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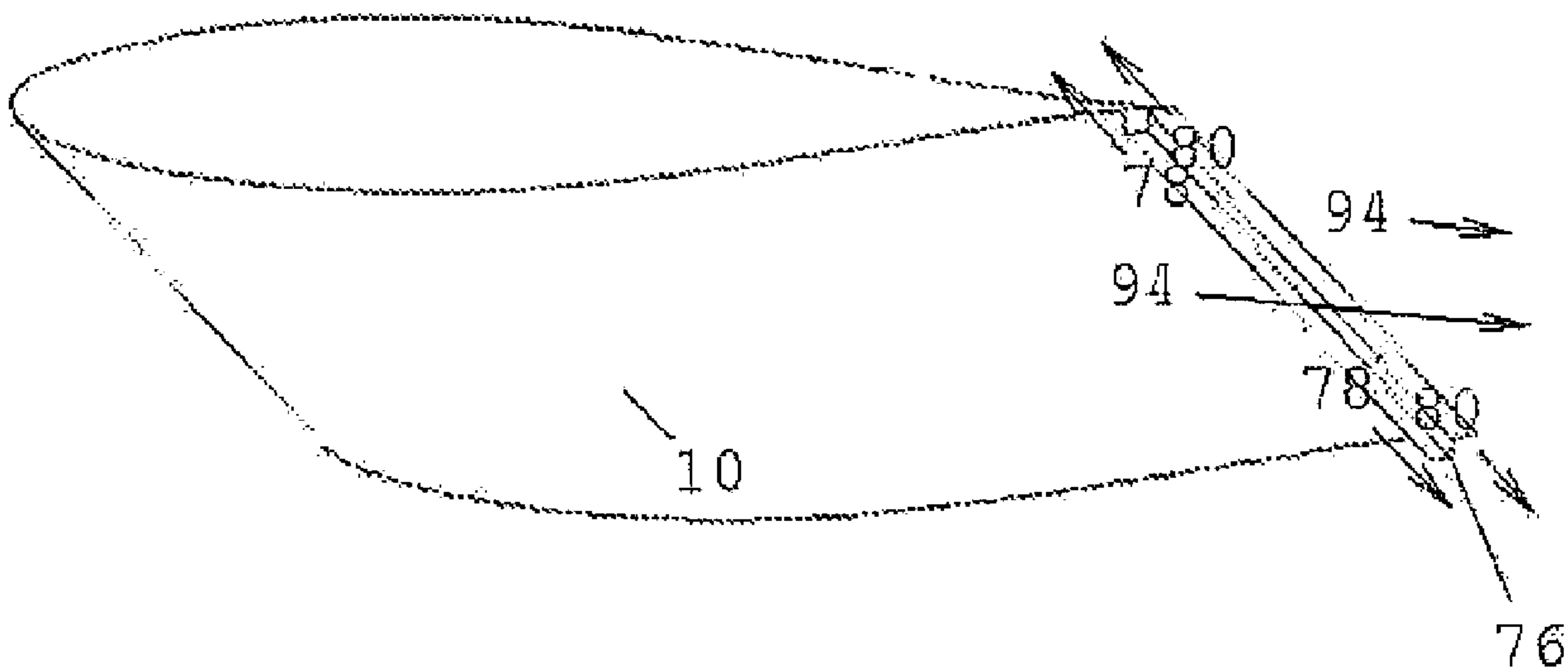
(54) **Titre : GENERATEURS DE TOURBILLONS ELASTOMERIQUES**
(54) **Title: ELASTOMERIC VORTEX GENERATORS**



(57) **Abrégé/Abstract:**
A method of improving aerodynamic performance of foils by the application of conformal, elastomeric vortex generators. The novel use of elastomers allows the application of various forms of vortex generators to sections that have been problematic from engineering and cost considerations. A novel and efficient vortex generator profile is identified, which develops an additional co rotating vortex at low energy expenditure. The mechanisms allow for the application of transverse vortex generators, or Gurney Flaps/Lift Enhancement Tabs/Divergent Trailing Edges, to propellers, rotorblades, and to wings/flaps/ control trailing edges. Cove Tabs are additionally described using an elastomeric transverse vortex generator to achieve performance improvements of a high lift device.

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ABSTRACT

A method of improving aerodynamic performance of foils by the application of conformal, elastomeric vortex generators. The novel use of elastomers allows the application of various forms of vortex generators to sections that have been problematic from engineering and cost considerations. A novel and efficient vortex generator profile is identified, which develops an additional co rotating vortex at low energy expenditure. The mechanisms allow for the application of transverse vortex generators, or Gurney Flaps/Lift Enhancement Tabs/Divergent Trailing Edges, to propellers, rotorblades, and to wings/flaps/ control trailing edges. Cove Tabs are additionally described using an elastomeric transverse vortex generator to achieve performance improvements of a high lift device.

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APPLICATION OF ELASTOMERIC VORTEX GENERATORS

Field of the Invention:

The present invention relates to improving foil aerodynamics and, more particularly, to improving lift and drag characteristics. It provides novel material and properties to the field of boundary layer modificaiton and separated flow control, and particularly in the use of blade, ramp, Gurney Flap/ Lift Enhancing tab or divergent trailing edge vortex generating systems.

BACKGROUND OF THE INVENTION

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.

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.

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.

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 reenrgising of the boundary layer to reduce surface drag. Alternatively, a rigid surface may be deformed by fluting or indentations that act as a form of flow modifier.

To change acoustic signature and/or lift/drag perforamnce, 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.

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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 streamwise vortices.

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 chort 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 aerodymanic 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, mimimum mass needs to be achieved at all times.

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

In a first aspect, this document discloses an elastomeric vortex generator for improving flow on a foil or a series of foils, thereby improving lift, drag, angle of attack capability or lift-to-drag ratios, the elastomeric vortex generator comprising: a means for forming transverse vortices, and a base surface for attachment to a foil or aero/hydrodynamic surface, wherein the means for forming transverse vortices is elastomeric and is configured to be bonded to the foil or aero/hydrodynamic surface, the means further comprising: a front surface configured at an angle normal to a free stream aero/hydrodynamic flow to generate a first vortex, and a rear surface configured at an angle normal to the free stream aero/hydrodynamic flow to generate a second vortex, whereby a body of the means for forming transverse vortices is configured for force balance between the first and second vortex forces so as to provide minimum force loading on the base surface, and the first and second vortices are configured to reenergize a downstream boundary layer, improving lift, drag, angle of attack capability or lift-to-drag ratios.

In accordance with the present invention, there is provided new and enhanced alternatives for the application of vortex-generating mechanisms. These mechanisms are fabricated from elastomeric materials, either by extrusions cut to form or by sheet stock cut to beneficial designs.

The use of elastomeric materials in a vortex-generating device is counterintuitive, in that the prior art has developed using either rigid-formed structures or air jet systems, and the ability of an elastomeric compound to retain a stabilised form arises from the surprising fact that the vorticities on each side of a blade once established are, in the main, both stable and both series of vortices support the structure between them, thereby retaining the structure in place when subjected to high velocity Newtonian fluid flows. This is valid for blade and tabs such as Gurney Flaps/Lift Enhancement Tabs, which are able to be formed form either an L or T form blade running transversely proximate to the trailing edge of a foil, or surprisingly, as a rectangular extrusion (or machined strip) section of elastomeric material.

The profiles of blade vortex generators additionally are improved by the incorporation of multi bladed sections, which increase the total fluid entrainment in vortices. these are described as F, or U forms with multiple parallel blades being fabricated in section, and the vortex generator being completed by trimming the extrusion to the desired length and lengthwise profile. This arrangement results in an additional central vortice being produced, which is co rotational with the 2 vortices that are produced from a single blade generator, however the total drag is nominally unchanged, as the central vortex efficiently develops in a chanel. Testing to date indicates that the vortex generator of multiple blades is effective at developing vortices, however comparative performance is not completed.

The use of elastomeric materials allows the designer new freedom to place a flow modifier such as these items in areas that are either sensitive to mass, such as the trailing edge of an aileron or other surface subject to flutter considerations, and in areas where the existing dynamic flexure and torsion of the structure would preclude safety attaching any additional structure which has different material properties to the substrate. This condition also includes cases where the materials may have been common, but the fabrication results in variation of the bending and torsional properties of the flow modifier and the substrate. A particular case in point is attempting to place a transverse device such as a Gurney Flap or Lift Enhancement Tab to the trailing edge of a helicopter rotor, where the attachment base and tab form an L or T form that increases rgidity in an area subject to cyclical bending loads, which cause spanwise distortion of the blade from a straight span. Such applicaiton of current art structure of vortex generators would generate high fatigue loads at the bond, resulting in failure or alternatively transfers high loads to the end sections of a strongly bonded/connected tab to blade, where the structural properties of the section with the tab vary from the section without such reinforcement. In the case of a rotor, additionally the increase in rgidity of the trailing edge by the applcaition of a rigid form of tab results in a change in characteristics between the trailing edge bending and the leading edge behavior to these cyclical loads, and results in torsional variations being introduced.

Gurney Flaps/Lift Enhancement Tabs have been the subject of substantial research, however the primary focus has been on the blade form extending normal to the lower rear surface of the foil. One series of experiments did evaluate alternative rigid forms, including triangular and concave profiles, at relatively low velocities, in the area of high lift capability, and separately current art has described rigid mechanisms of a divergent trailing edge to a foil at high velocities, and low angles of attack, consistent with cruise conditions for subsonic cruise. The flow structure of a trailing edge tab is in the main consistent with the structure of the dviergent trailing edge. The efficiency of a low aspect, below 0.5% chord blade form tab located within 2 x the tab height of the trailing edge of a foil is beneficial, and affects both low speed performance of lift, angle of attack capability and lift drag ratio, and at high speed can improve lift/drag ratio and additionally increasing the critical drag rise mach number, through lowering of the suction peak. Flight testing indicates that an elastomeric rectangular section bonded to the trailing edge in the manner of a Gurney Flap, acts as both a Gurney Flap, and as a Divergent

Trailing Edge device.

testing of an elastomeric Lift Enhancing Tab was conducted on an aircraft propellor, and also a helicopter Main Rotor.

In the case of the propeller, the 1.6mm high x 12mm wide elastomeric tape of EPDM foam was bonded to the pressure face trailing edge of the left hand engines propeller of the twin engined aircraft, a PA23-250. Spanwise location was varied in testing, however the applicaiton of the tape with the tape aft face parallel, and 1.6mm forward of the trailing edge of the blade in chordwise location, and extending as a continuous tape from 40%span to 85% span resulted in improved performance of the propeller. In comparison to baseline performance, the power settings to achieve equivalent thrust from the enignes resulted in a reduction of fuel flow required and manifold pressure of approximately 20%. where equal fuel flows and manifold pressures were used on boith engines, the indicated airspeed achieved by the aircraft was increased by approximately 5KIAS, with a notable assymetry in thrust evident supporting improved performance from the modified propellor. Application of the tape to the tip region, approximately 95% span, resulted in some wear of the leading edge of the outer section of the tape, in sandy environemntal conditions.

A limited test of elastomeric Lift Enhancement Tabs was conducted on an R22 helicopter main rotor. Acoustic signature variation was immediately noted, and a reduction in blade vortex interaction was also noted, but not empirically recorded due to testing constraints. The power required to hover was reduced by aproximately 15% from baseline, for a 3.0mm x 12mm x 1.0m tab section located 3.0mm forward of the lower trailing edge of the blade, in the mid span area, approximately 40-75% span. Of note, the normal low rotor RPM stall occured at 80% RPM for the baseline (manufacturer guidance value given as 83% for test conditions), whereas with the elastomeric tab, the stall occurred at 68%RPM. In the baseline case, the anti torque demanded to maintain directional control, approaches the control limit, whereas in the elastomeric tab test case, the control authority remaining was greater than baseline, even though the reduced RPM substantially reduces the anti torque force developed at the lower RPM. This finding is consistent with the tab developing lower drag, and increasing lift coefficient. The additional conclusion is that the secvtion of the span with the tab also increases the component of total lift that is produced, and reduces the aerodynamic loading at the tip of the blade, which is consistent with the reduction in blade vortex interaction. A reduction in vibration while passing through translational lift is also consistent with this conclusion. High speed flight was conducted up to manufacturers VNE, but was of a limited nature, howefver no adverse behavior was noted. Autorotation was not evaluated due to the limited nature of the testing, however, quick stop manoeuvers which enter autorotative flow conditions were conducted and were unremarkable.

The application of a tab in the cove of a wing/flap system has been shown by current art to be beneficial to improving flow attchment over the flap upper surface at high flap deflections. The current art uses a transverse blade in this area to achieve the transverse vortex that initiates the rather complex and interesting separated flow structure that results in the continued attachment of the boundary layer to the flap in conditions where normally the boundary layer would have separated. The invention as an elastomeric box or rectangular section has been applied in this area in flight test and acts as a Cove Tab, resulting in fully attached flow over a simple flap at 50 degrees flap deflection, as indicated by tuft testing. Lift and drag performance was as expected for the appliciation of a current art Cove Tab. When combined with a series of elastomeric blade vortex generators on the flap upper leading edge, and a series of elastomeric blade vortex generators in the area of the outer wing leading edge outboard of the flaps, the test aircraft, a PA23-250 which normally stalled at 52KIAS, had a resultant stall of 39KIAS, evaluated by GPS method. The cruise performance of this aircraft was improved by 2KIAS where the elastomeric Cove Tab acted as a flap gap seal in the flap retracted position. Drag in the landing configuration was reduced markedly, and aerodynamic vibration related to flow separation from the flaps was absent. Total fly by noise was diminished from the lower power setting required. It should be noted that Cove tabs are primarily beneficial at high deflections, and at lower deflections may cause a slight reduction in coefficient of lift. In testing, it was forund that the performance shift was significant to the extent that the aircraft with full flap deflection on takeoff performed to the same level as the aircrafts baseline performance with 1/4 or 1/2 flap deployment.

It would be advantageous to provide a structure of a vortex generator that does not alter the torsional and bending characteristics of the substrate structure

It would also be advantageous to provide a vortex generator in a material that allows for conformal attachment to a surface with simple or complex curvatures.

It would further be advantageous to provide increased vorticity for a given drag value, to minimise the size of a virtex generator.

It is advantageous to provide a structure for a vortex generating device that is tolerant of operational damage, whereby it may be deformed by excessive forces or impacts but revert to the design shape on removal of such disturbances.

It is advantageous to have a low density and mass material for a vortex generator applied at or near the rear of a foil section to minimise adverse aeroelastic dynamics.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

Figure 1 is a top perspective view of a generic foil;

Figure 2 is a section view of an of a foil showing general flow conditions;

Figure 3 is a top perspective view of an alternative blade form elastomeric extrusions, and vertical trimming;

Figure 4 is a top perspective view of a representative application of conformal elastomeric blade vortex generators to an aerodynamic surface;

Figure 5 is a front perspective view of an elastomeric vortex generator applied around the radius of a leading edge;

Figure 6 is a bottom perspective view of a 2 element wing and flap system, with an extruded elastomeric vortex generator fitted in the flap cove;

Figure 7 is a bottom detail view of a flap cove and tab location;

Figure 8 is a bottom detail view of a deflected flap showing the location of an extruded elastomeric cove tab, and a representation of a blade vortex generator mounted on the upper forward chord of the flap element;

Figure 9 is a top perspective view of an extrusion of ogival elastomeric vortex generator stock;

Figure 10 is a top perspective view of an extrusion of an ogival profile elastomeric stock trimmed vertically in a v form to produce a conformal elastoemric vortex generator; and

Figure 11 is a bottom perspective view of a foil section with an elastomeric section acting as a gurney flap/lift enhancing tab/divergent trailing edge element.

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

Figure 1 is a top perspective view of a generic foil, representation of a foil or aero/hydrodynamic surface 10, showing the general arrangement for the following figures. A foil leading edge 26 is identifable, as is the foil trailing edge 28. Representative flow directions are shown by annotation with an arrow head, in this case as streamwise flow 94, flowing from left to right in the image. Short streamwise flow 94 or spanwise flow 90 arrows indicate that the flow referred to is on the underside of the image. The arrows for aft face vortice 80, foreward face vortice 78 are indicative only of general flow location, and in the case of a transverse vortex, the direction of the convection of the vortex core is dependent on the incident angle of the streamwise flow 94 and the presence of spanwise flow 90 migration. It is best considered that the rotaional flow of the vortex is generally perpendicular to the direction of the vortex arrow, such that the arrow indicates an approximation of the core center.

Figure 2 is a section of a foil showing general flow conditions, being a representative arrangement of the boundary layer development of an arbitrary foil. it shows, qualitatively, the general location of the upper boundary layer transition point 32, lower boundary layer transition point 34, separation point 36, a laminar boundary layer region 38, turbulent boundary layer region 40, and separated flow region 42. These flow conditions are highly dependent on the foil, and Reynolds Number of a foil moving relative to a fluid. The exact location of vortex generators applied to any structure require a determination of the conditions of the boundary layer for the desired operating condition. In general however, it is noted that a vortex generator in the laminar bpoundary layer will have relatively high drag for a given height, due to the thin nature of the boundary layer. in this location, sub boundary layer vortex generators 24 are desirable from a drag outcome, but the mechanical constraints of fabrication may require a minimum height to be accepted. The vortex generator is usually located towards the rear of the extent of laminar flow for the condition that the applicaiton is desired. A Gurney Flap 56, Lift Enhancing Tab, or Divergent Trailing Edge transverse vortex generator exists in an area of thickened turbulent boundary layer.

Figure 3 is a top perspective of alternative blade form elastomeric extrusions, and vertical trimming representation of alternative arrangements for elastomeric blade vortex generators. Upper left to right are a U form double blade 66, F form vortex generator 68, single blade extrusion 70, with a series of L form extrusion 72 sections below, showing different trim line 64 configurations. A representation of streamwise flow 94 is shown with approximate lcoations of vortex development shown.

Figure 4 is a top perspective view of representative application of conformal elastomeric blade vortex generators to an aerodynamic surface.

Figure 5 is a front perspective view of detail of an elastomeric vortex generator applied around the radius of a leading edge.

Figure 6 is a bottom perspective view of a 2 element wing and flap 56 system, with an extruded elastomeric vortex generator fitted in the flap cove 52..

Figure 7 is bottom detail view of a flap cove 52 and tab location.

Figure 8 is a bottom detail view of deflected flap 56 showing the location of an extruded elastomeric cove tab 92, and a representation of a blade vortex generator mounted on the upper forward chord of the flap 56 element.

Figure 9 is a top perspective view of extrusion of ogival elastomeric vortex generator stock. This is manufactured from an EPDM type material or other elastomeric compound that achieves the desired mass, wear and adhesion properties.

Figure 10 is a top perspective view of an extrusion of an ogival profile elastomeric stock trimmed vertically in a V form to produce a conformal elastoemric vortex generator. The trim line 64 achieved by a rotary profile cutter, laser or water jet, results in a ramp vort4ex generator being produced. The trimmed sides may be angled as indicated, endeavouring to achieve a relative angle of the side to the freestream flow of between 15 and 25 degrees, or alternatively and more efficiently, may be planform profiled to an ogival shape consistent with a NACA inlet planform. The ramp angle is dependent on the use but data from NACA references indicate that between 4 and 8 degrees of rise from the leading edge of the ramp to the top is desirable. This profile wedge form may also be advantagely adjusted to incorporate an ogival form.

Figure 11 is a bottom perspective of a foil section with an elastomeric section acting as a Gurney Flap 56/Lift Enhancing Tab/Divergent Trailing Edge element. This is also a representative location for the employment of an L form elastomeric vortex generator applied as a Gurney Flap/Lift Enhancement Tab/Divergent Trailing Edge 88, or an inverted T form single blade extrusion 70, where the base is provided such that the trailing base element does not extend past the trailing edge. It should also be noted that the symmetrical positioning of transverse trailing edge forms such as these may be applied in special conditions, where pitching moment is excessive, or the foil is subject to both positiive and negative angles of attack, such as for a rudder or aileron system. In such a case, the mass will naturally be greater, however the effect is generally to shift the lift coefficient correlation to angle of attack to a higher angle per degree of angle of attack.

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

Attorney Ref: 1112P002CA02

What is claimed is:

1. An elastomeric vortex generator for improving flow on a foil or a series of foils, thereby improving lift, drag, angle of attack capability or lift-to-drag ratios, the elastomeric vortex generator comprising:

a means for forming transverse vortices, and

a base surface for attachment to a foil or aero/hydrodynamic surface,

wherein the means for forming transverse vortices

- is elastomeric and

- is configured to be bonded to the foil or aero/hydrodynamic surface,

the means further comprising:

- a front surface configured at an angle normal to a free stream aero/hydrodynamic flow to generate a first vortex, and

- a rear surface configured at an angle normal to the free stream aero/hydrodynamic flow to generate a second vortex, whereby

- a body of the means for forming transverse vortices is configured for force balance between the first and second vortex forces so as to provide minimum force loading on the base surface, and

- the first and second vortices are configured to reenergize a downstream boundary layer, improving lift, drag, angle of attack capability or lift-to-drag ratios.

2. The elastomeric vortex generator in accordance with claim 1, wherein the means for forming vortices is configured to be bonded directly onto a surface of the foil or aero/hydrodynamic surface to improve flow on a foil or series of foils, thereby improving lift, drag, angle of attack capability or lift-to-drag ratios.

3. The elastomeric vortex generator in accordance with claim 2, the elastomeric vortex generator being for improving flow on a foil or series of foils, thereby improving lift, drag, angle of attack capability or lift to drag ratios, wherein the means for forming vortices is passive or immobile, bondable, and is a conformal elastomeric extrusion or section for forming vortices.

4. The elastomeric vortex generator as recited in claim 3, wherein the means has a profile in one of: a U form, an F profile, an inverted T profile, and an L profile, the means being located on the surface of a section that is within 20% of a chord of a wing, flap or foil or aero/hydrodynamic surface on which the elastomeric vortex generator is applied thereon, and

is for developing vortices to re-energise the boundary layer, or to adjust existing flow to improve lift, drag or lift/drag ratios.

5. The elastomeric vortex generator as recited in claim 1, wherein the means is formed as a conformable, bondable, gurney tab that is aligned transversely to free stream,

- is parallel to trailing edge,

- is positioned on the lower surface, for generating an off body recirculation field and for increasing total lift and reducing drag, resulting in:

- increased aft aerodynamic loading,

- a reduction in leading edge suction, and

- reduced adverse pressure gradient development thereby increasing total lift, and reducing drag at low speeds, and increasing the critical Mach number/drag divergence Mach of the foil.

6. The elastomeric vortex generator as recited in claim 1, wherein the means for forming vortices

- is conformal, and

- has a bondable F form double blade for efficiently developing vortices,

- is rotated anticlockwise such that a bonding surface is the vertical stroke of the F form, and

- is for efficiently developing vortices and for developing a trapped vortex between the twin blades thus formed, the twin blades being normal to a substrate surface and are aligned with an extruded axis.

7. The elastomeric vortex generator as recited claim 1, wherein the means has a low profile wedge or ogival section, or F, T or U ogival section, or F, inverted T or U section extrusion, that is aligned with an aft face at, or forward from a lower trailing edge of a foil section, and wherein the means

- enhances lift at low velocities, and

- is configured to develop a transverse vortex proximate to the trailing edge thereby inducing an increase in the wake exit angle and local velocity at an upper trailing edge, resulting in increased aft aerodynamic loading and reduction in leading edge suction, thereby reducing upper surface velocities while maintaining total lift, and therefore reduces drag and increases the critical Mach number of the foil resulting in:

- increased aft aerodynamic loading,

- a reduction in leading edge suction, and

- reduced adverse pressure gradient development thereby increasing total lift, and reducing drag at low speeds, and increasing the critical Mach number/drag divergence Mach of the foil.

8. The elastomeric vortex generator as recited in claim 1, wherein the means is formed as a conformable, bondable, gurney tab that is aligned transversely to free stream, is parallel to trailing edge,

- has a constant span wise height from substrate,

- is positioned on a lower surface,

- is for generating an off body recirculation field and for increasing total lift and reducing drag and generating a transverse vortex proximate to the trailing edge which induces an increase in the wake exit angle and local velocity at an upper trailing edge, resulting in:

- increased aft aerodynamic loading,

- a reduction in leading edge suction, and

- reduced adverse pressure gradient development thereby increasing total lift, and reducing drag at low speeds, and increasing the critical Mach number/drag divergence Mach of the foil.

9. The elastomeric vortex generator as recited in claim 1, wherein the means is a conformal, bondable double blade with one of: an U form and a F form, wherein the double blade results in

trapped vortices, and is for efficiently developing vortices and is for maintaining a stable generator structure.

10. The elastomeric vortex generator as recited in claim 4, wherein the means is a conformal, bondable double blade with one of: an U form and a F profile, wherein the double blade results in trapped vortices, and is for efficiently developing vortices and is for maintaining a stable generator structure.

FIGURE 1

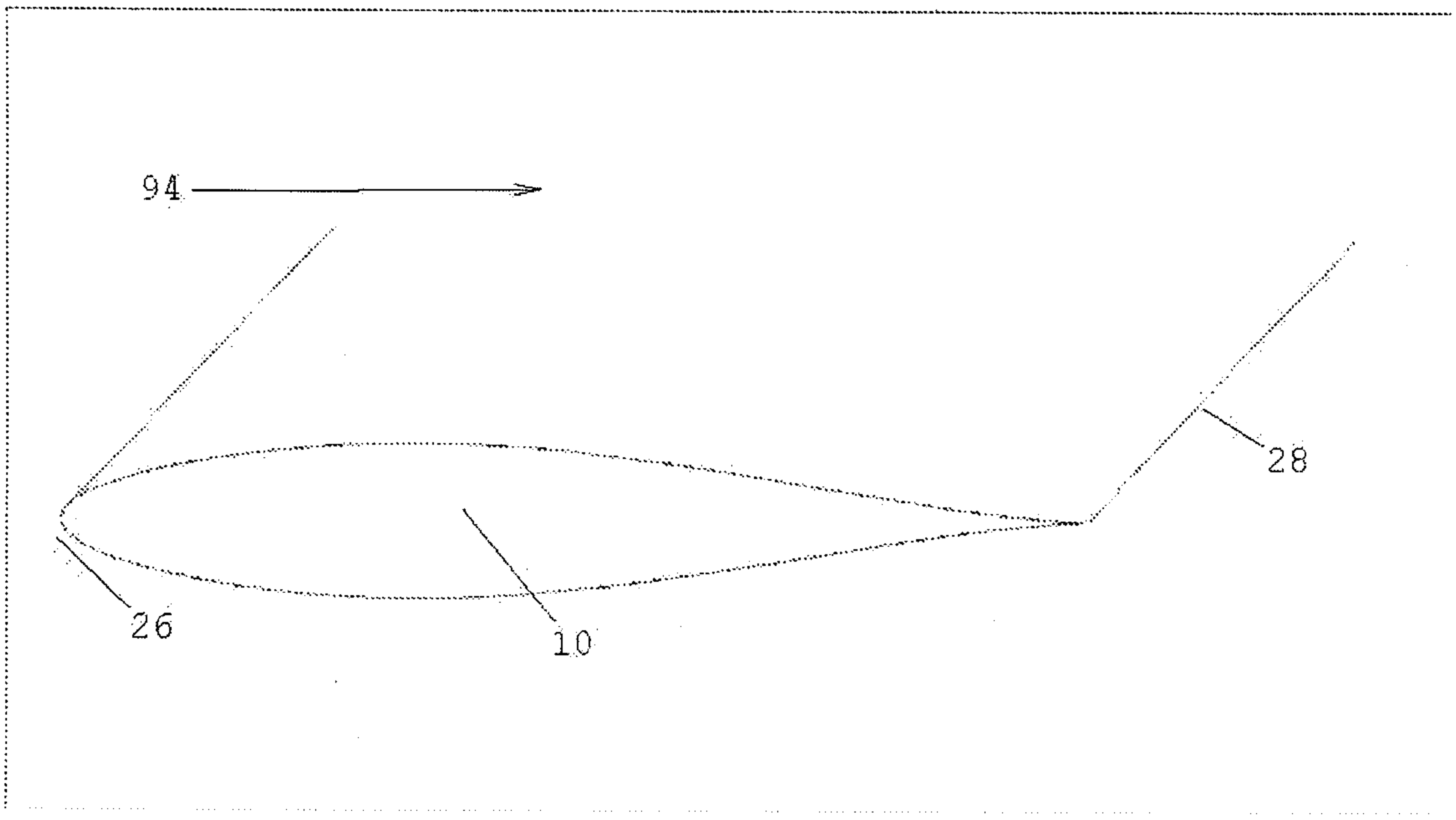


FIGURE 2

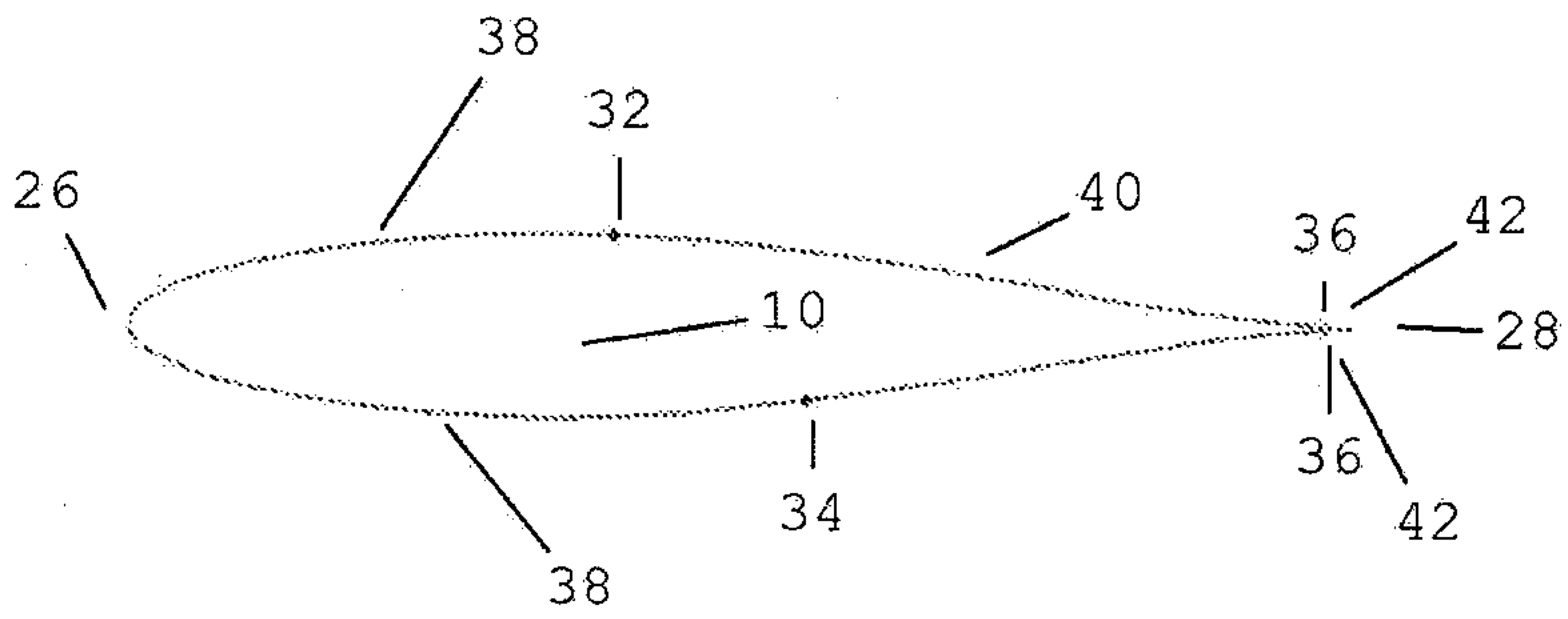


FIGURE 3

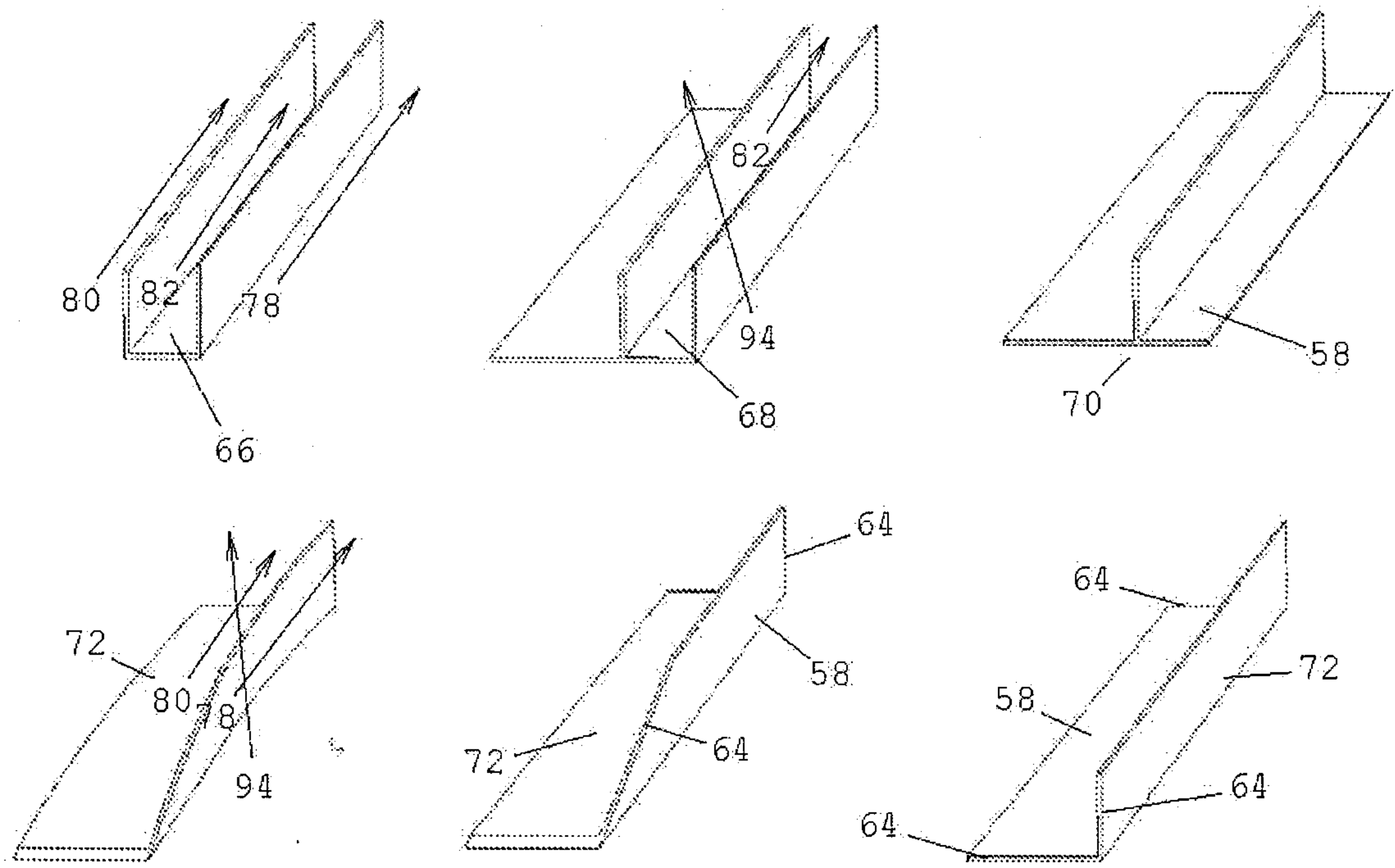
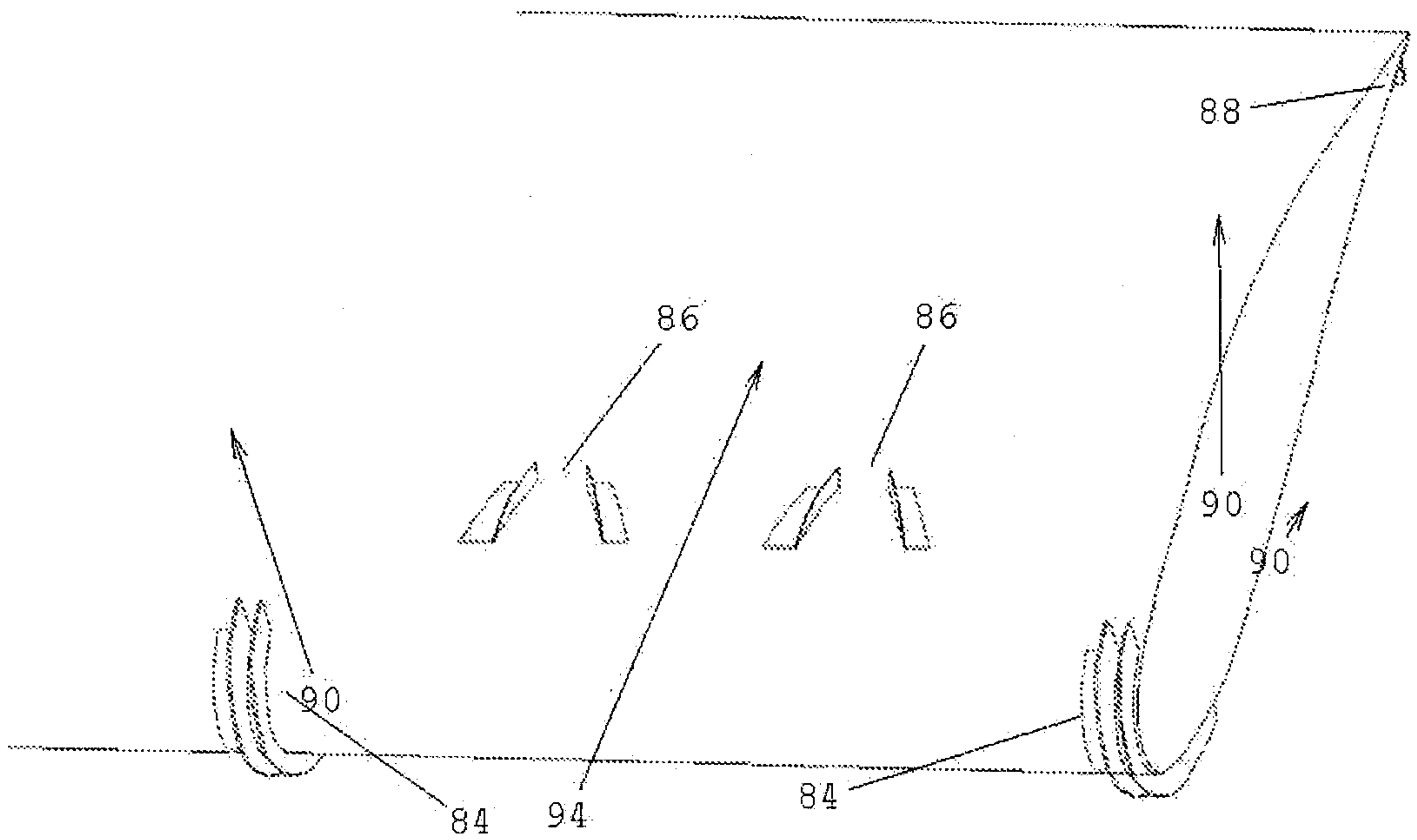


FIGURE 4



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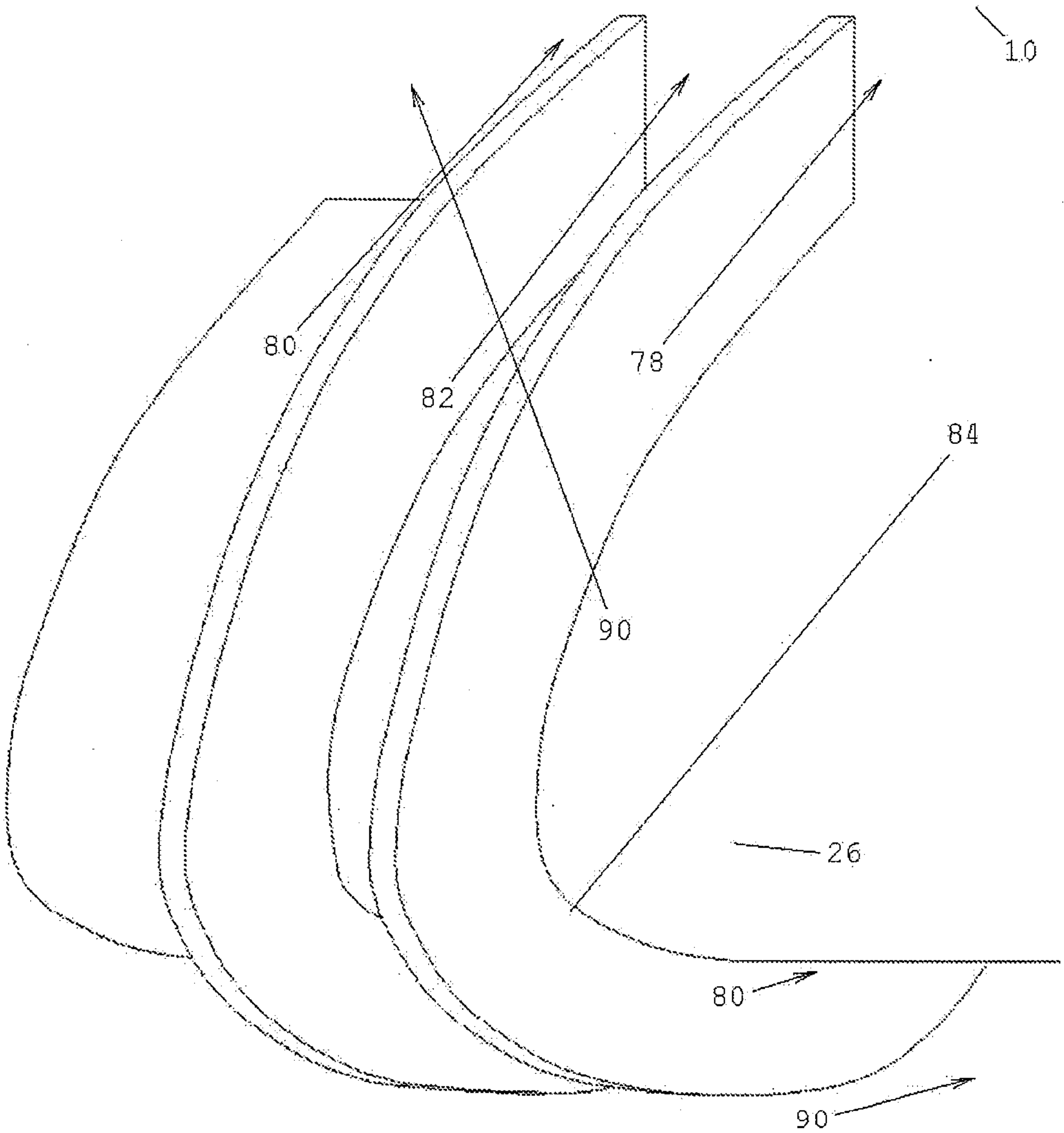


FIGURE 6

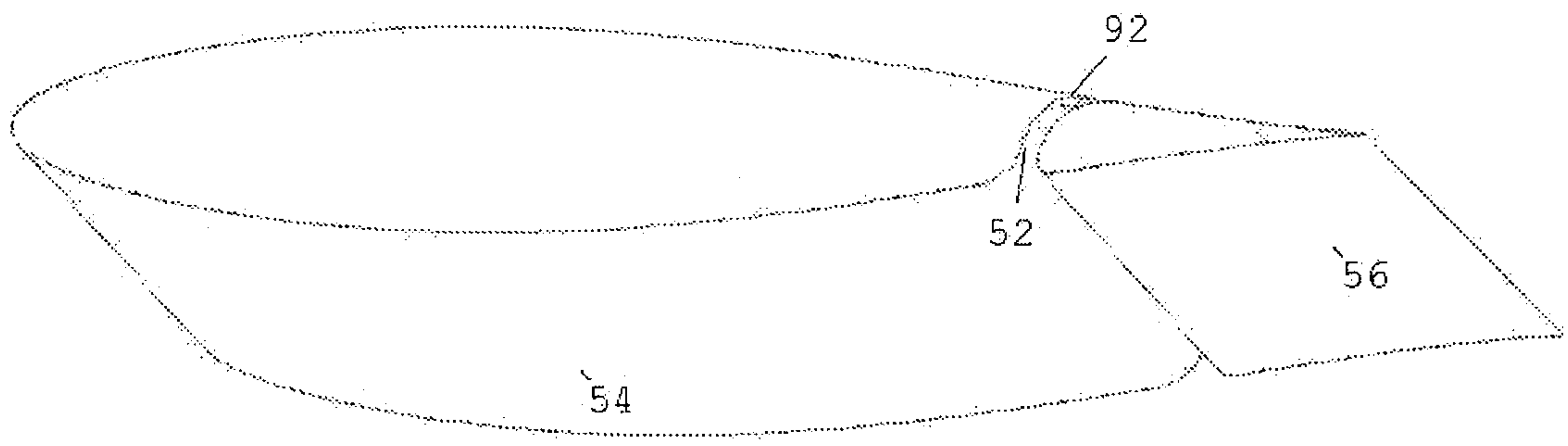


FIGURE 7

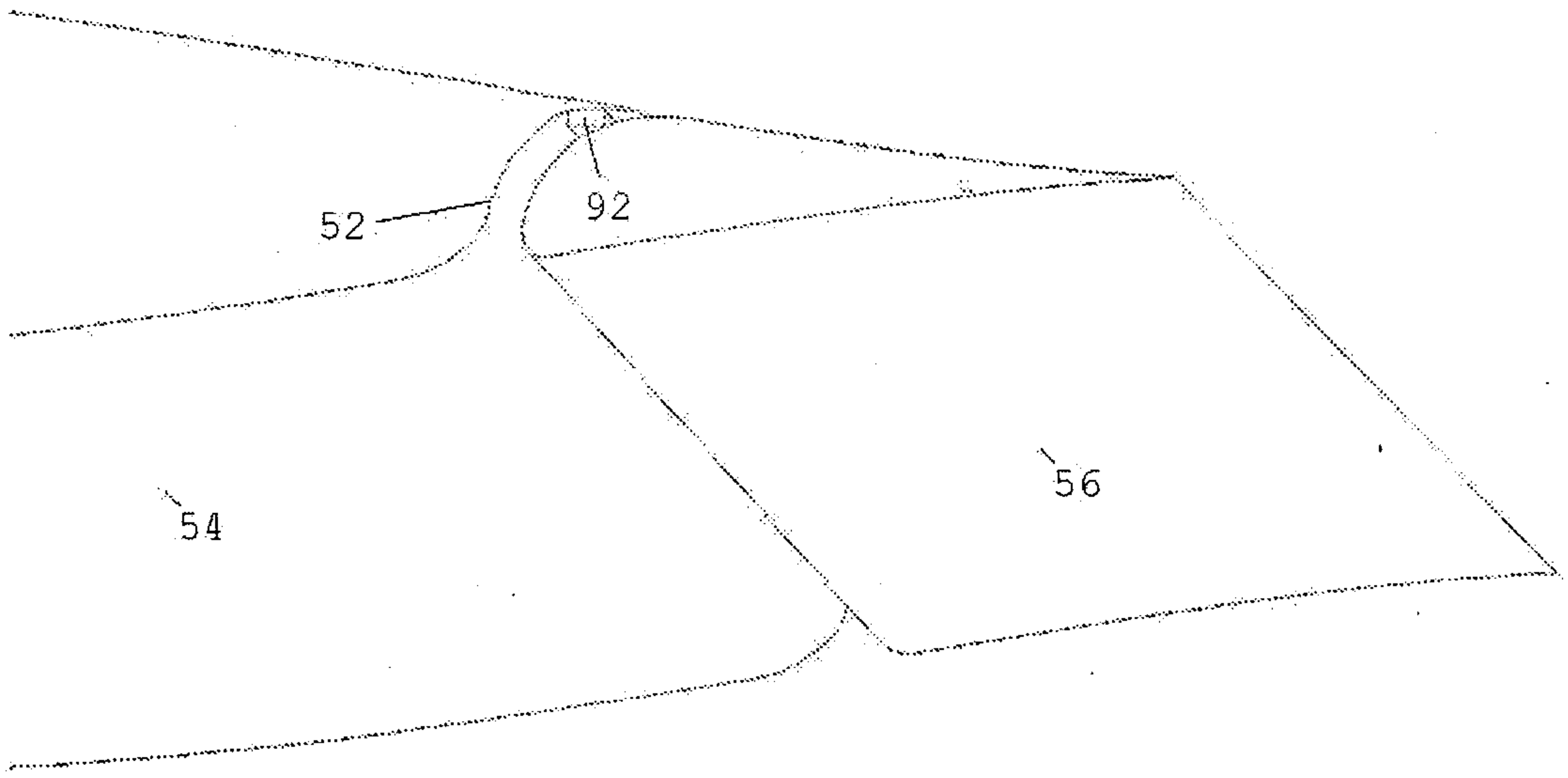


FIGURE 8

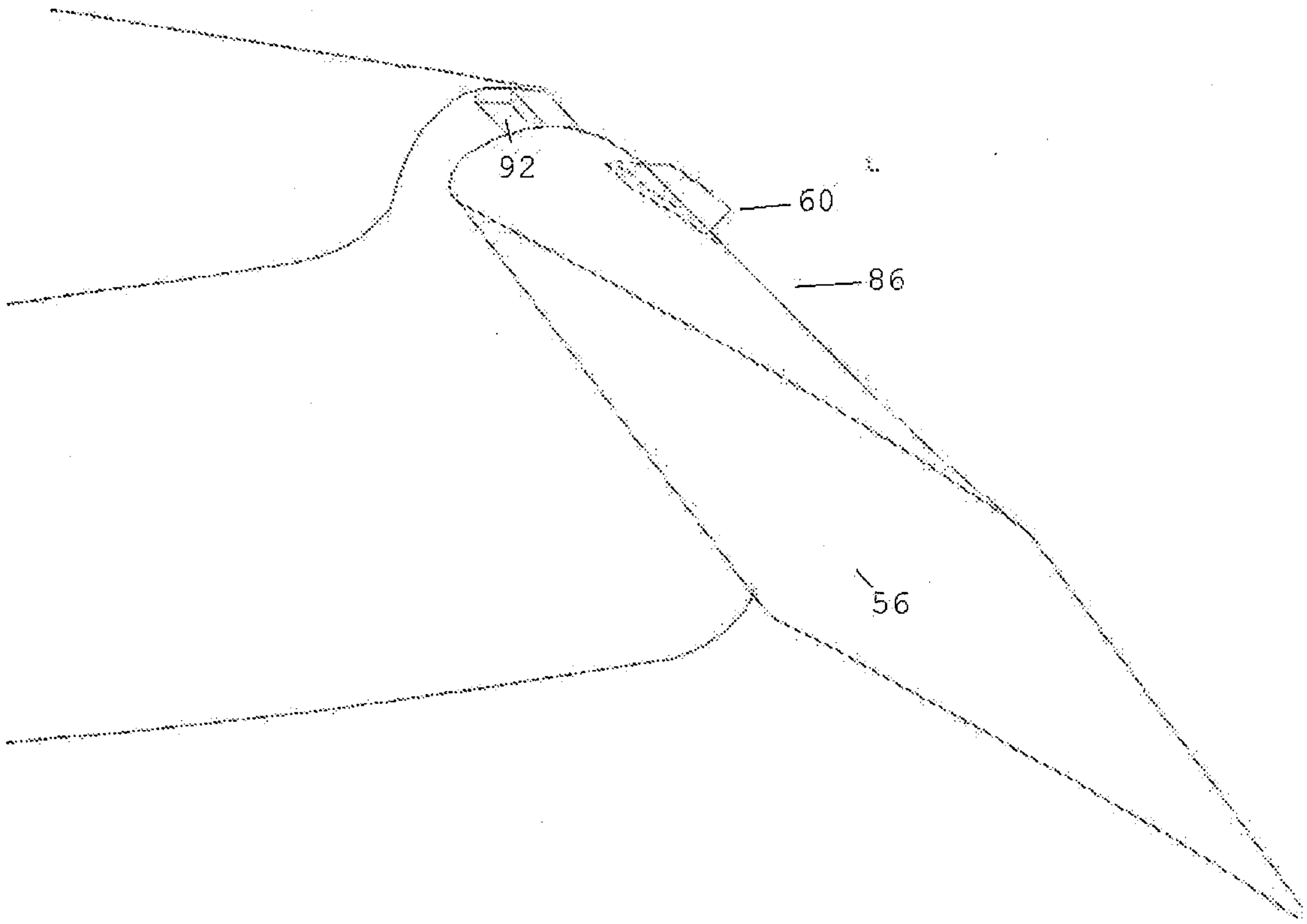


FIGURE 9

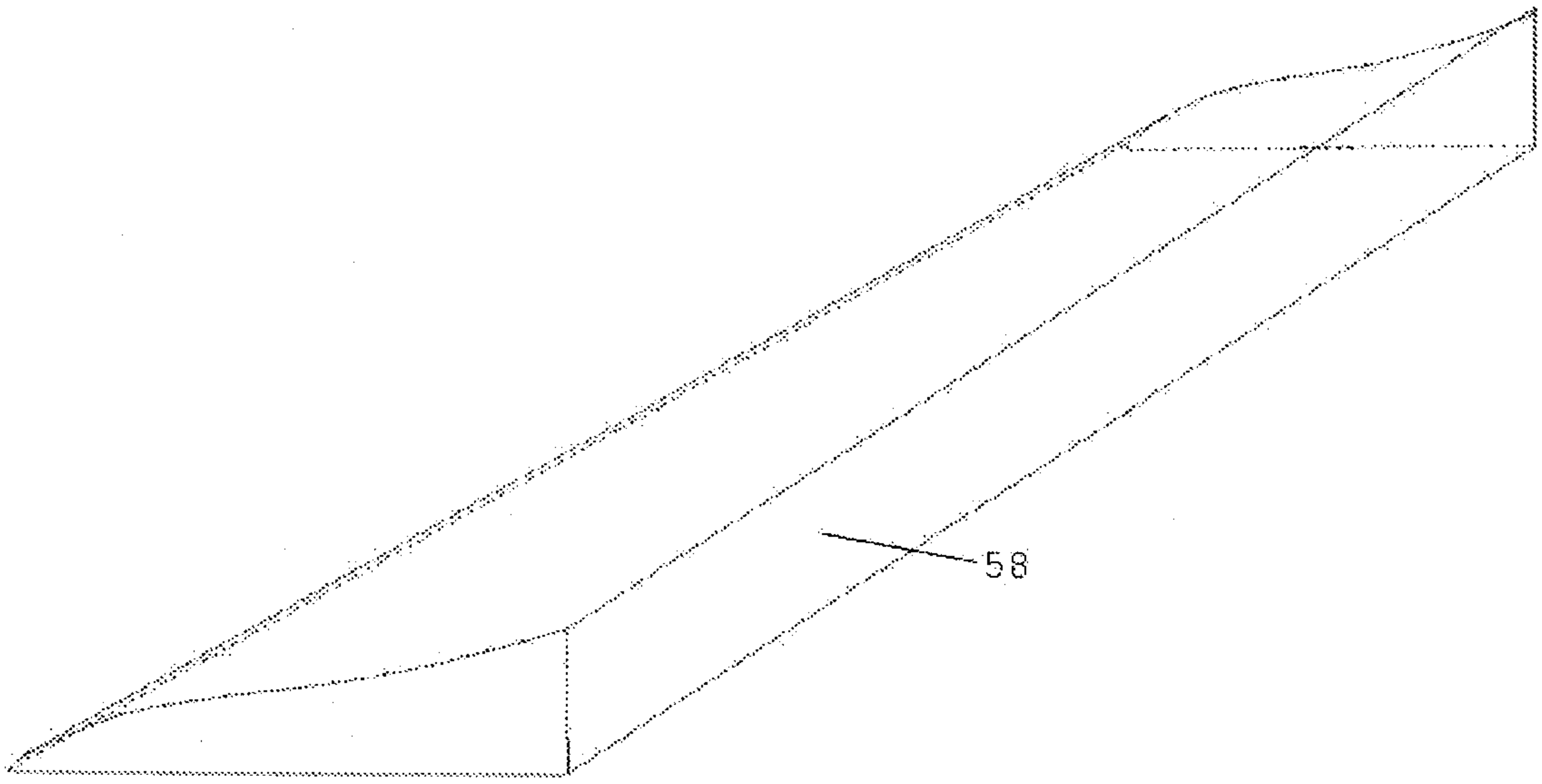


FIGURE 10

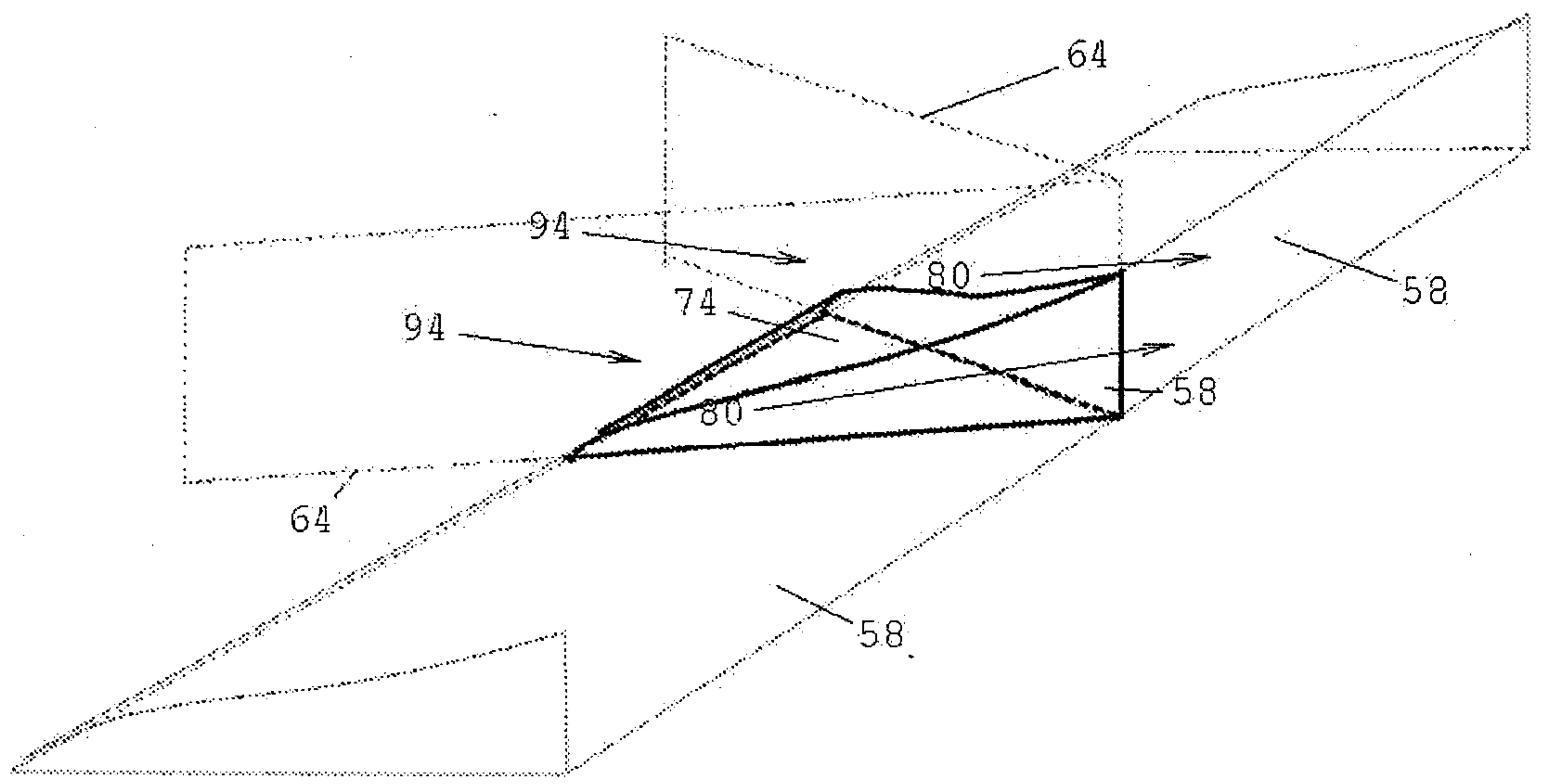
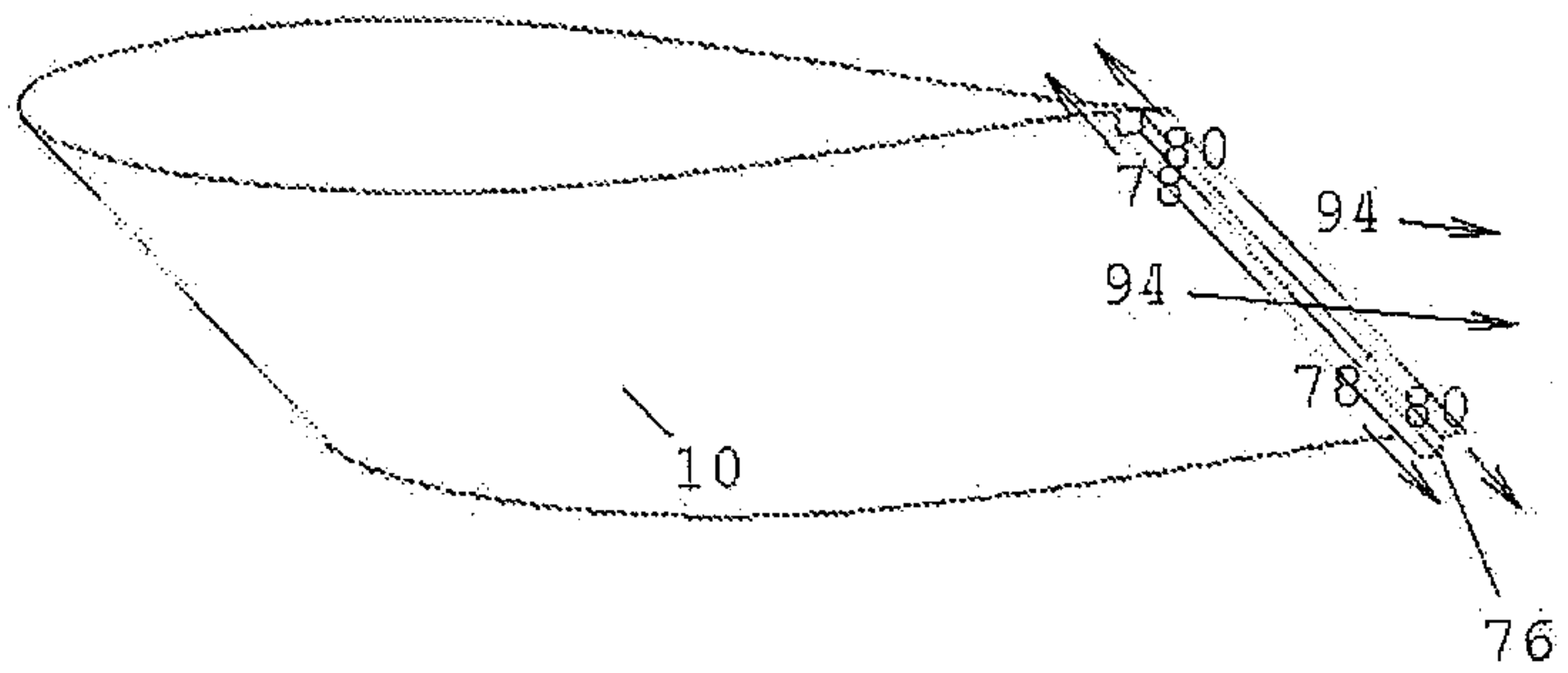
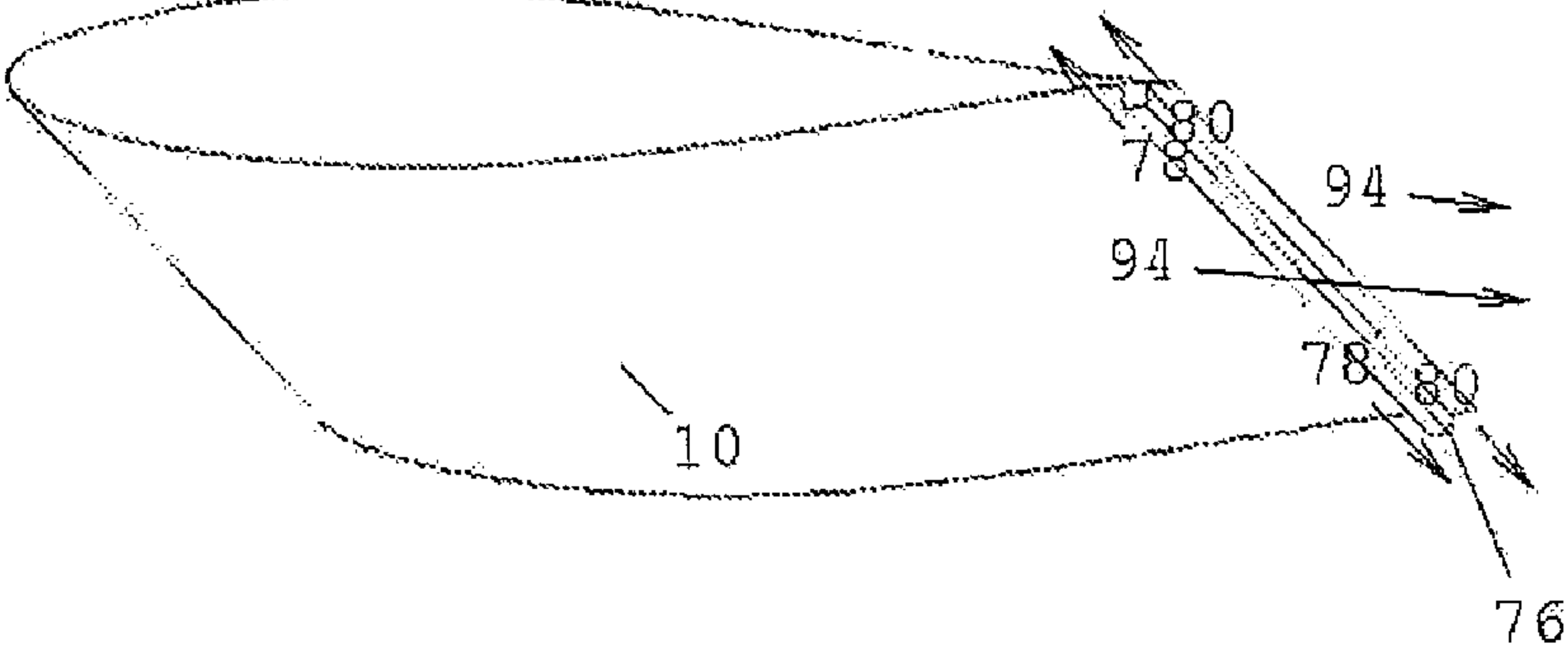


FIGURE 11

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