April 18, 1933. **V. LOUGHEED** **1,903,823**

AERODYNAMIC SURFACE

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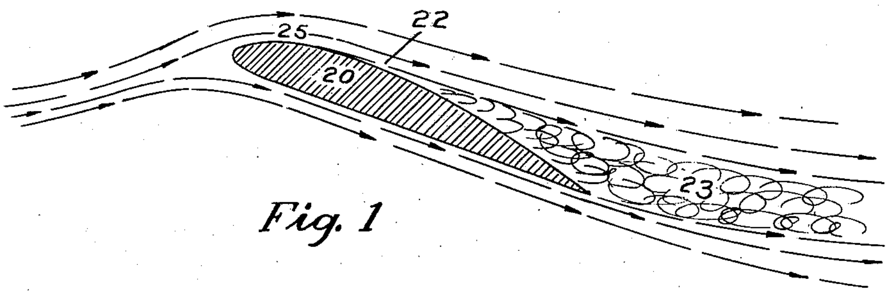

Fig. 1

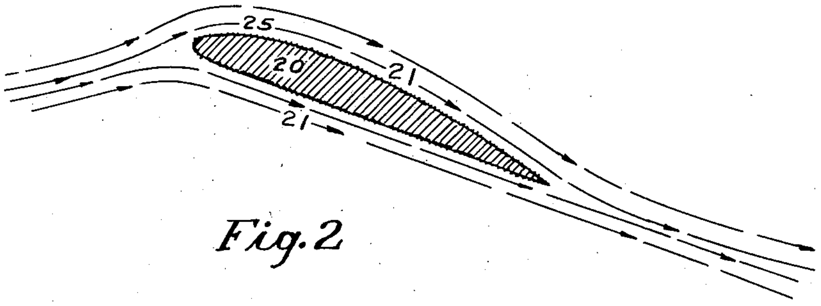

Fig. 2

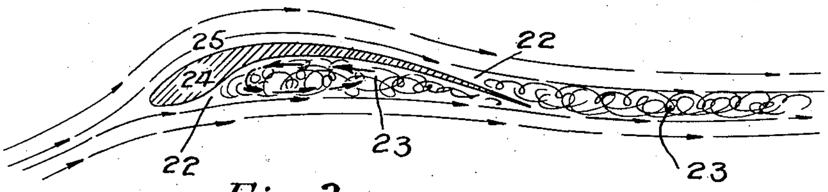

Fig. 3

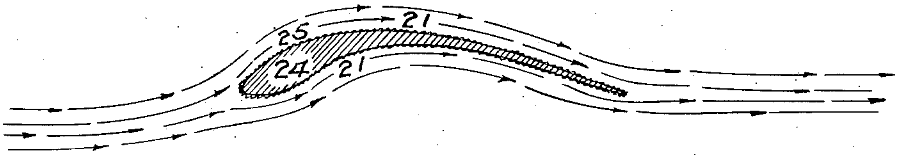

Fig. 4

INVENTOR.

Victor Lougheed

April 18, 1933. V. LOUGHEED **1,903,823**

AERODYNAMIC SURFACE

Filed Dec. 28, 1928 4 Sheets-Sheet 2

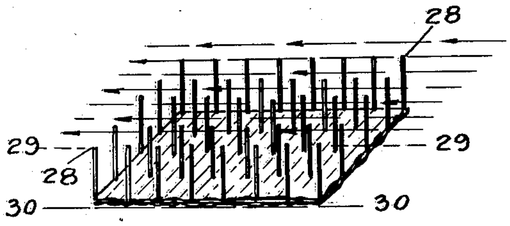

Fig. 5

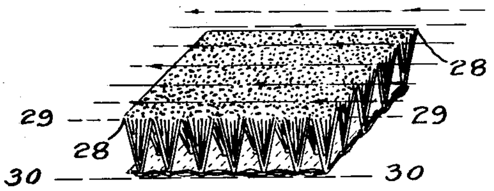

Fig. 6

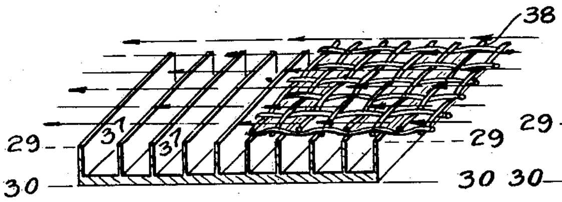

Fig. 7

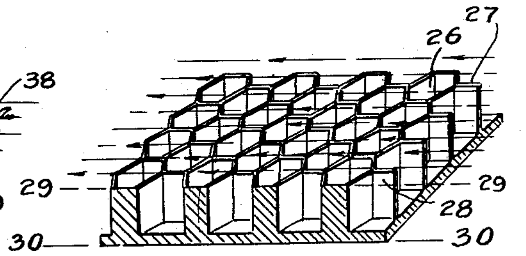

Fig. 8

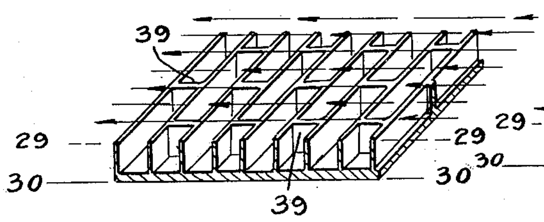

Fig. 9

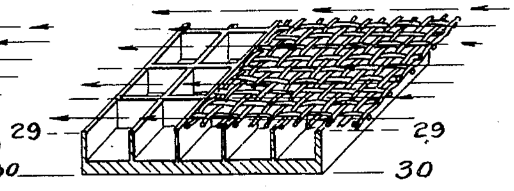

Fig. 10

INVENTOR.

Victor Lougheed

April 18, 1933. **V. LOUGHEED** **1,903,823**

AERODYNAMIC SURFACE

Filed Dec. 28, 1928 4 Sheets-Sheet 3

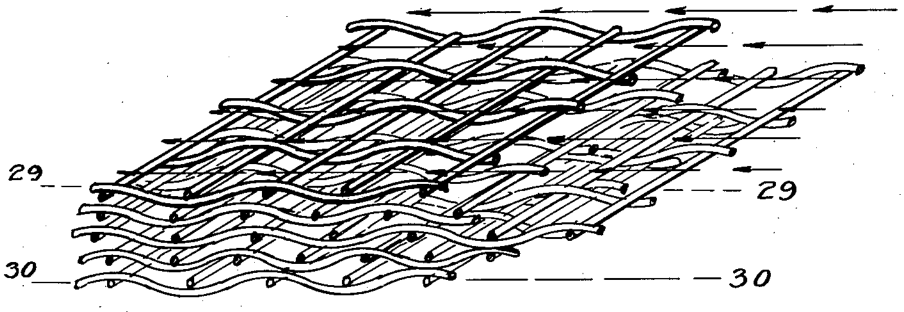

Fig. 11

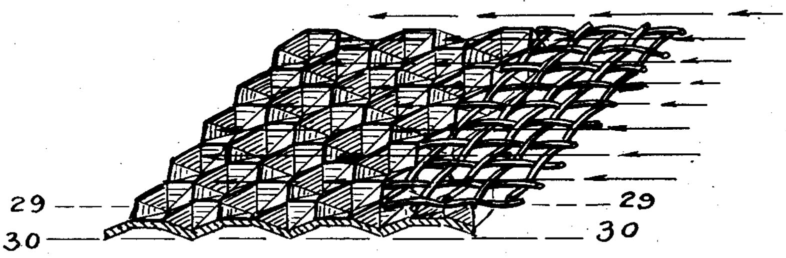

Fig. 12

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April 18, 1933. V. LOUGHEED 1,903,823

AERODYNAMIC SURFACE

Filed Dec. 28, 1928 4 Sheets-Sheet 4

Fig. 14

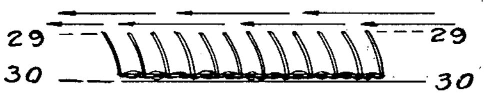

Fig. 13

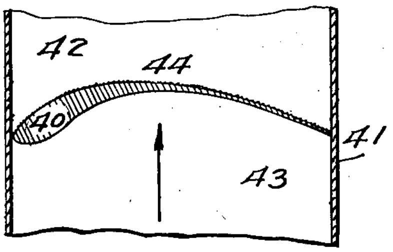

Fig. 15

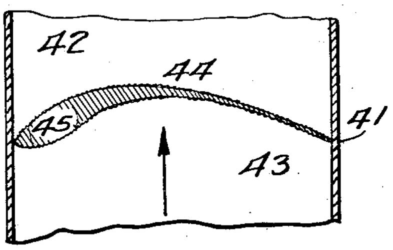

Fig. 16

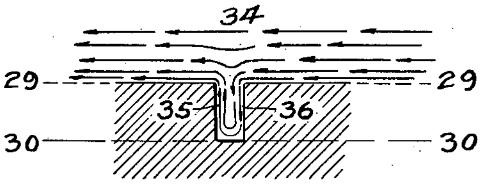

Fig. 17

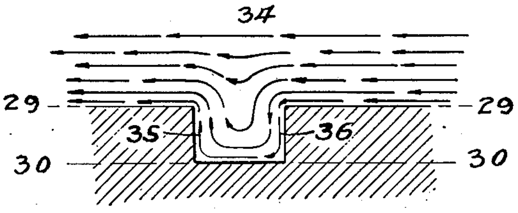

Fig. 18

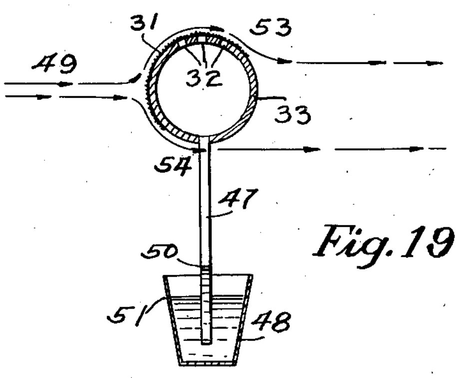

Fig. 19

INVENTOR.

Victor Lougheed

Patented Apr. 18, 1933 **1,903,823**

UNITED STATES PATENT OFFICE

VICTOR LOUGHEED, OF WASHINGTON, DISTRICT OF COLUMBIA

AERODYNAMIC SURFACE

Application filed December 28, 1928. Serial No. 328,982.

The principal object of my invention is for reducing the air friction on and improving the aerodynamic and other performance of wings, sustaining surfaces, bodies, and other elements of aircraft, required to derive sustention from their movement in or to pass freely through the atmosphere.

My discovery or invention thus particularly relates to all types of surfaces and forms of structures involved in aerial navigation. More broadly, however, its application may extend to other vehicles or devices moved or contacting with relatively-moving air or other fluids, including watercraft, though its most important and immediate application is to aeroplanes.

Since the entirety of all exterior surfaces of an aeroplane is in contact with air moving relatively thereto, it is to be understood that description, herein, to the extent that it may be confined to the application of my discovery or invention to certain specified portions of an aeroplane's surfaces, by way of clarifying the principles, structure, and relationships of its applications, is not thereby to be limited in its scope to such surfaces alone, for it also may be usefully applied to all other portions of aeroplane surfaces—as well as to the surfaces of aircraft other than aeroplanes, to watercraft, to the blades of helicopters and aircraft propellers, and to various devices and mechanisms the operation or functioning of which concerns the phenomena of fluid friction—without departing from the spirit or scope of my invention as defined by the claims appended hereto.

Assuming, therefore, that my discovery or invention will apply most usefully and importantly to aeroplanes—apart from its other probable and possible applications—and since in its application to aeroplanes the difficulties to be met are greatest and most complex, I deem it advisable hereinafter to discuss chiefly the relations of my discovery or invention to the phenomena of the relative wind, involved in the operation of an aeroplane.

In its maximum development, my discovery or invention consists in the combination of suitable wing sections and stream-line forms with suitable surfacings therefor—the two factors of sectional form and surface friction being inextricably interrelated in practical applied aerodynamics, as hereinafter will appear.

The essential features, however, of my discovery or invention, are usefully and beneficially applicable even to airfoil sections and strut and body forms not the best or most suitable. This is because its application can result in improved operating characteristics even in cases in which it cannot be applied to allow the best operating characteristics.

An incidental object of my discovery or invention, as will hereinafter appear, is its beneficial effect, in certain embodiments, in minimizing or preventing ice formation on aircraft surfaces.

It is fully understood by those skilled in the art of flight engineering that all present types of aircraft surfacing drag along with the surface air adjacent to the surface. This "boundary layer" of dragged air, the existence of which was determined and the laws of which were first formulated by Prandtl, is well known to occasion three most mischievous obstacles to the safe, efficient, and satisfactory functioning of aircraft.

First of these obstacles is that the attached air, enveloping the structure and dragged by its surfaces, in turn drags a larger envelope of air, and this a still larger, and so on, out to an extent the practical effect of which is greatly to increase the bulk and seriously to deform the shape, of the perhaps functionally-sound visible structure, by the adherence or attachment to it of an enveloping, undefined, and much larger or thicker invisible structure, possessed of functional characteristics as vague and beyond control as are its actual size and outline.

Second of these three obstacles—the succession of enveloping sheaths of air, which thus by their addition to it mask and distort the visible form, and so render aberrant its functioning, do not move uniformly as a mass, attached to their nucleus of visible structure, but like a series of moving sidewalks increasingly lag behind its surface with increasing distance from this surface, and hence, by a consequent suppression or tapering off of the normal velocity difference between the structure and the relative airflow, render further abnormal and inefficient its functioning.

Third—the final obstacle, involved by the phenomenon of the boundary layer, is that, in circumstances in which it does become detached—as a result of extreme angles of a surface to its direction of movement, or because of the accumulated friction of a very prolonged surface of contact, or as a result of exceedingly-high relative velocity—such detachment does not take the form of a low-friction slippage, parallel to the surface, but instead assumes the form of a departure of the relative airflow from the surface, with the consequence that there then intrudes between it and the surface an unwanted and exceedingly pernicious region of swirling and turbulent air, which adds a final increment to the utter derangement of the desired, intended, or ideal interaction between the contours of the surface and the flow of the relative wind.

This word picture of what invisibly goes on in the atmosphere, about the sustaining surfaces, body forms, and other elements, of artificial aircraft of all now-established and existing types, will be agreed upon by those familiar with this subject as not exaggerated or overdrawn, and as fairly applying to conditions of ordinary operation—just as correction of these faults of functioning must be recognized as the way to needed advances of the utmost moment to the future of human flight.

These features I have shown diagrammatically in Figures 1 and 3 of the drawings hereof.

The subject of natural flight has intrigued many investigators, and much has been written on this subject, though surprisingly little research into natural flight has been scientifically conducted or presented. In explaining my discovery or invention I will refer herein chiefly to my own work and investigations of this subject, the final results of which, derived from many years of study and research, were the discovery of the principles upon which my invention was founded. These principles are expounded in my recent book "Natural and Artificial Flight".

From my investigations, I have arrived at the opinion that there is much that is in error in the present accepted theory of dynamic support by artificial sustaining surfaces, as this theory has been developed and is understood, and particularly as its application has been loosely extended, without much warrant, to sustention with natural wings.

This accepted theory, it is here to be defined, basically premises that the important and essential means to sustention, with both the aeroplane and the bird, is the changing of the direction—with perhaps some retarding of the velocity—of the relative airflow, by the use of sections designed to gain, by the resulting reactions, the highest possible lift in combination with the lowest possible drag.

Tests directed to the confirmation and extension of this theory, checked and repeated, in the wind tunnels of the world by many investigators, have at least been consistent. But their invariable finding has been, paradoxically, that nature is wrong—that the bird's sustaining wings, deeply-concaved on their undersides, are inferior to the "airfoil" sections of all established flight practice, most of which are "substantially-flat", or even convexed, on their undersides, or because of some obscure, undefined reason, are limited to relatively-small and slow-flying devices, and are unsuited to the size and speed factors involved in the aeroplane.

Conforming to and based upon this accepted theory, and so designed with airfoil rather than wing sections, the maximum over-all efficiency of the entire machine, so far attained in any aeroplane, involves a resistance against which propulsion must be had of at least one-fifteenth of the weight of the machine. And even in the cases of sustaining sections alone, tested apart from the resistances of body and parasite elements, the highest lift-drag ratio that has been established, at any airspeed, certainly does not exceed thirty to one.

Corresponding values for birds in gliding flight, as determined by tests the manner and findings of which are fully set forth in my latest book "Natural and Artificial Flight," are far higher. I have established and confirmed repeated instances, in the flight structures of nature, in which there are achieved lift-drag ratios of at least as high as two-hundred to one—thus enabling gliding flight on a horizontal course to be maintained indefinitely by propulsive effort as low as one two-hundredth of the weight of the vehicle.

Many attempts, along many different lines, have been made to reduce the skin friction of a relative airflow across aircraft and other surfaces. The resultant structures, whether very smooth or very rough, have yielded no results to justify discarding the moderately smooth, or smoothly-corrugated surfaces at present in use for all external areas of all aircraft. Indeed, the roughest and most irregular surfaces tested have varied in their skin-friction characteristics from about the same to not seriously worse than the very smoothest surfaces. Certainly none of the rough surfaces have been shown to possess skin-frictional or other characteristics appreciably superior to those of smooth surfaces.

Other structures, of hollow wings slotted or perforated on their surfaces, and provided with special power-driven air-pumps, to blow air or to draw air through such slots or perforations, have yielded small gains in lifts and smaller gains in lift-drag ratio. But in all cases, without exception, these structures have proved impractical, and have failed to come into use, because the complication and difficulty of fabrication, the necessity for considerable power to maintain the pump in operation, and the danger of leaks or pump failure stopping the functioning, are adverse factors in their use which are not offset by the slight advantages.

These cumbersome devices and schemes, therefore, though of theoretical interest, have proved wholly impracticable for application to actual flight conditions. Moreover, as means of reducing skin friction, it is to be doubted if these schemes are of any particular value.

As for these schemes being applicable to body forms, strut sections, and other elements of an aeroplane than the sustaining surfaces; or to the envelope of a dirigible; or to the propeller blades of an aeroplane or helicopter; or to various other air-handling and air-driven machinery, there certainly is nothing done or known in this art that would even suggest these possibilities.

My discovery or invention, on the contrary, posseses all these objects and applications. It consists substantially in the constructions, combination, arrangement, and application of parts, and functions associated therewith, as are fully herein set forth, as are shown by the accompanying drawings, and as are finally pointed out in the appended claims.

Referring to the accompanying drawings, forming a part of this specification, it is to be noted that like reference numerals indicate corresponding parts throughout the several views, in which:—

Figure 1 is a diagrammatic view of the action of the relative airflow about a widely-used and one of the least-bad airfoil sections of present aeroplane practice, when the angle of incidence of this airfoil is increased or above to the "stalling" point.

Figure 2 is representative of the airflow about the same section at the same angle to the relative wind, when coated with a vesicular surface of the species herein described.

Figure 3 shows the airflow about a deeply-concaved wing section, as tested with a smooth surface.

Figure 4 shows a similar deeply-concaved wing section, more closely resembling that of a bird than the preceding, and which affects the relative airflow as shown, when provided with my vesicular surfacing as described herein.

Figure 5 is a sectional and perspective view of a most elementary embodiment of my invention, in the form of a pile fabric with relatively-stiff uniformly-spaced hair or wire pile.

Figure 6 is similar to Figure 5, except that the piles of the fabric are grouped in tufts.

Figure 7 shows an embodiment of my invention consisting of grooves relatively-fine, separated by relatively-thin partitions, running across the surface transversely to the relative airflow, and covered with a netting.

Figure 8 shows the vesicular surface of my invention in the form of honeycomb-like cells, in which the intercellular partitions expose a minimum length and area edge, and consume a minimum bulk of material, in proportion to the area and depth of the cells.

Figure 9 shows an embodiment of my invention in which the vesicles are elongated in a direction transverse to the airflow, so that the appearance is similar to the grooved surface of Figure 7, but modified by the provision of thin partitions at intervals in the grooves.

Figure 10 shows another embodiment, of a waffle-like vesicular surfacing of my invention, in which the vesicles may be readily produced by molding in rubber, papier mâché, or other material, and in which they are covered with a fabric or wire netting, with meshes smaller than the sizes of the mouths or openings into the vesicles.

Figure 11 shows a vesicular surface entirely constituted of a plurality of layers or plies of netting, in which the meshes are much larger than the cords or wires, and in which the plies, superimposed on one another, aggregate a greater total thickness that, in its best embodiment, is at least greater than the major dimension of the mesh openings.

Figure 12 shows a structure or embodiment of my discovery or invention, similar to that of Figures 8, 9, and 10, but in which the vesicles are adapted to be produced by pressing or forming from sheet metal, and in which the feature is to be noted that the size of mesh in the covering netting is preferably smaller than the average depth of vesicle under each opening of the mesh.

Figures 13 and 14 diagrammatically illustrate a difference which under certain operating conditions may connote the difference between a successful and a wholly-unsuccessful result, in the design and operation of a vesicular surface, thus showing the critical quality of this general type of surface, as distinguished from merely random rough surfaces, and further showing the necessity for clearly understanding and embodying its principle, in a given structure, to gain any benefit from its application and use.

Figures 15 and 16 are schematic illustrations, of vesicular-surfaced sustaining sections located within a tube, to show an effect that the attenuation of the air in the vesicles may have upon the sustention or lift of the section.

Figures 17 and 18 are cross sections of vesicles, designed to illustrate the principle of the evacuation of the vesicles by the relative airflow across them, and to show the superiority of deep and narrow to broad and shallow vesicles.

Figure 19 shows in a relative airflow a hollow cylinder, partially covered with a vesicular surface, the vesicles of which communicate with the interior of the cylinder, the only other opening into which is by way of a glass manometer tube, by the rise of water in which, the principle on which my vesicular surface or structure is designed, and the facts of its functioning as herein described, can be simply and conclusively demonstrated.

My experience so far inclines me to a preference for the particular embodiment of my vesicular surface in which the vesicles are cheaply produced by the superimposition of numerous plies of suitable netting, as illustrated in Figure 11. Such a surfacing can be quilted or loosely stitched together as a fabrication process, to expedite its subsequent economical and ready application to all sorts and contours of aircraft surfaces. Either wire or fabric netting may be employed, and in the latter case "cravenetting", or other waterproofing, or water-repellent, treatment may be provided. Made water-repellent, such an openwork fabric is distinctly resistant to the much-dreaded ice accumulations which in certain circumstances of operation in cold moist weather pile up dangerously on the surface of aircraft, but which on such a water-repellent netting surfacing as that described tend to draw into globules by the effect of surface tension, with consequent freezing into fine, non-adherent shot or granules from which the surface may continuously free itself.

Referring now specifically to Figure 1, which shows the airflows resulting from testing this section, smooth-surfaced, in a wind tunnel, the point to be understood is twofold: First, that the adherence of the boundary layers of the airflow to the surfaces gives rise to a skin-frictional drag proportionate to the viscosity of air at or close to normal atmospheric pressure; and, second, that the consequent lagging of the flow of the boundary layers, with their consequent final detachment as at 22, Figure 1, destroys the smooth and designed functioning of this sustaining section, by the turbulent, swirling, and recurving air movements at 23, which take the place of and suppress the proper streamline flow which is derived, and which must be had if there are to be realized the maximum advantages to be derived from the forms of the surfaces. It is true that turbulence develops, in the case of such a smooth-surfaced airfoil section as 20, of Figure 1, with moderate chord dimensions, only at high angles of incidence, such as that shown, and that this is not a normal operating angle. But as an abnormal operating angle, such an angle of incidence is frequently entailed, through various uncontrollable causes as well as through controllable causes, in the flying of aeroplanes. And when it occurs, it is the detachment of the boundary layer and the intrusion of turbulence that brings about the very dangerous condition known as a "stall".

Proceeding now to Figure 2, which illustrates the same airfoil section 20, at the same angle at which it is shown in Figure 1, this section now is to be regarded as provided with vesicular surfacing, as indicated. The result again is twofold, as in the cases of the smooth-surfaced sections of Figure 1. But now, first, the boundary flow of air, contacting only with the relatively-small areas of the hair or pile termini, or with the intercellular-partition edges, or with the wire or fabric covering of the vesicles, and with the relatively-large areas of attenuated air in the vesicle openings or mesh interspaces, flows freely across the surface, with little skin-frictional drag, so that the condition approximates the ideal condition of an inviscid fluid flow; and, second, the partial evacuation of the vesicle contents produces a suction powerful enough to cause adherence of the airflow to the contours of the section, in smooth streamlines, without turbulence, as depicted at 25, 25, Figure 2. A very low vacuum suffices to produce this adherence.

In consequence, with the airfoil section 20, of Figure 1, the stalling angle is greatly increased, if not completely suppressed.

With the wing section 24 of Figure 3, this section, heretofore unusable for aeroplanes, or, at best, only most inefficiently usable, because of the detachment of the boundary layer at 22, 22, with consequent turbulence at 23, 23, becomes, with vesicular surfacing, as in Figure 4, a section affording vastly higher lift-over-drag ratios, and other most-favorable characteristics, never heretofore realized in any aeroplane design or operation.

And the subatmospheric pressure, gained by the change in direction and speeding up of the airflow at 25, Figures 1, 2, 3, and 4, and which has in all aeroplane practice heretofore been an important source of lift, now has added to it other important sources of lift, as will hereinafter appear.

With a smooth-surfaced wing section such as 24, of Figure 3, operation at stalling angles need not be considered for the purposes of this specification, because operation even at normally-low angles of incidence is impossibly inefficient, in consequence of the detachment of the boundary layers at 26 and 27, and the resulting turbulence within the under concavity at 28, and behind the wing at 29.

The exact effect of a vesicular surface perhaps can be most clearly described by comparisons with an ordinary atomizer or paint sprayer. In this common device, there is a vertical riser tube, descending into the liquid to be sprayed, and with its open upper end traversed at substantially right angles by an air blast from a horizontal nozzle. The effect of the horizontal airflow is to produce, by continuously blowing away the uppermost contents of the riser tube, a rising flow through this tube. If, however, such flow be prevented by closing the bottom of the riser tube so that no liquid can enter it, the result of the horizontal airflow becomes a pumping out or attenuation of the gaseous contents of the riser tube, instead of the establishment of a continuous flow through it.

The same condition can be produced in the same manner with a large plurality of riser-tube openings traversed by the airflow—subject only to the consideration that in this case the horizontal transverse airflow must be correspondingly more extensive.

Strikingly analogous to the atomizer condition contemplated in the preceding paragraph is that afforded by the multitude of open cavities, vesicles, interspaces, and mesh interstices, of the various described and possible-embodiments of my vesicular-surface structure.

In connection with my discovery and invention of this structure, I have determined that the plumage or feather structure of a bird, with its myriads of minute processes dividing its mass into relatively-large interspaces, is an astonishingly-effective dynamic vacuum pump, which, traversed by a relative airflow, operates on the principle of the multiple-nozzle atomizer arrangement of the second preceding paragraph.

Any thorough microscopic examination of the structure of a bird's feathers at once discloses the utter impossibility of duplicating, in any artificial structure, their amazing subdivision into the millions upon millions of barbs, barbules, barbicles, and hamuli, of the anatomists.

But my researches, culminating in this discovery and invention, have shown me how vesicular structures affording substantially similar functional effects can be scientifically-designed and economically built, and can be depended upon to prove highly-effective and serviceable in practical use.

Continuing then, this explanation of my discovery and invention, it now must be apparent how a large number of superficial pits, 26, 26, with thin-edge partitions walls, 27, 27, and grouped into a honeycomb-like surface such as that, for example, of Figure 8, will, under the influence of a relative airflow or airstream traversing their open ends, undergo partial evacuation of their gaseous contents, to an attenuation determined by the velocity of the airflow; the thinness of the intercellular edges; the depth, size, and shape of the openings; their parallelism to or departure of parallelism from a normal to the airflow; as well as by other factors.

Moreover, systems of uniformly-spaced or tufted hair or wire piles, 28, 28, as illustrated in Figures 5 and 6, by the viscous adherence of the air to the ciliate elements of the surface, establishes much the same evacuating action, by the transverse airflow, which is realized in the more-specifically vesicular forms of surfaces, the essential condition being that the function of the hairs, as of the partitions, is to allow flow or jet air to shear across contained air, whether the latter be entrapped within netting or between partition walls, or merely enmeshed in fine cilia groups. In the first and third cases, however, though intercomunication between contained air within one portion of the surface and that within a nearby portion of the surface is not positively prevented by impermeable walls it nevertheless must be effectively prevented by a sufficient fineness of structure to impede such communicating circulation of contained air, by compelling it, as alternative to entrainment out into the relative airflow, to circulate through a complexity of netting or a thicket of bristles, presenting exceedingly small openings, or long and tortuous paths, or both. Naturally, with the pressure differentials from point to point on a surface small, and with the vesicular surface relatively shallow in proportion to its extent, intercommunication through the structure cannot at worst be as free as the direct outward escape of the air by evacuation into and by the effect of the relative airflow.

In any structure that can be designed, to embody the features of my discovery or invention, essential characteristics will be the presence of, and the distinctions between the superficial, or effective surface 29—29, and the sub-surface, 30—30, Figures 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17 and 18. The sub-surface must be substantially impermeable to air; the superficial or effective surface must be freely permeable to air.

In the design of a wing or sustaining surface, or of a body, strut form, or other element, it never is desirable that the evacuation of the vesicles be to the same degree over all portions of the surface, and it usually would be highly inconvenient, in practical engineering, to build these elements hollow and leakproof, and to give the hollows over to the wholly useless function of containing volumes of slight rarefied air appended to that properly required in the vesicular cavities themselves.

I mention this point at some length, because a vesicular surface 31, with a perforate subsurface 32, can be made to evacuate or attenuate the contents of a relatively large chamber 33, communicating with the perforations, as I show in Figure 19. And, this being the case, an approximation to the ideal vesicular surface, of isolated vesicles, independently evacuated to a substantially-uniform pressure gradient, could be made in an inferior embodiment of my discovery or invention, in the form of a series of one or more chambers, each evacuated through a group of openings, to a thus pronouncedly-stepped pressure gradient, over the surface. Indeed, in a way this is much what is done by the netting surfacing over the vesicle openings in Figures 7, 10, and 12. Conversely, evacuation through grouped openings of a large chamber, as in Figure 19, is no more than to allow similar intercommunication of a group of vesicles within which the same degree of evacuation is desirable or tolerable, and to remove the subsurface 30, 30, of Figures 7, 10, and 12, to an abnormal, unnecessary, and undesirable remoteness.

However, in all these cases, of conflicting means and various possibilities, an essential distinction still remains, clearly defining the structure of my discovery or invention. For I evacuate the vesicles, chambers, openings, or interspaces of my surfaces by flow outwardly, and I induce this outward evacuation by designing the structure of my discovery or invention so that it is the flow of the relative wind, over the effective surface, that produces this desired evacuation down to the sub-surface, by pumping the contained vesicular air out into and by the effect of the relative wind. And accordingly, by my discovery or invention, I can provide a most minutely- and progressively-graded change in value of the attenuation from vesicle to vesicle, to suit any condition of operation, or location of the surface on a machine.

Referring now to Figures 17 and 18, the first action of a relative air-flow, as shown by the horizontal arrows, 34, 34, over the superficial or effective surface 29—29, of the structure of my discovery or invention, is briefly to induce a free outward flow as suggested by the small vertical arrows at the left. This free flow, with the sub-surface 30—30 substantially impervious to air, and the vesicle connected to no chamber, nor with its neighboring vesicles, almost instantly must cease, as the contents of the vesicle reach the optimum attenuation. Thereafter, then, there can ensue only a slow leakage of air from the relative wind into the vesicle, as suggested by the small vertical arrows 36, 36, at the right, Figures 17 and 18, followed by this increment of air being pumped out again, as before. The degree to which such leakage can be reduced is a measure of the effectiveness of the particular vesicular surface, and if the width of the vesicle is made only a small proportion of its depth, from superficial or effective surface 29—29 to sub-surface 30—30, Figure 17, the leakage can be practically suppressed, and the resulting condition is much more efficient than that portrayed in Figure 18, in which the width of the vesicle is greater than its depth.

The difference between these conditions, therefore, as illustrated by Figures 17 and 18, may be the difference between a successful result and an unsuccessful result. Similarly, the use of pile fabric with a pile so weak that it flattens down in the relative wind, as illustrated in Figure 14, so that the effective surface is destroyed, will wholly fail to afford the evacuation of the surface that will be afforded by a pile stiff enough to bend only slightly from the force of the wind, as depicted in Figure 13.

The importance of thus establishing means, within the discontinuous solid structure of all possible embodiments of my discovery or invention, for the retention therein of attenuated air, preserved as much as may be against replacement, or loss of attenuation, definitely shows and proves that an integral and essential element of my vesicular surfacing, in all embodiments, is rarefied air, so that the structure becomes one truly constituted in part of solid and in part of gaseous constituents. Referring back to Figure 7, a system of fine and deep grooves, as shown therein at 37, 37, and especially if covered with the netting as at 38, may serve much the same purpose as vesicles, because airflow along the grooves, to equalize relatively-remote differences of pressure gradient on the surface, will not occur if the grooves are fine enough to provide proportionately great wall surface to small contents, with consequent maximum wall friction to impede flow.

A better design is that shown by Figure 9, in which the partitions 39, 39, at intervals along the grooves, are a positive prevention of flow, whereas the frictional resistance to flow in Figure 7 is non-positive. While the sort of elongated vesicle illustrated in Figure 9 is possibly the best theoretical form, it involves the practical disadvantage, which also pertains to Figure 7, that in applying such surfacing to aircraft it often will be difficult to be sure that the relative wind really flows squarely across the grooves, or across the shortest dimensions of the vesicles, as it must to provide the best results.

Randon types of rough surfaces that have been variously tested in aircraft design have failed because they have not been true vesicular surfaces, the principles of which up to this writing have not been known. Thus corrugated canton-flannel and gauze-covered, and other rough surfaces, which have been experimentaly applied without knowledge of the laws of realization of the effects my discovery or invention contemplates or embodies, have failed to provide the effects my discovery or invention gives, because their structures lacked such element of exact and foreknowing design, to meet the given conditions, as is a fundamental consideration and necessity, in the structure of any useful embodiment of my discovery or invention, if optimum—or even beneficial—results are to be had.

For, as has been suggested, designed variations in the size, shape, placing, angle, and type of the vesicles, to suit their many possible embodiments in my discovery or invention, and to meet different conditions of speed, loading, and pressure distribution, are essential to the effective application or use of my discovery or invention. Indeed, without such careful and understanding design, there may be striking simulation of my vesicular-surface structures, with total absence of their advantages.

Just as in the case of pressure jets for speeding up the boundary layer, thus crudely to prevent its detachment, and which to be of any benefit must be directed almost perfectly tangential to the curve of a surface, in the cases of various experiments made by others, the conditions for the functioning of the vesicular surface are quite critical, and so absolutely must be definitely and properly embodied or incorporated in the design of the surface, if the pumping or evacuating action is to be realized.

Now, to summarize, evacuated vesicles, filled with attenuated or vacuous air, constituting a major portion of a wing or other surface, the remainder of which is occupied by relatively-thin edges of the partitions between the air-filled openings, produce a series of remarkable effects, never heretofore attained in any artificial flight structure.

Not the least important of these effects is that the suction in the vesicles, which in the aggregate are substantially equal to the total area of the surface, enlists the static pressure of the atmosphere for the sustention or propulsion of the surface, or both, as the case may be. Considering that the full sea-level pressure of the atmosphere is 2116.225 pounds to the square foot, which could be realized against the underside of a wing to sustain it, if a perfect kinetic vacuum could be formed above it—it is evident that, even with very slight evacuation of the vesicles on the top side of a wing the consequent contribution to lift must still, in favorable circumstances, be radically more powerful than the comparatively-feeble dynamic sustention gained solely by the established procedure of changing the direction of the relative airflow by the contour of airfoil sections.

This effect may, in fact, with the bird be the major source of the sustention. The extreme degree to which birds can tolerate mutilation of their wings, by the removal of large primary-feather and other areas, strongly suggests that the exact cross-sectional or plan form of a natural wing may be of less importance than its vesicular surfacing.

Having regard now to Figures 15 and 16, these are designed to illustrate schematically this principle of vesicular sustention. For, if the wing section 40, of Figure 15, be conceived to occupy, as shown, the situation of a piston in the tube 41, which is to be assumed to fit closely against all edges of the wing, then removal of the air at 42 must allow the atmospheric pressure at 43 to exert, as just suggested, its full value of over a ton to the square foot against the underside of the wing 40. The top of the tube 41 is left open, to make it clear that any removal of the air at 42, above the wing, must result in its powerful support upon the air below it, at 43, as explained, whether or not additional air, above 42, be removed. In other words, with an indefinite amount of air above the wing any local removal of a zone or layer of it must result in at least momentary sustention just as positively as permanent sustention would result if the top of the tube 41 were sealed and the air in it at 42, above the wing 40, completely abstracted.

Consequently, evacuation of air from the entire vesicular top surface 44, of the wing 40 would be theoretically an effective means wherewith to secure an enormous sustention.

Of course, a perfect vacuum is impossible to create by any means, particularly with such a feeble dynamic air pump as that constituted of even the best vesicular surface cavities partially emptied of air, by the principle of the atomizer, through the effect of the relative airflow traversing them. But the practical value of even a feeble effect will be perhaps better appreciated, or more easily visualized, when it is considered that, with normal atmospheric pressure capable of balancing the weight of a column of water nearly 34 feet high, an average vacuum in a vesicular surface of only 3.4 inches of water is adequate to the sustention of the heaviest wing loading known to modern aeroplane practice, while only one half inch of water is equivalent to the suggestion of the heaviest-laden bird.

It is not to be overlooked, in the highly-schematic condition hypothecated in Figure 15, that any sustension due to vesicular vacua could exist only momentarily unless inflow of air into the vesicles or cells through their necessarily free or open surfaces, contacting with the atmosphere, were accompanied by reevacuation of the vesicles as fast as they might fill up. But, in the condition of actual flight, this is exactly what occurs as long as flight continues, because flight must involve the presence of the relative wind—the pumping jet of the atomizer.

With a wing such as 40, Figure 15, not open vesicular-surfaced beneath, there result high skin friction and the evil effects of boundary-layer detachment and turbulence on the lower side.

But with open vesicular or cellular surfacing beneath, as at 46, of the wing 45, Figure 16, as well as at 44, above and with equal evacuation of all the vesicles there would be as much down pull as up. So, in this case, with open vesicles or cells on the underside as well as the top side of the wing, the only support that come from attenuation of the air within the vesicles or cells must be gained from a differential effect—from a greater attenuation in the vesicles or cells above than exist in the vesicles or cells below.

Hence all attenuation in the underside vesicles or cells is obviously directly adverse to sustention, but its favorable effect upon skin friction, and consequently upon the adherence of the boundary layer, and so as a means of avoiding turbulence, introduces compensatory advantages which contribute to that portion of the total sustension which is derived from changing the direction of the airflow, as by the rarefied region 25, Figures 1, 2, 3, and 4—a factor in sustention that of course is not eliminated by the addition to it of the heretofore unknown suction effect, introduced by the application of the open vesicular or cellular surface.

Thus the phenomena of sustention by a vesicular-surfaced wing entail conditions in several respects quite different from sustention by heretofore-established artificial means. In the investigations, hereinbefore referred to, which I have made into gliding-bird flight, I have ascertained that speeds of gliding bird flight generally have been much overestimated, and that given wing loadings of birds, referred either to area or span, are very greatly higher than the corresponding pressures against normal surfaces, of equivalent area and shape, at similar wind velocities, or against any known airfoil sections, of similar sizes at similar speeds. Moreover, once the airspeed is such that there is sustention of the load, further increase in speed must necessarily increase the attenuation of the open vesicle or cell contents proportionately. Hence the principle effect of each further increment of vesicle or cell evacuation, with higher speed, may be to reduce further the skin-frictional resistance to such speed, instead of increasing it with the 1.85 power of the velocity, as has been found to be the case over smooth surface. And the dual consequence is that, while operation at a very low minimum speed is consistent with secure sustention of the load, without possibility of stall as it now occurs at the extreme angles of incidence which always are resorted to for the lowest speeds; yet a high maximum speed does not seriously increase resistance.

There thus is conferred upon an aeroplane, by the application of my invention—in addition to all the advantages of highly-efficient low-power operation, and other advantages—an extension of the range from minimum to maximum speed far exceeding that at present available for artificial flight, and so correspondingly advantageous in its bearings upon safe starting and alighting.

In the final illustration, Figure 19, in which the vesicular or cellular surfacing at 31, is shown placed over the openings 32 into the hollow cylinder 33, to which is affixed the glass tube 47, thus dips into the vessel of liquid 48. With this arrangement, the relative airflow at 49 partially evacuates and thereby causes a partial vacuum within the cylinder 33, such vacuum being demonstrated and measured by the extent to which the liquid rises, as to 50, into the glass tube, above the level 51 in the vessel 48. The adherence of the airflow 49 to the cylinder, to the point 53, is due to the suction effect it produces within 31, and is to be contrasted with the detachment of the boundary layer of the airflow 49, at 54, due to the absence of vesicular or cellular surfacing from the underside of the cylinder.

As shown in the drawings, and as described throughout this specification and claims, I use the terms vesicle or cell to describe and include any type of rarefied-air-containing open pit, pocket, pore, perforation, or honeycombing of a surface, or any substantially-equivalent structure of ciliate, piled, barbellate, or vascular surfacing, which will similarly, by the action of the relative wind or airflow, entrap, retain, contain, enclose, or carry along with itself a layer of relatively rarefied air, sliding in contact with the higher-pressure air of the relative wind or airflow.

It is to be understood that the foregoing figures are illustrative of only a few of the best modifications of my discovery or invention and that structures embodying the spirit of my discovery or invention, such as ones in which maximum efficiency has been sacrificed to reduce manufacturing complications, or to favor the most economical and rugged constructions, may be made within the scope of the appended claims without departing from the essential features of my invention.

Having thus described my invention, what I claim is:

1. In a covering for aircraft, a layer of material having open vesicules or cells therein, and a freely-permeable covering therefor.

2. In a covering for aircraft, a layer of material having open vesicules or cells therein and a freely-permeable covering therefor,

the perforations of the permeable covering being preferably less in size than the openings of said vesicules or cells.

3. In a covering for aircraft, a layer of material having open vesicles or cells therein, the vesicles or cells being substantially sealed from each other, the depth of said vesicles or cells being preferably substantially greater than the diameter thereof; and a freely-permeable covering therefor, the perforations of said permeable material being substantially less than the openings of said vesicles.

4. In a wing for aeroplanes, the combination of a supporting structure having an airfoil cross-section with upper and lower surfaces, portions or the entirety of both of said surfaces having a sub-surface substantially impermeable to airflow and a layer of material thereover, said layer being substantially impermeable to airflow therethrough in a direction parallel to the sub-surface and freely permeable to airflow in a direction substantially perpendicular to said sub-surface, whereby a layer of attenuated air is retained within said layer as the wing is propelled through the atmosphere.

5. In a wing for aeroplanes, the combination of a supporting structure having an airfoil cross-section with upper and lower surfaces, all or any portion of either or both of said surfaces having a sub-surface substantially impermeable to airflow, and a layer of material thereover, said layer being substantially impermeable to airflow therethrough in a direction parallel to the sub-surface and freely permeable to airflow therethrough in a direction substantially perpendicular to the sub-surface, the thickness of said layer being substantially greater than the porosity thereof, whereby a layer of attenuated air is retained within said layer when the wing is propelled through the atmosphere.

VICTOR LOUGHEED.