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[Continued on next page]

(54) Title: WINGLETS WITH RECESSED SURFACES, AND ASSOCIATED SYSTEMS AND METHODS

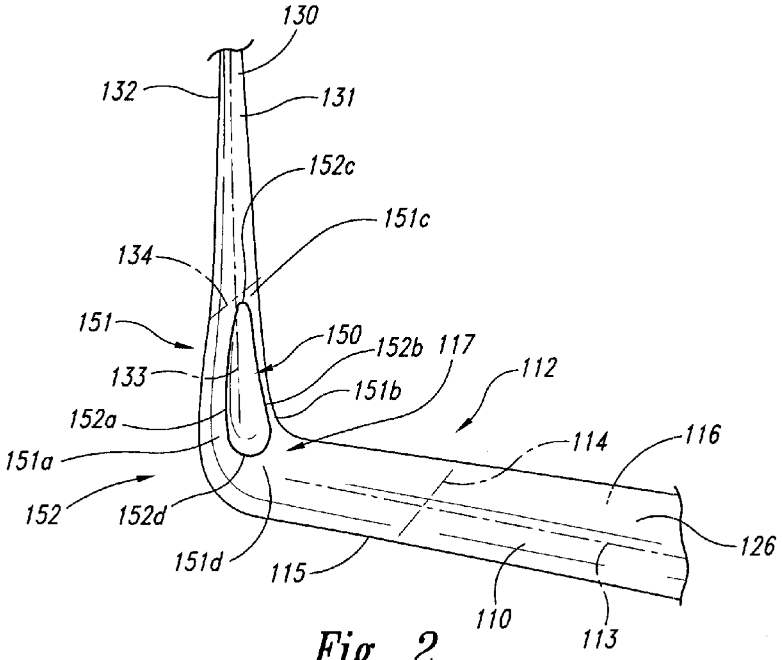

Fig. 2

(57) Abstract: Winglets (130) with recessed surfaces (150), and associated systems and methods are disclosed. A system in accordance with a particular embodiment includes a wing (110) having an inboard portion (111) and an outboard portion (112), and further includes a winglet (130) coupled to the wing at the outboard portion. The winglet can have a first surface (131) facing at least partially inboard and a second surface (132) facing at least partially outboard, with the first surface including a recessed region (150).

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WINGLETS WITH RECESSED SURFACES, AND ASSOCIATED SYSTEMS AND METHODS

TECHNICAL FIELD

The following disclosure relates generally to winglets with recessed surfaces, and associated systems and methods.

BACKGROUND

The idea of using winglets to reduce induced drag on aircraft wings was studied by Richard Whitcomb of NASA and others in the 1970s. Since then, a number of variations on this idea have been patented (see, for example, U.S. Patent No. 4,205,810 to Ishimitsu and U.S. Patent No. 5,275,358 to Goldhammer, et al.). In addition, a number of tip device variations are currently in service. Such devices include horizontal span extensions and aft-swept span extensions that are canted upward or downward at various angles. These devices can be added to a new wing during the initial design phase of an all-new aircraft, or they can be added to an existing wing as a retrofit or during development of a derivative model.

The induced drag of a wing or a wing/winglet combination can be calculated with reasonable accuracy using the classic “Trefftz plane theory.” According to this theory, the induced drag of an aircraft wing depends only on the trailing edge trace of the “lifting system” (i.e., the wing plus tip device), as viewed directly from the front or rear of the wing, and the “spanload.” The spanload is the distribution of aerodynamic load perpendicular to the trailing edge trace of the wing. Aerodynamicists often refer to this aerodynamic load distribution as “lift,” even though the load is not vertical when the trailing edge trace is tilted from horizontal. Adding a winglet or other wing tip device to a wing changes both the trailing edge trace (i.e., the “Trefftz-plane geometry”) and the spanload. As a result, adding such a device also changes the induced drag on the wing.

For a given Trefftz-plane geometry and a given total vertical lift, there is generally one spanload that gives the lowest possible induced drag. This is the “ideal spanload,” and the induced drag that results from the ideal spanload is the “ideal induced drag.” For a flat wing where the Trefftz-plane geometry is a horizontal line, the ideal spanload is elliptical. Conventional aircraft wings without winglets are close enough to being flat in the Trefftz-plane that their ideal spanloads are very close to elliptical. For conventional aircraft wings having vertical or near-vertical winglets (i.e., nonplanar lifting systems), the ideal spanload is generally not elliptical, but the ideal spanload can be easily calculated from conventional wing theory.

Conventional aircraft wings are generally not designed with ideal or elliptical spanloads. Instead, they are designed with compromised "triangular" spanloads that reduce structural bending loads on the wing. Such designs trade a slight increase in induced drag for a reduction in airframe weight. The degree of compromise varies considerably from one aircraft model to another. To produce such a triangular spanload, the wing tip is typically twisted to produce "washout." Washout refers to a wing that twists in an outboard direction so that the trailing edge moves upward relative to the leading edge. Washing out the wing tip in this manner lowers the angle of attack of the wing tip with respect to the wing root, thereby reducing the lift distribution toward the wing tip.

Designing a new wing and developing the associated tooling for a new wing is an expensive undertaking. Accordingly, some aircraft manufacturers develop derivative wing designs that are based at least in part on an initial design. While such designs can be less expensive to develop, they typically include at least some performance compromises. Accordingly, there remains a need for improved, cost-effective wing development processes.

SUMMARY

The present disclosure is directed generally to winglets with recessed surfaces, and associated systems and methods. A system in accordance with a particular embodiment includes a wing having an inboard portion and an outboard portion, and a winglet coupled to the wing at the outboard portion. The winglet has a first surface facing at least partially inboard and a second surface facing at least partially outboard, with the first surface including a recessed region. The recessed region can be concave relative to adjacent regions of the first surface, and the adjacent regions can include regions located on both sides of the recessed region in a chordwise direction, and a region positioned away from the wing along the spanwise axis of the winglet.

Other aspects of the disclosure are directed to methods for designing an aircraft system. One such method includes providing a design for a wing that includes airfoil sections from an inboard region to an outboard region of the wing. The method further

includes designing a winglet for use with the wing without changing the general shapes of the wing airfoil sections. The winglet has a first surface facing generally inboard and a second surface facing generally outboard away from the first surface. Designing the winglet includes at least reducing a performance impact of flow at a junction region of the wing and the winglet by designing a concave recess in the first surface of the winglet.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a partially schematic, isometric illustration of an aircraft having wings and wingtip devices configured in accordance with an embodiment of the disclosure.

Figure 2 is a partially schematic, isometric illustration of an outboard wing portion and winglet having a recessed region in accordance with a particular embodiment of the disclosure.

Figure 3 is a rear view (looking forward) of a portion of the wing and winglet shown in Figure 2.

Figure 4 is a front view (looking rearward) of a portion of the wing and winglet shown in Figure 2, with particular winglet sections identified.

Figures 5A-5F are nondimensionalized, cross-sectional illustrations of the winglet sections identified in Figure 4.

Figure 6 is a composite of the winglet sections shown in Figures 5A-5F, with the vertical scale exaggerated for purposes of illustration.

Figure 7 is a composite of the winglet camber lines shown in Figures 5A-5F, with the vertical scale exaggerated for purposes of illustration.

Figure 8 is a flow diagram illustrating a method in accordance with a particular embodiment of the disclosure.

DETAILED DESCRIPTION

The following disclosure describes winglets with recessed surfaces, and associated systems and methods. Certain specific details are set forth in the following description and in Figures 1-8 to provide a thorough understanding of various embodiments of the disclosure. Other details describing well-known structures and systems often associated with aircraft and aircraft wings are not set forth in the following description to avoid unnecessarily obscuring the description of the various embodiments.

Many of the details, dimensions, angles and other specifications shown in the Figures are merely illustrative of particular embodiments. Accordingly, other embodiments can have other details, dimensions, and specifications without departing from the present disclosure. In addition, other embodiments may be practiced without several of the details described below.

Figure 1 is a top isometric view of an aircraft 100 having a wing/winglet combination 105 configured in accordance with an embodiment of the disclosure. In one aspect of this embodiment, the aircraft 100 includes a lifting surface such as a wing 110 extending outwardly from a fuselage 102. The fuselage 102 can be aligned along a longitudinal axis 101 and can include a passenger compartment 103 configured to carry a plurality of passengers (not shown). In one embodiment, the passenger compartment 103 can be configured to carry at least 50 passengers. In another embodiment, the passenger compartment 103 can be configured to carry at least 150 passengers. In further embodiments, the passenger compartment 103 can be configured to carry other numbers of passengers, and in still other embodiments (such as military embodiments), the passenger compartment 103 can be omitted or can be configured to carry cargo.

The wing 110 has an inboard portion 111 that includes the wing root, and an outboard portion 112 that includes the wing tip. The wing 110 also includes a winglet 130. In some cases, the winglet 130 can be added to an existing wing design, and in other cases, the wing 110 and the winglet 130 can be designed together. In either case, the winglets 130 can be particularly selected and/or configured to account for constraints associated with the design of the wing 110.

Although the winglet 130 of the illustrated embodiment is combined with a wing, in other embodiments, the winglet 130 can be combined with other types of lifting surfaces to reduce aerodynamic drag and/or serve other purposes. For example, in one other embodiment, the winglet 130 can be combined with a forward-wing or canard to reduce the aerodynamic drag on the canard. In further embodiments, the winglet 130 can be combined with other lifting surfaces. In particular embodiments, the winglets can be vertical, while in other embodiments, the winglets can be canted from the vertical. Embodiments in which the winglets are vertical or at least canted upwardly from the horizontal can be particularly useful for reducing space occupied by the aircraft 100 at an airport gate.

Figure 2 is a partially schematic, isometric view (looking generally aft and slightly outboard) of an outboard portion 112 of the wing 110, along with the winglet 130. The wing 110 includes an upper surface 126 and extends outboard along a wing spanwise axis 113, and extends fore and aft along a wing chordwise axis 114 between a wing leading edge 115 and a wing trailing edge 116. At the outboard portion 112, the wing 110 includes a wing/winglet junction 117 at which the wing 110 transitions to the winglet 130. In a particular embodiment, the junction 117 can be generally curved and/or gradual to reduce flow interference between the wing 110 and the winglet 130. In other embodiments, the junction 117 can have other shapes and/or configurations, including a sharp corner and/or a tight radius corner. As used herein, the term sharp corner refers to a corner that includes a surface discontinuity and/or sudden change in shape, e.g., a non-gradual change in slope. In any of these embodiments, the winglet 130 includes a first (e.g., inboard-facing) surface 131 and a second (e.g., outboard-facing) surface 132. The winglet 130 extends away from the wing 110 along a winglet spanwise axis 133, and extends fore and aft along a winglet chordwise axis 134.

The winglet 130 can further include a recessed region 150 located in the first surface 131. The recessed region 150 can be particularly sized and located to account for (e.g., reduce or eliminate) possible interference effects between the wing 110 and the winglet 130 in the region of the wing/winglet junction 117. In a particular embodiment, the recessed region 150 is bounded by adjacent regions 151 that are not recessed. Such adjacent regions 151 can include a forward adjacent region 151a, an aft adjacent region 151b, an upper or distal adjacent region 151c and a lower or proximal adjacent region 151d. The adjacent regions 151 can be convex, in contrast to the concave recessed region 150.

In a particular embodiment shown in Figure 2, the recessed region 150 is generally pear-shaped. Accordingly, the chordwise extent of the recessed region 150 can decrease in an upward/outward direction along the winglet spanwise axis 133. The illustrated recessed region 150 is roughly bounded by four points 152, including a forward-most point 152a, an aft-most point 152b, an uppermost or distal point 152c, and a lowermost or proximal point 152d. In other embodiments, the recessed region 150 can have other shapes and/or boundaries.

In a representative embodiment, the location of the forward-most point 152a can range from about 20% to about 40% of the local chordlength of the winglet 130, and the location of the aft-most point 152b can range from about 45% to about 65% of the local chordlength. In a particular embodiment, the recessed region extends from about 25% of the local chordlength to about 65% of the local chordlength over its spanwise extent. The location of the uppermost point 152c can range from about 20% to about 40% (e.g., about 30%) of the spanwise dimension of the winglet 130, and the location of the lower-most point 152d can range from about 0% to about 20% of the spanwise dimension of the winglet. These locations can have other values and other embodiments, depending upon the particular installation, the orientation of the winglet 130 relative to the wing 110, and/or other design and/or operation features.

Figure 3 is a rear view (looking forward) of a portion of the wing 110 and the winglet 130 shown in Figure 2. Figure 3 accordingly illustrates the recessed region 150 from the rear, indicating the overall shape of the recessed region 150 and its location relative to both the winglet 130 (including the winglet trailing edge 136) and the wing 110.

Figure 4 is a front view (looking rearward) of the wing 110 and the winglet 130 shown in Figures 2 and 3, indicating representative wing sections 118, and representative winglet sections 137 (shown as first-sixth winglet sections 137a-137f). The first winglet section 137a is taken at a region positioned downward/inboard from the recessed region 150, and the sixth winglet section 137f is taken at a location that is above/outboard of the recessed region 150. The intermediate winglet sections 137b-137e intersect the recessed region 150 and are described in further detail below with reference to Figures 5A-7.

Figures 5A-5F illustrate the winglet chord sections 137a-137f, respectively, described initially above with reference to Figure 4. The leading edge portions of the winglet chord sections 137a-137f are illustrated with a representative contour that may be different in different embodiments. As is also illustrated in Figures 5A-5F, each winglet chord section 137a-137f includes a camber line 138, illustrated as corresponding first-sixth camber lines 138a-138f. As is evident from Figures 5A-5F, the camber distribution for each chordwise section is non-monotonic, and the chordwise camber distribution varies in a non-monotonic manner along the spanwise axis of the winglet 130 in the recessed region 150. In particular, the camber line is generally flat below/inboard of the recessed region 150 (see camber line 138a), becomes concave or more concave in the recessed region 150 (see camber lines 138b-138e), and then becomes generally flat or less concave at a distal spanwise location above/outboard of the recessed region 150 (see camber line 138f). The first surface 131 of the winglet 130 has a similar, non-monotonic variation as the sections progress in a distal direction along the spanwise axis. Accordingly, as used herein, the term non-monotonic is used to describe a variation that changes in sense or direction, e.g., a contour that initially becomes more concave and then becomes less concave.

Figure 6 illustrates the six winglet sections 137a-137f together, with the vertical scale exaggerated to highlight the presence of the recessed region 150. Figure 7 illustrates the six camber lines 138a-138f together to indicate the variation of the camber lines in the recessed region. Figure 6 illustrates the non-monotonic change in shape of the winglet first surface 131 in the recessed region 150 (see chord sections 137a-137f), and Figure 7 illustrates the corresponding non-monotonic change in shape of the camber lines 138a-138f in the recessed region 150.

Returning briefly to Figure 2, one expected advantage of embodiments of the winglet 130 that include the recessed region 150 is that the recessed region 150 can reduce or eliminate flow interference effects caused by the juxtaposition of the winglet 130 and the wing 110. In particular, without the recessed region 150, separated flow may develop at the wing/winglet junction 117, which can increase drag and/or reduce lift and in either case, can adversely affect aircraft performance. The recess 150 can also reduce or eliminate the likelihood for a “double-shock” pressure field in this region. In particular, the recess 150 can reduce the aerodynamic compression in the junction region 117 to reduce or eliminate such a shock pattern. This, in turn, can reduce the drag of the aircraft 100 (Figure 1) and can improve the high-speed buffet margin of the wing 110, when compared with a wing that includes a winglet without such a feature. In general, it is expected that the tighter the corner of the wing/winglet junction 117, the greater the potential benefit of the recessed region 150. Accordingly, the recessed region 150 can have particular benefit when incorporated into a winglet 130 that is added to an existing wing to reduce drag, but, due to constraints on the spanwise extent of the modified wing, benefits from or requires a wing/winglet junction 117 with a tight or sharp corner.

Another particular advantage of the foregoing arrangement is that the recessed region 150 can be applied to the winglet 130 without affecting the wing upper surface 126. In particular, the wing upper surface 126 need not include a flat region or a concave or recessed region to provide the foregoing aerodynamic advantages, because it is expected that the recess 150 in the winglet 130 will be at least adequate to do so. Accordingly, an advantage of this arrangement is that the winglet 130 can be retrofitted to an existing and/or aerodynamically optimized wing 110.

Figure 8 illustrates a representative process 160 for designing a winglet. The process 160 includes providing a design for a wing that includes airfoil sections (e.g., the wing sections 118 shown in Figure 4) extending from an inboard region to an outboard region of the wing (process portion 161). The method further includes designing a winglet for use with the wing, without changing the general shapes of the wing airfoil sections (process portion 165). The winglet can have a first surface facing generally inboard and a second surface facing generally outboard away from the first surface. Designing the winglet further includes at least reducing a performance impact of flow at a junction region of the wing and the winglet by designing a concave recess in the first surface of the winglet. The concave recess can be defined by a variety of methods, e.g., by altering the lines of an existing airfoil section in the recessed region, and/or by altering the lines of an existing airfoil section outside the recessed region (e.g., by “building up” regions outside the recessed region).

In particular embodiments, the process for developing the winglet contours can be iterative, and can include developing an initial winglet loft (process portion 166) and analyzing the performance of the loft (process portion 167). In process portion 168, the loft can be analyzed to determine whether it meets target performance levels. For example, the loft can be assessed using computational fluid dynamics (CFD) tools and/or wind tunnel testing to determine whether preselected target performance levels are met. If not, the initially developed loft can be revised (process portion 166) until performance levels are met, at which point the process can end.

From the foregoing, it will be appreciated that specific embodiments of the disclosure have been described herein for purposes of illustration, but that various modifications may be made in other embodiments. For example, the winglets can have different cant angles, different spanwise and/or chordwise extents and/or different configurations than are specifically identified in the Figures. Such configurations can include winglets that extend both above and below the wing, and/or spiroid winglets, and/or wingtip feathers. The recessed regions may also have different locations and/or extents depending upon the particular installation. Certain aspects of the disclosure described in the context of particular embodiments may be combined or eliminated in other embodiments. Further, while advantages associated with certain embodiments have been described in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages to fall within the scope of the disclosure. Accordingly, the disclosure can include other embodiments not specifically described or shown above.

CLAIMS

We claim:

1. An aircraft system, comprising:

a wing having an inboard portion and an outboard portion; and

a winglet coupled to the wing at the outboard portion, the winglet having a first surface facing at least partially inboard and a second surface facing at least partially outboard, the first surface including a recessed region.

2. The system of claim 1 wherein the recessed region is concave relative to adjacent regions of the first surface, the adjacent regions including regions located on both sides of the recessed region in a chordwise direction, and including a region positioned away from the wing in a spanwise direction.

3. The system of claim 1 wherein the winglet has a leading edge and a trailing edge, and wherein the first surface of the winglet is convex near the leading edge, convex near the trailing edge and concave between the leading and trailing edges.

4. The system of claim 1 wherein the recessed region has a forwardmost point and an aftmost point in a chordwise direction, the recessed region having a proximal point closest to the wing in a spanwise direction and a distal point furthest from the wing in the spanwise direction.

5. The system of claim 4 wherein the forwardmost point is located at between about 20% and about 40% of a chordlength of the winglet intersecting the forwardmost point.

6. The system of claim 4 wherein the aftmost point is located at between about 45% and about 65% of a chordlength of the winglet intersecting the aftmost point.

7. The system of claim 4 wherein the distal point is located at between about 20% and about 40% of a spanwise dimension of the winglet.

8. A method for reducing aircraft system drag, comprising:

providing a wing that includes airfoil sections from an inboard region to an outboard region of the wing; and

providing a winglet for use with the wing without changing the general shapes of the wing airfoil sections at the outboard region of the wing, the winglet having a first surface facing generally inboard and a second surface generally outboard away from the first surface, wherein the winglet includes at least reducing a performance impact of flow at a junction region of the wing and winglet with a concave recess in the first surface of the winglet.

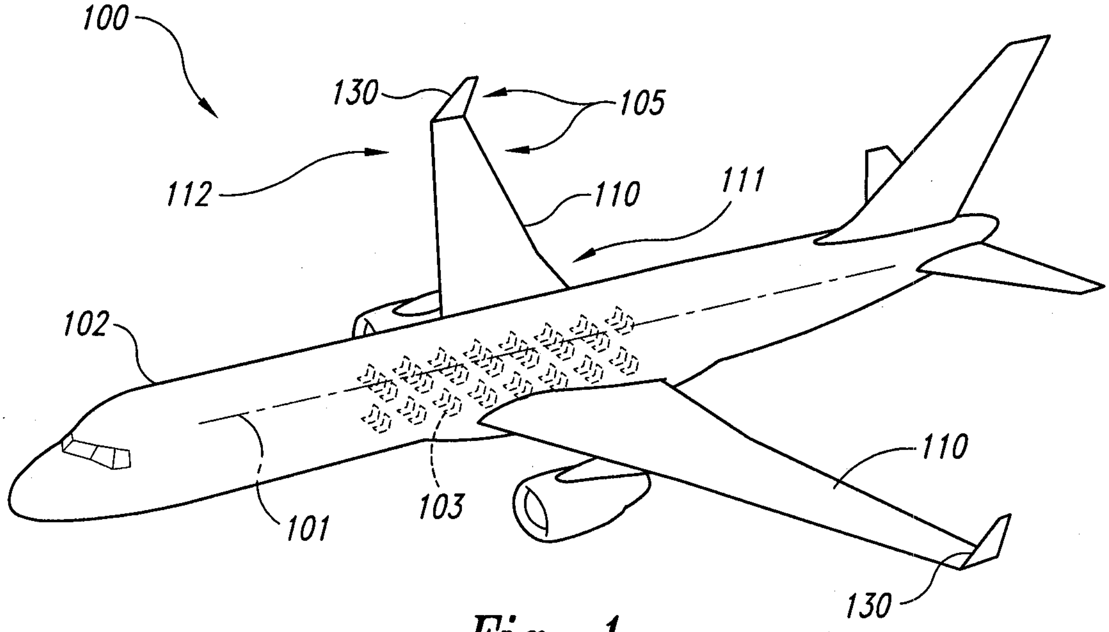
9. The method of claim 8, wherein a winglet includes a concave recess with a forwardmost point and an aftmost point in a chordwise direction, the concave recess having a proximal point closest to the wing in a spanwise direction and a distal point furthest from the wing in the spanwise direction.

10. The method of claim 9, wherein the forwardmost point to be located at between about 20% and about 40% of a chordlength of the winglet intersecting the forwardmost point.

11. The method of claim 9, wherein the aftmost point to be located at between about 45% and about 65% of a chordlength of the winglet intersecting the aftmost point.

12. The method of claim 8 wherein a concave recess includes a recess into an existing winglet loft.

13. The method of claim 8 wherein a concave recess includes built up regions of an existing winglet loft in a forward region and an aft region of the winglet.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130
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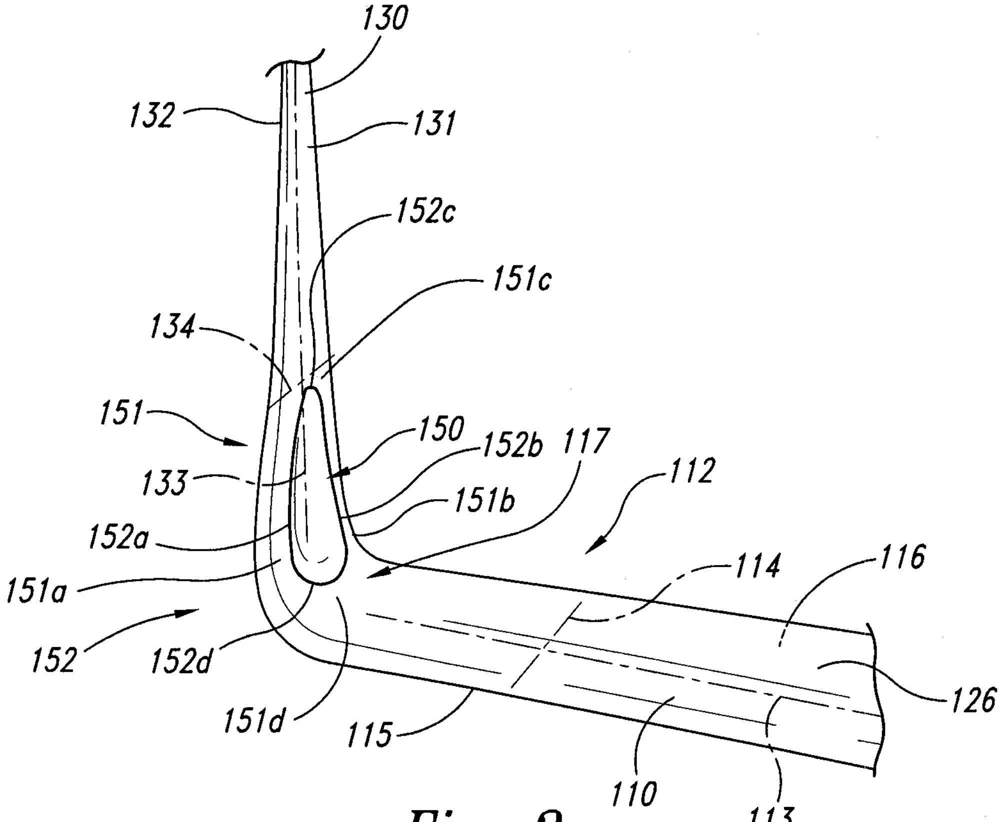
103
110
130

Fig. 1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132
131
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134
151
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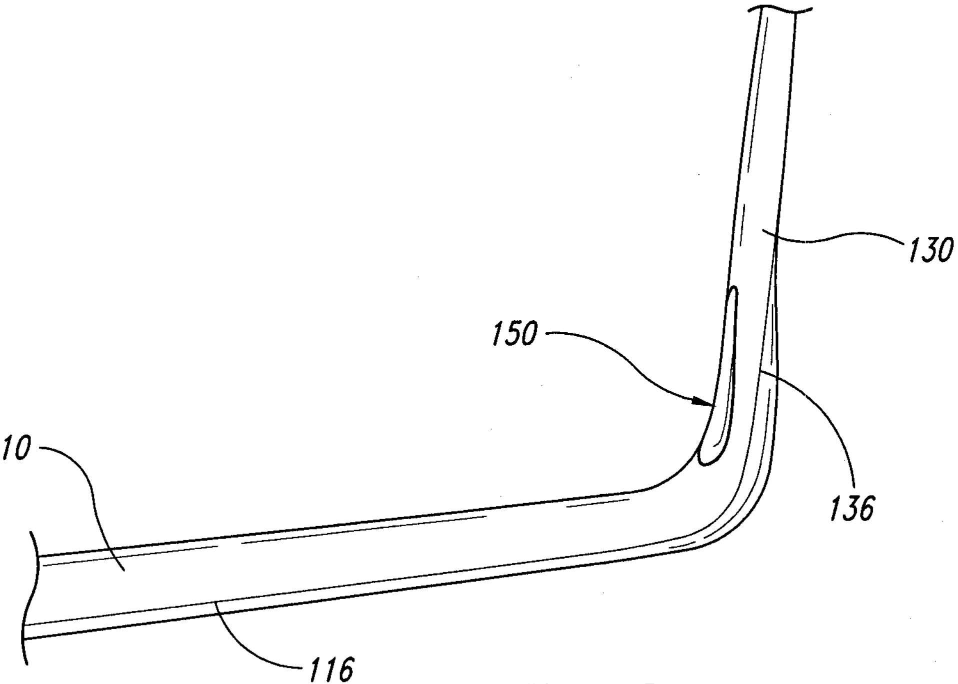
113

Fig. 2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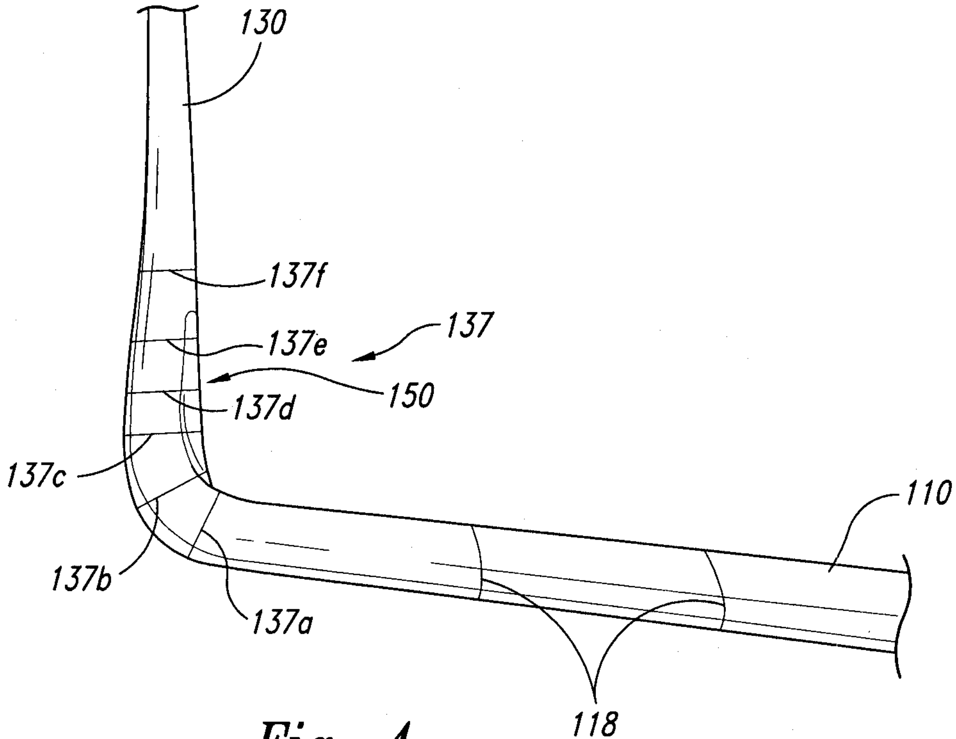
116

Fig. 3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137
137e
150
137d
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137b
137a
118

Fig. 4

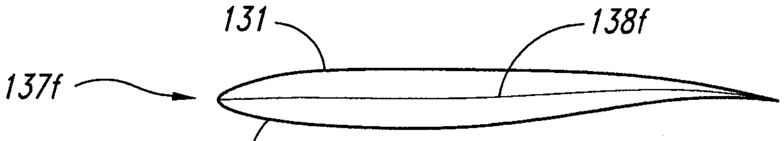


Fig. 5F

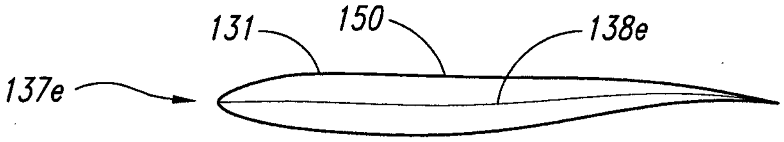


Fig. 5E

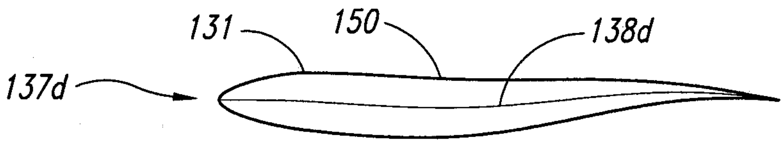


Fig. 5D

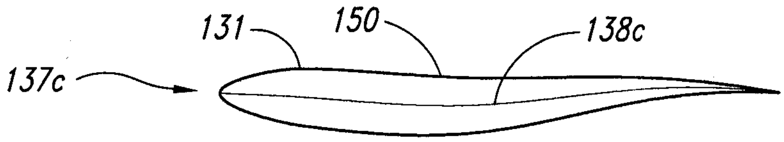


Fig. 5C

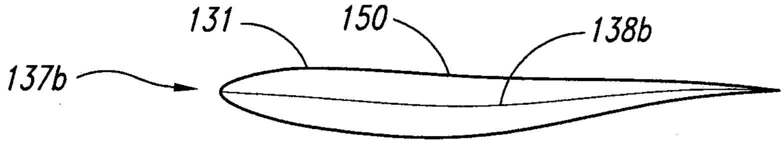


Fig. 5B

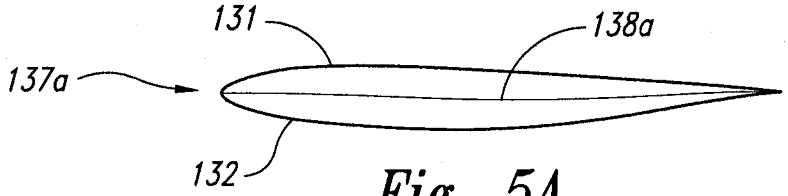
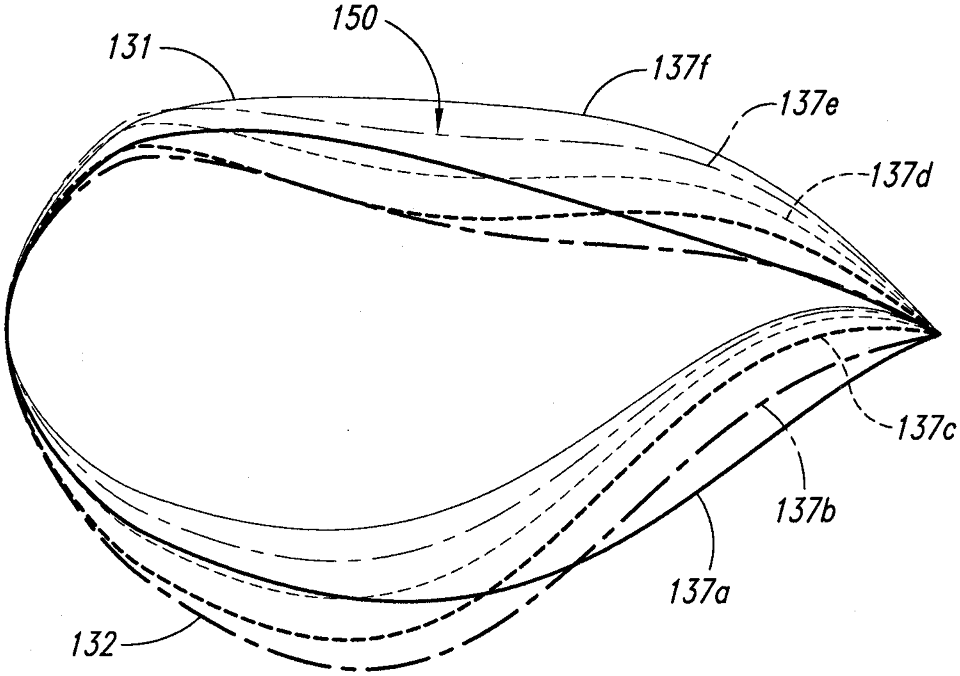


Fig. 5A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132

Fig. 6

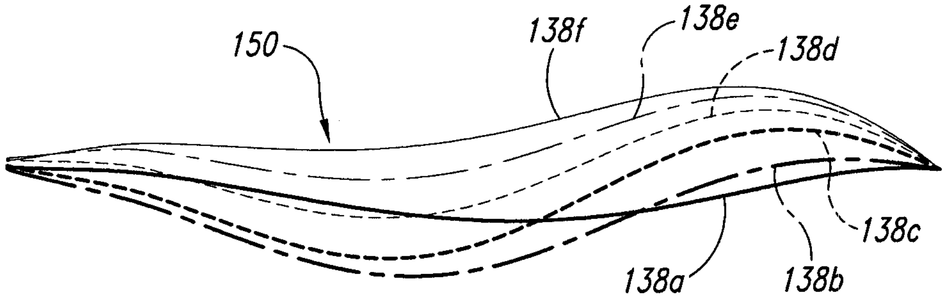
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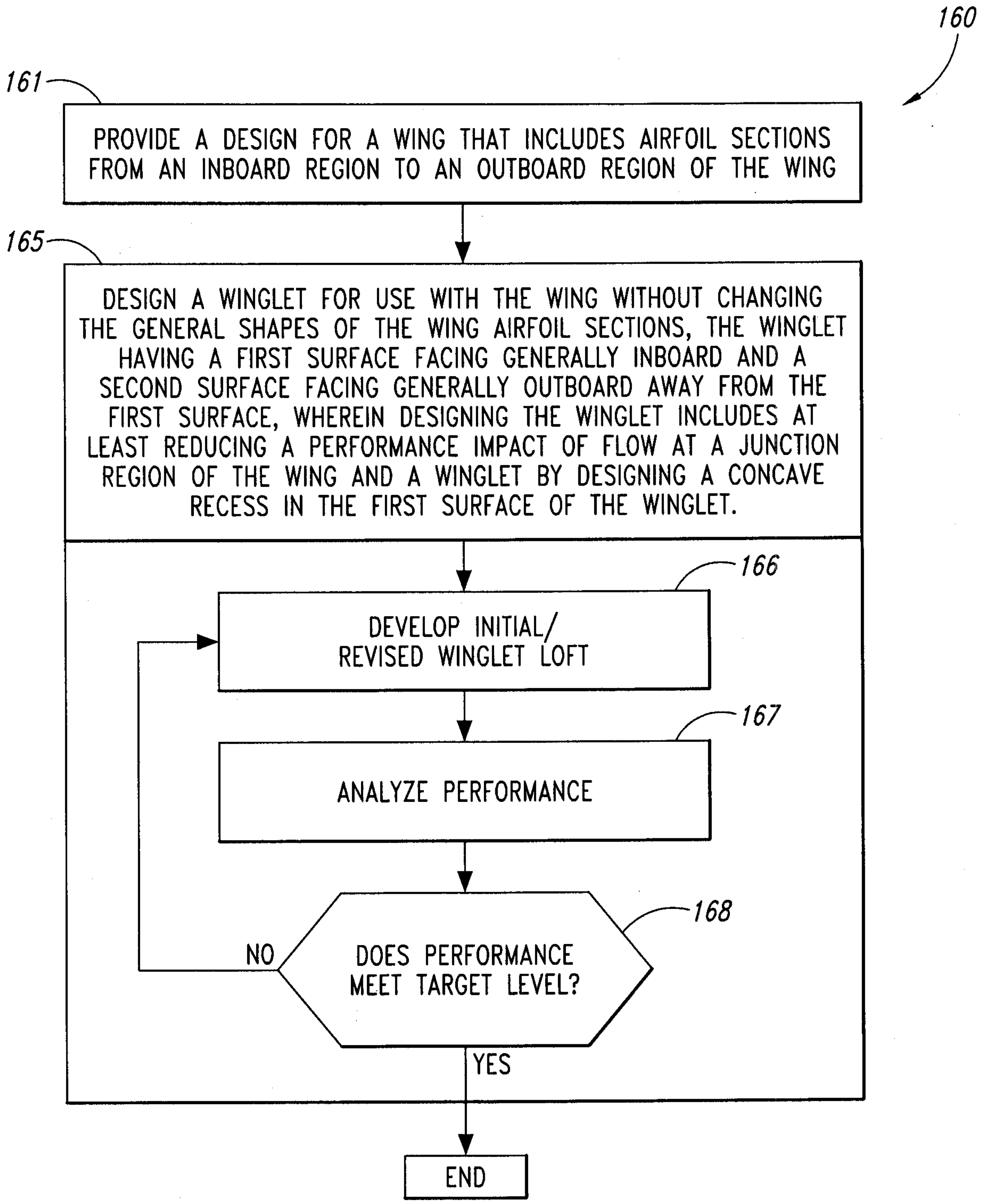
Fig. 7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161
PROVIDE A DESIGN FOR A WING THAT INCLUDES AIRFOIL SECTIONS FROM AN INBOARD REGION TO AN OUTBOARD REGION OF THE WING
165
DESIGN A WINGLET FOR USE WITH THE WING WITHOUT CHANGING THE GENERAL SHAPES OF THE WING AIRFOIL SECTIONS, THE WINGLET HAVING A FIRST SURFACE FACING GENERALLY INBOARD AND A SECOND SURFACE FACING GENERALLY OUTBOARD AWAY FROM THE FIRST SURFACE, WHEREIN DESIGNING THE WINGLET INCLUDES AT LEAST REDUCING A PERFORMANCE IMPACT OF FLOW AT A JUNCTION REGION OF THE WING AND A WINGLET BY DESIGNING A CONCAVE RECESS IN THE FIRST SURFACE OF THE WINGLET.
166
DEVELOP INITIAL/ REVISED WINGLET LOFT
167
ANALYZE PERFORMANCE
168
DOES PERFORMANCE MEET TARGET LEVEL?
NO
YES
END

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/037868

A. CLASSIFICATION OF SUBJECT MATTER
INV. B64C23/06
ADD. B64C5/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B64C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/155146 A1 (WYREMBEK SUSANNE [DE]; MAY PETER [DE]; MUTHREICH KLAUS [DE]) 12 August 2004 (2004-08-12)	1-7
A	paragraphs [0022] - [0024]; figure 1	8
X	US 4 382 569 A (BOPPE CHARLES W; HARVIE STUART G) 10 May 1983 (1983-05-10)	1,4
A	column 4, line 51 - column 5, line 24; figure 7	8
A	FR 2 780 700 A (HUGUES CHRISTIAN [FR]) 7 January 2000 (2000-01-07) abstract page 11, line 4 - line 32; figures 2,3,6,9,13	1,8

-/--

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search 4 August 2009	Date of mailing of the international search report 12/08/2009
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Fax: (+31–70) 340–3016	Authorized officer Kaysan, Rainer

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/037868

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/184196 A1 (SHMILOVICH ARVIN [US]; YADLIN YORAM [US]; CLARK ROGER [US]; LEOPOLD D) 25 August 2005 (2005-08-25) abstract; figures 5c,6,7 -----	1,8
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Information on patent family members

International application No
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