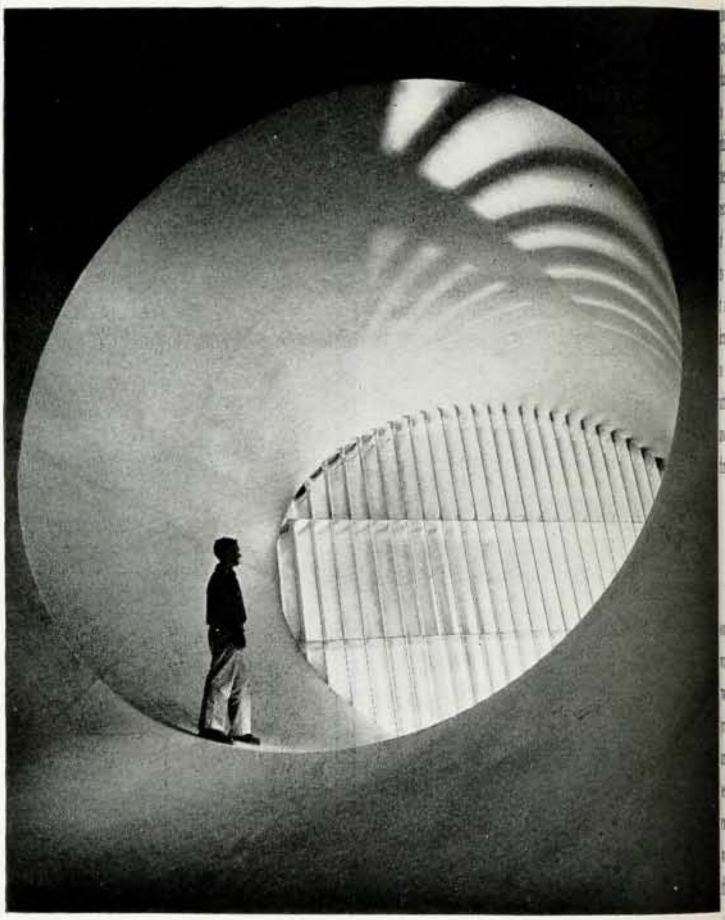
FASTER THAN SOUN[D]

Skystreak *U. S. Navy Photo*



Supersonic Wind Tunnel *NACA Phot[o]*

by ***Hugh L. Dryden***

The research that must be done on men and machines in supersonic flight is outlined by the Director of Aeronautical Research for the National Advisory Committee for Aeronautics.

USAF Photo

On October 14, 1947, Captain Charles E. Yeager, U. S. Air Force, became the first man to reach, in a piloted airplane, sustained horizontal flight at a speed faster than sound, marking the dawn of the supersonic age. Since that day many flights of the Bell XS–1 research airplane have been made at supersonic speeds by Captain Yeager and two other Air Force pilots, Major G. E. Lundquist and Captain J. T. Fitzgerald, and by Herbert H. Hoover and the late Howard Lilly, research pilots of the National Advisory Committee for Aeronautics.

Supersonic speeds have long been commonplace in the universe of the stars and meteorites, but the scientific study of terrestrial objects moving faster than sound may be traced back at least sixty years to the work of the noted Viennese physicist and philosopher, Ernst Mach. Mach first photographed the shock waves around a bullet in flight and first recognized the importance of the ratio of the speed of the bullet to the speed of sound in determining its aerodynamic characteristics (the forces acting on it as it moved in air). The Mach number, which denotes the ratio of the speed of aircraft or missile to the speed of sound, takes Mach's name in recognition of his work. The words subsonic, transonic, and supersonic simply tag speeds as below, passing through, or above the speed of sound.

Why Go So Fast?

The practical incentives to the study of supersonic aerodynamics arose first from the needs of war in the development of projectiles. Then, about twenty-five years ago, the tip speeds of airplane propellers began to approach the speed of sound, and interest developed in the behavior of the blade sections of propellers at high subsonic speeds. Early experiments showed that aerodynamic efficiency grew worse as the speed of sound was approached, and that the loss of efficiency was caused by a separation of air flow from the surface just beyond the maximum thickness of the blade section. Theoretical and experimental workers became more active in this field. A few of them began to speculate on the possibility of flight in the region of sonic speeds, but the power plants then known made people think there would be a sonic barrier which would make horizontal flight of a piloted aircraft unlikely for a long time.

But the development of jet and rocket propulsion, based on new information from research on heat-resistant materials, new fuels, and combustion, completely changed the picture. There *was* a power plant for supersonic flight. The successful development of the large V–2 rocket by German scientists and engineers, and the demonstration of its controllability at supersonic speeds, initiated a tremendous scientific effort in rocket and jet propulsion and supersonic aerodynamics.

Again it is the desire for national military security which constitutes the driving force. Air power is dominant in national security, and speed is a dominant element in the aircraft performance required for control of the air. There now seems to be no technical obstacle to the development of useful supersonic aircraft which cannot be overcome by research.

The technical problems now under study by research organizations may be grouped as those relating to the performance, stability, controllability, and structural integrity of the machine and hence of concern in unmanned missiles as well as piloted aircraft, and as those relating to the comfort, well-being, and performance of the human occupants.

Of Machines . . .

The first problem which had to be solved was to provide a power plant, light and small enough, but with sufficiently high thrust to overcome the resistance of air to motion at supersonic speeds. Ballisticians discovered many years ago that air resistance increases disproportionately as the speed of sound is approached. It was the development of rocket propulsion that provided a power plant which could give sufficient thrust to reach supersonic speeds with small aircraft of conventional design.

In addition to the rocket, two additional types of jet power plants are receiving much research effort: the turbo-jet and the ram-jet. Any boy who has blown up a toy balloon and let it escape from his hands has observed and can understand jet propulsion. The balloon recoils from the jet escaping from it. It is as if the myriads of air molecules rushing out were bullets being shot from a gun pointing away from a target and the recoiling gun itself used to get to the target. The newer engines use heat to produce the jet, producing thrust by squirting a hot jet of air to the rear. The rocket carries both fuel and oxygen and hence can operate anywhere, under water, in the air, or outside the earth's atmosphere. Turbo-jet and ram-jet engines get their oxygen from the atmosphere. The turbo-jet uses a mechanical compressor to compress the air and a turbine to drive the compressor. In the ram-jet, compression is produced by the rapid motion of the vehicle; hence a ram-jet-propelled vehicle must be brought to a high speed by other means, for example, booster rockets.

The jet and rocket power plants give a great deal of power per pound of weight and have the desirable characteristic that the power increases with the speed. But the relative merits of the several types are complicated functions of the speed and altitude of flight. The rocket motor furnishes most power for a given weight but burns fuel at the highest rate. Of the three types, the turbo-jet has the lowest fuel consumption and the least power for a given weight. With appropriate aerodynamic design and operating altitude, supersonic speeds can be reached with any of the three. Much research is required to improve their efficiency, reliability, and limits of operation in regard to speed and altitude.

The second main problem is to obtain an aircraft with suitable aerodynamic characteristics. The difficulties arise from the radical changes in the aerodynamic relationships at speeds faster than sound as compared with those prevailing at speeds slower than sound, and the necessity for any practical airplane to take off, land, and fly satisfactorily in both the subsonic and supersonic regions, as well as in the transonic region where the air flow is partly subsonic and partly supersonic.

One aspect of these phenomena of interest to physicists is the development of the disturbances known as shock waves in the flow near the wing at transonic speeds. Shock waves are abrupt changes in pressure and temperature which arise when air is decelerated at supersonic speed. They are often accompanied by separation of the flow from the surface of the wing, which usually produces a violently fluctuating motion shaking or buffeting the wing, and if the wake of the wing strikes the tail, the tail structure may be subjected to loads varying with violent irregularity sufficient to damage it. Considerable research is in progress on these fundamental matters utilizing the physicist's tools, interferometer, schlieren equipment, hot-wire anemometer, etc.

To the engineer these flow changes appear as troublesome effects on the forces and moments acting on the airplane. Perhaps the most difficult problems are those relating to control and stability. At subsonic speeds the lifting force on a wing acts through a point about one-quarter the distance from the leading edge to the trailing edge; at supersonic speeds it acts through a point half the distance from leading to trailing edge. Thus there are sudden changes in the angular trim of the airplane in the transonic region. There are also changes in the stability, produced partly by the change in the airflow at the tail which results from the loss of lift. A major research problem is the discovery of configurations which have the smallest changes in trim, control, and stability, in passing through the transonic region.

The third main problem is to maintain the structural integrity of the aircraft. Reference has already been made to buffeting loads, which must be kept to reasonable limits, preferably by finding wing sections and configurations which avoid flow separation. The air loads on the structure increase with the speed of flight. At high speeds the loads are large and produce deflections, twisting, and bending of the structure. The distortions in turn modify the air loads and there is thus a complicated interaction between aerodynamic and structural design. For example, the deflection of the aileron to correct a disturbance in roll may twist the wing enough to counteract the desired effect of the aileron, thus increasing the disturbance. Many difficult aeroelastic problems must be solved by the research worker and the designer.

Meteors traveling through the air at high supersonic speeds get so hot from friction with the air that their surfaces melt. Even at lower supersonic speeds the heating is not negligible and it is necessary to make certain that the structural materials used will withstand the temperatures actually encountered.

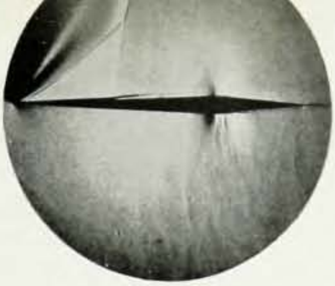
The fourth problem in dealing with machines in supersonic flight is the effect of the environment on their functioning. It requires little study to see that supersonic flight near the ground will be extremely costly in fuel, and that economy and efficiency are to be obtained by high altitude flight. The resistance to motion at high speeds can be greatly reduced by traveling at high altitude, where the air density is less, but high altitude flight introduces new problems for the ram-jet and turbo-jet power plants. As the air density is reduced, a greater and greater volume of air must be forced through the engine to supply the necessary oxygen to burn the fuel. It becomes more and more difficult to maintain the conditions needed for combustion, to "keep the fire lit" as the jet pilot says. Research workers are busily engaged on these problems. There is also progress in the determination of the physical properties of the air at very high altitudes, using sounding rockets, and in reproducing this environment in the laboratory for studying the problems to be encountered in high speed flight in the upper atmosphere.

. . . And Men

The general public has been more interested in the problems relating to the people who occupy the supersonic aircraft. The fact that five men have actually flown at supersonic speeds shows that the human problems are not insuperable, but the details of their experience are still not matters of public record. The possible difficulties to be overcome have long been anticipated, namely, the effects of the low atmospheric pressure at high altitudes where supersonic speeds will be realized most efficiently, the effects of the high temperature produced by the rapid motion, the effects of noise and vibration, the effects of high accelerations, the possible inadequacy of human sense perceptions and reactions to control a high speed vehicle, and finally the development of safe methods of escape in case of accident.

Research workers in aeromedicine have learned a great deal about the effect of altitude on human beings and how to alleviate it. And aviators have had considerable experience flying at high altitudes, both with the aid of individual oxygen masks and in pressurized cabins. The pressurized cabin is in principle the final answer and could, with some development, be used for extended periods even in empty space. In other words the solution of the problem is to supply the occupants of the aircraft with a suitable environment which is independent of the space outside the aircraft.

The same type of solution can be applied to temperature. Even in present aircraft traveling at



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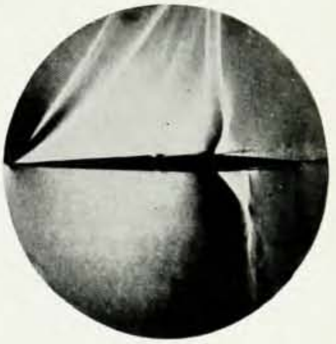

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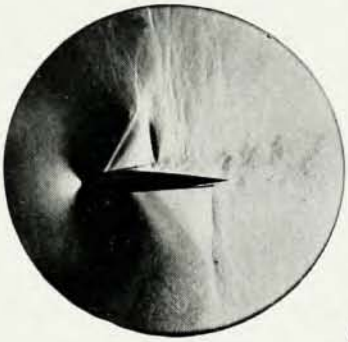

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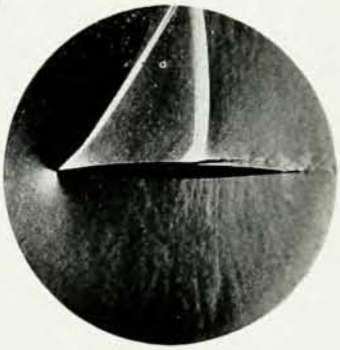

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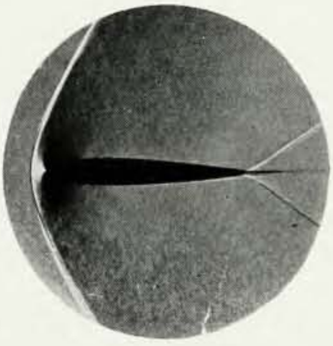

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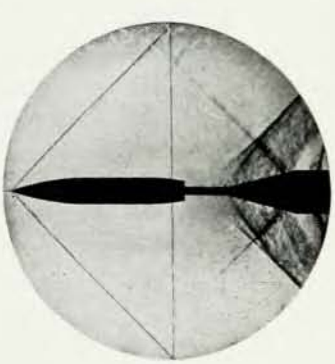

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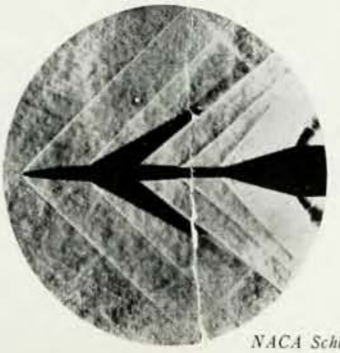

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NACA Schlieren Photos

subsonic speeds, refrigeration is required to keep reasonable cockpit temperatures, partly because of aerodynamic heating, but partly because of radiation from the sun. For short bursts of speed, in the low supersonic region, the heat capacity of the aircraft structure may be sufficient to keep the temperature rise small.

Noise and vibration have always been present in aircraft and have caused discomfort to the occupants. In jet-propelled aircraft at subsonic speeds the noise and vibration in the cockpit are usually less than in a propeller-driven aircraft, largely because the jet discharge is well behind the cockpit, a turbine operates smoothly as compared to a reciprocating power plant, and the sound-insulating properties of most materials improve at higher frequencies. Data for supersonic speeds are not available for public discussion, but noise and vibration inside the cabin can be controlled just as pressure and temperature can.

The noise level near the discharge jet of a turbojet or rocket engine is extremely high and contains much energy at high frequencies. The effect on workers making ground tests is under study.

In spite of our everyday use of machines, there are still many persons who fail to comprehend that the human being has no inherent sense of speed. Only changes in speed, that is, acceleration or deceleration, can be detected. Just as we do not perceive with our muscular sense the motion of rotation of the earth or the motion of the earth about the sun, so we cannot tell the difference between a speed of three thousand miles per hour and one of five hundred miles per hour, if the speeds are constant. Many who take their first airplane flight on a smooth day are astounded at the apparent absence of motion.

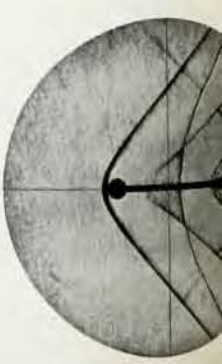
This popular misconception is probably related to everyday travel on land, where high speeds are usually accompanied by high accelerations produced by irregularities in the highway or railroad track. A similar effect is produced in an aircraft flying through turbulent air, and supersonic aircraft may be merely uncomfortable or even structurally unsafe in gusty air. Fortunately both comfort and safety are improved by merely slowing down.

Reference has already been made to the buffeting which comes from flow separation at high speeds. Buffeting means irregular accelerations which may be quite uncomfortable to the human occupants as well as dangerous to the structure, if it is a large one.

There has been much speculation as to whether or not the *human* machine can cope with the problem of controlling a high speed aircraft, especially in regard to reaction time when emergency action is needed. It is certainly clear that human faculties are inadequate to make effective use of supersonic aircraft. For example, the unaided eye cannot see far enough in relation to distance traveled to detect other aircraft for rendezvous before they have been left far behind. Undoubtedly the human senses will have to be extended by radar and other electronic aids, and it may prove desirable to use automatic pilots supervised by the human pilot. These are matters on which we will obtain further information as our supersonic experience is extended.

A problem of great concern in the experimental flying and military use of supersonic aircraft is that of escape from the aircraft in event of accident. It is not safe to jump from an aircraft at supersonic speeds or to open a parachute at high speeds. The essential point is to protect against high accelerations and decelerations either from contact with the tail or other part of the airplane, from the shock of the opening parachute, or from too rapid deceleration arising merely from air resistance. It has been proposed that the entire nose section containing the cockpit be jettisoned and slowed to a safe speed, permitting the pilot then to use his parachute in the normal way. Even then the accelerations must be kept within tolerable limits. For example, if the nose section tumbles at high speed, fatal or dangerous accelerations may be produced.

Such are the technical problems under study. The supersonic age will bring its human problems as well. As in the case of the atomic bomb there will be fear because of the military application of supersonic aircraft. But there will also be a lifting of intellectual horizons as man begins to think more seriously about the exploration of the high upper atmosphere, and even of venturing into outer space. The world itself will shrink further in space and time when he can outrun the sun.



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