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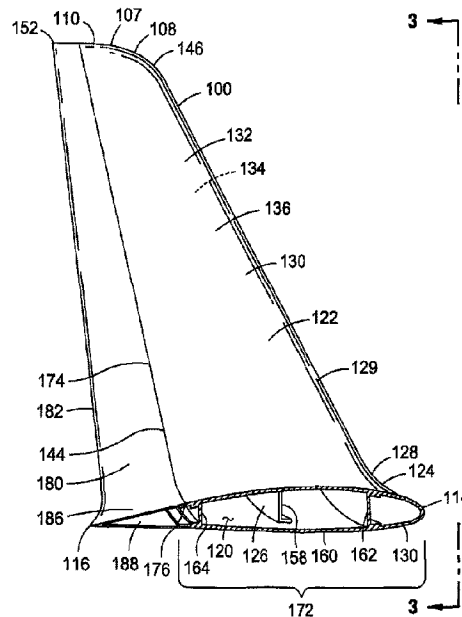
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(54) Title: NATURAL LAMINAR FLOW WINGTIP



(57) **Abrégé/Abstract:**

A winglet comprises a unitized, monolithic, integrally-formed, composite leading edge torque box comprising an outer mold line surface, the winglet comprising a curved transition positioned such that when the winglet extends outwardly from a wing of an aircraft, the curved transition is positioned between a wing tip of the aircraft and a canted section of the winglet, the leading edge torque box being formed of composite layups of polymer matrix fiber-reinforced material and including at least one composite spar or stiffener integrally-formed with and extending between opposing inner surfaces of a composite skin, an interior of the leading edge torque box containing two or more cavities that curve along the curved transition between the wing tip of the aircraft and the canted section of the winglet, the two or more cavities devoid of any mandrels along the curved transition. Methods are also disclosed.

ABSTRACT

A method comprises forming a wing tip device of an aircraft. The wing tip device, once formed, comprises a unitized, monolithic leading edge torque box. The forming comprises: forming the unitized, monolithic leading edge torque box of the wing tip device using a pair of rigid soluble
5 mandrels which expand upon heating such that the mandrels compact a skin of the leading edge torque box against an outer mold line (OML) tool surface while simultaneously compacting at least one internal component of the leading edge torque box which is positioned between the pair of mandrels; and removing the mandrels by solubilization. Once the wing tip device is formed, the skin defines a continuous, uninterrupted OML surface. The method further
10 comprises passing an airflow over the OML surface of the unitized, monolithic leading edge torque box of the wing tip device. Systems are also disclosed.

NATURAL LAMINAR FLOW WINGTIP

BACKGROUND

5 Winglets provide a means to reduce the negative effects of lift-induced wing drag by effectively increasing the length of the trailing edge of the wing. The effective increase in the length of the trailing edge may spread out the distribution of the vortices that are shed by the trailing edge and the wing tip as the wing flies through the air. The re-distribution of vortices may reduce aerodynamic losses from lift-induced drag. Winglets may provide an
10 increase in effective trailing edge length without increasing the length of the wing leading edge. In this regard, by adding winglets to the wings instead of increasing the wing span in the conventional manner, the added weight, cost, and complexity associated with the lengthening of leading edge lift-enhancement devices (e.g., slats, Krueger flaps) may be avoided.

15 Conventional winglets are fabricated as a hybrid assembly of components formed of different materials. For example, conventional winglets may be comprised of composite spars and skin panels that may be joined to a metallic leading edge and a metallic trailing edge, and which may include metallic attach fittings. Unfortunately, the assembly of the winglet components is a time-consuming and labor-intensive process requiring a large
20 quantity of mechanical fasteners. The large quantity of fasteners may increase the overall weight of the winglets. In addition, specialized tooling may be required for maintaining the relative positions of the components during fastener installation.

 Furthermore, fasteners that are installed in the outer mold line (OML) surface of the winglets may disrupt the airflow passing over the OML surface. The disruption in airflow
25 may minimize the distance over which the airflow is maintained in a laminar state before the airflow becomes turbulent with a resulting increase in aerodynamic drag. For example, in conventional winglets, the distance over which the airflow is laminar may be limited to approximately 10% of the chord length, with the downwind airflow becoming turbulent over the remaining portion of the winglet. The increase in aerodynamic drag due to turbulent
30 airflow over the winglet may limit the gains in aircraft fuel efficiency that would be possible

if the airflow were maintained in a laminar state over a longer portion of the winglet chord length.

As can be seen, there exists a need in the art for a winglet configuration that maintains the air flow in a laminar state over a relatively large portion of the chord length prior to the
5 airflow becoming turbulent.

SUMMARY

The above-noted needs associated with wing tip devices such as winglets may be specifically addressed and alleviated by embodiments of the present disclosure which
10 provides, in one embodiment, an aircraft wing tip device including a unitized, monolithic leading edge torque box formed of polymer matrix fiber-reinforced material. The leading edge torque box may include a skin that may define a continuous, uninterrupted outer mold line surface extending aftwardly from a winglet leading edge by a distance of approximately
15 60 percent or more of a local chord length. The leading edge torque box may further include at least one internal component extending between opposing inner surfaces of the skin and being integrally formed therewith.

In a further embodiment, disclosed is wing tip device having a unitized, monolithic leading edge torque box formed of polymer matrix fiber-reinforced material. The leading edge torque box may include a skin that may define a continuous, uninterrupted, outer mold
20 line surface that may extend aftwardly from the winglet leading edge by a distance of at least 60 percent or more of a local chord length. The leading edge torque box may further include an internal component extending between opposing inner surfaces of the skin and being integrally formed therewith. The leading edge torque box may comprise a co-cured assembly of composite layups of the skin and the internal component. The wing tip device may
25 include a trailing edge section that may be joined to the torque box aft end.

Also disclosed is a method of maintaining laminar flow over a wing tip device. The method may include passing airflow over an OML surface of a unitized, monolithic, leading edge torque box of a wing tip device of an aircraft. The leading edge torque box may be formed of polymer matrix fiber-reinforced material and may include at least one internal

component extending between opposing inner surfaces of a skin. The method may further include maintaining the airflow in a laminar state passing over the OML surface from a winglet leading edge aftwardly to a distance of at least 60 percent of a local chord length of the wing tip device.

5 In one embodiment, there is provided a method comprising: forming a wing tip device of an aircraft, the wing tip device, once formed, comprising a unitized, monolithic leading edge torque box, the forming comprising forming the unitized, monolithic leading edge torque box of the wing tip device using a pair of rigid soluble mandrels which expand upon heating such that the mandrels compact a skin of the leading edge torque box against an outer mold line
10 (OML) tool surface while simultaneously compacting at least one internal component of the leading edge torque box which is positioned between the pair of mandrels, and removing the mandrels by solubilization, the leading edge torque box being formed of polymer matrix fiber-reinforced material and including the at least one internal component extending between opposing inner surfaces of the skin, the skin defining, once the wing tip device is formed, a
15 continuous, uninterrupted OML surface; and passing an airflow over the OML surface of the unitized, monolithic leading edge torque box of the wing tip device.

In another embodiment, there is provided a system comprising a wing tip device for an aircraft, the wing tip device comprising a unitized, monolithic leading edge torque box formed of polymer matrix fiber-reinforced material and including: a skin defining a continuous,
20 uninterrupted outer mold line (OML) surface; and at least one internal component extending between opposing inner surfaces of the skin and being integrally formed therewith. The system further comprises a tooling system for forming the leading edge torque box, the tooling system comprising: an OML tool; and a pair of rigid soluble mandrels which expand upon heating such that, when the mandrels are within the skin of the leading edge torque box and within the OML
25 tool, the mandrels compact the skin of the leading edge torque box against a surface of the OML tool while simultaneously compacting the at least one internal component of the leading edge torque box which is positioned between the pair of mandrels.

The features, functions and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other

embodiments, further details of which can be seen with reference to the following description and drawings below.

In some embodiments, the OML surface extends continuously and uninterrupted from a leading edge of the wing tip device aftwardly to a distance of at least 60 percent of a local chord length of the wing tip device.

5 In some embodiments, the OML surface extends continuously and uninterrupted from a leading edge of the wing tip device aftwardly to a distance of approximately 60 percent of a local chord length of the wing tip device.

In some embodiments, the distance is at least 70 percent of the local chord length.

In some embodiments, the wing tip device comprises a winglet.

In some embodiments, the winglet extends outwardly from a wing of the aircraft.

10 In some embodiments, the winglet comprises a curved transition between a wing tip of the aircraft and a canted section of the winglet.

In some embodiments, the two or more cavities curve along the curved transition between the wing tip of the aircraft and the canted section of the winglet.

15 In some embodiments, the non-draftable geometry of the two or more cavities comprises the curved transition between the wing tip of the aircraft and the canted section of the winglet.

In some embodiments, the two or more cavities are curved.

In some embodiments, the two or more cavities are twisted.

In some embodiments, the wing tip device further comprises a trailing edge section joined to a torque box aft end of the leading edge torque box.

20 In some embodiments, the composite spar or stiffener comprises a spar extending at least partially along a spanwise direction of the wing tip device.

25 The features, functions and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings below.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the present disclosure will become more apparent upon reference to the drawings wherein like numbers refer to like parts throughout and wherein:

Figure 1 is a perspective view of an aircraft having winglets;

5 Figure 2 is a side view of a winglet having a unitized, monolithic, leading edge torque box formed of composite material;

Figure 3 is a front view of the winglet shown in Figure 2;

Figure 4 is an exploded side view of a winglet including the leading edge torque box and a separate trailing edge section that be attached to the leading edge torque box;

10 Figure 5 is a sectional side view of an assembly of composite layups of a skin and internal spars that may be co-cured into a unitized, monolithic leading edge torque box;

Figure 6 is a sectional side view of a unitized, monolithic leading edge torque box taken along line 6 of Figure 2 and illustrating a trailing edge section joined to an aft end of the leading edge torque box; and

15 Figure 7 is a flow diagram illustrating one or more operations that may be included in a method of maintaining laminar flow over a wing tip device.

DETAILED DESCRIPTION

Referring now to the drawings wherein the showings are for purposes of illustrating preferred and various embodiments of the disclosure, shown in Figure 1 is a perspective view of an aircraft 100 having a fuselage 102 extending from a nose of the aircraft 100 to an empennage of the aircraft 100. The empennage may include one or more tail surfaces for directional control of the aircraft 100. The aircraft 100 may further include a pair of wings 106 and a pair of propulsion units 104 that may be mounted to the wings 106. The aircraft 20 100 may include one or more aerodynamic structures 152 configured as wing tip devices 107 and which may be fabricated from composite material. In an embodiment, the wing tip devices 107 may comprise winglets 108 mounted on the tips of the wings 106.

The wing tip device **107** disclosed in one embodiment includes a unitized, monolithic, integrally-formed, composite leading edge torque box **172** having a smooth, continuous, uninterrupted, outer mold line (OML) surface **122** that extends from the winglet leading edge **114** to an aft end **174** (Figure 2) of the leading edge torque box **172**. The continuous, uninterrupted OML surface **122** of the unitized leading edge torque box **172** is configured such that airflow **146** over the OML surface **122** is maintained in a laminar state **143** over a distance from the winglet leading edge **114** of at least approximately 60 percent of the local chord **138** length (Figure 6). In the present disclosure, the local chord is defined as a line extending between the forward-most point on the leading to an aft-most point on the trailing edge of an airfoil section defined by a plane oriented generally parallel to a forward direction of the aircraft. Although the wing tip device **107** and leading edge torque box **172** disclosed herein are described in the context of a winglet **108**, the wing tip device **107** may be provided in any size, shape, and configuration, without limitation. For example, the wing tip device **107** may be configured as a raked wing tip (not shown), a split winglet having upper and lower winglets (not shown), or in other wing tip device configurations.

Referring to Figure 2, shown is a side view of an embodiment of a winglet **108**. The winglet **108** may include a winglet root **112** which may be joined to a wing **106** of an aircraft **100**. The winglet **108** may further include a winglet tip **110**, a winglet leading edge **114**, and a winglet trailing edge **116**. The leading edge torque box **172** may extend from winglet leading edge **114** to the torque box aft end **174**. The winglet trailing edge **116** may be defined by a separately-attached trailing edge section **180**. In an embodiment, the winglet trailing edge section **180** may be separately formed from the winglet **108** and may be attached to the torque box aft end **174** such as by mechanical fastening and/or adhesive bonding as described below.

In Figure 2, the unitized, composite leading edge torque box **172** may have a generally hollow configuration with three-dimensional geometry **126** comprised of a composite skin **160** and one or more internal components **158** formed of composite material. The internal components **158** may comprise composite stiffeners **162** or composite spars **164** extending between inner surfaces **120** of the composite skin **160** for increasing the bending stiffness and strength of the winglet **108**. However, it is contemplated that the trailing edge

section **180** and the leading edge torque box **172** may be integrally formed into a unitized, monolithic, composite structure such that the winglet **108** comprises a single, unitary structure from the winglet leading edge **114** to the winglet trailing edge **116**. Although a unitary structure from the winglet leading edge **114** to the winglet trailing edge **116** is not shown, such an arrangement may result in a winglet **108** having a substantially continuous, uninterrupted, outer mold line (OML) surface **122** which may result in laminar airflow **143** along a substantial portion of the distance from the winglet leading edge **114** to the winglet trailing edge **116**. For example, an uninterrupted, outer mold line (OML) surface **122** from the winglet leading edge **114** to the winglet trailing edge **116** may result in laminar airflow **143** over a distance from the winglet leading edge **114** of greater than approximately **80** percent of the local chord **138** length (Figure 6).

The unitized, monolithic, leading edge torque box **172** may be formed using a tooling system (not shown) comprising an outer mold line (OML) tool and one or more inner mold line (IML) tools or mandrels positioned within the OML tool. The IML tools or mandrels may be formed of a range of materials including, but not limited to, rigid composite mandrels covered by thin film or molded vacuum barrier materials, and/or expandable mandrels that expand when exposed to heat causing the expandable mandrels to generate internal compaction pressure for consolidation of the polymer matrix fiber-reinforced material **157**. The IML tools or mandrels may also be formed of rigid, soluble mandrels or removable rigid tools that have rates of thermal expansion matching the composite material of the composite article **150** being formed. For example, the IML tools may generate internal compaction pressure of the skin **160** against an OML tool surface (not shown) while simultaneously generating internal compaction pressure against an internal component **158** positioned between a pair of the IML tools. The tooling system may provide a means for co-consolidating and/or co-curing composite laminates that make up the skin **160** and the internal components **158** to produce a hollow, unitized, three-dimensional composite structure without the need for assembling winglet components by adhesive bonding or mechanical fastening. Three-dimensional geometry **126** may be defined as internal components **158** that extend laterally inwardly from the inner surfaces **120** of the skin **160** such as the composite spars **164** that extend between the opposing inner surfaces **120** of the

composite skin **160** on the upper side **132** and the lower side **134** of the winglet **108** in Figure 2.

Referring to Figure 3, shown is a front view of the winglet **108** illustrating the attachment to a wing tip of a wing **106**. The winglet **108** may include a curved transition **128** for transitioning the winglet **108** from a generally horizontal orientation or slight dihedral of the wing **106** to a canted section **129** of the winglet **108**. The curved transition **128** may represent non-draftable geometry **124** of the winglet **108** wherein the winglet root **112** is curved at a juncture with the wing **106**. In non-draftable geometry **124**, conventional internal tooling may be incapable of being extracted by sliding out of the interior of a cured composite article. However, the tooling system as may be used for manufacturing the leading edge torque box **172** disclosed herein may include the use of soluble internal tooling (not shown) that may be solublized or dissolved using water or other polar solvents into a partially liquid state to allow for removal of the internal tooling by pouring the solublized internal tooling out of the end of the cured composite article.

In Figure 3, the winglet **108** is shown with a canted section **129** that is relatively straight along a spanwise direction **136** of the winglet **108**. However, the canted section **129** may be curved and/or twisted along a spanwise direction **136** and/or the winglet **108** may have other non-draftable geometry **124** such as a swept winglet tip cap (not shown). In the embodiment shown, the winglet **108** has a winglet root **112** with a chord length that is substantially equivalent to a chord length of the wing tip. However, the winglet root **112** may be formed with a chord length that is less than the chord length of the wing tip. The chord length of the winglet **108** may taper at a relatively high rate within the curved transition **128** after which the winglet **108** may taper at a reduced rate from the end of the curved transition **128** toward the winglet tip **110**. The winglet **108** may be oriented at an outward cant angle of between approximately 0-45 degrees relative to vertical. However, the winglet **108** may be oriented at any cant angle, without limitation.

Referring to Figure 4, shown is a side view of the winglet **108** including the unitized, monolithic leading edge torque box **172** to which a separate trailing edge section **180** may be attached. The trailing edge section **180** may be formed of metallic material and/or composite

material and may be joined to the torque box aft end 174. For example, the trailing edge section 180 may be attached to a rear spar 170 that may be included with the leading edge torque box 172 and which may be located at the torque box aft end 174. In an embodiment, the trailing edge section 180 may include a forward end 184 that may be mechanically fastened or adhesively bonded to the torque box aft end 174 as described below.

In Figure 4, the leading edge torque box 172 may include one or more internal components 158 such as one or more spars 164 extending at least partially along a spanwise direction 136 of the wing tip device 107. For example, the leading edge torque box 172 may include a front spar 166 and a rear spar 170. The front spar 166 may be located aft of the winglet leading edge 114. The rear spar 170 may be located at the torque box aft end 174. The front spar 166 and the rear spar 170 may extend between and/or may interconnect the opposing inner surfaces 120 of the skin 160 on the upper side 132 and the lower side 134 of the winglet 108. The leading edge torque box 172 may include a mid spar 168 located between the front spar 166 and the rear spar 170 for stiffness and strength. One or more of the spars 164 may extend from the winglet root 112 to the winglet tip 110. However, one or more of the spars 164 may extend between any two locations between the winglet root 112 and the winglet tip 110. In this regard, the spars 164 are not limited to extending between the winglet root 112 and winglet tip 110

Referring to Figure 5, shown is a sectional side view of an assembly 154 of composite layups 156 of the skin 160 and the front spar 166, mid spar 168, and rear spar 170 and which may be co-cured with the skin 160 into the unitized, monolithic leading edge torque box 172. In this regard, the leading edge torque box 172 may be formed as a co-consolidated and co-cured assembly 154 of composite layups 156 of the skin 160 and the internal component 158 as mentioned above. In an embodiment, the composite layups 156 may comprise thermosetting composite material, thermoplastic composite material, pre-impregnated composite material, and/or resin-infused composite material polymer matrix. The polymer matrix fiber-reinforced material 157 may include carbon fibers, glass fibers, ceramic fibers, or other fibers types in a polymeric material or resin matrix such as epoxy. The resin matrix may comprise a thermosetting resin, or the resin matrix may comprise a thermoplastic resin.

Referring to Figure 6, shown is a sectional view of the unitized leading edge torque box 172 with integrally processed (e.g., co-cured) three-dimensional geometry 126 including the composite internal components 158 (e.g. spars 164) integrally-formed with the composite skin 160. As indicated above, the leading edge torque box 172 advantageously provides a unitized, integrally-formed, aerodynamic structure having a smooth and dimensionally-precise OML surface 122. The skin 160 defines a continuous, uninterrupted, outer mold line (OML) surface 122 on the upper side 132 and the lower side 134 of the winglet 108. The spars 164 and/or other internal component 158 (e.g., stiffeners 162, ribs - not shown) are shown oriented generally transverse to the skin 160. The spars 164 may be positioned at any location between the winglet leading edge 114 and an aft end 174 of the leading edge torque box 172. The front spar 166 and skin 160 may define an integrally-formed leading edge section 130 extending from the winglet leading edge 114 to the front spar 166. The leading edge torque box 172 may provide torsional rigidity and bending stiffness to the winglet 108 to resist deflection under static and/or dynamic loading that may undesirably alter the aerodynamics of the winglet 108.

In Figure 6, the trailing edge section 180 may comprise at least two separate panels including a trailing edge upper panel 184 and a trailing edge lower panel 186. The trailing edge upper panel 184 and the trailing edge lower panel 186 may each have a forward end 184 that may be joined to the torque box aft end 174. For example, the forward end 184 of each one of the trailing edge upper panel 184 and a trailing edge lower panel 186 may be mechanically fastened and/or adhesively bonded to the torque box aft end 174. In an embodiment, the torque box aft end 174 may include a recess 176 extending in a spanwise direction 136 along the winglet 108. The recess 176 may be sized and configured to receive the forward end 184 of the trailing edge upper panel 184 and trailing edge lower panel 186 such that the OML surface 122 of the upper side 132 and lower side 134 of the winglet 108 is at substantially the same level or height as the trailing edge upper surface 188 and trailing edge lower surface 190 respectively defined by the trailing edge upper panel 184 and the trailing edge lower panel 186.

In addition, the torque box aft end 174 is preferably configured to minimize the width of a gap (not shown) that may occur between the aft edge of the OML surface 122 and the

forward edge of the trailing edge upper panel **184** and trailing edge lower panel **186**. An aft end **182** of the trailing edge upper panel **184** and the trailing edge lower panel **186** may be joined together (e.g., mechanically fastened, adhesively bonded) at a convergence thereof. However, the trailing edge section **180** may be formed as a unitary structure comprising the trailing edge upper panel **184** and the trailing edge lower panel **186** integrally formed with the trailing edge upper panel **184**.

In Figure **6**, the leading edge torque box **172** may be configured such that the airflow **146** remains laminar over the OML surface **122** until the airflow **146** reaches a laminar-turbulent flow transition point **144** at an aft end of the OML surface **122** on the upper side **132** and the lower side **134** of the wing. The location **140** of the laminar-turbulent flow transition point **144** may be defined as a percentage of the local chord length. For example, the leading edge torque box **172** may provide a continuous, uninterrupted, OML surface **122** resulting in a laminar flow region **142** that extends aftwardly from the winglet leading edge **114** by a distance of at least **60** percent of a local chord **138** length. However, the leading edge torque box **172** may be configured such that the airflow **146** remains laminar over a distance from the winglet leading edge **114** of at least **70** percent to **80** percent or more of the local chord **138** length. In the present disclosure, the OML surface **122** may comprise the surface of the winglet **108** that is exposed to the airflow **146** passing along the OML surface, and excludes surfaces of the leading edge torque box **172** that are unexposed to the airflow **146**.

The integrally-formed and unitized leading edge torque box **172** may provide an advantage over conventional winglet (not shown) construction which may include mechanical fasteners (not shown) in the OML surface in the area adjacent to the winglet leading edge. For example, conventional winglet construction may include a plurality of mechanical fasteners installed at a junction of a separate leading edge skin (not shown) and front spar (not shown). As indicated above, such mechanical fasteners (not shown) in the OML surface may disrupt the airflow and may result in turbulent flow aft of the front spar (not shown) which may be located a distance from the winglet leading edge of approximately **10** percent or less of the local chord length. Disruption of the airflow by such mechanical fasteners or by other discontinuities in the OML surface of conventional winglets may cause

the airflow to become turbulent over a majority of the winglet which may increase aerodynamic drag and reduce aerodynamic performance of the winglet.

Referring to Figure 7, shown is a flow diagram illustrating one or more operations that may be included in a method 300 of maintaining laminar flow 143 (Figure 6) over a wing tip device 107 such as the winglet 108 illustrated and Figures 1-6.

Step 302 of the method 300 of Figure 7 may include passing airflow 146 (Figure 6) over an outer mold line (OML) surface 122 of a unitized, monolithic leading edge torque box 172 of a wing tip device 107 of an aircraft 100. Figure 6 illustrates the oncoming airflow 146 passing over the winglet leading edge 114. As indicated above, the leading edge torque box 172 is formed a unitized, integrally-formed, composite structure having a smooth, uninterrupted, and continuous OML surface 122. In addition, the leading edge torque box 172 provides a dimensionally-precise contour and finish of the OML surface 122 which is imparted by use of an OML tool (not shown) in combination of one or more inner mold line (IML) tools (not shown) to generate internal compaction pressure (not shown) of the skin 160 against a precisely-controlled contour and finish of the OML tool surface (not shown).

Step 304 the method 300 of Figure 7 may include maintaining the airflow 146 in a laminar state 143 when passing the airflow 146 over the OML surface 122 of the winglet 108 from the winglet leading edge 114 aftwardly to a distance of at least 60 percent more of a local chord 138 length of the winglet 108. In an embodiment, the leading edge torque box 172 airflow 146 may be configured such that the torque box aft end 174 is located at a distance from the leading edge of 60-70 percent or more of the local chord 138 length such that the airflow 146 remains laminar at least until reaching the torque box aft end 174. The method may include maintaining the airflow 146 in a laminar state 143 while passing the airflow 146 over the winglet 108 from the curved transition 128 located between the wing tip and the canted section 129 of the winglet 108.

Step 306 the method 300 of Figure 7 may include passing the airflow 146 over a trailing edge section 180 that may be joined to the torque box aft end 174 such as by mechanically fastening and/or adhesively bonding. The torque box aft end 174 may represent a laminar-turbulent flow transition point 144 where the airflow 146 may transition

from laminar flow **143** (Figure 6) to turbulent flow downwind of the laminar-turbulent flow transition point **144**. The turbulent flow may result from disruption of the airflow **146** at the juncture between the trailing edge section **180** and the aft edge of the OML surface **122** of the leading edge torque box **172**. For example, turbulent flow may result from airflow disruption
5 due to mechanical fasteners installed in the OML surface and/or as a result in a gap or a difference in height between the forward end **184** of the trailing edge section **180** and the aft end of the OML surface **122** of the trailing edge torque box.

The wing tip device **107** disclosed herein may provide a means for achieving natural laminar flow over a wing tip device **107** such as a winglet **108** without the use of flow
10 enhancement devices such as a porous skin surface (not shown) or other devices. In addition, the unitary, monolithic, leading edge torque box **172** may provide a continuous, uninterrupted OML surface **122** from the winglet leading edge **114** to an aft end of the leading edge torque box **172**. By providing a tightly-controlled contour and finish on the OML surface **122** of the leading edge torque box **172**, disruption of the airflow **146** may be minimized such that the
15 airflow **146** may be maintained in a laminar state **143**.

Additional modifications and improvements of the present disclosure may be apparent to those of ordinary skill in the art. Thus, the particular combination of parts described and illustrated herein is intended to represent only certain embodiments of the present disclosure and is not intended to serve as limitations of alternative embodiments or
20 devices within the spirit and scope of the disclosure.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method comprising:

forming a wing tip device of an aircraft, the wing tip device, once formed, comprising a unitized, monolithic leading edge torque box, the forming comprising forming the unitized, monolithic leading edge torque box of the wing tip device using a pair of rigid soluble mandrels which expand upon heating such that the mandrels compact a skin of the leading edge torque box against an outer mold line (OML) tool surface while simultaneously compacting at least one internal component of the leading edge torque box which is positioned between the pair of mandrels, and removing the mandrels by solubilization, the leading edge torque box being formed of polymer matrix fiber-reinforced material and including the at least one internal component extending between opposing inner surfaces of the skin, the skin defining, once the wing tip device is formed, a continuous, uninterrupted OML surface; and

passing an airflow over the OML surface of the unitized, monolithic leading edge torque box of the wing tip device.

2. The method of claim 1, wherein the OML surface extends from a leading edge of the wing tip device aftwardly by a distance of at least 60 percent of a local chord length of the wing tip device.

3. The method of claim 1, wherein the OML surface extends from a leading edge of the wing tip device aftwardly by a distance of approximately 60 percent of a local chord length of the wing tip device.

4. The method of claim 2, wherein the distance is at least 70 percent of the local chord length.

5. The method of claim 2, 3, or 4, further comprising maintaining the airflow in a laminar state over the distance from the leading edge.
6. The method of claim 2, 3, 4, or 5, wherein the OML surface extends continuously and uninterrupted from the leading edge of the wing tip device aftwardly by the distance.
- 5 7. The method of any one of claims 1 to 6, wherein the wing tip device is a winglet extending outwardly from a wing of the aircraft.
8. The method of claim 7, wherein the winglet comprises a curved transition between a wing tip of the aircraft and a canted section of the winglet.
9. The method of claim 8, wherein passing the airflow over the OML surface comprises
10 passing the airflow over the curved transition.
10. The method of claim 8 to 9, wherein an interior of the leading edge torque box contains two or more cavities that curve along the curved transition between the wing tip of the aircraft and the canted section of the winglet.
11. The method of claim 10, wherein the two or more cavities are twisted.
- 15 12. The method of any one of claims 1 to 11, wherein:

the wing tip device, once formed, further comprises a trailing edge section joined to an aft end of the leading edge torque box; and

the method further comprises passing the airflow over the trailing edge section.
13. The method of claim 12, wherein a forward end of the trailing edge section is
20 mechanically fastened to the aft end of the leading edge torque box.

14. The method of claim **12** or **13**, wherein:

the trailing edge section comprises at least two separate panels including a trailing edge upper panel and a trailing edge lower panel; and

the trailing edge upper panel and the trailing edge lower panel each have a forward end joined to the aft end of the leading edge torque box.

15. The method of claim **12** or **13**, wherein the trailing edge section comprises a unitary structure including a trailing edge upper panel and a trailing edge lower panel integrally formed with the trailing edge upper panel.

16. The method of claim **12**, **13**, **14**, or **15**, wherein the trailing edge section is attached to a rear spar located at the aft end of the leading edge torque box.

17. The method of any one of claims **1** to **11**, wherein the at least one internal component comprises at least one composite spar.

18. The method of claim **17**, wherein the at least one composite spar comprises a spar extending at least partially along a spanwise direction of the wing tip device.

19. The method of claim **17**, wherein:

the at least one composite spar includes a front spar and a rear spar;

the front spar is located aft of the leading edge of the wing tip device; and

the rear spar is located at an aft end of the leading edge torque box.

20. The method of any one of claims **1** to **16**, wherein the at least one internal component comprises at least one composite stiffener.

21. The method of any one of claims **1** to **20**, wherein the leading edge torque box is formed as a co-cured assembly of composite layups of the skin and the internal component.

22. The method of claim 21, wherein the composite layups comprise thermosetting composite material.
23. The method of claim 21 or 22, wherein the composite layups comprise thermoplastic composite material.
- 5 24. The method of claim 21, 22, or 23, wherein the composite layups comprise pre-impregnated composite material.
25. The method of claim 21, 22, 23, or 24, wherein the composite layups comprise resin-infused composite material.
26. A system comprising:
- 10 a wing tip device for an aircraft, the wing tip device comprising:
- a unitized, monolithic leading edge torque box formed of polymer matrix fiber-reinforced material and including:
- a skin defining a continuous, uninterrupted outer mold line (OML) surface; and
- 15 at least one internal component extending between opposing inner surfaces of the skin and being integrally formed therewith; and
- a tooling system for forming the leading edge torque box, the tooling system comprising:
- an OML tool; and
- 20 a pair of rigid soluble mandrels which expand upon heating such that, when the mandrels are within the skin of the leading edge torque box and within the OML tool, the mandrels compact the skin of the leading edge

torque box against a surface of the OML tool while simultaneously compacting the at least one internal component of the leading edge torque box which is positioned between the pair of mandrels.

- 5 **27.** The system of claim 26, wherein the OML surface extends continuously and uninterrupted from a leading edge of the wing tip device aftwardly by a distance of at least 60 percent of a local chord length of the wing tip device.
- 28.** The system of claim 26, wherein the OML surface extends continuously and uninterrupted from a leading edge of the wing tip device aftwardly by a distance of approximately 60 percent of a local chord length of the wing tip device.
- 10 **29.** The system of claim 27, wherein the distance is at least 70 percent of the local chord length.
- 30.** The system of claim 27, 28, or 29, wherein the OML surface extends continuously and uninterrupted from the leading edge of the wing tip device aftwardly by the distance.
- 15 **31.** The system of any one of claims 26 to 30, wherein the wing tip device is a winglet extending outwardly from a wing of the aircraft.
- 32.** The system of claim 31, wherein the winglet comprises a curved transition between a wing tip of the aircraft and a canted section of the winglet.
- 20 **33.** The system of claim 32, wherein an interior of the leading edge torque box contains two or more cavities that curve along the curved transition between the wing tip of the aircraft and the canted section of the winglet.
- 34.** The system of claim 33, wherein the two or more cavities are twisted.
- 35.** The system of any one of claims 26 to 34, further comprising a trailing edge section joined to a torque box aft end of the leading edge torque box.

36. The system of claim **35**, wherein a forward end of the trailing edge section is mechanically fastened to the aft end of the leading edge torque box.

37. The system of claim **35** or **36**, wherein:

the trailing edge section comprises at least two separate panels including a trailing edge upper panel and a trailing edge lower panel; and

the trailing edge upper panel and the trailing edge lower panel each having a forward end being joined to the aft end of the leading edge torque box.

38. The system of claim **35** or **36**, wherein the trailing edge section comprises a unitary structure including a trailing edge upper panel and a trailing edge lower panel integrally formed with the trailing edge upper panel.

39. The system of claim **35**, **36**, **37**, or **38**, wherein the trailing edge section is attached to a rear spar located at the aft end of the leading edge torque box.

40. The system of any one of claims **26** to **34**, wherein the at least one internal component comprises at least one composite spar.

41. The system of claim **40**, wherein the at least one composite spar comprises a spar extending at least partially along a spanwise direction of the wing tip device.

42. The system of claim **40**, wherein:

the at least one composite spar includes a front spar and a rear spar;

the front spar is located aft of the leading edge of the wing tip device; and

the rear spar is located at an aft end of the leading edge torque box.

43. The system of any one of claims **26** to **39**, wherein the at least one internal component comprises at least one composite stiffener.

44. The system of any one of claims 26 to 43, wherein the leading edge torque box is formed as a co-cured assembly of composite layups of the skin and the internal component.
45. The system of claim 44, wherein the composite layups comprise thermosetting composite material.
- 5 46. The system of claim 44 or 45, wherein the composite layups comprise thermoplastic composite material.
47. The system of claim 44, 45, or 46, wherein the composite layups comprise pre-impregnated composite material.
- 10 48. The system of claim 44, 45, 46, or 47, wherein the composite layups comprise resin-infused composite material.

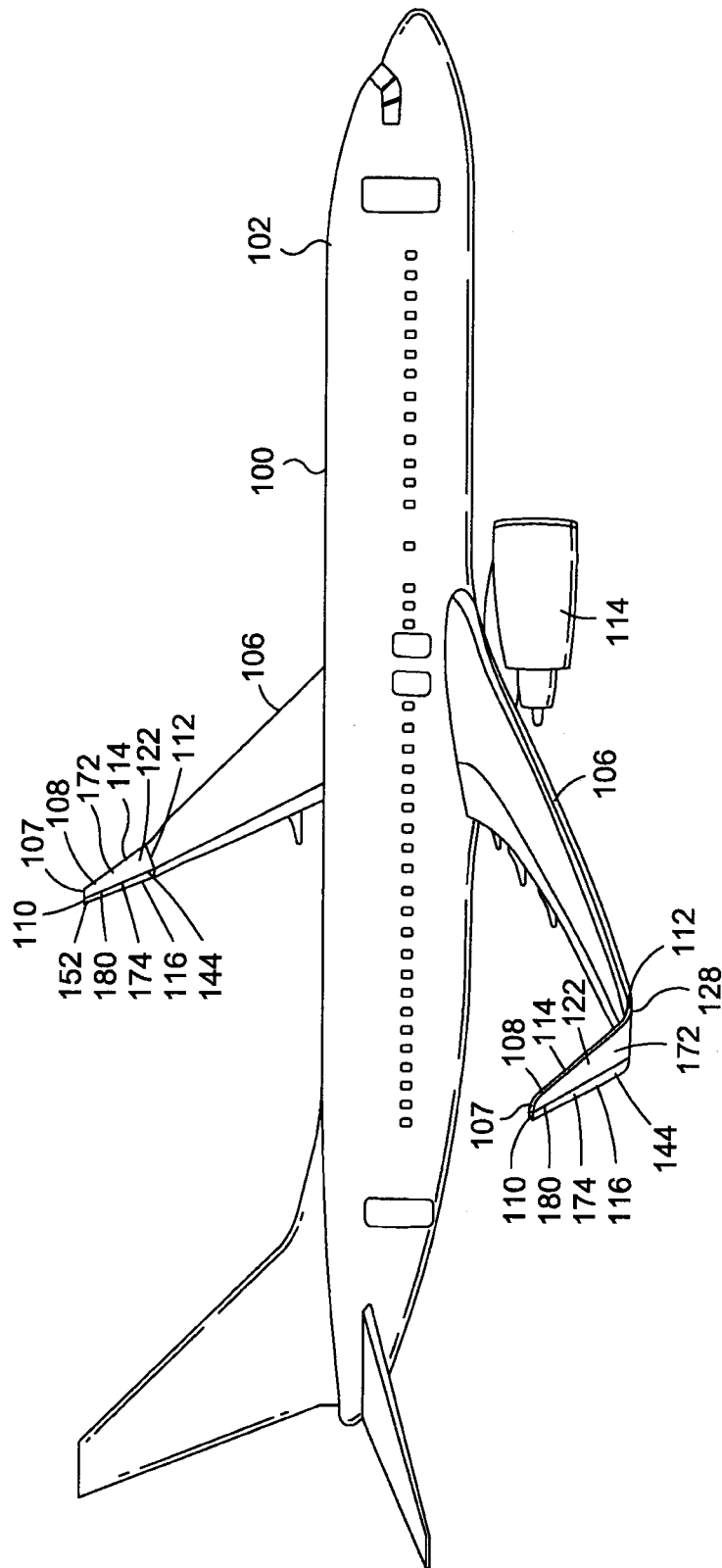


FIG. 1

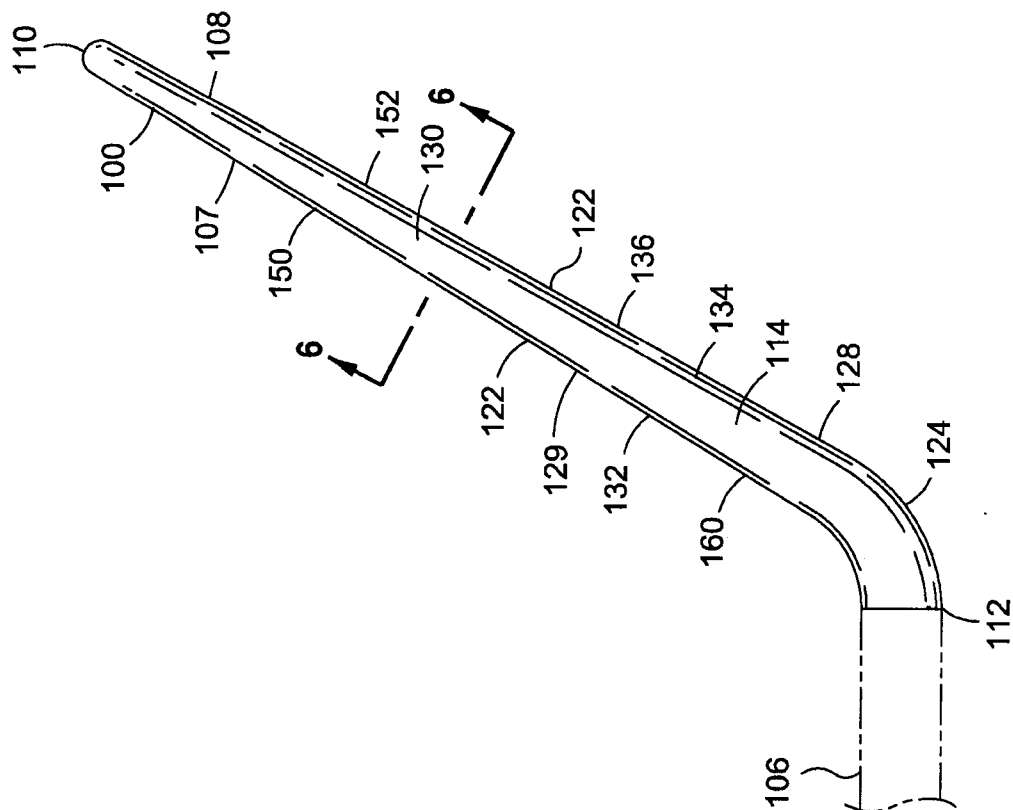


FIG. 3

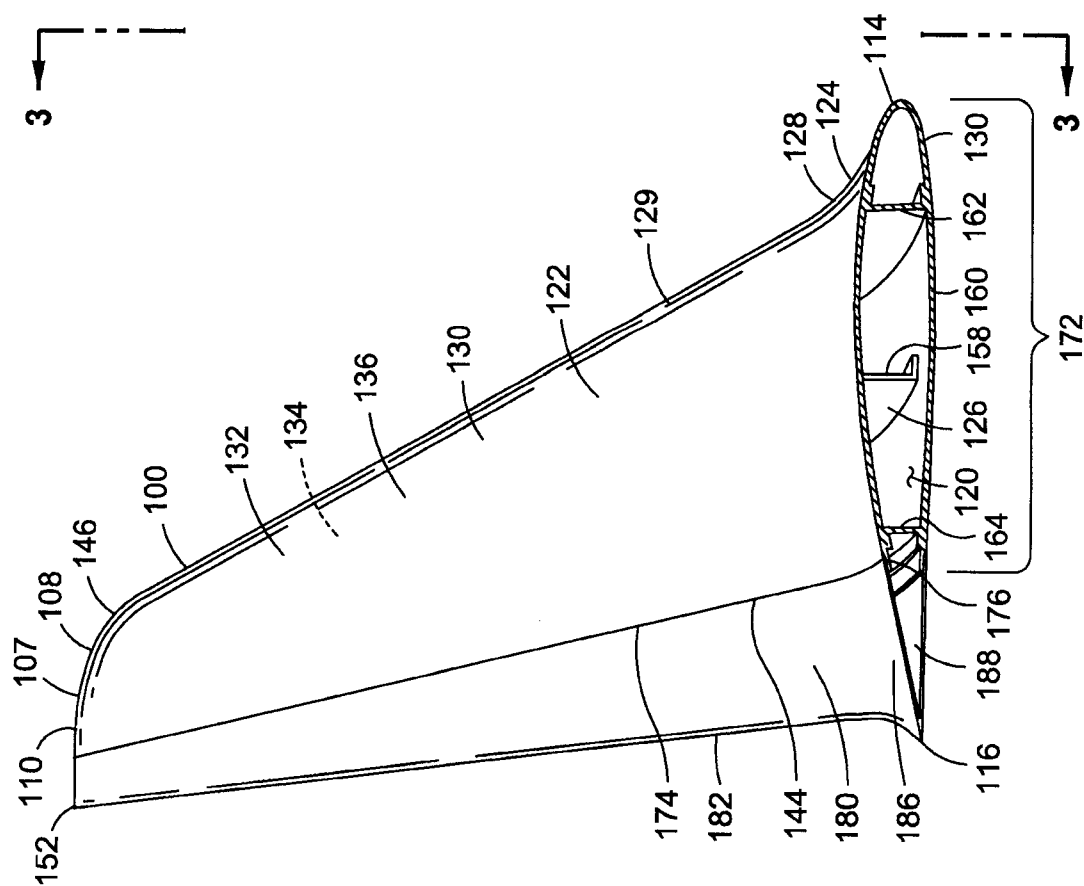


FIG. 2

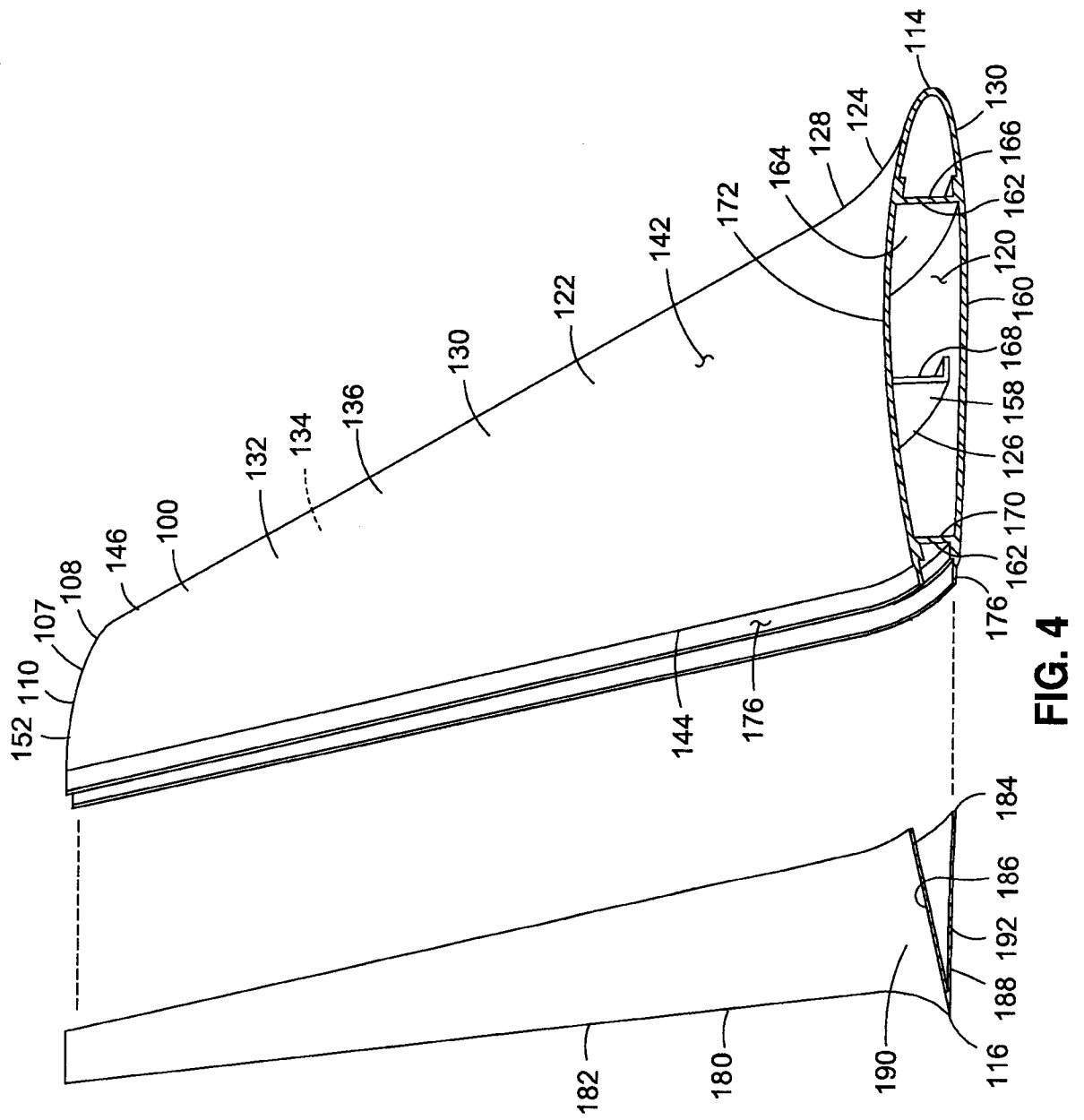


FIG. 4

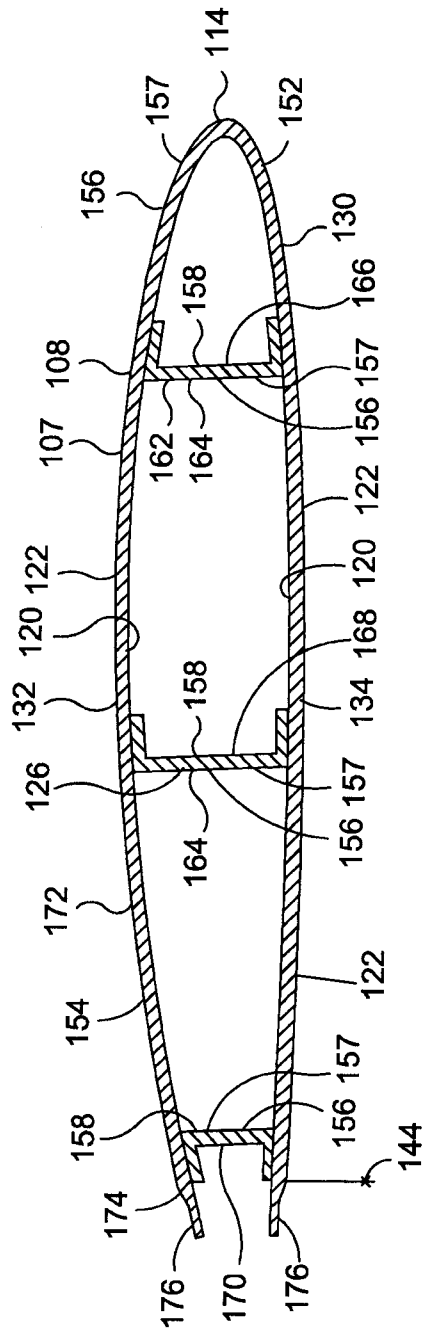


FIG. 5

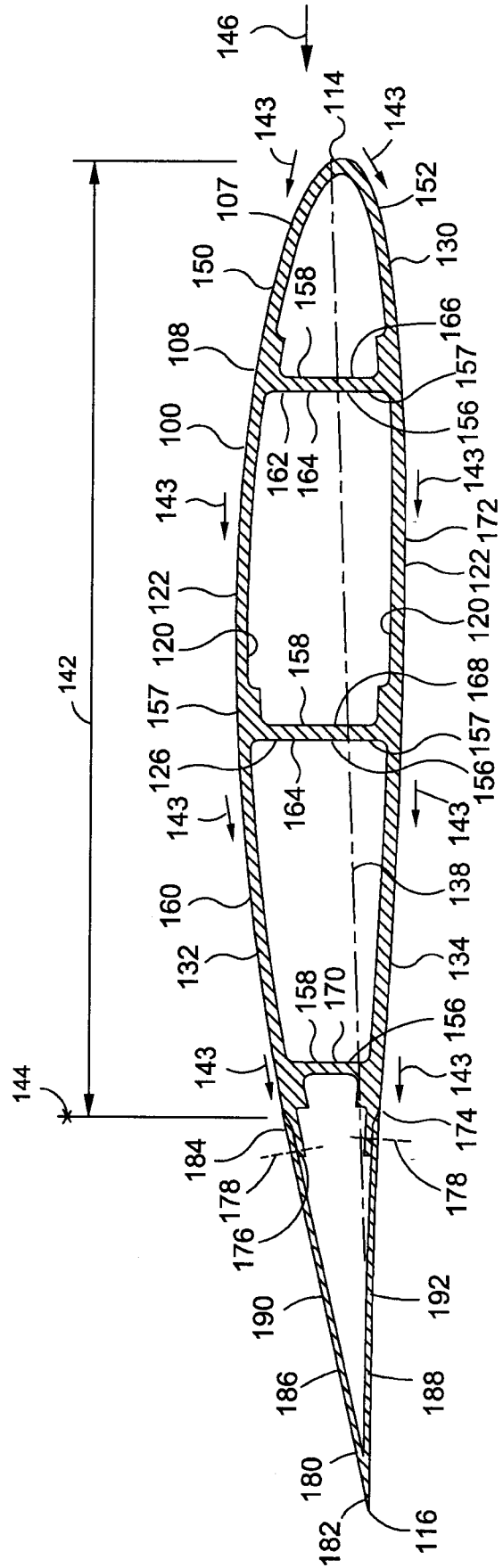
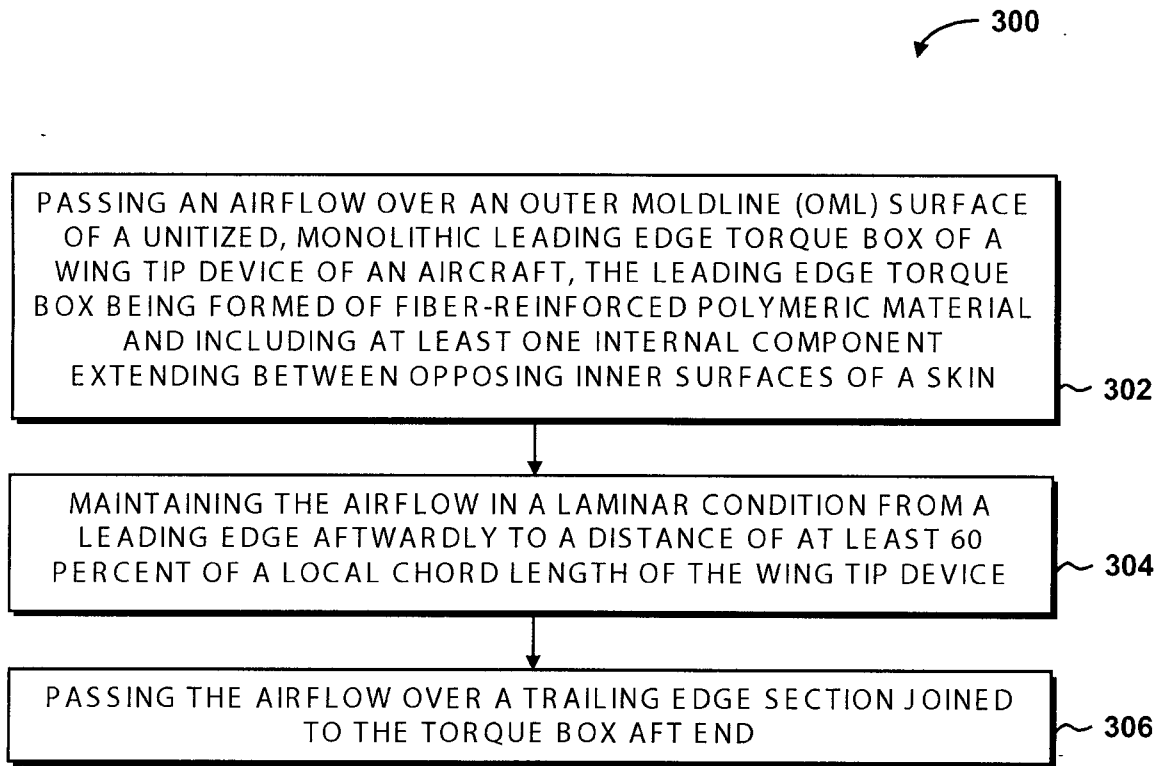


FIG. 6

**FIG. 7**

