

Description

Background of the invention

There are many applications where it is desired to have a low drag method of delaying or preventing flow separation between a flowing fluid and a flow-control surface in regions where, due to contours of the flow-control surface, the fluid's boundary layer is subjected to adverse pressure gradients normally sufficient to cause flow separation.

The purpose of such boundary layer control is to delay or prevent flow separation. When a viscous fluid boundary layer flows from a region of low static pressure to a region of high static pressure, as when passing over a wing toward the trailing edge, it is said to be in a region of adverse pressure gradient. This results in forces tending to retard the boundary layer which can become strong enough to arrest and reverse the flow. This in turn causes the fluid to separate from the flow-control surface and no longer be influenced predictably by the downstream contour. The result is increased drag due to the large cross-sectional area of separated flow in the wake of the flow control surface. In the case of a stalled wing, degraded lift is accompanied by a rise in drag.

One useful but relatively high drag method heretofore used is to generate streamwise vortices for the purpose of mixing free-stream flow with the boundary layer to delay or totally prevent flow separation. Generally, there are two categories of vortex generators. The first category covers those devices that protrude well into and usually somewhat above the 99% boundary layer height. Included in this category are conventional vane-type vortex generators as well as prior art ramp-type generators of varying planform shapes. Unfortunately, these devices achieve boundary layer control only at the penalty of considerable drag. An example of the ramp-type vortex generator is shown in Stephens, U.S. Patent US-A-2,800,291 forming the basis of the preamble of claim 1. Stephens teaches the use of ramp-type generators positioned in rows at right angles to the flow with the generators extending back to some intermediate position on the flow-control surface.

The second and less familiar category of vortex generators uses the "Taylor-Goetler instability" to generate streamwise vortices within the boundary layer when a fluid is caused to flow over a concave surface. This alternative is more subtle, but the vortices are still left to travel downstream on the primary flow-control surface, causing turbulent mixing between the boundary layer and the free-stream and resulting in an unwanted drag increment. Devices of this category are disclosed by Kueth in U.S. Patents US-A-3,578,264 and US-A-3,741,285. Kueth teaches selected discontinuities positioned both above and below the level of the adjacent flow-control surface which in effect squeeze the boundary layer between adjacent protrudences to eject a vortex into the boundary layer and cause mixing.

It is unfortunate that the prior art vortex generators either operate relatively ineffectively or cause an excess in drag since devices are needed which enable the turning of air flows about sharp cambers. Normally, conventional attempts to reduce the wake and hence the drag of a body moving with respect to a fluid medium by mere curved and tapered body contours in the rear result in pressure recovery regions that are limited by flow separation occurring in the regions of adverse pressure gradients. The flow separation in such instances normally occurs downstream of a body's maximum cross-section.

For example, road vehicles, which are designed for low drag must include very gentle rear deck curvatures to maintain attached flow over a substantial region behind the maximum cross-section. Except in the instance of specially constructed high-speed race cars, full recovery cannot be achieved in the length available on roadable vehicles. A Porsche 924, which is a well streamlined vehicle still has a coefficient of drag (C_D) of approximately .35. If all the wake drag caused by flow separation could be eliminated, the C_D could approach .25 and result in a considerable fuel savings or speed capability. For comparison, a utilitarian car, such as a Volkswagen Rabbit, (where there is very little attached flow past the maximum cross-section) has a C_D of about .45. Elimination of the wake drag caused by flow separation could in theory reduce the C_D to about .30 with no other changes to the vehicle. Although there have been countless attempts to reduce the drag of road vehicles by maintaining attached flow, considerations such as structural weight and aesthetics restrict the length of road based vehicles to such an extent that at some point the body contours must be so abrupt that adverse pressure gradients occur. These produce flow separations which generate a relatively large separation wake. The wake is aerodynamically disadvantageous causing drag and increased fuel consumption especially at higher cruising speeds. This heretofore unavoidable wake is the reason visibly streamlined road cars have heretofore exhibited only small drag advantages over properly designed vehicles with bluff or abrupt tails.

Some vehicles have used wing-like airfoils as turning vanes to assist in directing external flow to reduce the adverse pressure gradients. However, the mass flow of air moved by these add-on devices never comes close to filling the large wake behind a body proportioned like a normal road vehicle. Therefore, the effect is helpful but minor.

There have been suggestions that the application of powered suction at discrete locations near the rear of a vehicle might provide a method for achieving wake reduction. However, wind tunnel studies show that the power required by such suction systems rivals the amount needed to power the original standard vehicle and therefore does not accomplish the overall result of reducing the total energy requirement of the vehicle. If a method could be found to reduce the energy

required to move a poor slenderness ratio body through the air by providing means to maintain attached flow in the areas of adverse pressure gradients, the reduced energy requirement would translate directly into reduced fuel consumption.

As reported in NACA Research Memorandum, A8F21 entitled "An Experimental Investigation of a Large Scale of Several Configurations of a NACA Submerged Air Intake", published 19 October, 1948, devices are known for generating strong vorticity by passing flow over the sharp corners of the intersections between channel walls and a reference body surface adjacent an inlet ramp surface. Typically, NACA inlets have a ramp surface of generally V-shape which extends to an inlet duct lip thereabove and is bounded on the opposite sides by reflexed sidewalls extending upwardly to the body surface at approximately 90°. However, since all NACA inlets are intended to be inlets for rectangular cross-section intake ducts, their sidewalls must become parallel to the connecting duct sidewalls, hence the reflex and inlet duct lip must be carefully designed. The inlet lip forms the beginning of a fourth wall for the duct at the location of flow entry into the vehicle. The planform of a NACA inlet is always defined by the chosen ramp angle, that is, the included angle between the flat ramp floor and the body's external body surface. The length of the NACA inlet is always a direct result of that choice of angle. This grossly reduces the design choices available, especially when it is desired to reduce the aerodynamic drag of a body having a poor slenderness ratio.

The NACA inlets were designed to be located in regions of positive pressure since their purpose is to take air on board a vehicle, either to provide combustion air to an engine, flow to a heat exchanger or simply provide ventilation. NACA inlets are known to perform poorly in regions of great negative static pressure. NACA inlets are never used for the purpose of influencing external flow conditions on a basic body, other than to take in air and have never been used for the purpose of achieving aerodynamic drag reduction for a body passing through a flowing medium.

Therefore, even though various types of devices are known which produce vortices, none are effective in assuring attached flow in an adverse pressure gradient region with low drag. Brief description of the present invention

Generally, the present invention is embodied in the provision of nested triangular channels or ridges in a flow-control surface as defined in the claims below. The intersection between the flow-control surface adjacent the channels or ridges and the divergent wall preferably has a sharp radius of near 90° to generate strong vortices which rotate toward each other. The vortices energize the flow in the channel maintaining flow attachment to the ramp thereof and also maintaining flow attachment to the flow-control surface upstream and beside the channel. The channels or ridges themselves are aligned generally with the direction of local flow in front of

the V-point thereof and to function most efficiently, the front of the channel should be at least adjacent a region where attached flow would exist if the channel was not present. The exit of the last of the nested channels are preferably positioned at or near the rearmost edge of the flow-control surface to release the flow at a revised height or width and thereby effect a reduction in wake cross-section area.

The present invention assures boundary layer control on the flow-control surface through simple thinning of the boundary layer with dynamic turbulent mixing between vortices, boundary layer, and the free-stream fluid constrained within the submerged channels to prevent adverse drag.

As is known, there is a tendency of a fluid to form a strong vortex when caused to flow over a sharp edge at an appropriate angle. This phenomenon is seen along the sharp leading edges of delta wings at high angles of attack. In the present invention, the submerged channels have a nominally triangular planform shape permanently formed into the flow-control surface. These channels have sharp upper edges for effective vortex formation, divergent sidewalls essentially normal to the flow-control surface, and floor contours arranged to immediately conduct the streamwise vortices below the level of the local flow control surface. The nesting of the submerged channels creates a streamwise cascade, new vortices can be generated downstream as often as required to replace vortices generated upstream which are about to burst and degenerate because of a strong adverse pressure gradient.

Vortex bursting is characterized by a sudden and pronounced increase in vortex diameter followed by disintegration and decay. This natural phenomenon normally would occur downstream of the flow-control surface's trailing edge. However, as the amount of adverse pressure gradient is increased, the location of vortex bursting moves forward until it coincides with a trailing edge. At this stage, the maximum effect of the invention is realized. Any further increase in adverse pressure gradient simply drives the vortex bursting location farther forward toward the vortex source and causes flow separation upstream of the trailing edge. As a consequence, and because pressure recovery requirements are frequently most severe toward the trailing edge of a flow-control surface, the use of the present invention is very effective. Such extreme adverse pressure gradients are encountered for example at the rear of a roadable vehicle, the aerodynamic tunnel of a ground-effects race car or the aft fuselage of a rear loading cargo aircraft.

The invention has application to prevent flow separation from a flow-control surface in, for example aircraft wings, flaps or propellers, a windmill blade, airfoil, fan rotor, stator, inlet, diffuser or the inside radius of bends in pipes, ducts and engine ports. The invention can also be used to provide means to facilitate aggressive boat-tailing at the rear of a poor slenderness ratio

body such as a commonly shaped automobile, aircraft, golf driver club, or boat where considerations such as interior volume and restricted length make effective rear end streamlining impossible. By use of the invention the need for long tapered streamlined tails on vehicles is reduced while decreasing the drag of the vehicle and thereby eliminating the attendant penalties of length, weight and wetted area of streamlined tails. It can be used to reduce aerodynamic drag of bodies immersed in a flowing medium when such bodies have poor slenderness ratios. A further advantage is that the aerodynamic improvement for example when applied to conventional land vehicles is versatile enough to be blended into various styling themes and therefore provide a pleasing appearance as well as an increased efficiency for the vehicle.

The present invention will now be illustrated by a detailed description of a number of embodiments and with reference to the accompanying drawings wherein:

Brief description of the drawings

Figure 1 is a perspective view of a single submerged channel showing how two vortices are formed thereby;

Figure 2 is a perspective view of a series of submerged channels embedded in a flow-control surface including indications of the fluid flow thereabout;

Figure 3 is a perspective view of a wing segment including a spanwise array of submerged channels nested in cascade;

Figure 4 is a rear view of the wing segment in Figure 3;

Figure 5 is a typical spanwise cross-sectional view of the wing segment of Figure 3;

Figure 6 is a perspective view of an airfoil constructed with an alternate form of submerged channels nested in cascade;

Figure 7 is a rear view of the airfoil of Figure 6;

Figure 8 is a typical spanwise cross-sectional view of the airfoil of Figures 6 and 7;

Figure 9 is a diagram of typical planform shapes for submerged channels;

Figure 10 is a lateral cross-section of an alternate form of channel having lips that protrude into the boundary layer;

Figure 11 is a perspective view of a motor car showing the application of the present invention to maintain attached flow and thereby eliminate flow separation from the rear thereof;

Figure 12 is a rear view of the automobile of Figure 11;

Figure 13 is a top plan view of the automobile of Figure 11 and 12;

Figure 14 is a side view of a ground effects racing car;

Figure 15 is a rear view of the racing car of Figure 14 showing the application of the present invention to the ground effect tunnels thereof; and

Figure 16 is a side elevational view of the rear bumper area of a production motor car with the present invention incorporated therein.

Detailed description of the shown embodiments

The principle of vortex generation is illustrated in Figures 1 and 2. In Figure 1 a channel 20 is submerged in a flow-control surface 22 of a body 24. The channel 20 includes a pair of sidewalls 26 and 28 which are generally perpendicular to the surface 22 and converge toward each other as they progress upstream to the flow of fluid medium 30. The sidewalls 26 and 28 form relatively sharp edges 32 and 34 respectively, with the surface 22. This generates a pair of counter-rotating vortices 36 and 38 from the flow 30 which passes thereover. The channel 20 is bounded at its bottom by a lower triangular surface 40 which in cross-section is generally parallel to the surface 22, but in length extends from beneath the flow-control surface 22 upwardly to a point of intersection 42 therewith at the upstream end of the walls 26 and 28. The intersections 43 between the sidewalls 26 and 28 and the floor surface 40 are shown with sharp radii but radii up to the radii of the local radii of the adjacent vortex 36 or 38 can be used. As shown, the edges 32 and 34 have an ogee shape and the height of the walls 26 and 28 at any location therealong and hence the distance the lower surface 40 is from the surface 22 at any point is designed so that the vortices 36 and 38 preferably are completely submerged within the channel 20 to prevent drag. As can be seen from the flow arrows 44, the vortices 36 and 38 tend to thin the boundary layer keeping attached flow on the surface 22 and on the floor surface 40 of the channel 20.

A different visualization of this process is shown in Figure 2, wherein a plurality of channels 20 are provided submerged in a body 46. The vortices 36 and 38 of opposite rotations, vortex 36 rotating clockwise and vortex 38 rotating counterclockwise as viewed to the upstream, are formed by drawing flowing fluid from the lowest portion of the boundary layer of the flow-control surface 48. This causes the boundary layer to thin as the flow follows the streamlines indicated by the arrows 50 which generally curve into the channels 20. An increase in space between adjacent streamlines as the flow progresses downstream indicates a thinning of the boundary layer which protects against flow separation such as might be caused by regional adverse pressure gradients. The streamlines indicated by the arrows 52 and 54 do not curve because of their symmetrical position with respect to the apices 56 of the channels 20 in the case of arrows 52, their symmetry between adjacent channels 20 in the case of arrows 54. If the channels 20 are to be divided by an aerodynamic fence, not shown, it should be run along the length of arrows 52 or 54.

The vortices 36 and 38 travel downstream within the channels 20 adjacent the channel walls 26 and 28 effecting boundary layer control on the channel walls 26 and 28 and the floor surfaces 40 through dynamic turbulent mixing. The local flow velocity on the channel floor surface 40 is maintained at a very high percentage of free-stream velocity and the flow is well protected against incipient separation.

Although streamwise vortices have a low rate of viscous decay, they are subject to a natural mechanism of breakdown that begins with an abrupt bursting or expansion of the vortex diameter, after which the vortex is no longer effective in terms of boundary layer control. As explained previously, the actual location of this bursting point is dependent upon the regional adverse pressure gradient. If the adverse pressure gradient is large enough, it is possible to burst the vortices 36 and 38 soon after they are formed within the channels 20.

Figure 3 shows an arrangement embodying the invention. One or more similar channels 57 are nested within the channels 30, thereby forming a flow-wise cascade in an airfoil segment 58 to counteract any tendency for the vortices to burst. With this nested geometry, discrete new streamwise vortices 60 and 62 are generated from fluid drawn off the floor surface 40 of the preceding channel 30. The general flow streamlines are analogous to those shown in Figures 1 and 2. These freshly generated vortices 60 and 62 are usually as strong as the original vortices 36 and 38. They effect boundary layer control further downstream because they are formed farther aft and therefore can resist bursting further aft along the airfoil segment 58. The channels 57 have sidewalls 64 and 66 similar to sidewalls 26 and 28, floor surfaces 68 which intersect the floor surfaces 40 of the channels 30 at their apices 69, and edges 70 and 72 similar to the edges 32 and 34. This can be further visualized by reference to Figures 4 and 5. The cascade concept shown in Figures 3, 4 and 5 is particularly useful because the vortices 60 and 62 in the downstream channels 57 maintain full boundary layer control effectiveness even if the previously generated vortices 36 and 38 were subject to bursting as far forward of the trailing edge 74 of the airfoil segment 58 as the aft termini 76 of the sidewalls 26 and 28. It should be noted, that the aft termini 76 of the walls 26 and 28 are relatively sharp and streamlined for a low drag release of the vortices 36 and 38 formed adjacent thereto. To be most effective in preventing vortex bursting and the large drag penalty associated therewith, it is preferable that the aft termini 78 of the walls 64 and 66 of the last channels 57 in the cascade be at or closely adjacent the trailing edge 74. Of course, this is not required when a negative pressure gradient sufficient to cause the vortices 60 and 62 to burst will never be present at the trailing edge 74 under the expected operating conditions.

In Figures 6, 7 and 8, an alternate form of submerged vortex generating channels nested in cascade is shown in connection with an airfoil segment 90. In the form illustrated, three channels 92, 94 and 96 are positioned in each cascade 97a, 97b or 97c with each channel 92, 94 and 96 having sidewalls 98 and 100, 102 and 104 and 106 and 108 and floor surfaces 110, 112 and 114 respectively. The channels 92, 94 and 96 are similar to channels 20 and 57, except that the floor surfaces 110 and 112 are reenterant with the flow

control surface 116. This arrangement of the floor surfaces 110, 112 and 114 has proved to function at least as well as the embodiment shown in Figures 3 through 5 and offers possible advantages in areas such as structural integrity, manufacturing cost, and aesthetics.

There is a well known tendency of adjacent streamwise vortices of the same sign of rotation to join and roll into a single vortex sheet. This form of the invention uses that tendency to good effect. The vortices 118 and 120 of the channel 92, tend to roll over the adjacent edges 122 and 124 of the adjacent channel 94 to join with the vortices 126 and 128 generated thereby and to form combined vortices 130 and 132. In so doing the vortices 118 and 120 do not stick up into the adjacent flow field to cause undue drag. The vortices 130 and 132 likewise have a tendency to roll over the adjacent edges 134 and 136 respectively of the channel 96 to combine with the vortices 138 and 140 generated thereby and to form combined vortices 142 and 144. Although this is shown for the case of three channels 92, 94 and 96, it can be repeated as often as desired to extend the benefits of boundary layer control from the leading edge 146 to the trailing edge 148 of the airfoil segment 90, should such be necessary.

The nominal included planform angle between the divergent walls 26 and 28, 64 and 66, 98 and 100, 102 and 104 or 106 and 108 should be near 30° although generally good results are obtainable between 15 and 45 degrees. At narrower included angles, vortex formation is strong but the vortices within a particular channel tend to touch and because they are rotating in opposite directions one may roll above the other in an asymmetric manner extending into the surrounding flow and causing drag and unstable performance. Conversely, when the included angles are too wide, vortex formation tends to be weak leading to potentially premature vortex bursting.

Since the flow-control surface, 22, 48 or 116 and the channel floor surface 40, 68, 110, 112 or 114 may be highly cambered from front to rear, it is not appropriate to refer to a simple angle between the channel floor surface 40 and the flow-control surface thereabout. However, the channel floor contour is fundamentally important because the rate of expansion of channel volume must not be so great as to cause flow separation within the channel. Therefore, abrupt changes in depth or cross-sectional areas of the channel 20, 57, 92, 94 or 96 are to be avoided. As a guide to contouring the channel floor the local depth at any channel station should not be made greater than half the local planform width because two rolled up sheet vortices must be accommodated side-by-side within the confines of the channel. Said another way, the minimum cross-section aspect ratio ($\text{width}^2/\text{area}$) is approximately 2. In general, cross-section aspect ratios of 3 and above provide excellent protection from choosing a floor contour so radical as to cause flow separation in the channel itself.

As will be discussed hereinafter, the walls 26 and 28, 64 and 66, 98 and 100, 102 and 104, or 106 and 108 need not be at right angles to either the flow-control surface or the channel floor. Therefore, when the channels are to be stamped or molded, very large draft angles are tolerable. It is also acceptable to radius the intersections such as intersections 43, of the channel walls and floor with radii no larger than the outer radius of the local vortex.

Figures 6, 7 and 8 illustrate a specific example of a modified Liebeck airfoil segment 90 which was tested in a wind tunnel. The particular modified Liebeck airfoil section was chosen for the airfoil segment 90 because of its known high-lift and low-drag characteristics. A 25 cm (10") chord, 41 cm (16") span wing without end plates was suspended at the center of the wind tunnel and tested at 12 m/sec (38 ft/sec.) wind speed. The low Reynolds number of 200,000 was chosen because of an interest in a high-performance windmill blade application. To insure satisfactory vortex formation at air speeds as low as 24 Km/h (15 mph), each channel was made 15 cm (6") in length. The modified wing was built with five span-wise rows, each containing six submerged vortex generating channels nested in streamwise cascade similar to that shown in Figure 6. The clean wing yielded a maximum 3-D lift coefficient of 1.03 at an angle of attack of 16°. The wing modified with the present invention developed a maximum 3-D lift coefficient of 1.48 at an angle of attack of 26°. This is a very high three-dimensional lift coefficient considering the test wing's aspect ratio was only 1.6.

At lower angles of attack where neither wing experienced detectable flow separation, the modified wing exhibited a lift/drag advantage ranging from 14% greater lift at equal drag, to 20% less drag at equal lift. The 99% boundary layer, is the thickness of the boundary layer at which the relative velocity between the surface and the fluid is 99% of that of free-stream. At the trailing edge of the unmodified wing the 99% boundary layer was 1.6 cm (.62") thick. However, along the modified wings trailing edge, the 99% boundary layer was only 0.8 mm (.03") thick. Therefore, the tests showed that effective delay of flow separation by thinning the boundary layer can be achieved with the present invention without the drag increment normally associated with the prior art devices.

Figure 9 illustrates several typical planform contours useful with the present invention, including an ogee contour 160, a straight triangular contour 162, a convex triangular contour 164 and a concave triangular contour 166. The contours 160, 162, 164 and 166 are only typical of possible shapes. However, the ogee contour 160 seems to have advantages in that the forward portions 168 of its sidewalls 169 and 170 fair easily into the adjacent surface 171, the trailing portions 172 of the sidewalls 169 and 170 fair into an adjacent channel or the trailing edge 173 at a very small included terminus angle, and its

center portion 174 has a sufficient angle with respect to the normal flow direction, as indicated by the arrow 176, or flows off angle therefrom, to produce the strong vortices desired.

In Figure 10, a channel 180 is shown whose sidewalls 181 and 182 upper edges 183 and 184 are in the form of upwardly extending lips which protrude above the adjacent flow-control surface 186. Such lip structures even with the rounded edge cross-sections 188 and 190 tend to have greater drag than fully submerged and sharp geometries. Nevertheless, they are quite functional for use when structural or molding considerations do not allow sharp edges, like edges 32 and 34 of the preferred cross-section. As shown, the intersection 192 and 194 of the sidewalls 181 and 182 with the floor surface 196 is also rounded. As aforesaid, this does not adversely affect the performance of the channel 180 so long as the intersection 192 and 194 do not extend more than halfway up the walls 181 and 182.

A practical example of the present invention's ability to maintain attached flow in an extreme adverse pressure gradient situation is shown in Figures 11 through 13. Figure 11 is a perspective view of a detailed 1/10th scale wind tunnel model, 200 of a Gas Camel automobile (trademark of Daniel S. Gurney, Newport Beach, California) employing the present invention in the form of channels 202, 204 and 206 on the opposite sides of the model. The channels 202, 204 and 206 which are similar to the channels 92, 94 and 96 of Figure 6, are positioned on the opposite rear fenders 208 and 210 of the model 200, in order to permit radical "boat-tailing". In this instance, the choice of size for the channels 202, 204 and 206 was largely one of aesthetics, they in fact being large enough to generate vorticity below 8 Km/h (5 mph) on a full-sized car. The radical extent of the "boat-tailing" accomplished in just 0.9 m (3') of scale rear-axle overhang is shown in Figure 13. Upon reaching the rear license plate area 212 of the model 200, the flow on each side of the model is turned through 65°. Although it is difficult to see, the floor surfaces 213 and 214 of the channels 202 and 204 are not parallel to the flow-control surface 215 thereabout or the floor surface 216 of the channel 206. The angle chosen tilts the edges 217 and 218 of the channels 204 and 206 upwardly into the 3-D airstream in channels 202 and 204 to assure vortex formation. This is especially important in the lower half of the channels behind the rear wheels 219 which disturb the flow and make vortex formation difficult.

Wind tunnel tests at a Reynolds number of 600,000 verified the maintenance of fully attached flow to the rear area 212 of the model 200. Since the rear area 212 had an area reduced to little more than the cross-sectional area of a rear license plate, there was a large reduction in the wake of separated flow behind the model 200. If the flat rear license plate area 212 was not legally required, the opposite rear fenders 208 and 210 could have been merged together in the form of a



tiny stinger 212a as shown in dotted outline in Figure 13, for still lower drag.

The model 200 as pictured, yielded a drag coefficient $C_D = .157$ when no air gaps were present between the tires and the ground plane. For comparison, when the channels 202, 204 and 206 were filled in and faired so as to be removed, the drag of the model 200 rose nearly 30% to $C_D = .203$. The model 200 with the channels 202, 204 and 206 was yawed up to 40° in the wind tunnel without provoking flow separation on the downwind flank. This presented the interesting spectacle of flow on the downwind side of the yawed model 200 leaving the rear 212 in a direction that was literally 15° upstream.

When a duplicate model without the channels 202, 204 and 206 was given a long tapered tail in an attempt to equal the low drag achieved by the channels 202, 204 and 206, a rear axle scale overhang of 1.5 m (5') was required to provide sufficient pressure recovery zone length for attached flow to be maintained to the same size rear area 212. However, the boundary layer was quite thick and the best C_D that could be obtained was .162 making it appear that the conventionally streamlined, long-tailed model could not be made to equal the low drag of the model 200. Furthermore, 20° of yaw angle would provoke flow separation on the downwind side of the long tail indicating comparatively poor aerodynamic stability in cross winds. These tests show that in some instances, the drag increment of the present invention may be less than the viscous friction that would exist on the long flow-control surface which they can replace. This would suggest applications in the aircraft industry where it may be possible to better the drag performance and reduce fuselage tail structure and weight by using the present invention.

In full-scale tests, using a stock 1980 Volkswagen diesel pickup truck, a camper shell was constructed with an array of individual channels 30, as shown in Figure 2, which commenced at the shell's upper surface immediately behind the truck's roof. The upper surface of the shell was then curved downward 30° over the bed of the truck to terminate at tailgate height. Tufts verified the flow was attached to all surfaces. Despite a severe induced drag penalty due to lift, the C_D fell from the .49 of a stock truck and the .47 of a commercially available streamlined fiberglass shell to .42 allowing the otherwise stock truck to give over 2.56 l, per 100 Km (60 mpg) in steady state cruise at 89 Km/h (55 mph). The unwanted lift and drag increment, which in this case arose from the use of an upper surface for boat-tailing, could have been avoided by simply utilizing flow control surfaces of aerodynamic symmetry, such as the rear fenders 208 and 210, as shown in Figures, 11, 12 and 13.

Although side-by-side cascades of channels have been shown herein, there are some applications where endplates positioned along the streamlines indicated by the arrows 54 or 52 can be used. Figures 14 and 15 illustrate such a case

wherein a ground effects race car 220 is pictured. Such cars 220 use aerodynamic tunnels 222 and 224 positioned on each side of the driver 226 and the engine 228. Each tunnel has a top surface 230 contoured away from the road surface 232 to generate low static pressures underneath the car 220 between two sidewalls 234 and 236. The top surfaces 230 of the tunnels 222 and 224 act as flow control surfaces which face the road surface 232 and their effect is to improve the tire to road adhesion in much the same manner as also is achieved by the use of inverted airfoils 238 and 240.

The flow through the tunnels 222 and 224 is subject to pressure gradients so severe that heretofore separation inevitably occurred near the rear axle 242. This prevented predictable flow from reaching the trailing edge 244 of the tunnel ceiling surface 230, thereby creating a large drag wake and less down-force than was desired requiring the use of the rear auxiliary wing 238 with its attendant further increase in drag of the car 220. The vortex generators of the prior art have been tried in the tunnels 222 and 224 in almost every conceivable arrangement with such poor results that they now are seldom seen.

Figures 14 and 15 are views of an actual 1/10th scale wind tunnel model of the 1982 Indianapolis Eagle planned to be manufactured by All American Racers, Inc. of Santa Ana, California. The model included the channels 92, 94 and 96, shown in Figure 6 with one cascade 245 in each tunnel 222 and 224, the end plates 234 and 236 acting as outer edge end plates for the cascades 245 and the engine and transmission fairing sidewalls 246 and 248 acting as inner edge end plates. The model of the car 220 was tested with and without the channels 92, 94 and 96. Regardless of the ride height, the model without the channels, 92, 94 and 96 suffered flow separation from the ceilings of the tunnels near the area of the rear axle 242. The flow exited the tunnels in a discrete stream positioned midway between the ground surface and the trailing edge of the tunnels. With the model of the car 220 was equipped with the channels 92, 94 and 96, tufting and local total head readings showed fully attached flow had been established over the entire lengths of the tunnels 222 and 224. The result was that the downforce increased over 25%, while the downforce to drag ratio was improved 7%, meaning that a car built like the model with less horsepower will be faster both in the corners and on the straightaways if the present invention is included therein.

In Figure 16, channels 300, 302 and 304 similar to the channels 202, 204 and 206 in Figures 11 through 13 are shown applied to modify an existing car 306 whose rear end 308 exists with an unfavorable height 310 so that as the channels 300, 302 and 304 camber around the rear end 308, the floor surface 312 of the last channel 304 must become unacceptably wide. To assure that separation does not occur on the floor 312 a pair

of walls 314 and 316, similar to those shown between the dotted lines 317 in Figure 7, are employed to generate vortices and prevent flow separation adjacent the sides of the license plate area 318 thereof. The effect is the creation of two half channels 320 and 322 like half of channel 96 of Figures 6, 7 and 8. The protruberance 324 out of the floor surface 312 formed by the two walls 314 and 316 can be blended into the styling of the car 306 and provides a convenient place to position tail lights 326.

Thus there has been shown and described vortex generating, flow separation preventing channels which can be used in numerous ways to improve the lift and drag characteristics of flow-control surfaces subjected to adverse pressure gradients or to eliminate surface structure otherwise required to avoid adverse pressure gradients, which fulfill all the objects and advantages sought therefore.

Claims

1. A substantially impervious body (58 Fig. 3) for movement relative to a fluid medium, and at least one first triangularly shaped channel (30) in the surface of said body, said first channel (30) having a first apex (56) at the upstream end of the first channel (30) and a first floor (40) between a pair of diverging walls (26, 28), the first floor (40) merging into said surface at the first apex (56) of the first channel (30), characterized in that there is provided a second channel (57), said second channel (57) emerging from said first channel (30) and having a second apex (69) at the upstream end of said second channel (57) and a second floor (68) between a pair of diverging walls (64, 66), the second floor (68) merging into the first floor (40) of the first channel (30) at the second apex (69) of the second channel (57) and the upstream end of the walls (64, 66) of the second channel (57) extending beyond the downstream end of the walls (26, 28) of the first channel (30).

2. The substantially impervious body of Claim 1, wherein there is provided a first series of said first channels (30) and further characterized in that there is provided a second series of said second channels (57), the apexes (69) at the upstream end of said second channels (57) merging with respect of ones of the first floors (40) of the first channels (30).

3. The body of Claim 2, further characterized in that the diverging walls (26, 28) of neighboring channels in said first series terminate at an edge (76).

4. The body of Claim 2, wherein the surface of the body (58) between said first series of channels (30) merge on to a surface defined between the walls (64, 66) of the second channel (57) downstream of the end of the walls (26, 28) of the first channel (30).

5. The body of any one of the preceding claims, wherein said walls are either straight, concave, convex or ogee in shape.

6. A substantially impervious body (58 Fig. 3)

having means to maintain attached a flow of a flowing medium to a flow control surface, said means comprising:

at least one first triangular shaped channel (30), said first channel having:

an apex portion (56) contiguous with said flow control surface and facing the flow of flowing medium;

an end portion (28);

a first floor portion extending from said apex portion (56) of said first channel to said end portion (28) of said first channel downstream from said apex portion (56) and spaced from said flow control surface (58); and

sidewalls (28) on each side of each channel between said first floor portion (40) and said flow control surface (56) from said apex portion (56) to said end portion; characterized by:

at least one second triangularly shaped channel (57), said second triangularly shaped channel (57) being submerged in the floor portion (40) of a corresponding first channel (30), said second channel having:

a second apex portion (69) facing the flow of the flowing medium;

a second end portion (68) positioned downstream in the flow of the flowing medium from said second channel apex portion (69);

a second floor surface (68) extending from the flow control surface at said second apex portion (69) to said second end portion;

a second channel first sidewall (66) extending between the flow control surface and said second channel floor surface (57), and extending between said second channel apex portion (69) and said second channel end portion, said second channel first sidewall (66) forming:

a second channel first sidewall edge between said second channel first sidewall (66) and the flow control surface, said second channel first sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said second channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a second channel second sidewall (64) extending between the flow control surface and said second channel floor surface (57), and extending between said second channel apex portion (69) and said second channel end portion (68), said second channel second sidewall forming:

a second channel second sidewall edge between said second channel second sidewall (64) and the flow control surface, said second channel second sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said second channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby first and second counterrotating vortices form over said second channel first and second sidewall edges in said second channel which thin

of walls 314 and 316, similar to those shown between the dotted lines 317 in Figure 7, are employed to generate vortices and prevent flow separation adjacent the sides of the license plate area 318 thereof. The effect is the creation of two half channels 320 and 322 like half of channel 96 of Figures 6, 7 and 8. The protruberance 324 out of the floor surface 312 formed by the two walls 314 and 316 can be blended into the styling of the car 306 and provides a convenient place to position tail lights 326.

Thus there has been shown and described vortex generating, flow separation preventing channels which can be used in numerous ways to improve the lift and drag characteristics of flow-control surfaces subjected to adverse pressure gradients or to eliminate surface structure otherwise required to avoid adverse pressure gradients, which fulfill all the objects and advantages sought therefore.

Claims

1. A substantially impervious body (58 Fig. 3) for movement relative to a fluid medium, and at least one first triangularly shaped channel (30) in the surface of said body, said first channel (30) having a first apex (56) at the upstream end of the first channel (30) and a first floor (40) between a pair of diverging walls (26, 28), the first floor (40) merging into said surface at the first apex (56) of the first channel (30), characterized in that there is provided a second channel (57), said second channel (57) emerging from said first channel (30) and having a second apex (69) at the upstream end of said second channel (57) and a second floor (68) between a pair of diverging walls (64, 66), the second floor (68) merging into the first floor (40) of the first channel (30) at the second apex (69) of the second channel (57) and the upstream end of the walls (64, 66) of the second channel (57) extending beyond the downstream end of the walls (26, 28) of the first channel (30).

2. The substantially impervious body of Claim 1, wherein there is provided a first series of said first channels (30) and further characterized in that there is provided a second series of said second channels (57), the apexes (69) at the upstream end of said second channels (57) merging with respect of ones of the first floors (40) of the first channels (30).

3. The body of Claim 2, further characterized in that the diverging walls (26, 28) of neighboring channels in said first series terminate at an edge (76).

4. The body of Claim 2, wherein the surface of the body (58) between said first series of channels (30) merge on to a surface defined between the walls (64, 66) of the second channel (57) downstream of the end of the walls (26, 28) of the first channel (30).

5. The body of any one of the preceding claims, wherein said walls are either straight, concave, convex or ogee in shape.

6. A substantially impervious body (58 Fig. 3)

having means to maintain attached a flow of a flowing medium to a flow control surface, said means comprising:

at least one first triangular shaped channel (30), said first channel having:

an apex portion (56) contiguous with said flow control surface and facing the flow of flowing medium;

an end portion (28);

a first floor portion extending from said apex portion (56) of said first channel to said end portion (28) of said first channel downstream from said apex portion (56) and spaced from said flow control surface (58); and

sidewalls (28) on each side of each channel between said first floor portion (40) and said flow control surface (56) from said apex portion (56) to said end portion; characterized by:

at least one second triangularly shaped channel (57), said second triangularly shaped channel (57) being submerged in the floor portion (40) of a corresponding first channel (30), said second channel having:

a second apex portion (69) facing the flow of the flowing medium;

a second end portion (68) positioned downstream in the flow of the flowing medium from said second channel apex portion (69);

a second floor surface (68) extending from the flow control surface at said second apex portion (69) to said second end portion;

a second channel first sidewall (66) extending between the flow control surface and said second channel floor surface (57), and extending between said second channel apex portion (69) and said second channel end portion, said second channel first sidewall (66) forming:

a second channel first sidewall edge between said second channel first sidewall (66) and the flow control surface, said second channel first sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said second channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a second channel second sidewall (64) extending between the flow control surface and said second channel floor surface (57), and extending between said second channel apex portion (69) and said second channel end portion (68), said second channel sidewall forming:

a second channel second sidewall edge between said second channel second sidewall (64) and the flow control surface, said second channel second sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said second channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby first and second counterrotating vortices form over said second channel first and second sidewall edges in said second channel which thin



the boundary layer of the flow of flowing medium at the adjacent flow control surface and provide turbulent mixing within said second channel so that the flow of the flowing medium remains attached to the flow control surface and said second floor surface.

7. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 6 further including:

at least two of said first triangular shaped channels; and

at least two of said second triangular shaped channels.

8. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 6 wherein said second triangular shaped channel is non-symmetrical to said first triangular shaped channel.

9. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 6 further including:

intersections between said sidewalls of said first channel and said floor surface thereof, said intersections having local radii not greater than one half the local elevation distance from said floor surface to the flow control surface.

10. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 6 further including:

at least one last triangularly shaped channel, said last triangularly shaped channel being submerged in the floor portion of a corresponding first channel, said last channel having:

an apex portion facing the flow of the flowing medium;

an end portion positioned downstream in the flow of the flowing medium from said last channel apex portion;

a floor surface extending from the flow control surface at said last apex portion to said last end portion;

a last channel first sidewall extending between the flow control surface and said last channel floor surface, and extending between said last channel apex portion and said last channel end portion, said last channel first sidewall forming;

a last channel first sidewall edge between said last channel first sidewall and the flow control surface, said last channel first sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said last channel first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a last channel second sidewall extending between the flow control surface and said last channel floor surface, and extending between said last channel apex portion and said last channel end portion, said last channel sidewall forming;

a last channel second sidewall edge between said last channel second sidewall and the flow control surface, said last channel second sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said last channel second sidewall central portion being positioned out of alignment with the flow of the flowing medium.

11. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 6 wherein the flow control surface has a trailing edge, said last channel second sidewall extending to the trailing edge of the flow control surface.

12. A substantially impervious body having means to maintain attached a flow of a flowing medium to a flow control surface, said means comprising:

at least one first triangular shaped ramp, said first ramp having:

an apex portion contiguous with said flow control surface and facing away from the flow of flowing medium;

an end portion;

a floor portion extending from said apex portion of said first ramp to said end portion of said first ramp upstream from said apex portion and spaced from said flow control surface; and

sidewalls on each side of each ramp between said floor portion and said flow control surface from said apex portion to said end portion; characterized by:

at least one second triangularly shaped ramp, said second triangularly shaped ramp being intersected by said apex of a corresponding first ramp, said second ramp having:

an apex portion facing away from the flow of the flowing medium;

an end portion positioned upstream in the flow of the flowing medium from said second ramp apex portion;

a floor surface extending from the flow control surface at said second end portion to said second apex portion;

a second ramp first sidewall extending between the flow control surface and said second ramp floor surface, and extending between said second ramp apex portion and said second ramp end portion, said second ramp first sidewall forming;

a second ramp first sidewall edge between said second ramp first sidewall and the flow control surface, said second ramp first sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said second ramp first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a second ramp second sidewall extending between the flow control surface and said second ramp floor surface, and extending between said second ramp apex portion and said second ramp end portion, said second ramp sidewall forming;

a second ramp second sidewall edge between said second ramp second sidewall and the flow control surface, said second ramp second sidewall edge having:



a forward portion;
a rearward portion; and

a central portion, said second ramp second sidewall central portion being positioned out of alignment with the flow of the flowing medium, whereby first and second counterrotating vortices form over said second ramp first and second sidewall edges in said second ramp which thin the boundary layer of the flow of flowing medium at the adjacent flow control surface and provide turbulent mixing within said second ramp so that the flow of the flowing medium remains attached to the flow control surface and said second floor surface.

13. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 12 further including:

at least two of said first triangular shaped ramps; and

at least two of said second triangular shaped ramps, said ramps being raised above the flow control surface.

14. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 12 wherein said second triangular shaped ramp is non-symmetrical to said first triangular shaped ramp.

15. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 12 further including:

intersections between said sidewalls of said first ramp and said flow control surface, said intersections having local radii not greater than one half the local elevation distance from said floor surface to the flow control surface.

16. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 12 wherein the flow control surface has a trailing edge, said means further including:

at least one last triangularly shaped ramp, said last triangularly shaped ramp having:

an apex portion extending to the trailing edge;
an end portion positioned upstream in the flow of the flowing medium from said last ramp apex portion;

a floor surface extending from the flow control surface at said last end portion to said last apex portion;

a last ramp first sidewall extending between the flow control surface and said last ramp floor surface, and extending between said last ramp apex portion and said last ramp end portion, said last ramp first sidewall forming:

a last ramp first sidewall edge between said last ramp first sidewall and the flow control surface, said last ramp first sidewall edge having:

a forward portion;
a rearward portion; and

a central portion, said last ramp first sidewall central portion being positioned out of alignment with the flow of the flowing medium; and

a last ramp second sidewall extending between the flow control surface and said last ramp floor surface, and extending between said last ramp

apex portion and said last ramp end portion, said last ramp sidewall forming;

a last ramp second sidewall edge between said last ramp second sidewall and the flow control surface, said last ramp second sidewall edge having:

a forward portion;

a rearward portion; and

a central portion, said last ramp second sidewall central portion being positioned out of alignment with the flow of the flowing medium.

17. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 12 wherein said apex portion of said first ramp overlaps said second ramp end portion and terminates above said floor portion of said second ramp.

18. The means to maintain attached a flow of a flowing medium to a flow control surface as defined in Claim 12 wherein said apex portion of said first ramp overlaps said second ramp end portion and terminates at said floor portion of said second ramp.

Patentansprüche

1. Im wesentlichen undurchlässiger Körper (58, Figur 3) für eine Bewegung relativ zu einem Fluid, wobei in der Oberfläche des Körpers mindestens eine erste dreieckige Rinne (30) ausgebildet ist, die an ihrem stromaufwärtigen Ende einen ersten Scheitel (56) besitzt und die zwischen zwei divergierenden Wänden (26, 28) einen ersten Boden (40) besitzt, der an dem ersten Scheitel (56) der ersten Rinne (30) in die genannte Fläche übergeht, dadurch gekennzeichnet, daß eine zweite Rinne (57) vorgesehen ist, die sich von der ersten Rinne (30) erstreckt und an dem stromaufwärtigen Ende der zweiten Rinne (57) einen zweiten Scheitel (69) besitzt und die ferner zwischen zwei divergierenden Wänden (64, 66) einen zweiten Boden (68) besitzt, der an dem zweiten Scheitel (69) der zweiten Rinne (57) in den ersten Boden (40) der ersten Rinne (30) übergeht, wobei sich Wände (64, 66) der zweiten Rinne (57) über das stromabwärtige Ende der Wände (26, 28) der ersten Rinne (30) hinaus erstrecken.

2. Im wesentlichen undurchlässiger Körper nach Anspruch 1 mit einer ersten Reihe der ersten Rinnen (30), dadurch gekennzeichnet, daß eine zweite Reihe der zweiten Rinnen (57) vorgesehen ist und die Scheitel (69) am stromaufwärtigen Ende der zweiten Rinnen (57) in je einen der ersten Böden (40) der ersten Rinnen (30) übergehen.

3. Körper nach Anspruch 2, dadurch gekennzeichnet, daß die divergierenden Wände (26, 28) einander benachbarter Rinnen der ersten Reihe an einem Rand (76) enden.

4. Körper nach Anspruch 2, dadurch gekennzeichnet, daß die zwischen den Rinnen (30) der ersten Reihe angeordnete Oberfläche des Körpers (58) stromab des Endes der Wände (26, 28) der ersten Rinne (30) in eine von den Wänden (64, 66) der zweiten Rinne (57) begrenzte Fläche übergeht.



5. Körper nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die genannten Wände gerade, konkav, konvex oder S-förmig sind.

6. Im wesentlichen undurchlässiger Körper (58, Figur 3) mit einer Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche, wobei diese Einrichtung umfaßt:

mindestens eine erste dreieckige Rinne (30) mit einem an die strömungsbeeinflussende Fläche anschließenden und der Strömung des strömenden Mediums zugekehrten Scheitelteil (56),

einem Endteil (28),

einem ersten Bodenteil, der sich im Abstand von der strömungsbeeinflussenden Fläche (58) von dem Scheitelteil (56) der ersten Rinne stromabwärts zu dem genannten Endteil (28) der ersten Rinne erstreckt, und

auf beiden Seiten jeder Rinne zwischen dem ersten Bodenteil (40) und der strömungsbeeinflussenden Fläche (56) angeordneten Seitenwänden (28), die sich von dem Scheitelteil (56) zu dem genannten Endteil erstrecken, gekennzeichnet durch:

mindestens eine zweite dreieckige Rinne (57), die in dem Bodenteil (40) einer entsprechenden ersten Rinne (30) versenkt ist und umfaßt:

einen zweiten Scheitelteil (69), der der Strömung des strömenden Mediums zugekehrt ist;

einen zweiten Endteil (68), der in der Strömung des strömenden Mediums stromab des Scheitelteils (69) der zweiten Rinne angeordnet ist;

eine zweite Bodenfläche (68), die sich von der strömungsbeeinflussenden Fläche an dem zweiten Scheitelteil (69) zu dem zweiten Endteil erstreckt,

eine erste Seitenwand (66) der zweiten Rinne, wobei sich diese erste Seitenwand zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche (57) der zweiten Rinne und zwischen dem Scheitelteil (69) der zweiten Rinne und dem genannten Endteil der zweiten Rinne erstreckt und:

zwischen der ersten Seitenwand (66) der zweiten Rinne und der strömungsbeeinflussenden Fläche einen ersten Seitenwandrand der zweiten Rinne bildet, der umfaßt:

einen vorderen Teil

einen hinteren Teil und

einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist; und die zweite Rinne ferner umfaßt:

eine zweite Seitenwand (64) der zweiten Rinne, wobei diese zweite Seitenwand sich zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche (57) der zweiten Rinne und zwischen dem Scheitelteil (69) der zweiten Rinne und dem Endteil (68) der zweiten Rinne erstreckt und

zwischen der zweiten Seitenwand (64) der zweiten Rinne und der strömungsbeeinflussenden Fläche einen zweiten Seitenwandrand der zweiten Rinne bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist,

so daß über dem ersten und dem zweiten Seitenwandrand der zweiten Rinne ein erster und ein zweiter Wirbel mit einander entgegengesetzten Drehrichtungen erzeugt werden und daher die Grenzschicht der Strömung des strömenden Mediums an der benachbarten strömungsbeeinflussenden Fläche geschwächt und in der zweiten Rinne eine turbulentes Mischen bewirkt wird und dadurch die Strömung des strömenden Mediums an die strömungsbeeinflussende Fläche und die zweite Bodenfläche angehalten wird.

7. Einrichtung nach Anspruch 6 zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche, gekennzeichnet durch:

mindestens zwei der ersten dreieckigen Rinnen und

mindestens zwei der zweiten dreieckigen Rinnen.

8. Einrichtung nach Anspruch 6 zum Anhalten der Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche, dadurch gekennzeichnet, daß die zweite dreieckige Rinne in Bezug zu der ersten dreieckigen Rinne unsymmetrisch ist.

9. Einrichtung nach Anspruch 6 zum Anhalten der Strömung eines strömenden Mediums an eine strömungsbeeinflussenden Fläche, gekennzeichnet durch

zwischen den Seitenwänden und der Bodenfläche der ersten Rinne vorgesehene Schnittlinien, deren örtliche Radien nicht größer sind als die Hälfte des örtlichen vertikalen Abstandes zwischen der genannten Bodenfläche und der strömungsbeeinflussenden Fläche.

10. Einrichtung nach Anspruch 6 zum Anhalten der Strömung eines strömenden Mediums an eine strömungsbeeinflussenden Fläche gekennzeichnet durch:

mindestens eine letzte dreieckige Rinne, die in dem Bodenteil einer entsprechenden ersten Rinne versenkt ist und umfaßt:

einen der Strömung des strömenden Mediums zugekehrten Scheitelteil,

einen in der Strömung des strömenden Mediums stromab des Scheitelteils der letzten Rinne angeordneten Endteil,

eine Bodenfläche, die sich von der strömungsbeeinflussenden Fläche an dem Scheitelteil der letzten Rinne zu deren Endteil erstreckt,

eine erste Seitenwand der letzten Rinne, wobei sich diese erste Seitenwand der letzten Rinne zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche der letzten Rinne und zwischen dem Scheitelteil der letzten Rinne und dem Endteil der letzten Rinne erstreckt und

zwischen der ersten Seitenwand der letzten Rinne und der strömungsbeeinflussenden Fläche einen ersten Seitenwandrand der letzten Rinne bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist,



mung des strömenden Mediums versetzt ist, und die letzte Rinne ferner umfaßt:

eine zweite Seitenwand der letzten Rinne, wobei sich diese zweite Seitenwand zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche der letzten Rinne und zwischen dem Scheitelteil und dem Endteil der letzten Rinne erstreckt und

zwischen der zweiten Seitenwand der letzten Rinne und der strömungsbeeinflussenden Fläche einen zweiten Seitenwandrand der letzten Rinne bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist.

11. Einrichtung nach Anspruch 6 zum Anhalten der Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche, dadurch gekennzeichnet, daß die strömungsbeeinflussende Fläche einen stromabwärtigen Rand besitzt und sich die zweite Seitenwand der letzten Rinne bis zu dem stromabwärtigen Rand der strömungsbeeinflussenden Fläche erstreckt.

12. Im wesentlichen undurchlässiger Körper mit einer Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche, wobei diese Einrichtung umfaßt:

mindestens eine erste dreieckige Rampe, die umfaßt:

einen an die strömungsbeeinflussende Fläche anschließenden und von der Strömung des strömenden Mediums abgekehrten Scheitelteil, einen Endteil,

einen im Abstand von der strömungsbeeinflussenden Fläche angeordneten Bodenteil, der sich von dem Scheitelteil der ersten Rampe stromaufwärts zu dem genannten Endteil erstreckt, und

auf beiden Seiten jeder Rampe zwischen dem Bodenteil und der strömungsbeeinflussenden Fläche angeordneten Seitenwänden, die sich von dem Scheitelteil zu dem Endteil erstrecken, gekennzeichnet durch:

mindestens eine zweite dreieckige Rampe, die von dem Seitel einer entsprechenden ersten Rampe geschnitten ist und umfaßt:

einen von der Strömung des strömenden Mediums abgekehrten Scheitelteil,

einen in der Strömung des strömenden Mediums stromauf des Scheitelteils der zweiten Rampe angeordneten Endteil,

eine sich von der strömungsbeeinflussenden Fläche an dem genannten Endteil der zweiten Rampe zu dem Scheitelteil der zweiten Rampe erstreckende Bodenfläche,

eine erste Seitenwand der zweiten Rampe, wobei diese erste Seitenwand sich zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche der zweiten Rampe und zwischen dem Scheitelteil der zweiten Rampe und dem genannten Endteil der zweiten Rampe erstreckt und

zwischen der ersten Seitenwand der zweiten Rampe und der strömungsbeeinflussenden Fläche

che einen ersten Seitenwandrand der zweiten Rampe bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

5 einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist, und die zweite Rampe ferner umfaßt:

10 eine zweite Seitenwand der zweiten Rampe, wobei sich diese zweite Seitenwand zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche der zweiten Rampe und zwischen dem Scheitelteil der zweiten Rampe und dem Endteil der zweiten Rampe erstreckt und

15 zwischen der zweiten Seitenwand der zweiten Rampe und der strömungsbeeinflussenden Fläche einen zweiten Seitenwandrand der zweiten Rampe bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

20 einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist, so daß über dem ersten und dem zweiten Seitenwandrand der zweiten Rampe ein erster und ein zweiter Wirbel in einander entgegengesetzten Drehrichtungen erzeugt werden und daher die Grenzschicht der Strömung des strömenden Mediums an der benachbarten strömungsbeeinflussenden Fläche geschwächt und in der zweiten Rampe ein turbulentes Mischen bewirkt wird und dadurch die Strömung des strömenden Mediums an die strömungsbeeinflussende Fläche und die zweite Bodenfläche angehalten wird.

25 13. Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche nach Anspruch 12, gekennzeichnet durch:

mindestens zwei der ersten dreieckigen Rampen und

40 mindestens zwei der zweiten dreieckigen Rampen, wobei diese Rampen sich oberhalb der strömungsbeeinflussenden Fläche erstrecken.

45 14. Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche nach Anspruch 12, dadurch gekennzeichnet, daß die zweite dreieckige Rampe in Bezug auf die erste dreieckige Rampe unsymmetrisch ist.

50 15. Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche nach Anspruch 12, gekennzeichnet durch zwischen den Seitenwänden und der strömungsbeeinflussenden Fläche vorgesehene Schnittlinien, deren örtliche Radien nicht größer sind als die Hälfte des örtlichen vertikalen Abstandes zwischen der genannten Bodenfläche und der strömungsbeeinflussenden Fläche.

55 16. Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche nach Anspruch 12, in der die strömungsbeeinflussende Fläche einen hinteren Rand hat, gekennzeichnet durch:

60 mindestens eine letzte dreieckige Rampe, die umfaßt:



einen Scheitelteil, der sich zu dem stromabwärtigen Rand erstreckt,

einen in der Strömung des strömenden Mediums stromauf des Scheitelteils der letzten Rampe angeordneten Endteil,

eine Bodenfläche, die sich von der strömungsbeeinflussenden Fläche an dem letzten Endteil zu dem letzten Scheitelteil erstreckt,

mindestens eine erste Seitenwand der letzten Rampe, wobei sich diese erste Seitenwand zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche der letzten Rampe und dem genannten Endteil der letzten Rampe erstreckt und

zwischen der ersten Seitenwand der ersten Rampe und der strömungsbeeinflussenden Fläche einen ersten Seitenwandrand der letzten Rampe bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist, und die letzte Rampe ferner

eine zweite Seitenwand der letzten Rampe besitzt, wobei sich diese zweite Seitenwand zwischen der strömungsbeeinflussenden Fläche und der Bodenfläche der letzten Rampe und zwischen dem Scheitelteil der letzten Rampe und dem genannten Endteil der letzten Rampe erstreckt und

zwischen der zweiten Seitenwand der letzten Rampe und der Rampe und der strömungsbeeinflussenden Fläche einen zweiten Seitenwandrand der letzten Rampe bildet, der umfaßt:

einen vorderen Teil,

einen hinteren Teil und

einen mittleren Teil, der gegenüber der Strömung des strömenden Mediums versetzt ist.

17. Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche nach Anspruch 12, dadurch gekennzeichnet, daß der Scheitelteil der ersten Rampe den genannten Endteil der zweiten Rampe überlappt und oberhalb des genannten Bodenteils der zweiten Rampe endet.

18. Einrichtung zum Anhalten einer Strömung eines strömenden Mediums an eine strömungsbeeinflussende Fläche nach Anspruch 12, dadurch gekennzeichnet, daß der Scheitelteil der ersten Rampe den genannten Endteil der zweiten Rampe überlappt und am Bodenteil der zweiten Rampe endet.

Revendications

1. Corps essentiellement étanche (58, figure 3), destiné à avoir un mouvement relatif par rapport à un milieu fluide et dont la surface présente au moins une première rainure (30) de forme triangulaire, cette première rainure (30) ayant un premier sommet de triangle (56) à l'extrémité amont de la première rainure (30), de même qu'un premier fond (40) entre deux parois (26, 28) divergentes, le premier fond (40) rejoignant la surface du corps au premier sommet (56) de la

première rainure (30) caractérisé en ce qu'une deuxième rainure (57) prévue, cette deuxième rainure (57) partant de la première rainure (30) et ayant un deuxième sommet (69) à l'extrémité amont de la deuxième rainure (56), de même qu'un deuxième fond (68) entre deux parois (64, 66) divergentes, le deuxième fond (68) rejoignant le premier fond (40) de la première rainure (30) au deuxième sommet (69) de la deuxième rainure (57), et l'extrémité amont des parois (64, 66) de la deuxième rainure (57) s'étendant au-delà de l'extrémité aval des parois (26, 28) de la première rainure (30).

2. Corps selon la revendication 1, dans lequel est prévue une première série des premières rainures (30) et caractérisé, en outre, en ce qu'il est prévu une deuxième série de deuxièmes rainures (57), les sommets (69) à l'extrémité amont des deuxièmes rainures (57) rejoignant des fonds respectifs (40) des premières rainures (30).

3. Corps selon la revendication 2, caractérisé, en outre, en ce que les parois divergentes (26, 28) de rainures voisines de la première série se terminent à une pointe (76).

4. Corps selon la revendication 2, dans lequel la surface du corps (58) entre la première série de rainures (30) rejoint une surface définie entre les parois (64, 66) de la deuxième rainure (57) en aval de l'extrémité des parois (26, 28) de la première rainure (30).

5. Corps selon l'une quelconque des revendications précédentes; dans lequel les parois ont une forme droite, concave, convexe ou en S.

6. Corps essentiellement étanche (58, figure 3), comportant un dispositif pour maintenir un écoulement de fluide attaché à une surface de guidage d'écoulement, dispositif qui comprend:

au moins une première rainure (30) de forme triangulaire, cette première rainure possédant:

une partie sommitale (56) contiguë à la surface de guidage et faisant face à l'écoulement de fluide; et

une partie terminale (28);

une première partie de fond s'étendant à partir de la partie sommitale (56) de la première rainure jusqu'à la partie terminale (28) de la première rainure, située en aval de la partie sommitale (56) et espacée de la surface de guidage (58); et

des parois latérales (28) situées de chaque côté de chaque rainure entre la première partie de fond (40) et la surface de guidage (56), à partir de la partie sommitale (56) jusqu'à la partie terminale; caractérisé par:

au moins une deuxième rainure (57) de forme triangulaire, cette deuxième rainure (57) étant noyée dans la partie de fond (40) d'une première rainure (30) correspondante, la deuxième rainure possédant:

une deuxième partie sommitale (69) faisant face à l'écoulement de fluide;

une deuxième partie terminale (68) disposée en aval de la partie sommitale (69) de la deuxième rainure, dans le sens de l'écoulement du fluide;

une deuxième surface de fond (68) s'étendant



depuis la surface de guidage au droit de la deuxième partie sommitale (69) jusqu'à la deuxième partie terminale;

une première paroi latérale (66) de la deuxième rainure, s'étendant entre la surface de guidage et la surface de fond (57) de la deuxième rainure, ainsi qu'entre la partie sommitale (69) de la deuxième rainure et la partie terminale de celle-ci, la première paroi latérale (66) de la deuxième rainure formant:

un bord de première paroi latérale de la deuxième rainure, bord qui s'étend entre cette première paroi latérale (66)

une partie avant;

une partie arrière; et

une partie centrale, laquelle est désalignée par rapport à l'écoulement du fluide;

une seconde paroi latérale (64) de la deuxième rainure, s'étendant entre la surface de guidage et la surface de fond (57) de la deuxième rainure, ainsi qu'entre la partie sommitale (69) de la deuxième rainure et la partie terminale (68) de celle-ci, cette seconde paroi latérale formant:

un second bord de paroi latérale, bord qui s'étend entre la seconde paroi latérale (64) de la deuxième rainure et la surface de guidage d'écoulement et qui comporte:

une partie avant;

une partie arrière; et

une partie centrale qui est désalignée par rapport à l'écoulement de fluide, de sorte que des premier et second tourbillons contrarotatifs se forment dans la deuxième rainure au droit des bords des parois latérales, tourbillons qui amincissent la couche limite de l'écoulement de fluide sur la surface de guidage adjacente et provoquent un mélange tourbillonnaire dans cette deuxième rainure, si bien que l'écoulement de fluide reste attaché à la surface de guidage et à la deuxième surface de fond.

7. Corps selon la revendication 6, dans lequel le dispositif pour maintenir l'écoulement de fluide attaché à la surface de guidage, comporte en outre:

au moins deux desdites premières rainures triangulaires; et

au moins deux desdites deuxièmes rainures triangulaires.

8. Corps selon la revendication 6, où, dans le dispositif pour maintenir l'écoulement de fluide attaché à la surface de guidage, le deuxième rainure triangulaire a une disposition dissymétrique par rapport à la première rainure triangulaire.

9. Corps selon la revendication 6, dans lequel le dispositif pour maintenir l'écoulement de fluide attaché à la surface de guidage comporte en outre:

des intersections entre les parois latérales de la première rainure et la surface de fond de cette rainure, les intersections ayant localement des rayons qui ne dépassent pas la moitié de la hauteur mesurée à cet endroit entre la surface de fond et la surface de guidage d'écoulement.

10. Corps selon la revendication 6, dans lequel le dispositif pour maintenir l'écoulement de fluide

attaché à la surface de guidage comporte en outre:

au moins une dernière rainure triangulaire, laquelle est noyée dans la partie de fond d'une première rainure correspondante, la dernière rainure comportant:

une partie sommitale faisant face à l'écoulement de fluide;

une partie terminale disposée en aval de cette partie sommitale, dans le sens de l'écoulement du fluide;

une surface de fond s'étendant depuis la surface de guidage au droit de la partie sommitale de la dernière rainure jusqu'à la partie terminale de celle-ci;

une première paroi latérale de la dernière rainure, s'étendant entre la surface de guidage et la surface de fond de la dernière rainure, ainsi qu'entre la partie sommitale et la partie terminale de la dernière rainure, cette première paroi latérale formant:

un premier bord s'étendant entre la première paroi latérale de la dernière rainure et la surface de guidage d'écoulement et comportant:

une partie avant;

une partie arrière; et

une partie centrale, laquelle est désalignée par rapport à l'écoulement du fluide;

une seconde paroi latérale de la dernière rainure, s'étendant entre la surface de guidage d'écoulement et la surface de fond de cette rainure, ainsi qu'entre la partie sommitale et la partie terminale de la dernière rainure, cette seconde paroi latérale formant:

un second bord s'étendant entre la seconde paroi latérale de la dernière rainure et la surface de guidage d'écoulement et possédant:

une partie avant;

une partie arrière; et

une partie centrale qui est désalignée par rapport à l'écoulement du fluide.

11. Corps selon la revendication 6, dans lequel la surface de guidage d'écoulement présente un bord arrière, la seconde paroi latérale de la dernière rainure s'étendant jusqu'à ce bord arrière.

12. Corps essentiellement étanche, comportant un dispositif pour maintenir un écoulement fluide attaché à une surface de guidage d'écoulement, ce dispositif comprenant:

au moins une première rampe de forme triangulaire, cette première rampe possédant:

une partie sommitale correspondant à un sommet de triangle, qui est contiguë à la surface de guidage d'écoulement et est dirigée dans le sens de l'écoulement du fluide;

une partie terminale;

un dessus de rampe s'étendant de la partie sommitale de la première rampe à sa partie terminale, située en amont de la partie sommitale et espacée de la surface du guidage d'écoulement; et

une paroi latérale sur chaque côté de chaque rampe, entre le dessus et la surface de guidage, depuis la partie sommitale jusqu'à la partie termi-



nale; caractérisé par:

au moins une deuxième rampe de forme triangulaire, cette deuxième rampe étant coupée par la partie sommitale d'une première rampe correspondante, la deuxième rampe comportant:

une partie sommitale dirigée dans le sens de l'écoulement du fluide;

une partie terminale disposée en amont de la partie sommitale de la deuxième rampe, dans le sens de l'écoulement du fluide;

un dessus de rampe s'étendant depuis la surface de guidage d'écoulement au droit de la partie terminale de la deuxième rampe jusqu'à la partie sommitale de la deuxième rampe;

une première paroi latérale de la deuxième rampe, s'étendant entre la surface de guidage d'écoulement et le dessus de la deuxième rampe, ainsi qu'entre la partie sommitale et la partie terminale de la deuxième rampe, cette paroi latérale formant:

un premier bord s'étendant entre la première paroi latérale de la deuxième rampe et la surface de guidage d'écoulement et possédant:

une partie avant;

une partie arrière; et

une partie centrale qui est désalignée par rapport à l'écoulement du fluide; et

une seconde paroi latérale de la deuxième rampe, s'étendant entre la surface de guidage d'écoulement et le dessus de la deuxième rampe, ainsi qu'entre la partie sommitale et la partie terminale de la deuxième rampe, cette seconde paroi latérale formant:

un second bord s'étendant entre la seconde paroi latérale de la deuxième rampe et la surface de guidage d'écoulement et possédant:

une partie avant;

une partie arrière; et

une partie centrale, laquelle est désalignée par rapport à l'écoulement du fluide, de sorte que des premier et second tourbillons contrarotatifs se forment dans la deuxième rampe, au droit du premier et du second bord des parois latérales de la deuxième rampe, tourbillons qui amincissent la couche limite de l'écoulement de fluide à la surface de guidage d'écoulement adjacente et provoquent un mélange tourbillonnaire dans la deuxième rampe, si bien que l'écoulement de fluide reste attaché à la surface de guidage et au dessus de la deuxième rampe.

13. Corps selon la revendication 12, dans lequel le dispositif pour maintenir l'écoulement de fluide attaché à la surface de guidage comporte en outre:

au moins deux desdites premières rampes triangulaires; et

au moins deux desdites deuxièmes rampes triangulaires, les rampes étant surélevées par rapport à la surface de guidage d'écoulement.

14. Corps selon la revendication 12, dans lequel la deuxième rampe triangulaire possède une disposition dissymétrique par rapport à la première rampe triangulaire.

15. Corps selon la revendication 12, dans lequel le dispositif pour maintenir l'écoulement du fluide attaché à la surface de guidage comporte en outre:

5 des intersections entre les parois latérales de la première rampe et la surface de guidage, ces intersections ayant localement des rayons qui ne dépassent pas la moitié de la hauteur mesurée à cet endroit entre le dessus de la rampe et la surface de guidage d'écoulement.

10 16. Corps selon la revendication 12, dans lequel la surface de guidage d'écoulement présenté un bord arrière et le dispositif pour maintenir l'écoulement de fluide attaché à la surface de guidage comporte en outre:

au moins une dernière rampe de forme triangulaire, avec:

une partie sommitale s'étendant jusqu'au bord arrière;

20 une partie terminale située en amont de la partie terminale de la dernière rampe, dans le sens de l'écoulement du fluide;

un dessus de rampe s'étendant depuis la surface de guidage d'écoulement au droit de la partie terminale de la dernière rampe jusqu'à la partie sommitale de celle-ci;

30 une première paroi latérale de la dernière rampe, s'étendant entre la surface de guidage d'écoulement et le dessus de la dernière rampe, ainsi qu'entre la partie sommitale et la partie terminale de la dernière rampe, cette première paroi latérale formant:

un bord s'étendant entre la première paroi latérale de la dernière rampe et la surface de guidage d'écoulement et possédant:

35 une partie avant;

une partie arrière; et

une partie centrale, laquelle est désalignée par rapport à l'écoulement du fluide; et

40 une deuxième paroi latérale de la dernière rampe, s'étendant entre la surface de guidage d'écoulement et le dessus de la dernière rampe, ainsi qu'entre la partie sommitale et la partie terminale de la dernière rampe, cette seconde paroi latérale formant:

45 un second bord s'étendant entre la seconde paroi latérale de la dernière rampe et la surface de guidage d'écoulement et possédant:

une partie avant;

50 une partie arrière; et

une partie centrale, laquelle est désalignée par rapport à l'écoulement du fluide.

55 17. Corps selon la revendication 12, dans lequel la partie sommitale de la première rampe recouvre la partie terminale de la seconde rampe et se termine au-dessus de la partie de la deuxième rampe formant le dessus de celle-ci.

60 18. Corps selon la revendication 12, dans lequel la partie sommitale de la première rampe recouvre la partie terminale de la deuxième rampe et se termine à la partie formant le dessus de la deuxième rampe.

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