

March 12, 1963

E. E. VETTER
SUPERSONIC AIR DIFFUSER

3,080,707

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3 Sheets-Sheet 1

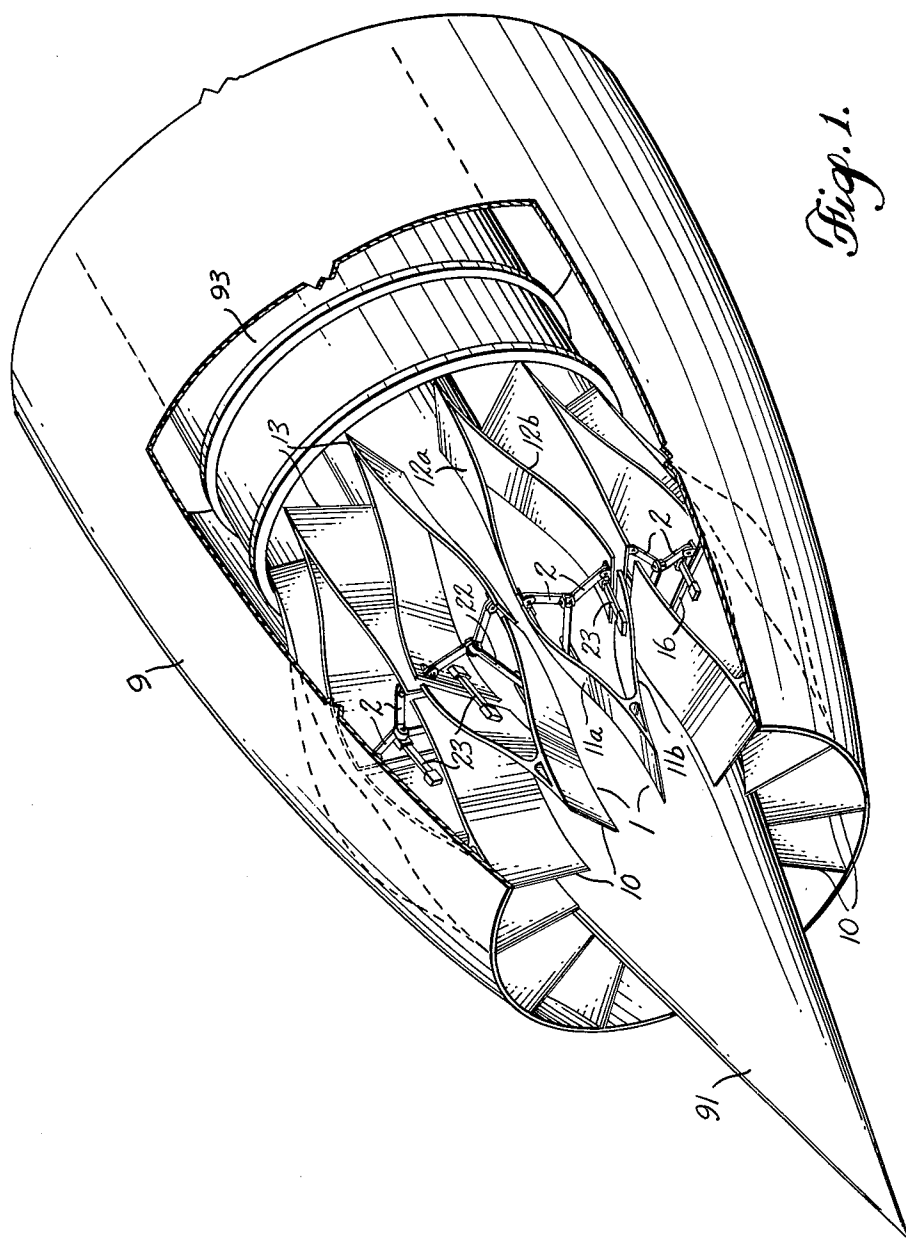


Fig. 1.

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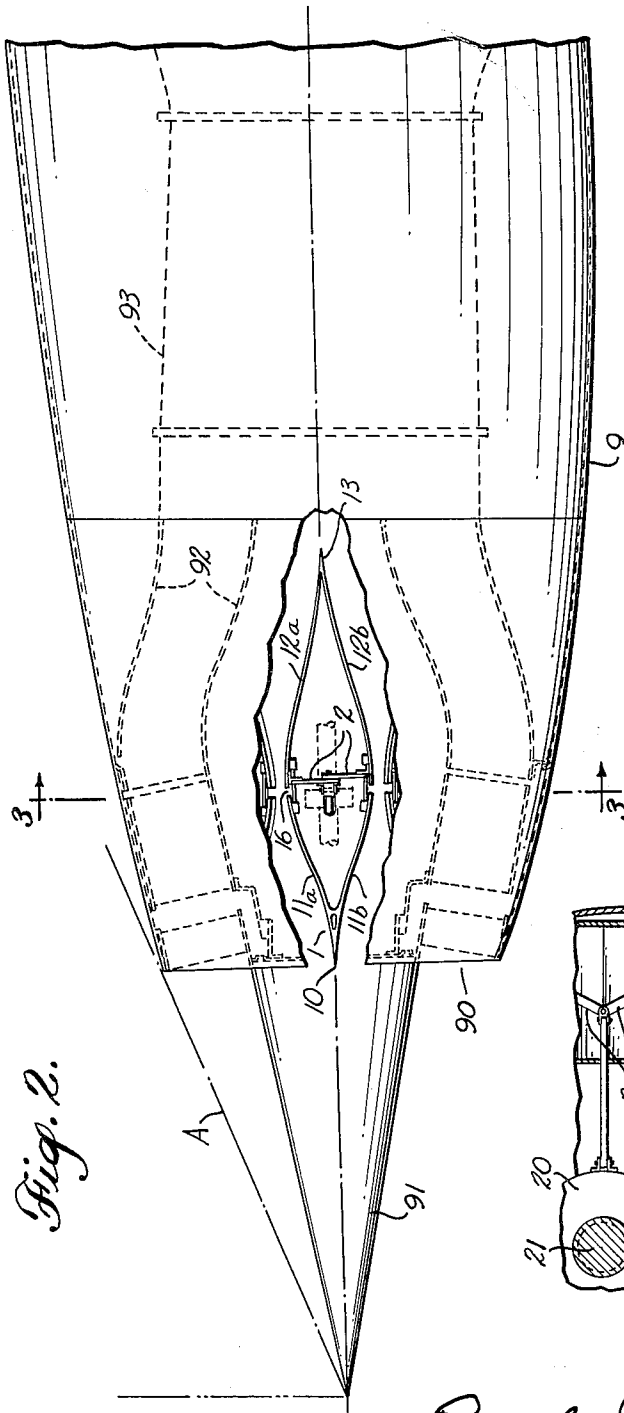


Fig. 2.

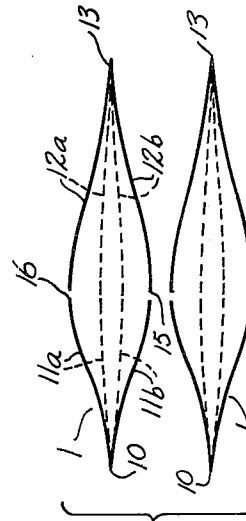


Fig. 4.

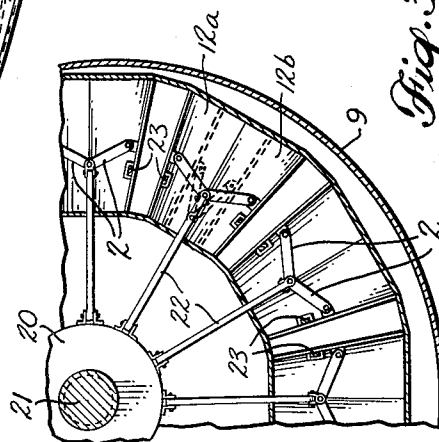


Fig. 3.

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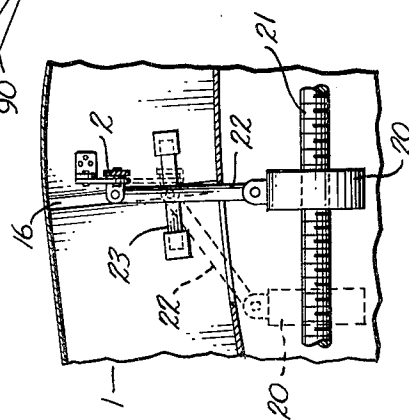
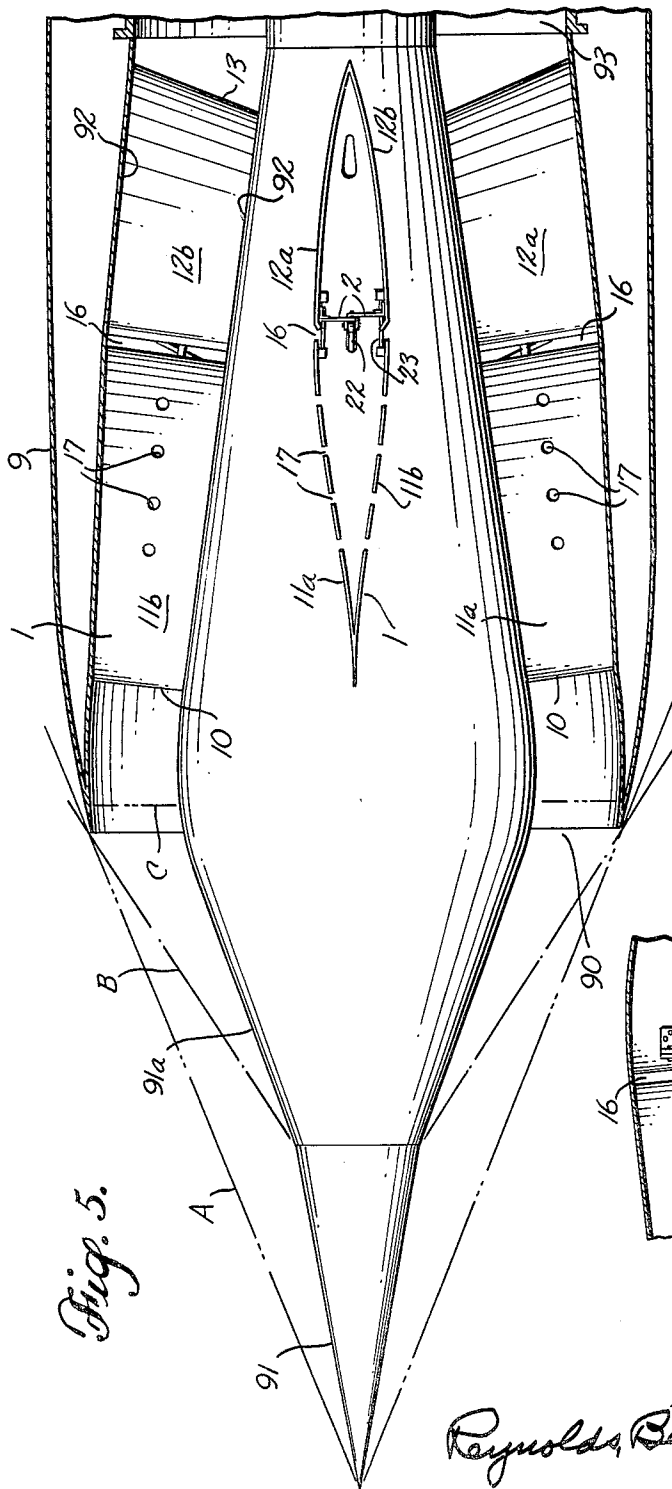
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3 Sheets-Sheet 3



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SUPERSONIC AIR DIFFUSER

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5 Claims. (Cl. 60—35.6)

Airbreathing engines, of whatever type (commonly called jet engines), as used for propulsion of aircraft, require large volumes of air, but not the same volume under all conditions. The required volume is a function of such factors as velocity or airspeed, air density which is usually dependent on altitude, rate of fuel consumption, etc. Such air is intaken through a forwardly or frontally facing air intake opening, which usually is of fixed frontal area. This air intake opening conventionally is made sufficiently large that under least favorable conditions, say at low altitudes and low airspeeds, below Mach 1.0, its frontal projection will encompass and in-breathe and adequate volume of air. Air at such a subsonic velocity can be diverted and its kinetic energy converted into pressure energy by known means and without undue difficulty, and certainly without the production of a shock wave within the captive air, at a conversion rate approaching isentropic.

At higher velocities, above Mach 1.0, the air volume inbreathed at the same fixed air intake opening may well be considerably in excess of the engine's requirements. Air intaken at such supersonic velocities acts quite differently from air at subsonic velocity; it is not susceptible of change of direction without production of possibly destructive shock fronts within the confines of the air passages; the location and shape of all shock fronts vary with the relative velocities of the external supersonic air flow and of the captive air flow; and the conversion at such supersonic velocities is far from isentropic, being in fact quite inefficient, producing large losses, and drag. Supersonic captive air must be slowed to a subsonic value before its conversion becomes efficient, yet unless the volume of the captive air can be automatically regulated to accord with the volume that can be effectively slowed to a subsonic value, or conversely, unless the varying volume intaken at different velocities can be effectively slowed by means that accord with the differences in the intaken volume, the air-breathing system is of low conversion efficiency, and liable to damage from uncontrolled shock fronts. Moreover, slowing of the captive air within the shortest possible length is imperative for many and rather obvious reasons.

Parenthetically, it will be recognized that such an engine will of necessity be required to operate efficiently under varying conditions of flight—at subsonic velocities during take-off, at sonic or supersonic velocities during climbing in powered flight, and at altitudes and ambient pressures all the way from ground level to many thousands of feet.

It is necessary, therefore, to reduce the velocity of air flow to a subsonic value before completing conversion of its kinetic energy into pressure energy, and before attempting to direct the captive air flow in a curved path. In addition, this must be done by a diffuser operable over a wide range of Mach numbers, with stable subcritical flow, high recovery of energy, and low drag. The diffuser must be such as will handle three types of flow, namely, subcritical, critical, and supercritical, with generally the same facility. Such diffuser must be located close to the air intake opening, and under all operating conditions must effect the conversion in a path of minimum length. The accomplishment of these aims is the object of this invention.

Diffusers used heretofore in such installations have been

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some one of a few characteristic types. The Pitot diffuser, of increasing area rearwardly from a minimum-area entrance, produces plane shock, and its recovery decreases markedly with increase of Mach number beyond, say, 1.6. It is impractical at Mach 3.0 or even lower. The Ferri diffuser, a spike projecting from within an intake opening, produces an oblique shock at the nose followed by normal shock at the air intake opening. Its recovery rate is better, but still is low at Mach 3.0. The pressure recovery is dependent upon the cone angle, between the cone and the direction of the oncoming air. The multiple oblique shock type (Oswatitsch) is a modification of the Ferri type, and is better at velocities in excess of Mach 2.5, but less efficient at lower Mach numbers. The Kantrowitz convergent-divergent diffuser has also been used, and when designed for and operated at any given Mach number operates with good efficiency, but since the Mach number in supersonic flow decreases with decreasing throat area, but in subsonic flow decreasing the throat area results in increasing the Mach number, hence the throat area for any given flow rate is rather critical, it follows that a Kantrowitz diffuser has not the flexibility nor adaptability to different velocities over a range involving subcritical, critical, and supercritical values. In addition, it requires an inconvenient length if it alone is required to effect all conversion of the entire volume required.

The present invention differs from the single-type diffusers heretofore proposed, in that it selects and combines the Ferri or the Oswatitsch diffusers with the Kantrowitz type, modifying the latter by effecting adjustment of the throat area in accordance with the airflow rate after it passes the spike, and so in a relatively short distance reduces the airflow to a subcritical value, and only thereafter does it divert the airflow and control its direction, at the subsonic velocities. By so doing the recovery is of a high order, and shocks within the captive air are avoided, or if they occur, they do so before the airflow is diverted from its straight-line path. The subcritical flow is at a stable rate, and drag is low. In addition the diffuser is thus operable over a wide range of Mach numbers, such as correspond to the speed range of the aircraft.

One further known principle is preferably incorporated to advantage in the diffuser of this invention, namely, the use of spillage to get rid of the boundary layer and so to avoid choking. Spillage has been proposed in the perforated inlet of a Kantrowitz type of diffuser, and can be so employed in the diffuser of this invention; preferably spillage is arranged to occur at least from the entrance to the reduced throat, in a region where the airflow has been reduced to near subcritical values, or in advance thereof to avoid choking at the throat.

The invention will be more readily understood from the detailed description which follows, in conjunction with the accompanying drawings, wherein various forms of the invention are illustrated diagrammatically. The novel principles of the invention are set forth in the appended claims.

FIGURE 1 is a broken away isometric view of the diffuser incorporating this invention.

FIGURE 2 is in the nature of a side elevational view, partly broken away.

FIGURE 3 is a transverse sectional view, substantially at the line 3—3 of FIGURE 2, illustrating a quarter segment of the diffuser.

FIGURE 4 is a diagram of the range of adjustment of the throat area which is possible in accordance with the principles of this invention.

FIGURE 5 is an axial sectional view of the diffuser of this invention, incorporated in a form somewhat modified from the form of FIGURES 1 to 3.

FIGURE 6 is in the nature of an axial sectional view, illustrating a detail of the operating mechanism.

The diffuser is housed within an elongated or barrel-like housing 9, open for intake of air at its front end. Internally it supports a spike 91 directed forwardly ahead of the open front end and coaxial with but smaller than the housing 9 at this end, to define an air intake orifice 90 and an internal passage leading thence rearwardly, both of annular shape. The housing also contains a series of radiating diffuser vanes, directed longitudinally within the annular air intake opening and passage, the nature of which will be explained more particularly later, and the function of which is to reduce the velocity of the captive air to a subsonic value. After being so reduced in velocity, the air is directed inwardly towards the axis by inwardly curved air passage walls 92 and collects and moves rearwardly within a chamber 93 to its point of use, such as the compressor section of a jet engine, or the combustion chamber thereof, or both. Such usage of the air being conventional, and having per se no immediate relationship to the diffuser of this invention, the means for its utilization are omitted from the illustration.

The spike 91 will have a fixed cone angle, commensurate with other details of the design. At maximum demand, usually at highest airspeeds, it would be designed to have a cone angle A (FIGURES 2 and 5) such that it grazes the outer periphery of the air intake orifice 90, and there is minimum or zero spillage of air externally of that intake orifice. At lower but still supersonic velocities, the cone angle would be wider, spillage of air externally of the intake orifice 90 would be greater, according to known principles, and the lessened intake would automatically accord with lessened demand. All this is true whether the spike be a single Ferri type, FIGURES 1 and 2, or of the multiple Oswatitsch type, including a secondary cone 91a with its secondary shock wave B, as in FIGURE 5, or even a tertiary cone and shock wave. There is, then, reduction of the velocity of intaken air by its passing the oblique shock wave front or fronts, to a value somewhat above the critical value, yet the velocity can not be so reduced to one given value, notwithstanding that the volume intaken is automatically varied in accordance with demand.

The reduction in velocity from any such reduced yet supercritical value to a subcritical value is the function of the diffuser vanes within the air intake passage, and their functioning is greatly simplified by the fact that they need not handle a larger volume of air than the engine is demanding, the excess volume having been eliminated as explained above. The Kantrowitz type of diffuser, it will be remembered, functions best at some one flow rate, yet the flow rate through the intake orifice varies rather widely. Accordingly, instead of using fixed throat areas in this vane diffuser, the vanes are made adjustable to vary the throat area, and now regardless of variation in the flow rate past the Ferri or Oswatitsch diffusers, the Kantrowitz type diffuser will reduce the final flow rate to a subcritical value, in a minimum length, and thereafter the air is controllable in normal manner and by normal means. A normal shock front can be expected at C, in advance of the throat (see FIGURE 5), but this can be accommodated by the design.

The longitudinally directed diffuser vanes within the air intake opening, referred to above, are arranged to converge towards a number of annularly distributed throats of minimum area and to diverge beyond each such throat, as in a Kantrowitz diffuser, but the throat area is not fixed, but variable. Thereby the decrease in velocity across the throat can be varied in consonance with the decrease in velocity at the preceding shock front or fronts, at any air speed, to give the best entropy and the best overall pressure recovery, and to decrease the velocity beyond the throat to a subsonic value. At this subsonic value the air can be diverted and directed, without shock, hence

can be utilized in whatever manner may be required or desired, converted to the form of pressure energy.

The principle of the variable throats is illustrated in FIGURE 4. Each radially oriented and axially directed vane, designated generally by the numeral 1, comprises two forward walls 11a and 11b, joined and sharply pointed at their forward end 10, and two rear walls 12a and 12b, joined at a streamlined rear end 13. The walls are not fixed in position, except at 10 and 13, but rather are relatively movable in the circumferential direction, to separate the walls 11a and 11b, and 12a and 12b, or to effect their approach. To enable this the walls may be of flexible material. The approximate range of such movement is shown by comparison of the full line showing in FIGURE 4 with the dash line showing.

It will be understood that the movement of all the walls occurs simultaneously and by like amounts, not only in a given vane 1 but in all thereof. As a result, between each two adjacent vanes is defined a convergent-divergent air passage through a throat 15. This throat is of greatest area in the dash line position of the vanes, and produces the minimum of choking, whereas in the full line position its area is a minimum, and its choking effect is greatest.

The mechanical means to produce such variation in the throats' area is relatively unimportant. Toggle link mechanism designated by the numeral 2, for spreading or effecting approach of the free ends of the walls is shown by way of example in FIGURES 2 and 3, and in FIGURE 6. Any suitable mechanism may be employed. By way of example, a nut 20 (FIGURE 6) is threaded upon an axially directed jack screw 21, and is linked by the link 22 with the common pivot of the toggle links 2. Any axial movement of the nut 20 will spread or draw together the opposite walls of a vane 1. A longitudinal link 23 causes the free ends of the walls 11 and 12 to move alike. This or any other suitable mechanism will serve to actuate the walls of vanes 1.

By adjusting the cumulative area of the throats 15, in accordance with the air speed and the decrease in velocity effected at the shock fronts A and B, for example, the location of the shock front C can be controlled, and the air velocity past the throats can be reduced below Mach 1.0. For higher initial velocities, ordinarily the throats 15 would be of smaller area to effect this result, and for lower initial velocities, or with a larger conversion factor in the preceding shock fronts, the throat area would normally be larger. The ability to adjust the throat area to conform to existing conditions, in conjunction with the use of preceding diffusers which are better suited to the higher velocities which they encounter, makes the diffuser of this invention efficient in use over a wide range of Mach numbers, within the minimum length of diffuser.

With the air velocity past the throats 15 reduced below Mach 1.0, the air is susceptible to guidance and control in normal ways. Thus the inward direction of the air passage walls 92 can now direct the air inwardly, where in its approach to the throat it was inclined outwardly, and at its velocity exceeding Mach 1.0 its direction was impracticable.

At the upper range of Mach numbers even the combination of the several diffuser types already described may be inadequate to effect the desired result of reducing the air velocity below Mach 1.0 beyond the throat, and choking may result. In such case use may be made of the perforated inlet or modified Kantrowitz type of diffuser. For example, the walls 11a and 12a, and 11b and 12b, may be of such length that they abut at their free ends when defining the maximum throat area, as in the dash line showing of FIGURE 4, but when the vanes are expanded to minimum throat area, as in the full line showing, a gap 16 is opened from the throat to the interiors of the several vanes, whence spillage may be relieved in any suitable manner. Alternatively, the forward walls 11a and 11b may be perforated ahead of the

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throat, for spillage to the interior of the vanes. Such perforations act as automatic valves, being open during the starting process and partly closed, in terms of mass flow rate, during operation. Perforations 17 are shown in FIGURE 5 for this purpose. Provision is made for escape of spilled air from the interiors of the vanes, but the ports and passages for such escape have been omitted, to avoid obscuring the principal features of the invention.

I claim as my invention:

1. A diffuser for reduction of supersonic air velocities to subsonic velocity, and for conversion of its kinetic energy to pressure energy, comprising a barrel-like housing open at its forward end, a spike projecting forwardly from within the housing and spaced from the perimeter of the open forward end to define an annular air intake orifice, a plurality of radially oriented and longitudinally directed vanes spaced angularly about and within the air intake orifice, and each of greater circumferential thickness intermediate its ends than at such ends, to define a plurality of convergent-divergent diffusers, each including a reduced throat in the region of such thicker portions, and means to vary the circumferential thickness of said vanes thereby to alter the area of such throats.

2. A diffuser for conversion of air flow throughout a wide range of supersonic Mach numbers to pressure energy at a subsonic value, comprising a barrel-like housing having its axis disposed in the direction of air flow and open at its forward end, a spike constituting a preliminary Ferri type diffuser coaxial with and directed ahead of and from within such open front end, and spaced from the perimeter thereof to define an annular air intake orifice, a plurality of longitudinally directed vanes within said air intake orifice, generally radially oriented, each vane having two walls joined at the forward end and diverging thence rearwardly to define, in conjunction with like walls of the adjacent vanes, a restricted throat, and converging thence rearwardly, and means to vary the spacing between adjacent walls of adjacent vanes, to vary the areas of the respective throats.

3. A diffuser as in claim 2, wherein each wall of each vane is formed of separate forward and rearward portions, of such relative length that a gap is opened between their inner ends by spreading apart of the oppo-

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site walls of each vane, for spillage of air through such gap.

4. A diffuser as in claim 2, wherein the housing encloses air passages to the rear of the throats, receiving air flowing therethrough, said rearward air passages being directed inwardly towards the axis of the housing.

5. A diffuser for inbreathing of air in amounts consonant with the demands of an airbreathing engine for aircraft or the like, at airspeeds ranging from supersonic to subsonic, comprising a barrel-like housing leading to a combustion chamber and having a forwardly facing intake opening and an interior wall for guidance of intaken air, a spike projecting forwardly from within the housing, spaced from the perimeter of the intake opening and from said interior wall to define an annular air intake orifice of fixed frontal area and an axially directed air passage, said spike being of a shape and so positioned with relation to the intake opening to produce a converting and slowing oblique shock wave at supersonic velocities of a conformation to divert externally of the intake orifice such air as is in excess of the engine requirements at each such velocity, a plurality of radially oriented and longitudinally directed vanes spaced angularly about and within the air passage, adjacent the intake orifice and ahead of the combustion chamber, and each of greater thickness in the circumferential direction in a region intermediate its ends than at such ends, said vanes cooperating to define a plurality of convergent-divergent diffusers, having throats in the region of such thicker portions, and means to vary the thickness of said vanes, to alter the area of said throats, and so to slow down air intaken at different supersonic velocities, and initially slowed by said spike, within a minimum length to a subsonic velocity.

References Cited in the file of this patent

UNITED STATES PATENTS

2,763,426	Erwin	Sept. 18, 1956
2,772,620	Ferri	Dec. 4, 1956
2,788,635	Ford	Apr. 16, 1957

FOREIGN PATENTS

614,548	Great Britain	Dec. 17, 1948
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