# 6- BY 6-FOOT SUPERSONIC WIND TUNNEL

## PROBLEMS AND TECHNIQUES OF TRANSONIC AND SUPERSONIC RESEARCH

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The Ames Laboratory has recently added to its facilities this 6- by 6-foot supersonic wind tunnel. You are now located in the test chamber. Before describing this equipment, we would like to discuss briefly a number of problems and techniques of high-speed research as it is being conducted today.

Aerodynamic research can be pursued along two courses – either theoretical or experimental. The theoretical approach applies mathematical methods to analyze, and thus understand, physical processes; whereas the experimental approach utilizes wind tunnels and actual flight to determine the nature of aerodynamic phenomena. Each approach has its advantages and limitations and, wherever possible, both should be employed. In such relatively new fields as transonic and supersonic research this need for one approach to supplement the other is particularly great.

In the transonic speed range the limitations on both the theoretical and experimental approaches are serious. Few mathematical solutions have been found which describe adequately the mixed subsonic and supersonic flows which characterize the transonic range. Thus, the exploration of this field has been left largely to experiment.

A considerable amount of transonic experimental research has been conducted along more or less conventional lines using wind tunnels and actual flight test. Unfortunately wind-tunnel experiments at speeds close to that of sound require that the size of the wind tunnel be very large compared to that of the model in order that correct results may be obtained. The reason for this is that constriction effects due to the presence of the tunnel walls destroy the similarity between flow about the model in the wind tunnel and in free flight. At Mach numbers slightly below 1, these effects are manifested in the form of tunnel choking. At Mach numbers slightly in excess of 1, similarity of flow is destroyed primarily by reflection of the bow shock from the walls onto the surface of the model. The first chart (fig.4(b)) illustrates the extent to which these phenomena affect the test section size of a wind tunnel required to test a model having a fuselage 48 inches long and a diameter of 6 inches. This size of model is convenient for simulating all components including control surfaces and for maintaining adequate test Reynolds numbers. It can be seen that in the transonic range very large, and thus costly, wind tunnels are needed to test adequately models of this size. Of course testing of small models in existing facilities can produce considerable useful information. This procedure has been resorted to whenever practicable; however, with the small models required, the objections of low Reynolds number and difficulty of exact reproduction of all elements cannot be overcome.

Exploration of the transonic speed range by actual flight test has been done with such aircraft as the XS-1 and D-558 "Skystreak." This research has been conducted by the NACA working in cooperation with the military services and the aircraft industry. It is at best hazardous, costly and requires intricate instrumentation to produce useful data. However, since the data are obtained under full-scale flight conditions they are invaluable for designing and predicting the behavior of similar aircraft intended to fly at these speeds.

In view of the urgent need for transonic data and the limitations of the conventional methods, numerous experimental techniques have been developed to provide additional data. Two of these techniques stem from the fact that local regions of accelerated flow may be obtained over a convex surface, as for example, a wing. In one of these techniques, the wing-flow method, a small model is placed, as shown (fig. 4(c)), on the upper surface of an airplane wing. If the speed of flight is great enough a region of transonic flow will exist in the vicinity of the model as shown here. The Mach number distribution will be approximately as shown (fig. 4(d)) for flight speeds of about 70 to 80 percent of the speed of sound. Excellent qualitative data at transonic speeds have been obtained by this procedure and in some instances good quantitative agreement with data from other sources has been found.

The other experimental method employing the transonic flow over a curved surface makes use of a bump placed on the floor of a subsonic wind tunnel. Here again (fig. 4(d)) a small model is placed in the region of accelerated flow and data obtained. Both the "wing-flow" and "bump" methods suffer from the small sizes required for models in order that only that portion of the accelerated flow which has nearly constant velocity is encountered.

Two other methods now in use for experimentally investigating the transonic speed range concern models freely moving through the air. In one case models are launched from the ground by means of rockets, as illustrated here (fig. 4 (c)); in the other the models are dropped from aircraft flying at high altitudes. Telemetering equipment within the models transmits data concerning forces on the bodies, wings and controls to receiving stations on the ground. The paths of these models in flight are tracked and recorded by radar. Valuable information has been obtained in this manner although instrumentation, launching techniques and analysis of the data present difficult problems. By controlling either the propulsive force of the rockets or the altitude of release and mass density of the dropped models the entire transonic speed range can be explored. With the rocket-propelled models it has been possible to go beyond the transonic range into the regime of purely supersonic flight. Here a new set of research techniques and problems are encountered.

Fortunately in the supersonic regime theoretical and experimental research can supplement each other. Paralleling the established techniques of subsonic research the wind tunnel again becomes a most valuable tool for assessing the validity of theoretical developments. Hence, most experimental supersonic data will be obtained in wind tunnels but will be augmented by data from flights of actual aircraft and rocket propelled models. Referring again to the first chart (fig. 4(b)) it will be seen that a wind tunnel of reasonable size can be used. For example, this Ames 6- by 6-foot supersonic wind tunnel was designed to test models of the size indicated at Mach numbers above 1.4 and at Reynolds numbers approaching full scale.

Although the size of supersonic wind tunnels may be small compared to those required for transonic research, several new problems of design, construction and operation are encountered. Foremost among these problems is development of a method for continuous variation of the Mach number. This problem arises from the fundamental difference in operation of wind tunnels at subsonic and supersonic speeds. Up to a Mach number of 1 the maximum speed of the wind tunnel is obtained at the section of minimum cross-sectional area. (See fig. 4(f).) Speed variation is readily obtained by controlling the speed of the wind-tunnel fan. Above a Mach number of 1.0 the maximum speed is attained in an expanded section downstream of the section of minimum area. The ratio of these areas uniquely determines the Mach number. Thus to provide Mach number variation the area ratio must be changed. This can be accomplished in general in three ways: by building a number of nozzles of fixed shape for different Mach numbers, by providing flexible walls which can be moved with jacks, or by use of the Allen asymmetric sliding-block nozzle recently developed by the NACA and used in the 6- by 6-foot wind tunnel. Of the three methods, the asymmetric-type nozzle offers the least mechanical complication with a maximum of flexibility in Mach number variation.

Mr.__________ will now describe the 6- by 6-foot supersonic wind tunnel and this nozzle.

# DESCRIPTION OF THE 6- BY 6-FOOT WIND TUNNEL

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We would like very much to conduct all of you on a tour through the 6- by 6-foot tunnel. However, the time allotted us will not make this possible, so in order that you may see a little of the inside of the tunnel and how it operates, we have prepared a motion picture which shows the significant parts of the tunnel in detail.

First, I would like to orient you with the wind tunnel (fig.4(g)) from where you are now seated in the test chamber. In the film a few introductory and construction shots are shown, and then the description of the various parts of the tunnel starts with the compressor and drive motors. This is followed in order with the cooling coils and cooling tower, corner turning vanes, and the adjustable nozzle and test section to complete the circuit around the tunnel. The model and model support are also shown, and some of the methods used to obtain data; and finally the auxiliary equipment.

# SCRIPT FOR 6- BY 6-FOOT WIND TUNNEL MOVIE

The design and construction of this new wind tunnel required more than 3 years to complete. With the assistance of the United States Navy and with the aid of experts from industrial firms, major construction was completed in June of ~~this year.~~ 1948. The latest laboratory facility . . . the Ames 6- by 6-foot supersonic wind tunnel is now in operation.

This building at the Langley laboratory houses the NACA's first supersonic wind tunnel, a small tunnel with a 9-inch test section, which was built in 1943. Since that time, the facilities of the NACA for experimental research at supersonic speed have been increased to 14 wind tunnels. The 6- by 6-foot wind tunnel is the latest addition to this group.

Several phases of construction work on the wind tunnel are shown here . . . 1-inch thick double-curved plate is being erected and welded into the 38-foot diameter sphere used for the tunnel dry-air supply . . . The rotor of the drive compressor is shown being run without blades for balancing. The slots to hold the blades in the discs may be seen in this view. Because of the large size of the installation, balancing of both the rotors for the compressor and the drive motors was done at the site . . . The large cooling tower, shown here under construction, is built entirely of redwood.

Let us take a look through the completed tunnel . . . Starting with the 8-stage axial-flow compressor which drives the air around the wind-tunnel circuit . . . The 140-ton rotor assembly consists of eight steel discs bound into a single rigid body with long alloy-steel bolts running the entire length of the rotor . . . Each disc holds 52 precisely machined aluminum-alloy blades . . . The compressor handles 1,700,000 cubic feet of air per minute at a compression ratio of 2.1 . . . Normal operating speeds vary from 775 to 860 rpm . . . When the tunnel is not operating, the compressor must be turned at slow speed to prevent unbalance in the rotor caused by sag or temperature variations.

The compressor casing, 15 feet 9 inches in diameter, is fitted with nine rows of adjustable steel stator blades . . . 50 to 64 per ring. Each row of blades has an inner shroud ring 12 feet 4 inches in diameter which fits between the discs of rotor blades. With the two halves of the casing closed and the compressor operating, there is only a quarter-inch clearance between the tips of the rotor blades and the stationary casing . . . A hollow steel shaft equipped with solid couplings and a labyrinth air seal through the tunnel shell connects the compressor to the motors anchored on this concrete structure outside the tunnel shell.

Electric energy supplies the power for the wind-tunnel drive . . . Power at 110,000 volts is channeled to the substation where it passes through large circuit breakers and transformers to be reduced to 6,600 volts. Through a large bank of switchgear the operator closes the circuit breaker and energizes the drive motors . . . These two 25,000-horsepower motors coupled with the compressor rotor make a total rotating mass of 225 tons. The motors are controlled through a slip regulator and are brought up to operating speed automatically in approximately 3 minutes. After they are cut off the line it requires 30 minutes for the rotating machinery to stop.

Downstream past the compressor fairing . . . following the path of the air . . . are the cooling coils . . . the tunnel shell expanding to a diameter of 41 feet to house them. These coils are all located in a single bank with flexible mountings to compensate for temperature variations . . . The coils are cooled by 12,000 gallons of water per minute circulated through the cooling tower . . . equipped with fans, motors, and pumps. The water absorbs the heat generated by the compressor and maintains the tunnel stagnation temperature at 110° F.

Beyond the cooling coils . . . at the first right-angle turn of the tunnel, stands a set of turning vanes . . . a cascade of airfoils preserving the even distribution of air flow that comes down the channel . . . More of these turning vanes located at the next corner elliptical ring . . . turn the air smoothly into the adjustable nozzle.

Here the air passage changes from circular to rectangular . . . contracting to the throat and then expanding to a square measuring 6 feet across each wall forming the test section . . . On each side of the test section is mounted a 50-inch diameter optical glass window . . . From an isolated framework is mounted the sting-type model support.

~~With the aid of the model-tunnel nozzle . . . we have a glimpse into the mechanism that has made it possible to vary the opening of the tunnel throat which controls the speed of the air stream. This model was originally built as a pilot tunnel to verify the operation of this type of nozzle . . . This adjustable portion of the nozzle, forming a part of the bottom wall . . . moves horizontally to vary the throat opening without changing the test-section dimensions. A motor-driven lead screw moves this section throughout its travel. The maximum Mach number occurs when the sliding block is in the forward position . . . The range of operating Mach numbers is variable from 1.1 to 1.8.~~

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Here in the test section . . . with its walls polished to eliminate shock waves . . . will be mounted a test model . . . held in the supersonic air stream on the tip of this cantilever support, which is bored to receive the strain-gage balance. This balance consists of three pairs of small cantilever beams restraining the model and flexing normal to each of the principal axes. This type of balance is described today at the 12-foot tunnel. The balance is assembled within a cylindrical case and mounted on the end of the sting . . . The model is placed over the balance and it is then ready for test . . . This is a view upstream showing the model, the sting tube, . . . and the supporting struts . . . The strain-gage readings are measured on a sensitive galvanometer with photo-electric cells following the movement of the light beam to transmit the readings to dials and printers recording the data.

Another source of data is also available . . . Since supersonic flow entails large changes in air density . . . Light rays generated in a high-pressure mercury-vapor lamp, when reflected from spherical mirrors, form parallel rays which pass through the high-speed air stream, and thereby reveal the density variations.

This sequence shows the establishment of supersonic flow in the model tunnel . . . The black vertical line shown here is a normal shock wave . . . the boundary between supersonic and subsonic flow characteristic of flow in a wind tunnel . . . As the normal shock passes downstream, a conical shock wave emanates from the nose of the model . . . Reduction in pressure across the nozzle causes the normal shock wave to retreat back into the throat.

The operation of the wind tunnel is centered in this angular-control console . . . Here the airspeed, density, temperature, and the model attitude are under finger-tip control.

A sensitive pressure controller at the console actuates automatic control valves from the high-pressure dry-air storage tank and a battery of vacuum pumps to maintain any desired operating pressure between 1.5 and 25 pounds absolute.

Many types of auxiliary equipment are needed for the operation of this type wind tunnel . . . Air compressors compress the required make-up air to 80-pound gages and silica gel dryers dry it to a dew point of -5° F.

~~The 6- by 6-foot tunnel is now in the process of calibration which will require considerable time to complete. Compressor and tunnel operating characteristics must be determined before the 6- by 6-foot tunnel can join the NACA's program of aerodynamic research.~~

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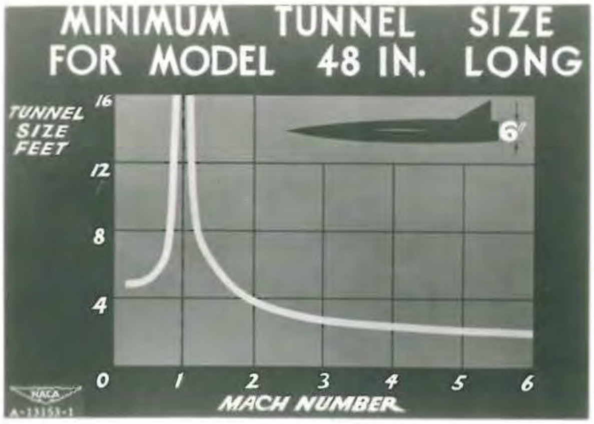
(a) General view.

Figure 4.- 6- by 6-foot supersonic wind-tunnel exhibit.



MINIMUM TUNNEL SIZE FOR MODEL 48 IN. LONG

(b) First chart.

WING-FLOW MODEL INSTALLATION

(c) Second chart.

TRANSONIC RESEARCH TECHNIQUE USING LOCAL HIGH-SPEED FLOW

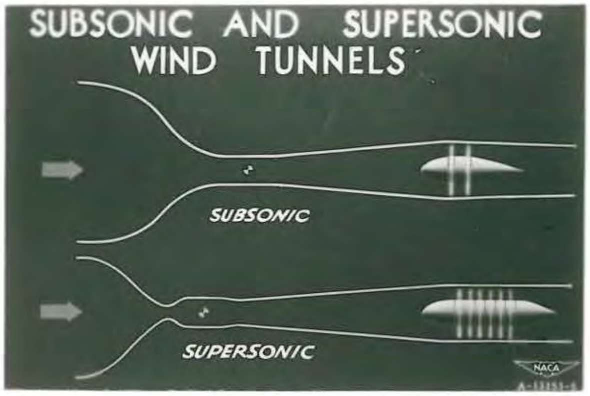
FLIGHT
WING-FLOW METHOD

WIND - TUNNEL
BUMP METHOD

(d) Third chart.

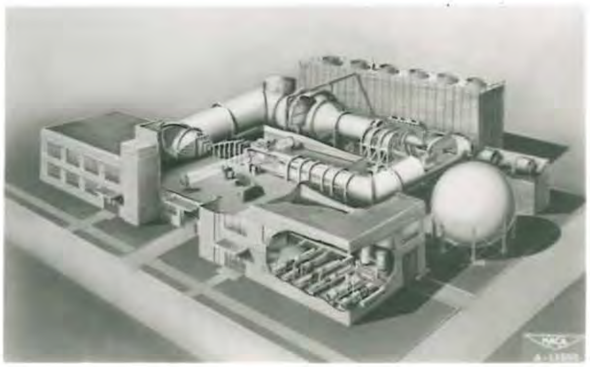
RESEARCH WITH ROCKET

(e) Fourth chart.



SUBSONIC AND SUPERSONIC WIND TUNNELS

(f) Fifth chart.



(g) Drawing of wind tunnel.

Figure 4.– Concluded.

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