Feb. 21, 1956 G. F. HAUSMANN 2,735,612

BLADE PASSAGE CONSTRUCTION FOR COMPRESSORS AND DIFFUSERS

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FIG. 1

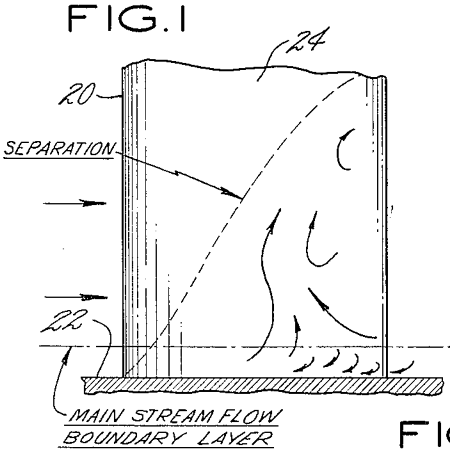

FIG. 2

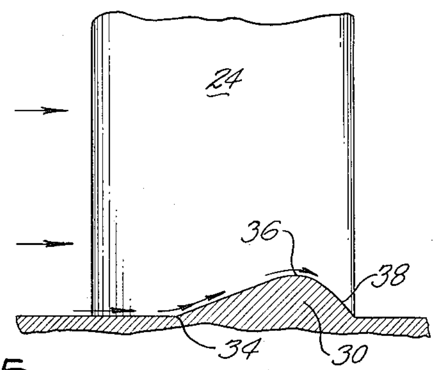

FIG. 5

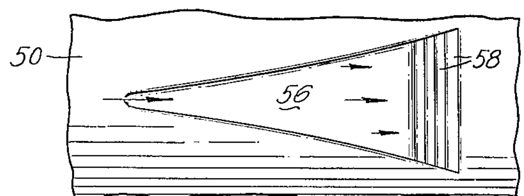

FIG. 4

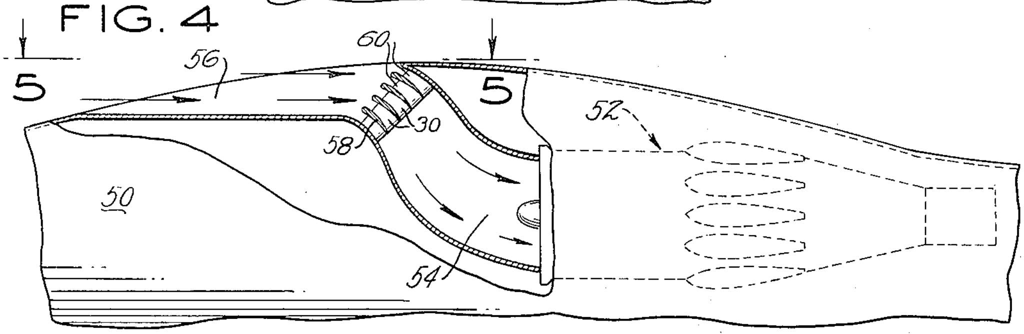

FIG. 3

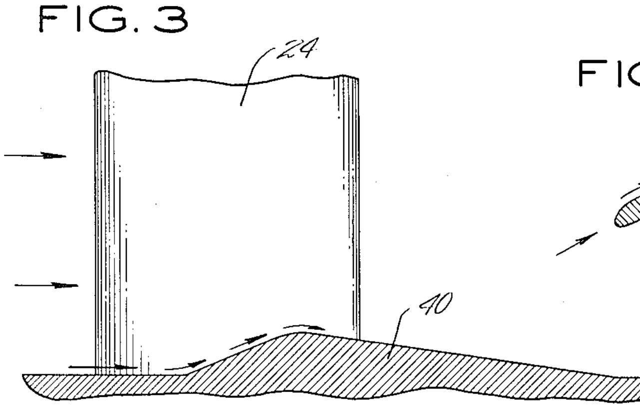

FIG. 1A

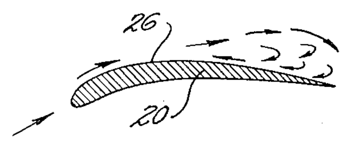

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FIG. 6

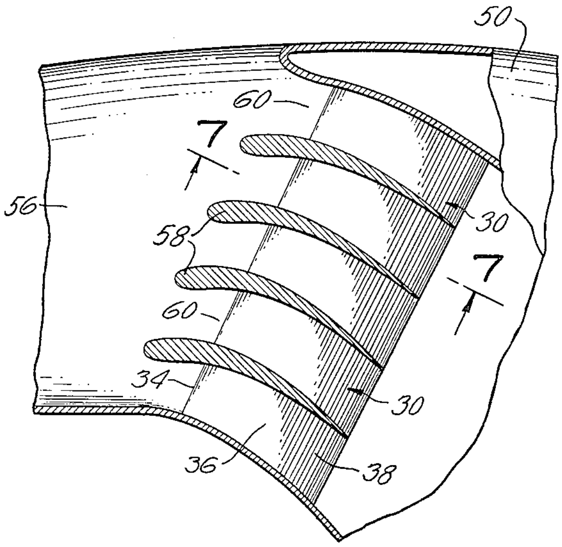


FIG. 7

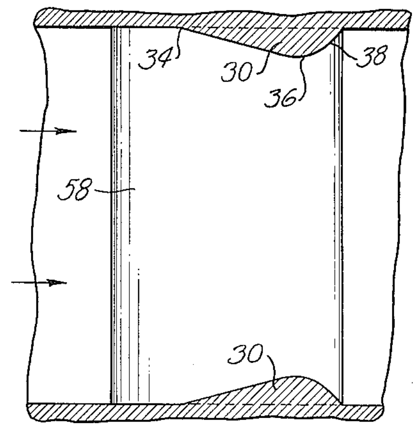


FIG. 8

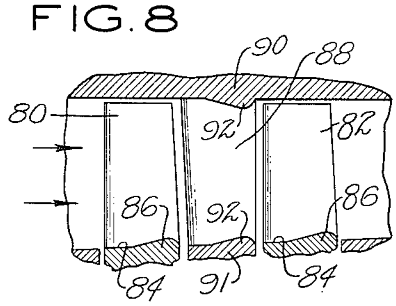


FIG. 9

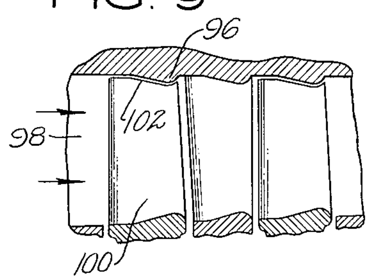


FIG. 10

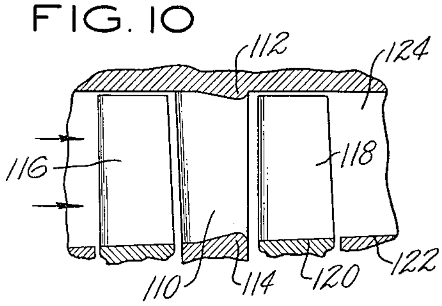
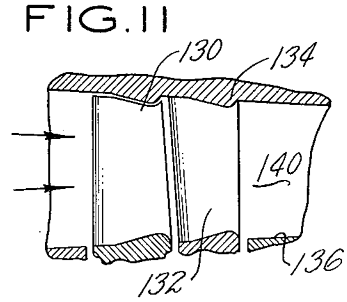


FIG. 11



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BLADE PASSAGE CONSTRUCTION FOR COMPRESSORS AND DIFFUSERS

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Application April 20, 1950, Serial No. 157,138

2 Claims. (Cl. 230—122)

This invention relates to improvements in confined fluid flow and more specifically to improved passage configurations for interblade passages in compressors and diffusers as for example in the air inlet diffusers for high performance aircraft.

It is an object of this invention to provide improved means for redistributing or energizing boundary layer flow along the confining wall of a fluid passage particularly in the immediate vicinity of rapid expansion regions such as is experienced between adjacent stator vanes of compressors, rotor blades or diffuser type turning vanes in air inlet passages.

Another object of this invention is to provide an improved boundary layer energizing mechanism of the type described herein comprising a substantially streamlined protrusion extending from the confining surface and located adjacent the blade extremities for varying the local pressure gradient by means of varying the flow passage along the axis of flow in order to obtain the particular aerodynamic advantages described hereinafter.

A further object of this invention is to provide protrusions of the type described to delay separation over the blades thereby obtaining maximum efficiency of diffusion and energy conversion within a minimum distance along the axis of flow. Therefore, a feature of this invention resides in improving the flow efficiencies over higher ranges of Mach numbers and lift coefficients of adjacent diffuser blades having a cascade arrangement.

These and other objects of this invention will become readily apparent from the following detail description of the drawings in which:

Figs. 1 and 1A illustrate flow separation over an airfoil shaped blade as caused by adverse effects of the boundary layer along an adjacent confining surface.

Figs. 2 and 3 illustrate the flow improving protrusions according to this invention.

Fig. 4 is a partial view of an aircraft fuselage illustrating a flush air inlet having diffuser type turning vanes for providing a high diffusion rate within a minimum of axial length.

Fig. 5 is a side view taken along the line 5—5 of Fig. 4.

Fig. 6 is an enlarged detail view of a portion of Fig. 4.

Fig. 7 is a detail view taken along the line 7—7 of Fig. 6.

Figs. 8 through 11 illustrate various modifications of this invention as applied to axial flow compressors.

In confined fluid flow or in fluid passages wherein a cascade of airfoil shaped vanes are arranged, for example so as to form diffuser passages therebetween, it is desirable to obtain a high rate of diffusion within a short distance along the axis of flow while also insuring maximum efficiency. In confined fluid flow where the blades ends are in substantially juxtaposed relationship with the confining surface, it has been found that the boundary layer along the confining surface sets up secondary flows particularly in the diffuser passages between the blades so that fluid separation obtains and the aerodynamic efficiency of the blades is not at an optimum value.

By way of example, and referring to Fig. 1, a blade 20 is shown extending from a wall 22 of a flow confining surface. The blade 20 may be one of a group of blades spaced transversely of the axis of flow so as to provide diffuser passages therebetween, as for example the stator blades of a compressor. As seen herein, the boundary layer along the confining surface having a lower velocity than that of the main fluid stream sets up secondary flows particularly in the vicinity of the blade 20 where rapid expansion of the air may be taking place so that an adverse pressure grading and subsequent fluid separation over the cambered surface 26 may result. Hence, although the blade itself will normally have a boundary layer over its major surfaces which may under certain conditions cause fluid separation, the interaction of the boundary layer of the confining surface therewith accelerates these poor flow conditions and effects the flow a substantial distance away from the confining surface over the span of a particular blade or blades as illustrated by the arrows in Figs. 1 and 1A. Therefore, it is apparent that the range of blade lift coefficients at which high efficiency can be maintained is substantially reduced over the ideal flow condition.

To this end then and in order to increase the ranges of efficient operation, a protrusion 30 is provided which extends into the fluid stream from the confining surface adjacent the blade 24. These protrusions may normally have a span transversely of the axis of flow such as to extend from one blade to the other, as for example illustrated in Fig. 6. The protrusion 30 is of substantially streamline shape and has its leading edge 34 located within the first third of the chordwise dimension of the blade 24 measured from the leading edge of the blade. The maximum point of protrusion 36 is preferably located within the last fourth of the chordwise dimension of the blade 24 measured from the leading edge thereof. A downstream or trailing portion 38 of the protrusion 30 may terminate adjacent the trailing edge of the blade 24 as illustrated in Fig. 2, or it may assume the shape as illustrated in the protrusion 40 in Fig. 3.

It has been found that extending the trailing edge of the protrusion in the manner illustrated in Fig. 3 does not provide a great improvement over a trailing edge of the type illustrated in Fig. 2. The reason for the slight difference is attributed to the fact that immediately aft of the blade 24 where diffusion between the blades has caused an increase in pressure and a decrease in velocity, an abrupt contour like the trailing edge 38 of Fig. 2 is of little consequence.

It is then apparent that the protrusion 30 in effect produces a gradual convergence of the confining fluid surface in the vicinity of the blade 24 so as to accelerate the boundary layer air in the critical region where it might otherwise cause secondary flows which are adverse to that of the main stream so as to cause fluid separation over the adjacent blade. This increase in boundary layer velocity reaches its peak near the trailing edge of the blade 24 thereby delaying separation from the blade in this vicinity to minimize the dilatorious effect which would obtain over a large portion of the span of the blade.

The utilization of a protuberance on the hub wall and/or outer casing wall adjacent the outer end of the vanes has particular effect on the flow conditions where boundary layer flow along the duct wall and the flow conditions over the vanes interact to cause unsatisfactory conditions leading to separation and high drag. The maximum point of protuberance of the wall contour is located as shown downstream of the maximum thickness location of the vane. Location of the protuberance in this manner provides a local acceleration of the flow over the airfoil shaped vane in the vicinity of the vane-wall intersection. Considering the flow over the vane then, a normal decrease in velocity is experienced aft of the maximum thickness of the vanes due to the diffusion taking place. This condition along with the rise in pressure tends to prematurely retard flow of the boundary flow along the duct wall causing local separation along the wall and also over a large section of the adjacent vane.

From the foregoing it will be evident that the leading edge of the protrusion as shown is located downstream of the leading edge of the vanes since local acceleration of the boundary layer along the duct wall is desirable at approximately the point where diffusion commences between the major vane surfaces.

The advantages of the use of protrusions **30** makes them particularly adaptable for air inlets of high performance aircraft for it is desirable to reduce the velocity and increase the pressure of the air within a very short distance.

Referring to Fig. 4, a fuselage **50** is shown having imbedded therein one or more turbo-jet power plants **52** which induct air via a passage **54**. A substantially flush air inlet **56** is provided in the fuselage **50** and includes a plurality of vanes **58** of airfoil shape which are arranged in a cascade so as to form a plurality of diffuser type diverging passages **60** therebetween (Fig. 6). The blades **58** extend completely across the air inlet passage and are of such configuration with regard to camber and angle of incidence so as to provide a high rate of expansion therebetween within a relatively short distance along the axis of flow. The expansion, of course, causes a transfer of velocity energy into pressure energy. In order to obtain this high rate energy conversion the blades must be highly aerodynamically loaded and operate efficiency over a wide range of Mach numbers.

Hence, in order to improve the efficiency of the diffusion and to improve pressure recovery at the engine, a plurality of protrusions **30** are provided on the confining wall of the air inlet passage **56** adjacent the extremities of the blades **58** with the protrusions extending transversely of the axis of fluid flow so as to span the spaces between the blades **58** as seen in Fig. 7. It will be noted that the protrusions **30** will then progressively vary the area of the fluid passages **60** and in effect further provide diffusion at their trailing edges in a plane parallel to the span of the blades **58**. The passage **54** may gradually diverge along the axis of flow so as to constitute a diffuser in itself to further increase the pressure of the fluid after it has moved past the vanes **58**.

The use of protrusions in the manner described is also readily adaptable to axial flow compressors, as shown for example by the modifications illustrated in Figs. 8 to 11. The protrusions in these modifications assume a shape similar to the protrusions **30** described above. Referring to Fig. 8, for example, the first stage compressor blades **80** and the second stage compressor blades **82** may have their rotor rims **84** formed with protrusions **86** while the stator blades **88** may have their adjacent confining walls **90** and **91** provided with protrusions **92**. Fig. 9 illustrates a similar arrangement with the additional feature that a protrusion **96** is provided in the outer wall of the annular compressor passage **98** while the compressor blade **100** has its tip extremity **102** indented so as to complement the configuration of the projection **96**.

Figs. 10 and 11 illustrate further modifications of the configurations shown in Figs. 8 and 9. Thus in Fig. 10 the stator vane **110** has protrusions **112**, **114** adjacent the extremities there while the confining walls in the vicinity

of the rotor blades **116**, **118** are devoid of any protrusions. However, the rotor rim **120** and the adjacent confining wall portion **122** are of larger diameter than the upstream confining surface so that the annular passage **124** is of lesser cross-sectional area than the upstream portion of the passage as is conventional in multi-stage compressors.

In Fig. 11, on the other hand, the extremities of both the rotor blade and the stator blade **132** have inwardly directed protrusions adjacent thereto while the confining walls **134**, **136** gradually converge to diminish the cross-sectional area of the passage **140** in a downstream direction.

The amount that the protrusion extends into the main stream is preferably determined by test so that it will produce the maximum flow improvement consistent with the flow parameters such as the size of the boundary layer along the main confining surface, and the boundary layer over the blade surfaces as effected by blade camber and blade chordwise and spanwise dimensions.

As a result of this invention it is apparent that a simple but effective means has been provided for increasing flow efficiencies through blades having a cascade arrangement as for example in compressors, diffusers and the like while maintaining high aerodynamic loading on the blades.

Although certain embodiments of this invention have been illustrated and described herein, it will be apparent that various changes and modifications may be made in the arrangement and construction of the various parts without departing from the scope of this novel concept.

What it is desired to obtain by Letters Patent is:

1. In a compressor having inner and outer walls of predetermined diameters respectively forming an annular passage, said passage having a longitudinal axis, a row of vanes fixed to said walls of airfoil shape and circumferentially spaced transversely of the axis of said passage, each of said vanes substantailly spanning said annular passage in a radial direction and extending from one of said walls to the other, said vanes having a chordwise length extending along the longitudinal axis of said passage, and a protrusion extending into said passage from at least one of said walls and spanning the entire space between circumferentially adjacent vanes, said protrusion having a smoothly curved shape diverging at a predetermined rate from the diameter of said one wall and subsequently converging at a greater rate to the diameter of said one wall in a direction downstream along said longitudinal axis, said protrusion having its point of maximum divergence located approximately within the last downstream quarter of the chordwise length of the vanes but upstream of the trailing edge thereof.

2. In a compressor according to claim 1 wherein said protrusion has its leading edge located within the first third of the chordwise dimension of said vanes.

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