FLAP EDGE NOISE REDUCTION FINS

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A flap of the type that is movably connected to an aircraft wing to provide control of an aircraft in flight includes opposite ends, wherein at least a first opposite end includes a plurality of substantially rigid, laterally extending protrusions that are spaced apart to form a plurality of fluidly interconnected passageways. The passageways have openings adjacent to upper and lower sides of the flap, and the passageways include a plurality of bends such that high pressure fluid flows from a high pressure region to a low pressure region to provide a boundary condition that inhibits noise resulting from airflow around the end of the flap.

20 Claims, 10 Drawing Sheets
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Fig. 6
Fig. 13

Fig. 13A
FLAP EDGE NOISE REDUCTION FINS

CROSS-REFERENCE TO RELATED APPLICATION


STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

FIELD OF THE INVENTION

The present invention relates to reduction in aircraft noise, and in particular to aircraft noise generated by the airframe of the aircraft during operation.

BACKGROUND OF THE INVENTION

One of the more important constraints to the continued growth of air traffic is the related concern regarding aircraft noise. This concern has resulted in increasingly stringent noise restrictions for airports. During aircraft take-off, the dominant aircraft noise source is generally the propulsion noise from the engines of the aircraft. During aircraft approach and landing, airframe noise becomes a prominent component on par with the engine noise. This airframe noise is caused by the interaction of the unsteady and typically turbulent airflow with the aircraft structures. The sound radiated from the side edge of a partial-span flap is one of the major contributors to airframe noise during aircraft approach and landing.

Previous approaches for reducing noise at the flap side edge have included protruding brushes and structural links between flap side edge and the main wing element. Although use of brushes at flap and slat tips has generally been effective for reducing noise produced by these components, the use of brushes has negative side effects. These side effects include degradation in aerodynamic performance of the high-lift wing during landing, and alteration of stall characteristics of the aircraft due to reduction in the maximum lift coefficient.

BRIEF SUMMARY OF THE INVENTION

One aspect of the present invention is a flap of the type that is movably connected to an aircraft to provide control of an aircraft in flight. The flap includes an elongated flap structure defining first and second opposite ends and leading and trailing edges extending lengthwise between the opposite ends. The elongated flap structure defining upper and lower side surfaces extending lengthwise between opposite ends and fore-aft between the leading and trailing edges. In use, airflow adjacent to the opposite ends forms high pressure and low pressure regions along the lower and upper sides, respectively. At least a portion of the first opposite end includes a plurality of substantially rigid laterally extending protrusions that are spaced apart to form a plurality of fluidly interconnected passageways between the protrusions. The passageways have openings adjacent to the upper and lower side of the surfaces of the elongated flap structure. The passageways include a plurality of generally horizontal rows, and the protrusions of each row may be horizontally spaced apart to form horizontal gaps. Protrusions of vertically adjacent rows are generally aligned vertically with the horizontal gaps such that the passageways comprise a plurality of vertically juxtaposed S-shaped bends.

Another aspect of the present invention is a flap of the type that is movably connected to an aircraft wing to provide control of the aircraft in flight, wherein the flap includes a flap structure having leading and trailing edges and defining a chord extending between the leading and trailing edges in a fore-aft direction. The structure has upper and lower surfaces extending between the leading and trailing edges. The flap structure further defines first and second opposite ends. At least the first end includes end surfaces forming a plurality of passageways extending vertically between the upper and lower surfaces, and a plurality of passageways extending fore-aft. The vertically extending passageways and the fore-aft passageways intersect and fluidly interconnect with each other at a plurality of horizontally and vertically spaced apart locations such that, in use, air flows from the vertically extending passageways into the fore-aft passageways. At least some of the vertical passageways and the fore-aft passageways are generally U-shaped in cross-section and open outwardly away from the first end of the flap structure such that air can’t flow transversely out of the passageways. The end surfaces may comprise a plurality of spaced apart rigid protrusions defining the passageways.

Yet another aspect of the present invention is a method of reducing noise radiated from a side edge of a partial-span wing flap during aircraft approaching and landing. The method includes providing a plurality of rigid protrusions on the side edge of the wing flap, and utilizing the protrusions to reduce a steady pressure differential experienced by the side edge in use. The method further includes utilizing the protru-
An aircraft 1 (FIG. 1) includes a fuselage 2, wings 3, and turbofan engines 6 or other propulsion system such as open rotor engines. The fuselage 2, wings 3, horizontal and vertical rear stabilizers 4 and 5, respectively. The aircraft 1 also includes turbofan engines 6 or other propulsion system such as open rotor engines. The fuselage 2, wings 3, horizontal and vertical rear stabilizers 4 and 5, respectively.

The aircraft may include an elongated flap structure 10 that is movably connected to the wing 3 adjacent to rear edge 14. The flap 10 is movably interconnected with the wing 3 by connectors 15 to provide control of aircraft 1. In general, powered actuators (not shown) or the like may be utilized to provide movement of flap structure 10 relative to the wing 3. The connecting structures 15 and powered actuators may also be of a conventional type, and are not therefore described in detail herein.

The flap structure 10 includes inboard and outboard ends 20 and 22, respectively, and forward and rearward portions 24 and 26, respectively. The flap structure 10 further includes an upper side 28 having an upper surface 29 and a lower side 30 having a lower surface 31 (see also FIG. 3).

Wing design for conventional transport aircraft is driven largely by cruise efficiency, i.e., the need to generate adequate lift with minimal drag for level flight at high speeds. Conventional high-lift systems (leading-edge slats and trailing-edge flaps) are designed to augment lift and improve stall characteristics at the low landing speeds required under many circumstances. These multi-element airfoil systems increase the effective chord (streamwise dimension) of the wing and thus its effective area. The major effect of the multi-element airfoil arrangement is to generate a much larger pressure difference (lift) between the upper (suction) and lower (pressure) surfaces than would be possible utilizing a single airfoil element. However, the multi-element implementation of the high-lift system presents many discontinuities and other unfavorable geometric characteristics to the flow. These geometric features cause considerable unsteadiness in the flow, which is the primary source of aeroacoustic noise.

The principal geometric features responsible for producing flow unsteadiness around flap 10, and thus noise, are the inboard and outboard edges 21 and 23, respectively, at the inboard and outboard ends 20 and 22, respectively. Computational results display strong suction peaks at the inboard and outboard edges 21 and 23, respectively of flap 10. The suction peaks are attributed to the presence of strong stream-wide vortices. Existence of a strong pressure differential between the bottom and top surfaces of the flap results in the formation of a complex dual-vortex system. Specifically, near the flap leading edge, the boundary layer on the bottom surface separates at the sharp corner and rolls up to form a stronger of the two vortices. Similarly, the thin boundary layer on the side edge separates at the sharp top corner and forms what is initially the weaker of the two vortices. Both vortices gain strength and size along the flap chord because of the sustained generation of vorticity. Downstream of the flap mid-chord, the side vortex begins to interact and merge with the vortex on the top surface. Eventually, a single dominant stream-wise vortex is formed.

Considerable flow unsteadiness (noise sources) is produced during the shear layer roll up, vortex formation and vortex merging process as well as by the interaction of the vortices with the sharp corners at the flap edge. The multi-element airfoil reverts to a smooth single-element profile during the cruise phase of flight to reduce wing drag. In current practice, the multiple airfoil elements are nested together in a retracted position.
The present invention includes a method and structure that reduces this source of airframe noise without compromising cruise efficiency, lift, and stall characteristics at landing. As discussed in more detail below, one aspect of the present invention is the use of acoustic liners that are imbedded within the flap structure to target the propagation phase of acoustic disturbances generated elsewhere. It also targets the very process of noise generation via interaction of the unsteady flow with the flap side edges 21 and 23. By limiting the control action to fluctuations within the flow, the gross aerodynamic dynamics are left unaltered and, hence, the expected aerodynamic penalty is small or none at all. However, the limited volume within the flap edge creates a significant packaging challenge. In addition, the broad frequency range (potentially greater than 3.5 octaves) to be attenuated reduces this source of airframe noise without compromising aerodynamic efficiency.

Known technology used in current commercial aircraft to reduce noise generated at the flap side edges involves implementation of “clean” configurations. Prior concepts include the application of fences, continuous moldline link, porous treatment, and brushes at the flap side edges. Given the critical functionality of aircraft flaps in the control of the aircraft, the presence of one or more acoustic liners according to the present invention. Similarly, acoustic liner 38 on the bottom portion of flap 10 may comprise a thin sheet of material 54 having a plurality of perforations 55 that permit sound to enter acoustic chambers 60 formed in body 18 of flap structure 10. The flap 10 may include only a top acoustic liner 34, or it may include only an end acoustic liner 36, or only a bottom acoustic liner 38, or it may include any combination of theliners 34, 36, and 38, depending upon the requirements of a particular application. Also, the acoustic liners 34, 36, and 38 may cover substantially all of the upper and lower surfaces at end portion 40, or they may extend over only a segment of end portion 40 of flap structure 10. Similarly, the end acoustic liner 36 may cover substantially all of the end 20 (or 21), or it may cover only a portion thereof. The acoustic liners 34 and/or 36 and/or 38 are designed to absorb sound having a specific acoustic frequency profile, and to provide optimum aerodynamic characteristics.

With further reference to FIG. 3, acoustic liner 34 on upper side 28 of flap 10 may comprise a plurality of internal acoustic chambers 60A-60E having openings 62A-62E at a porous upper surface 48 that form outer ends of chambers 60A-60E. In the liner 34 shown in FIG. 3, the acoustic chambers 60A-60E each include an outer portion 64A-64E, respectively, that extends inwardly in a direction that is generally transverse or perpendicular to porous upper surface 48. Also, chambers 60A and 60B have inner end portions 66A and 66B, respectively, that extend transverse relative to the outer portions 64A and 64B. A center chamber 60C, however, only includes a straight portion 64C. Acoustic chambers 60D and 60E also include inner, transversely-extending inner end portions 66D and 66E. The inner end portions generally extend at an angle in the range of about 30°-90° relative to outer portion 64A-64E. In general, the key constraint for the orientation of the internal chambers is the requirement that all of the chambers must fit within the volume 10 of the flap. The required chamber length can be realized utilizing straight, bent, L-shaped, or U-shaped configurations. The shape or combination of shapes chosen is dependent upon the lengths required to achieve optimal sound absorption (or pressure release) as well as the amount of volume available for the internal chambers. The acoustic chambers or passageways may have a uniform circular cross-sectional shape, or the cross-sectional shape may be quadrilateral of other geometry. For example, the cross-sectional shapes may be square, octagonal, hexagonal, diamond shaped, or irregularly shapes. The cross-sectional shape may be chosen to provide optimal use of the available internal space for a particular application. The cross-sectional area of the chambers/passageways may be substantially uniform along the length of the passageway, or it may increase or decrease. The specific orientations of the chambers 60 is typically not at all critical with respect to acoustic effects, and the orientation of the internal chambers 60 is largely driven by the need to fit the desired chamber lengths within the limited volume. The fact that most of the chambers 60 of FIG. 3 are nearly perpendicular to the surface at the surface was chosen to simplify the packaging requirement.

With further reference to FIG. 4, flap structure 10 may include a plurality of acoustic chambers 60, each having an opening 62. The acoustic chambers 60 may form an upper acoustic liner 34, a lower acoustic liner 38, and/or an end acoustic liner 36 (not shown in FIG. 4). Each of the acoustic chambers 60 may have a different length and/or shape to thereby absorb sound at different frequencies. Each chamber 60 may be configured to behave as a quarter-wavelength resonator (sometimes called an organ-pipe resonator). Thus,
the different lengths of the chambers 60 are selected for optimal absorption of different frequencies. By proper selection of the combination of lengths (in a general sense, length is measured along the center line of the chamber, whether that is a straight path or it includes one or more bends), a broadband sound absorber can be achieved. Also, the chambers 60 within flap 10 (FIG. 4) may be connected by optional internal passageways 72, such that sound enters through the porous surfaces and travel in multiple directions within the flap 10. Chambers or passageways 60 may have opposite ends that are both open on either the upper surface or the lower surface of flap 10, or they may have one end that is on the top side of flap 10, and an opposite end that is on the bottom of flap 10. For example, the chambers 60F and 60G (FIG. 4) could comprise a single chamber extending all the way through flap 10 whereby noise is transmitted internally from the lower surface 12 of flap 10 to the upper surface 11 of flap 10, and/or visa-versa. Designing chambers or passageways 60 such that sound travels in multiple directions within the flap 10 via interconnecting passageways, and exits the flap 10 at a different portion of the porous surface represents one way to provide broadband sound absorption and/or dampening of hydrodynamic fluctuations (i.e. to reduce efficiency of their conversion to propagating sound).

The internal chambers 60 (or the entire flap interior) can also be filled with foam or other acoustic filler material, which changes the manner in which sound is absorbed as it travels through the flap 10. The flap 10 may include a single internal chamber 60, a plurality of substantially identical internal chambers 60, or a plurality of internal chambers 60 having different lengths and/or shapes. If a number of variable-depth chambers, separated by impervious partitions and terminated within the body of the flap, are imbedded within the flap side edge 21 (or 23), a local-reacting liner results. In the configuration shown in FIG. 4, the internal chambers 60 (or channels) have a circular cross-sectional shape with relatively small diameters, such that a large number of the internal chambers 60 can fit within the relatively small volume of flap 10. According to other aspects of the present invention, the diameter of the interior chambers can be increased, with a porous face sheet covering the resultant openings at the porous surface to provide the desired acoustic resistance. A large number of configurations may be utilized to achieve similar surface acoustic impedance boundary conditions by varying the geometry of the internal chambers and the surface face sheet.

With further reference to FIG. 5, a flap 10A according to another aspect of the present invention may include upper and lower surfaces 48A and 55A that are porous or have porous portions. Internal space 80 of flap 10A is partially or completely filled with filler material such as foam 82. Foam 82 may comprise metallic foam or other suitable material. The upper and lower surfaces 48A and 55A, respectively, may comprise thin upper and lower sheets of material 84 and 86 having a plurality of perforations therethrough. Sheets of material 84 and 86 may be aluminum, fiber composites, or other suitable material.

The acoustic liners may also comprise extended-reaction liners. For example, the internal volume of the flap side edge 21 (or 23) may be filled with a bulk material such as foam, and allowing communication between the interior and exterior of the flap side edge via a porous surface such as a perforated face sheet, wire mesh, or the like.

Because of the porous nature of one or more segments of the flap surface near the side edge 21 (or 22), the aeroacoustic environment outside the flap 10 can communicate with the chamber or chambers 60 within the flap 10. As discussed above, the interior volume of the flap 10 contains one or more chambers 60, which may or may not be filled with sound-absorbent acoustic material such as a porous bulk material such as, but not limited to, foam or the like. The acoustic treatment imbedmed within the volume of the flap 10 changes the boundary condition at the surface of the flap 10, such that the strength of the local hydrodynamic fluctuations associated with the scrubbing of the unsteady flow over the side edge surface is reduced. Furthermore, the change in the boundary condition also inhibits the conversion of hydrodynamic fluctuations into noise, and also inhibits near field propagation of this noise. The boundary condition presented at the porous surface is such that it inhibits sound from being generated by the flow interaction with this surface.

Software design tools are available to assist in the design of the interior chambers 60 of the flap 10. Known software previously utilized for design of acoustic liners in engine nacelles may be utilized to assist in the design of chambers 60. Such software may also be modified somewhat to thereby adapt it for use in designing chambers 60 in flap 10. The use of these design tools allows the efficient design of acoustic liners with multiple chambers, each of which can be designed with unique geometries. This design tool also allows a convenient evaluation of configurations designed to fit within a small volume, while exploring combinations of chambers that result in broadband noise reduction.

With further reference to FIGS. 6-8, a wing flap 100 according to another aspect of the present invention includes a first end portion or region 102 including a plurality of protrusions 105 that reduce noise production at edge 104 of flap 100. As discussed in more detail below, the protrusions 105 form a plurality of intricate, interconnected passages such that high pressured fluid entering the space between protrusions 105 flows toward one or more regions of lower pressure on other parts of the flap end portion 102. The high losses/damping induced by the intricate internal structure provides a strong mechanism for equalizing the steady pressure field on the surfaces adjacent to the edge 104 of flap 100, and also reduces the amplitude of fluctuations in the flow near the flap edge 104.

Wing flap 100 may have an overall construction that is substantially similar to the flap 10 described in more detail above in connection with FIG. 1. Wing flap 100 may be operably connected to an aircraft wing structure 103 utilizing known mechanisms (not shown) that provide for deployment of wing flap 100, for example, during takeoff and landing. It will be understood that wing flap 100 may include an opposite end portion (not shown) that may also include a plurality of protrusions 105. Flap 100 may include an upper surface 106, a lower surface 108, a leading edge 110, and a trailing edge 112.

With further reference to FIG. 9A, wing flap 100 defines a chord length "C" between the leading edge 110 and trailing edge 112. In one embodiment, the protrusions 105 are positioned in a region 102 between first line 114 and second line 116. The first line 114 may comprise a 90% chord line, and line 116 may comprise a 10% chord line. That is the line 114 may be spaced a distance equal to 10% of the chord C from leading edge 110, and line 116 may be spaced a distance equal to 90% of the chord from leading edge 110. In this example, the region 102 that includes protrusions 105 extends a length that is equal to 80% of the chord C. Depending on the specifics of the design and application of the wing flap 100, and the lift wing configuration of a given application, the protrusions 105 may extend closer to leading edge 110 and/or closer to trailing edge 112, or the protrusions 105 may be spaced further from leading edge 110 and/or trailing edge.
passageways extend between and fluidly interconnect as described above, it will be understood that the protrusions are staggered. Thus, the gap \( g \) of a given protrusion may form generally uniform cross-sectional shape, or the protrusions may be tapered (e.g. cone-shaped, etc.) such that the sides of the "U-shape" of the passageways or channels are not linear in cross-section.

The numerous bends resulting from the staggered position of protrusions prevents the creation of direct passageways between the upper and lower surfaces of wing flaps. Also, because the vertical passageways are fluidly connected to the horizontal passageways at junctions, every region within the internal flow passages is in fluid communication with all other regions in volume. Due to significant interactions between the wakes produced by each protrusion, viscous losses within the volume are significant, thus substantially affecting the steady component of the airflow around or at edge of wing flap. Because the protrusions are relatively stiff/structural, the loss in flap lift is typically much less than the loss in flap lift experienced with conventional known softer brushes. The global communication that exists among the flow passages provides a mechanism to lessen the pressure gradients in the vicinity of the flap edge. This creates a desired alteration to both the steady and unsteady (fluctuating) components of the flow field at flap side edge. In addition to the flow losses, the interconnection of the internal passageways presents a reactive connection to the impendence of the tip surface.

The overall characteristics of the protrusions and their effectiveness in positively altering the edge flow field depend on several parameters. With reference to Fig. 11A, the fin width \( w \), spacing \( s \), thickness \( d \), gap \( g \), the length of the individual protrusions, and the extent of the edge surface area where the protrusions are applied (i.e. the distance between lines and of Fig. 9A) are significant parameters. In general, the ratio of protrusion spacing \( s \) to protrusion width \( w \) preferably falls within the range of \( 1.2w/s < 1.6 \). The ratio of protrusion width \( w \) to the protrusion thickness \( d \) preferably falls within the range of \( 1.0w/d < 5.0 \).

With further reference to Figs. 12, 13, and 13A the limit of \( w/d \) approaching 1.0 corresponds to protrusions having a circular cross-section. Circular protrusions have a diameter \( d \), and define at center 160. The protrusions may be spaced apart by distances \( s \) such that each circular protrusion is equally spaced from adjacent protrusions. Referring again to Fig. 11, the ratio of the gap \( g \) to the protrusion thickness \( d \) is preferably within a range of about 0.5 \( g/d < 1.2 \). Protrusions may form generally linear rows 236A-236I, and curved rows 238A-238C. Protrusions form a plurality of interconnected passageways in substantially the same manner as protrusions. In addition to the oblong and circular cross-sectional configurations described above, it will be understood that the protrusions may have other cross-sectional shapes (e.g. triangular, square, diamond, etc.). Furthermore, a general flap edge may include protrusions having different shapes and/or different sizes in different regions.
The edge treatment described above in connection with FIGS. 6-13A reduces the amount of airflow noise radiated to a community adjacent to an airport or other such facility. Unlike known soft brushes, the protrusions/edge treatment of the present invention specifically addresses the process of noise generation. This is a result of the interaction of unsteady flow with the flap side edge 104. This edge treatment also simultaneously minimizes the aerodynamic penalties/losses. By limiting the control action to the steady and fluctuating fields within a very small region near the edge 104, the gross aerodynamic characteristics of the flap 100 are left unaltered and there is little, if any, aerodynamic penalty. Because of the gaps between the protrusions 105 and/or 105A protruding from one or more segments of the flap surface 124, the aeroacoustic environment outside the flap 100 can communicate with the complex and elaborate passages 142 and 150 associated with the substantially rigid and/or 105A embedded within the solid structure. The intricate passages 142 and 150 alter the effective boundary condition at the end edge 104 of the flap 100, significantly reducing the pressure differential experience by the edge 104. As a result, the vortex formation process at the edge 104 is either delayed or substantially weakened in such a way that the strength of the local hydrodynamic fluctuations associated with the scrubbing of the unsteady flow over the side edge surface 104 is diminished. Furthermore, the change in boundary condition is also believed to inhibit the conversion of hydrodynamic fluctuations to noise and the far-field propagation of this noise. While preferred embodiments of the present invention are shown and described, it is to be understood that variations and modifications can be made on the aforementioned structure without departing from the concepts of the present invention, and further it is to be understood that such concepts are intended to be covered by the following claims unless these claims by their language expressly state otherwise.

The invention claimed is:

1. A flap of the type that is movable connected to an aircraft wing to provide control of an aircraft in flight, the flap comprising:

an elongated flap structure defining first and second opposite ends and leading and trailing edges extending lengthwise between the opposite ends, the elongated flap structure defining upper and lower side surfaces extending lengthwise between opposite ends and fore-aft between the leading and trailing edges, and wherein, in use, air flow adjacent to the opposite ends forms high pressure and lower pressure regions;

wherein at least a portion of the first opposite end includes a plurality of substantially rigid, laterally extending protrusions that are contained within the volume of the flap structure and are spaced apart to form a plurality of fluidly interconnected passageways between the protrusions, the passageways having openings adjacent to the upper and lower side surfaces of the elongated flap structure, wherein the protrusions maintain the profile of the flap and wherein the protrusion distribution is not segmented by significant voids in the fore-aft direction between the leading and trailing edges; and further wherein the passageways include a plurality of bends whereby, in use, high pressure fluid enters the openings at a high pressure region and flows through the passageways to a low pressure region to thereby provide a boundary condition that inhibits noise resulting from airflow around the first opposite end of the elongated flap structure.

2. The flap of claim 1, wherein:

the protrusions form a plurality of continuous and generally horizontal rows.

3. The flap of claim 2, wherein:

at least some of the horizontal rows are substantially linear.

4. The flap of claim 2, wherein:

the protrusions of each row are horizontally spaced apart to form horizontal gaps having a horizontal gap dimension thereof, and wherein protrusions of vertically adjacent rows are generally aligned vertically with the horizontal gaps such that the passageways comprise a plurality of vertically juxtaposed S-shaped bends.

5. The flap of claim 4, wherein:

the one end defines a base surface extending transversely between the upper and lower side surfaces, and wherein the protrusions extend from the base surface to define lengths, and wherein at least some of the protrusions are adjacent to the leading and trailing edges, and wherein the lengths of the protrusions adjacent to the leading edge are significantly less than the lengths of the protrusions adjacent to the trailing edge.

6. The flap of claim 5, wherein:

the upper and lower sides of the elongated flap structure define a maximum thickness therebetween, and wherein the protrusions adjacent to the leading edge have a length that is in a range of about 30% to about 40% of the maximum thickness, and the protrusions adjacent to the trailing edge have a length that is in a range of about 100% to about 130% of the maximum thickness.

7. The flap of claim 6, wherein:

the protrusions define generally planar end surfaces, and wherein the end surfaces are substantially coplanar.

8. The flap of claim 6, wherein:

each protrusion defines a distance from the leading edge; the base surface is generally planar such that the lengths of the protrusions increase linearly as a function of the distances of the protrusions from the leading edge.

9. The flap of claim 4, wherein:

the protrusions include forwardly and rearwardly facing surfaces that define a width therebetween, the protrusions further including upwardly and downwardly facing surfaces defining a thickness therebetween, and wherein a ratio of the width to the thickness of the protrusions is in a range of about 1.0 to about 5.0.

10. The flap of claim 9, wherein:

a ratio of the horizontal gap dimension to the thickness is in a range of about 0.5 to about 1.2.

11. The flap of claim 9, wherein:

the protrusions define centers, and the centers of adjacent pairs of protrusions in each row define a spacing dimension therebetween, and wherein a ratio of the spacing dimension to the width of at least one of the protrusions of each adjacent pair of protrusions falls in a range of about 1.2 to about 1.6.

12. The flap of claim 11, wherein:

the protrusions of each row have substantially identical cross sectional shapes and sizes.

13. The flap of claim 12, wherein:

the protrusions in each row are equally spaced apart from adjacent protrusions in each row.

14. A flap of the type that is movably connected to an aircraft wing to provide control of an aircraft in flight, the flap comprising:

an elongated flap structure defining first and second opposite ends and leading and trailing edges extending lengthwise between the opposite ends, the elongated flap structure defining upper and lower side surfaces
13. extending lengthwise between opposite ends and fore-aft between the leading and trailing edges, and wherein, in use, air flow adjacent to the opposite ends forms high pressure and lower pressure regions; wherein at least a portion of the first opposite end includes a plurality of substantially rigid, laterally extending protrusions that are contained within the volume of the flap structure and are spaced apart to form a plurality of fluidly interconnected passageways between the protrusions, the passageways having openings adjacent to the upper and lower side surfaces of the elongated flap structure, wherein the protrusions maintain the profile of the flap and wherein the protrusion distribution is not segmented by significant voids in the fore-aft direction between the leading and trailing edges; and further wherein the passageways include a plurality of bends whereby, in use, high pressure fluid enters the openings at a high pressure region and flows through the passageways to a low pressure region to thereby provide a boundary condition that inhibits noise resulting from airflow around the first opposite end of the elongated flap structure; wherein the protrusions form a plurality of continuous and generally horizontal rows; wherein the protrusions of each row are horizontally spaced apart to form horizontal gaps, and wherein protrusions of vertically adjacent rows are generally aligned vertically with the horizontal gaps such that the passageways comprise a plurality of vertically juxtaposed S-shaped bends; wherein the one end defines a base surface extending transversely between the upper and lower side surfaces, and wherein the protrusions extend from the base surface to define lengths, and wherein at least some of the protrusions are adjacent to the leading and trailing edges, and wherein the lengths of the protrusions adjacent to the leading edge are significantly less than the lengths of the protrusions adjacent to the trailing edge; wherein the upper and lower sides of the elongated flap structure define a maximum thickness therebetween, and wherein the protrusions adjacent to the leading edge have a length that is in the range of about 30% to 40% of the maximum thickness, and the protrusions adjacent to the trailing edge have a length that is in a range of about 100% to about 130% of the maximum thickness; wherein each protrusion defines a distance from the leading edge; the base surface is generally planar such that the lengths of the protrusions increase linearly as a function of the distance of the protrusions from the leading edge; and wherein: the elongated flap structure defines a chord length at the first opposite end; the elongated flap structure defines a smoothly curved concave outer surface extending along the leading edge such that the elongated flap structure is generally U-shaped in cross section adjacent to the leading edge, and wherein the upper and lower sides converge at the trailing edge such that the elongated flap structure is generally V-shaped in cross section adjacent to the trailing edge, and wherein the first opposite end of the elongated flap structure includes a generally planar forward surface portion that is generally orthogonal to the concave outer surface and intersects the concave outer surface to define a curved perimeter portion, the planar forward surface portion defining a generally vertical rear edge, the elongated flap further including a generally planar rearwardly facing vertical surface that intersects the planar forward surface portion along the vertical rear edge, and wherein the generally planar rearwardly facing vertical surface is spaced apart from the leading edge at a distance that is equal to approximately 10% of the chord length; the first opposite end of the elongated flap structure further including a generally planar rearward surface portion that is coplanar with the generally planar forward surface portion and with the generally planar end surfaces of the protrusions, the elongated flap structure further including a generally planar forwardly facing vertical surface that intersects the generally planar rearward surface portion such that the rearward surface portion defines a perimeter that is approximately triangular, and wherein the generally planar forwardly facing vertical surface is spaced apart from the trailing edge a distance that is equal to approximately 10% of the chord length.

14. A flap of the type that is movably connected to an aircraft wing to provide control of the aircraft in flight, the flap comprising: a flap structure having leading and trailing edges and defining a chord extending between the leading and trailing edges in a fore-aft direction, the flap structure having upper and lower surfaces extending between the leading and trailing edges, the flap structure further defining first and second opposite ends; wherein at least the first end includes end portions forming a plurality of passageways contained within the volume of the flap structure and extending vertically between the upper and lower surfaces, and a plurality of passageways extending fore-aft, and wherein the vertically extending passageways and the fore-aft passageways intersect and fluidly interconnect with each other at a plurality of horizontally and vertically spaced apart locations such that, in use, air flows from the vertically extending passageways into the fore-aft passageways, and wherein at least some of the vertical passageways and the fore-aft passageways are generally U-shaped in cross section and open outwardly away from the first end of the flap structure such that air can flow transversely out of the passageways.

15. A flap of the type that is movably connected to an aircraft wing to provide control of the aircraft in flight, the flap comprising: a flap structure having leading and trailing edges and defining a chord extending between the leading and trailing edges in a fore-aft direction, the flap structure having upper and lower surfaces extending between the leading and trailing edges, the flap structure further defining first and second opposite ends; wherein at least the first end includes end portions forming a plurality of passageways contained within the volume of the flap structure and extending vertically between the upper and lower surfaces, and a plurality of passageways extending fore-aft, and wherein the vertically extending passageways and the fore-aft passageways intersect and fluidly interconnect with each other at a plurality of horizontally and vertically spaced apart locations such that, in use, air flows from the vertically extending passageways into the fore-aft passageways, and wherein at least some of the vertical passageways and the fore-aft passageways are generally U-shaped in cross section and open outwardly away from the first end of the flap structure such that air can flow transversely out of the passageways.

16. The flap of claim 15, wherein: the end portions comprise a plurality of spaced apart rigid protrusions.

17. The flap of claim 16, wherein: the protrusions are disposed in rows, wherein the protrusions of adjacent rows are staggered such that the passageways form a plurality of vertically juxtaposed S-shaped bends.

18. A method of reducing noise radiated from a side edge of a partial-span wing flap during aircraft approach and landing, the method comprising: providing a plurality of rigid protrusions on the side portion of the wing flap; utilizing the protrusions to reduce a steady pressure differential experienced by the side edge in use; utilizing the protrusions to reduce the strength of local hydrodynamic fluctuations associated with scrubbing of unsteady flow over the side edge.

19. The method of claim 18, wherein: the protrusions form a plurality of interconnected non-linear passageways; and including: forming regions of high air pressure on the side edge and regions having lower air pressure on the side edge; causing at least some of the air to flow through the passageways from the high pressure regions to the lower pressure regions.

20. The method of claim 19, including: positioning at least some of the protrusions in generally parallel rows.