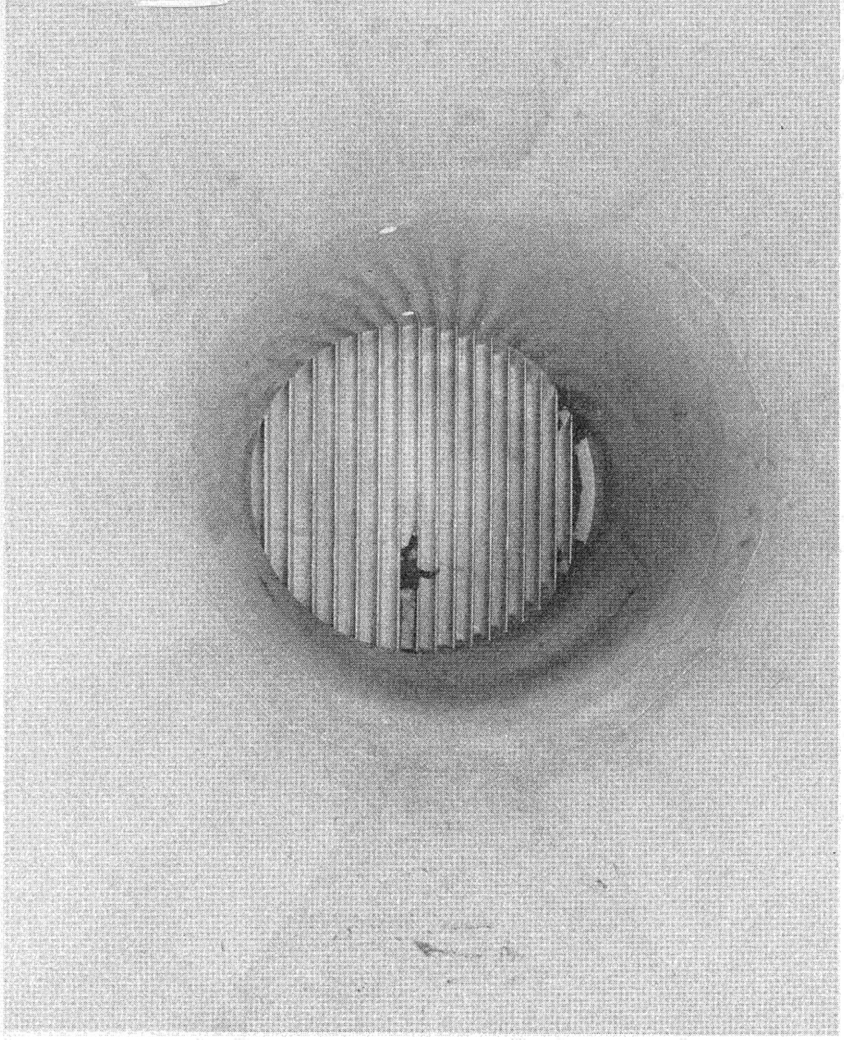

FIG. 6. Turning vanes downstream from working section.

(FIG. 5. Cover illustration, shows adjustable turning vanes at one corner of tunnel.)

left center of *Fig. 1.* This chamber, which may be entirely closed off from the rest of the tunnel in less than a minute, is essentially an air lock, 31½ feet in diameter, and contains a throat or Venturi which is 12 feet wide and eight and one-half feet high. Dynamometers are provided for use in conjunction with power models. The dynamometer room is shown adjacent to the control room in the lower left portion of *Fig. 1.*

The fan system, shown in the right center portion of *Fig. 1*, is connected through the 30-foot steel shaft to two-power units with a total capacity of 12,000 *hp*. These units consist of a 2,000 *hp* direct current motor, supplied by a motor-generator set, and a 10,000 *hp* alternating current induction motor.

Several separate types of mountings are provided for the models, depending upon the type of models tested and the nature of the test to be performed. Test mounts are installed on small flat cars, which operate on steel floor rails that may be pushed directly from the model room into the decompression sphere.

A unique feature of the tunnel operation is an ingenious system of translating the test data to the final results by means of equipment supplied by International Business Machines Corporation. The data are recorded automatically on printed working sheets and on punched cards. The final result is obtained through additional I. B. M. machine operations. Provision is made for the control of temperature and humidity of the air within the tunnel. Some of the interesting features of the wind tunnel are discussed in some detail in the following sections.

PURPOSE AND REQUIREMENTS

THE general purpose of all wind tunnel tests is to obtain data from which the airplane designer can develop the design of a new airplane. Because of the extreme complexity of modern high performance airplanes, a great many varieties of data are required before it is possible to lay out a balanced design. In most instances it is impossible or at least very uneconomical to obtain accurate design information from airplanes in flight, thus making it highly desirable to be able to obtain data by other methods than flight testing. For this reason wind tunnels have been developed.

Many types of wind tunnels have been built, but all have the purpose of creating a uniform stream of air which passes through a test chamber in which a scale model of an airplane is mounted. The model is mounted on struts or wires fastened to a system of balances which enable the tunnel operator to measure the forces and moments acting on the model.

The forces and moments which act on the airplane, and on the model in the wind tunnel, depend on its attitude with respect to the direction of the air stream. That is, they depend on its angle of attack and angle of yaw. The variation of the forces and moments with these angles is important to the airplane designer. For this reason it is necessary that the model-supporting mechanism which is attached to the balances be capable of varying the angles of attack and yaw of the model in the wind tunnel. In fact a typical run of a wind tunnel test consists of varying either the angle of attack or the angle of yaw, while holding the other angle at a fixed value, and recording the magnitudes of the forces and moments at each of a number of positions of the model.

Certain types of investigations which may be carried out in a wind tunnel are of more theoretical interest than of immediate applicability in the design of aircraft, and really belong to the field of fluid mechanics. Apart from investigations of this sort, wind tunnel tests fall generally into one of two classifications. Tests may be conducted for the purpose of obtaining basic aerodynamic data

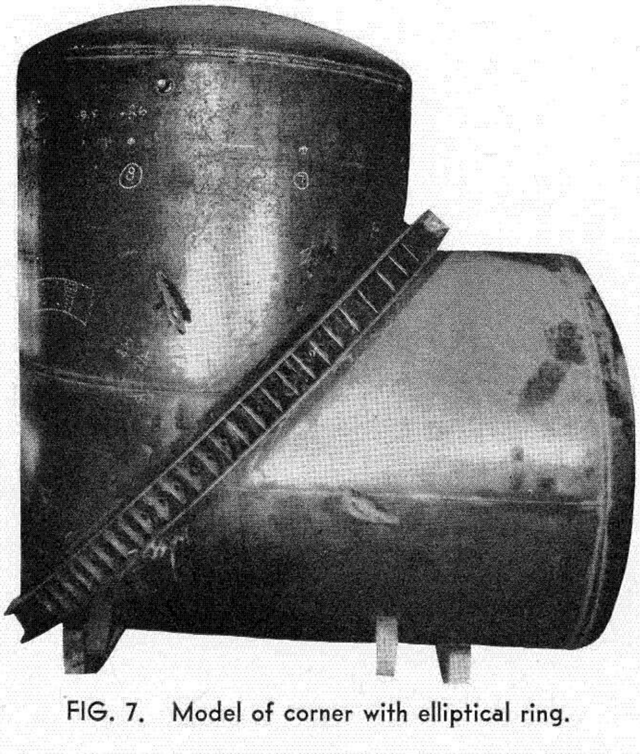

FIG. 7. Model of corner with elliptical ring.

without having in mind a specific airplane to which the results are to be applied, or they may be conducted on a scale model of an existing or proposed airplane with a view to predicting the performance and flying qualities of the full-scale airplane.

Tests of the first class usually involve systematic changes in the model configuration and routine measurements of the forces and moments acting on the model. The model might for example represent a horizontal tail surface consisting of the stabilizer and a movable elevator. Systematic changes could be made in the elevator nose-shape, and the investigation could be extended by testing each nose-shape with each of several elevator hinge-line positions. The data accumulated from such a series of tests would be of value to an airplane designer because it might turn out that one of the combinations of elevator nose-shape and hinge-line locations tested had just the characteristics he requires, but whether this were true or not, the data would enable him to predict, probably with considerable accuracy, the characteristics of a new and untried combination.

Even though the airplane designer makes use of many data of the sort just described, he must still resort to tests of the complete airplane in order to make sure that the final design meets all requirements. A scale model of the airplane is built which reproduces very accurately all the details of the external shape of the airplane. The internal structure of the airplane is not reproduced in the wind tunnel model, since the forces measured by the wind tunnel balances are caused solely by the flow of air over the model. In addition to including such details as gun turrets, bomb-bay doors, retractable landing gears, etc., wind tunnel models have movable flaps and control surfaces, and are frequently tested, with running propellers driven by small electric motors contained within the model. From the point of view of design, it is necessary to know not only the forces and moments acting on the complete airplane, but also the increment added by each part of the airplane separately. For this reason, the model is built so that the wing alone may be tested without the fuselage, nacelles, or tail surfaces. The model may be built up by adding the fuselage, nacelles, tail surfaces, gun turrets, etc., in turn, so that the effects of each component of the airplane on the characteristics of the airplane as a whole may be investigated. Thus it is possible to trace the origin of good or bad characteristics and to determine details of the design which require revision to effect improvements.

With the development on the one hand of airplanes of very large size, and on the other of airplanes with extremely high speeds, it has become necessary to build wind tunnels of greater and greater complexity in order to enable the testing of models under conditions which correspond closely to those met by the full-size airplane.

The Cooperative Wind Tunnel is capable of producing an air stream of very high speed and it is anticipated that tests will be carried out at air speeds up to the speed of sound (750 miles per hour). Such tests will provide much useful information regarding the so-called "compressibility effects" which play such a large part in the flight of a high-speed airplane, but concerning which there is much to be learned.

Aerodynamic theory demonstrates, and it may be observed experimentally, that under identical conditions a small scale model does not possess exactly the same characteristics as the full-size airplane, so that the forces and moments measured by the wind tunnel balances do not correspond exactly to those which affect the motion of the full-size airplane. However, the small scale of the wind tunnel model may be compensated for by increasing the density of the air stream in which it is tested. It is for this reason that the Cooperative Wind Tunnel is of the variable-density type, capable of testing models at air pressures up to four times atmospheric pressure (58.8 pounds per square inch absolute). The tunnel may also be operated under reduced pressures down to approximately 0.1 of atmospheric pressure (1.5 pounds per square inch absolute). An advantage of this arrangement is that at low pressures, less power is required to produce a high-speed air stream than is required at atmospheric or higher pressures.

STRUCTURAL FEATURES

THE geometry of the Cooperative Wind Tunnel is similar to that of other well-known wind tunnels now in operation, such as the Wright Field 20-foot tunnel, the Wright Brothers Memorial Wind Tunnel at Massachusetts Institute of Technology, and the Boeing Tunnel at Seattle. Since there are great advantages in being able to control the pressure of the air in the duct, the Cooperative Wind Tunnel was designed so that air could be maintained at any desired pressure between approximately 1.5 pounds per square inch absolute and 58.8 pounds per square inch absolute.

Since the duct acts as a pressure vessel, it was designed in accordance with standard practice for such vessel. The duct is constructed of steel plate approximately one inch thick and is arc welded. Approximately 3,000,000 pounds of steel were used in the fabrication and erection of the tunnel. Approximately 17 miles of electric arc welding were required. Large sections of the duct were prefabricated in the shops of the Consolidated Steel Corporation in Maywood, California, and trucked from there to Pasadena, where they were erected by the company's field force.

The tunnel is supported on eight columns, as indicated in *Fig.* 3. The general construction is shown in *Fig.* 4. These columns have spherical ends so that each is the equivalent of a portion of a sphere 18 feet in diameter. The tunnel is free to "roll" on the eight columns—at least so far as the columns are concerned. The tunnel is restrained from moving horizontally (in any direction) by a pin which is located midway between columns three and four and engages a plate welded to the tunnel. The tunnel is restrained from rotating about this pin by a link which connects the tunnel and the base of column seven. Thus the tunnel is restrained horizontally in a statically determinate manner. It can expand or contract without restraint.

After the tunnel was completed (structurally) the distribution of the weight between the eight columns was measured and then redistributed to conform to design assumptions. The load in each column was measured by mounting a special (20-foot) extensometer on each column. The zero reading was determined by jacking the tunnel up so as to take the weight off the columns (four at a time). It was found that column three was carrying about 50 per cent more than its design load and that column four was correspondingly unloaded.

The problem of transferring the concentrated loads from the columns to the shell in such a manner as to avoid unduly high stresses is a complicated one. The basic theory can be found in Timoshenko's *Theory of Plates and Shells*. Herman Schorer in an article entitled "Design of Large Pipe Lines," published in *Transactions of the A. S. C. E. 1933*, clearly illustrates the application of the theory.