AIR INLETS

by

1- BY 3-FOOT SUPERSONIC WIND TUNNEL

Jet engines for high speed aircraft require that large quantities of air be supplied to them with a minimum loss in the energy imparted to the air by flight, and a minimum increase in the drag force acting on the aircraft. As flight speeds increase, larger engines that require more air are necessary. The efficiency of the air induction system then becomes a greater factor in the overall efficiency of the aircraft.

Present engines, either turbojet or ramjet, must have a relatively low velocity at the face of the engine. Therefore, the rate of slowing the air must increase as the flight speed becomes greater. The greatest difficulty is that, in general, the possibility of compressing the air efficiently is lessened as the rate of slowing the air increases, because of certain inherent characteristics of air flow.

Since subsonic and supersonic flows present problems of different natures, the problem of providing air at subsonic flight speeds will be discussed first, and followed by a discussion of the situation in supersonic flight, and a demonstration at a Mach number of 2.0 in the wind tunnel.

This chart (CHART 1) illustrates an inlet for subsonic flight at two conditions. In cruising or high speed flight, the inlet is designed to receive air at a velocity which is low compared to the free stream velocity. The reason for this design condition is that the external compression produced is inherently more efficient than internal compression. The shaded streamtube, representing air which flows through the engine, increases in size as the air compresses externally (CHART 1). The flow velocity increases rapidly on the external surfaces, however, as shown by the converging streamlines (CHART 1). Thus, the external surfaces must be carefully designed so that abrupt increases in pressure, following the high velocity, low pressure region, will be avoided. The flow will then smoothly follow the external surfaces. If the external surfaces are poorly designed, the flow may separate from the surface and leave a region of turbulent, eddying air, causing large increases in external drag. In the take-off or wave-off condition, (CHART 1) the engine is drawing a large amount of air through the inlet. Thus the inlet velocity is high compared to the free stream, and the shaded streamtube (CHART 1) contracts in approaching the inlet. Since the airplane is moving slowly external compression is not possible for this condition, the internal surfaces must be designed with care, so that abrupt pressure increases will be avoided and the flow will smoothly follow the internal surfaces. If the surfaces are poorly designed, the flow may separate internally at the take-off or wave-off condition. Considerable loss in pressure, and therefore engine thrust, will then be experienced. Thus, from observation of the different streamline patterns (CHART 1) for the two conditions, it is apparent that some compromise in the shape of the inlet is required to obtain a satisfactory solution to the problem.

The next chart (CHART 2) shows several typical examples of subsonic air inlets, designed according to these principles, which have been investigated by the NACA. The advantage of the nose inlet (CHART 2) over the other types is that it is located in a natural stagnation region, wherein external compression can be accomplished at a very high efficiency. In addition, it has been found by experiment that the external drag of a body with a properly designed nose inlet is as low as, or lower than the drag of a solid streamlined body. On the other hand, nose inlets have the disadvantage of requiring a great deal of space for ducting in the forward portion of the aircraft. This space could otherwise be used to good advantage for radar, armament, or cargo. The wing-fillet inlet avoids this disadvantage (CHART 2), but it is in a region where it can receive some of the boundary layer, air that has been slowed down by friction in flowing over the fuselage. Some measure, such as a boundary layer scoop, which will be shown later, is necessary to prevent this low energy air from flowing into the ducts. The wing-fillet inlet provides a large amount of usable volume in the nose, and has some advantages of the nose inlet, but in general, it presents a more complicated structural design. The submerged inlet (CHART 2), which is flush with the fuselage, is comparable in performance to the other types, and provides ample space in the nose of the aircraft. Boundary layer control is attained by proper shaping of the approach ramp. (CHART 2) The scoop inlet, (CHART 2) placed in a region of relatively thick boundary layer, involves primarily the problem of boundary layer control. If this were neglected, separation of the internal and external flows would inevitably result, at certain operating conditions, causing serious reduction in engine output and increased external drag. The scoop inlet (CHART 2) has the obvious advantages of providing ample space in the nose of the aircraft and of possible avoidance of structural difficulties.

Through wind tunnel research, systematic design information is being provided on inlets such as these, for all possible flight conditions, and to the maximum speed at which each type of subsonic inlet is practical.

At supersonic speed, the characteristics of airflow differ radically from those at subsonic speed. This next chart (CHART 3) shows several types of supersonic inlets: a convergent-divergent diffusor operating at designed conditions and off-design conditions, a conical shock diffusor at design and off-design conditions, and a scoop inlet at its design condition.

With the convergent-divergent diffusor, (CHART 3) the flow enters at supersonic speed, is slowed down by contraction, and reaches sonic speed near the minimum area section, after which the flow is further slowed at subsonic speed in the diverging passage. Note here one of the fundamental differences between subsonic and supersonic flows. You will recall that at subsonic speeds, the air is compressed in an expanding streamtube. In contrast, at supersonic speeds, the air is compressed or slowed down by a contraction in the streamtube. In the actual case, the transition from supersonic to subsonic speed occurs through a normal shock wave. (CHART 3).

Since the pressure losses through this shock wave increase as the speed at which it occurs increases, the losses are minimum when the normal shock occurs near the minimum area section. (CHART 3) For this type of inlet, the normal shock wave is stable in either of two positions: downstream of the minimum area section (CHART 3), or outside of the inlet (CHART 3). One of the principal disadvantages of this type of inlet, in which inlet contraction cannot be varied, results from the fact that at speeds below that for which the inlet is designed, the normal shock jumps from the downstream stable position (CHART 3) to the stable position outside of the inlet. There, compression occurs through a single, very strong, normal shock wave, with attendant high losses and increased drag. Behind the normal shock wave, the air compresses subsonically in an expanding streamtube.

The conical shock inlet (CHART 3) is designed for supersonic compression to occur both externally through an oblique shock wave, and internally through a contracting passage. It has, in general, the most desirable qualities, but at off-design conditions (CHART 3) it can suffer from flow instability. This flow instability is caused by separation of the flow on the cone ahead of the entrance. Flow separation occurs (CHART 3) when the normal shock wave is forced out of the inlet by an increase in settling chamber pressure. The separation results from the abrupt pressure rise through the normal shock wave (CHART 3). After separation has occurred, the pressure in the subsonic settling chamber decreases, permitting the normal shock to re-enter the inlet, and the cause of the separation is thus removed. The high energy air once again entering the inlet causes the pressure in the settling chamber to increase rapidly, and the normal shock is again forced outside (CHART 3). The cycle thus repeats, at a frequency which depends on the geometry of the ducting system. The conical shock inlet (CHART 3) converts flight energy to pressure energy very efficiently, and is able to handle a large quantity of air with a relatively small inlet area. This latter property provides a large amount of usable volume in the centerbody (CHART 3).

The scoop inlet (CHART 3) utilizes a ramp preceding the inlet to create oblique shock waves through which partial supersonic compression is attained. The intensity and losses through the normal shock wave inside of the inlet (CHART 3) are thereby decreased. Since the scoop inlet is usually located at a considerable distance from the nose of the aircraft, the boundary layer is relatively thick by the time it arrives at the inlet. Some provision must therefore be made for the removal of this low energy air. On the inlet illustrated, (CHART 3) a boundary layer removal scoop is shown at the beginning of the ramp. One practical advantage of the scoop inlet is the large amount of usable volume afforded by the forebody (CHART 3).

The next speaker, Mr. ___________, will discuss the factors involved in supersonic inlet performance, and will demonstrate the operation of one of the inlets at a Mach number of 2.0 in the wind tunnel. Mr. __________ .

This chart (CHART 4) illustrates the variation of the factors which play the most prominent parts in inlet performance. The characteristics of the scoop inlet have been chosen to indicate the significance of the variation of these quantities. To develop a large amount of thrust by burning a large amount of fuel efficiently, an engine must be provided with a great quantity of air at high pressure. Thus it is advantageous to design an inlet which attains maximum pressure recovery with a high mass flow of air. Pressure recovery is a measure of the efficiency with which energy due to velocity is converted to pressure energy. Mass-flow is a measure of the amount of air flowing through the engine. In order to obtain a satisfactory design, the external drag must be small. Both external drag and pressure recovery depend, in part, on the mass flow through the inlet (CHART 4). Therefore, the most desirable inlet is one which provides a high pressure at the engine, a low drag, while providing a large amount of air. When the mass flow is reduced below this point for the scoop inlet illustrated (CHART 4), separation and unsteady flow occur, as indicated by the dashed portions of the curves, resulting in increased drag and lower pressure recovery.

A comparison of the performance of the conical shock, convergent-divergent, and scoop inlets is shown in this chart (CHART 5), in the form of the available thrust coefficient over a range of Mach numbers. The Mach number, as you know, is the ratio of the flight speed to the local speed of sound. The available thrust of the propulsive unit is defined as the difference between the gross thrust of the engine and the external drag of the propulsive unit. The gross thrust of the engine depends on the pressure recovery, the mass flow of air, the engine efficiency, and the rate of fuel consumption. This chart (CHART 5) shows the results of NACA. tests performed on these inlets. The available thrust coefficient becomes smaller with increasing speed for all three types. There are two reasons for this performance: first, the possibility of slowing the air efficiently decreases, and second, the drag coefficient in some conditions increases with higher speed. The conical shock diffusor exhibits the highest available thrust coefficient (CHART 5) over the speed range. This is not conclusive evidence that the conical shock type is the optimum, because the data merely compare the abilities of three specific models. Means of effective boundary layer control for the scoop inlet are presently being developed which may enable it to approach the conical shock diffusor in performance.

Turning now from the more general considerations of air induction, we will discuss one of the detailed problems that the N A C A Laboratories are studying, and illustrate the phenomena in the wind tunnel. On this chart (CHART 6) are shown two conical shock inlets: one which has been designed to avoid flow separation on the cone, and one which will suffer separation and unsteady flow. It should be mentioned that unsteady flow is not a phenomenon which occurs only with this type of inlet. As a result of unsteady combustion or poor aerodynamic design, it can occur with any type. Poor aerodynamic design can be illustrated by a conical shock inlet with centerbody cone angle which is too small (CHART 6). This permits the initial oblique shock compression to be relatively weak, causing the normal shock compression to be quite strong. This strong normal shock acts on a relatively thick boundary layer, causing separation and flow oscillation. The large effect of the external normal shock wave on the flow through the engine is indicated by this considerable reduction in the width of the shaded streamtube (CHART 6). Flow oscillations are highly undesirable, because engine thrust decreases while the aircraft drag increases, and violent shaking of the whole aircraft may occur. The N A C A is currently making gains in the solution to this problem of flow instability.

A wind tunnel demonstration of flow instability will now be presented, but first a few remarks about the wind tunnel and its associated apparatus. The wind tunnel to your right is of the blowdown type, utilizing air which has been compressed to about six atmospheres and stored in the neighboring twelve foot wind tunnel. Mach numbers between 1.2 and 3.0 can be attained, with flows similar to those about full scale aircraft.

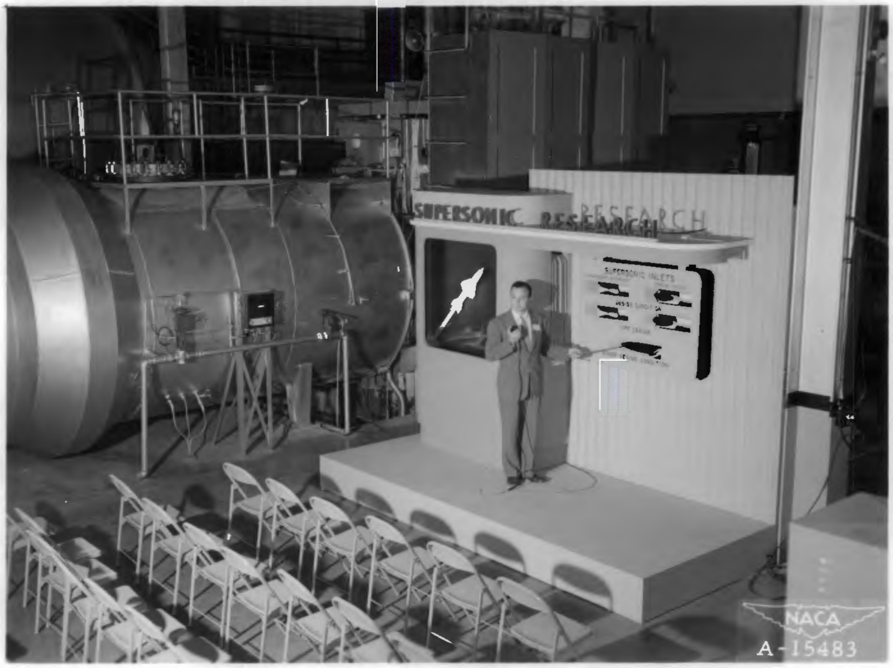
The model to be used in the demonstration of flow instability is of the conical shock type, with a centerbody whose cone angle is too small (CHART 6). As explained previously, the external normal shock wave acting on the relatively thick boundary layer causes flow separation and oscillations.

The schlieren system to be used in the wind tunnel demonstration is an optical device that makes visible density variations, and therefore, pressure variations. A stroboscopic attachment has been added to facilitate observation of the fluctuating flow about the conical shock inlet.

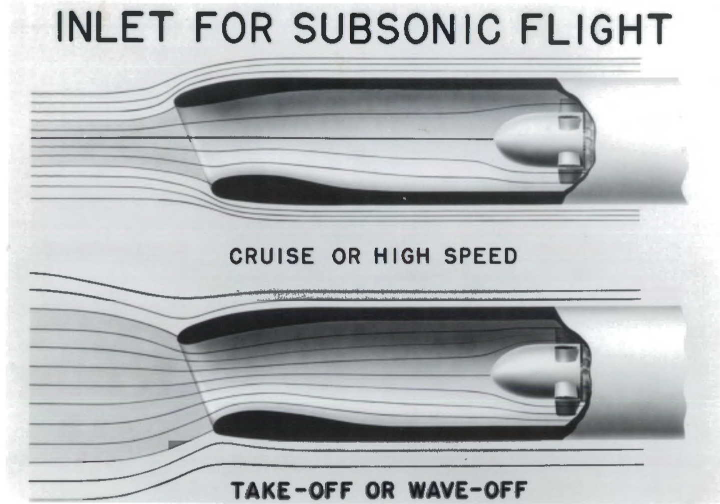
Before supersonic flow is established in the wind tunnel test section, there is no definite pattern to be observed in the schlieren field. However, when supersonic flow is established, observe the oblique shock waves inclined at angles which depend on the speed of the flow and the shape of the object creating the disturbance. Notice in particular, the normal shock wave at the inlet lip of the model as it bounces in and out of the inlet, as a result of fluctuating flow separation. It is interesting to note that the frequency of this oscillation is very steady with this model — about 19 cycles per second. The stroboscope has been set so that these fluctuations are visible.

The wind tunnel demonstration will start in a few seconds. Please be prepared for a great deal of noise.

START THE TUNNEL PLEASE.



Display for Presentation of "Air Inlets" Presented
by the 1- by 3-Foot Supersonic Tunnel



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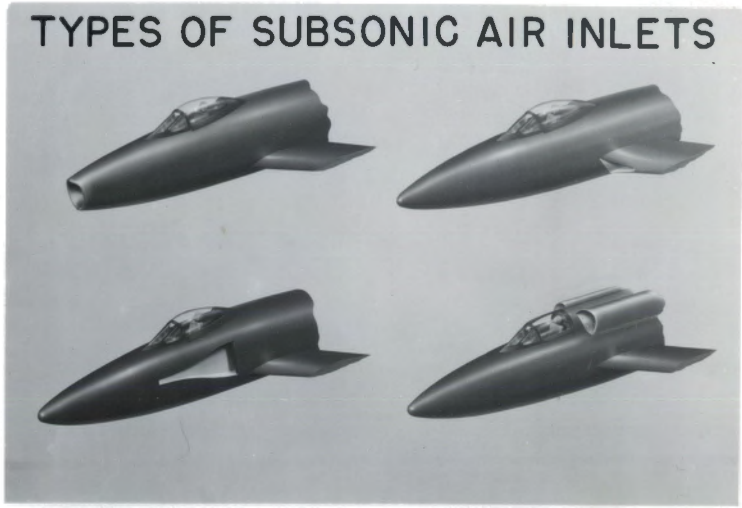

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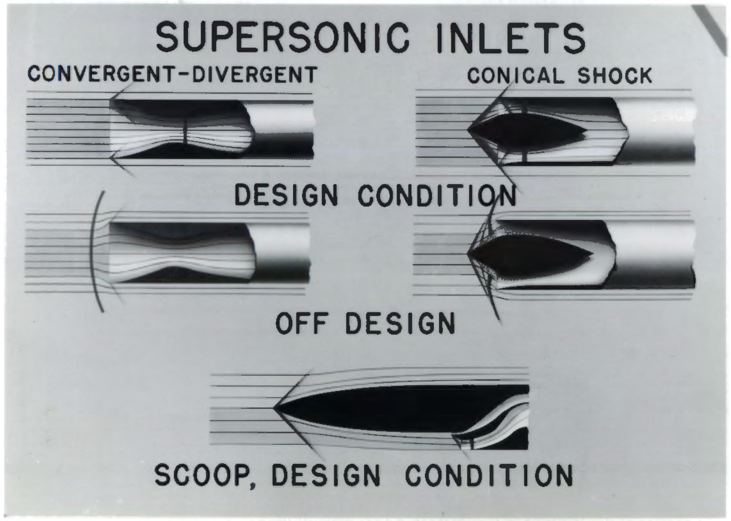

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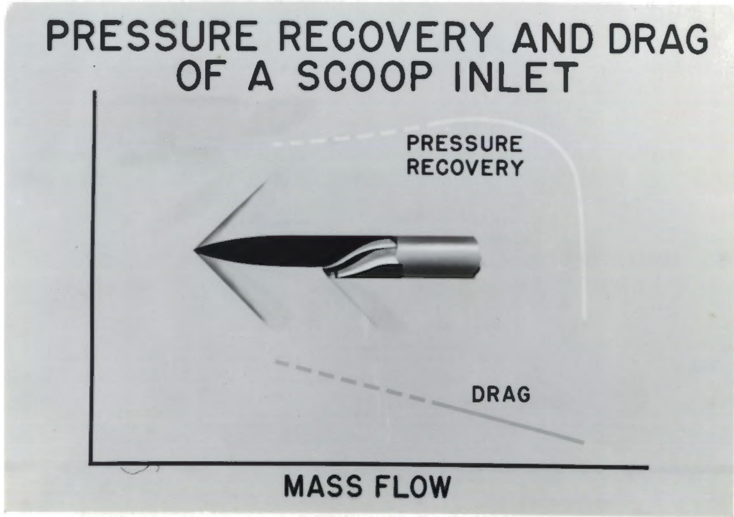

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