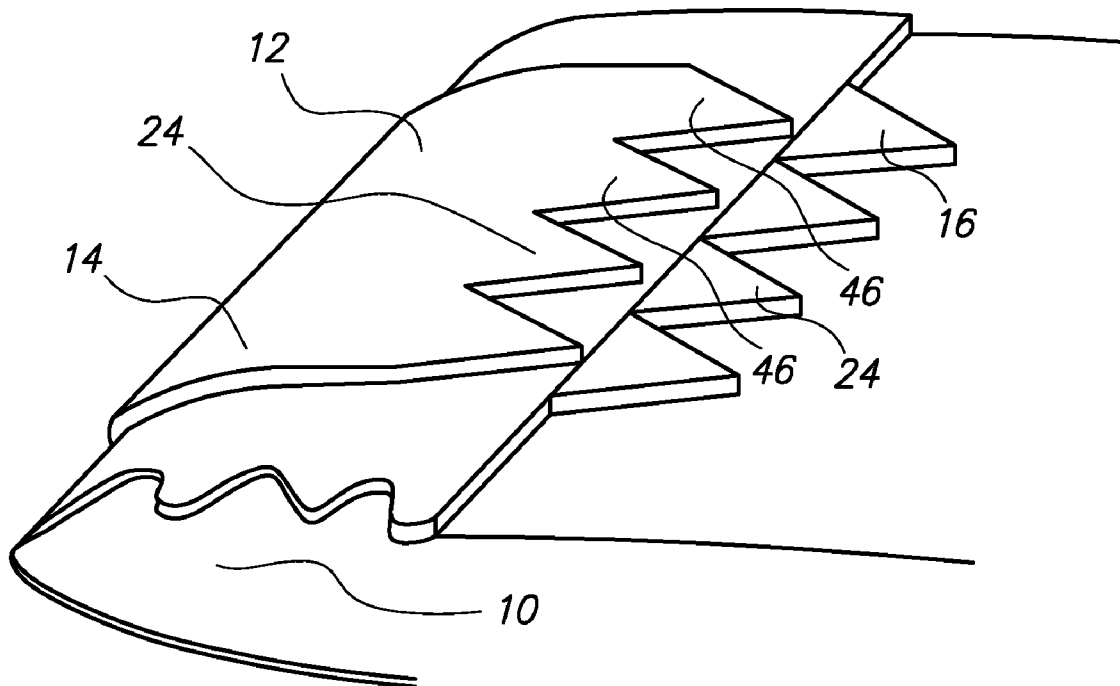




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(19) **United States**(12) **Patent Application Publication**
Ireland(10) **Pub. No.: US 2011/0006165 A1**(43) **Pub. Date: Jan. 13, 2011**(54) **APPLICATION OF CONFORMAL SUB
BOUNDARY LAYER VORTEX GENERATORS
TO A FOIL OR AERO/ HYDRODYNAMIC
SURFACE****Publication Classification**(51) **Int. Cl.**
B64C 21/10 (2006.01)(52) **U.S. Cl.** **244/200.1**(57) **ABSTRACT**(76) **Inventor:** **Peter Ireland**, Wenworth Falls
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Oakland, CA 94610 (US)(21) **Appl. No.:** **12/832,967**(22) **Filed:** **Jul. 8, 2010****Related U.S. Application Data**(60) **Provisional application No. 61/224,481, filed on Jul.**
10, 2009.

A method of improving aerodynamic performance of foils by the application of conformal, low drag vortex generators. A film of erosion protection material or other conformal material is placed on the foil to provide a medium for the incorporation of planform edge vortex generators. The form edge is shaped to achieve submerged vortex generating shapes of chevron or ogival planforms, extending primarily chordwise on the foil surface. The vortex generators promote improved boundary layer dynamics by mixing free stream flow into the boundary layer while minimising separation and fluid losses. At the trailing edge, the shape formed with the chevrons applied apex forward, acts as a vented gurney tab series and additionally as disruptors to the Von Karman Street wake, delaying sheet rollup into the tip vortice.



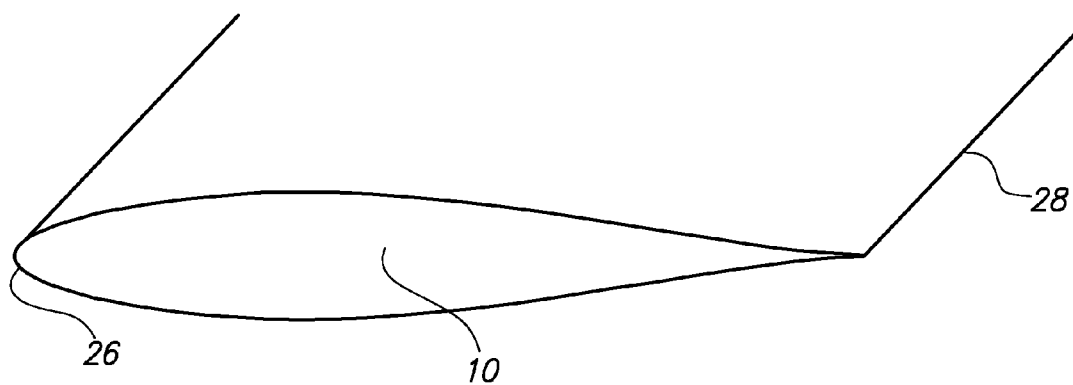


FIG. 1

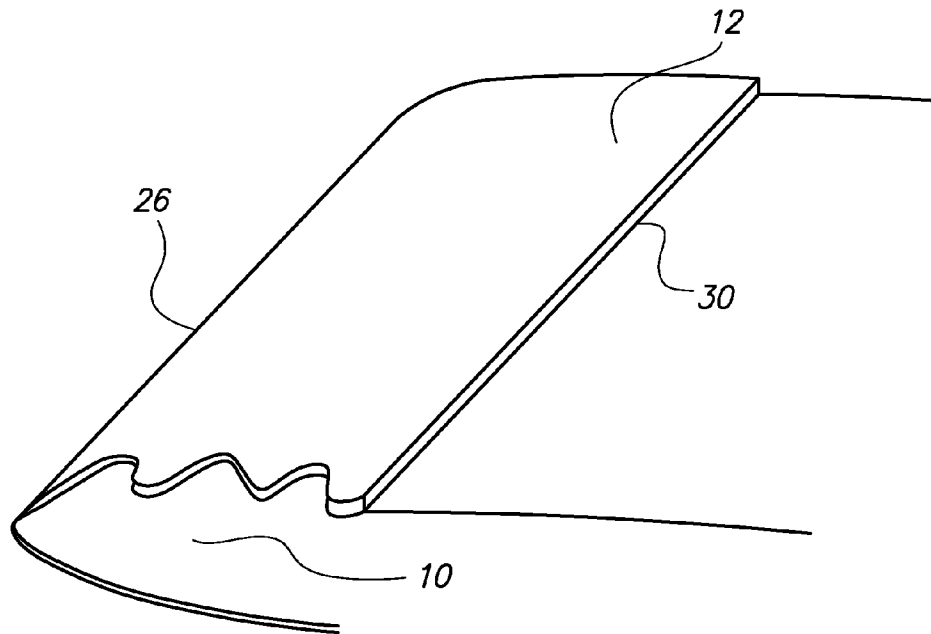


FIG. 2

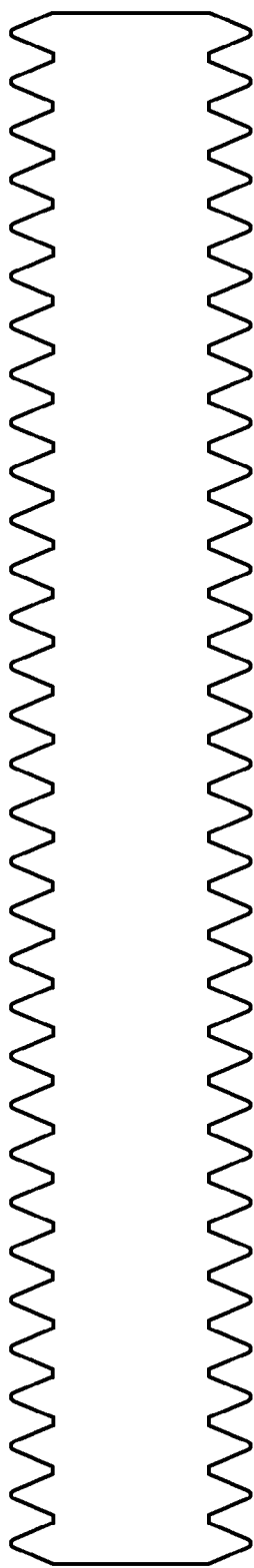


FIG. 3

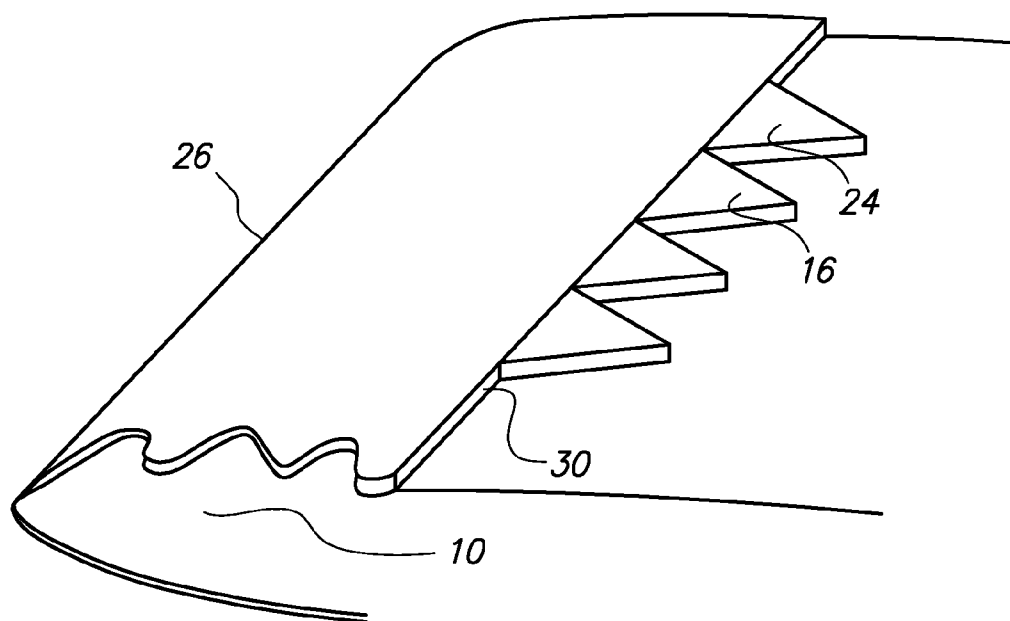


FIG. 4

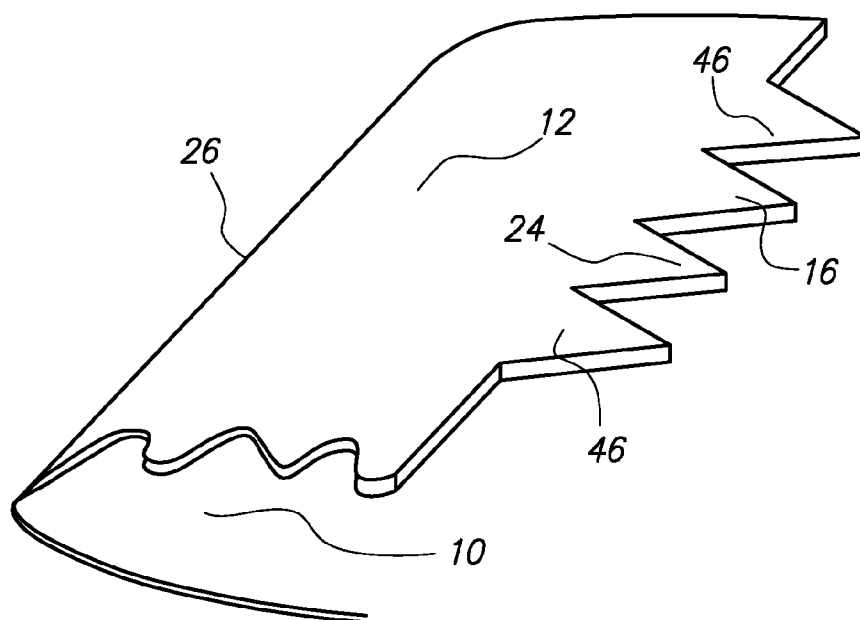


FIG. 5

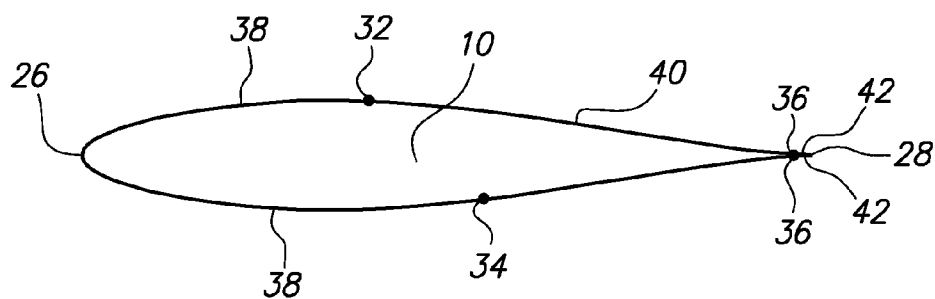


FIG. 6

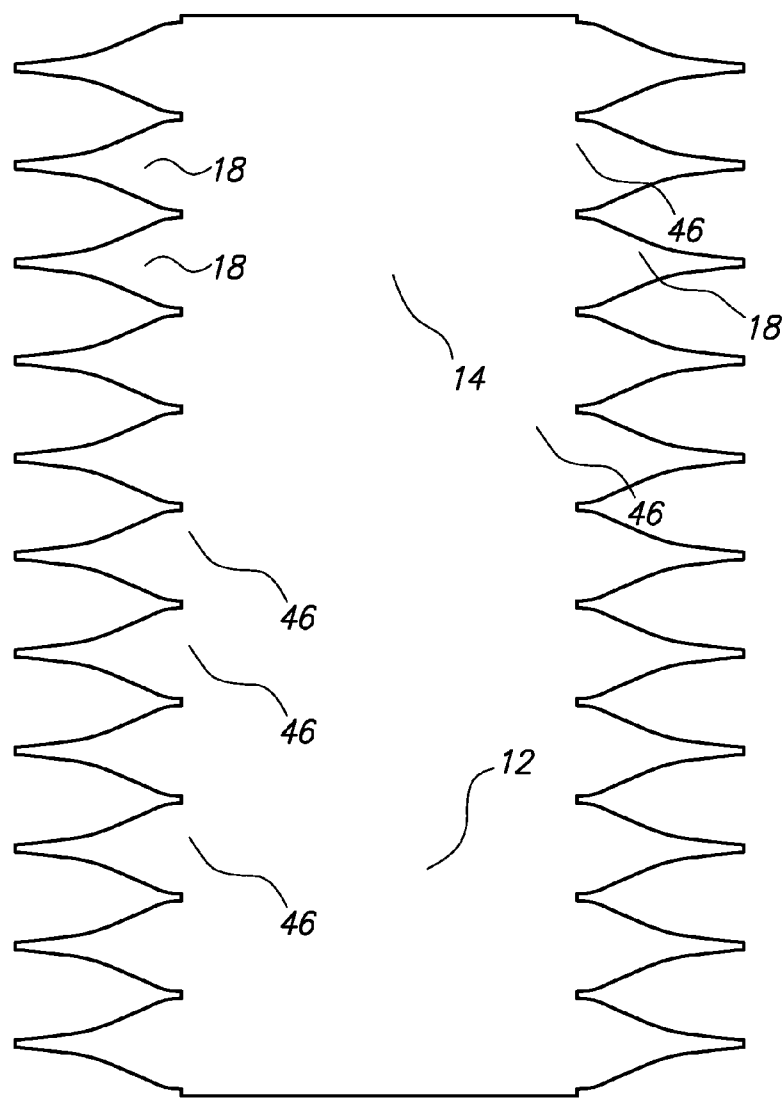


FIG. 7

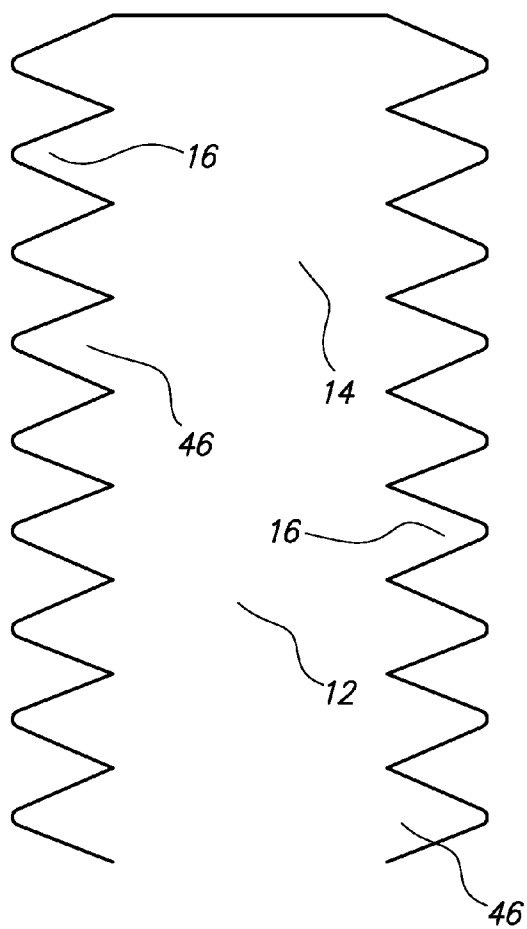


FIG. 8

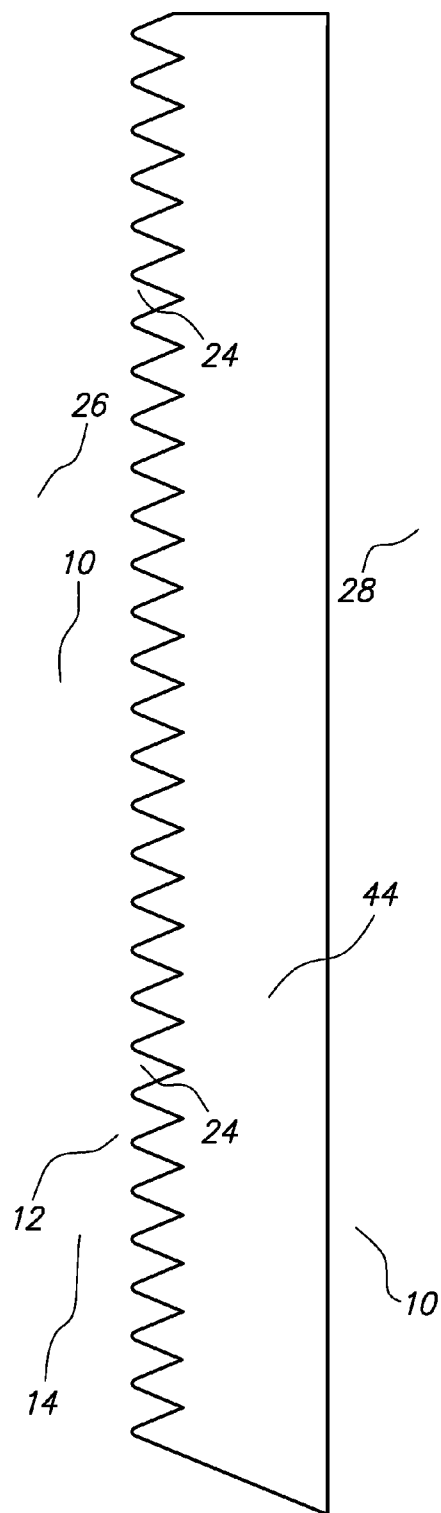


FIG. 9

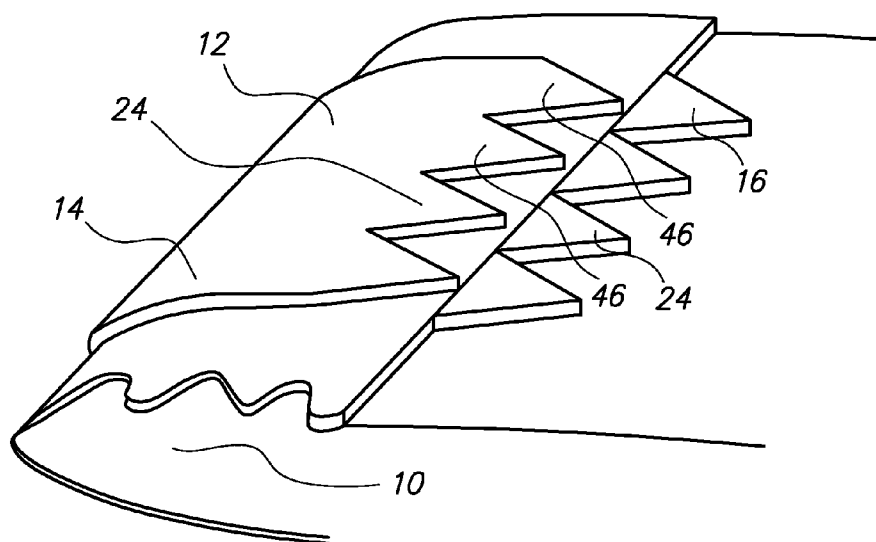


FIG. 10

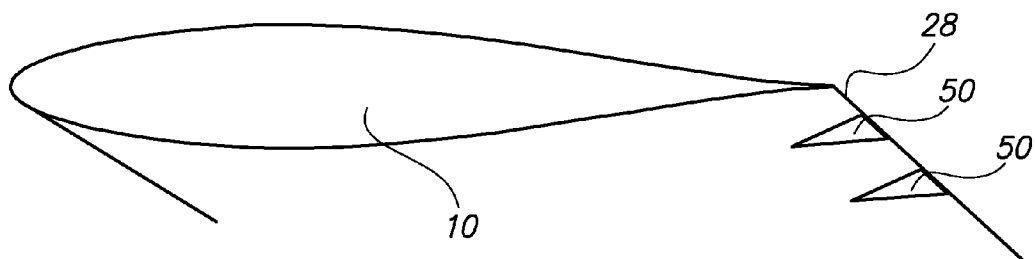


FIG. 11

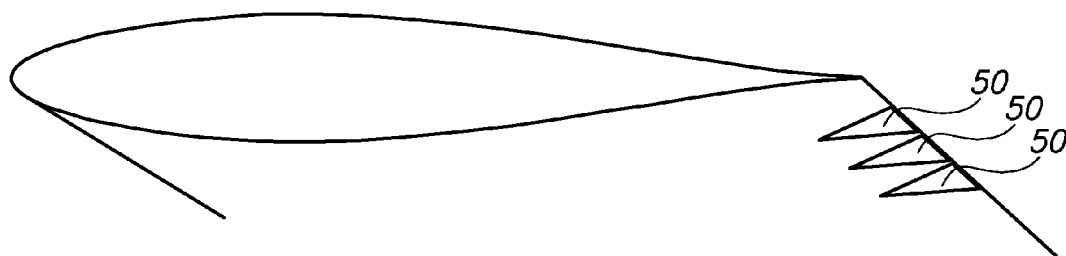


FIG. 12

APPLICATION OF CONFORMAL SUB BOUNDARY LAYER VORTEX GENERATORS TO A FOIL OR AERO/ HYDRODYNAMIC SURFACE

RELATED APPLICATIONS

[0001] The present application is a continuation-in-part application of U.S. provisional patent application, Ser. No. 61224481, filed Oct. 7, 2009, for ELASTOMERIC VORTEX GENERATORS, by Peter S. Ireland, included by reference herein and for which benefit of the priority date is hereby claimed.

[0002] Elastomeric Vortex Generator Provisional patent, Ireland P S, of 10 Jul. 2009. (EFS ID 5676629 Application Number 61224481 Confirmation Number 2708 Title Elastomeric Vortex Generator(s) First Named Inventor Peter Stephen Ireland)

FIELD OF THE INVENTION

[0003] The present invention relates to the addition of low drag fully submerged conformal vortex generators to a surface in relative motion to a Newtonian fluid and, more particularly, to aeronautical and marine surfaces, blades, rotors, and appendages having a boundary layer with fluid flow across such surface.

BACKGROUND OF THE INVENTION

[0004] Performance of a foil or surface in a flow of fluid such as air or water is critical for a system performance, affecting lift, drag and vibration of a system.

[0005] The leading section of the foil is usually an area of increasing thickness and results in a thin laminar boundary layer until such point that viscous drag, surface friction or pertuberances causes turbulence to occur in the boundary layer. The turbulent boundary layer has characteristically higher drag than the laminar flow region, however may also have improved stability of flow. The development of an adverse pressure gradient results in separation of the flow from the surface, and a further large increase in drag occurs from this point rearwards. While a foil section may be designed to maintain a large area of laminar boundary layer, practical limitations of manufacture and cleanliness generally preclude widescale laminar boundary layer development.

[0006] Leading edges of foils on blades are subject to erosion and can benefit from the application of a protective abrasable layer. The abrasable or protective surface may be applied as an adhesive sheet to the foil leading edge, or alternatively as a high build polymeric material that is sprayed on or otherwise applied to the desired leading edge area. Unfortunately, in current art, where this is applied, this results in an alteration of the basic foil shape aerodynamically, and causes a ridge to occur at the trailing edge of the protective layer. The current art protection mechanisms result in these mechanisms having a trailing edge form of an aft facing step aerodynamically, which causes an increase in drag and develops a transverse vortex to occur on the foil. This step/vortex tends to disrupt the laminar boundary layer and cause early transition to turbulent boundary layer or in extreme cases, separation of flow.

[0007] In manufacture of rotor blades, a bond line is often found at approximately 15-20% of the chord back from the leading edge of the foil. This bond line is the join between the surface skins and the extrusion used as a spar. The painted

surface protecting this bond is susceptible to being eroded and following erosion of the paint protection it is possible for moisture to enter the bond and result in bond failure. Such failure can be catastrophic.

[0008] Noise signature of a blade, or other foil is affected by the vortex development in the wake of the section. Additionally, lift and drag performance can be affected greatly by the use of trailing edge modifiers. In practice, this performance is not attained due to constraints of engineering a suitable mechanism.

[0009] Leading edge erosion protection has been provided generically by application of tapes to the leading edge surface of the foil or blade, using a polymeric material such as polyurethane, or other elastomeric compounds.

[0010] Micro Vortex generators, microVG's, are fabricated from a rigid material such as aluminium are used to reenergise boundary layers. Large Eddy Breakup Units, or LEBU's are occasionally used to adjust a boundary layer condition, and are constructed from rigid materials. A drag modifying surface is manufactured by 3M under the tradename "Riblet". This surface is a thin textured film, designed to provide a reenergising of the boundary layer to reduce surface drag.

[0011] To change acoustic signature and/or lift/drag performance, fluting of the trailing edge of a foil or section has been accomplished, and tabs such as lift enhancing tabs or gurney tabs have been applied in experimentation. Fluting has been accomplished on jet engine exhaust systems in current art.

[0012] Leading edge erosion protection films, tapes or shaped boots result in disrupting the boundary layer in a critical area of the foil, due to the aft facing step between the trailing edge of the treatment and the upper surface of the foil. This results in developing a local flow pattern which causes thickening of the boundary layer from laminar to turbulent and causing separation of the local flow, in both cases reducing lift and increasing drag. Fairing of the aft edge to the surface may often exacerbate the performance degradation as the stability of the transverse vortex generated at the aft face of the step often has less drag than a less abrupt face which causes irregular flow dynamics and results in more turbulence and greater likelihood of separation of flow.

[0013] Current boundary layer modifiers such as micro VG's and LEBU's are rigid in structure. The material they are made from allows limited flexure of the structure, and will not permit the underlying surface to flex. Where there is substantial structural flexing and the modifier extends over any length, these solutions are unable to be used without affecting the torsional or flexing characteristics of the underlying structure. This can result in serious aeroelastic effects, causing structural failure or damage, and are inherently impacted by any alternating loads, bending or flexing resulting in material fatigue. The micro VG's, and similar current art vortex generators are often characterised as being "micro", however as a percentage of the boundary layer height, they are multiples of the laminar boundary layer height in the region of the forward chord of the blade, whereas conventional design optimisation of micro VG's indicate that their height should be less than the boundary layer and generally of the order of 20% or less of the boundary layer thickness to minimise drag losses, while maintaining effectiveness of developing stream-wise vortices.

[0014] Structural mass of any addition to a foil must be considered for the tensile loading of the foil, particularly for a blade, and also the location on the blade relative to the chord must be considered: weight added at the trailing edge is

potentially adverse to the dynamic stability of the foil (flutter). This may be offset by related aerodynamic effects if those effects move the centre of pressure rearward more than the weight addition shifts the centre of mass of the foil section. Addition of mass to a rotor system increases inertial loading in the feathering axis, pitching axis, and increases radial shear loads. Therefore, minimum mass needs to be achieved at all times.

[0015] Fluting of a section involves complex engineering, and can result in structural problems such as material fatigue. Gurney tabs are predominately mechanical devices, and the structure adds weight and additionally affects torsional and bending moments of inertia of a structure. This may cause bond or fastener failure over time through fatigue and incompatibility of the attachment system.

SUMMARY OF THE INVENTION

[0016] In accordance with the present invention, there is provided a film surface being an advantageously machined polymeric or polyurethane tape element. This film is attached by a high shear strength adhesive that permits flexure of the film for conformal fitment to the substrate, being a wing, surface or foil such as a rotorblade, and allows for the removal of the film after use. The film is advantageously shaped so as to have a regular series of V shapes on both of the transverse edges of the film. This film is applied around the leading edge of the foil to result in these V shapes facing away from the leading edge towards the trailing edge. Thus the film is a method of incorporating a vortex generating profile planform, which also minimises the extent of straight transverse aft facing steps that exist when the film is attached around the leading edge of a foil. The commencement and termination of these V shapes are determined by the boundary layer characteristics of the foil that the surface is applied to, however in general will be applied in the region of 5% to 25% of the chord of the foil. The sizing of the V shapes is determined by the foil dimensions and Reynolds number, and can be optimised by numeric analysis or by parametric testing for any foil, or surface.

[0017] When applied near the leading edge of the blade or foil, as a vortex generator, the film is used to form a final polymeric layer being either a performance enhancement treatment or an erosion protection layer, with the beneficial effect of reducing drag either comparative to existing protective treatments or baseline, and or increasing lift, or lift to drag ratios by promoting spanwise vortices to be generated, assisting in reenergising the boundary layer aft of the film section. Thus, the invention both removes or minimises the causal mechanism of the aft facing step, thereby avoiding the adverse effects on lift and drag associated with such a step, and further, provides a series of conformal sub boundary layer vortex generators that enhance the boundary layer compared to a clean baseline blade configuration.

[0018] The v form planform is designed to achieve optimal vortex generation, and this results generally in having both hypotenuse attaining a relative angle to the free stream flow (being the adjacent direction) of between 15 degrees and 25 degrees included angle on each side of the adjacent direction. It should be noted that in cases where a squat triangular form is produced, and the hypotenuse to adjacent angle is large, in excess of 60 degrees, then the resultant flow may actually be adversely affected such as to increase drag compared to a continuous transverse aft facing step. It is therefore critical that the shape of the vortex generator applied acts to develop

streamwise vorticity. The macro sizing of the planform is a function of relative position on the chord and number of vortex generators than can be applied, and results in approximately a repeat or base width of the shapes at $0.1 \times$ Chord width. The height of the V is approximately $2 \times$ the repeat base width. Where the thickness of the protection film is of the order of 0.2% of the chord width, the sub boundary layer vortex generator achieves streamwise vorticity over the full chord of a foil.

[0019] The development of persistently streaming vorticity on both a pressure and a suction face of a foil from a very low profile vortex generator is contrary to published opinion by NASA, where testing has shown that current art "micro" VG's on a flat surface tend to develop vorticity downstream for no more than 40 times their height. A difference in the conditions tested by NASA and the observation of test of the invention is the surfaces that the invention is applied to, when said surface is a foil, are not flat, and they also operate at an angle of attack that allows the vortex to retain sufficient energy to remain attached to the trailing edge of the foil or blade.

[0020] The V form may be alternatively shaped as an ogival plan, which is more effective at generating a streaming vorticity than a V however has limited surface area for adhesion.

[0021] The polyurethane tape provides a moderately robust erosion protection surface, which can be readily replaced in the field, following damage or excessive wear. The material is effective in rain and sand erosion conditions as an erosion protection surface.

[0022] An alternate application may use the reverse form as a mask to terminate the sprayed or rolled on erosion protection polymer in an advantageous arrangement. The film has a planform arrangement that promotes advantageous development of vortices in either streamwise or transverse directions, dependent on the application sought. Variations of this film may optionally be applied beneficially to the leading edge or trailing edge of a foil or blade. In the case of the trailing edge, the mask film results in a transverse polymer being formed on the trailing edge lower surface which acts as a gurney tab.

[0023] Comparative to existing sprayed on or rolled on leading edge erosion treatments, the invention removes the adverse effects of an aft facing step at the trailing edge of the current art protective tape layer which acts to trip the boundary layer and cause premature transition to turbulent flow conditions in the boundary layer, or in extreme cases premature separation of the boundary layer. This condition increases drag of the surface, and acts generally to reduce circulation and therefore lift coefficients. The invention acts instead to additionally promote streamwise vorticity, which reenergises the boundary layer, promoting improved lift and potentially drag performance over a base section without any treatments. Existing erosion protection surface including tapes and paint adversely affect blade performance by approximately 2% to 4%. The application of the vortex generating system by use of the advantageous incorporation in an erosion protection surface, tape or other medium results in improved drag and lift performance of the blade in comparison to untreated blades of between 7% to 10%. The difference in performance between current art protection systems and the invention is approximately a 12% to 15% improvement in drag performance, and an additional improvement in lift coefficient, and angle of attack capability for the treated surface. For indicative initial values, a 120 mm tape applied to a 25' rotor leading edge, with a 183 mm chord 63015 profile, operating at an RPM of 530 RPM, with vortex generator plan-

forms of 18 mm length $\times$ 12 mm base, applied at the outer 1.0 m of the blade span, and with a 38 mm wide tape with ogival planform vortex generators of a size of 12 mm length by 8 mm width applied to the outer 250 mm of the leading edge of the tail rotor, which is 1.2 m span, operating at approximately 3500 RPM, reduces drag by approximately 10%. Additional indicative performance shifts include a reduction in autorotation sink rate, of approximately 10% consistent with the alteration of the figure of merit by a similar amount, reduction in torque required to maintain the constant operating rotor RPM of 10%, and a reduction in fuel flow of a similar amount. Additionally, it is notable that rotor deceleration on power loss to the rotor drive is at a lesser rate of RPM decay than the baseline blade, which is consistent with an improved figure of merit, resulting in an increase of Tau, the characteristic time. For a helicopter rotor blade so modified, the increase in Tau increases the time available for the crew to respond to a power failure and to enter autorotation. Further, on commencing an autorotative flare, the rotor RPM recovery is enhanced over current art, in that the RPM rise per g as a result of the flare is greater due to the reduced drag, and improved figure of merit. This factor results in an improved flare condition where RPM rise is higher, and the system has additional performance available to effect a successful landing. It should be noted that current art erosion protection tapes and paint surfaces which result in an aft facing step, adversely affect autorotation for the same reasons, that the current art adversely affects figure of merit through the reduction in lift and increase in drag over baseline configuration.

[0024] It is obvious to a person skilled in the art that application of a mass at the outer leading edge of a blade or rotor affects inertial loadings. The most significant loadings so affected are radial shear moment, pitch inertial moment, and in the case of a rotor or blade, feathering inertial moment. For a case where the invention directly replaces a current art erosion protection surface, there is minimal variation in these values. For a case where the invention is applied to a system that has not had current art erosion protection mechanisms applied, then an analysis of the impact of the additional mass to these areas is necessary, to ensure that the specific case retains adequate structural loading margins. Feedback through the flight control system in a helicopter is important, and may be affected by such mass additions, and needs to be assessed as a natural part of certification for aircraft or helicopter application of the invention. It is notable however, that in the case of the helicopter, the reduction in drag results in a lowering of in plane drag asymmetries, and thus acts to lower vibrational loads in flight. Additionally, where applied further inboard in the rotor span, the vortex generators delay stall condition occurring and therefore reduce slightly the periodic perturbation to the blade span from variations in spanwise lift development. In the case of a helicopter, it is noted that the reduction in torque requirement has impacts positively on torque loads throughout the transmission system, lowering applied torque to all components. Additionally, the lower torque requirement reduces the antitorque force required to be applied to maintain directional control, and therefore results in increased operational safety margins, lessening the risk of loss of tail rotor effectiveness, in single rotor helicopter configurations.

[0025] Manufacture of the film incorporating vortex generators is able to be accomplished using CAD/CAM plotter cutter systems, or alternatively by use of rotary cutters with the vortex generator shape embodied as a continuous series.

As the sizing of the vortex generators, and width of the tape form by which the location of the vortex generators is effected are determined by the blade profile, Reynolds number and operating angles of attack, it is more effective to conduct CAAD/CAM production for small run production of tapes. The repeatability and registration accuracy of commercial plotter cutters is adequate to achieve low mass variations between tapes. Film with suitable properties for subsonic application in areas without intense thermal heating are available as current art paint protection films from 3M, such as the 8760 & 8999KIT series, and from Avery Dennison, "Series 2010 Stoneguard". Additional and comprehensive data on application of such tapes is available from the US Army Erosion Protection Manual, and from the respective manufacturers. MSDS data is available from the manufacturer providing information on the suitability of the material to the application desired.

[0026] Alternative application of a painted or rolled erosion surface to a blade may be preferred in some embodiments, using the mask to form the vortex generating shapes, however the application of the erosion protection material will have larger variations in the applied profile and therefore mass distribution. The final product needs to be statically and preferentially dynamically balanced to compensate for these mass variations.

[0027] Where a lap joint may be used in a product fabrication, the application of a vortex generating trailing edge abutting to the trailing edge of said lap joint would act to promote boundary layer re-energising. This can be readily machined by CAD/CAM routing of materials such as aluminium and glass or carbon reinforced plastics. Additionally, plan shape can be incorporated by water jet cutting or laser cutting dependent on the material.

[0028] An alternative mechanism for applying a conformal sub boundary vortex generator to a lap joint may be achieved by attachment of a plurality of chevrons which are abutted to the aft face of the lap joint, with the apex of the chevron facing downstream. The thickness of this chevron is preferably equal to the lap joint thickness. While not the most desirable methodology for reducing drag at a lap joint, this does allow a retrofit of a mechanism to an existing structure, such as a current art airframe, wing, or hull.

[0029] It should be noted that in any application of conformal sub boundary vortex generators, the step pairing of said vortex generators can be accomplished, however this is not suitable on any component that is rotating, such as a blade or rotor, as the intermix of the vortices from the upper or leading vortex generator and the following step that develops the following vortices causes a separation of the upper vortices from the surface, and these are centrifuged radially as a consequence. Testing shows that the centrifuging of these vortices then affect in turn the outboard and lower series of vortices, with a resultant spanwise flow developing that is adverse to performance. In non rotating applications, this effect is not observed, and series may be employed effectively.

[0030] A plurality of conformal sub boundary vortex generators may also be attached at the trailing edge of a section, with the apex forward, and the base parallel with the trailing edge of the section, but preferably located in the region of 0 to 2 times the height of the vortex generator. The height of the vortex generator should always be a low order of the local boundary layer thickness, however vorticity is evident at very low heights, on the order of the generators applied to the leading edge. At the trailing edge, the reversed generator so

described acts to develop 2 counter rotating vortices that develop along the sides of the generator from the apex, but tend to lift above the surface of the generator towards the trailing edge. Additionally, at the trailing chordwise or transverse edge of the generator, a further vortice is generated bound by this edge and the surface of the section the generator is attached to. This vortice acts in the same manner as a very low height lift enhancing tab, or gurney tab. The streamwise vortices so developed interact with the Von Karman Street vortex sheet developed at the trailing edge of the section, and acts to disrupt this into streaming filaments instead of a sheet. This action reduces the momentum loss in the wake, and acts to delay tip vortice rollup of the Von Karman Street, thus acting to lessen lift induced drag. Application of any mechanism altering asymmetrically the trailing edge of a section will develop a pitching moment coefficient, which needs to be considered in the application. The pitching moment if resulting in excessive moment may cause an undesirable control demand or trim drag outcome, which can be mitigated by the application of such vortex generating elements on the opposite surface as well. Where applied on both sides, the designer has an alternative to locate such additional generators either in alignment or out of phase with the generators located on the other side of the section. In general but not all cases, it is desirable to attach such generators out of phase to promote the interaction of the vortices from both sides of the section acting on the Von Karman Street. In the case of a rotating blade or rotor, the alteration of the vortex rollup will have an effect on the intensity of the tip vortice and it's location. This change will generally impact the intensity of the blade-vortice interaction, but the extent will be dependent on the configuration and size of the generators. While evidence on tab application from computational fluid dynamics indicates that it is desirable to apply a series of tabs (as the invention acts when attached proximate to the trailing edge), along the complete span of a rotor, full scale testing shows that this may be the result of computer model limitations, and that in the case of a helicopter rotor, the application is best embodied in the mid span region. The aerodynamic pitching moment in such an embodiment of the invention is moderate as long as the generators are kept to a low height, which is also desirable from a lift/drag variation design consideration. Inertial pitching moment needs to be considered, which may increase control loads and vibration for conditions where cyclic pitch is applied, however testing shows the effects are not significant for low height generators. In testing, this moment was offset by application of conformal sub boundary layer vortex generators at the leading edge of the foil, balancing the inertial moments around the blade feathering axis. Testing further showed substantial vibration reduction, and substantial torque reduction, indicative of the lift enhancing tab effect being developed. Acoustic signature is changed by application of a tab system (vented by spacing gaps or otherwise). A designer versed in the art would naturally be aware that the addition of mass on a section can be adverse to flutter boundary margins. Analysis and testing indicate that the aerodynamic pitching moment is more significant than the center of mass shift, and that with care taken to minimise mass addition, the net outcome is an improved flutter margin. In the case of a helicopter rotor, the onset of flutter is additionally mitigated by the cyclical pitch rates. Application of a mechanism acting as a mid span trailing edge tab, additionally develops greater lift in the mid span region of a foil and unloads the tip, thereby allowing a lower collective blade angle to be applied

for a given total lift developed, minimising the impact of critical mach number on the tip of the foil, and resultant drag.

[0031] It is evident from the preceding that the invention is a passive mechanism, that mitigates the effects of current art structural design and erosion protection methods, and results in performance enhancement. A review of the bibliographic references will identify the basic mechanisms of flow that exist, and provides sufficient data for a parametric optimisation by a person skilled in the art.

[0032] It is advantageous to form a serrated or multiple V shaped trailing edge to an erosion layer on a foil or blade.

[0033] For a sprayed on or rolled on polymeric erosion surface applied to a surface, a mask with an embedded shape will result in advantageous profile being laid.

[0034] It would be advantageous to provide an elastomeric film that can conform to the surface profile of the foil or blade.

[0035] It would also be advantageous to provide a planform shape to the film which provides for chordwise or near chordwise promotion of vortices in the boundary layer of the foil or blade. These are applied to the upper surface, and in general to the lower surface.

[0036] It would further be advantageous to provide a high shear adhesive that allows for some movement of the substrate and surface treatment.

[0037] At a lap joint, it would be advantageous to apply a plurality of conformal sub boundary layer vortex generators with the apex aligned towards the rear, to re energise the boundary layer.

[0038] At a trailing edge of a foil or surface, it is advantageous to apply a series of conformal sub boundary layer vortex generators, with the apex facing forward toward the flow, to develop a set of counter rotating vortices to interact with and disrupt the Von Karman Street sheet into filaments, thereby delaying the onset of tip vortex rollup. Said trailing edge mechanisms additionally advantageously develop a transverse vortex in the wake of the base of the generator, which acts as a lift enhancing tab, advantageously improving lift and drag ratios in specific operational cases. Such an application advantages the lift distribution on a span, by unloading the tip of the span.

[0039] It is further advantageous to provide vortex generation with a mechanism that adds low mass to a system.

[0040] Damage tolerance by material and by design is advantageous for a vortex generating and flow modification system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] A complete understanding of the present invention may be obtained by reference to the accompanying drawings, when considered in conjunction with the subsequent, detailed description, in which:

[0042] FIG. 1 is a top perspective view of a generic foil;

[0043] FIG. 2 is a top perspective view of a foil with a current art erosion protection layer or tape applied;

[0044] FIG. 3 is a top plan view of an elastomeric erosion protection tape or application medium tape element incorporating sub boundary vortex generators;

[0045] FIG. 4 is a top perspective view of a current art erosion protection tape with v form sub boundary vortex generators applied at the aft facing step;

[0046] FIG. 5 is a top perspective view of a foil with a vortex generating application medium or vortex generating erosion protection layer applied;

[0047] FIG. 6 is a section view of an of a foil showing general flow conditions;

[0048] FIG. 7 is a plan view of an elastomeric erosion protection tape or application medium tape element incorporating ogival form sub boundary vortex generators;

[0049] FIG. 8 is a plan view of an elastomeric erosion protection tape or application medium tape element incorporating v form sub boundary vortex generators;

[0050] FIG. 9 is a plan view of a mask tape element incorporating v form sub boundary vortex generator shapes and a tip half v vortex generator form to facilitate application of an erosion protection paint or medium of beneficial planform shape;

[0051] FIG. 10 is a top perspective view of a series of vortex generators applied by an erosion protection layer or application medium incorporating sub boundary layer vortex generators;

[0052] FIG. 11 is a bottom perspective view of a series of asymmetrically applied trailing edge chevrons; and

[0053] FIG. 12 is a bottom perspective view of a series of out of phase upper and lower trailing edge chevrons.

[0054] For purposes of clarity and brevity, like elements and components will bear the same designations and numbering throughout the Figures.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0055] FIG. 1 is a top perspective view of a generic foil. This drawing shows the foil leading edge 26, foil or aero/hydrodynamic surface 10, and foil trailing edge 28.

[0056] FIG. 2 is a top perspective view of a foil with a current art erosion protection layer 12 or tape applied, to a foil or aero/hydrodynamic surface 10. It can be seen that the process of placing a tape around a foil leading edge 26 results in two aft facing edge 30 elements being produced, on the upper and lower faces of the foil or aero/hydrodynamic surface 10.

[0057] FIG. 3 is a top plan view of an elastomeric erosion protection layer 12 tape or application medium 14 tape element incorporating sub boundary vortex generators.

[0058] FIG. 4 is a top perspective view of a current art erosion protection tape with v form sub boundary layer vortex generators 16 applied at the aft facing edge 30. sub boundary layer vortex generators 24 are applied abutted in this case to the aft facing step or lapjoint 48 of the structure, depicted as v form sub boundary layer vortex generators 16. Such an application may be conducted on a current structure to minimise the area of aft facing edge 30 that exists at the location of lapjoints, generally in elastomeric application medium 14 of the same thickness as the lap joint. In this application, either v form chevrons or ogival form chevrons may be applied adhesively to the substrate. In such an application laminate substrate vents 46 may be incorporated to increase adhesion and minimise distortion of the application layer to the substrate.

[0059] FIG. 5 is a top perspective view of a foil with a vortex generating application medium 14 or vortex generating erosion protection layer 12 applied. the sub boundary layer vortex generators 24 thus applied develop a plurality of counter rotating vortices, one form each face, which convect along the freestream flow. These vortices act to re-energise the lower boundary layer by entraining fluid from the free stream and directing this flow towards the lower boundary layer. The re-energising of a boundary layer has a known

capacity to promote reduced drag in the boundary layer, by reducing the momentum layer thickness. The improved dynamics lead to a delay of development of the thickening of the boundary layer at the transition point into a turbulent boundary layer, and also delay the adverse pressure gradient in the boundary layer that ultimately results in separation of the boundary layer flow from the surface. The outcome of these improvements is improved drag characteristics, improved coefficient of lift for a given angle of attack, and increased angle of attack capability before aerodynamic stall occurs.

[0060] FIG. 6 is a of a foil showing general flow conditions as discussed above. The application of sub boundary layer vortex generators 24 is generally in the region forward of the transition point, in the laminar boundary layer region 38. The vorticity generated extends up the trailing edge of the foil. The position of the upper boundary layer transition point 32, lower boundary layer transition point 34 and separation point 36 can be evaluated using current art analysis based on Reynolds number, the arbitrary foil or aero/hydrodynamic surface 10 shape and knowing the angle of attack of the shape.

[0061] FIG. 7 is a plan view of an elastomeric erosion protection layer 12 tape or application medium 14 tape element incorporating ogival planform sub boundary vortex generator 18 planforms.

[0062] FIG. 8 is a plan view of a elastomeric erosion protection layer 12 tape or application medium 14 tape element incorporating v form sub boundary layer vortex generators 16.

[0063] FIG. 9 is a plan view of a sub boundary layer vortex generator mask 44 tape element incorporating v form sub boundary layer vortex generators 16 shape and a tip half v vortex generator form to facilitate application of an erosion protection paint or medium of beneficial planform shape. The vortex generating structure is applied as a sprayed or rolled application medium 14, which is preferred by the designer. Such medium may be a paint, or other erosion protection material as chosen by the designer as incorporating desirable properties.

[0064] FIG. 10 is a top perspective of a series of vortex generators applied by an erosion protection layer 12 or application medium 14 incorporating sub boundary layer vortex generators 24, to a foil or aero/hydrodynamic surface 10.

[0065] FIG. 11 is a bottom perspective view of a series of asymmetrically applied trailing edge chevrons. The sub boundary layer trailing edge chevron 50 series is located with the base from 2 times the height of the chevron to zero times the height forward of the trailing edge. The distance between the chevrons may be in the order of 1 to 10 times the width of the base, dependent on application velocities, and the apex angle. It can be assumed that an ogival planform may be applied as an alternate planform.

[0066] FIG. 12 is a bottom perspective view of the series of out of phase upper and lower trailing edge chevrons. The dotted centre chevron is located on the upper surface, whereas the other two solid line delineated chevrons are on the lower surface of the foil. The sub boundary layer trailing edge chevron 50 may be a triangular planform or alternatively an ogival form. The base is parallel to the trailing edge, and where incorporated on a swept trailing edge, it will result in a planform that is not symmetrical across the height of the chevron from the base.

[0067] Since other modifications and changes varied to fit particular operating requirements and environments will be

apparent to those skilled in the art, the invention is not considered limited to the example chosen for purposes of disclosure, and covers all changes and modifications which do not constitute departures from the true spirit and scope of this invention.

[0068] Having thus described the invention, what is desired to be protected by Letters Patent is presented in the subsequently appended claims.

What is claimed is:

1. An application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface for reducing drag or improving lift or lift to drag ratios, comprising:

means for developing a pair of counter rotating streamwise vortices for the purpose of re-energising the boundary layer, thereby improving lift or drag or lift to drag ratios.

2. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface in accordance with claim 1, wherein said means for developing a pair of counter rotating streamwise vortices for the purpose of re-energising the boundary layer, thereby improving lift or drag or lift to drag ratios comprises a conformal to substrate, elastomeric, planform for generating predominately streamwise vortices, that minimises extent of transverse linear trailing edge, thermally stable, chevron or triangular planform, with a planform of linear v sides, or, with a planform of ogival sides sub boundary layer vortex generators.

3. An application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface for reducing drag or improving lift or lift to drag ratios, comprising:

a conformal to substrate, elastomeric, planform for generating predominately streamwise vortices, that minimises extent of transverse linear trailing edge, thermally stable, chevron or triangular planform, with a planform of linear v sides, or, with a planform of ogival sides sub boundary layer vortex generators, for developing a pair of counter rotating streamwise vortices for the purpose of re-energising the boundary layer, thereby improving lift or drag or lift to drag ratios.

4. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

an elastomeric, thermally stable within operational limitations, bondable, erosion resistant polymer erosion protection layer, for providing erosion protection, integrally conformed to said sub boundary layer vortex generators.

5. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

an elastomeric, thermally stable, bondable application medium, for providing a medium to embed performance enhancing sub boundary layer vortex generators upon, integrally constructed to said sub boundary layer vortex generators.

6. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

a planform of aft facing steps preferentially angled to relative flow, fabricated in an erosion protection material, conformal, bondable, located with abutted to a lapjoint and with height equal to the lapjoint step v form sub boundary layer vortex generators, for generating a pair of counter rotating streamwise vortices that re-energise the boundary layer.

7. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

a sub boundary layer vortex generator mask, for masking a planform shape that is beneficial for developing a surface layer edge shape that promotes vorticity in the boundary layer.

8. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium.

9. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

10. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 3, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

11. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 4, further comprising:

a planform of aft facing steps preferentially angled to relative flow, fabricated in an erosion protection material, conformal, bondable, located with abutted to a lapjoint and with height equal to the lapjoint step v form sub boundary layer vortex generators, for generating a pair of counter rotating streamwise vortices that re-energise the boundary layer, adhesively appended to said lapjoint.

12. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 4, further comprising:

a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium.

13. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 4, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are

generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

14. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 4, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

15. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 5, further comprising:

a planform of aft facing steps preferentially angled to relative flow, fabricated in an erosion protection material, conformal, bondable, located with abutted to a lapjoint and with height equal to the lapjoint step v form sub boundary layer vortex generators, for generating a pair of counter rotating streamwise vortices that re-energise the boundary layer, adhesively appended to said lapjoint.

16. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 5, further comprising:

a sub boundary layer vortex generator mask, for masking a planform shape that is beneficial for developing a surface layer edge shape that promotes vorticity in the boundary layer.

17. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 5, further comprising:

a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium.

18. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 5, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

19. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 5, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter

rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

20. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 6, further comprising:

a sub boundary layer vortex generator mask, for masking a planform shape that is beneficial for developing a surface layer edge shape that promotes vorticity in the boundary layer.

21. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 6, further comprising:

a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium.

22. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 6, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

23. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 6, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

24. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 9, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

25. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 11, further comprising:

a sub boundary layer vortex generator mask, for masking a planform shape that is beneficial for developing a surface layer edge shape that promotes vorticity in the boundary layer.

26. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **11**, further comprising:

a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium.

27. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **11**, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

28. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **11**, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

29. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **12**, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

30. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **12**, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

31. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **13**, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of

chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

32. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **15**, further comprising:

a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium.

33. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **18**, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

34. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **21**, further comprising:

a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

35. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **21**, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

36. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim **22**, further comprising:

a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a

transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

37. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 26, further comprising:

- a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators.

38. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 26, further comprising:

- a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

39. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 27, further comprising:

- a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

40. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 29, further comprising:

- a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

41. The application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface as recited in claim 34, further comprising:

- a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow,

with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

42. An application of conformal sub boundary layer vortex generators to a foil or aero/hydrodynamic surface for reducing drag or improving lift or lift to drag ratios, comprising:

- an elastomeric, thermally stable within operational limitations, bondable, erosion resistant polymer erosion protection layer, for providing erosion protection;

- an elastomeric, thermally stable, bondable application medium, for providing a medium to embed performance enhancing sub boundary layer vortex generators upon;

- a planform of aft facing steps preferentially angled to relative flow, fabricated in an erosion protection material, conformal, bondable, located with abutted to a lapjoint and with height equal to the lapjoint step v form sub boundary layer vortex generators, for generating a pair of counter rotating streamwise vortices that re-energise the boundary layer;

- a conformal to substrate, elastomeric, planform for generating predominately streamwise vortices, that minimises extent of transverse linear trailing edge, thermally stable, chevron or triangular planform, with a planform of linear v sides, or, with a planform of ogival sides sub boundary layer vortex generators, for developing a pair of counter rotating streamwise vortices for the purpose of re-energising the boundary layer, thereby improving lift or drag or lift to drag ratios, integrally constructed to said application medium, and integrally conformed to said erosion protection layer;

- a sub boundary layer vortex generator mask, for masking a planform shape that is beneficial for developing a surface layer edge shape that promotes vorticity in the boundary layer;

- a series of, linear penetration of laminate, aligned parallel to flow, of a length of between 2 to 10 times the laminate height laminate substrate vents, for venting the base of the laminate to atmosphere to mitigate bubble formation, completely inserted to said application medium;

- a trailing edge planform that promotes streamwise vorticity, overlaps trailing component surface lapjoint, for join of component sections whereby streamwise vortices are generated to re-energise the boundary layer, and reduce drag, increase lift or improve lift/drag ratios, adhesively appended to said v form sub boundary layer vortex generators; and

- a plurality of separate, elastomeric, conformal, sub boundary layer height, series with spacing between chevrons of a minimum of 2 times base width, tip forward, base aft chevron configuration, relative to the freestream flow, with base located between 2 to zero times the height of chevron from the trailing edge of the surface sub boundary layer trailing edge chevron, for developing 2 counter rotating vortices proximate to the trailing edge, and a transverse vortex across the base of the chevron, bounded by the trailing edge surface and the aft face of the chevron.

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