University of Michigan 8 x 13 inch Intermittent-flow Supersonic Wind Tunnel

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Aeronautical Research Center
University of Michigan
External Memorandum UMM-59
June 1950

ACKNOWLEDGEMENT

The authors wish to acknowledge the combined efforts of the wind tunnel staff which made this facility possible and, in addition, the guidance of their colleagues on the Wind Tunnel Committee:

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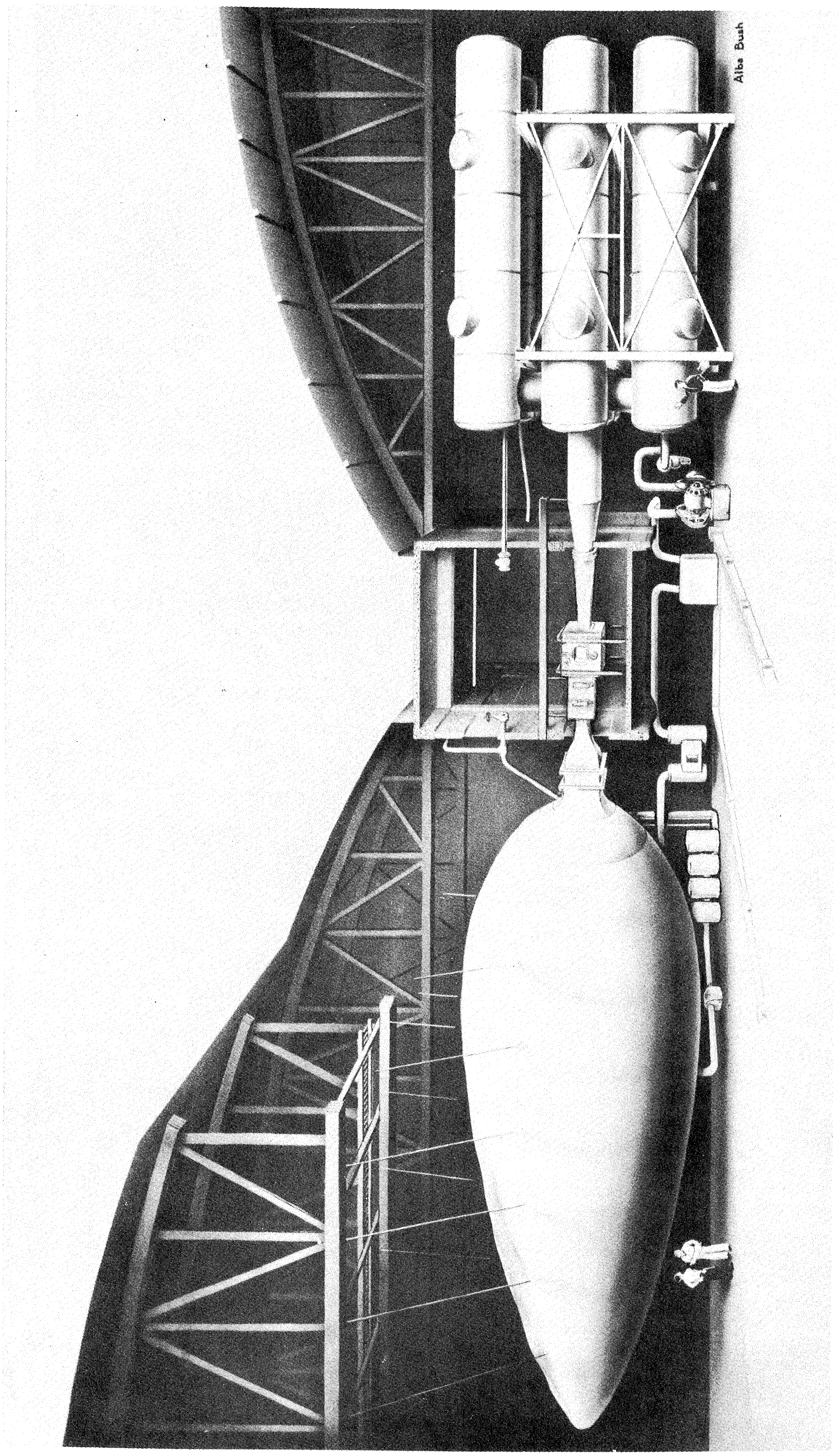


FIG. 1 UNIVERSITY OF MICHIGAN SUPERSONIC WIND TUNNEL

I INTRODUCTION

It is the purpose of this report to present an over-all picture of the supersonic wind tunnel facility built and operated by the University of Michigan for the Air Forces. It should be realized at the outset that this vacuum tunnel was one of the first systems of this type to be built in the United States and certain features are unique. The main problems and solutions are presented together with improvements which could be incorporated in future tunnels of this general type.

II HISTORICAL

Early in 1946, the University of Michigan undertook an Air Force contract. Initial aerodynamic survey work indicated that the extensive use of a supersonic wind tunnel would be necessary.

In June of 1946; Air Force contractual arrangements were completed for the design and construction of a supersonic wind tunnel. It was contemplated that such a facility would provide needed test data for the University of Michigan and other Air Force contractors, as well as to provide a pilot facility for the unique type of circuit being considered.

The site selected was the large hangar immediately south of the Willow Run Airline Terminal, approximately 12 miles east of Ann Arbor. Following a period of active design work, construction was started in September of 1946 and it was initially operated in June of 1947. A summary of the experiences gained in construction and operation up to May, 1948, was issued as reference 1. By July of 1948, the wind tunnel and its associated equipment had been developed, improved, and calibrated to a state where active test programs were underway.

III DESCRIPTION OF WIND TUNNEL CIRCUIT

The wind tunnel is of the intermittent-flow, vacuum type, a sectional view of which is shown in figure 1. Operating potential is established by evacuating a 13,000 cu. ft. vacuum tank and utilizing the pressure differential between the atmospheric air storage bag and the tank to establish supersonic flow in the test section. With atmospheric temperature and

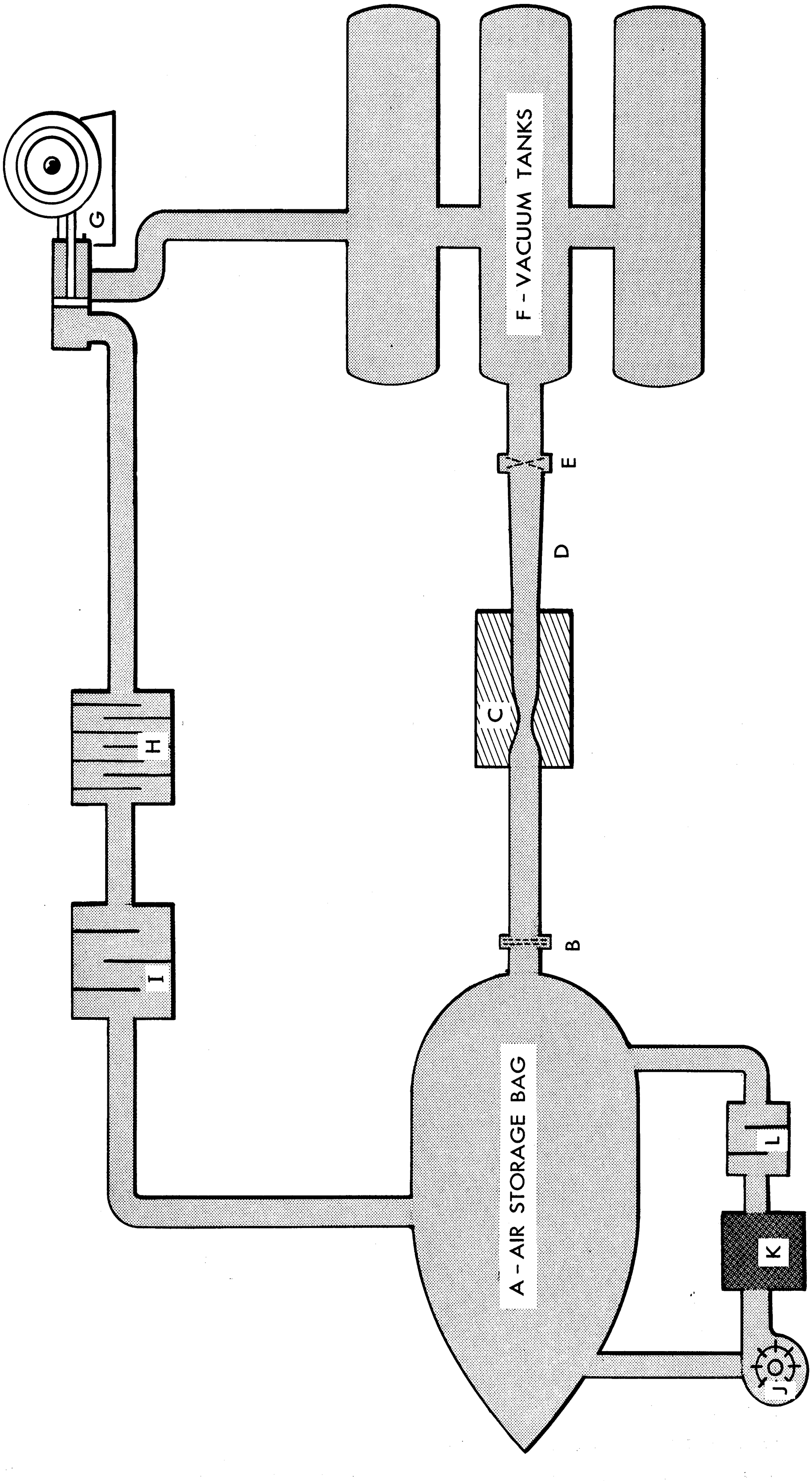


FIG. 2 DIAGRAM OF TUNNEL CIRCUIT

pressure in the air storage bag, uniform conditions are maintained in the test section throughout the run. A block diagram of the circuit is shown in figure 2. After the vacuum tanks (F) have been evacuated to a sufficiently low pressure, the master control valve (E) is rapidly opened and air which has previously been cleaned and dried flows from the air storage bag (A) through the converging section and turbulence screens (B) into the nozzle and test section (C) and out through the diffuser (D) into the vacuum tanks (F). During operation, the increase in pressure within the vacuum tank causes the diffuser shock to move upstream through the diffuser and to the rear of the test section. At this point the master control valve is closed and the run terminated. A normal run is of the order of 5 to 15 seconds in duration with approximately 5 to 15 minutes of vacuum pump operation required before the next run can be made.

The wind tunnel circuit is unique in that it employs a closed return circuit in order to reduce the problem of drying and cleaning the test air. In the return circuit the discharged air from the vacuum pump (G) is returned to the air storage bag by way of a surge chamber (H) and an electronic dust collector (I). In addition, a secondary circuit exists for the air drying equipment. During operation, a blower (J) continually circulates air from the storage bag through the driers (K), through a dust collector (L), and back into the storage bag. Because of this closed return circuit feature, the air drying equipment is minimized to that necessary for initially charging the storage bag plus overcoming air leakage and water leakage into the circuit.

The major pieces of capital equipment used in the wind tunnel circuit are listed in the appendix.

IV NOZZLE AND TEST SECTION

The nozzle support and mounting section is distinct from the test section, with a juncture between the two. Two symmetrical nozzles machined from aluminum forgings are used to effect a two-dimensional expansion to supersonic speeds. The nozzle contours have been computed by standard methods and boundary layer corrections applied to them. The nozzles are inserted by removing one or both of the parallel side plates and sliding the nozzle blocks into place in machine grooves which properly orient them. After replacing the side plates, dowel pins are inserted in the assembly in order to transfer part of the nozzle air load into the side plates and help reduce deflections. From 1 to 2 hours are required to

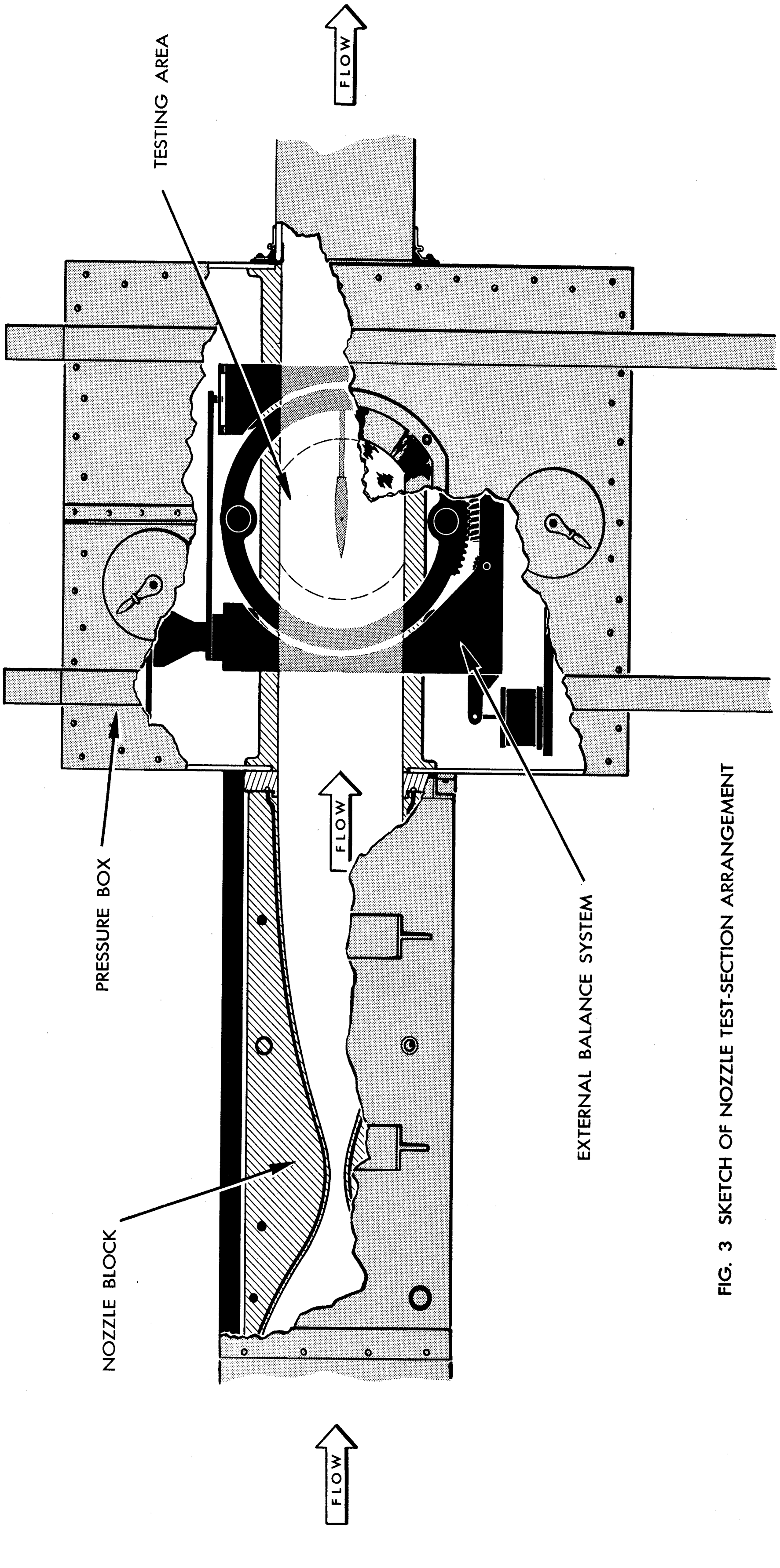


FIG. 3 SKETCH OF NOZZLE TEST-SECTION ARRANGEMENT

change a set of nozzle blocks. The machining tolerances of the nozzle blocks have been held to ± 0.001 inches with minimum departure from a faired curve.

The test section configuration has been determined primarily by the initial concept of a pressure-tight box enclosing the balance system and surrounding the test section (Fig. 3). This box is vented to the test section through gills located downstream from the model support strut.

The test section is rectangular in shape, having plane parallel walls with the dimensions of: height - 13 inches, width - 8 inches, and an overall length of 54 inches. The window center is located 27 inches downstream from the nozzle juncture and the angle of attack mechanism is such that models are pivoted about this point.

The test section has provision for floor and wall mounting of models (Fig. 4) as well as the conventional rear sting mounting for force and pressure testing.

Inflatable $\frac{1}{4}$" diameter rubber tubing with 80 psi internal air pressure is used throughout the nozzle and test section as air seals. In addition the chief structural design criterion has been to limit all deflections to 0.0005 inches or less under a pressure load of 1 atmosphere, and to require all surface fits exposed to the air channel to be within a tolerance of ± 0.0010 inches.

At the exit of the test section a simple diffuser expands the air channel over a 9-foot length into a 22-inch diameter circle at the master control valve.

V VACUUM TANK AND DISCHARGE CIRCUIT

Test air leaving the diffuser passes the master control valve and enters the vacuum tanks. This valve is a 22-inch diameter butterfly valve with a rubber seat and has an electric motor drive with approximately $1\frac{1}{2}$ seconds required to either fully open or close.

The vacuum tank has a volume of 13,000 cu. ft. and is composed of nine reinforced railroad tank cars manifolded together. This arrangement of war surplus materials was used in order to save construction time. They have

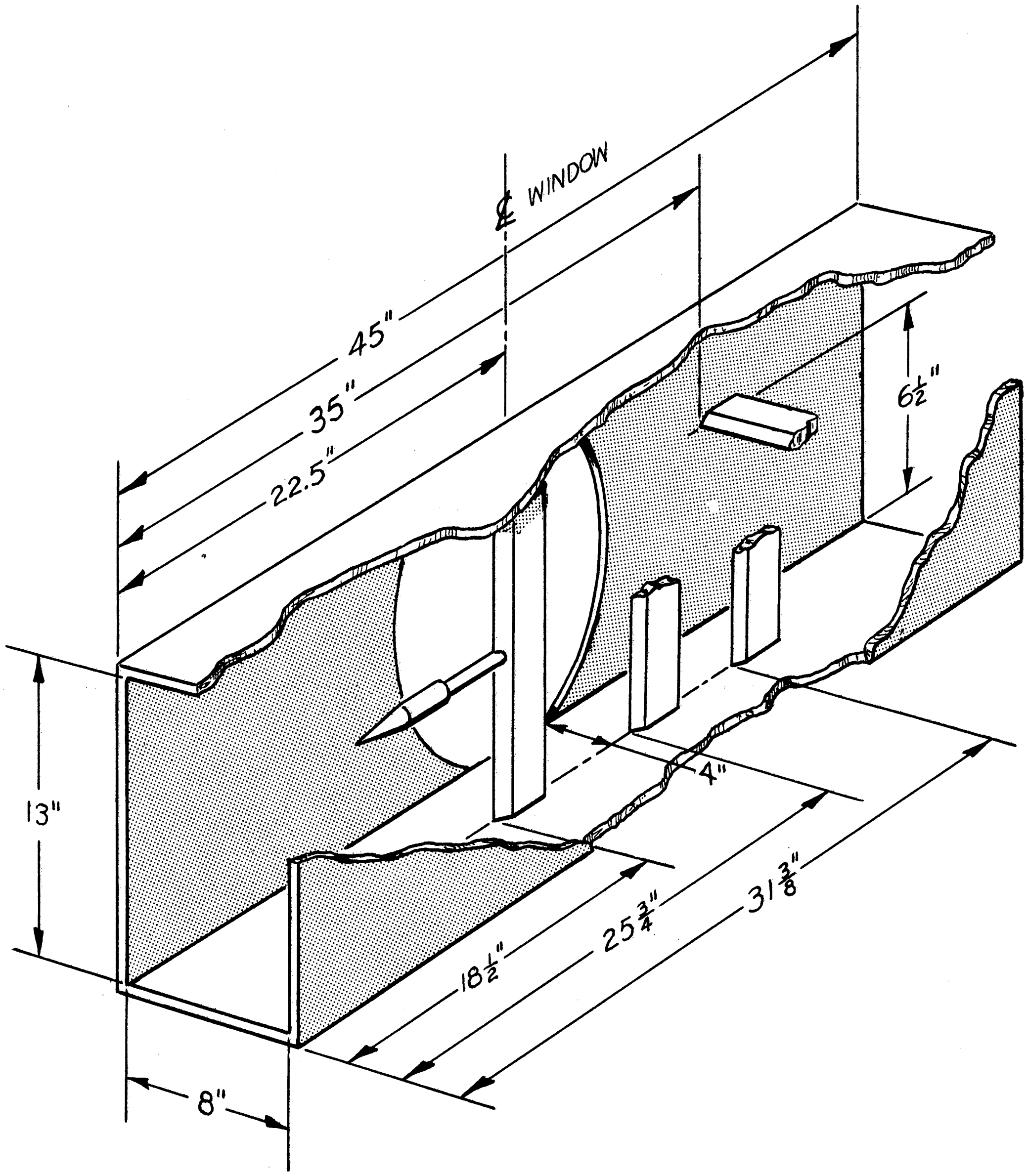


FIG. 4 CUTAWAY OF TEST SECTION SHOWING STRUT LOCATIONS

been sealed externally with an automotive type undercoating to minimize air leakage at the joints.

The present positive displacement type vacuum pump was selected in order to eliminate the contaminating effects of oil vapor and water vapor from the air stream. The air, upon discharge from the vacuum pump, is passed through a surge chamber in order to dampen pulsations due to the reciprocating action of the pump. Following this an electronic precipitron type dust collector is used to remove dust particles from the flow. Some oil contamination does occur from the pump and both of the above items have also acted as oil collectors. This scheme has been moderately satisfactory, although for certain critical temperature and pressure conditions, condensation or pump cooling water tends to leak from the cooling jacket into the pump cylinder and hence into the test air. Under these conditions, the return circuit is opened and the wet air is discharged directly to the atmosphere - throwing an added load on the driers which are then required to replenish the test air in the storage bag from the atmosphere.

VI AIR STORAGE BAG AND DRYING CIRCUIT

The primary purpose of the air storage bag is to contain the cleaned and dried test air at constant pressure and temperature. For this purpose a surplus barrage balloon has been modified and used. The bag was stripped of its appendages, inverted and suspended from the hangar roof. The bag material is a double thickness cotton cloth, impregnated with neoprene and coated on the outer surface with a special aluminum paint developed by the University after a study of coating materials. This coating consists of a plastic called SARAN to which aluminum flakes have been added, and is quite flexible with good adherence to the bag surface.

In order to maintain dewpoints of the order of -20°F or lower in the air storage bag, a separate drying circuit is used. Air is continually taken from the bag, passed through a drier, filtered and returned. Analysis of the drying problem has indicated that three parameters must be controlled: water vapor permeability of the storage bag fabric, adequate drier outlet dewpoints, and rate of circulation of air through the drier. The limit dewpoint of the air storage bag is given in figure 5 as a function of the fabric permeability and the drier flow rate. It may be noted that the lowering of dewpoints by increasing the flow rate is an asymptotic function with the drier outlet dewpoint as the limit value.

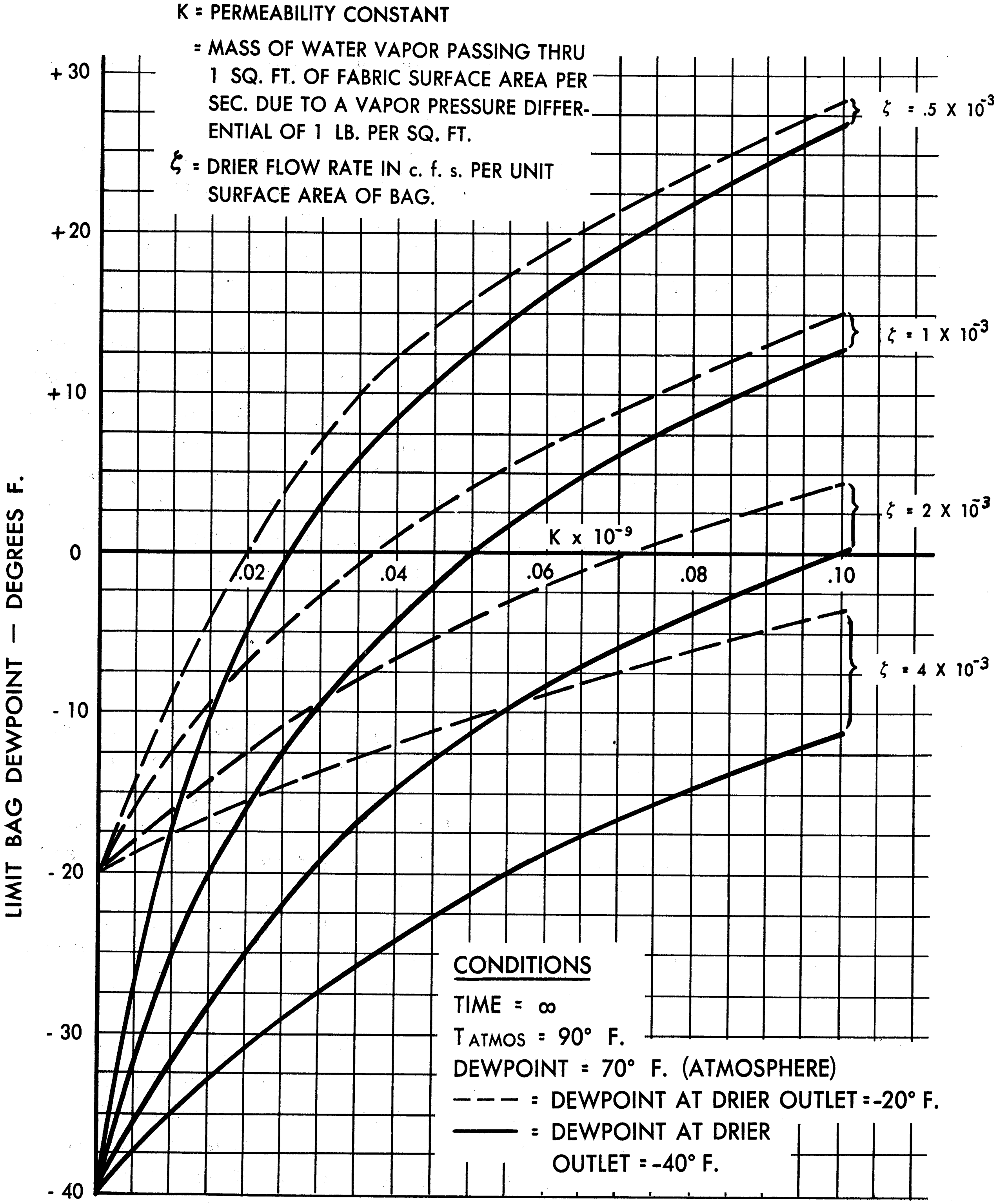


FIG. 5 INFLUENCE of BAG PERMEABILITY & DRIER FLOW RATE UPON LIMIT BAG DEWPOINT

The drying system consists of two activated alumina driers operated in parallel with a combined flow rate of 1,000 cfm which recirculate the air continually throughout the test day. The drier capacities are such that they are in balance with the pumping capacity for open circuit operation under normal operating conditions. During summer operation, the air temperature entering the drier beds can be well above 100°F with consequent lowering of the desiccant efficiency, and it was found necessary to install air coolers immediately ahead of the driers in order to maintain entering air temperatures of 80°F or lower.

Experience gained to date has indicated the desirability of decreasing the permeable surface of the air storage bag to a minimum. This could be accomplished most readily by using a large metal can to form the sides and bottom of the reservoir, with a flexible hemispherical diaphragm forming the dome. The use of deep-bed driers has been found desirable in producing low dewpoints. However, a dehumidifier could be added in order to remove the bulk of the water vapor when charging directly from the atmosphere, thereby relieving the driers.

Because of the complexity of the associated air-drying and charging equipment, it is essential that adequate safety devices be installed in order to prevent over-inflation of the air storage bag. In the present installation two mercury switches actuated by the bag displacement are installed, which first give an audio signal followed by shutdown of all charging equipment if the critical point is reached.

At the forward end of the bag a large circular screen shaped to the balloon nose contour forms the beginning of the contraction section for air entering the nozzle region. In the contraction section there are three turbulence screens of No. 30 mesh wire located 8 inches apart. The drop in total head pressure through these screens is very nearly compensated by the pressure increase because of the weight of the air storage bag. Tests have shown that there is little measurable change in total head pressure at the entrance to the nozzle section during a test run.

A special gate valve is installed immediately upstream of the nozzle section. Its purpose is to allow evacuation of the nozzle, test, and diffuser sections without air flow, by closing the gate valve and opening the master control valve. This permits checking these sections for leakage prior to running and also permits the calibration of pressure sensitive instruments - particularly those employing an electrical circuit in which

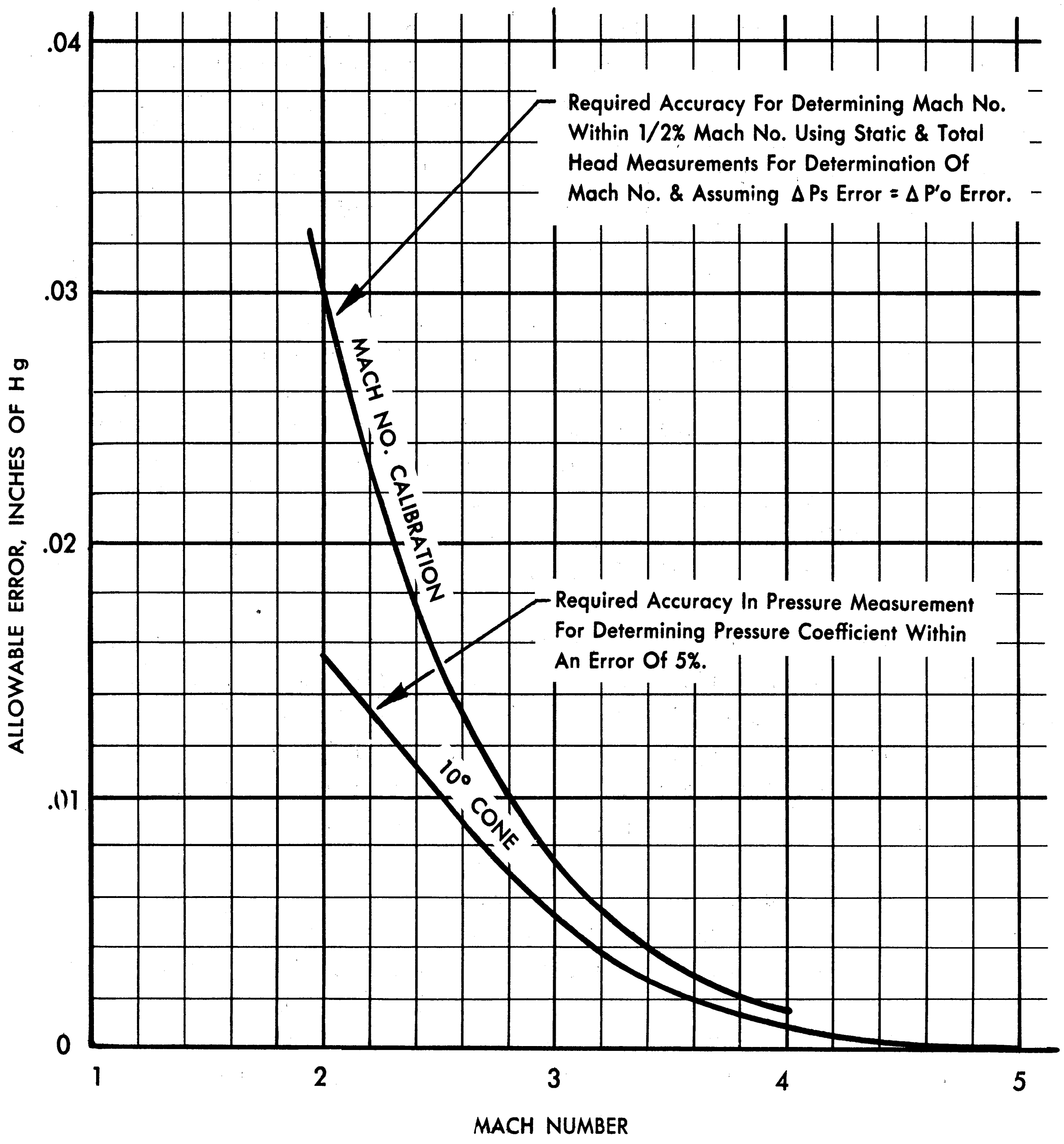


FIG. 6 ALLOWABLE ERROR IN PRESSURE MEASUREMENT FOR DETERMINATION OF TUNNEL MACH NUMBER AND PRESSURE COEFFICIENT OVER A CONE

the surroundings may influence the responses. This gate valve also permits isolation of the test section from the rest of the circuit during model changes.

VII INSTRUMENTATION

In general three basic techniques are employed for obtaining aerodynamic data: pressure measurement, utilizing multiple manometers and electric gages; optical techniques, utilizing the Schlieren and shadowgraph systems; and the measurement of over-all aerodynamic loads by means of a balance system.

An intermittent vacuum tunnel presents numerous problems in instrumentation. In the Mach number range from 1.5 to 4.0 there is a considerable spread in the magnitude of the physical quantities being measured, and also in the required accuracy of the measurement. In addition, stabilization of recorded data within the short run time of approximately 5 to 15 seconds must be accomplished. This short run time requires that all data be recorded during the run by photographic or other means.

A major requirement of the pressure measuring system is that the absolute accuracy for pressure measurement be held within prescribed limits which vary with Mach number if reasonable accuracy is to be obtained in the calculated parameters, such as pressure coefficients and Mach number. To determine Mach number within an accuracy of $\frac{1}{2}\%$ of Mach number, the accuracy of the required pressure measurement is shown in figure 6. This figure is based on two primary assumptions: the Mach number determination is obtained by pressure measurement of the total and static head at a particular point, and the same absolute error in the pressure measurement exists for both total and static tubes. It will be noted that the allowable error in pressure measurement of ± 0.030 inches of mercury at Mach number 2 is decreased to ± 0.002 inches of mercury at Mach number 4. An even more stringent requirement is placed on the pressure measuring device in the case of pressure coefficient determination for bodies of revolution. Figure 6 also shows the required accuracy of pressure measurements in order to determine the pressure coefficient within an accuracy of 5% of the theoretical value. It will be noted that at Mach number 4, with a 10° cone, it becomes necessary to measure with an accuracy of ± 0.0015 inches of mercury.

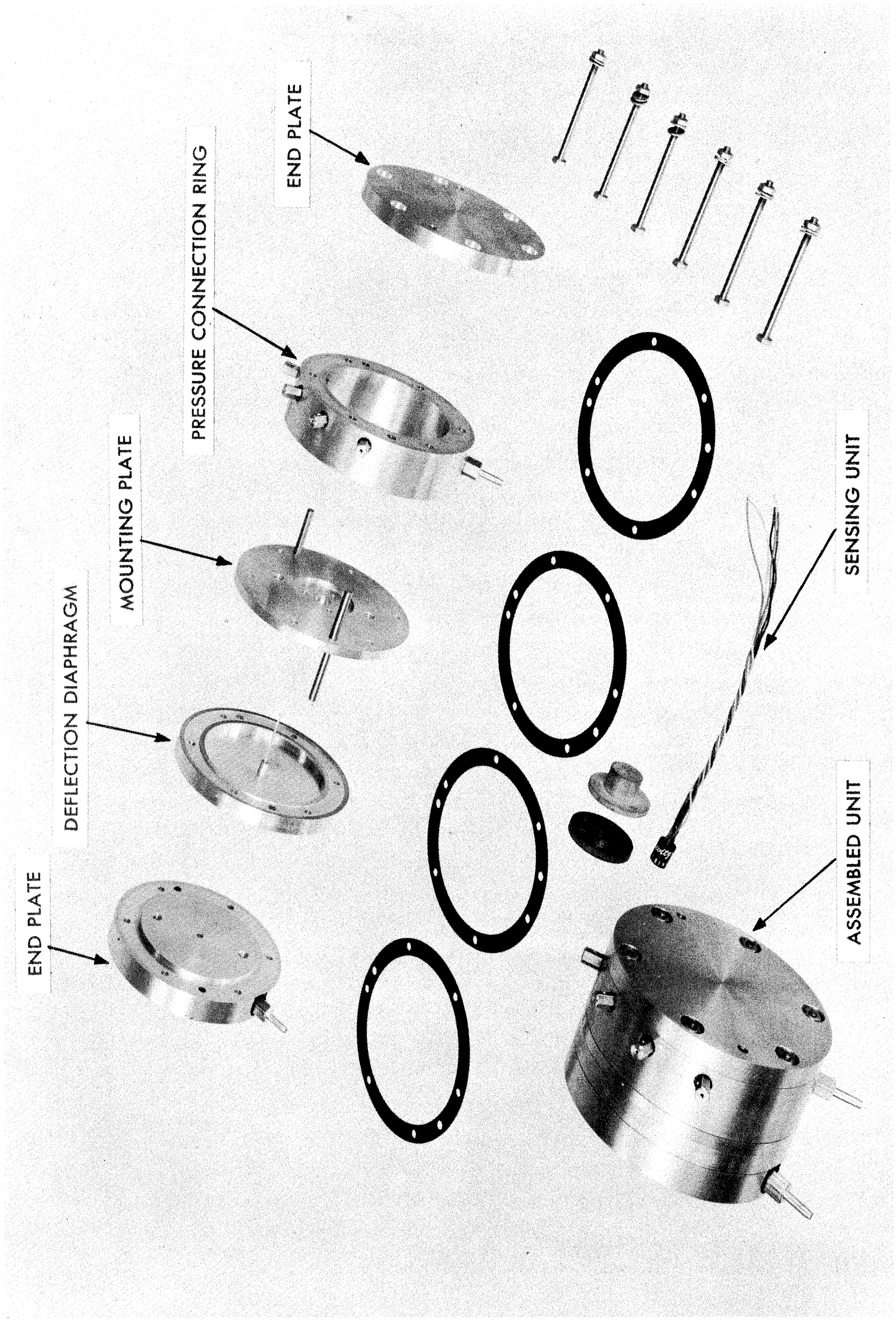
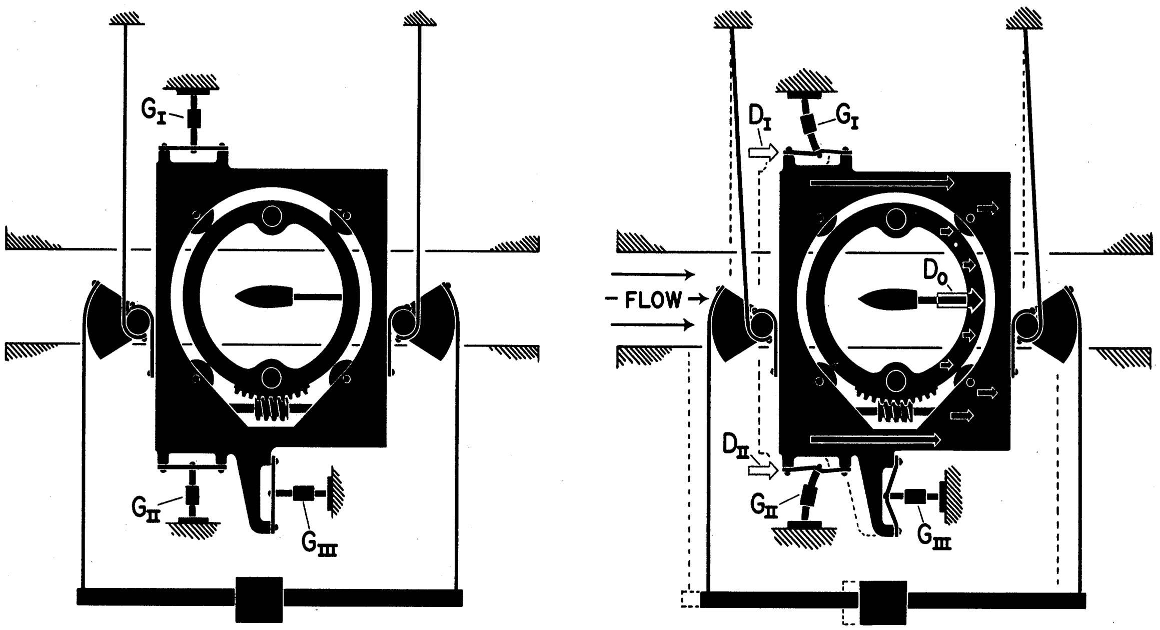


FIG. 7 COMPONENT PARTS OF ELECTRICAL PRESSURE GAGE

Manometric measurements are made with a 4 bank, 100 tube, 5 foot vertical manometer. Back lighting is provided for photographic recording. In order to provide pressure stabilization within the run time, a guillotine clamp is employed between the manometer bank and pressure orifices. By closing the guillotine prior to shutdown, the manometer pattern is preserved and usually permits rapid stabilization in the succeeding run. A statistical study of errors arising when using mercury for testing at Mach number 1.9 has indicated a standard deviation of ± 0.030 inches of mercury. At the present time a study is being made of the accuracy of measurement when using oil as a manometer fluid. Preliminary data indicate that the use of such a fluid offers considerably greater accuracy than mercury. However, annoying problems arise such as de-gassing of the oil and that of air leakage into the manometer system. As a result of these problems, which invariably cause test delays, work is being done on electrical pressure gages.

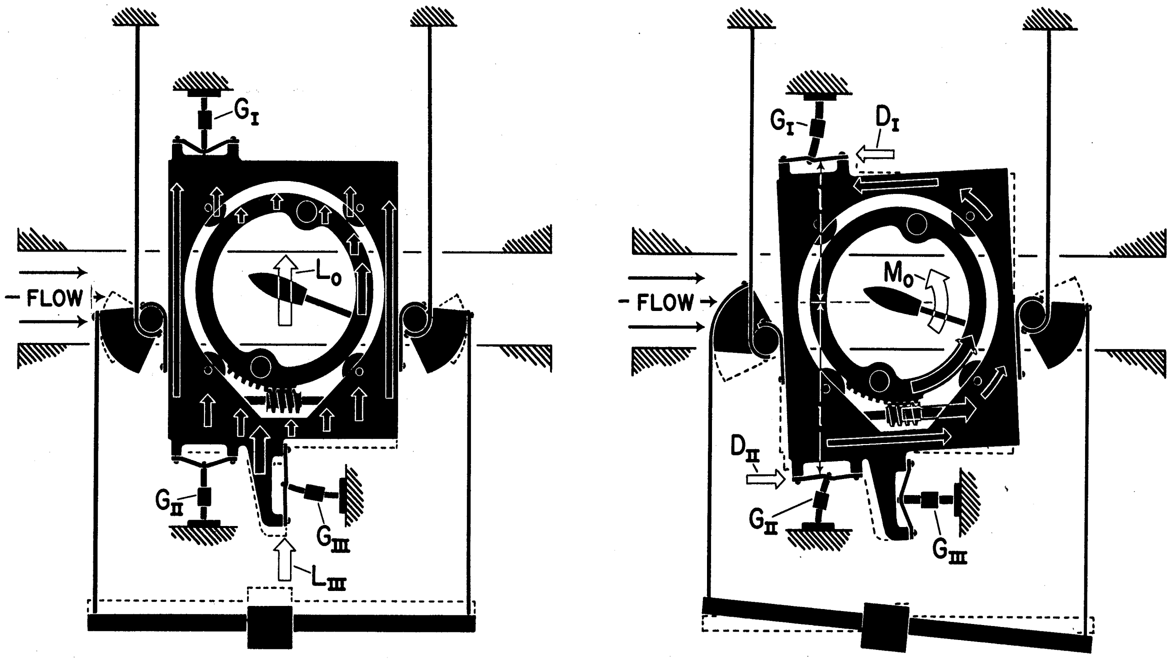
The pressure gages in use thus far have been designed and constructed by the wind tunnel instrumentation group. They consist basically of a flat diaphragm which deflects under a pressure differential and activates a Schaevitz linear variable differential transformer (Fig. 7). To date these gages have been constructed having a maximum sensitivity of .0002 psi and a range of 5.0 psi within which it is linear to ½%. For maximum sensitivities it is necessary to refer one side of the gage to a pressure nearly equal to the measured quantity. McLeod type gages are being installed to increase the accuracy of measuring the reference pressure.

The optical equipment consists primarily of a conventional single-coincidence type Schlieren system utilizing 16-inch diameter parabolic mirrors with a focal length of 10 feet, and a high intensity mercury vapor light source. This system is so arranged that it may be operated continuously for visual observation of the test section flow, or intermittently with a 2 to 4 microseconds flash for photographic purposes. In order to observe dynamic flow conditions, a high-speed motion picture camera is used in the Schlieren system at speeds up to 5,000 frames per second. Portable floor mountings are provided for special Schlieren setups. A removable light tube has been installed to enclose the entire light path from the source to the camera, in order to improve the quality of the higher Mach number Schlieren photos. It has also been found necessary to stop the reciprocating vacuum pump when taking highly sensitive Schlieren pictures, since the pump vibrations transmitted through the building are noticeable.



NEUTRAL POSITION

DRAG -- $D_0 = D_I + D_{II}$



LIFT --- $L_0 = L_{III}$

PITCHING MOMENT -- $M_0 = l(D_{II} + D_I)$

FIG. 8 SKETCH OF EXTERNAL THREE-COMPONENT BALANCE SYSTEM

RESPONSE TO AERODYNAMIC LOADS

As mentioned previously in Section IV, one of the major initial design criteria was the use of a balance system external to the test section. Figure 8 shows a schematic diagram, illustrating the principle of operation for the external three-component system. The portion of the balance system supporting the model is suspended and counter-weighted in such a manner that it is effectively bouyant and tends to translate or rotate in response to the aerodynamic loads on the model. This floating structure is restrained by force-sensing elements in such a manner that interaction is minimized. These elements are essentially cantilever beams with electric strain gages mounted near their bases. Operation of the above balance system under test conditions brought to light several inherent difficulties due to the method of support of the balance from the pressure box and the venting of this box to the air stream. A balanced diaphragm seal was then developed and installed internal to the windshield (Fig. 9) which, along with other minor changes, made the pressure box unnecessary. Dash pots were installed to damp the oscillation of the balance system so that test data for one model setting could be obtained in an 8-second run.

Because of inherent difficulties of the external balance system, a balance system completely internal to the test section has also been designed and built (Fig. 10). With this internal balance system, normal force and moment are measured by strain gages mounted on the model sting. The after portion of the sting is ball-bearing mounted in a track which allows freedom of motion in the axial direction only. Axial force is measured by strain gages mounted on a compression ring which restrains the axial motion.

The use of this internal balance system has proved it to be a faster recording unit than the external system and in many respects more reliable and easier to maintain than the external system. It is therefore planned to use the internal balance system for all force measurements wherever possible, and to use the external system only for special testing arrangements.

Electrical measurements and recording for the pressure gages and the balance system are made through an alternating current Wheatstone bridge circuit. Measurements are observed by a string galvanometer which records upon photographic paper. Calibration of this equipment indicates that the complete system is linear over a 4-inch recorded scale and the standard deviation is approximately 0.25% of full-scale.

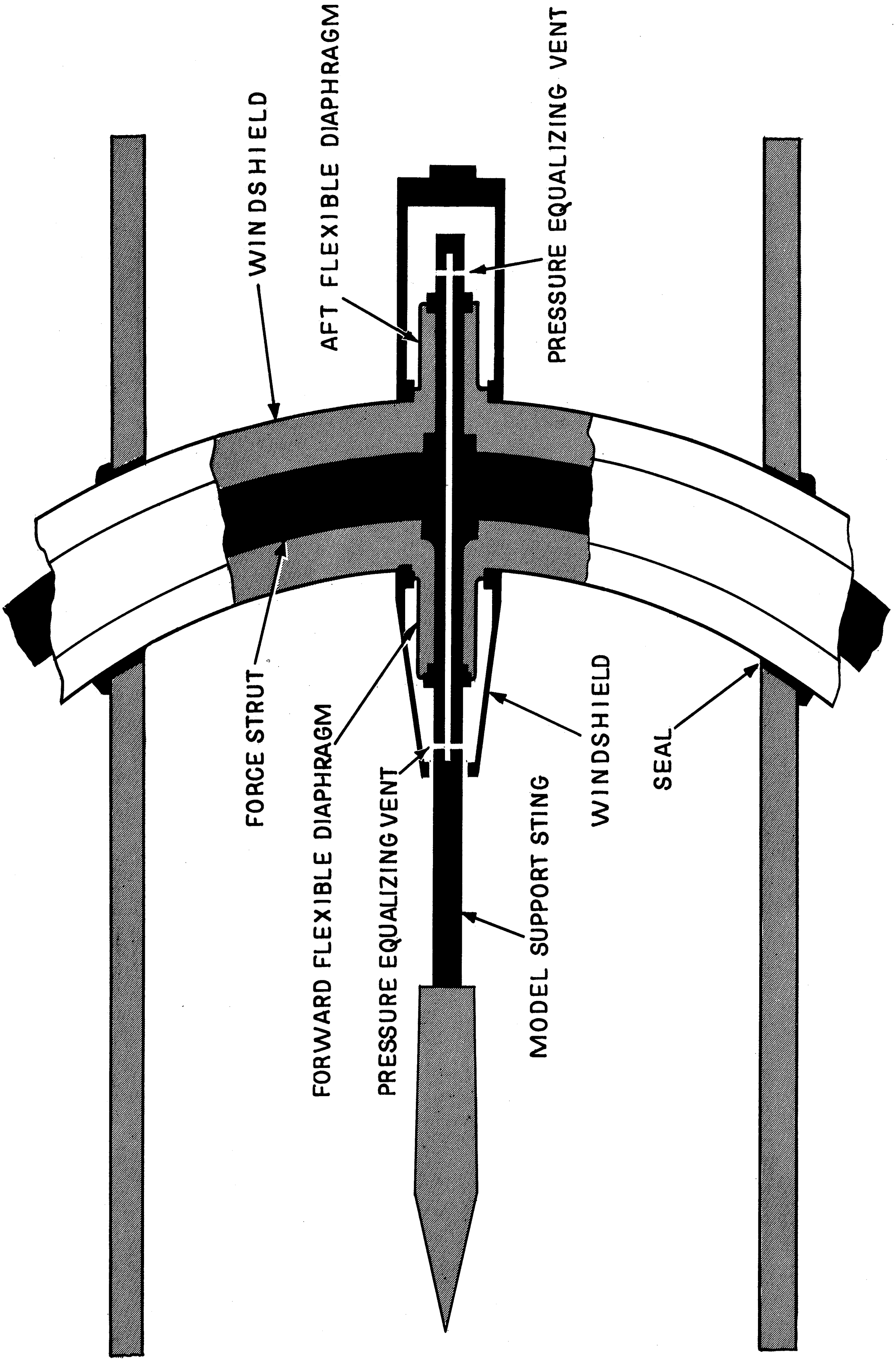
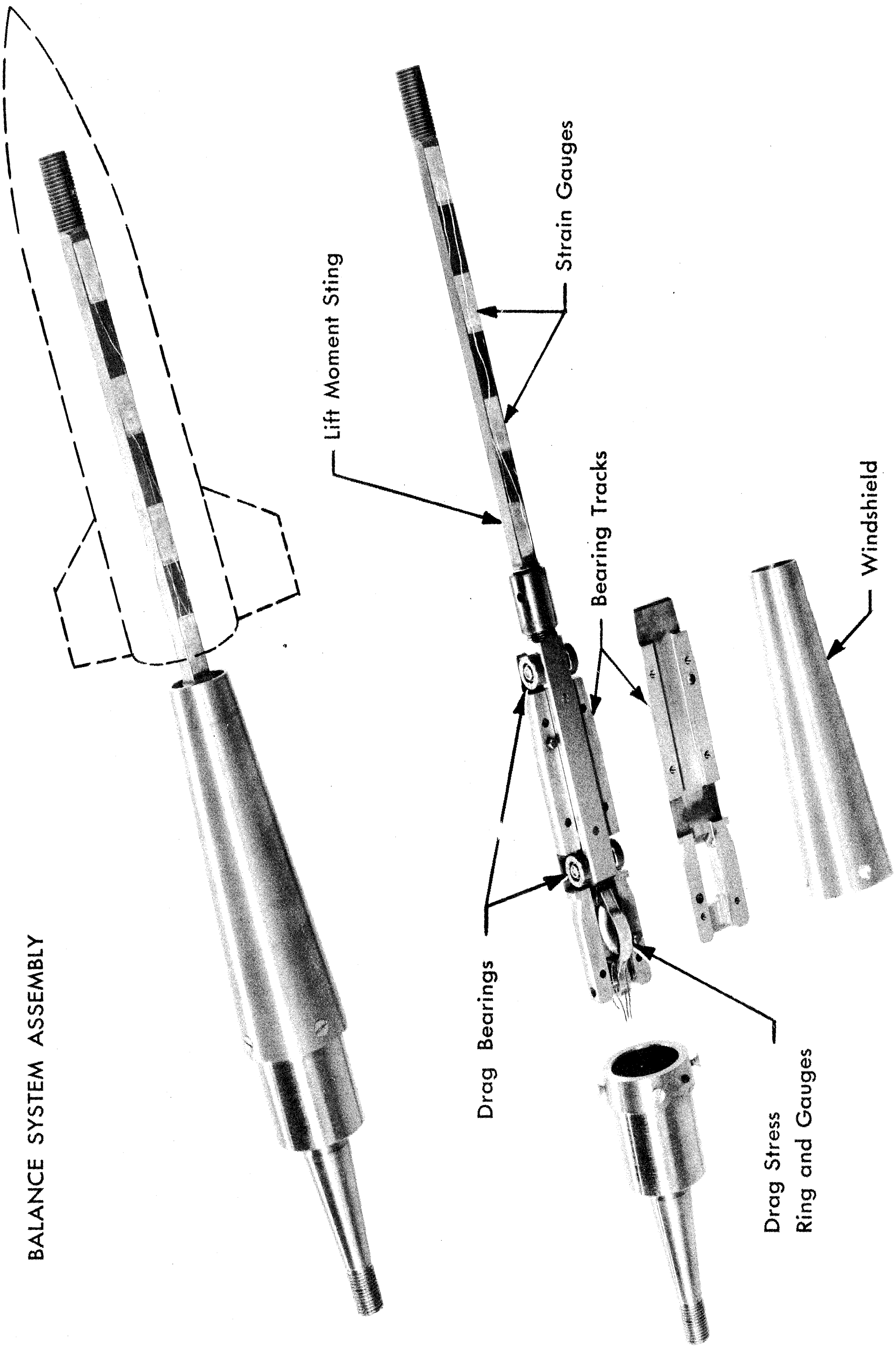


FIG. 9 BALANCED DIAPHRAM ASSEMBLY



BALANCE SYSTEM ASSEMBLY

FIG. 10 EXPLODED VIEW OF BALANCE SYSTEM

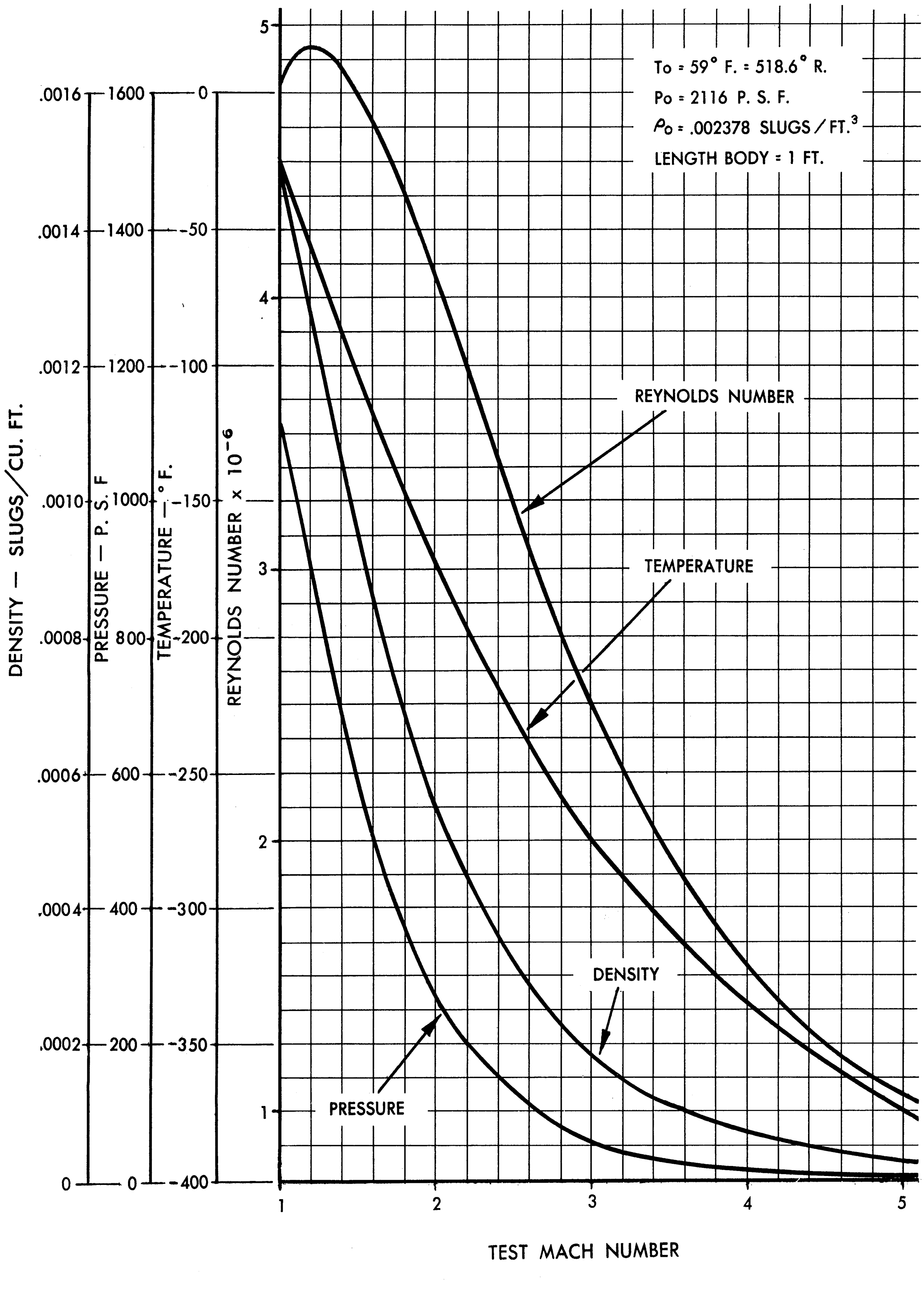


FIG. 11 AERODYNAMIC CONDITIONS IN TEST SECTION AS A FUNCTION OF MACH NUMBER

VIII AERODYNAMIC CHARACTERISTICS AND CALIBRATION

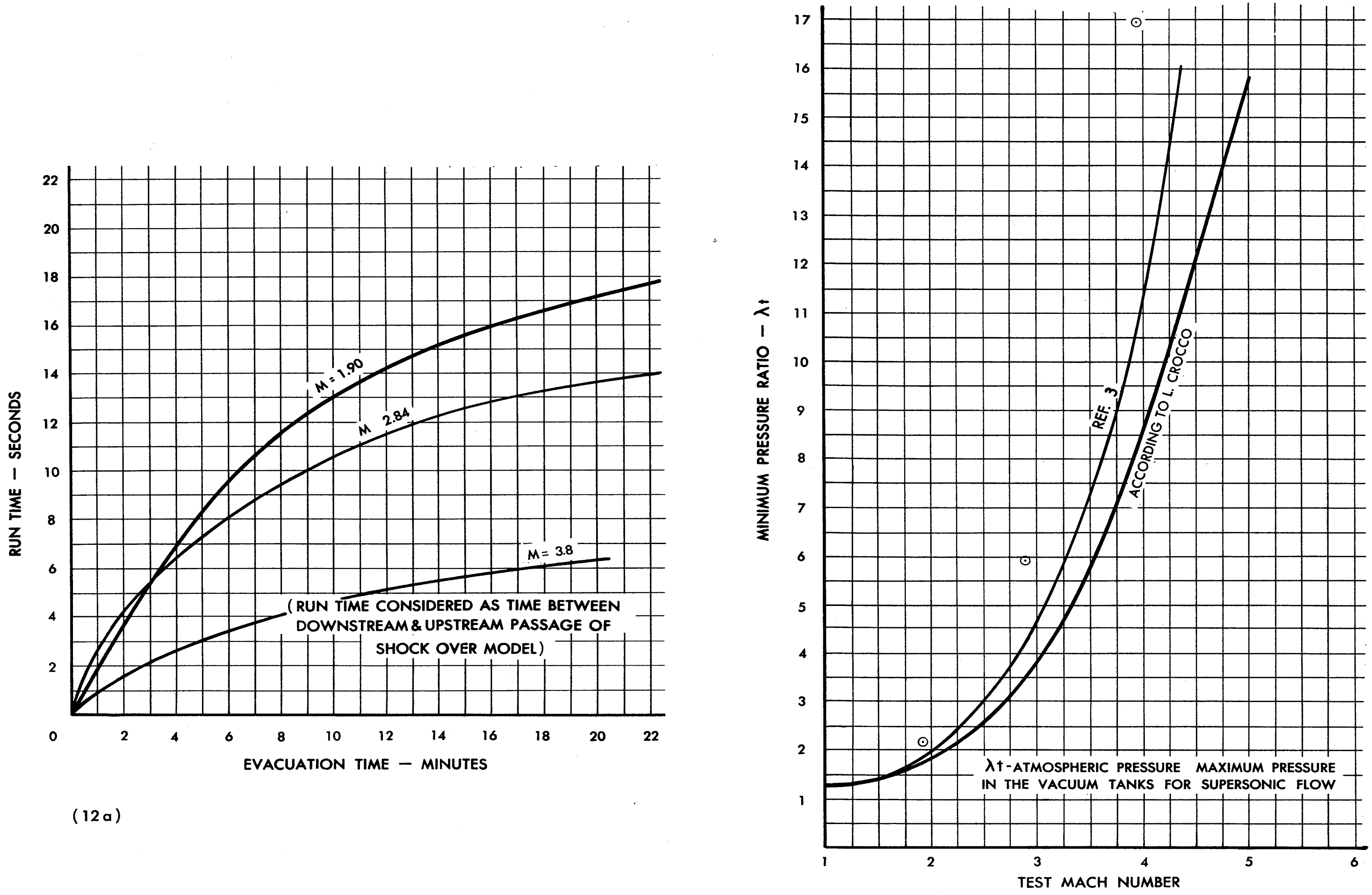
In a vacuum tunnel of this type, the test section stagnation conditions are essentially those existing in the air reservoir. Based upon an isentropic expansion, the calculated test section conditions are plotted in figure 11 as static pressure, dynamic pressure, stagnant temperature, and Reynolds number vs. Mach number.

The length of uniform supersonic run time is shown as a function of evacuation time in figure 12a. It is experimentally observed that as the tank pressure approaches the limiting value, flow in the test section becomes unsteady. In the above figure only the steady running period is considered. In figure 12b is shown the diffuser efficiency obtained with the simple diffuser in use, again only for the uniform supersonic flow. As seen from this curve, there is need for improvement of diffuser efficiency. For this reason a variable geometry spike diffuser has been designed and is ready for installation.

In view of aerodynamic and instrumentation limitations, it is contemplated to operate over a Mach number range of 1.5 to 4.0. To date nozzles for design Mach numbers of 1.5, 2.0, 2.5, 3.0, and 4.0 have been released and are in the various stages of production, installation, and calibration.

Of the various methods available for calibration, analysis has indicated that one of the more accurate techniques is to measure the static and total head pressure at a series of points in the test channel. At each point sufficient data are taken to obtain a statistical value of the measured pressure. From these data, values of stagnation pressure are calculated. It has been observed that the stagnation pressure, P_o, is lower than that measured in the air storage bag but it appears to remain constant within the test section. By means of a total head probe, a complete survey is then made of the entire test section and the Mach number distribution obtained by relating P_o' to P_o. P_o' is the stagnation pressure behind a shock measured by a total head probe. Figure 13a is a plot of the experimental Mach number in the test section determined in the above manner for the 1.90 Mach number nozzle (see reference 2 for further details).

Flow inclination is determined by use of a double wedge with pressure orifices on both of the forward surfaces. Knowing the geometric angle of attack and the pressure differential across the probe, the flow inclination can be obtained (Fig. 13b).



(12a)

(12b)

FIG. 12 SUPERSONIC RUN TIME AS A FUNCTION OF PUMPING TIME AND DIFFUSER EFFICIENCY AS A FUNCTION OF MACH NUMBER

FIG. 13a MACH NO. VARIATION ALONG ℄ OF WIND TUNNEL CORRECTED TO STAGNATION DEW POINT OF -25° F

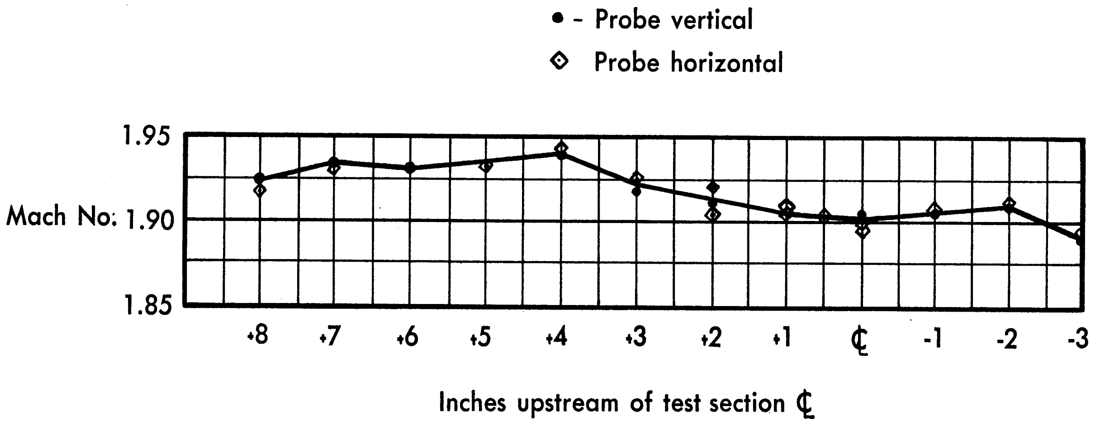


FIG. 13b FLOW INCLINATION, PROBE HORIZONTAL POSITIVE INCLINATION INDICATES POSITIVE ANGLE OF ATTACK FOR MODEL AT GEOMETRIC ZERO

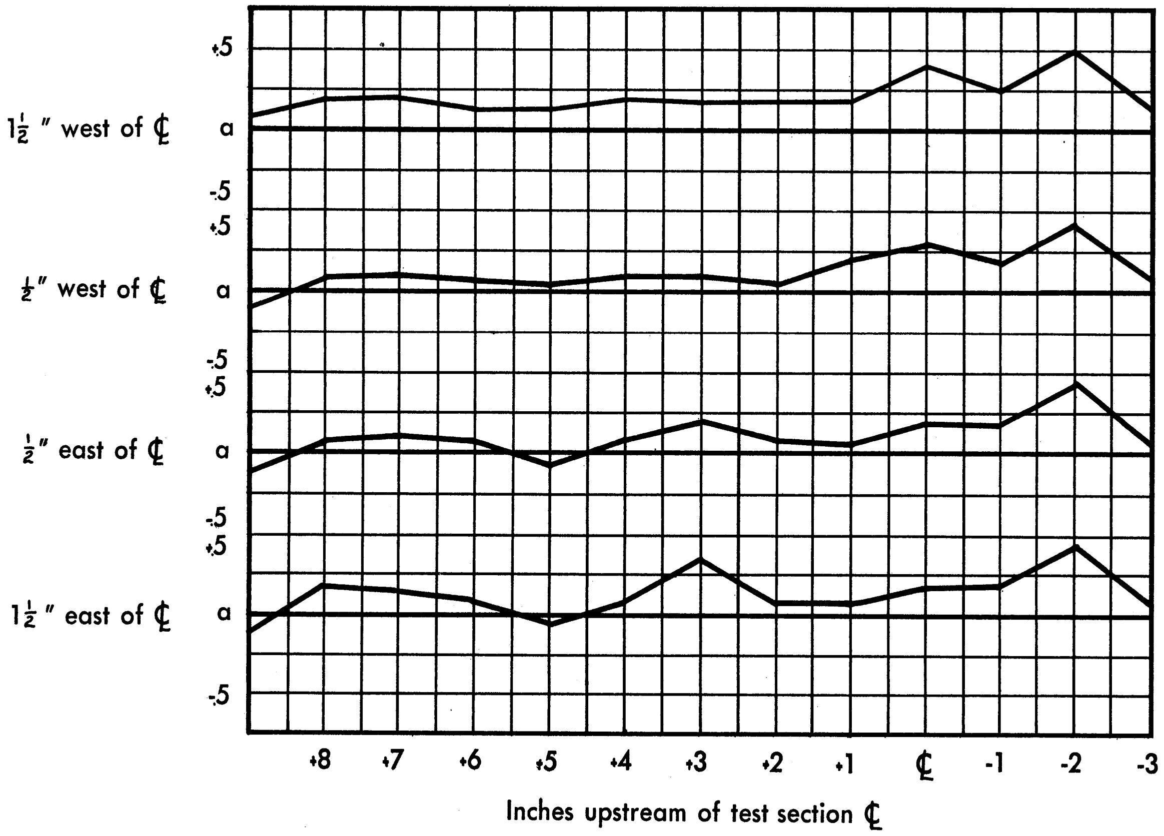
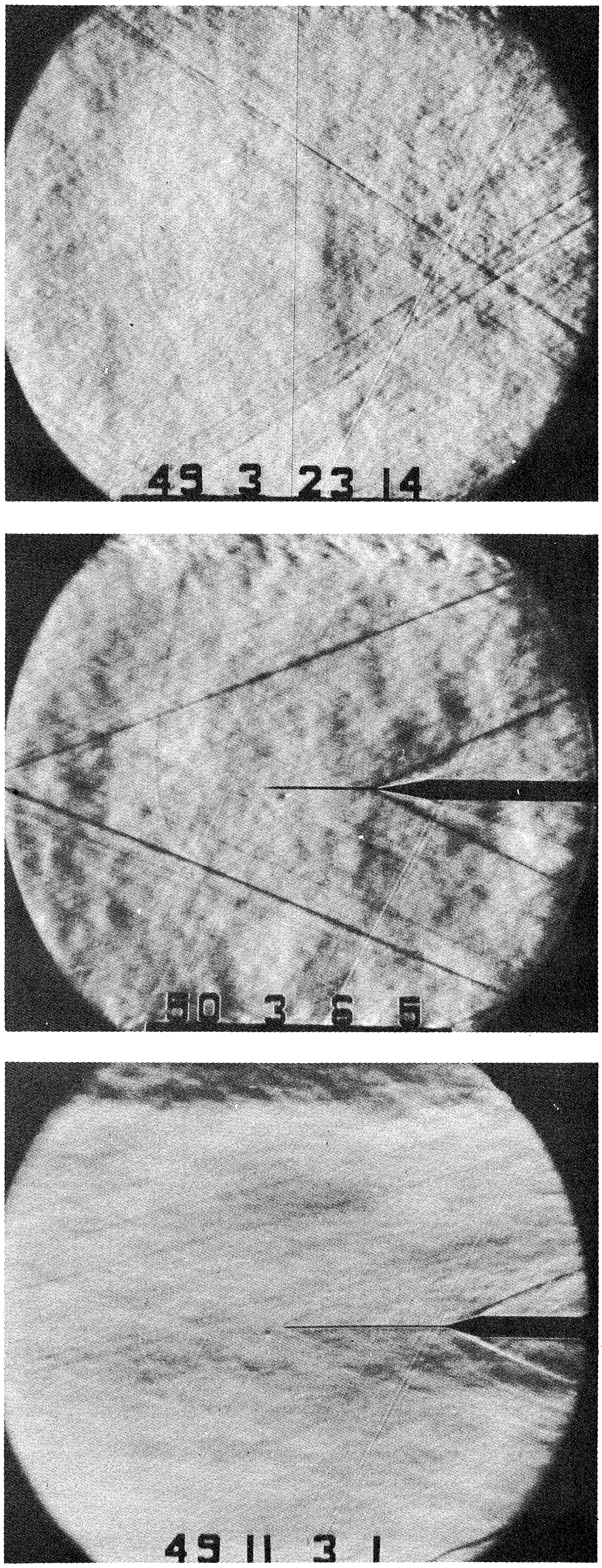


FIG. 13 MACH NUMBER AND FLOW INCLINATION IN TEST SECTION FOR MACH 1.90



M = 1.90

M = 2.84

M = 3.80

FIG. 14 SCHLIEREN PHOTOGRAPHS OF TEST SECTION AT VARIOUS MACH NUMBERS

Schlieren photos showing the quality of flow in the test section for Mach numbers 1.90, 2.84, and 3.8 are given in figure 14.

IX TESTING PROCEDURES

A large number of tests have been run to obtain pressure distributions and force measurements for several bodies of revolution. Shown in figure 15 is a comparison of the normal force coefficient for a 10-degree half-angle cone as computed by linearized theory with that obtained by pressure distribution and also by force measurements. More recent data have shown further improvement in the agreement between pressure and force measuring techniques.

Using the internal balance system to measure the aerodynamic forces on bodies of revolution, it is possible in general to measure the lift within 0.04 pound, drag within 0.02 pound, and moment within 0.15 inch pounds. Maximum loads compatible with these figures are approximately 50 lbs. lift, 15 lbs. drag, and 420 in. lbs. moment. The internal balance system is so constructed that the normal force and moment sting is readily removable, making for ease in range shifting. Alternate stings are available so that tests for a given load range may be conducted with maximum sensitivity.

In order to allow adequate time for stabilization of the instrumentation and the recording of sufficient data, it requires approximately 15 seconds of supersonic operation for manometer pressure measurements, and 5 seconds for force data. All data are recorded photographically and the film developed in the wind tunnel building.

The critical dimension for most models is length, which is limited by the reflection of the nose shock upon the model support sting. A model length of 8 inches at Mach number 1.90 is sufficient to allow accurate aerodynamic data to be taken and is small enough for economical fabrication. Blocking considerations frequently limit the combined frontal area of the model and support system. Both of the above limitations are, of course, a function of the Mach number and model geometry. A load factor of approximately 5 is generally employed in the model design in order to adequately stress for the critical condition. Peak stresses are encountered during tunnel starting when the normal shock is passing the body. At this time the loads reach a maximum for a period of approximately $\frac{1}{2}$ second after which they quickly subside.

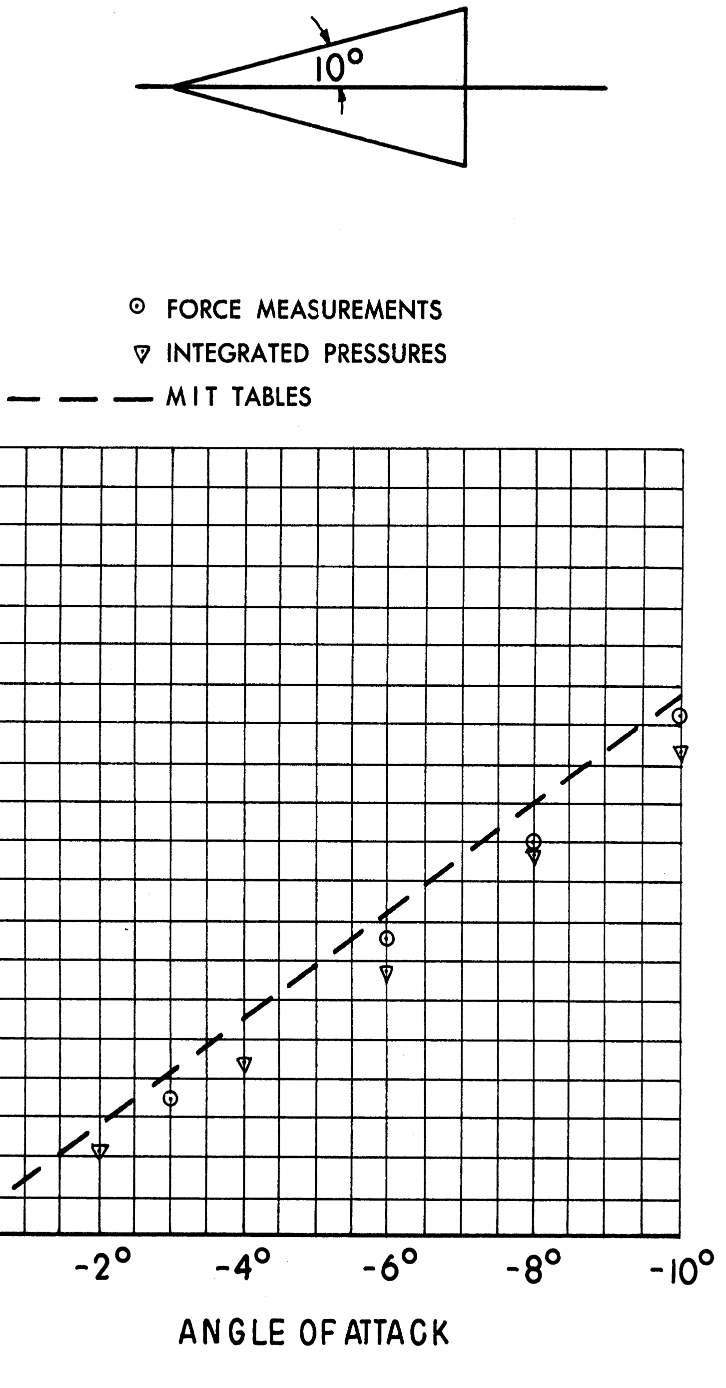


FIG. 15 COMPARISON OF COMPUTED AND MEASURED NORMAL FORCE COEFFICIENT FOR A 20° CONE AT ANGLES OF ATTACK

Separate support systems are employed for pressure models and force models. Force models are hollow from the base forward and attachment to the strain sensitive sting is made well toward the model nose. The internal balance system is mounted upon a support sector which provides angle of attack control. For pressure models a straight tubular sting extends back from the model base with pressure leads internal to the sting. This unit is then mounted in a sector for angle of attack control. The pressure leads are carried out in such a manner that it is relatively easy to orient the model in roll through a 180° range and also adjust its longitudinal position in the test section.

Operating experience has demonstrated that every possible consideration should be given to make the test section easily accessible and to provide adequate model support mechanisms. Consideration is also being given to the use of a support sector such that more than one model attitude may be tested during a single run.

In order to coordinate the operation of the various wind tunnel circuit mechanisms, and to facilitate the recording of test data, all major controls essential to the operation of the tunnel have been placed on a central panel (Fig. 16). This panel is situated in the test area and is so placed that the tunnel operator has a clear view of the Schlieren screen and also of the test section window. When testing, a crew of two or three is required - a technician who mans the control panel, together with one or two engineers to observe the test and operate the electrical and recording equipment. The personnel necessary for the reduction and analysis of the test data are mainly graduate students employed on a part time basis.

X CONCLUSIONS

The University of Michigan supersonic wind tunnel has proven to be a reliable and economical type of test facility for particular types of work. A wide range of Mach numbers is readily obtained over relatively low but constant Reynolds numbers. The intermittent type of operation has proven particularly useful for development programs where frequent model configuration changes are necessary and can be made during the evacuation period.

Both the type of facility and its size have favored economical operation and staffing by an educational institution. Tunnel circuit changes have been found to be relatively straightforward and inexpensive.

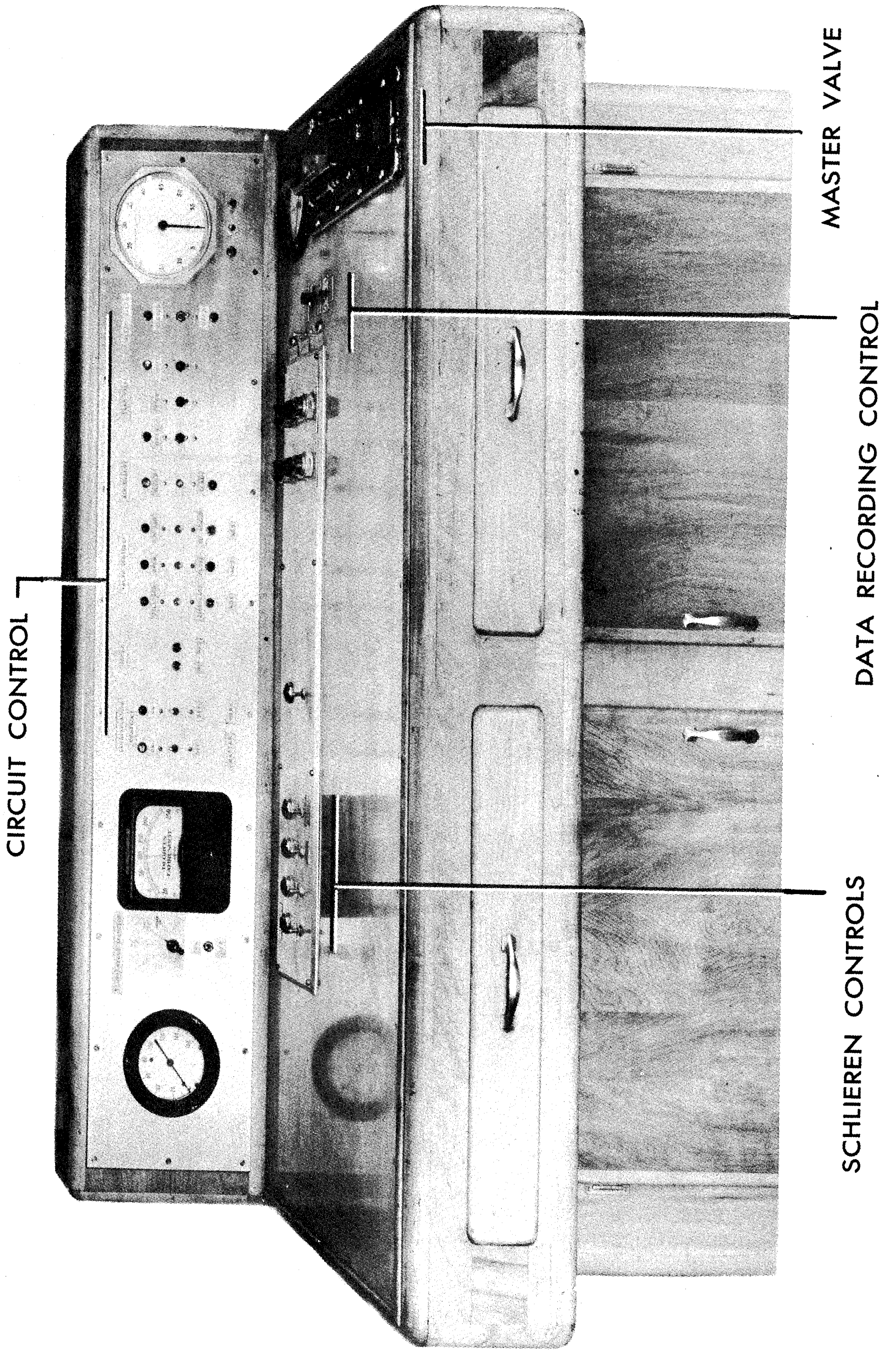


FIG. 16 VIEW OF MAIN CONTROL PANEL

The closed circuit from the vacuum pump to the air storage bag is a desirable feature, although careful attention must be given to the selection of a suitable vacuum pump.

The use of a flexible air storage bag has proven to be practical, although the fabric surface area should be minimized because of water vapor permeability.

The associated instrumentation for intermittent operation with the required short run lengths has been adequately developed and further improvement is being carried out.

APPENDIX

Tabulated below is a listing of some of the capital equipment used in the tunnel. Many items in the system have been especially built by the University shop and are not listed below.

FLOW CIRCUIT

I Air Reservoir

Barrage Balloon -Model ZKA

II Vacuum Pump

Chicago Pneumatic Tool Company
Simplate Valve Vacuum Pump -Model TVB-2
(1700 CFM Displacement)

III Master Valve

Henry Pratt Company
(22-inch diameter rubber seat butterfly valve)

IV Valve Operator

Philadelphia Gear Works
Limitorque Control -Model Gs

V Driers

Lectrodryer Corporation
Lectrodryers -Model BWC-1500
(2 units are used in parallel)

VI Dust Collectors

1. Pump Return Circuit
   American Air Filter -Type MW
2. Drier Circuit
   Dollinger Corporation
   Pipe Line Filter -Model CFHS

INSTRUMENTATION

I Electronic Recording System

Principle electronic recording is accomplished with an Oscillograph-Amplifier unit manufactured by the Wm. Miller Company. The component parts are listed below:

Oscillograph	-Model H
Oscillograph Power Supply	-Model HP 110-3
Amplifier	-Model CA 12-2
Amplifier Power Supply	-Model CP 12-2

(2000 cps, 10-volt input)

II Manometers

Trimont Instrument Company
(100 tube, 60" vertical, 4 bank unit)

III Schlieren System

1. Optics
   Wm. Buchele Company - Parabolic Mirrors and Glass Windows

2. Light Source
   General Electric
   Mercury Vapor Lamp -Model BH6

IV Dew Point Equipment

1. General Electric
   Dew-Point Indicator -Model G6

2. Illinois Testing Laboratories, Inc. -Model 7000 H

REFERENCES

1 Schneyer, R. I., "Interim Report, Intermittent Supersonic Wind Tunnel", University of Michigan, ERI Report EMP-16, 1 June 1948.

2 Culbertson, P. E., "Calibration Report on the University of Michigan Supersonic Wind Tunnel", Parts I and II, University of Michigan, Aeronautical Research Center Report UMM-36, November 1949.

3 Wegener, P., "On the Experimental Investigation of Hypersonic Flow", Naval Ordnance Laboratory, Report NOLM 9629, 29 July 1948.

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