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Slemmons

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[54] **AIR FOIL WITH VORTEX GENERATORS**

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95030

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[52] **U.S. Cl.** **114/103**, 244/145
[51] **Int. Cl.** **B63h 9/06**
[58] **Field of Search** 114/103, 39; 244/142, 145

[56] **References Cited**

UNITED STATES PATENTS

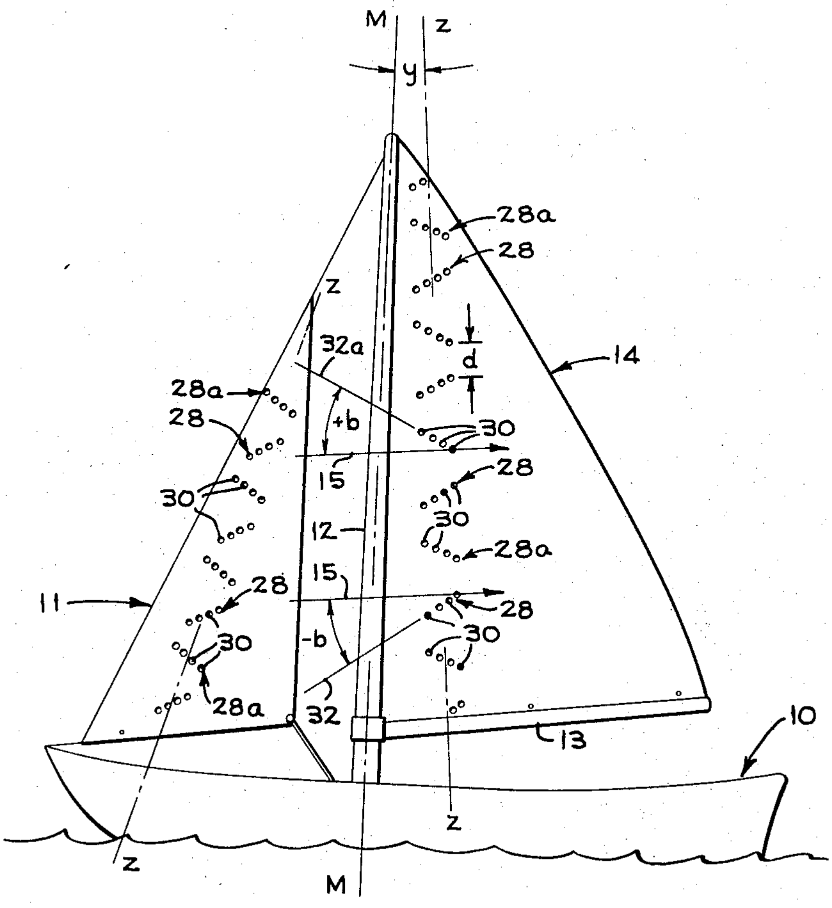
2,971,488	2/1961	Morisette	114/103
3,174,453	3/1965	Lemoigne	114/103
3,612,449	10/1971	Sepp	244/145

Primary Examiner—Trygve M. Blix

[57] **ABSTRACT**

A sail is provided with short rows of closely spaced holes, with the axes of the rows converging and being inclined at an acute angle to the path of the free air past the sail. The converging ends of individual rows are relatively widely spaced and the rows are arranged in an array from the head to the foot of the sail. The angle between the axis of each row of holes and the direction of the free air flow path is alternated along the array from a positive to negative angle. The rows of holes, in turn, produce a row of discrete air jets on the convex, low pressure side of the sail, forming angled aerodynamic "fences." These fences present a partial obstruction to the flow of the free air past the sail, causing the air to form twisted streams when spilling over the aerodynamic fences. These streams form continuous, helical trailing vortices that mix the free air stream with the slower moving boundary layer of air next to convex surface of the sail. The resulting mixing action continually re-energizes the boundary layer of air, thus preventing stall and improving the driving force of the sail. The principle is also useful in the control of parachutes and other thin air foils.

16 Claims, 13 Drawing Figures



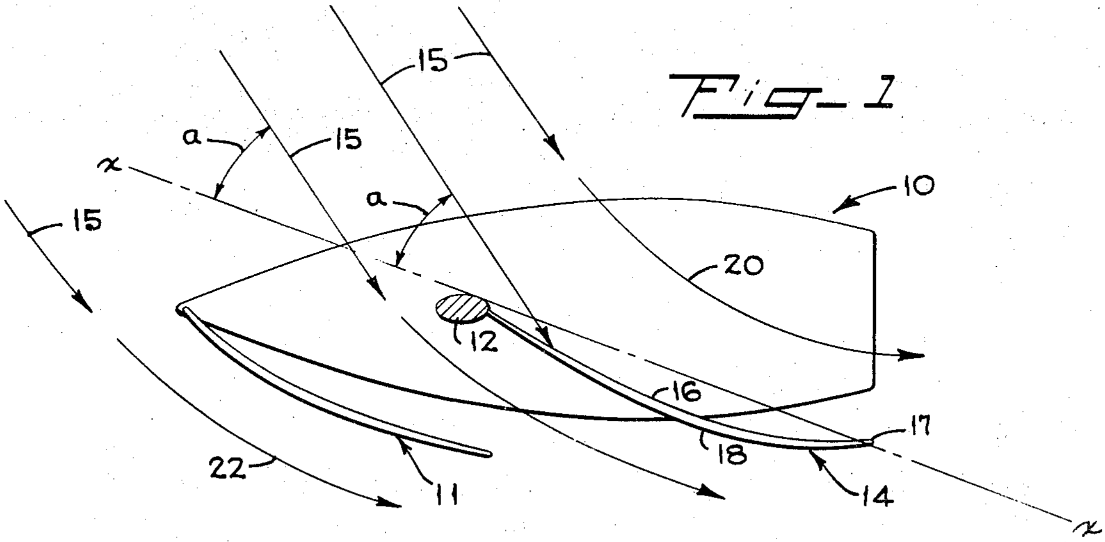


Fig-1

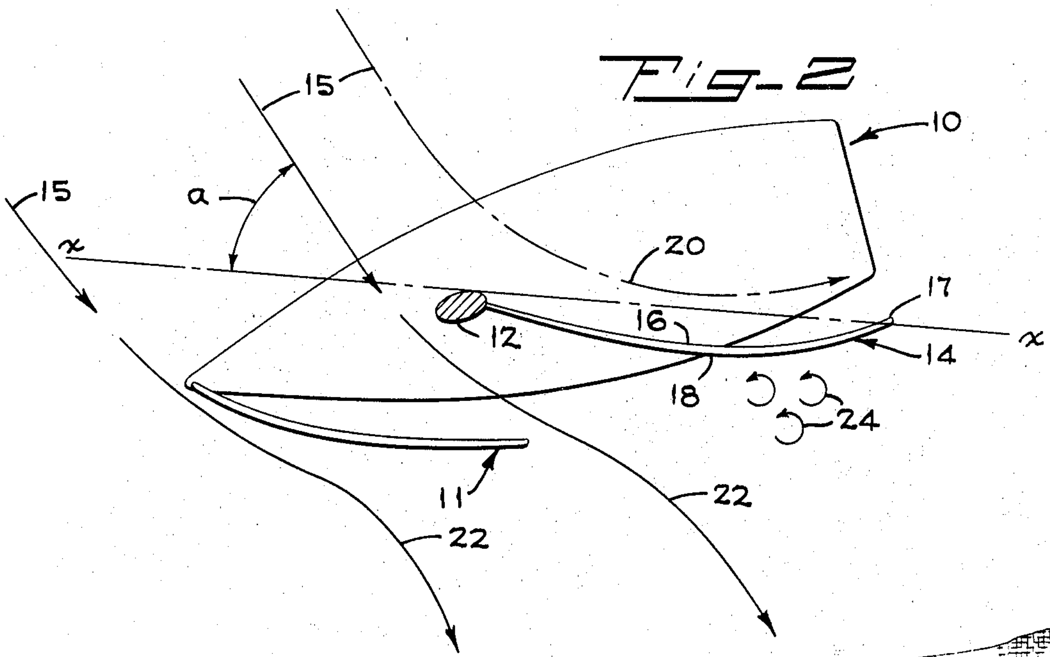


Fig-2

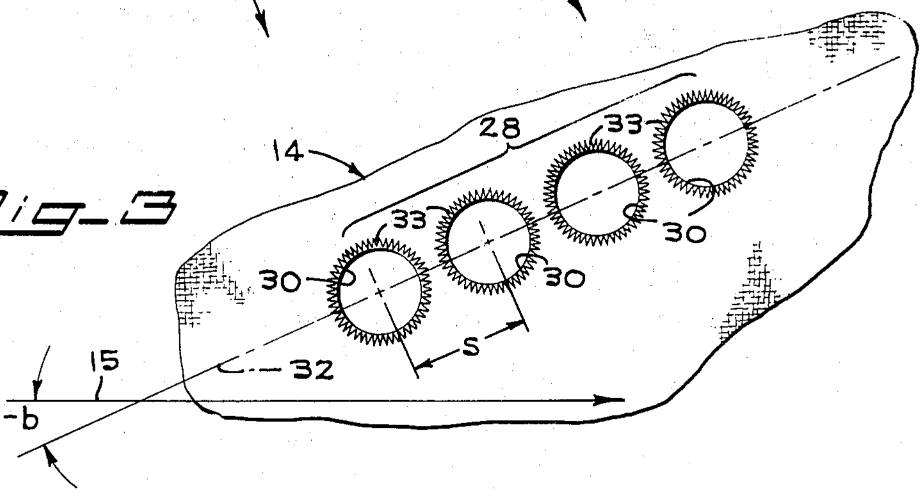
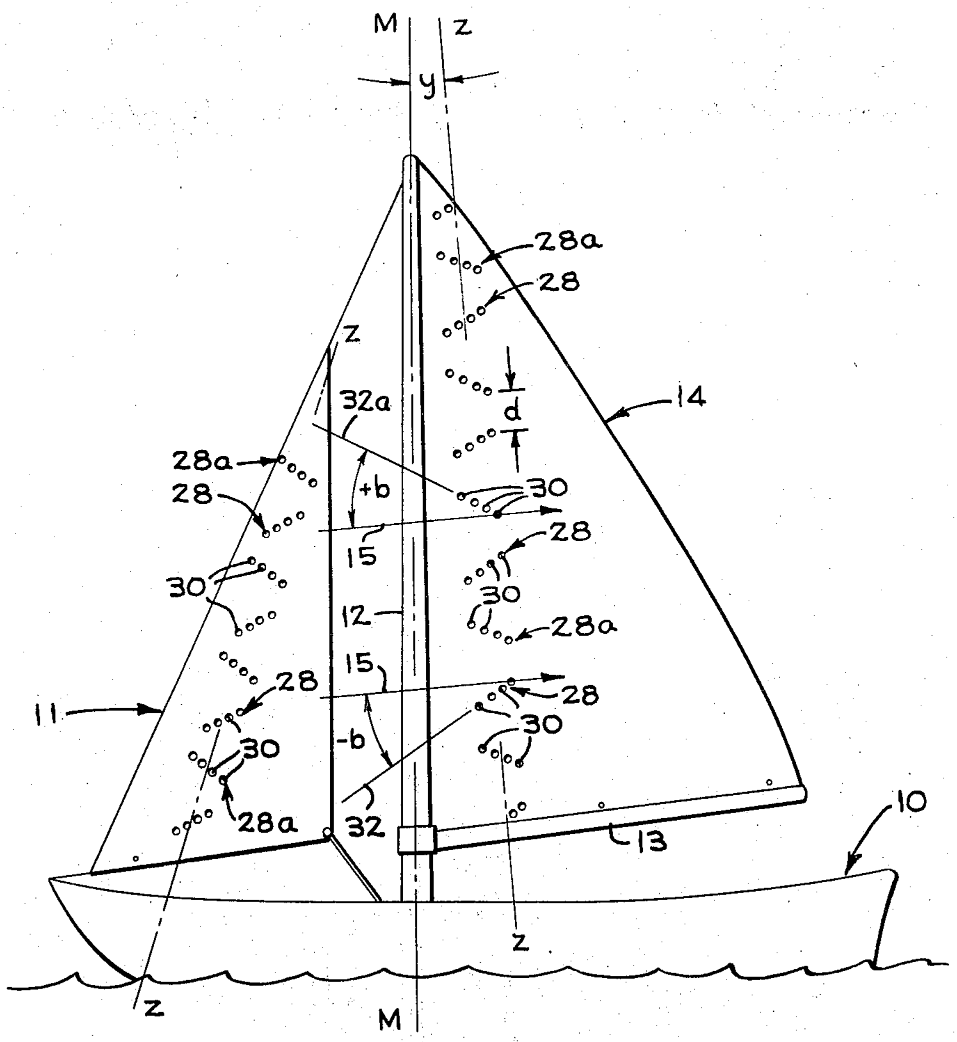


Fig-3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z
y
28a
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Fig-4

Fig-5

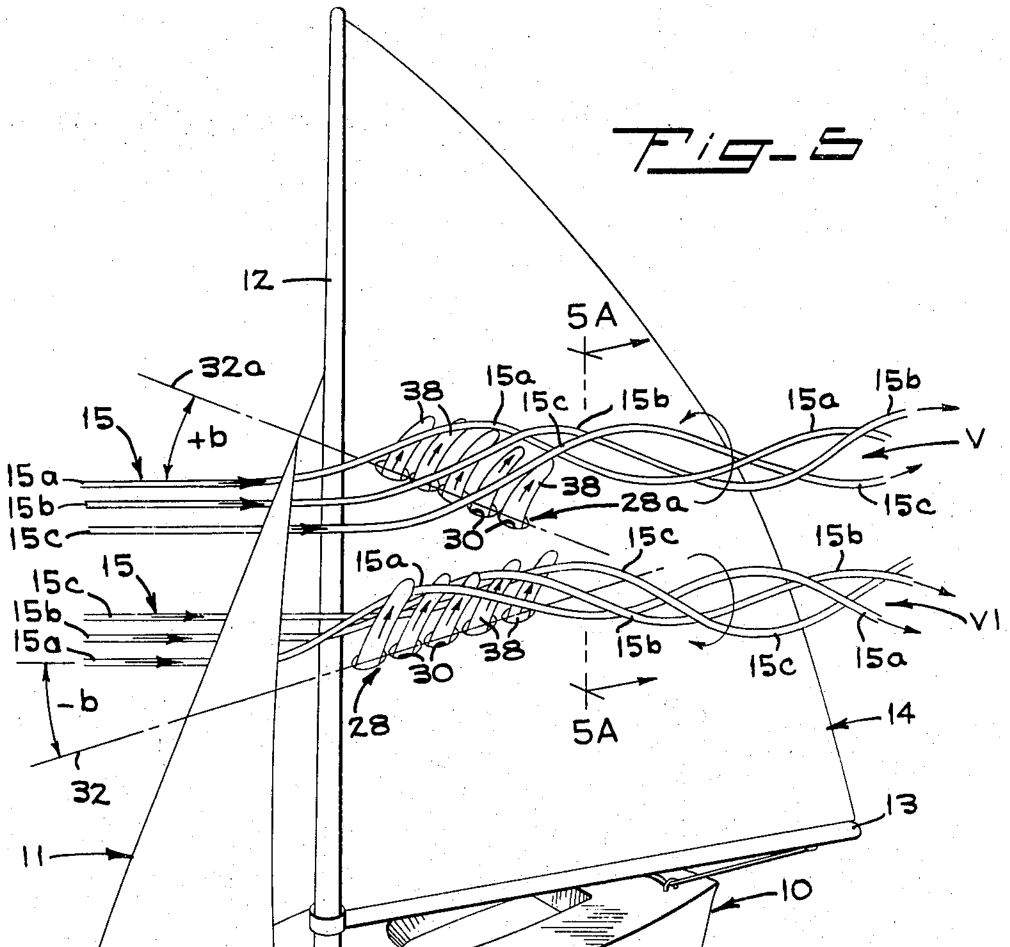


Fig-5A

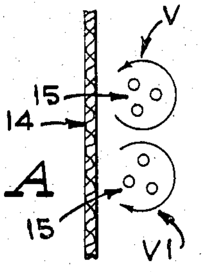


Fig-6

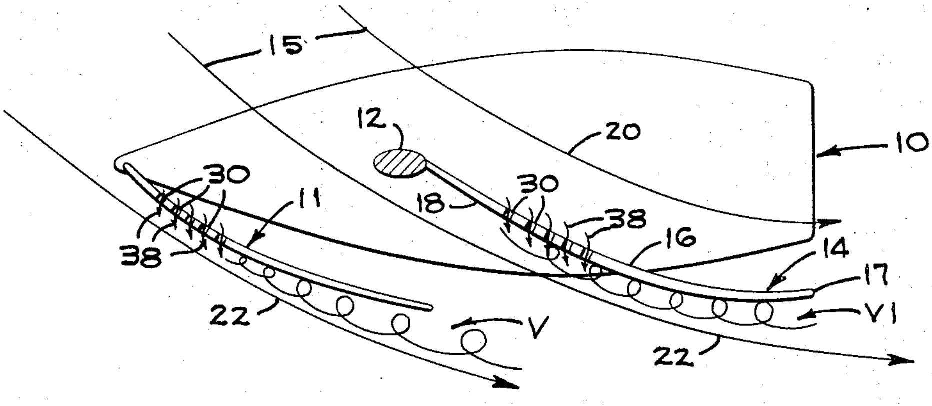


Fig-9

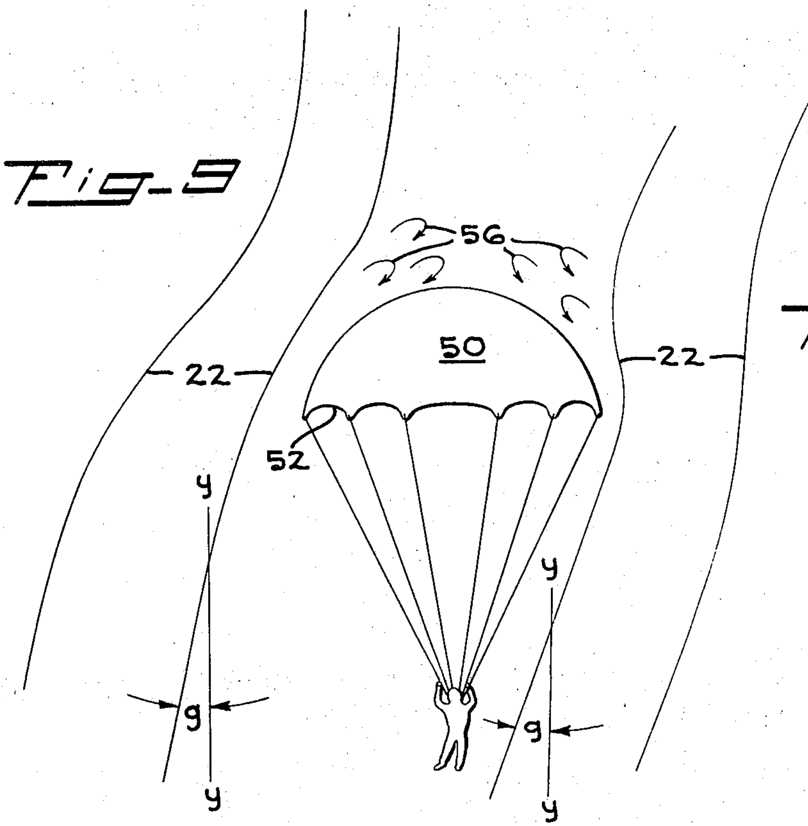


Fig-11

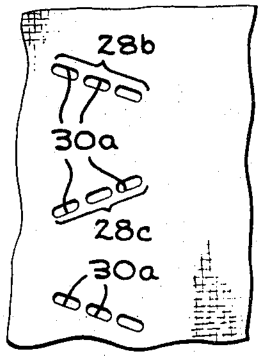
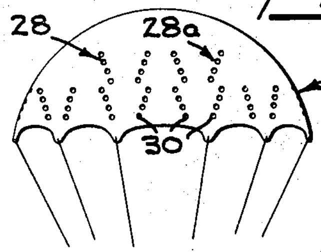


Fig-10A



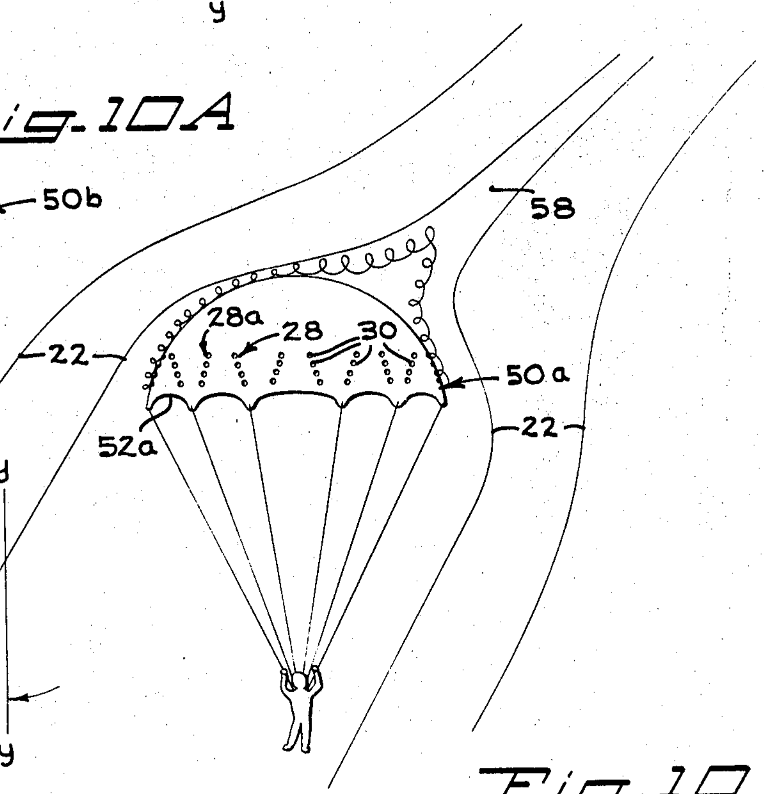
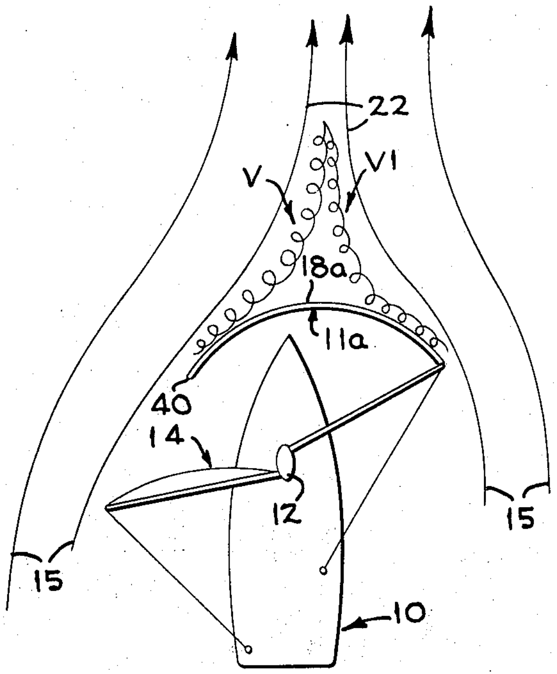


Fig-10

Fig-8



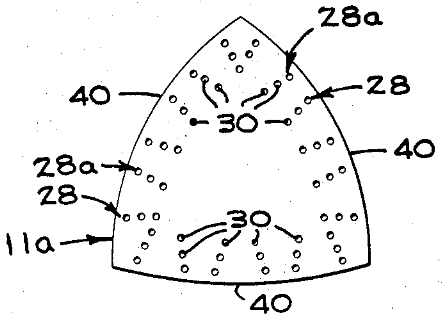


Fig-7

AIR FOIL WITH VORTEX GENERATORS

FIELD OF THE INVENTION

The present invention relates to thin air foils in general, and particularly to sails as a means of propelling boats.

DESCRIPTION OF PRIOR ART

The U.S. Pat. No. to Vaile 1,864,964, June 28, 1932, shows a sail boat wherein fabric scallops or pockets are provided at the leading edge of the sail adjacent the mast. These pockets are directed to one side of the sail or the other by means of ropes under control of the helmsman. The stream caused by the pockets deflects the air stream away from the leeward side of the sail to increase the negative pressure at the area adjacent the front or mast zone of the sail.

In FIG. 6 of the Vaile patent, a parachute is shown having a double circumferential row of large apertures. Diagonally disposed pairs of two holes are thus formed, each pair sharing a common hole, so that the converging ends of each two hole row are not spaced. The apertures of Vaile form horizontal streams that deflect the normal air current to a path further away from the parachute canopy than would be their path if the apertures were absent.

The U.S. Pat. No. to Morisette 2,971,488, Feb. 14, 1961, shows a sail boat with one long line of single holes disposed along the rear or trailing edge of the sail and just ahead of a hinged boom and sail flap arrangement that terminates the trailing edge of the sail. This single line of relatively large holes is intended to prevent turbulence at the trailing edge of the sail.

The U.S. Pat. No. to Karpf 3,152,782, Oct. 13, 1964, shows a parachute wherein frusto-conical nozzles terminating in tubular extensions are formed in staggered circumferential rows around a specially provided torodial bulge adjacent the lower portion of the parachute canopy. These nozzles are provided to maintain a constant turbulence around the canopy bulge. The nozzles form interlaced or crossing rows of three, each row of three sharing a common nozzle, so that the rows of three have no gap between them at the converging ends of the rows.

Canadian patent 701,079, issued Jan. 5, 1965 teaches the provision of rows of long slots formed over substantially the entire surface of a sail which slots direct the air flowing therethrough flowing tangentially along the convex or leeward side of the sail. These slots are also intended to act as reactive jets.

None of these devices provide apertures dimensioned and disposed so as to provide individual low profile aerodynamic fences with spaces between the fences at their closest portions, and which fences serve as vortex generators for generating spiral vortices that flow along the convex or leeward side of the sail.

BACKGROUND OF THE INVENTION

The art of sailing includes the technique of setting sails in that relation to the wind direction which obtains the highest boat speed. Not only does the wind change direction but the boat's direction is changed quickly during maneuvering and maintenance of the best setting of the sail is difficult. In addition, mainsails and foresails such as the genoa jib have large curvatures that result in natural twist from the head to the foot giving variations in the angle of attack from the head to the foot when set for crosswind sailing. This large curvature and inescapable poor set of at least part of the sail often causes the direction of the air flow on the lee (convex) side of the sail to diverge from the sail contour with a resulting reduction of driving force, a condition that may be termed "aerodynamic stall." Even flat jibs and mainsails are often improperly set when beating to windward, especially in light wind, and stall occurs. If wind direction changes suddenly, stall can result, quickly reducing driving force on the sail. I have observed these effects several ways. I have seen evidence of back flow on the lee side of the sail by observing that the reefing lines hanging on the lee side of the sail slanted in the forward direction during stall conditions. I have further observed that pennants on the trailing (leech) edge of the sail sometimes curl behind the sail and fly in the forward direction. These phenomena are often accompanied by an audible, unstable buffeting or flapping of the sail itself in strong winds.

SUMMARY OF THE INVENTION

I recognized the effects last mentioned as demonstrating that the air adjacent the lee side of the sail slows down as it progresses rearward and does not follow the contour of the sail as a unidirectional stream flowing smoothly to the trailing edge of the sail. The flow separates from the sail, eddies form, and the air near the sail will flow back again toward the front of the sail. I perceived that if means could be found to mix the high speed stream of free air flowing past the sail with the slower, eddying or stagnant boundary layer of air next to the sail, the boundary layer of air would be induced to maintain its rearward flow. Thus separation of the free air from the lee side of the sail could be prevented right up to the trailing edge of the sail.

Having observed that fluid vortices act as discrete, relatively stable bodies or entitles in phenomena such as whirlpools and smoke rings, I conceived that if vortices could be generated on the lee side of the forward portion of the sail, the vortices should mix the faster free air stream with the slower air near the sail for a considerable distance toward the rear of the sail and thereby prevent the air adjacent the lee side of the sail from slowing down or forming eddies.

I further conceived that a row of short, discrete air jets projecting past the lee side of the sail and disposed at an angle to the free air stream direction, would act as a deflector of the main air stream to impart a local twisting motion to the main air stream. The stream would be deflected over the row of short, discrete air jets, thereby generating a relatively stable, trailing spiral or helical vortex in the air stream. The rows of air jets can be provided simply by forming short rows of small, flat edged holes in the sail. The rows of jets would be disposed at alternating angles to the air stream, with each row of jets jutting out into the main air stream and thus forming an "aerodynamic fence" which acts as a vortex generator. The converging ends of adjacent rows of holes or jets would be substantially spaced. Since adjacent vortices of opposite twist would thus be provided by the converging aerodynamic fences, the adjacent vortices of the main stream would reinforce and stabilize each other.

In accordance with my invention, as applied to a fore and aft sailboat sail, I form adjacent the aforesaid rows of small, short and discrete air jets at acute angles of opposite sign relative to the free air direction, thereby providing a zig-zag vertical array of holes at the leading portion or luff of the sail. The resulting air jets generate continuous vortices streaming rearwardly on the lee side of the sail. These vortices continually mix the faster moving air in the free air stream with the slower moving boundary layer air near the lee side of the sail. In the preferred embodiment each row of holes is separated from the adjacent row by about one row length at their nearest point of convergence, to enhance the formation of discrete individual vortices by each row. Since these rows of air jets are generated simply by forming rows of small, flat edged, reinforced holes in the sail cloth, the sail itself is devoid of the drag that would result from mechanical projections such as nozzles, and furthermore, the vortex forming action is equally effective on both port and starboard tacks with no manual adjustment or mechanisms from tack to tack being necessary.

More specifically and when applied to a sail boat, the preferred embodiment of the invention provides an elongate zig-zag array of individual rows of holes in the sail, preferably at the luff of the sail, near the mast. Air from the windward side of the sail generates corresponding rows of short, discrete air short jets jutting out into but not forming a significant part of the free air stream flowing along the lee side of the sail. Each row of jet forming, small holes is disposed at an acute angle to the direction of flow of the free air stream, and each row forms what I have called an aerodynamic fence. Each aerodynamic fence of air jets first deflects the free air stream away from the sail as the free air flows over the top (ends) of the air jets forming the fence. The free air stream then curves toward the axis of the fence as it flows back behind the fence. This deflecting action of the fence imparts a twisting motion to individual air stream elements or streamlets of the main air stream and forms these streamlets into a trailing helical vortex.

As mentioned, adjacent rows of holes (each row of holes being a vortex generator) are alternately arranged at opposite angles to the air stream (zig-zag formation) and hence form angles to the air stream (zig-zag formation) and hence form adjacent vortices with opposite directions of twist or rotation. As the vortices trail toward the leech or trailing edge of the sail, the mixing effect of the oppositely rotating or twisting vortices will stabilize the air boundary layer near the convex lee side of the sail and prevent or delay divergence of the main air stream from that surface of the sail. It will be noted, that contrary to the principles of certain prior art patents, it is not my purpose to physically deflect the main air stream from the sail, but rather to generate vortices in the main air stream which follow the sail. These vortices minimize eddying and back flow along the lee side, reducing noisy buffeting and the associated loss of driving thrust on the sail. The result is an increased net driving force on the sail. Two or more zig-zag arrays of these vortex generators could be used with locations at two or more diverging lines from the head to the foot of the sail.

Additional arrays will be desirable for sails whose curvature is greater or whose curvature varies from the head to the foot of the sail. Generally, the greater the sails curvature, the greater will be the need for additional zig-zag arrays of the vortex generators.

Applicant's invention is applicable to other thin foil aerodynamic devices, including spinnakers, parachutes, kites and windmills.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic plan view of a sloop rigged sailboat showing the air flow past the sails without stall.

FIG. 2 is a schematic plan view of the sailboat showing the air flow past the sails during stall conditions.

FIG. 3 is an enlarged view of one row of reinforced holes formed in a sail in accordance with the present invention.

FIG. 4 is a side elevation of a sloop rigged sailboat with arrays of holes formed in the sails in accordance with the present invention.

FIG. 5 is a diagrammatic perspective view showing the principal of vortex formation at two adjacent rows of air jets formed by two adjacent rows of holes in a sail.

FIG. 5A is a section through two adjacent trailing vortices taken as indicated on line 5A—5A of FIG. 5.

FIG. 6 is a plan section through the sail of the sailboat with rows of holes in the sail and showing the paths of the generated vortices.

FIG. 7 is an elevation view of a parachute spinnaker showing arrays of vortex generators around the edge of the spinnaker.

FIG. 8 is a plan view of a sloop rigged sailboat with a parachute spinnaker embodying the invention.

FIG. 9 is an elevation view showing the relative flow of air past a conventional parachute.

FIG. 10 is an elevation view showing the relative flow of air past a parachute equipped with the applicant's vortex generators.

FIG. 10A shows a parachute canopy having a full row and a partial row of vortex generators.

FIG. 11 shows the use of short slots instead of round holes for producing vortex generators.

DESCRIPTION OF PREFERRED EMBODIMENT

FIG. 1 is a simplified plan of a sloop **10** having a jib **11**, a mast **12**, a mainsail **14**. The mast, rigging and a boom **13** for the mainsail **14** support the two sails in the usual manner. Arrows **15** indicate the free stream wind direction with the wind initially impinging on the windward side **16** of the main sail **14** at an angle of attack (a) to the chordal base line $x — x$ of the mainsail **14**, extending between the mast **12** and the leech **17** of the sail.

Of course the air flows on both sides of the sails, including the leeward side **18** of the mainsail. The arrow **20** indicates the direction of free air flow on the windward side **16** of the mainsail **14**, and the arrow **22** indicates the theoretically ideal direction of the free air flowing past the leeward side **18** of the sail. The air pressure on the sail is greater on the windward side **16**, with the pressure on the leeward side **18** often being less than atmospheric pressure.

At low angles of attack (a) between the wind direction **15** and the chord $x — x$, the free air paths **20** and **22** may follow the contour of the sails closely on both the windward and leeward sides, as shown in FIG. **1**.

However, and as seen in FIG. **2**, at larger angles of attack (a) the free air path **20** follows the sail on the windward side, but the path **22** often fails to follow the leeward side **18** for the full distance to the leech **17**. Usually, the flow **22** on the leeward side separates from the sail and back flow currents or eddies **24** are formed. This condition results in an increase of pressure to near atmospheric conditions at this portion of the sail and hence reduces the thrust of the sail. This condition is corrected by the present invention.

FIG. **3** shows an enlarged view of a single row **28** of small, reinforced flat edged holes **30** formed in a sail or air foil in accordance with my invention. The axis **32** of the row **28** of holes **30**, is disposed at an acute angle "b" to the direction **15** of the flow path of the free air past the sail. When the axis **32** diverges upwardly and rearwardly from the leading edge of the sail, as shown in FIG. **3**, the angle "b" is arbitrarily designated as a minus angle, (*–b*).

Thread reinforcements **33** commonly used for cringles in sails and for buttonholes in clothing are provided around the holes **30** to prevent tearing of the sail cloth. Other reinforcement means known in the art, such as patches, grommets, or heat sealing (if applicable) can be used to reinforce the sail at the holes **30.** These holes will be termed "small flat edged" holes to distinguish over holes associated with nozzles or the like such as those in the parachute of the aforesaid U.S. Pat. No. to Karpf 3,152,782. They are defined as "small" holes because they are small enough to produce a short row of discrete air jets that serves as an aerodynamic fence or vortex generator, as will be described presently in connection with FIG. **5.** Although two holes **30** disposed as in FIG. **3** might be considered to be a "row" of holes, under the present invention a two hole row would be relatively ineffective, and the term "row" as employed herein refers to a row of three or more jet forming holes.

FIG. **4** is a diagrammatic view of the lee side of a sailboat **10** showing the jib **11**, the mast **12**, the boom **13**, the mainsail **14**, with a vertical zig-zag array of rows **28,28*a*** of holes **30** formed in the sails. The entire zig-zag array has a generally vertical axis *Z — z*. Because of the zig-zag formation of the individual rows **28,28*a*** of holes **30**, and referring to the mainsail **14**, the upwardly converging rows **28** have their axes **32** at an angle (*–b*) to the direction **15** of the free flowing air, and the alternate, downwardly converging rows **28*a*** have their axes **32*a*** at an angle (*+b*) to the direction **15** of the free flowing air. The jib **11** is provided with a similar vertical zig-zag array of rows **28** and **28*a*** of small holes **30.**

Each row **28,28*a*** of small, flat edged holes **30** forms an aerodynamic fence which acts as a vortex generator. As seen in the schematic diagram of FIG. because becuase the holes **30** are relatively small, and since the air pressure is higher on the windward side of the sail, short, small and discrete air jets **38** come through the small holes **30** and project into the path of the free flowing air **15** on the lee side of the sail **14.** When the free flowing air **15** meets the vortex generators formed by the angled rows or fences of air jets **38** formed by the rows of holes **28,28*a***, the air stream **15** is deflected outward (away from the sail) by each fence, spills over the top of the fence and then flows back behind each fence of air jets **38.** The result of this deflection is a rolling, twisting, or vortex motion of the air stream deflected by each fence.

For purposes of explanation of this rolling vortex motion, in FIG. **5** the air stream **15** is arbitrarily assumed to be made up of individual streamlets, such as streamlets **15*a***, **15*b*** and **15*c***. Reference will now be made to the action on these streamlets by the aerodynamic fence formed at the downwardly converging row **28*a*** of the air jets **38.** Since the axis **32*a*** of the fence of air jets **38** is at an acute angle (*+b*) to the direction of the stream of free air **15**, the local air streamlets reaching the fence are partially diverted by the fence and hence tend to flow along the fence as the streamlets are simultaneously diverted away from the sail and hence roll over and behind the fence. This deflection of the streamlets in two planes results in a localized, continuous twisting, vortex motion of the air stream as the air streamlets are deflected, roll over, turn down behind, and partially continue on along the rear side of the fence.

The continuous twisting motion of the localized portions or streamlets **15*a***, **15*b***, **15*c*** of the air stream **15** thereby forms a trailing vortex V. For example, at the fence of jets **38** formed by the row **28*a*** of holes, the uppermost air streamlet **15a** reaches the fence first and flows up and over the fence of air jets **38.** As streamlet **15*a*** rolls up and curls over the top of the fence its path is partially deflected in the direction of the axis **32*a*** of the fence, and this new direction is maintained as the streamlet flows down behind the row of jets **38.** In following the aforesaid deflected path, the streamlet **15a** curls under the next lower air streamlet **15b** which has just begun to curl over the top of the row of jets **38.** In a like manner, the streamlet **15*b*** curls under the next lower streamlet **15*c***. In this manner, the localized air streamlets **15*a***, **15*b***, etc. are caused to twist around each other into a continuous, helical vortex bundle V. At the fence of jets **38** formed by the upwardly converging row **28** of holes **30**, a mirror image group of streamlets **15*a***, **15*b***, **15*c*** are partially deflected by and curl over the row of air jets **38** to form another vortex **V1**. However, the vortex **V1** twists in the opposite direction relative to the twist of the vortex V, because the axes **32, 32a** of the rows of jets **38** converge in the direction of air flow. Stated differently, the angles (*+b*) and (*–b*) of the axes **32a** and **32** of the rows **28*a*** and **28** of jets **38** to the direction **15** of the free flowing air are of opposite sign. Thus adjacent rows **28*a***, **28** of holes **30** form trailing helical vortices V, **V1** having opposite directions of twist or rotation as shown in the diagrammatic section of FIG. 5A. Since the adjacent vortices are of opposite twist, their rotational components are in the same direction at their nearest zones, so that they do not disrupt or counteract each other.

To summarize, and as shown in FIG. **4**, rows of holes **28**, **28*a*** that act as vortex generators are arranged on the sails **14** and **16** near their leading edges and in a zig-zag array along an axis *z — z* from the head to the foot of the sails. The individual axes **32*a***, **32** of adjacent rows **28*a***, **28** of holes converge and hence are at angles (b) and (*–b*) to the direction **15** of the free flow path of the air past the sails. The advantage of this preferred convergence or alternation of angles is that the adjacent vortices rotate in opposite directions as shown in FIG. 5A, but both vortices V and V1 flow along the sail in the same direction, as shown in FIG. **5**. Because of their opposite relative rotations, adjacent vortices V, V1 reinforce each other in their motion and stability. In order to maintain the integrity of individuality of adjacent vortices, the rearwardly converging ends of the rows **28**, **28*a*** of holes **30** are substantially spaced, preferably by a distance or gap "*d*" (FIG. **4**) which is at least equal to the extent of one of the rows as measured along the axis $z - z$ of the entire array and preferably is at least equal to the axial length of a row.

As is also shown in the simplified schematic plan diagram of FIG. **6**, the rows of holes **30** in the sails allow air to pass through the sails from the concave windward side, to form small jets (see FIG. **5**). The resulting aerodynamic fences or vortex generators form continuous, trailing helical vortices, such as a vortex V. The vortices mix the free stream of air **22** adjacent the convex, leeward side of the sail, with the boundary layer of air next to that side of the sail.

The mixing of the faster free air stream **22** with the slower boundary layer of air near the leeward side of the sail prevents the boundary layer from slowing down. The mixing action continually re-energizes the boundary layer. Referring to the main sail **14**, for example, this causes the free air stream **22** to follow the contour of and flow along the leeward side **18** of the sail. This prevents eddy formation and hence the back flow of air near the sail, which phenomena are associated with separation of flow from the sail that normally occurs with conventional sails. Such separation reduces the driving force of the sail, and hence by maintaining said contour flow the present invention increases the driving thrust of the sail. The action at the mainsail **14**, just described in detail, also takes place at the jib **11**.

EXAMPLES

In a typical example of construction, the rows **28, 28***a* of holes **30** are inclined at angles $(+b)$ and $(-b)$ of about 20°, to the free air path. In a fore and aft sail, the rows of holes are in a generally vertical zig-zag array near the luff of the sail. For a small (e.g. 6 – 10 feet high) sail said holes can be about ½ inches in diameter and spaced by a distance "s" (FIG. **3**) which is equal to two hole diameters, center to center. If the holes **30** are too close together, the sail will be unduly weakened along the rows **28,28***a* of holes **30**. The holes **30** as shown in FIG. **3** are, considering their diameter, illustrated as being closer than the preferred spacing. Taller sails (e.g. 30 ft. high) have holes of a larger diameter, such as 1 inch diameter holes. There will be at least three, and preferably about four holes in each row.

As mentioned, the gap "d" (FIG. **4**) between the rearwardly converging ends of the rows **28,28***a*, is preferably about equal the length of a row **28,28***a* along the row axis, in order to avoid interference between adjacent vortices V, V1. However, satisfactory results may be obtainable if this space at least equals the projected length of the rows looking in the direction of the wind, or normal to the array axis $z - z$. If the aforesaid gap "d" is appreciably greater than the length of a row of holes, the mode of operation is the same but the number of vortices decreases with a corresponding decrease in the mixing action.

As a matter of practice, the inclination angle $(+b)$ for rows **28** can be 10° to the horizontal and the angle $(-b)$ for rows **28***a* at 30° to the horizontal, to compensate for the change in free air path relative to the sail during heeling of the boat. This difference in row inclination is readily accomplished on the mainsail by forming both rows **28,28***a* at a 20° angle to the free stream wind direction **15** and inclining the array axis itself at an angle "y" of about 10° to the vertical, that is, to the axis M — M of the mast **12** (FIG. **4**). For convenience the angle "y" wherein the axes $z - z$ and M—M converge upwardly will be referred to in the claims as a positive angle.

SPINNAKER APPLICATION

As shown in FIGS. **7** and **8**, the invention is also applicable to spinnakers **11a** and especially to spinnakers of the balloon or parachute type. The vortex generators formed by the zig-zag or angled rows **28,28***a* of holes **30** placed near the edges **40** of the spinnaker **11***a* (FIG. **7**) will generate vortices V. V1 (FIG. **8**) on the convex or lee side **18***a* of the spinnaker, in the manner previously described. By maintaining the continuity of flow along the convex surface of the sail, the vortices increase the outward and lateral thrust along the edges **40** of the spinnaker **11a** and hence increase the forward thrust of the center of the spinnaker. The outward or lateral components along the edges of the spinnaker tend to pull the edges outward thereby increasing the frontal area of the spinnaker. This gives a greater area of sail presented to the wind and increases the driving force on the boat **10.** The resultant delay or minimization of separation of flow of the streams **22** at the forward center of the convex or lee side **18***a* of the spinnaker **11***a*, increases the driving force of the sail by developing a negative pressure over a larger area on the lee side of the spinnaker.

PARACHUTE APPLICATION

Another application of the invention is to parachutes. These, too, are thin aerodynamic devices developing lift and thrust. FIG. **9** shows a descending conventional parachute **50** with a glide angle (g) to the vertical $y - y$. The air stream **22** flowing over the scalloped edge **52** of the parachute initially follows the top convex surface **54**, and thus develops an upward lift and an outward radial thrust on the canopy. However, as the boundary layer **22** of air next to the convex surface **54** slows down, the negative pressure on this surface decreases. When the flow stops, the free air stream **22** separates from the surface **54**, eddies **56** are formed, and back flow occurs. The air pressure at this portion of the surface **54** returns to near atmospheric and the lift and thrust developed by that portion of the surface area is greatly reduced. The velocity of descent of the parachute is consequently increased, and the glide angle (g) is reduced, an undesirable condition.

FIG. **10** shows utilization of the applicant's invention on a parachute **50***a*. Vortex generators formed by separated rows **28,28***a* of holes **30**, as in the applicant's previous embodiments, are shown around and above the edge **52***a* of the canopy. Adjacent rows **28,28***a* of holes forming the vortex generators are at an angle of opposite sign to the vertical, in other words, the rows are in zig-zag formation. As before, trailing vortices V and V1 of opposite twist are formed by jets **38** (not shown) emitting from the rows of holes, and these trailing vortices mix the free air **22** with the boundary layer of air on the top convex surface of the canopy. Separation of the free air streams **22** from the canopy is thus delayed until the streams **22** flowing from around the edge **52***a* meet at a common zone **58.** As a result, the lift is increased and the glide angle (g) becomes correspondingly greater. For example, a gliding parachute at a large angle (g) parachute may have a rate of descent at sea level of about only 16 ft./sec., as compared to the same parachute which is non-gliding and is falling straight down, which parachute may descend at 23 ft/sec. Thus, since application of the present invention to parachute increases the gliding angle (g) of the parachute, this invention will either permit the use of smaller parachutes for the same rate of descent or will reduce the rate of descent for a given size of parachute.

Use of the applicant's vortex generators on only one third of the periphery of a parachute canopy or as seen in FIG. **10**A, the use of a dual concentric array to provide more generators on about one third of the periphery than around the rest of the canopy will develop an increased lift and lateral thrust on that portion, as well as improving the lift of the parachute **50**b. This construction will also given the parachute a directional gliding characteristic that can be used for safer landings, or the occupant can manipulate the direction of glide by any of the various means known in the art to avoid landing on buildings, lakes and trees.

MODIFIED HOLE DESIGNS

Although the preferred design includes four holes **30** in each row, I contemplate that a row of fewer elongated holes could provide a suitable aerodynamic fence. Thus, as shown in FIG. **11**, holes **30***a* can be formed as narrow slots oriented in the axis of the rows **28***b*, **28***c* in order to produce short, discrete jets of air that create an aerodynamic fence.

Applications on the applicant's invention to other thin, aerodynamic devices or foils will be apparent to those knowledgeable in the art of fluid mechanics.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from what is regarded to be the subject matter of the invention.

What I claim Is:

1. A thin air foil such as a sail or the like of the type having apertures thereon to improve its aerodynamic effectiveness; the improvement wherein said apertures are formed in discrete rows of three or more apertures with each row providing an aerodynamic fence of small air jets that produces a trailing vortex, said rows of apertures being formed in an elongated array the axis of the array being generally normal to the free air stream flowing along the foil, the axes of said rows being at acute angles to the free air stream, said rows of apertures being spaced along the array axis by a distance sufficient to present a gap to the air stream that is not substantially less than the extent of one of said rows as measured along the axis of the array.

2. The air foil of claim **1**, wherein the rows of apertures in said array are disposed in zig-zag fashion.

3. The air foil of claim **1**, whereby there are at least four apertures in each row.

4. The air foil of claim **1**, wherein the angle of inclination of the rows of apertures to the array axis and the angle of inclination of the array axis to the air stream are selected so that during normal operation of the air foil the angle of inclination of the rows to the air stream is about **20** degrees.

5. The air foil of claim **4**, wherein said rows of apertures are arranged in zig-zag formation along the array axis.

6. The airfoil of claim **5**, wherein the air foil is a fore and aft sailboat sail, and the array axis extends along the luff of the sail.

7. The sail of claim **6**, wherein the array axis is inclined from the mast axis at a positive acute angle.

8. The sail of claim **7**, wherein said positive acute angle of inclination is about 10°.

9. The sail of claim **6**, wherein the diameter of the holes is about ½ to 1 inch, the diameter increasing with the height of the sail.

10. The air foil of claim **2**, wherein said air foil is a parachute, and the zig-zag array of holes extends circumferentially adjacent the lower edge of the parachute.

11. A fore and aft sail boat sail of the type having apertures thereon to improve its aerodynamic effectiveness; the improvement wherein said apertures are formed in discrete rows of three or more apertures with each row providing an aerodynamic fence of small air jets that produces a trailing vortex, said rows of apertures being formed in a zig-zag array near the luff of the sail, the axes of the individual rows of holes being at acute angles to the array axis, the rearwardly converging ends of said rows of apertures being spaced along the array axis by a distance such that the rearwardly converging ends of the rows of holes present a gap to the air stream that is not substantially less than the extent of one of said rows as measured along the axis of the array.

12. The air foil of claim **11**, whereby there are at least four apertures in each row.

13. The sail of claim **11**, wherein the angle of inclination of the rows of apertures to the array axis and the angle of inclination of the array axis to the air stream are selected so that during normal operation of the air foil the angle of inclination of the rows to the free air stream is about 20°.

14. The sail of claim **13**, wherein the axis of the array is inclined to that of the mast at a small positive acute angle of compensate for heeling of the boat.

15. The sail of claim **11**, wherein the gap between the rearwardly converging ends of the rows of holes is about equal to the axial length of an individual row.

16. The sail of claim **11**, wherein the diameter of each hole is about ½ to 1 inch, depending on the height of the sail.

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