April 29, 1969 E. ARNHOLDT 3,441,236

AIRFOIL

Filed Jan. 16, 1967

FIG. 1

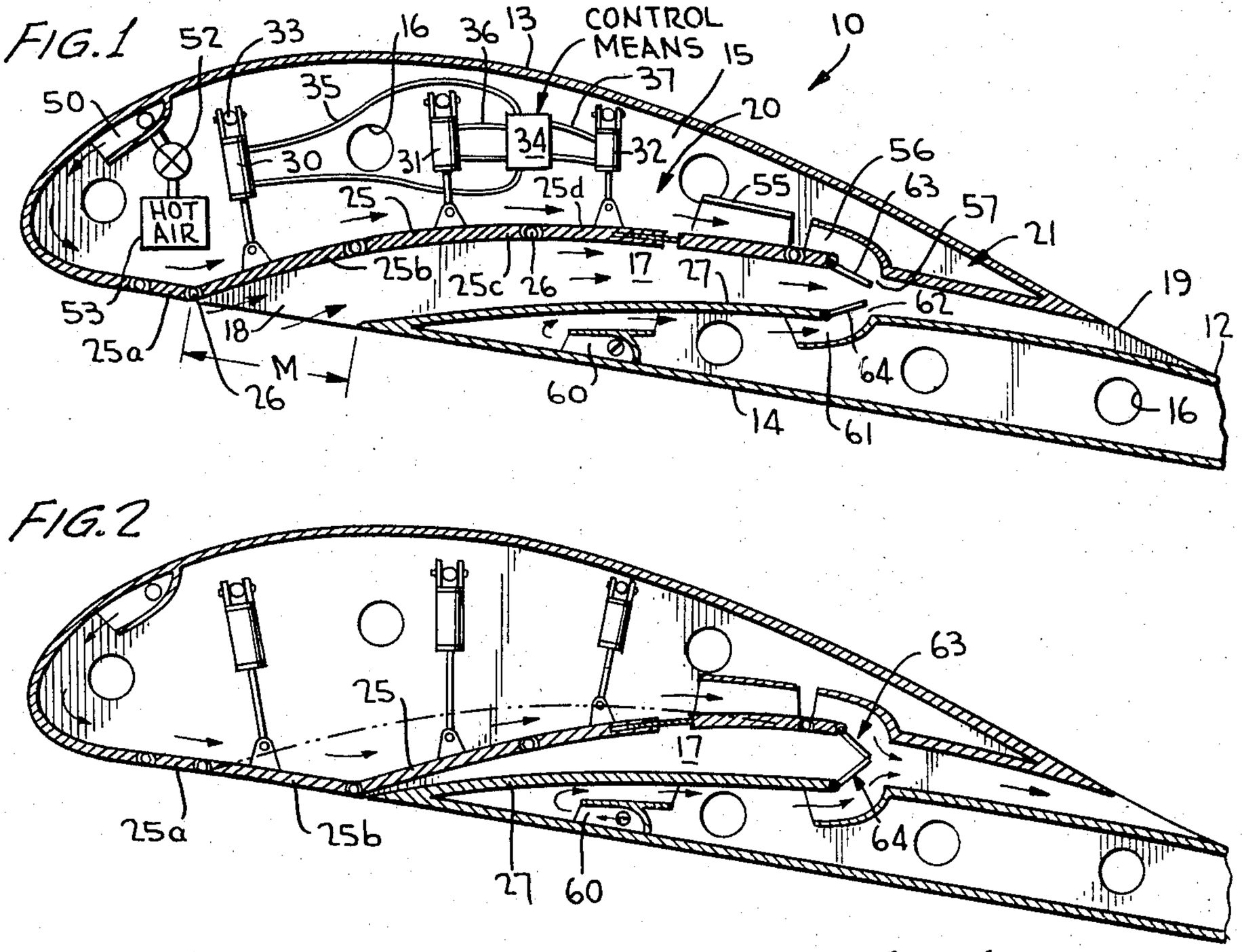



FIG. 2




FIG. 3

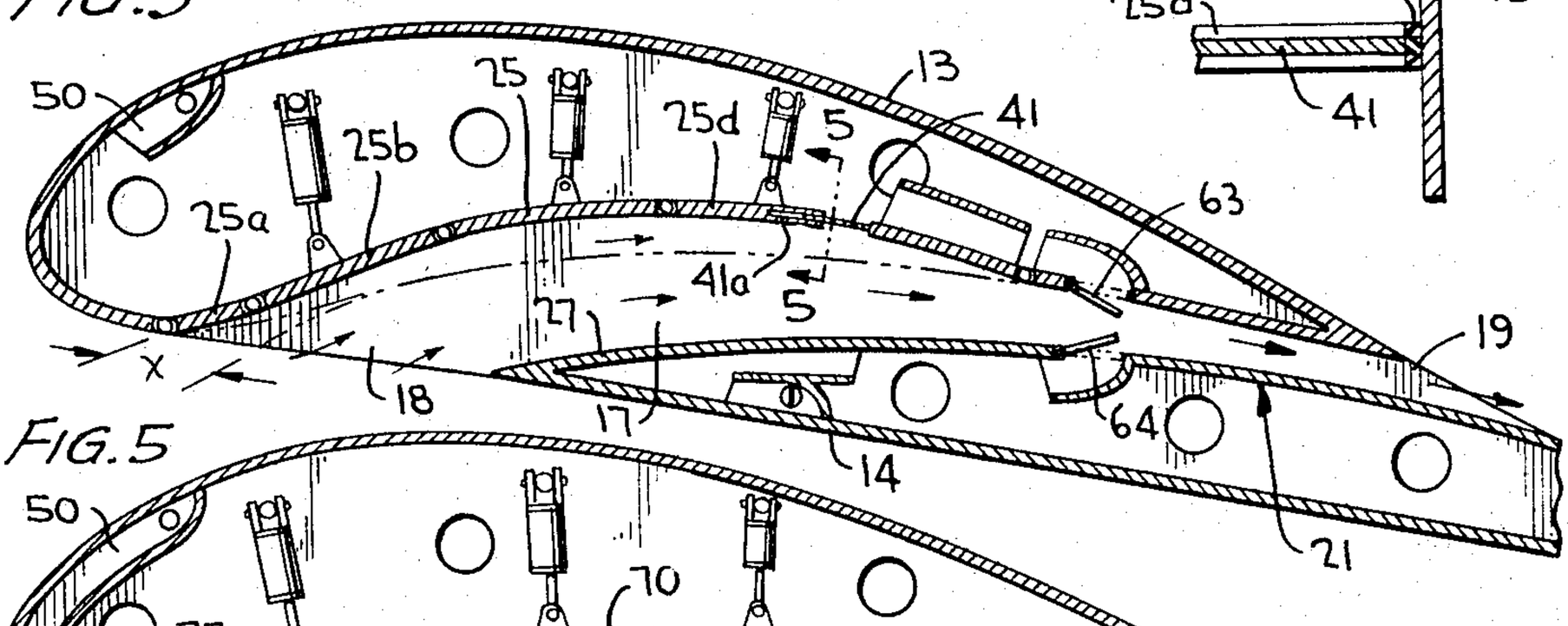
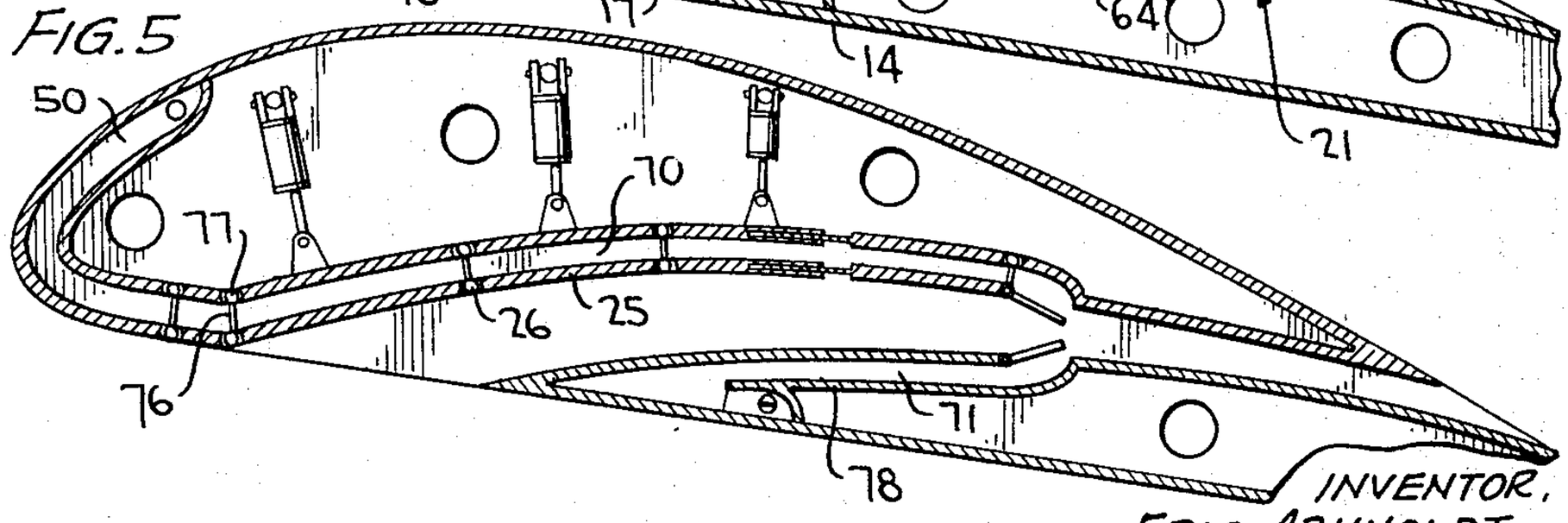



FIG. 4




FIG. 5




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# AIRFOIL

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10 Claims

## ABSTRACT OF THE DISCLOSURE

An apparatus for providing lift in a fluid medium having an adjustable slot-like passage extending from the underneath pressure surface to the upper suction surface for providing additional high velocity fluid flow over the latter. A deicing system channeling heated air chordwise along the passage and through its discharge nozzle is positioned within the airfoil.

The present invention relates to improvements in airfoils and, more particularly, relates to improvements in airfoils having a lift modifying passage formed therein.

In my prior U.S. patent application, Ser. No. 425,853, filed Jan. 15, 1965, entitled, "Airfoil," now U.S. Patent 3,298,636, issued Jan. 17, 1967, there is provided an improved airfoil having an upper suction surface formed in an undulating fashion with relatively spaced crests and valleys for enhancing the lift-to-drag ratio. As explained in this earlier patent this desired result is accomplished by providing a passage through the airfoil extending substantially parallel to the fluid flow from the underneath pressure surface to the upper suction surface. This passage terminates in a restricted nozzle to cause a high velocity stream of fluid to be expelled tangentially of said valley thereby causing the fluid flow to follow the curvature of the valley as well as the crest in a fashion to materially improve the lift and reduce the drag, and to thus enhance the lift-to-drag ratio.

The present invention is concerned with the provision of structure used to control the flow of air through this type of lift modifying passage and thus a main objective is to thereby provide a means for efficiently controlling the velocity and mass flow of air through the passage and into the boundary layer region of the slipstream over the lift or suction surface. Broadly speaking, the apparatus of the present invention is not limited to use with the specific airfoil disclosed and claimed in this previous patent, but can be utilized for the control of the fluid flow through similar passages in conventional airfoils, which are primarily designed to prevent premature separation of the fluid flow and thus a reduction in the drag coefficient, for example, as shown in the U.S. patent to Grant, No. 2,649,265, issued Aug. 18, 1953.

It is an additional objective of the present invention to provide an airfoil with a passage of the type described having a novel deicing arrangement, which is effective to prevent the undesirable build-up of ice in the passage.

Briefly, the apparatus of the present invention includes a passage in the airfoil which is formed of opposed inner wall members, the inner wall members being spaced to form an enlarged mouth opening at the pressure surface and a restricted nozzle opening at the suction surface. At least one of the wall members is movable, and preferably the upper wall member is formed of a series of articulated sections which are capable of being selectively moved toward and away from the opposed or lower wall member. With this construction, the cross sectional area of the passage may be easily adjusted to vary the mass flow of fluid through the passage, and thereby vary the velocity and effectiveness of the lift modifying stream of fluid exiting through the nozzle and tangentially onto the



suction surface. Also, of importance is the provision of an extensible joint in said upper wall member, which allows a maximum adjustable range of movement of said wall member. As a result of this feature, the forwardmost articulated sections may assume in one limit position, a closing relationship across the mouth of the passageway to cut off the flow of fluid through the passage, and at the other limit of movement, the mouth is allowed to be wide open for maximum flow through the passage, as desired. Thus, in accordance with the present invention, the lift modifying passage may be fully opened for maximum mass flow during periods when high lift is required, such as during take off and landing; then the passage can be adjusted to assume an intermediate position for normal flight; and finally the passage can be fully closed whenever the lift modifying effect is not desired.

It should be noted that the adjustable lift modifying effect of the airfoil of the invention is gained without a change in the camber of the wing or a change in the rearward sweep of the wing, as has been proposed in the past, and the airfoil of the invention is accordingly of much simpler design for savings in cost and weight, which factors are of utmost importance in craft of this type. Furthermore, since the cross section and the position of the wing remain unchanged in the airfoil of the present invention, it is considered to be more reliable and not subject to the costly maintenance problems usually associated with these prior art variable shaped or variable sweep wing constructions.

In accordance with the other but related aspect of the present invention, the airfoil is provided with means for preventing the build-up of ice in the passage, thus insuring efficient operation of the apparatus under adverse weather conditions. Preferably, the working medium for the deicing system is supplied by the hot air exhaust or compressor bleed from the aircraft's engines and this air is directed first along the inside surfaces of the wall members forming the passage and then directed into the restricted nozzle of the passage where icing conditions are more prevalent. With this arrangement, it has been found that maximum ice prevention is obtainable along the entire length of the passage with a minimum amount of adverse turbulence being introduced into the stream of fluid passing through the passage. Furthermore, flap valves are provided on the orifices which introduce the heated air into the restricted nozzle to allow the proper proportioning of the heated fluid with the high velocity stream of air for maximum acceleration of said stream resulting from the mixing of the fluids.

In a modification of the deicing system of the present invention, continuous passageways are provided along the inside of the wall members forming the passage to confine the flow of heated air adjacent said wall member for maximum heat transfer. On the upper wall member, which, it will be remembered, has articulated sections in the preferred embodiment illustrated, this passageway is preferably formed by a series of articulated parallel deflectors interconnected to said sections by links for adjustable movement therewith.

Still other objects and advantages of the present invention will become readily apparent to those skilled in this art from the following detailed description, wherein I have shown and described only the preferred embodiments of the invention, simply by way of illustration of the best modes contemplated by me of carrying out my invention. As will be realized, the invention is capable of other and different embodiments, and its several details are capable of modification in various obvious respects, all without departing from the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

In the drawings:

FIGURE 1 is a cross-sectional view of a preferred embodiment of the airfoil of the present invention having a lift modifying passage shown in the normal open mode of operation for normal lift modifying and anti-icing effects;

FIGURE 2 is a cross-sectional view of the airfoil of FIGURE 1 illustrating the closed mode of operation for no-lift modifying and maximum deicing effects;

FIGURE 3 is a cross-sectional view of the airfoil of FIGURE 1 showing the operating mode for maximum lift effect on the airfoil;

FIGURE 4 is a detailed cross-sectional view taken along line **4—4** of FIGURE 3 showing the sealing arrangement at the edges of the wall members; and

FIGURE 5 illustrates a modification of the airfoil of the invention having continuous heated air passageways along the upper and lower wall members of the passage.

Referring now specifically to FIGURE 1 of the accompanying drawing, there is illustrated an airfoil **10** having a leading edge **11** and a trailing edge **12**; it being understood that said trailing edge **12** may lead to a valley of an undulating type airfoil such as shown in my previous patent or may terminate in a conventional trailing edge, as desired. In any case, the airfoil **10** has a conventional upper suction surface **13** and a lower pressure surface **14** extending between the leading and trailing edges **11, 12**.

Any number of vertical ribs **15** (only one being shown in the drawing) are provided to afford stability to the airfoil construction, and if desired conventional lightening holes **16** may be incorporated in the interior areas, as illustrated. Bounded on the sides by adjacent ones of these ribs **15** is a slot-like passage **17**, which extends substantially parallel to the flow of the slipstream across the airfoil **10** from a mouth **18** formed in the pressure surface **14** to an egress opening **19** formed in the suction surface **13**. For ease of discussion, the passage **17** itself may be defined as having a forward accelerating section, generally designated by the reference numeral **20**, and a restricted nozzle, generally designated by the reference numeral **21**. As will be realized, during the operation the fluid entering the mouth **18** is accelerated over the lentgh of the forward section **20** and ejected at a high velocity through the nozzle **21** into the boundary layer region of the fluid flowing over the airfoil **10** for improving the lift on the airfoil **10**.

The forward section **20** of the passage **17** is formed by an upper wall member **25**, which in the preferred embodiment shown includes any number of articulated sections **25***a*–**25***d* connected together by pivot hinges **26** and a lower wall member **27** which in the embodiment illustrated is fixed. It is contemplated that other types of movable wall structures could be utilized in lieu of the wall member **25** if desired in accordance with the broader teachings of the present invention, and that the fixed wall **27** could, if required, also be made to be adjustable.

In the preferred embodiment illustrated, each of the sections **25***b*, **25***c*, **25***d* is adjustably operated by any number of hydraulic cylinder units **30**, **31**, **32** (only one each being shown) that are connected in any suitable manner to the airfoil structure, as by a cross bar **33** carrier between the ribs **15**. As shown, the forwardmost section **25***a* is preferably shorter than the remaining sections **25***b*–**25***d* and performs the important function of varying the width of the mouth **18**. For example, note the position of the section **25***a* in the plane of the mouth **18** in FIGURE 1, thus limiting the cross sectional size of the same to that shown by the reference indicia M in this figure. Also, it should be noted that the forwardmost section **25***a* does not include a separate operating cylinder and thus is operated as a follower, i.e. movement of section **25***a* is gained from the combined operation of the hydraulic cylinders **30**, **31** to properly position the pivot hinges **26**, as shown in the drawing. The hydraulic cylinders **30–32** are provided with suitable control means **34**, which is interconnected by hydraulic lines **35**, **36**, **37** to the respective cylinders; said control means being capable of selectively positioning each section **25***b*–**25***d* as required. The position of the wall member **25** as shown in FIGURE 1 can be considered to be the normal flight position with increased lift being provided by the airfoil **10** from the flow of fluid through the passage **17** as noted by the flow arrows in this figure.



As can best be seen in FIGURE 2, the rearwardmost section **25***d* includes an extensible joint, generally designated by the reference numeral **40**, which allows the wall member **25** to expand whereby the passage **17** may be closed at the mouth **18** by deployment of the articulated sections **25***a*, **25***b* as shown. This position of the wall member **25** thus represents a limit position in the direction toward the fixed wall member **27** and is utilized when the lift modifying effects of the stream of fluid afforded by the passage **17** are not desired. At any intermediate position between the positions of FIGURES 1 and 2, a reduced amount of fluid flows through the passage **17** for reduced velocity in the nozzle **21** and a corresponding reduction in lift effect along the suction surface **13**.

As shown in FIGURE 3, the control means **34** can, on the other hand, be effective to increase the lift effect by moving the wall member **25** to the full open position shown in FIGURE 3, wherein the maximum amount of fluid is scooped into the passage **17** for discharge at increased velocity through the nozzle **21**. As shown, the forwardmost or follower section **25***a* is, in this position, removed from the plane of the mouth **18** thus increasing the size of the mouth **18** by an amount indicated by the reference indicia X so as to be coordinated with the increase in size of the passage **17**. Thus, with this arrangement it can be seen an infinitely variable mass flow of fluid can be received, accelerated and directed through the restricted nozzle **21** for any desirable velocity flow from the egress orifice **19**.

As best shown in FIGURES 3 and 4, the extensible joint **40** preferably takes the form of a reduced tongue **41** integrally formed with the rear half of the section **25***d*, which tongue works in a slot **41***a* formed in the forward half of said section **25***d*. Sealing strips **42** of molded nylon or other suitable material may be provided along the entire length of the edges of the articulated wall member **25** for cooperation with the adjacent rib **15** (note FIGURE 4) so as to confine the stream of fluid to the passage **17**, as desired.

With reference once again to FIGURE 1 of the drawing, the deicing system for the leading edge **11** and the lift modifying passage **17** of the present invention will now be described. Thus, a blast nozzle **50** is positioned on the underneath side of the upper surface **13** and directed chordwise around the interior of the airfoil **10** so as to direct a flow of heated air in the direction shown by the flow arrows in this figure. The flow of air from the nozzle **50** may be regulated as desired by a suitable valve **52** which serves to interconnect the nozzle **50** with a suitable source of heated air **53**, which for example, may be gained from the exhaust system of a piston engine, compressor bleed from a turbine engine, bleed from the aircraft's pneumatic system or any other suitable means carried by the aircraft. After the flow of heated air has passed over the entire surface of the wall member **25**, it is received by a deflector horn **55** carried by the rear half of the section **25***d* and then directed through a fixed transfer passageway **56** and out a discharge orifice **57**, which is located immediately upstream of the nozzle **21**.

Similarly, the lower wall member **27** is provided with a suitable blast nozzle **60** for directing hot air along the same with a fixed transfer passageway **61** located adjacent a discharge orifice **62**. These orifices **57**, **62** are provided with suitable flap valves **63**, **64**, respectively, which are pivoted on the upstream side of their respective orifices so as to operate in response to the differential

in pressure between the high velocity fluid stream in passage **17** and the pressure of the heated air exiting through the orifices **57, 62**. These flaps valves **62, 64** allow the proper proportioning of the mixing fluids for maximum efficiency and are effective to maintain the desired laminar flow of fluid through the nozzle **21**. This is so since, as shown by the flow arrows in FIGURE 3, the flap valves **63, 64** form an interface between the streams at the orifices **57, 62** so that when they join in the nozzle **21** they are both traveling substantially parallel to the longitudinal axis of said nozzle **21**. It will be realized that the heated air entering the nozzle **21** not only serves the important function of preventing and/or removing the formation of ice along said nozzle **21**, but also serves to give additional mass flow and velocity to the lift modifying stream of fluid exiting through the egress opening **19**.

As shown in FIGURE 2, when the articulated wall member **25** is positioned in the lower limit position, the flow of fluid into the mouth **18** and the accelerating section **20** of the passage **17** will be cut off thereby allowing the flap valves **63, 64** to open to their full open position to cause the maximum flow of heated air through the nozzle **21**. In this mode of operation the heated air will be effective to free the nozzle **21** of ice formations in the event that such should develop at any time during operation. After the nozzle **21** has been freed of ice in this position, the wall member **25** can be moved to the normal position of FIGURE 1 whereby maximum flight efficiency can be resumed.

During any mode of operation it may be desirable to terminate the flow of heated air to the nozzles **50** by closing the valves **52** whereupon the flap valves **63, 64** will assume their fully closed position (note dotted line position of FIGURE 3) thus allowing the maximum flow of unheated air from the pressure surface **14** to the suction surface **13**.

In the modification of the deicing system shown in FIGURE 4, continuous passageways **70, 71** are formed from the blast nozzles **50, 60**, respectively, to channel the heated air immediately adjacent the respective surfaces **25, 27**. Thus, the passageway **70** is preferably formed by an articulated series of deflector members **75***a*–**75***d* corresponding to the articulated sections **25***a*–**25***d* with the sections being constrained for movement with the wall member **25** by provision of connecting links **76**, which interconnect pivot pins **77** of the deflector member **75** with the corresponding pivot pins **26** of the wall member **25**. Similarly, the blast nozzle **60** is connected to the transfer passageway **61** by a continuous deflector wall **78**, as shown in this figure.

It should now be apparent to those skilled in this art that an adjustable lift modifying passage **17** has been provided with an efficient deicing system wherein a maximum amount of deicing is obtained with a minimum amount of disturbance of the laminar flow of fluid in the passage **17**. Further, since the heated air is introduced directly into the nozzle **21**, the maximum amount of deicing effect can be obtained in this critical area. Also, of course, as pointed out above, the introduction of the heated air into the nozzle tends to increase the velocity and mass flow of the fluid thereby improving the overall operation of the lift modifying passage **17**.

In this disclosure, there is shown and described only the preferred embodiments of the invention, but, as aforementioned, it is to be understood that the invention is capable of various changes or modifications within the scope of the inventive concept.

I claim:

**1.** In an airfoil having leading and trailing edges and relatively fixedly spaced suction and pressure surfaces extending between said edges, the improvement comprising a passage in said airfoil extending substantially parallel to the fluid flow relative to said surfaces of said airfoil, said passage being formed by opposed inner wall members in said airfoil, said wall members being spaced to form an enlarged mouth opening through said pressure surface and a restricted nozzle opening through said suction surface so as to form a high velocity stream of fluid and direct the same tangentially along said suction surface whereby to cause said fluid flow to follow said suction surface, at least one of said wall members being movable toward and away from the other wall member and means for selectively moving said one wall member whereby the cross sectional area of said passage may be adjusted to vary the mass flow of fluid through said passage and the velocity of said stream exiting through said nozzle, said wall members being located at all times wholly between said relatively fixedly spaced surfaces, and one of said wall members being disposed for movement into and from closing relation with respect to said mouth opening.

**2.** The combination of claim **1** wherein said one wall member includes articulated sections and an extensible joint whereby said mouth may be closed by at least one of said sections when said one wall member is moved to the limit position toward said other wall member.

**3.** The combination of claim **2** wherein the forwardmost one of said sections is a follower section positionable in response to the movement of the second in-line section, said follower section being positionable across a portion of said mouth to vary the size thereof in accordance with the adjusted size of said passage.

**4.** In an airfoil having leading and trailing edges and relatively fixedly spaced suction and pressure surfaces extending between said edges, the improvement comprising a passage in said airfoil extending substantially parallel to the fluid flow relative to said surfaces of said airfoil, said passage being formed by opposed inner wall members in said airfoil, said wall members being spaced to form an enlarged mouth opening through said pressure surface and a restricted nozzle opening through said suction surface so as to form a high velocity stream of fluid and direct the same tangentially along said suction surface whereby to cause said fluid flow to follow said suction surface, at least one of said wall members being movable toward and away from the other wall member and means for selectively moving said one wall member whereby the cross sectional area of said passage may be adjusted to vary the mass flow of fluid through said passage and the velocity of said stream exiting through said nozzle, said wall members being located at all times wholly between said relatively fixedly spaced surfaces, and one of said wall members being disposed for movement into and closing relation with respect to said mouth opening, means defining an orifice opening into said passage immediately upstream of said nozzle, means communicating with said orifice for introducing heated air into said nozzle to prevent the formation of ice, a flap valve for cooperating with said orifice to open and close the same, said valve being pivoted at its upstream edge so as to be responsive to the differential in pressure between said heated air and said high velocity stream.

**5.** The combination of claim **4** wherein said orifice communicates with the interior of said airfoil and said means for introducing heated air includes a blast nozzle positioned in said interior to direct heated air chordwise around the inside of said leading edge and back along said one wall member and deflector means for receiving said heated air and directing the same through said orifice.

**6.** In an airfoil having leading and trailing edges and relatively spaced suction and pressure surfaces extending between said edges the improvement comprising a passage in said airfoil extending substantially parallel to the fluid flow relative to said surfaces of said airfoil, said passage being formed by opposed inner wall members in said airfoil, said wall members being spaced to form an enlarged mouth opening at said pressure surface and a restricted nozzle opening at said suction surface so as to form a high velocity stream of fluid and direct the same tangentially along said suction surface whereby to

cause said fluid flow to follow said suction surface, deicing means for preventing the formation of ice along said wall members including first and second blast nozzle means on the interior of said airfoil for directing heated air along the inside surfaces of said wall members, first and second orifices formed in the respective wall members immediately upstream of said nozzle for introducing said heated air into said nozzle whereby maximum ice prevention is obtainable along the length of said passage with flow of said heated air in said passage only through said nozzle.

7. The combination of claim 6 wherein are further provided first and second flap valves for cooperating with the respective orifices, said valves being pivoted at their upstream edge so as to be responsive to the differential in pressure between said heated air and said high velocity stream, and means for adjusting the cross section of passage and said mouth to limit said stream and allow increased flow of heated air through said nozzle.

8. The combination of claim 7 wherein said adjusting means includes at least one of said wall members, said one wall member being formed of articulated sections, means for selectively moving said sections of said one wall member toward and away from the other wall member, and an extensible joint in said one wall member, whereby said mouth may be closed by at least one of said



sections when said one wall member is moved to the limit position toward said other member.

9. The combination of claim 7 wherein is further provided means for forming first and second continuous passageways along the inside of said one and said other wall members, respectively, to confine the flow of said heated air adjacent said wall members.

10. The combination of claim 8 wherein is further provided means for forming first and second continuous passageways along the inside of said one and said other wall members, respectively, to confine the flow of said heated air adjacent said wall members, said means for forming said first passageway including a series of articulated deflectors connected to said sections for adjustable parallel movement therewith.


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