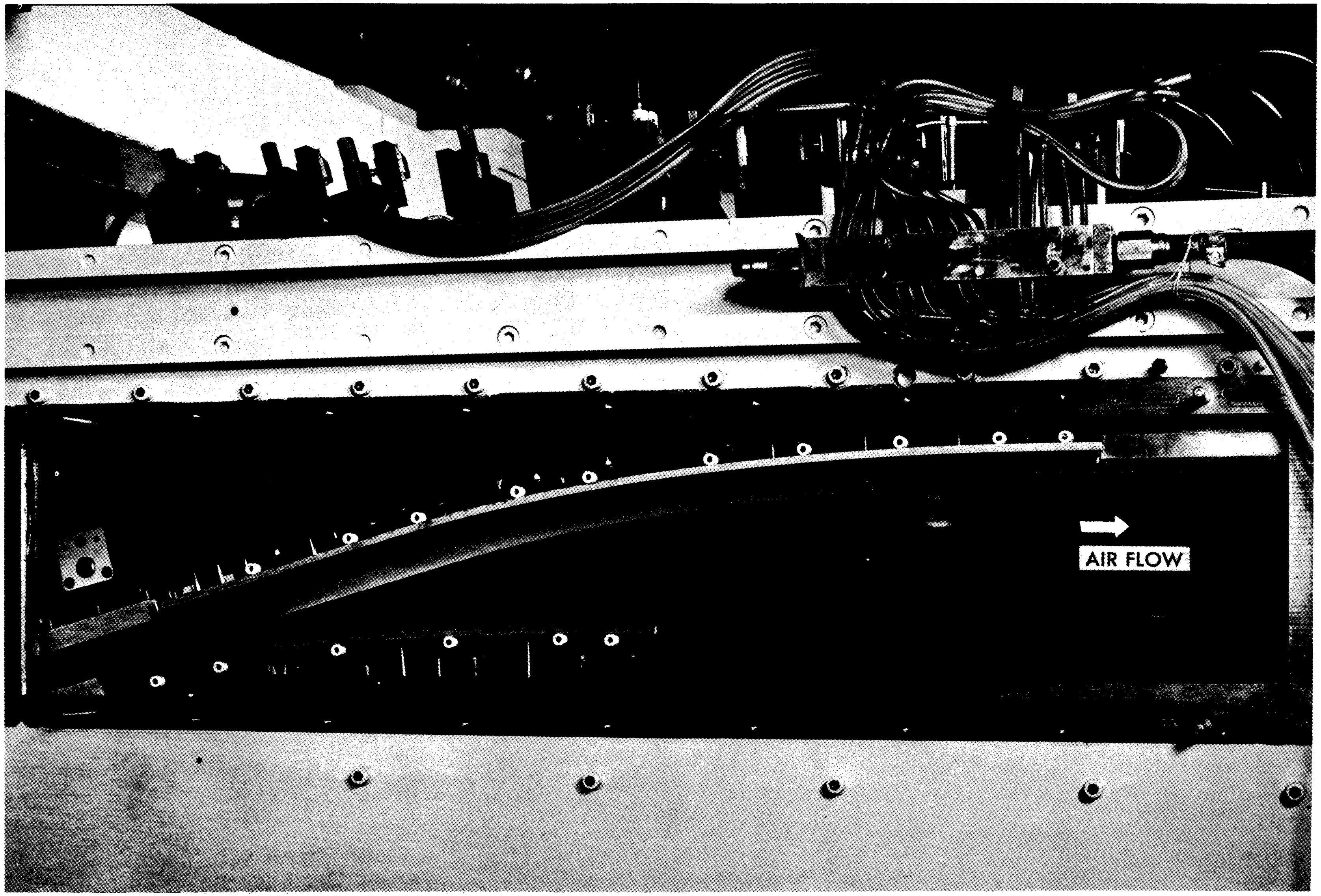

FIG. 4 CLOSE-UP OF CORNER NOZZLE IN MACH 4 POSITION

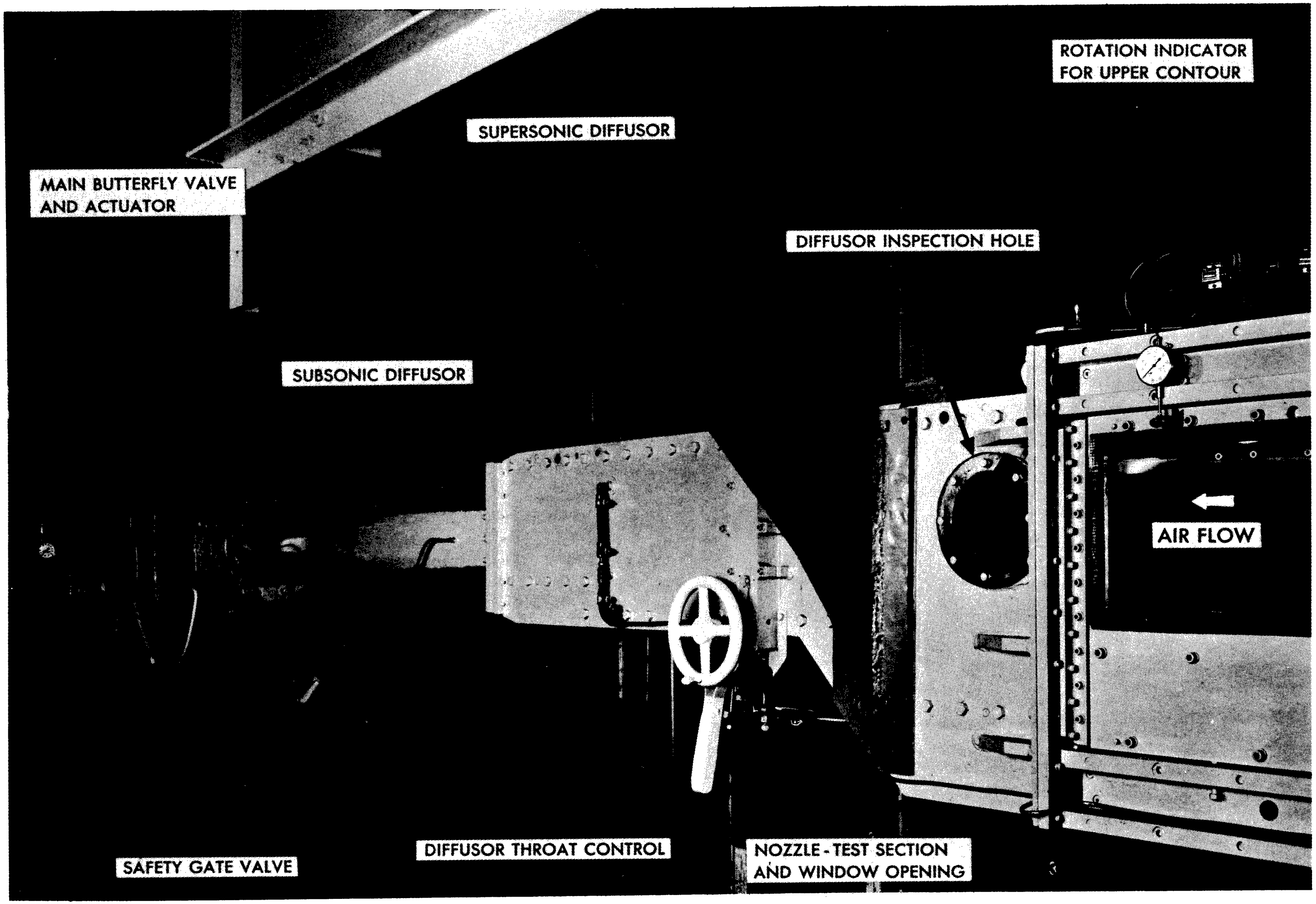

FIG. 5 DOWNSTREAM PORTION OF CORNER NOZZLE CHANNEL

The final construction may be seen in the photographs (Figs. 3 and 4). The section is 8 inches wide, 28 inches high, and 7 feet long. The gross weight is approximately 4000 pounds. The unit may be considered as being composed of three major subassemblies, (1) the exterior frame and sidewalls, (2) the upper contour plate assembly, and (3) the lower contour plate assembly.

The motions and adjustments of the contour plate assemblies are as required by the specifications (see Appendix A) except that the translation of the lower plate assembly was increased from the original required 10 inches to 14 inches of axial adjustment relative to the nozzle frame. Each of the motions is accomplished by screw-jacks having a large mechanical advantage, so that a desired position is obtainable with micrometer adjustment. After positioning, the controls may be locked.

The frame is made from machined heavy steel plate. The larger sections, where dimensional stability is particularly difficult to retain (i.e., sideplates), were annealed between rough and finish machining operations. The entire assembly is fastened with screws and dowels; welding was not employed. The method was also followed in the subassembly units within the nozzle frame.

The frame sidewalls are ground flat to a close tolerance on the inside surface; this forms the sidewalls of the aerodynamic channel. The sidewalls also hold window frames for the 8- by 42-inch windows. These are flush on the interior wall and make the aerodynamic channel visible from the throat area through the test section.

As previously mentioned, the upper and lower contour plate assemblies are within the frame, each having a flexible plate mounted on screw-jacks. There are ten screw-jacks for the upper plate and six for the lower. Each jack assembly has integral with its mechanism a rotation counter so that a given contour corresponds to a particular set of counter readings. The jacks are fixed to a definite place through tangs that are machined integral with the back side of the plates. The jack positions are critical and were precalculated to produce the desired contours within $\pm$ 0.002 inch. Numerical iterative methods applicable to the solution of multiple redundant structures were used. The method and results of the computation are given in a report by H. Alden, now on file at the Wind Tunnel Instrument Company, Cambridge, Massachusetts. Since the heat-treated material used in the plates (SAE 4130) has a yield point of about 140,000 psi, the thickness of the plate was controlled to allow an initial maximum stress of 70,000 psi. The margin of 70,000 psi was retained as a safety factor to absorb additional stress introduced by any error in jack adjustment.

During the initial operation of the nozzle, it was of particular interest to have a measured evaluation of the change in stress in the flexible plates due to applied air loads. For this purpose, strain gages were bonded at several points to the back sides of the plates between jack supports. The change in stress to be anticipated at these locations was then calculated[3]. Later, the stress change was measured with Sanborn equipment and found to agree with the expected values to within about 5%.

Orifice holes for pressure taps have been provided along the centerline of the contour plates in the flat and low-curvature regions. There are 24 taps along the lower contour and 12 along the upper.

Since the aerodynamic contours of both the top and bottom plates are adjustable, axial displacements are introduced at the downstream end of the plates. This is particularly true for the bottom plate, which, as mentioned earlier, has in addition an axial translational adjustment of 14 inches.

This axial motion introduced a design problem at both ends of the contour plates which has been handled in the following manner: the forward ends tie into flat plates which form the top and bottom surfaces of the aerodynamic channel. These plates in turn are retained in position by pins mounted in the tunnel sidewalls. These can be seen on the forward wall of the sidewall photograph, Fig. 3. The downstream ends of the contour plates are made to pin directly to the forward ends of the diffuser plates; the axial motion is then taken in the mechanism designed into the diffuser section, as described earlier in this report.

As required in the original specifications, a system of thin-walled rubber tubing was designed into the unit to seal the aerodynamic channel from atmospheric pressure. The tubing is inflatable and the pressures are controlled within the limits required for effective sealing.

IV. CONTROLS AND ACCESSORY EQUIPMENT

Flow measurement and analysis in the 4- by 4-inch channel depends on two kinds of data, pressure measurement and optical analysis. These complement each other in that the second is largely qualitative while the first is quantitative.

A. Model Probe Support

The pressure measurements are taken by movable probes and fixed orifices on the contoured surfaces. In the top plate a cutout has been provided in the aft test section for the introduction of a probe support into the test-section region. The probe support (see Fig. 6) has three controls that enable

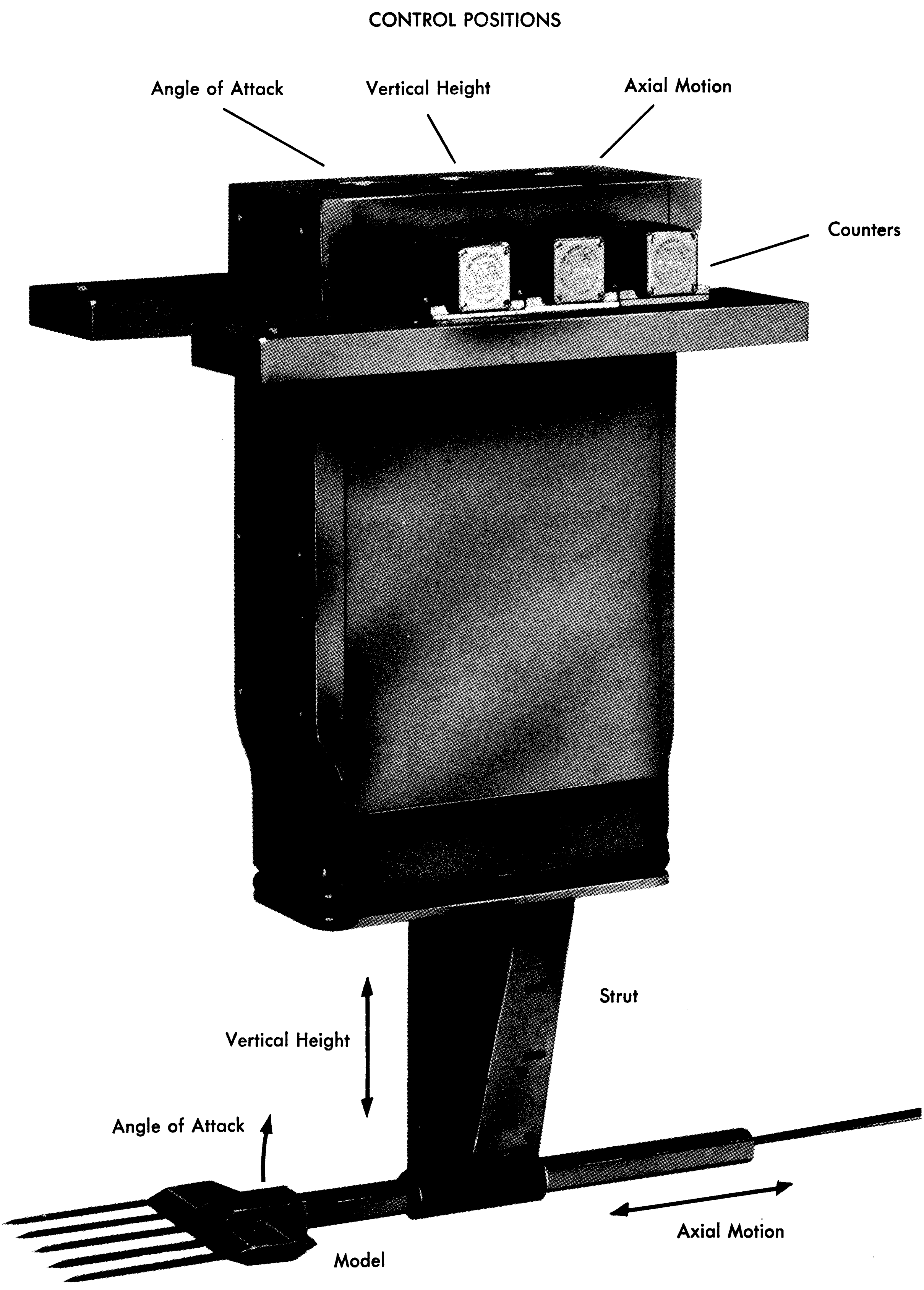

FIG. 6 PROBE SUPPORT

the test engineer to adjust height, angle of attack, and fore-and-aft position of the probe from outside the tunnel. O-ring seals are provided so that the motions can be accomplished with the tunnel in operation. Counters are provided integral with the mechanism so that, after calibration, any probe position or combination of motions corresponds with particular counter readings. When the probe support is not installed in the tunnel, a close-tolerance plug with four orifices fits the cutout.

B. Schlieren Camera and Viewer

The optical system (see Figs. 7 and 8) consists of a schlieren system with a specially designed camera and viewer. The basic system is of the standard double-mirror type with 8-inch-diameter parabolic reflectors. This basic system is mounted on an overhead boom which in turn is mounted on a rail system. With this arrangement, schlieren photographs and visual observations can be made at any position along the window areas. The suspension system has an internal drive mechanism and this, together with another feature of the camera-viewer, makes it possible to scan the flow rapidly and meanwhile take photographs of phenomena that should be recorded. Another control makes it possible to traverse the window area automatically with enough exposures to give a continuous record of the nozzle-section flow. A description of this design and its required calculations is given in a report by R. H. Fashbaugh[4].

C. Control Panel

The control panel is a desk-like structure made from wood and mounted on casters so that it can be moved about. Flexible conduits connect the panel to a circuit box on the tunnel-area wall.

In general, the panel controls all major operations incident to the operation and the testing of the tunnel.

V. CONCLUSION

The foregoing paragraphs have attempted to describe in a general way the 4- by 4-inch pilot-model corner nozzle. It is believed that the design and construction phase of the channel was completed as of June, 1953, and that the test phase of the program has begun.

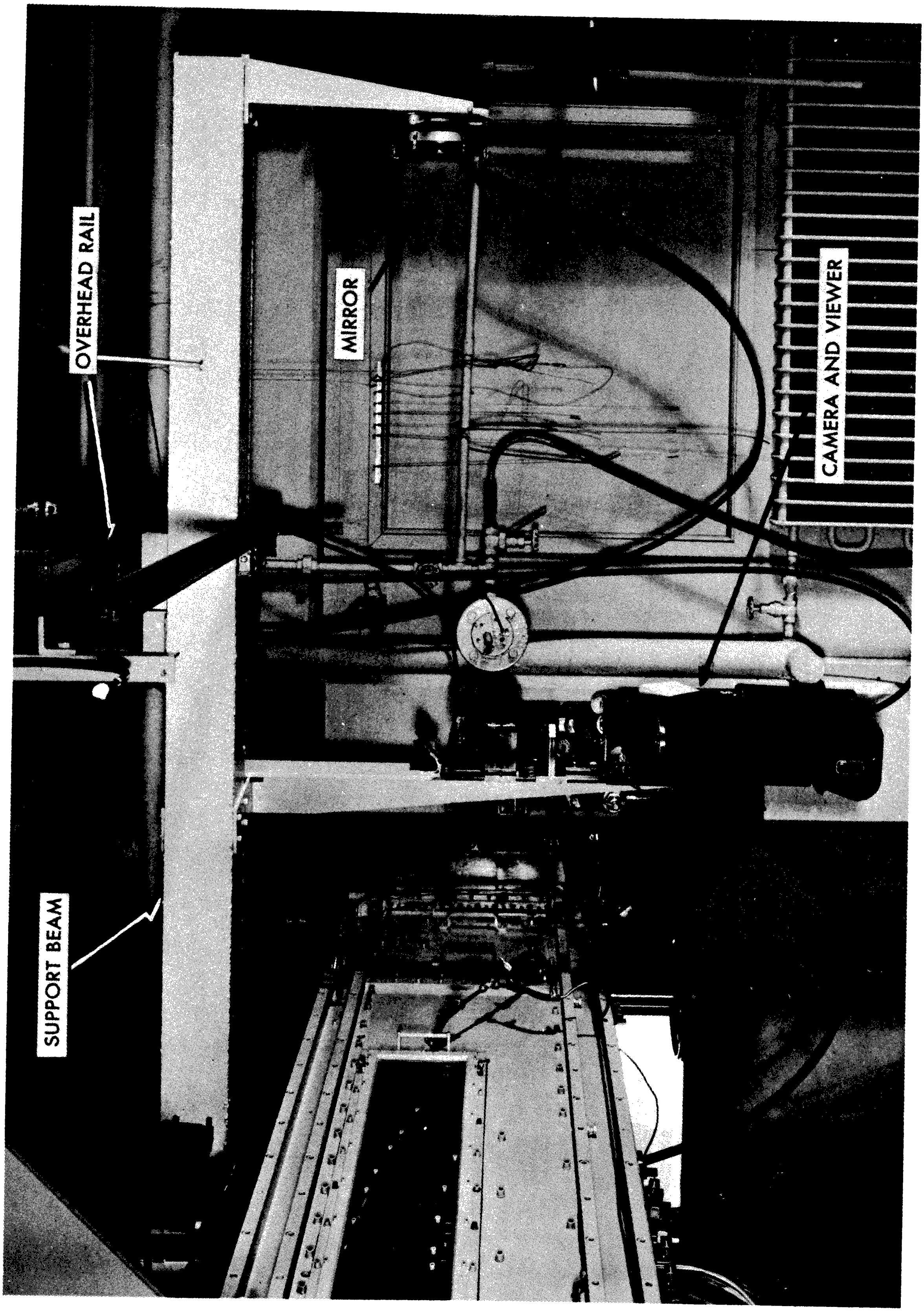

FIG. 7 SCHLIEREN SYSTEM (RIGHT SIDE)

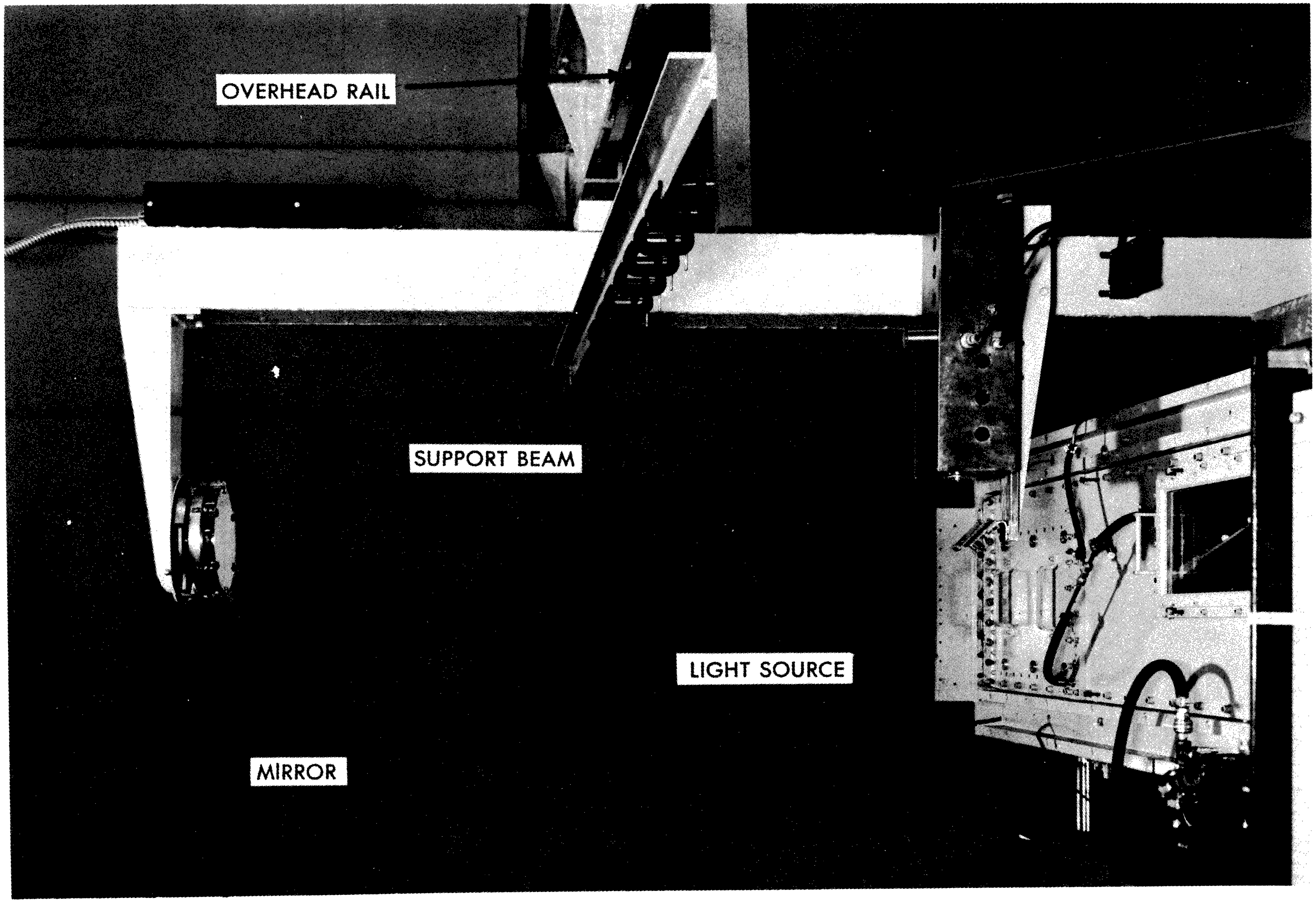

FIG. 8 SCHLIEREN SYSTEM (LEFT SIDE)

VI. REFERENCES

1. Murphy, J.S., and Buning, H., Theory and Design of a Variable-Mach-Number Corner Nozzle, University of Michigan WTM-221.

2. Garby, L.C., and Nelson, W.C., University of Michigan 8 x 13 Inch Intermittent-Flow Supersonic Wind Tunnel, University of Michigan UMM-59.

3. Nourse, J.H., A Summary of the Plate Stresses in the Flexible Portion of the 4 x 4 Inch Supersonic Nozzle, University of Michigan WTM-241.

4. Fashbaugh, R.H., Supersonic Wind Tunnel, 8 Inch Schlieren System - Operation and Maintenance Manual, University of Michigan WTM-243.

APPENDIX A

SPECIFICATIONS FOR THE DESIGN AND CONSTRUCTION OF A CORNER NOZZLE

Nozzle Tes. Section, General

a) The nozzle section must consist of two sidewalls with top and bottom movable inserts.
b) Sidewalls must be flat and contain windows for visual access to the entire nozzle flow channel.
c) The top and bottom inserts must have variable aerodynamic contours.
d) The contours will be furnished by the University of Michigan

Top Insert

a) The top insert must rotate about a point near the throat so that a point in the aft test section would be displaced 1 inch outward from nominal position.
b) The downstream half of the aerodynamic contour must be flexible so as to move $\pm$ 1/8 inch from nominal position. (This is to be accomplished by means of a flexible steel plate positioned by screw-jacks.)

Bottom Insert

a) The bottom insert must incorporate the same motions and adjustments as the top insert.
b) In addition, it must translate along the horizontal tunnel axis not less than 10 inches.

Detail Considerations

a) Overall structural deflections in the presence of aerodynamic loads, 0.005 inch maximum.
b) Deviation from nominal contour on nozzle surfaces, $\pm$ 0.002 inch maximum.
c) Aerodynamic surface finish, 40 R.M.S.
d) Pressure orifices are required along the centerlines of both nozzle inserts.
e) Neither insert is required to move during tunnel operation, but the flexible contours must be capable of adjustment (i.e., the jack-screws must be operable from the tunnel exterior).
f) There must be no discontinuity or juncture between the throat and the test section.
g) Pressure seals must be provided to seal the aerodynamic channel from atmospheric pressure without leakage.