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[54] **NATURAL FLOW WING**

[75] Inventors: **Richard M. Wood,** Virginia Beach; **Steven X. S. Bauer,** Newport News, both of Va.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration,** Washington, D.C.

[21] Appl. No.: **560,923**

[22] Filed: **Jul. 31, 1990**

[51] Int. Cl.^{5} **B64C 3/14**
[52] U.S. Cl. .... **244/35 R;** 244/36
[58] Field of Search .... 244/34 R, 35 R, 35 A, 244/45 R, 36

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Primary Examiner—Galen Barefoot
Attorney, Agent, or Firm—George F. Helfrich

[57] **ABSTRACT**

The invention is a natural flow wing and a method for constructing the same. The method comprises contouring a three-dimensional upper surface and a three-dimensional lower surface of the natural flow wing independently of one another into a prescribed shape. Experimental data and theoretical analysis show that flow and pressure-loading over an upper surface of a wing tend to be conical about an apex of the wing, producing favorable and unfavorable regions of performance based on drag. The method reduces these unfavorable regions by shaping the upper surface such that a maximum thickness near a tip of the natural flow wing moves aft, thereby contouring the wing to coincide more closely with the conical nature of the flow on the upper surface. Nearly constant compressive loading characterizes the flow field over a lower surface of the conventional wing. Magnitude of these compressive pressures on the lower surface depends on angle of attack and on a streamwise curvature of the lower surface of the wing and not on a cross-sectional spanwise curvature. The method thereby shapes the lower surface to create an area as large as possible with negative slopes. Any type of swept wing may be used to obtain the final, shaped geometry of the upper and lower surfaces of the natural flow wing.
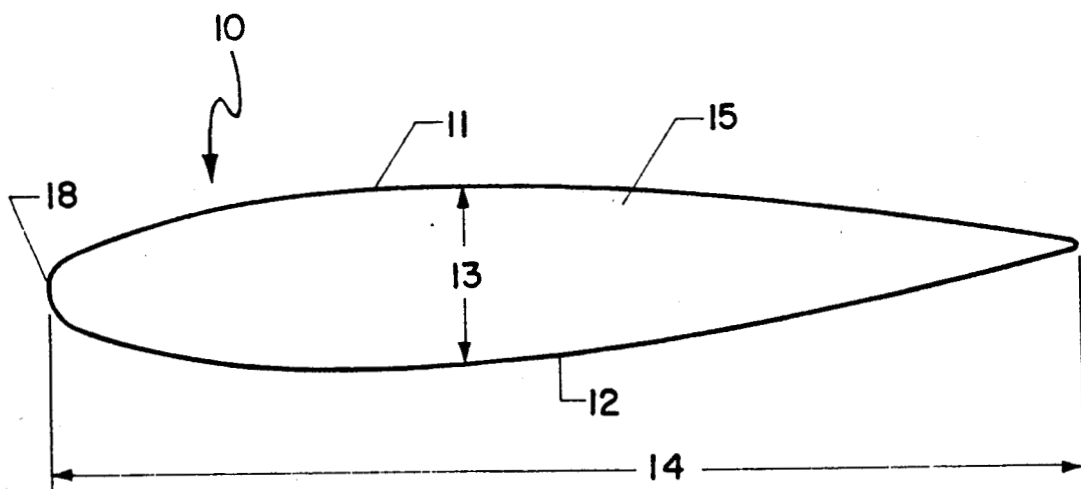
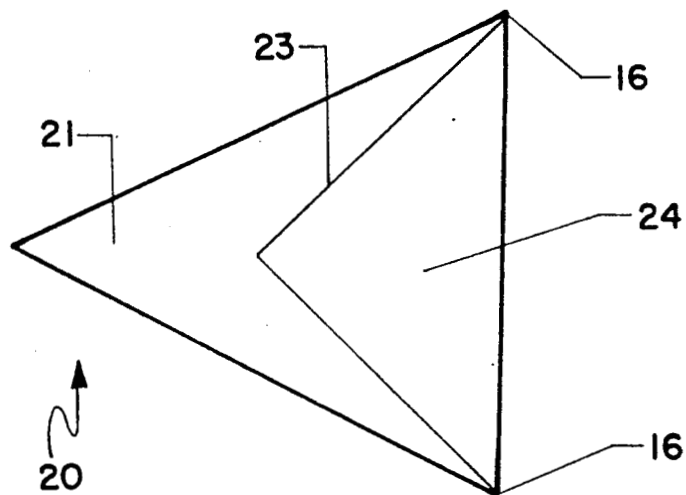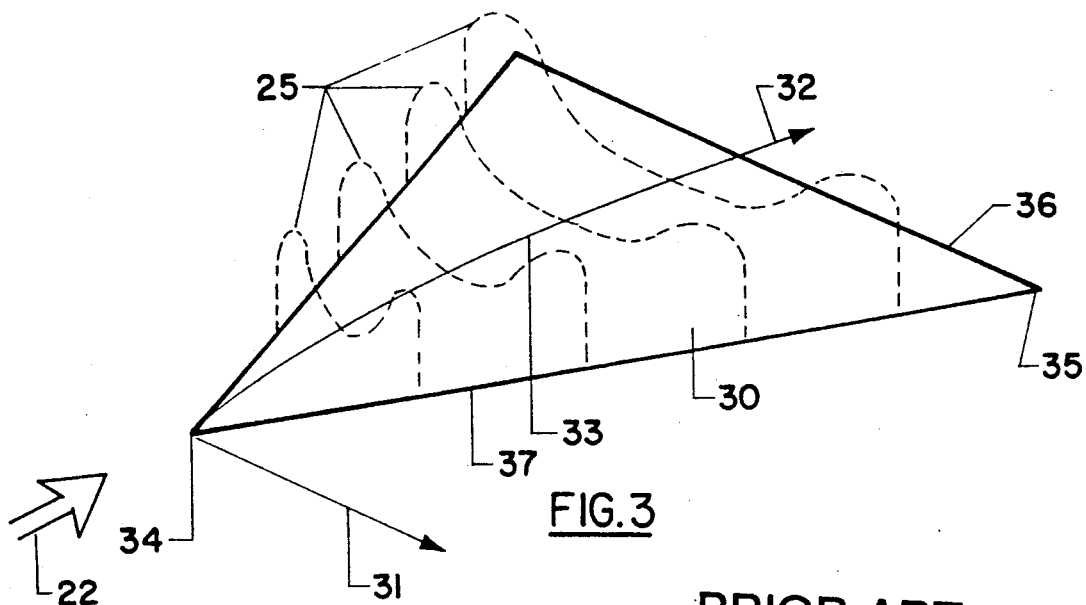**17 Claims, 8 Drawing Sheets**
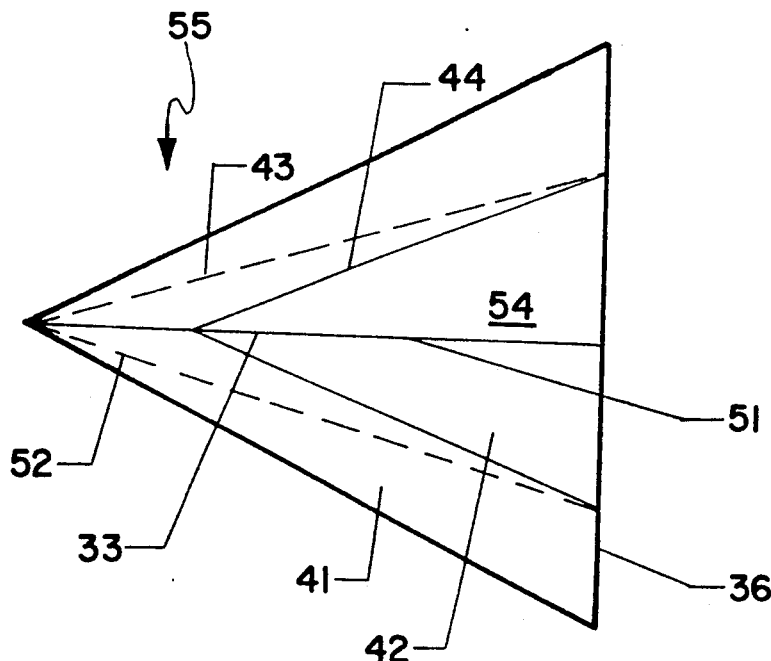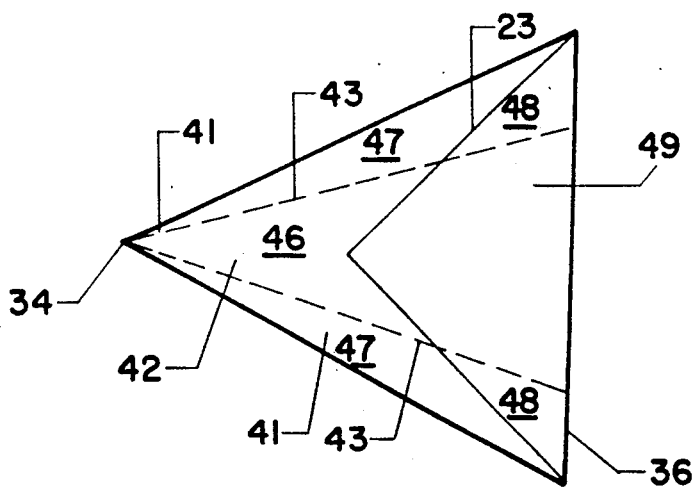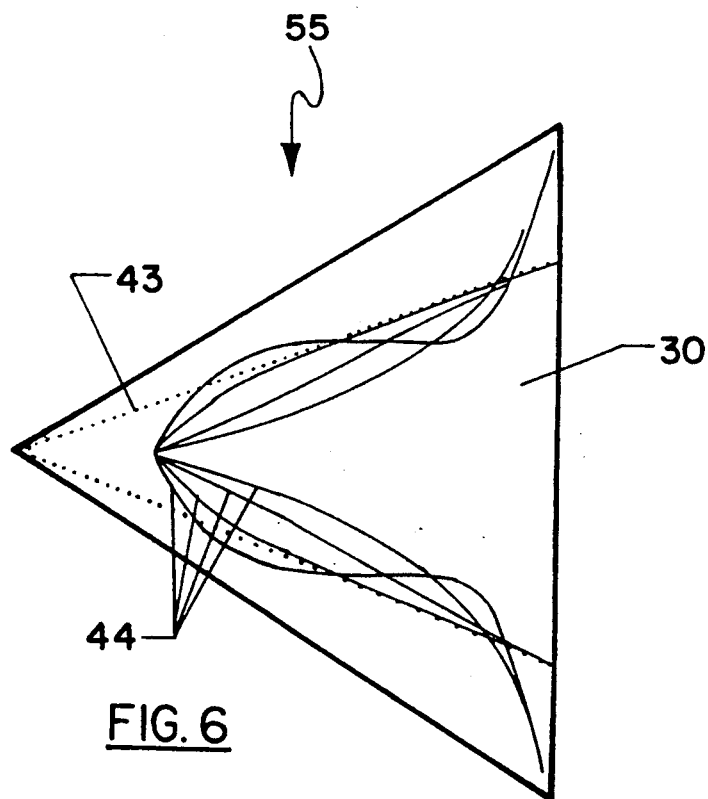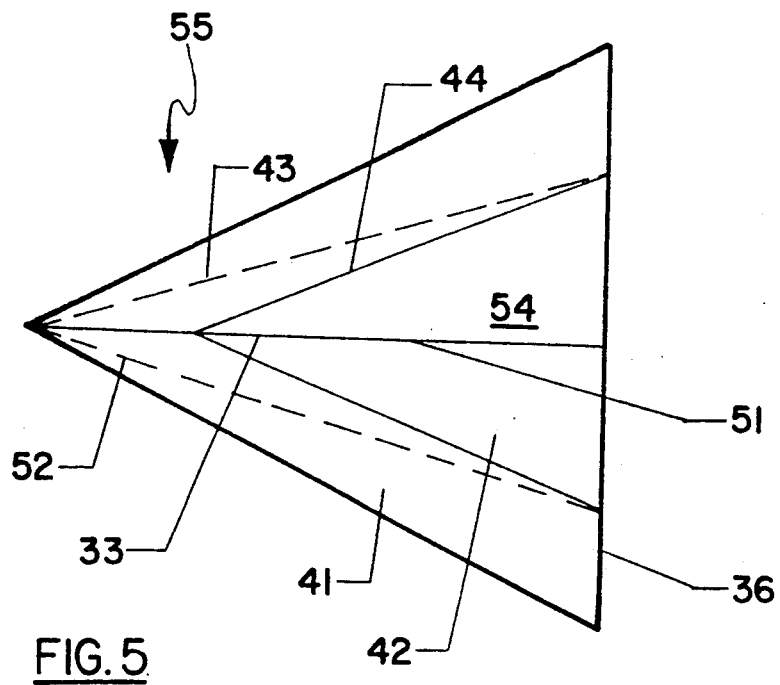
FIG. 1

PRIOR ART

FIG. 2

PRIOR ART

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FIG.3

PRIOR ART

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FIG. 4

PRIOR ART

FIG. 5

FIG. 6
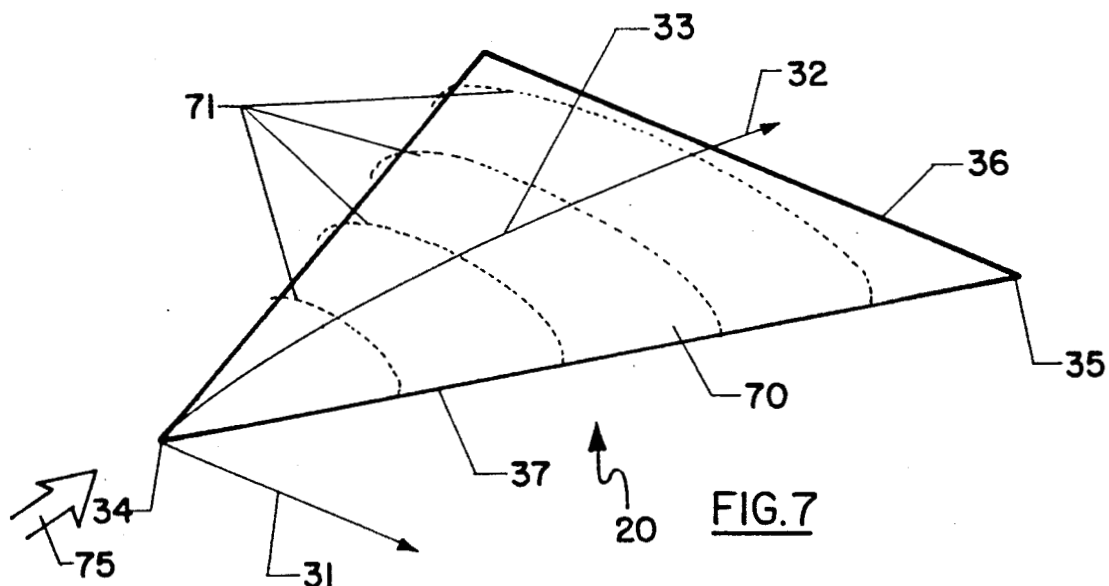
FIG.7

PRIOR ART

FIG.8

PRIOR ART

FIG. 9
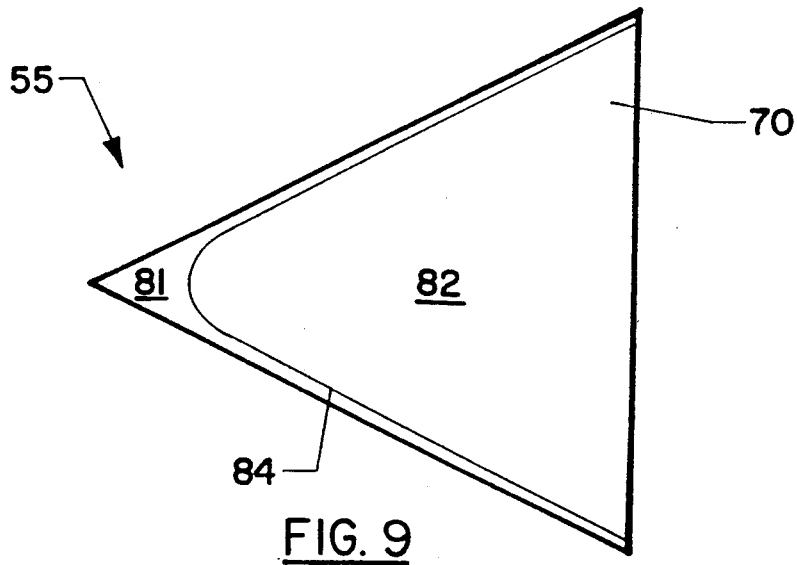
FIG. 10

PRIOR ART

FIG. 11
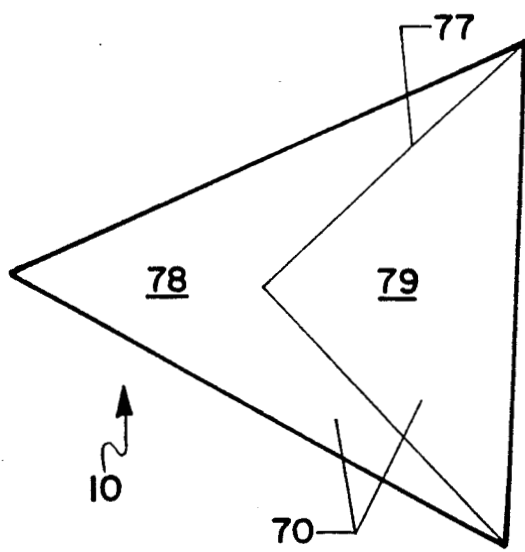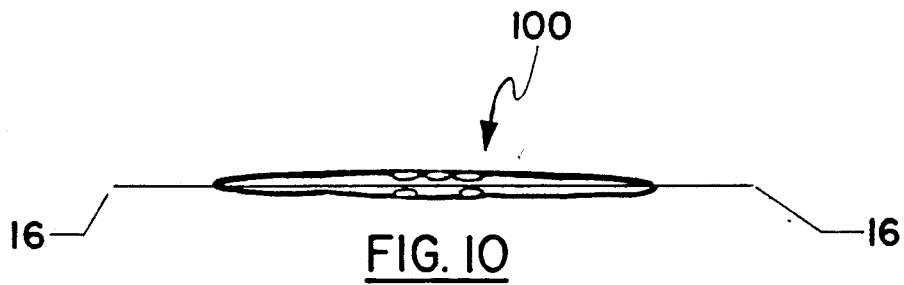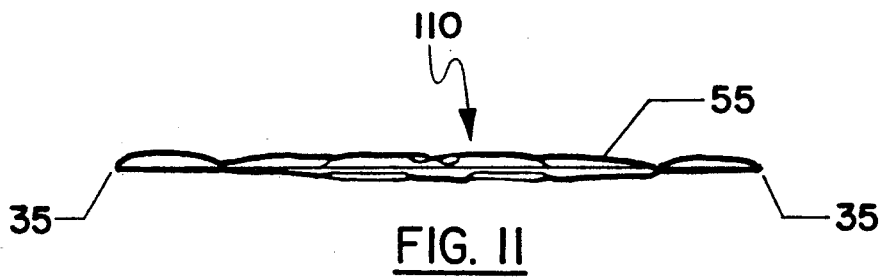
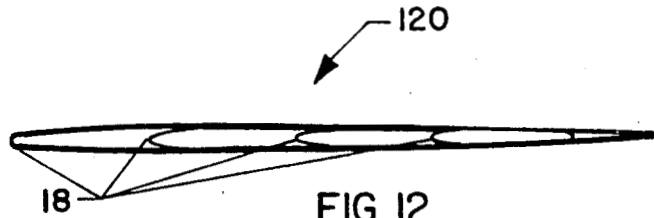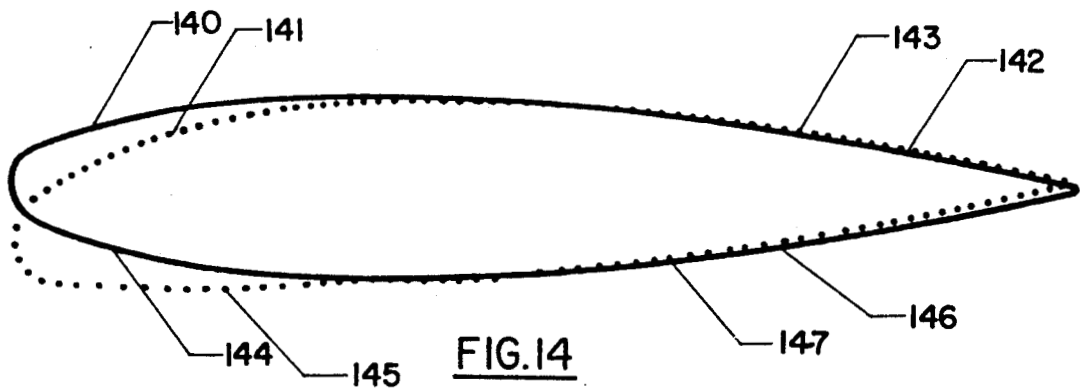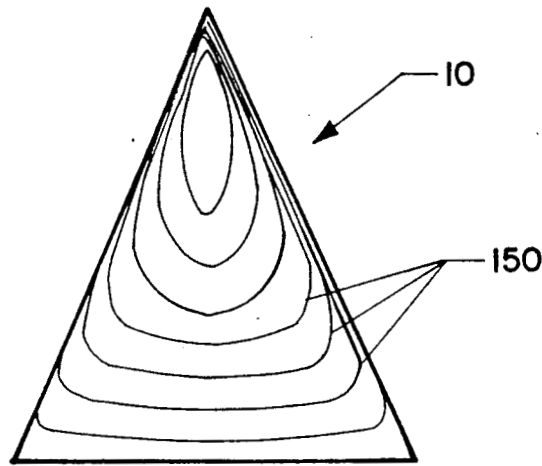FIG. 12

PRIOR ART

FIG. 13

FIG. 14

FIG.15

PRIOR ART
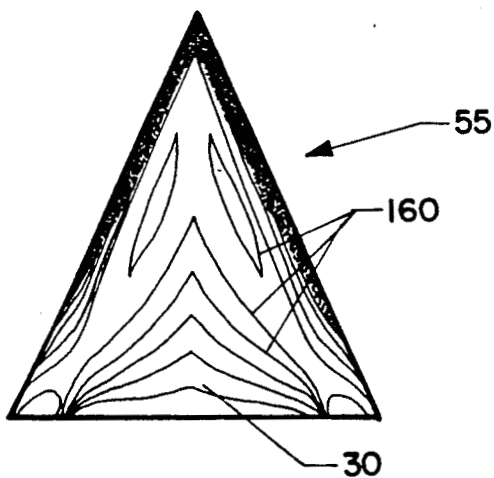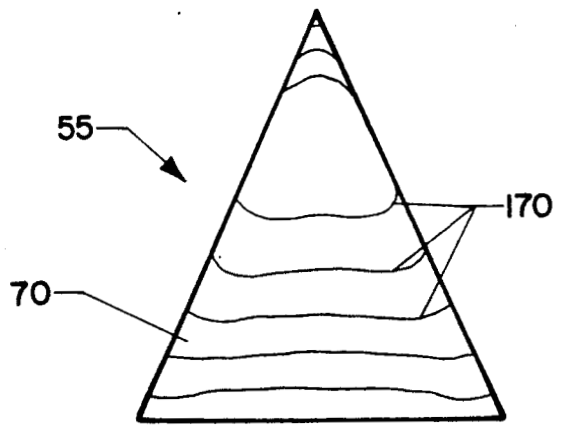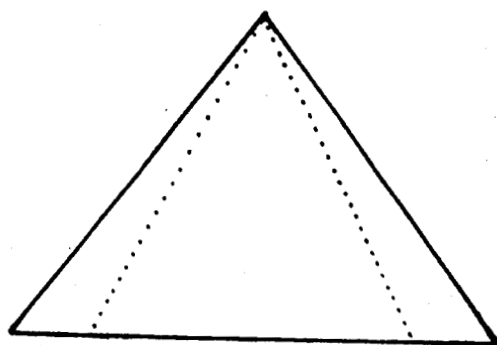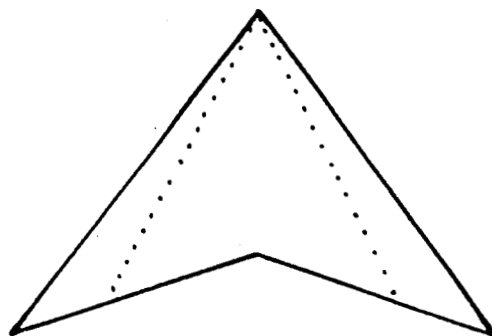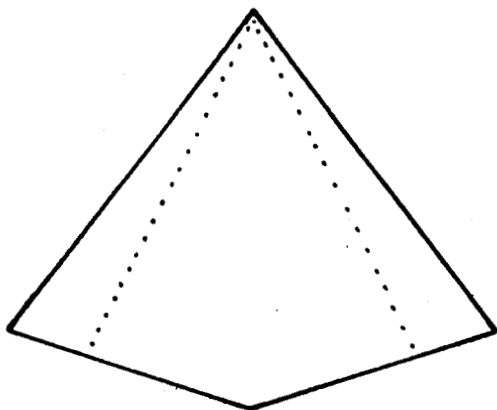

FIG.16

FIG.17

FIG. 18(a)
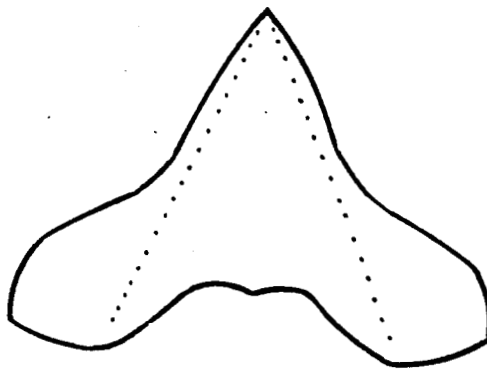
FIG. 18(b)

FIG. 18(c)

FIG. 18(d)

NATURAL FLOW WING

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the U.S. Governement and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a wing and, more specifically to a wing contoured to match the natural flow of air about the wing, and to a method of designing such a wing.

2. Description of the Related Art

Future supersonic military and commercial aircraft will be required to have high levels of lifting efficiency at subsonic, transonic, and supersonic speeds. Present philosophies for the design of wings vary greatly in addressing multi-point design conditions. A review of existing philosophies of wing design for subsonic, transonic, and supersonic flight reveals both contradictions and similarities.

The contradictions exist mainly between the philosophies for subsonic and transonic (low-speed) cruise design and the schemes for supersonic cruise design. For low speed designs, the tendency is toward a low wing sweep, thick airfoils, and blunt leading edges, with supercritical airfoils being most commonly used. On the other hand, supersonic designs typically employ high-sweep wings with thin airfoils and sharp leading edges. Methods involving linear theory usually provide wing twist and camber.

At maneuvering conditions, designs for both low-speed and supersonic wings utilize variable-camber devices such as leading-edge and trailing-edge flaps. At subsonic and transonic speeds, leading-edge flaps have succeeded fairly well. At supersonic speeds, however, leading-edge flaps have accomplished only minimal benefits in performance. Variable camber devices also have the added drawbacks of increased complexity in design, increased wing weight, and loss in usable volume.

An alternate approach for meeting the required maneuvering conditions is developing a fixed camber wing. Generally, these wing designs have succeeded at their designed lift conditions but have suffered severe camber drag penalties at lower lift conditions.

A conventional uncambered delta wing is conical about the wing tip. Experimental data in "Supersonic Aerodynamics of Delta Wings", NASA TP-2771, March 1988, and theoretical analysis in "The NCOREL Computer Program for 3-D Nonlinear Supersonic Potential Flow Computations", NASA CR-3694, August 1983, show, however, that the flow and pressure loading over the upper surface of a swept delta wing at subsonic, transonic, and supersonic speeds tend to be conical about the apex of the wing. The conical nature of the field of flow on the upper surface of the wing produces favorable and unfavorable pressure fields based on considerations involving drag.

SUMMARY OF THE INVENTION

An object of the invention is to address problems in wing design over a broad range of Mach numbers and lift conditions.

Another object of the invention is to capitalize on the naturally-occurring flow field and resulting pressure distributions over a wing.

A further object of the invention is to improve the structural and volumetric efficiency of swept wings by eliminating the need for variable-camber devices for flow management.

Yet another object of the invention is to provide a wing with fixed geometry that reduces pressure drag from zero-lift through high-lift conditions.

The present invention attains the foregoing and additional objects by contouring a three-dimensional upper surface and a three-dimensional lower surface of a wing independently of one another into a presecribed shape. As discussed earlier, experimental data and theoretical analysis show that flow and pressure loading over the upper surface of a swept delta wing at subsonic, transonic, and supersonic speeds tend to be conical about the apex of the wing. This conical nature of the flow field on the upper surface of the wing produces favorable and unfavorable regions of performance based on drag. The present invention reduces these unfavorable regions of performance by shaping the upper surface such that a maximum thickness at a center of the wing moves forward and that a maximum thickness near a tip of the wing moves aft, thereby contouring the wing to coincide more closely with the conical nature of the flow on the upper surface.

A nearly constant compressive loading characterizes the flow field over the lower surface of the wing. Magnitude of these compressive pressures on the lower surface depends on angle of attack and a streamwise curvature of the lower surface of the wing and not on a cross-sectional spanwise curvature. The present invention thereby shapes the lower surface to create an area as large as possible with negative slopes.

The present invention employs a scheme that redistributes an area from the lower surface to the upper surface of the wing at a given streamwise cross-section. The scheme optimizes a cross-sectional slope of the upper surface.

Any wing defined by a leading-edge sweep, a position of a maximum thickness, a distribution of an airfoil thickness and a leading-edge radius may be used to obtain the final, shaped geometry of the upper and lower surfaces of the present invention. Compared to a conventional constant airfoil swept wing, a natural flow wing has an increased forward-sloping projected area and more gradual slopes on the upper surface forward of the maximum thickness, reduced slopes on the upper surface aft of the maximum thickness, and a lower surface with negative slopes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a streamwise cut of a conventional, constant airfoil of a swept wing;

FIG. 2 is a planform view of the conventional swept delta wing;

FIG. 3 is an orthogonal view of an upper surface of the delta wing showing a typical pressure distribution;

FIG. 4 is a planform view of the upper surface of the conventional swept wing showing a recompression line;

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FIG. **5** is a planform view of the upper surface of a natural flow wing;

FIG. **6** illustrates alternative locations of a maximum thickness line for the upper surface of the natural flow wing;

FIG. **7** is an orthogonal view of a lower surface of the delta wing showing a typical pressure distribution;

FIG. **8** is a planform view of the lower surface of the conventional swept wing;

FIG. **9** is a planform view of the lower surface of the natural flow wing;

FIG. **10** shows spanwise cuts of the conventional swept wing;

FIG. **11** shows spanwise cuts of the natural flow wing;

FIG. **12** illustrates streamwise cuts of the conventional swept wing;

FIG. **13** illustrates streamwise cuts of the natural flow wing;

FIG. **14** is a comparison between a streamwise section of the conventional wing and the natural flow wing;

FIG. **15** shows elevation cuts of the conventional wing;

FIG. **16** shows elevation cuts of the upper surface of the natural flow wing;

FIG. **17** illustrates elevation cuts of the lower surface of the natural flow wing; and

FIGS. **18**(*a*), **18**(*b*), **18**(*c*) and **18**(*d*) illustrate possible wing planform shapes that may be used to obtain the natural flow wing.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** illustrates a streamwise cut of a conventional, constant airfoil swept wing **10** with an upper surface **11**, a lower surface **12**, a leading edge **18**, a maximum thickness **13**, and a chord length **14**. An airfoil shape **15** is constant along the span of the wing. The conventional, constant airfoil swept wing also has along the span a constant thickness ratio, defined as the maximum thickness **13** divided by the chord length **14**, or the thickness ratio might decrease along the span.

As shown in FIG. **2**, a line of maximum thickness **23** locates the maximum thickness **13** of each airfoil shape **15** along the span of the wing. Standard application of the thickness **13** to an uncambered swept delta wing **20** results in a wing which is conical about a wing tip **16** as depicted in FIG. **2**. Area in front of maximum thickness line **23** has a forward-sloping surface **21** and area behind line **23** has a rearward-sloping surface **24**.

FIG. **3** shows an upper surface **30** of the swept delta wing **20**. Results obtained for the delta wing **20** are readily transferable to other planforms due to the generic nature of the geometry of the delta wing **20**. The upper surface **30** extends in a spanwise direction **31** from a root **33** to a wing tip **35** and in a streamwise direction **32** from an apex **34** to a trailing edge **36**. A leading edge **37** extends from the apex **34** to the tip **35**.

Experimental data and theoretical analysis show that for flow direction **22** a pressure loading **25** over the upper surface **30** of the swept delta wing **20** at subsonic, transonic, and supersonic speeds tends to be conical about the apex **34** and not conical about the tip **35**. The conical nature of the pressure field **25** on the upper surface **30** of wing **20** produces favorable and unfavorable pressure fields based on considerations involving drag.

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As demonstrated in FIG. **4**, the pressure **25** over upper surface **30** for wing **20** at lifting conditions is characterized by an outboard region **41** of pressure below freestream static pressure and an inboard region **42** of more positive pressure. A line of recompression **43**, which can be straight as shown or curvilinear, emanates from apex **34** and extends toward trailing edge **36**. The line of recompression **43** is generally independent of wing geometry and marks a border between outboard region **41** and inboard region **42**.

As shown in FIG. **4**, maximum thickness line **23** and recompression line **43** intersect one another and divide upper surface **30** into four zones **46**, **47**, **48**, and **49** that identify two favorable and two unfavorable zones of performance. The two unfavorable zones of performance are inboard forward zone **46** and outboard aft zone **48**. Inboard forward zone **46** experiences a compression of flow ahead of the maximum thickness line **44**, resulting in more positive pressures acting on the forward-facing surface **21** that produce high drag levels. Rearward-facing surface **24** combines with high negative pressure coefficients in outboard aft zone **48** to produce high drag levels. The two other zones **47** and **49** of upper surface **30** have pressure fields **25** which combine favorably with the local surface geometry to produce reductions in drag.

The present invention reduces or eliminates the unfavorable zones with high drag **46** and **48** by locating a first maximum thickness line **44** near the recompression line **43** as depicted in FIG. **5** for natural flow wing **55**. By moving the maximum thickness line **44** forward at centerline **51** and sweeping line **44** aft to the trailing edge **36**, a first forward-sloping surface **52** is minimized in inboard region **42** and maximized in outboard region **41**. Further, a first rearward-sloping surface **54** is maximized in inboard region **42** and minimized in outboard region **41**. The resulting shape of upper surface **30** has a small forward-sloping surface **52** ahead of line **44** and a large rearward-sloping surface **54** behind line **44** in the inboard region **42**. Upper surface **30** also has, in outboard region **41**, a large forward-sloping surface **52** and a small or no rearward-sloping surface **54** behind line **44**. The shape of upper surface **30** thus coincides with the conical nature of the pressure field **25**.

FIG. **6** illustrates alternative locations of maximum thickness line **44** on upper surface **30** that would provide the favorable results of a natural flow wing **55**. The alternatives shown in FIG. **6**, however, are not exclusive. Preferably, the maximum thickness line **44** meets centerline **51** at a 20 percent chord length to provide a smooth airfoil at the root **33** as illustrated in FIG. **5**.

As appears in FIG. **7**, a lower surface **70** of the swept delta wing **20** extends in the spanwise direction **31** from the root **33** to the wing tip **35** and in the streamwise direction **32** from the apex **34** to the trailing edge **36**. The leading edge **37** extends from the apex **34** to the tip **37**.

Flow **75** over the lower surface **70** of wing **20** behaves quite differently at positive angles of attack than the upper surface **30**. Lower surface **70** thus requires a different type of geometry. FIG. **7** demonstrates that the flow **75** over lower surface **70** is characterized by a nearly constant compression loading **71**. The magnitude of compressive pressure **71** primarily depends upon wing-surface streamwise curvature and not on spanwise cross-sectional curvature. The most beneficial lower surface **70** would thus have as large an area as possible with a rearward slope.

Conventional wing **10** typically has a second line of maximum thickness **77** for lower surface **70** as illustrated in FIG. **8**. Area in front maximum thickness line **77** has a second forward-sloping surface **78** and area behind line **77** has a second rearward-sloping surface **79**.

The present invention maximizes a second rearward-sloping surface **82** and consequently minimizes a second forward-sloping surface **81** by locating a second maximum thickness line **84** as demonstrated in FIG. **9** for natural flow wing **55**. The resulting shape of lower surface **70** has a small forward-sloping surface **81** and a large rearward-sloping surface **82** as shown in FIG. **9**.

Additional modifications to the conventional wing **10** would further improve aerodynamic performance. Referring to FIG. **10**, spanwise cuts **100** reveal that the thickness **13** of conventional wing **10** typically decreases in the spanwise direction **31** and that thickness **13** approaches zero at wing tip **16**. Referring now to FIG. **5**, maximum thickness line **44** meets centerline **51** at a 20 percent chord length to provide a smooth airfoil at the root **33**. This location of line **44** is not ideal because the more positive pressures of inboard region **41** are acting on forward-sloping surface **52** and thereby producing high drag levels. To compensate for this drawback while retaining a smooth airfoil at the root **33**, the present invention decreases maximum thickness **13** at root **33** and increases thickness **13** at the tip **35**, with an example of one possible final shape of natural flow wing **55** depicted with spanwise cuts **110** in FIG. **11**.

Referring to FIG. **12**, streamwise cuts **120** of the conventional wing **10** illustrate that leading edge **18** has a constant bluntness as the wing extends in spanwise direction **31**. The present invention preferably contours upper surface **30** and lower surface **70** to form leading edge **37**, as shown in FIG. **13**, with increasing bluntness in the inboard-to-outboard spanwise direction. The combination of increasing the thickness ratio and leading-edge bluntness from the root **33** to the wing tip **35** provides a more constant wing thickness **13** from the root **33** to the tip **35**. Thus, lower drag levels are achieved because the nearly constant low pressure at the leading edge **37** has a better surface geometry to act upon.

Referring to FIG. **14**, the forward-sloping surface of upper surface **11** of conventional wing **10** has a forward slope **140** and the rearward-sloping surface has a rearward slope **142**. A steeper forward slope provides greater frontal area as discussed above. The present invention preferably changes the conventional, constant airfoil wing **10** such that upper surface **30** of natural flow wing **55** has a majority of forward-facing slopes **141** steeper than forward slope **140** and a majority of rearward-facing slopes **143** less steep than rearward slope **142**, as shown in FIG. **14**.

FIG. **14** also demonstrates that the forward-sloping surface of lower surface **12** of the conventional wing **10** has a forward slope **144** and the rearward slope of **146**. The present invention preferably contours lower surface **70** of natural flow wing **55** such that a majority of forward-facing slopes **145** are less steep than forward slope **144** and a majority of rearward-facing slopes **147** are steeper than rearward slope **146**, as illustrated in FIG. **14**. Frontal area should be minimized on the lower surface because no region of low pressure (expansion) exists.

Elevation cuts **150** of the conventional wing **10**, which are identical for both the upper surface and lower surface, appear in FIG. **15**. FIGS. **16** and **17**

illustrate preferred elevation cuts **160** and **170** for natural flow wing **55**. Note that elevation cuts **160** for upper surface **30** differ in pattern from elevation cuts **170** for lower surface **70**.

A wing geometry generation scheme would allow for a broad range of analytical wing surfaces to be developed from a few input parameters. Any wing defined by a leading-edge sweep, a position of maximum thickness, a distribution of an airfoil thickness, and a leading-edge radius may be used to obtain the final, shaped geometry of upper surface and lower surface **70** of natural flow wing **55**. Distribution of the airfoil thickness and maximum thickness position may be defined by the equation:

$$\phi_t = \sum_{n=0}^{\infty} a_n \eta^n + \sum_{n=1}^{\infty} \frac{b_n}{\eta^n},$$

where a_n and b_n are variables which can be series themselves and η is the nondimensionalized spanwise location. For the conventional wing **10**, a constant airfoil **15** is employed which has a variation in airfoil thickness and airfoil thickness position defined by all a_n and b_n equal to zero for $n > 0$. Examples of possible wing shapes which may be defined by the above equation are demonstrated in FIGS. **18**(*a*), **18**(*b*), **18**(*c*) and **18**(*d*). Preferably, a wing with a positive leading edge sweep greater than 20° and a trailing edge sweep of any value may be used to obtain the final, shaped geometry of natural flow wing **55**.

The present invention also employs a scheme that redistributes an area from lower surface **70** to upper surface **30** at a given streamwise cross-section in order to optimize local cross-sectional slopes of upper surface **30**. The scheme to redistribute the area is defined by the equation:

$$\phi_c = \sum_{n=0}^{\infty} a_n \xi^n + \sum_{n=1}^{\infty} \frac{b_n}{\xi^n}$$

where a_n and b_n are variables as discussed above and ξ is the nondimensionalized streamwise location.

What is claimed is:

1. A natural flow wing for providing improved drag and lift performance comprising:

an upper surface and a lower surface, each surface extending in a streamwise and in a spanwise direction and being three-dimensional;

the upper surface having an outboard region of pressure below freestream static pressure and an inboard region of pressure higher than the outboard region, with a line of recompression emanating from an apex of the wing and extending toward a trailing edge, the line of recompression marking a boarder between the outboard region and the inboard region;

the upper surface further having a first line of maximum thickness extending from a root of the wing to the trailing edge, the first line of maximum thickness marking a border between a first forward-sloping surface, the first line of maximum thickness being located near the line of recompression;

the inboard region providing a small first forward-sloping surface area ahead of the first line of maximum thickness and a large first rearward-sloping surface area behind the first line of maximum thickness;

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the outboard region providing a large first forward-sloping surface area ahead of the first line of maximum thickness and a small first rearward-sloping surface behind the first line of maximum thickness;

the lower surface having a second line of maximum thickness extending from the root of the wing toward the trailing edge; and

the lower surface further providing a small second forward-sloping surface area ahead of the second line of maximum thickness and a larger second rearward-sloping surface behind the second line of maximum thickness.

2. A natural flow wing according to claim 1, wherein the inboard region of the upper surface provides a first forward-sloping surface area ahead of the first line of maximum thickness comprising no more than about 5% of the inboard region and a first rearward-sloping surface area behind the first line of maximum thickness comprising the remainder of the inboard region:

the outboard region of the upper surface provides a first forward-sloping surface area ahead of the first line of maximum thickness comprising at least about 95% of the outboard region and a first rearward-sloping surface area behind the first line of maximum thickness comprising the remainder of the outboard region; and

the lower surface provides a second forward-sloping surface area ahead of the second line of maximum thickness comprising no more than about 5% of the lower surface and a second rearward-sloping surface behind the second line of maximum thickness comprising the remainder of the lower surface

3. A natural flow wing according to claim 2, wherein the upper surface and the lower surface combine to form a thickness which does not approach zero at wing tip.

4. Natural flow wing according to claim 2, wherein the upper surface and the lower surface combine to form a leading edge, the leading edge having an increasing bluntness to chord ratio in the inboard-to-outboard spanwise direction.

5. A natural flow wing according to claim 2, wherein at least about 95% of the wing thickness is projected as forward slope on the upper surface ahead of the first line of maximum thickness.

6. A natural flow wing according to claim 2, wherein no more than about 20% of the wing thickness is projected as rearward slope on the upper surface behind the first line of maximum thickness.

7. A natural flow wing according to claim 2, wherein no more than about 5% of the wing thickness is projected as forward slope on the lower surface ahead of the second line of maximum thickness.

8. A natural flow wing according to claim 2, wherein at least about 80% of the wing thickness is projected as rearward slope on the lower surface behind the second line of maximum thickness.

9. A method of constructing a natural flow wing for providing improved drag and lift performance comprising:

shaping an upper surface of the natural flow wing such that

(a) the upper surface has an outboard region of pressure below freestream static pressure and an inboard region of pressure higher than the outboard region;

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(b) a small first forward-sloping surface area is formed in the inboard region and a large first forward-sloping surface area is formed in the outboard region;

(c) a large first rearward-sloping surface area is formed in the inboard region and a small first rearward-sloping surface area is formed in the outboard region; and

shaping a lower surface of the natural flow wing such that

(a) a small second forward-sloping surface area and a large second rearward-sloping surface are formed.

10. A method according to claim 9, further comprising:

shaping an upper surface of the natural flow wing such that

(a) the first forward-sloping surface area in the inboard region comprises no more than about 5% of the inboard region and the first rearward-sloping surface area comprises the remainder of the inboard region;

(b) the first forward-sloping surface area in the outboard region comprises at least about 95% of the outboard region and the first rearward-sloping surface area comprises the remainder of the outboard region; and

shaping a lower surface of the natural flow wing such that

(a) the second forward-sloping surface area of the lower surface comprises no more than about 5% of the lower surface and the second rearward-sloping surface area comprises the remainder of the lower surface.

11. A method according to claim 10, further comprising:

minimizing a thickness taper in a spanwise direction, such that thickness of the natural flow wing does not approach zero at wing tip.

12. A method according to claim 10, further comprising:

shaping a leading edge of the natural flow wing to form an increasing bluntness to chord ratio of a leading edge in an inboard-to-outboard spanwise direction.

13. A method according to claim 10, wherein the method of shaping the upper surface of the natural flow wing further comprises making at least about 95% of the wing thickness forward-facing slopes.

14. A method according to claim 10, wherein the method of shaping the upper surface of the natural flow wing further comprises making no more than about 20% of the wing thickness rearward-facing slopes.

15. A method according to claim 10, wherein the method of shaping the lower surface of the natural flow wing further comprises making no more than about 5% of the wing thickness forward-facing slopes.

16. A method according to claim 10, wherein the method of shaping the lower surface of the natural flow wing further comprises making at least about 80% of the wing thickness rearward-facing slopes.

17. A natural flow wing according to claim 2, wherein the upper surface and the lower surface combine to form a wing shape with a positive leading edge sweep greater than 20° and a trailing edge sweep of any value.

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