Aug. 26, 1969 E. S. MIKSCH 3,463,418

VORTEX GENERATOR FOR AIRPLANE WING

Filed March 20, 1968 4 Sheets-Sheet 1

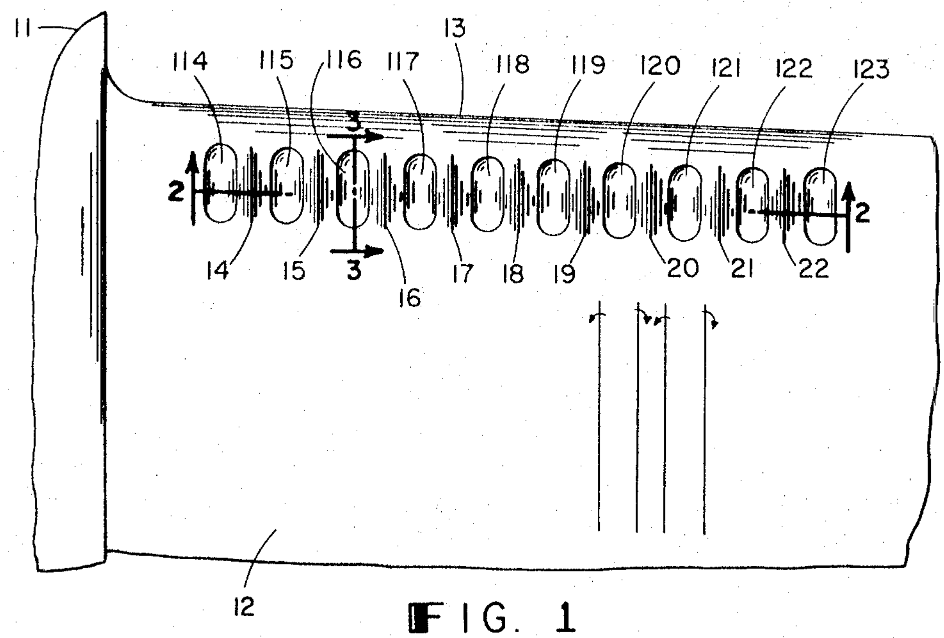

FIG. 1

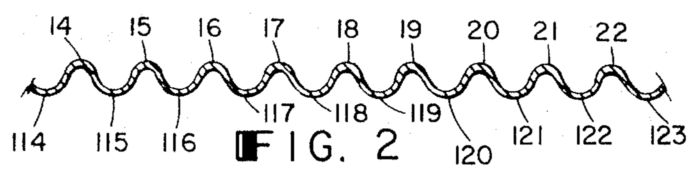

FIG. 2

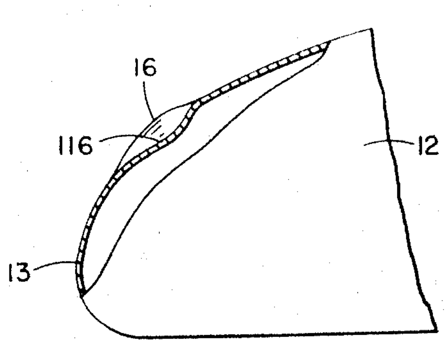

FIG. 3

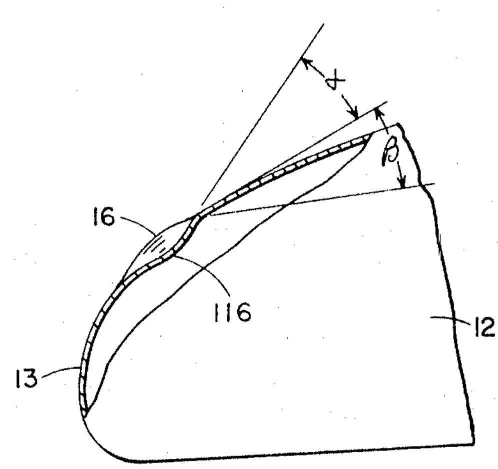

FIG. 4

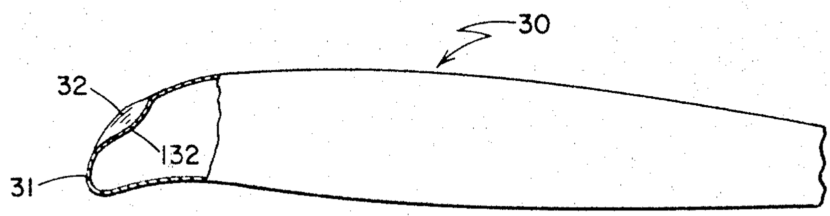

FIG. 5

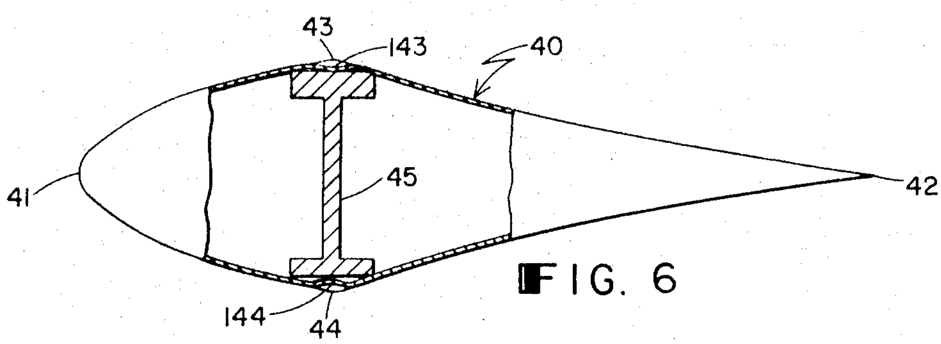

FIG. 6

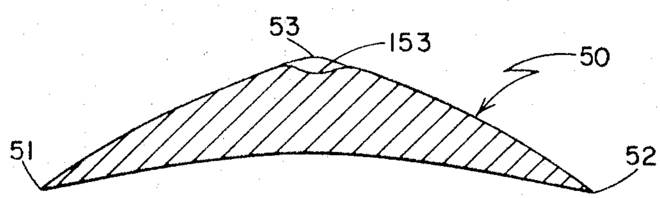

FIG. 7

VORTEX GENERATOR FOR AIRPLANE WING

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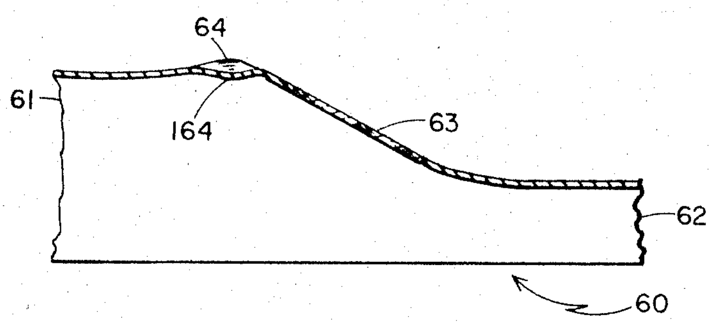
FIG. 8



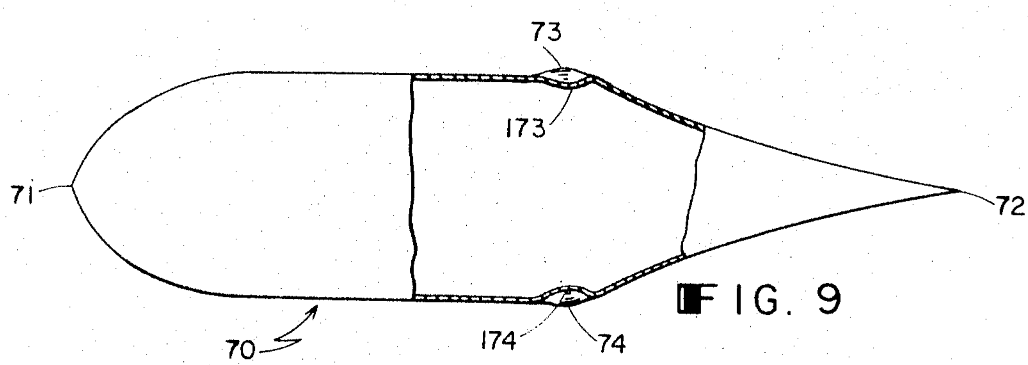


FIG. 9

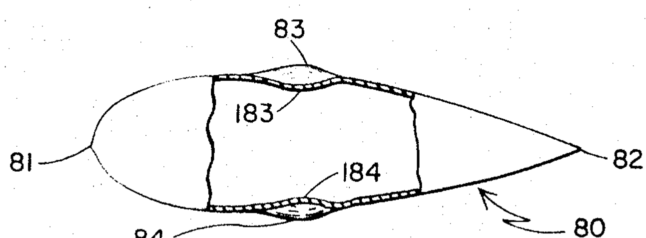
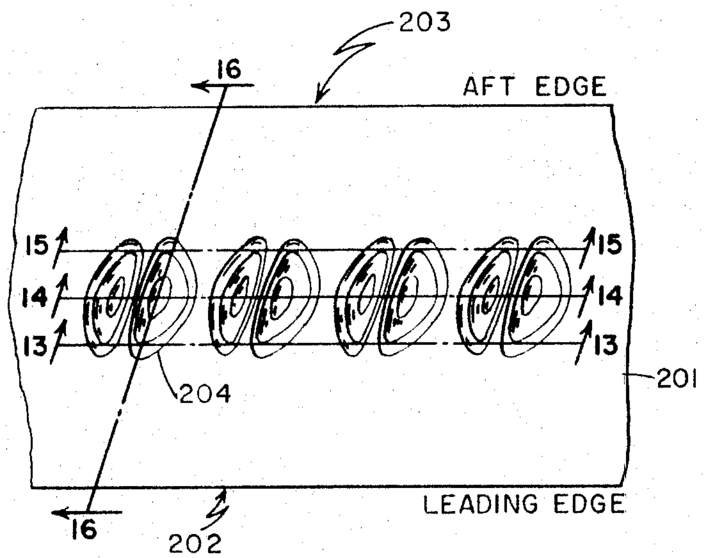


FIG. 10

FIG. 12



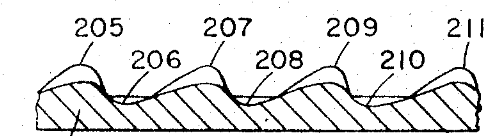


FIG. 13

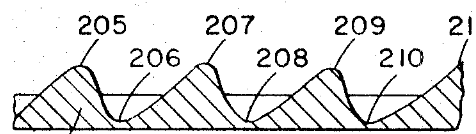


FIG. 14

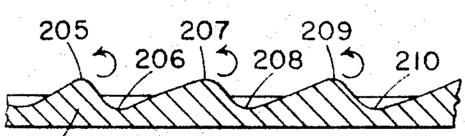


FIG. 15

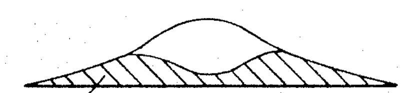


FIG. 16

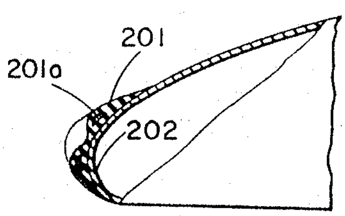


FIG. 17

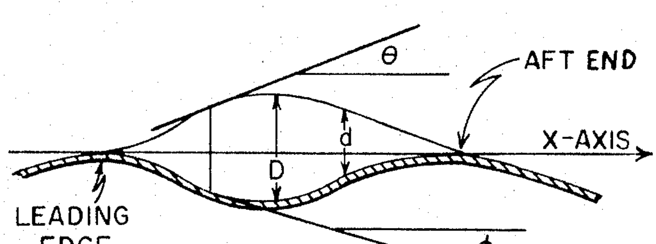


FIG. 11

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VORTEX GENERATOR FOR AIRPLANE WING

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Continuation-in-part of application Ser. No. 599,776, Dec. 7, 1966. This application Mar. 20, 1968, Ser. No. 729,855
Int. Cl. B64c 3/16
U.S. Cl. 244—41 3 Claims

ABSTRACT OF THE DISCLOSURE

Airplane wings and fuselages are described which have improved lift and less drag. Corrugations are placed upstream of regions where counterflow is expected. The alternating grooves and ridges of the corrugations are so shaped that they deflect the air flowing along the surface, forming vortices trailing downstream and serving to bring fast moving air into the boundary layer.

BACKGROUND OF INVENTION

This application is a continuation-in-part of Ser. No. 599,776, filed Dec. 7, 1966, now abandoned.

This invention relates to an airplane wing, fuselage, voluminous chamber or similar body designed for motion through the air. In particular, it relates to such an airplane wing or similar body which is so constructed as to eliminate or reduce the counterflow of air.

Counterflow is the flow of air in a region near a wing in a direction opposite to that of the surrounding airflow and is caused by a pressure gradient known as "adverse pressure gradient." The adverse pressure gradient is brought about by a low pressure region on the wing followed by a relatively high pressure region further aft. In general, regions of very low air pressure exist where air flows over a convex region having a small radius of curvature, which is characteristic of an airplane wing. In particular, the air in the boundary layer next to the wing cannot overcome this adverse pressure gradient and flows forward. This results in increased drag and decreased lift and where it is sufficiently large causes the dangerous condition of loss of lift known as "stall."

SUMMARY OF INVENTION

The improved airplane wing or similar body of this invention has corrugations in the region of adverse pressure gradient or may be upstream of regions where counterflow is expected if the aft end of the corrugations is a distance equal to no more than about twenty times the depth of a groove upstream from the region of adverse pressure gradient in the operational mode in which the region of adverse pressure gradient extends farthest forward.

The corrugations of this invention provide vortex generators which accomplish improved lift and less drag. The corrugations may be built into the skin of the wing or may be formed on rubber strips which are attached to the wing.

DEFINITIONS

To facilitate description of the corrugations, descriptive terms are used which apply to the case of corrugations on the upper surface of a wing. It is understood that once the form of the corrugations is defined, they may be applied to a surface in any orientation.

FIG. 11 provides a frame of reference for describing the corrugations. This figure is a vertical, spanwise-looking section cut along the deepest path through the groove from its leading end to its trailing end. This section is extended upstream and downstream of the corrugations along paths which in plan view are parallel to the chord of the wing. The surface cut by this section has a region which

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is concave upward. A straight line is considered in this drawing which is tangent to the surface at two points, one upstream of, and one downstream of the concave region. The points of tangency may be either in the groove, or on the adjacent wing surfaces. This is labeled the X-axis. Distance along this axis is labeled x.

The depth of the groove at any point along its length is measured relative to the height of the adjacent ridge in a sectional drawing such as FIG. 11. This depth is measured by drawing a line segment in the sectional drawing perpendicular to the X-axis between a point on the contour of the groove and a point on the contour of the ridge. The length of this segment is denoted d, and the maximum value of d is denoted D.

DIMENSIONAL LIMITS OF INVENTION

(1) A lower limit to the maximum depth of the groove, D, is obtained from the thickness of the boundary layer. D should be at least one half as great as the thickness of the boundary layer existing at the forward end of the corrugations in the operational mode for which the boundary layer is thinnest.

(2) An upper limit to D is obtained from the length (measured parallel to the airflow) of the region downstream of the corrugations in which an adverse pressure gradient exists. D should be no more than one-third of the length of that region in the operational mode in which that region has the greatest length.

(3) The corrugations may be placed in the region of adverse pressure gradient, or may be located upstream of it, provided the aft end of the corrugations is a distance of no more than 20D upstream of the region of adverse pressure gradient in the operational mode in which the region of adverse pressure gradient extends farthest forward.

(4) That portion of the corrugations for which d is greater than ¾D should have a length (measured parallel to the corrugations) of no more than 10D (to avoid excessive increases of surface area, which would cause increased drag).

(5) The spanwise distance between the highest points on two ridges separated by a groove of depth D should be no less than D (to avoid excessive increases in the surface area).

(6) The spanwise distance between the deepest point in a groove and the highest point on the adjacent ridge should be no greater than 4D.

(7) It is a necessary characteristic of the groove that in a vertical section cut through it following the deepest path from its forward end to its aft end, there is a portion of its contour in the region for which d is greater than ½D which is concave upward. (The term "concave" is meant to include the case of a V-shaped contour.)

(8) It is a necessary characteristic of the ridge that in a vertical section looking in the spanwise direction, three regions may be found on the contour of the ridge; #1 at its leading end, #2 at or near its highest point, and #3 at its trailing end such that the average curvatures in the regions satisfy the inequalities:

$$K_2>K_1,\ K_2>K_3$$

(The average curvature in a region is defined to be the angular difference between the tangents to the contour at the ends of the region divided by the length of the contour in the region. Curvature is here defined to be positive if convex upward.)

(9) In the case of grooves and ridges which are symmetrical in any section containing the spanwise and vertical directions, some portion of the corrugations should run parallel to the nominal airflow direction, or at an angle (viewed from above) of no more than 20° from the nominal airflow direction.

(10) For grooves and ridges which are asymmetrical in some section containing the spanwise and vertical directions, some portion of the grooves and ridges should be at an angle (viewed from above) of no more than 40° from the nominal airflow direction.

(11) The grooves and ridges should have some steep slopes. In a spanwise-looking section cut along the deepest path through the groove from its leading end to its aft end, a line segment is drawn perpendicular to the X-axis between a point on the contour of the ridge and a point on the contour of the groove. Where this segment meets the contour of the ridge, a tangent to the ridge is drawn. This tangent is at an angle θ relative to the X-axis. Likewise, where the segment meets the groove, a tangent to the groove is drawn, which is at an angle ϕ relative to the X-axis. These angles are taken to be positive when they label upward slopes, and negative for downward slopes, relative to the X-axis. The inequality below would then hold:

$$\int \left| \frac{d}{dx}(\theta-\phi) \right| dx > 60°$$

The vertical lines denote absolute magnitude, and the integral is taken from a point upstream of the corrugations to a point downstream of them.

VARIATIONS IN SHAPE

There are many variations in the shape of the grooves and ridges which are capable of functioning with some degree of efficiency. For example, the highest point on the ridge may be upstream of, adjacent to, or downstream of the deepest point in the groove. The ridge may be either wider or narrower than the groove. In several cases it is desirable for a high, narrow ridge to accompany a wide, shallow groove. The ridge may be so high that it takes the form of a conventional vortex-generating vane. However, it possesses enhanced efficiency because of the accompanying groove.

The grooves and ridges may be either tapered or flared at either or both ends. It is a generally desirable but not necessary feature for the deepest path through the groove from its leading end to its aft end to be parallel to the highest path along the ridge from its leading end to its aft end.

The leading ends of the grooves and ridges may be either gently or steeply inclined. Gentle slopes tend to introduce less drag, whereas steep slopes permit short grooves and ridges; these having the advantage that they retain their efficiency better when the air flows obliquely over the wing (case of sideslip or skid).

The grooves and ridges may be either curved or straight when viewed from above. If they are curved, it is perferable for them to have a greater inclination to the nominal airflow direction at their aft ends than at their leading ends.

It is generally desirable for the surface to be smooth with no abrupt changes in slope. For example, the ridge should be faired smoothly into the bottom of the groove without an inside corner. (Such an inside corner would be visible in FIG. 14.) Such an inside corner would cause a slight loss of efficiency. A sharp break in slope at the top of a ridge, hwever, may be aceptable. In FIG. 14 the top of the ridge would then appear as an outside corner. Abrupt changes of slope which would be visible in FIG. 16 at the leading or aft ends of the grooves or ridges would generally be disadvantageous.

It is usually contemplated that substantially uniform alternating grooves and ridges be employed. This is not a necessary feature, since in some cases nonuniform grooves and ridges can function efficiently.

In some cases vortex generators running parallel to the airflow direction may produce vortices whose sign is reversed relative to the directions shown in FIG. 1. This appears to occur when the boundary layer is relatively thick. Such reversal does not impair operation of the device, provided the vortices are of sufficient strength.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a top view of a portion of an airplane wing attached to a fuselage and showing schematically the vortices formed in the two grooves adjacent a ridge.

FIG. 2 is a transverse section along line **2—2** of FIG. 1.

FIG. 3 is a partial section along line **3—3** of FIG. 1 showing the leading edge.

FIG. 4 is a similar view to FIG. 3 but emphasizing the various angles of the surface.

FIG. 5 is a view taken in a similar manner as FIG. 3 but illustrating a modified NACA 63012 wing section.

FIG. 6 is a similar section to FIG. 3 but taken of a thick wing with a spar.

FIG. 7 is a transverse section of a helicopter rotor modified in accordance with this invention.

FIG. 8 is a partial longitudinal section of a fuselage showing a rear window.

FIG. 9 is a schematic diagram in partial section showing the invention applied to a different shape of voluminous chamber.

FIG. 10 is a schematic diagram with partial section showing another form of voluminous chamber adapted to this invention.

FIG. 11 is a vertical spanwise section of corrugations in a wing cut along the deepest path from its leading end to its aft end.

FIG. 12 is a top view of a portion of an airplane wing on which is mounted a flexible rubber strip containing a plurality of corrugations forming vortex generators.

FIG. 13 is a median portion of a section along line **13—13** of FIG. 11.

FIG. 14 is a median portion of a section along line **14—14** of FIG. 11.

FIG. 15 is a median portion of a section along line **15—15** of FIG. 11.

FIG. 16 is a median portion of a section along line **16—16** of FIG. 11.

FIG. 17 is a section along line **16—16** where the strip is mounted at the extreme leading edge of a wing.

SPECIFIC EXAMPLES OF INVENTION

Referring now to FIGS. 1, 2 and 3, the functioning of this invention is illustrated therein. The fuselage **11** is attached to the wing **12** having a leading edge **13**. Adjacent the leading edge is a plurality of substantially identical parallel ridges and grooves designated as: ridges **14** through **22** and grooves **114** through **122**. The vortex directions are shown in respect to ridge **20** and grooves **120** and **121**. Each vortex is indicated by a line and a curved arrow. The line represents the core of the vortex and the curved arrow indicates the direction of rotation of the air in the vortex. As can be seen in FIG. 3, the grooves and ridges are fairly smooth and have gentle slopes at their leading ends and steep slopes at their trailing ends.

Referring now to FIG. 4, angle alpha labels the steepness with which the grooves terminate while angle beta indicates the steepness with which the ridges terminate. Such angles may advantageously be made as great as 30°. Angles much larger than 30° should be avoided as they tend to decrease excessively the downstream velocity of the air, this velocity being the one which must overcome the adverse pressure gradient.

The wing **30** shown in FIG. 5, which is a modification of NACA 63012 wing section, has the corrugations visible at the leading edge. (See NACA report #610, "Tests of Related Forward Camber Airfoils in the Variable Density Wind Tunnel," E. N. Jacobs, 1937.) The wing has a leading edge **31** with ridge **32** and groove **132** shown in section but otherwise arranged in a parallel array as illustrated in FIGS. 1 and 2. In this wing the counterflow occurring in the upper surface of the wing is reduced so that it can be used for the highest possible lift coefficient. This wing could be used, for example, in aircraft having short-field landing and takeoff capability, but lacking high-speed cruise capability.

FIG. 6 shows the invention as applied to a wing **40** which has considerable thickness and in symmetrical about a horizontal plane. Such a symmetrical wing permits inverted flight. The thickness is necessary to accommodate a spar **45** usually required to provide sufficient strength with little weight. The wing **40** has a leading edge **41** and a trailing edge **42**. Shown in partial cross-section is an upper corrugated zone, as for example, ridge **43** and grove **143** and a lower corrugated zone, as for example, ridge **44** and groove **144**. These corrugated zones are placed just ahead of the highly curved regions on the surfaces where the air attains its lowest pressures. The result is that vortices are formed downstream thus suppressing counterflow.

The wing shown in FIG. 7 is actually a helicopter rotor **50** in which **51** designates the forward edge and **52** the rearward edge at a particular instant of time. The rotor, symmetrical front to back, has an upper corrugation area placed symmetrically in the center of the upper surface of the wing and shown illustratively as ridge **53** and groove **153**. Whichever way the air flows, vortices are formed downstream of the central regions, where they serve to suppress counterflow. This wing is particularly intended for convertible aircraft having a rotary wing for takeoffs and landings; in which the wing is stopped for crusing flight and held fixed, transverse to the airflow.

FIGS. 8, 9, and 10 illustrate the invention as applied not to a wing, but to the fuselage of an airplane or a similar voluminous chamber intended for motion through the air. Thus, in FIG. 8, a portion of an airplane fuselage **60** is shown with the forward end **61** to the left and the tail end **62** to the right. There is a rear window **63** facing aft. This window normally is at a steep angle in order to have good visibility. The result is a highly curved region upstream of the window. Accordingly, corrugations comprising ridges **64** and grooves **164** are provided upstream to reduce the counterflow in accordance with the principles of this invention.

FIG. 9 shows the invention as applied to a voluminous chamber **70** having a constant cross-section over a substantial portion of its length towards the forward end **71** and tapering at the tail **72**. Such a construction is often desirable to maximize the capacity for carrying freight or passengers. The highly curved regions at the aft end **72** are designed to assist in providing rapid convergence of air at the aft end. Upper and lower corrugated sections are therefore provided just forward of this curved section (ridge **73**, groove **173**, ridge **74**, and groove **174**) in order to reduce the counterflow formed by this rapid convergence.

The voluminous chamber illustrated in FIG. 10 and designated by the numeral **80** is teardrop in shape with a forward end **81** and a tail **82**. There are upper corrugations (ridge **83**, grooves **183**) and lower corrugations (ridges **84**, grooves **184**) located approximately at the point of maximum width of the body so as to reduce or eliminate counterflow on the after portion of the body. A voluminous chamber of this design might be used for carrying a fluid.

FIGS. 12 through 17 show the invention embodied in a flexible strip **201** of solid or foam rubber. This strip is meant to be mounted with its major dimension perpendicular to the direction of the airstream, so air flows across it from its leading edge **202** to its trailing edge **203**. It is provided with a large number of identical vortex generators **204**, each consisting of a ridge **205** next to a groove **206**. The ridge is close to the groove so the surface of the rubber slopes steeply from the top of the ridge to the bottom of the groove. This steeply sloping surface has the function of pushing laterally on the air in the grove, and thereby introducing vorticity.

FIGURES 13, 14 and 15 show sections cut parallel to the major dimension of the strip; the direction of viewing being parallel to the groves and ridges. Sections **13** and **15** are cut through the leading and trailing portions (respectively) of the grooves and ridges. Section **14** cuts through the deepest points in the grooves, and the highest points on the ridges. FIGURE 16 is a section cut through the bottom of a groove, facing the steeply sloping surface. This figure shows how the grooves and ridges are faired smoothly into the adjacent surfaces upstream and downstream.

The vortices produced all rotate in the same direction, and are located approximately as indicated in FIG. 15.

In some cases it is desirable to provide for removal of ice from the vortex generators. This may be accomplished by providing passages in the strip of flexible material; these running along its length. Ice elimination can then be accomplished either by flowing a warm fluid through the passages, or by periodically varying the pressure of the fluid in the passages to break the ice. Both of these methods are traditionally used in de-icing boots placed at the leading edges of airplane wings. In this application, the present invention is similar to conventional de-icing boots, but has the added feature of grooves and ridges which produce vortices.

FIG. 17 shows a profile section of the leading edge of an airplane wing, with the vortex-generator strip attached to it. De-icing passages **201***a* are visible in the cross-section of the strip.

OTHER EXAMPLES OF INVENTION

The embodiments described and illustrated above are not intended to limit the scope of this invention. Thus, depending on the construction and design of the wing, the corrugated zone may be located in many other positions. In a wing having two highly curved regions on the underside of the leading edge the corrugated zone would be located between such regions. Such a wing would provide efficient performance at both very high and very low angles of attack. The invention is also applicable to a wing with a slotted flap. In this case the corrugations can be placed at the leading edge of the flap where they help the air change direction to flow downward over the flap. In addition, the invention can be applied to a bi-plane by applying corrugations on the bracing members and wings just upstream of the regions where counterflow tends to occur. Also, corrugations can be provided where the wings are attached to the fuselage, since adverse pressure gradients produced by the wings tend to cause counterflow on the fusellage. In general it is desirable that the surface of the wing or other body and the corrugations on it be smooth and devoid of protruding rivets and the like. Relatively short grooves and ridges are usually employed.

I claim:

1. An airplane wing, fuselage, voluminous chamber, or similar body having surface corrugations in or near a region where counterflow is expected; said corrugations comprising alternating ridges and grooves shaped so as to deflect the air flowing along the surface of the body to produce vortices which trail downstream and serve to bring fast moving air into the boundary layer; said corrugations being spread either in the region of adverse pressure gradient of upstream thereof no further than twenty times the maximum depth of the groove relative to the adjacent ridge; said grooves and ridges having some steep slopes; the grooves and ridges being so shaped that a sectional view looking along the surface of the body in a direction perpendicular to the ambient airstream reveals a portion of the groove contour having depth exceeding one half the maximum depth and curvature which is concave toward the airstream; a portion of the ridge contour in said view being convex toward the airstream with regions of less curvature upstream and downstream; that portion of the corrugations for which the depth of the groove exceeds three fourths of the maximum depth having a length no greater than ten times the maximum depth of the groove.

2. Claim **1** wherein the corrugations are contained in a flexible strip attached to the body.

3. Claim **2** wherein said strips contain passageways for ice removal liquids.

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U.S. Cl. X.R.

244–17.11, 36, 134.