April 27, 1948. J. O. ANTONSON 2,440,240

PROTECTIVE COVERING FOR PREVENTING ACCUMULATION OF ICE ON AIRFOILS

Filed Dec. 29, 1944 3 Sheets-Sheet 1

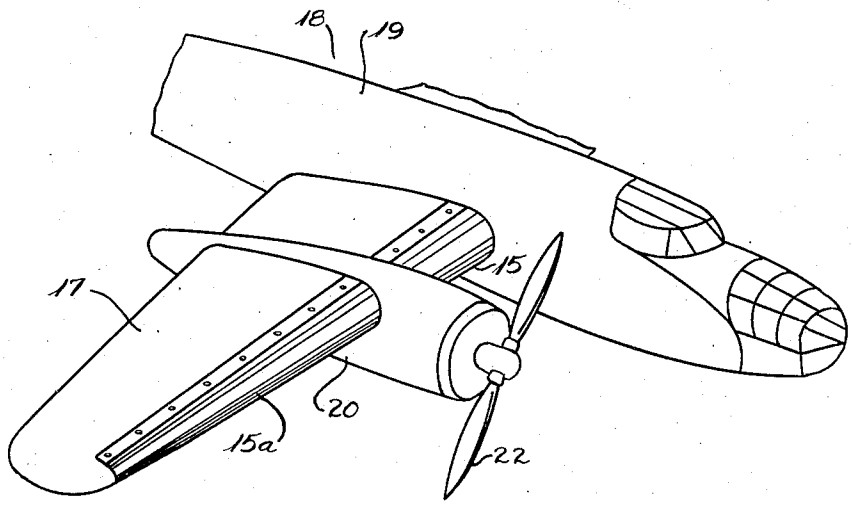


Fig-1

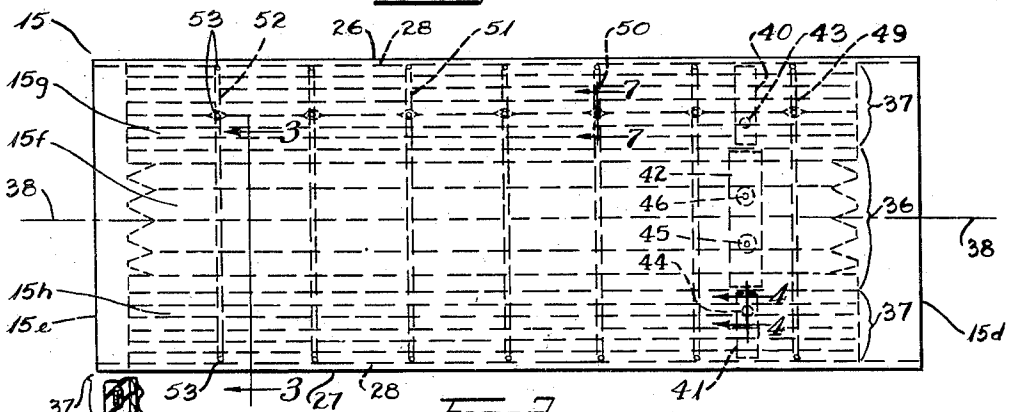


Fig-2

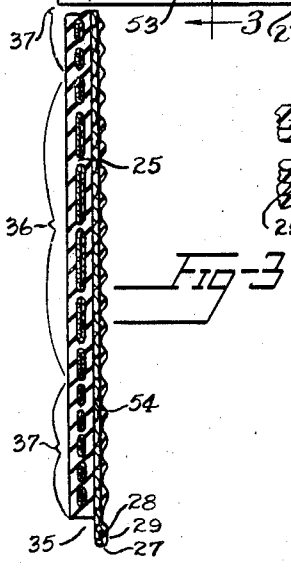


Fig-3

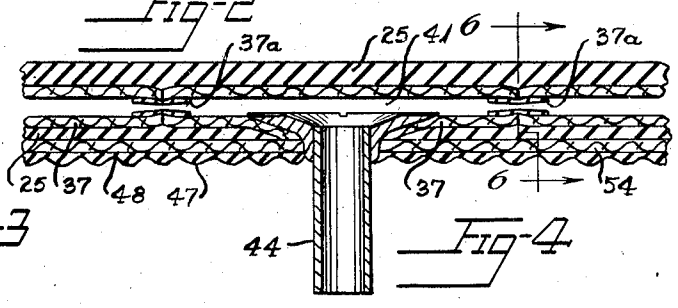


Fig-4

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PROTECTIVE COVERING FOR PREVENTING ACCUMULATION OF ICE ON AIRFOILS

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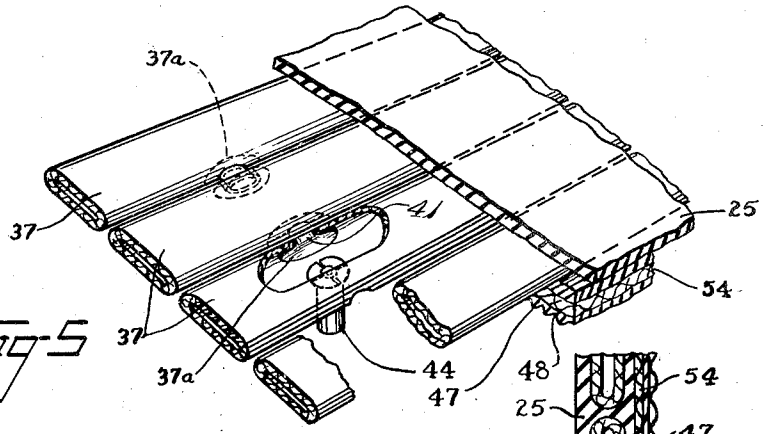


Fig-5

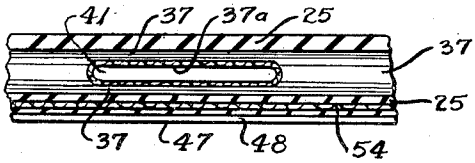


Fig-6

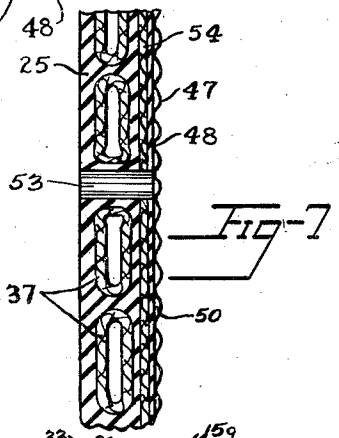


Fig-7

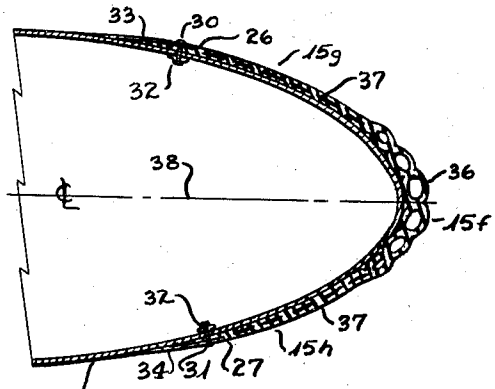


Fig-8

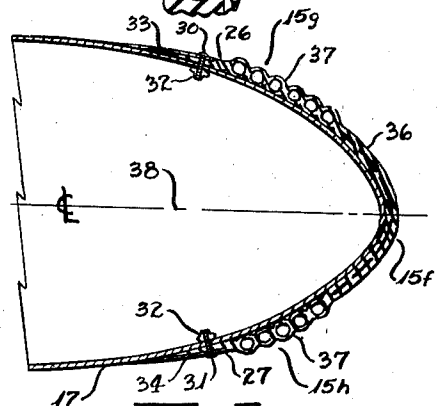


Fig-9

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PROTECTIVE COVERING FOR PREVENTING ACCUMULATION OF ICE ON AIRFOILS

Filed Dec. 29, 1944 3 Sheets-Sheet 3

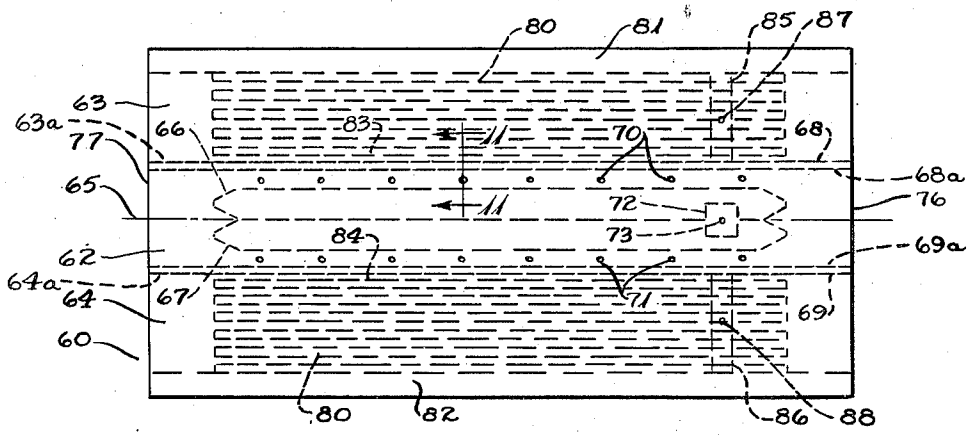


Fig-10

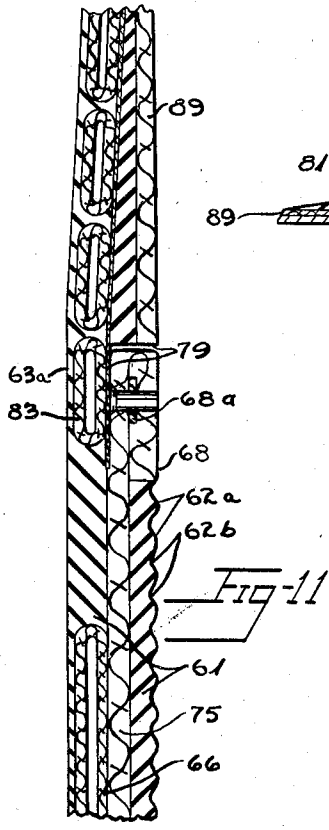


Fig-11

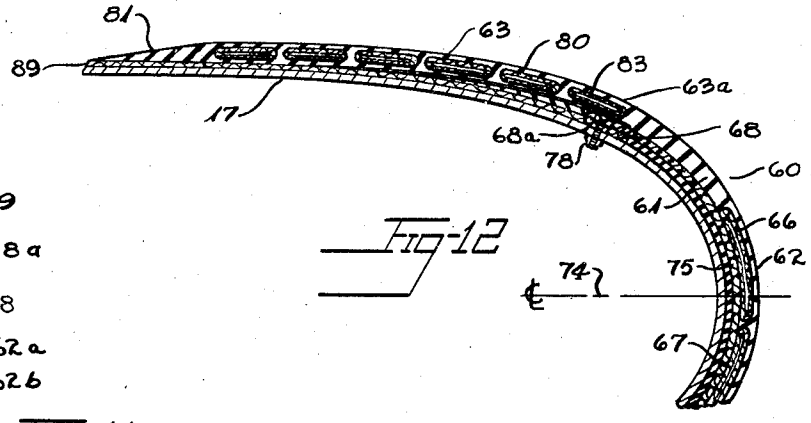


Fig-12

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UNITED STATES PATENT OFFICE

2,440,240

PROTECTIVE COVERING FOR PREVENTING ACCUMULATION OF ICE ON AIRFOILS

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Application December 29, 1944, Serial No. 570,308

10 Claims. (Cl. 244—134)

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This invention relates to protective coverings for the surfaces of structures such, for example, as aircraft and other vehicles, and especially to covering apparatus for preventing the accumulation of ice on the leading edges of wings and other airfoils, empennage fin structures, struts, and other structures of aircraft.

It is an object of the invention to provide a protective covering having inflatable passages positioned over the chordwise extent of the leading edge coverage, which passages are of a size and expansive excursion commensurate with the thickness of ice at the respective positions so that the individual passages are most effective for ice removal at their individual positions and at the same time offer minimum aerodynamic disturbance. Related objects are to provide for maximum effectiveness of ice removal throughout the extent of the covering together with maximum security of attachment against objectionable lifting under aerodynamic forces, and to provide for cleanliness of aerodynamic design.

Other objects are to provide inflatable coverings adapted for arrangements of varied chordwise extent as desired, especially for thick-section airfoils; to provide for distending such coverings at chordwise positions in accordance with the requirements of the ice formations at such positions for effective removal of the ice; to provide for removing effectively heavy ice-caps over the central zones of the inflatable coverings and for removing effectively very thin ice formations throughout the extent of such coverings; to provide inflatable ice-removing means of varied expansive excursion in adjacent portions of the coverings for outwardly distending the coverings into spanwise ridges in series, which ridges in the central zones of the coverings at the regions of sharp curvature of the leading edges are relatively larger than the ridges in the rearward portions of the coverings at the regions of lesser curvature of such leading edges; to provide inflatable passages in the coverings which passages are of uniform size along their extent but are decreasing in width as the radii of curvature of the leading edges increase; and to provide for simplicity of construction, efficiency of operation, and facility of installation.

Further objects of the invention are to provide for distending the central zones of the coverings with little or no exertion of stretching force on portions of such coverings extending rearwardly from the central zones; to provide for preventing objectionable lifting of the coverings away from the supporting surfaces despite the distention of the coverings and especially such lifting at the rearward portions thereof; to provide for venting

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the coverings; to provide for the secure attachment of the coverings, especially along the margins of the central zones thereof; and to provide for maintaining the aerodynamic characteristics of the airfoils.

These and other objects and advantages of the invention will be apparent from the following description.

In the accompanying drawings which form a part of this specification and in which like numerals are employed to designate like parts throughout the same,

Fig. 1 is a perspective view from above of a twin engine aircraft having protective coverings disposed thereon and constructed in accordance with and embodying the invention, parts being broken away,

Fig. 2 is a plan view from above of the covering before attachment to the leading edge of a wing or other airfoil of the aircraft,

Fig. 3 is a sectional view on an enlarged scale taken along line 3—3 of Fig. 2,

Fig. 4 is a view like Fig. 3 taken along line 4—4 of Fig. 2,

Fig. 5 is a perspective view showing a manifold arrangement for inflating a series of tubes, parts being broken away and in section,

Fig. 6 is a view like Fig. 3 taken along line 6—6 of Fig. 4,

Fig. 7 is a view like Fig. 3 taken along line 7—7 of Fig. 2,

Fig. 8 is a view showing the covering installed on the airfoil and showing distention of the covering at the central zone thereof, parts being broken away and in section,

Fig. 9 is a view like Fig. 7 but showing distention of the covering in portions thereof extending rearwardly from the central zone,

Fig. 10 is a plan view like Fig. 2 showing a modification of the covering,

Fig. 11 is a sectional view on an enlarged scale taken along line 11—11 of Fig. 10, parts being broken away, and

Fig. 12 is a view showing the modified covering installed on the leading edge of an airfoil, parts being broken away and in section.

In the illustrative form of the invention shown in Figs. 1 to 9 inclusive, protective coverings 15, 15a, each comprising a body 25 of elastic material such, for example, as resilient rubber or other rubber-like material having inflatable passages extending spanwise therein, may be positioned at the leading edge of an airfoil or wing 17 of an aircraft 18, which aircraft includes a fuselage 19, a streamlined motor housing 20 at such leading edge, and a propeller 22. The coverings are desirably of generally rectangular shape but may

be tapered or other suitable shape, the ends of which, for example, at 15*d* and 15*e* of the covering 15, may be tailored to fit as desired especially along the sides of the fuselage or the motor housing, or both, in order to conform to the curvature thereof and for facilitating venting at such ends, if desired, by virtue of the interference effects which cause greater negative pressure closely adjacent such sides than are present around the profile of the wing at a distance from the junction of such parts and the wing. The coverings 15, 15*a*, are constructed alike except with respect to the tailoring at the ends thereof, in view of which only the construction of the covering 15 will be described in detail hereinafter.

For effective ice removal substantially throughout the extent of the covering 15, the invention provides spanwise-extending inflatable tubes 36 and 37 having walls of suitable resilient rubber-like material, which walls may be reinforced with highly extensible fabric therein, the tubes being positioned in series within the covering and over the chordwise extent of the leading edge coverage and being of a size and expansive excursion commensurate with the thickness of ice deposited at the respective positions so that the individual tubes are most effective for ice removal at their individual positions and at the same time offer minimum aerodynamic disturbance. The highly extensible reinforcing material in the walls of the tubes may be stockinette or other knitted or otherwise stretchable fabric, preferably of nylon or rayon, although cotton or other suitable material may be used. The nylon stockinette fabric is stretchable both circumferentially and longitudinally of the tubes which permits stretching of the tube walls for expanding the covering locally at such tubes to break and loosen the ice thereon.

The inflatable tubes 36 are disposed spanwise along a front portion or central zone 15*f* of the covering 15 for positioning at the region of sharp curvature of the leading edge of the wing 17 where heavy ice-caps graduated-in-thickness substantially symmetrically about the chord line of the wing tend to be deposited. The tubes 36 in such central zone are arranged in series chordwise for positioning symmetrically about the chord line 38 of the leading edge, the widths of the tubes being graduated so that such widths decrease with the increase in radius of curvature of such leading edge and hence are proportioned in accordance with the change in thickness of the ice deposited thereon. Such an arrangement together with the extensible wall construction makes possible a change in the extent of the local distention of the covering at each of such tubes with respect to that of an adjacent tube and a corresponding change in the extent of stretching of the outer surface material of the covering for effective ice removal at such central zone 15*f*. In the preferred construction, a plurality of graduated tubes 36 are provided in the rubber material of and substantially throughout the extent of the central zone, the adjacent tubes of greatest width, which, for example, may be 2 inches, being disposed symmetrically about the longitudinal center line of such zone, which center line corresponds to the chord line 38 when the covering is mounted on the airfoil.

When the tubes 36 are inflated, preferably simultaneously, they distend outwardly from the wing 17, as shown especially in Fig. 8, and assume a relatively sharp curvature afforded by a semicircular shape in section by virtue of the uniform

and high stretchability of the walls thereof. As the tubes 36 are thus highly distended, they operate not only to crack the heavy ice-cap on the leading edge but also operate to shift the pieces of the cracked ice-cap somewhat in the chordwise direction so as to subject such pieces to the force of the airflow rather than to permit the pieces of ice to remain static especially in the stagnation region immediately at the chord line 38.

The local outward distention and stretching of the series of symmetrically graduated tubes 36 about the chord line at the region of sharp curvature of the leading edge has been found to be especially effective in the full and prompt removal of the heavy ice-caps which tend to form at such region. By virtue of such localized distention and stretching of the tubes especially along the opposite margins of the central zone 15*f*, little or no exertion of stretching force is imparted to rearwardly extending portions 15*g* and 15*h* of the covering 15. Also, such local action of the tubes 36 avoids to a large extent outward movement of such rearward portions relative to the supporting surface of the wing 17 thereby avoiding entrapment of substantial quantities of air beneath the covering and preventing objectionable bulging thereof.

In prior constructions of protective coverings in which a stretchable rearward portion between a central inflatable tube zone and an attached margin has been subjected to stretch for removing ice from such portion upon the inflation of each tube in such zone, the action of such coverings under some ice conditions of particular severity has not been effective to obtain full cleanliness of ice removal in the stretchable portion and the tube zone. The rapidly repeated stretching of the stretchable rearward portion has under some ice conditions tended to craze or merely crack the ice repeatedly rather than break or remove it thoroughly from the surface of the covering. To the end of overcoming such difficulties, the invention further provides inflatable tubes 37 in series and extending spanwise substantially throughout the extent of the rearward portions 15*g* and 15*h* of the covering between the central zone 15*f* and attaching margins 26 and 27. The tubes 37 which are positioned preferably closely adjacent one another, may be of the same construction as the tubes 36 except that each of the tubes 37 may be of the same diameter such, for example, as ¾ inch and relatively small in width as compared to that of the large tubes 36. By virtue of their construction, the respective series of tubes 37, which tubes are desirably inflated simultaneously, distend locally at each tube 37 and distend the outer surface of the covering at such rearward portions into ridges of relatively small radius of curvature thereby effectively breaking the bond of the ice deposited and lifting and rocking the latter for removal by the scavenging action of the flow of the ambient air.

For inflating the tubes 37 in each of the rearward portions 15*g* and 15*h*, the invention provides respective manifolds 40 and 41 of suitable construction, desirably in the covering, in communication with the respective series of small tubes 37. Such manifold construction may comprise locally slitted portions of the tubes including annular tape reinforcing elements 37*a* of suitable fabric at the junctions of such portions adhered thereto whereby the walls of the tubes define the interconnecting manifold passageway,

as shown especially in Figs. 2, 4, 5 and 6, in which Figs. 4 and 5 the tube walls, for purposes of clarity, are shown in separated relation although they may be contacting one another for the deflated condition of the covering. A manifold **42** of similar construction to the manifolds **40** and **41** and within the covering in communication with the tubes **36** in the central zone **15***f* provides for inflating such tubes simultaneously. The manifolds **40**, **41** and **42** are connected to a suitable source of air under pressure, which may be disposed, for example, within the fuselage of the aircraft, by means of suitable conduits (not shown) extending from connection members **43**, **44**, **45** and **46** to such source of air, the respective connection members being in communication with the respective manifolds **40**, **41** and **42** as shown especially in Figs. 2, 4 and 5.

The covering **15** may be provided with a highly elastic fabric reinforcement **54** in the rubber body thereof substantially throughout its entire extent, which reinforcement is adjacent the under surface of the covering and beneath the inflatable tubes **36** and **37**. This highly elastic fabric is stretchable chordwise and such result may be provided by a woven fabric having straight warp threads with adjacent filling threads highly twisted in reverse directions, which fabric has extensive stretchability along the filling threads, disposed chordwise, and has little or no stretchability along the warp threads, disposed spanwise. By virtue of such woven construction, the elastic fabric does not require the force of the resilient rubber with which it is impregnated and coated to return to its original condition after being stretched, being in itself highly resilient. Thus, both the rubber and the fabric are better able to resist the development of objectionable permanent set. The elastic fabric is advantageous in giving added resistance throughout its coverage to objectionable lifting of the covering in any part of its extent and also is not subject to objectionable contraction spanwise of the covering. Such an arrangement, by virtue of the elasticity of the reinforcement **54**, further facilitates maintaining the covering in the desired condition of relatively uniform stretch between the attaching margins **26** and **27** and also minimizes objectionable restriction to the expansive excursion of the tubes with respect to the leading edge.

To facilitate the attachment of the covering **15** to the wing **17** along spanwise margins **26** and **27**, each such margin **26**, **27** includes desirably a bead reinforcement **28** of stiff material such, for example, as flat steel wire imbedded in the rubber body **25** and around which bead wire may be positioned a folded strip **29** of relatively non-stretchable fabric material such, for example, as square-woven bias-cut fabric of cotton, rayon, silk and other filamentary material. The covering **15** is mounted on the leading edge of the wing **17** in a condition of stretch between the margins **26** and **27** and secured thereto as by suitable spaced-apart screw fasteners **30** and **31** extending through fairing strips **33** and **34** of aluminum or magnesium alloy, for example, seated in marginal recesses **35**, **35** in the rubber body, through the covering inwardly of the bead wires **28**, **28**, and engaging threaded members **32**, **32** suitably attached to the skin or other structure of the wing **17**, as shown especially in Figs. 8 and 9. Such marginal arrangement makes possible substantially smooth surfaces across the margins **26** and **27** whereby turbulent

flow of air is avoided and also facilitating maintaining the aerodynamic characteristics of the airfoil.

For venting the undersurface of the covering, such undersurface may have a multiplicity of ribs **47** extending spanwise substantially throughout the extent of the covering, which ribs may extend to the ends **15***d* and **15***e* for facilitating end venting action at the regions of the interference effects discussed hereinabove. The ribs define a multiplicity of spanwise venting channels **48** desirably in communication with a plurality of spaced-apart chordwise-extending venting grooves such, for example, as the grooves designated by the numerals **49**, **50**, **51** and **52**, although a greater or lesser number of grooves may be provided, if desired. The venting grooves are each in communication with the atmosphere through suitable apertures **53** in the rearward portions **15***g* and **15***h*, as shown especially in Figs. 2 and 7. Thus all parts of the undersurface of the covering are in communication with the outside atmosphere through such channels and venting grooves, the air flowing therethrough in directed paths from such parts of the undersurface to the outer regions of lesser pressure. This arrangement provides effectively for venting the covering including the central zone and preventing objectionable lifting thereof relative to the airfoil.

In the operation of the protective covering **15**, the series of tubes **36** in the central zone **15***f* are desirably inflated simultaneously and first in the cycle of inflation. The tubes **36** distend locally outward relative to the wing, as shown especially in Fig. 8, with little or no exertion of stretching force imparted to the rearward portions **15***g* and **15***h*. Such distention distorts the covering at the region of sharp curvature of the leading edge into symmetrically graduated ridges about the chord line and correspondingly stretches the material of the outer surface of the covering at such region, thereby effectively cracking and breaking the ice deposited into pieces and moving such pieces especially chordwise into the flow of air for subjecting such pieces of ice to the scavenging action of the air. The respective tubes **36** coact one with another in effectively removing the ice at such region of sharp curvature even though the ice be in the form of heavy ice-caps or a relatively thin film.

In the second phase of the cycle of inflation, the respective series of tubes **37**, **37** in each of the rearward portions **15***g* and **15***h* are desirably inflated simultaneously distending the covering locally at such portions into substantially uniform and relatively small ridges as compared to those at the central tube zone, as shown especially in Fig. 9. Such inflation of the small tubes **37**, **37** also stretches locally the material of the outer surface of the rearward portions **15***g* and **15***h*. In this manner the relatively thin ice deposited at such portions is removed effectively by the breaking and cracking action of the tubes **37**, **37** permitting the flow of ambient air to remove the cracked pieces therefrom throughout the extent of the rearward portions.

Since the covering is in a condition of relatively uniformly transmitted stretch throughout the rubber body **25** especially at the elastic fabric **54** beneath the tubes, the inflation of the tubes **36** and **37** causes only minor inward distention relative to the wing, which inward distention is resisted by the stressed fabric **54** and rubber material at the undersurface; hence the covering

may be lifted away from the wing only a relatively small extent thus avoiding entrapment of harmful quantities of air between the covering and the wing skin. However, the relatively small quantity of air which may be entrapped beneath the covering, quickly flows in directed paths through the venting channels and grooves in such undersurface and through the respective venting apertures to the outer atmosphere. Also, when the channels 48 extend to the ends 15*d* and 15*e* of the covering, the entrapped air is vented additionally at such ends by virtue of the changing negative pressures around the profile of the wing especially when such ends are positioned to take advantage of the interference effects at the junctions of parts of the aircraft, as described hereinabove. Thus, the respective elements comprising the covering 15 coact one with another in combination to provide a covering capable of removing effectively ice deposited on the leading edge of the wing regardless of the thickness characteristics of such ice.

The modified construction 60 of the covering shown in Figs. 10, 11 and 12 is in many of its aspects like the covering 15 and is applicable especially to the leading edges of thick-section wings and where extensive chordwise coverage may be required. The covering 60 includes a body 61 of suitable resilient rubber-like material and also includes a front or central tube portion or zone 62 for the sharply curved region of the leading edge and rearwardly extending portions 63 and 64 for the relatively less-sharply curved regions of the leading edge.

For effectively removing the ice deposited at the front portion or central tube zone 62 by the outward distention of the latter, two relatively large inflatable tubes 66 and 67 having walls of suitable resilient reinforced-rubber construction may be positioned within the covering symmetrically about the longitudinal center line 65 of said zone and extending in side-by-side relation in the spanwise direction along such zone, as shown especially in Fig. 10. However, a greater or lesser number of such tubes may be provided in such zone 62. The width of each of the tubes 66 and 67 is desirably such that their combined width coverage includes the major part of the chordwise extent of the zone 62 between attaching margins 68 and 69 providing relatively narrow venting regions adjacent such margins, in which regions may be respectively a series of spaced-apart venting apertures 70 and 71 extending through the covering.

The large tubes 66 and 67 are preferably inflated simultaneously and for this purpose a suitable manifold 72 and connection member 73 arrangement in communication with the tubes is provided, the connection member 73 being interconnected with a suitable source of air under pressure, as described hereinabove for the covering 15. When the tubes 66 and 67 are inflated, they distend locally outward from the leading edge and assume a relatively sharp curvature afforded by a semi-circular shape in section by virtue of the uniform and high stretchability of the walls thereof. For the distended condition of such tubes, they operate not only to crack the heavy ice-cap on the leading edge, but also operate to shift the pieces of the cracked ice-cap somewhat in the chordwise direction so as to subject such pieces to the force of the airflow rather than to permit the pieces of ice to remain static especially in the stagnation region immediately at the chord line 74 of the leading edge. Such chord line corresponds to the center line 65 of the covering 60 when the latter is mounted on the leading edge.

The covering 60 at the central zone 62 is maintained in a condition of stretch between rearwardly extending underlying portions or attaching margins 68 and 69. To the end of providing uniformity of stretch throughout the extent of the zone together with reinforcing the rubber body of such zone, it is desirable that a suitable highly elastic fabric reinforcement 75 be disposed in such rubber body adjacent the undersurface thereof and beneath the inflatable tubes 66 and 67, such fabric reinforcement extending around reinforcing metal bead wires 68*a* and 69*a* and between the attaching margins 68 and 69. The zone 62 of the covering 60 is attached to the leading edge of the wing as by suitable screw fasteners extending through the underlying portions 68 and 69 and bead wires 68*a* and 69*a* and engaging interiorly threaded hollow rivets 78 suitably attached to the skin or other structure of the wing, as shown especially in Fig. 12.

For coacting with the venting apertures 70 and 71 to vent the zone 62, the rubber undersurface of such zone may be provided with a multiplicity of suitable spanwise ribs 62*a* and venting channels 62*b* throughout the extent thereof and the venting channels may also be in communication with the atmosphere at the ends 76 and 77 of the covering for advantageously permitting end-venting action by virtue of interference effects at such ends in the manner described above for the covering 15. It has been found that chordwise venting grooves may be dispensed with, if desired; since the aforesaid end-venting action in combination with the venting of the respective series of venting apertures 70 and 71 is usually sufficient to accomplish the desired venting.

To facilitate mounting the rearward portions 63 and 64 after the central zone or portion 62 has been attached to the leading edge and to make possible continuity of smooth surface over the attaching margins, in continuation with the outer surface of the central zone, the rubber body of the covering is divided into rearwardly extending underlying and overlying portions 63 and 63, and 63*a* and 64*a*, respectively, and the opposing areas of such portions are in unadhered relation immediately at the respective attaching margins, as shown especially in Fig. 11 at 79 for the margin 68. The overlying portions or inner margins 63*a*, 64*a* of the rearward portions extend over the attaching margins and are secured integrally to the rubber body of the central portion 62. With this divided marginal arrangement, the underlying attaching margins and screw fasteners are covered by the overlying portions 63*a* and 64*a* of the rubber body at such marginal regions; thus providing the desired smooth outer surface continuity.

The rearward portions 63 and 64 including the overlying portions 63*a* and 64*a* are each provided with a series of inflatable tubes 80, 80 therein having walls of suitable resilient reinforced-rubber construction which tubes are relatively small in width as compared to the large tubes 66 and 67. The tubes 80 in each of the rearward portions extend desirably spanwise in side-by-side, closely adjacent relation throughout chordwise coverage of such rearward portions, except at rearward margins 81 and 82 of such portions 63 and 64, which latter margins are desirably tapered to a relatively thin edge, as shown especially in Fig. 12, for facilitating smooth flow of

air thereover. To provide continuity of ice removal from the central tube zone rearwardly, the respective series of inflatable tubes **80**, **80** in each of the rearward portions **63** and **64** begins with respective tubes **83** and **84** positioned in the overlying portions **63***a* and **64***a* of the covering at the attaching margins **68** and **69** where the distending and stretching action of the large tubes **66** and **67** may not be entirely effective to remove ice by virtue of such attachment and the local distending action of such tubes **66** and **67**. Each of the respective series of tubes **80**, **80** are desirably inflated simultaneously and for this purpose suitable manifolds **85**, **86** and connection members **87**, **88** in communication with such series of tubes **80**, **80** and with a suitable source of air under pressure are provided.

The rearward portions **63** and **64** are adhesively or otherwise suitably secured to the wing throughout their extent and may be reinforced in the rubber body thereof by a reinforcement **89** of relatively non-stretchable fabric material such, for example, as square-woven bias-cut cotton fabric. The rearward portions **63** and **64** may be slightly tapered in section, as shown especially in Fig. 12, for providing continuity of relatively smooth curvature of the covering **60** around the profile of the leading edge thereby facilitating maintaining the aerodynamic characteristics of the wing.

In the operation of the covering **60**, the large tubes **66** and **67** are desirably inflated first distending the covering at the central tube zone into relatively large spanwise ridges for breaking and cracking the ice thereon and permitting its removal by the flow of ambient air. Such distending action of the tubes being localized between the attaching margins **68** and **69**, imparts little or no stretching force to the rearward portions. Air, which may be trapped within the central portion upon inflation of the large tubes, is vented rapidly to the atmosphere through the venting channels at the respective ends **76** and **77** and the series of venting apertures **70** and **71** thus preventing objectionable bulging at such zone.

In the second phase of the inflation cycle, the tubes **80**, **80** in the rearward portions are desirably inflated simultaneously thereby distending such portions outwardly into a series of relatively small spanwise ridges beginning at the attaching margins **68**, **69** which effectively cracks and breaks the ice deposited thereon into pieces for removal by the flow of air. Since the rearward portions are adhesively secured to the wing, objectionable bulging and movement of the rearward portions is effectively eliminated regardless of the chordwise extent thereof and venting of such rearward portions is likewise eliminated. Thus the construction of the covering **60** provides advantageously for effectively removing ice from the leading edges of thick-section airfoils and facilitates providing chordwise coverage of the leading edge to any desired extent in addition to facilitating installation thereon.

The fabric and rubber parts of the coverings **15** and **60** are united desirably by vulcanization under heat and pressure.

Variations may be made without departing from the scope of the invention as it is defined in the following claims.

I claim:

1. Apparatus for preventing the accumulation of ice on a surface exposed to ice-forming conditions in airflow, said apparatus comprising a covering of elastic material for said surface including a front portion and a rearward portion and including a plurality of inflatable passages in each of said portions for distending said covering into a series of ridges, said plurality of passages in said front portion being wholly disposed within the latter said portion and of widths gradually narrower throughout their lengths toward said rearward portion, and said plurality of passages in said rearward portion being wholly disposed therein closely adjacent one another and being of less width throughout their lengths than the width of each of said passages in said front portion, whereby said covering is distensible into ridges relatively small and closely adjacent one another in said rearward portion as compared to the ridges in said front portion.

2. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising a covering for said leading edge including a distensible portion for said sharply curved region and a second distensible portion for said less-sharply curved region, said portions having a chordwise series of inflatable passages extending spanwise thereof and said second portion having a plurality of said passages wholly disposed therein closely adjacent one another, a passage in the first said portion being of a greater width than the width of individual passages in said second portion, and the closely adjacent passages in said second distensible portion having aligned openings directly through the adjacent walls thereof for simultaneous inflation of said passages.

3. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising a covering for said leading edge including a distensible portion for said sharply curved region and a second distensible portion for said less-sharply curved region, said portions each having a plurality of inflatable passages extending spanwise thereof for distending the latter, said passages in the first said portion each being relatively greater in width than the width of individual passages in said second portion, and said plurality of passages in each of said portions being wholly disposed closely adjacent one another in the portion and having aligned openings directly through the adjacent walls thereof for simultaneous inflation of the passages of the portion.

4. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising an elastic covering for said leading edge including a zone for said sharply curved region and a portion extending rearwardly from said zone for said less-sharply curved region, and said covering including a plurality of inflatable passages wholly disposed in said zone closely adjacent one another and being of widths gradually narrower toward the rearward portion, the closely adjacent passages in said zone having aligned openings directly through the adjacent walls thereof for simultaneous inflation of said passages, and a plurality of inflatable passages wholly disposed in said rearward portion closely adjacent one another for distending said covering into ridges closely adjacent one another in said rearward portion, the latter said passages in said rearward portion being individually of less width than the width of a passage in said zone and having aligned openings directly through the adjacent

walls of the closely adjacent latter said passages for simultaneous inflation of the latter said passages.

5. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising a covering for said leading edge including a distensible portion for said sharply curved region and a second distensible portion for said less-sharply curved region, said portions each having a plurality of inflatable passages wholly disposed thereon and extending generally parallel to one another for distending said covering into ridges, said passages in the first said portion each being relatively larger in width than the width of each of said passages in said second portion, and said plurality of passages in said second portion being disposed closely adjacent one another and having aligned openings directly through the adjacent walls thereof for simultaneous inflation of said passages.

6. Apparatus for preventing the accumulation of ice on a surface exposed to ice-forming conditions in airflow, said apparatus comprising a covering of elastic material for said surface divided at a margin thereof into an underlying portion and a portion overlying the same and extending rearwardly of said margin, portions of the covering forwardly and rearwardly of said margin being distensible and having a plurality of inflatable passages therein for distending the covering into a series of ridges, a plurality of passages in the rearward distensible portion wholly disposed within the latter said portion closely adjacent one another and being individually of less width than a passage in the forward distensible portion whereby said covering is distensible into ridges closely adjacent one another in said rearward distensible portion and relatively small in said rearward distensible portion as compared to a ridge in said forward distensible portion of the covering, and means for mounting the covering by attachment through said underlying portion.

7. Apparatus for preventing the accumulation of ice on a surface exposed to ice-forming conditions in airflow, said apparatus comprising a covering of elastic material for said surface divided at a margin thereof into an underlying portion and a portion overlying the same and extending rearwardly of said margin, portions of the covering forwardly and rearwardly of said margin including said portion overlying the margin being distensible and having a series of inflatable passages therein for distending the covering into a series of ridges, a plurality of passages in the rearward portion including a passage in said portion overlying said margin wholly disposed therein closely adjacent one another and being individually of less width than each of the passages in the forward portion of the covering, whereby said covering is distensible into ridges relatively small and closely adjacent one another in said rearward portion including the overlying portion as compared to the ridges in said forward portion of the covering, and means for mounting the covering by attachment through said underlying portion.

8. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising a covering of elastic material for said leading edge including a portion for said sharply curved region having a rearward margin for attachment of the covering to said leading edge and a portion overlying said margin and extending rearwardly from the first said portion for coverage of said less-sharply curved region, said portions being distensible and having a plurality of inflatable passages extending spanwise therein for distending the covering into a series of spanwise ridges, a plurality of passages in the rearward distensible portion wholly disposed therein closely adjacent one another and being individually of less width than a passage in the first said portion whereby said covering is distensible into ridges closely adjacent one another in said rearward portion and relatively small in said rearward portion as compared to a ridge in the first said portion, and means for attaching the covering at said margin to said leading edge.

9. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising a covering of resilient rubber-like material for said leading edge having attaching margins and including a central zone for said sharply curved region, rearward portions extending from the margins of said zone for said less-sharply curved regions, means for attaching the covering at said attaching margins to said surface, and a plurality of inflatable tubes extending spanwise in said zone and said rearward portions, said tubes in said zone being of widths gradually narrower toward the rearward portions, and said tubes in said rearward portions being less in width than the width of each tube in said zone whereby the expansive excursion of said tubes in said zone and said portions is in accordance with the thickness of the ice deposited at the respective positions of the tubes.

10. Apparatus for preventing the accumulation of ice on the sharply curved and relatively less-sharply curved regions of the leading edge of an airfoil, said apparatus comprising a covering of resilient rubber-like material for said leading edge including a central zone for said sharply curved region and portions extending rearwardly from said zone for said less-sharply curved regions, said covering at said zone comprising spaced-apart attaching margins, a pair of inflatable tubes extending spanwise between said margins and a layer of said material thereover, each of the rearward portions comprising a plurality of inflatable tubes extending spanwise closely adjacent one another each of which being relatively small as compared to the first said tubes, and a second layer of said material thereover in continuation of the first said layer and overlying said attaching margins for presenting a substantially smooth outer surface of the covering at the attaching margins, and means for mounting said covering at said attaching margins to said leading edge and for securing said rearward portions to said leading edge.

JOHN O. ANTONSON.

REFERENCES CITED

The following references are of record in the file of this patent:

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Number	Name	Date
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1,998,809	Geer	Apr. 23, 1935

Certificate of Correction

Patent No. 2,440,240. April 27, 1948.

JOHN O. ANTONSON

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 11, line 12, claim 5, for the word "thereon" read *therein*;

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 1st day of March, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.