

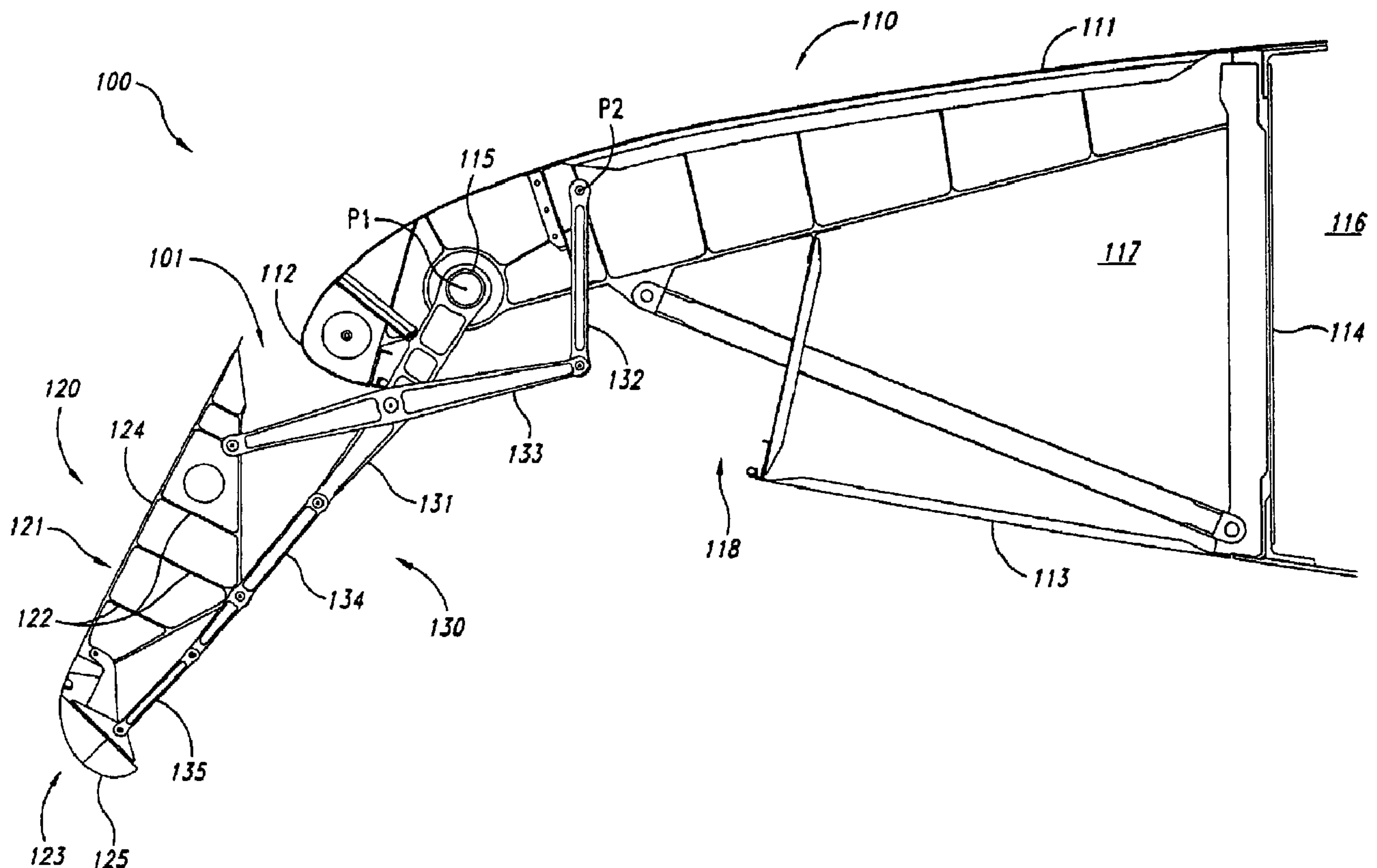


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(54) Title: LINK MECHANISMS FOR GAPPED RIGID KRUEGER FLAPS, AND ASSOCIATED SYSTEMS AND
METHODS



(57) Abrégé/Abstract:

Link mechanisms for gapped rigid Krueger flaps, and associated methods and systems are disclosed. A system in accordance with one embodiment includes a deployable leading edge assembly (120) that in turn includes a deployable leading edge panel (121)



(57) Abrégé(suite)/Abstract(continued):

having a generally fixed-shape flow surface, a bullnose (123) coupled to the panel,, and a link mechanism (130) coupled to the panel and the bullnose to move the panel between a stowed position and a deployed position. The mechanism includes a first support link (131), a second support link (132), and first (133), second (134), and third (135) positioning links. The positioning links are pivotably connected among the leading edge panel, the bullnose, the first support link and the second support link so that the leading edge panel forms a gap (101) with the airfoil when in the deployed position. The positioning links are the only positioning links coupled between the support links, the leading edge panel, and the bullnose at a particular wing span location.

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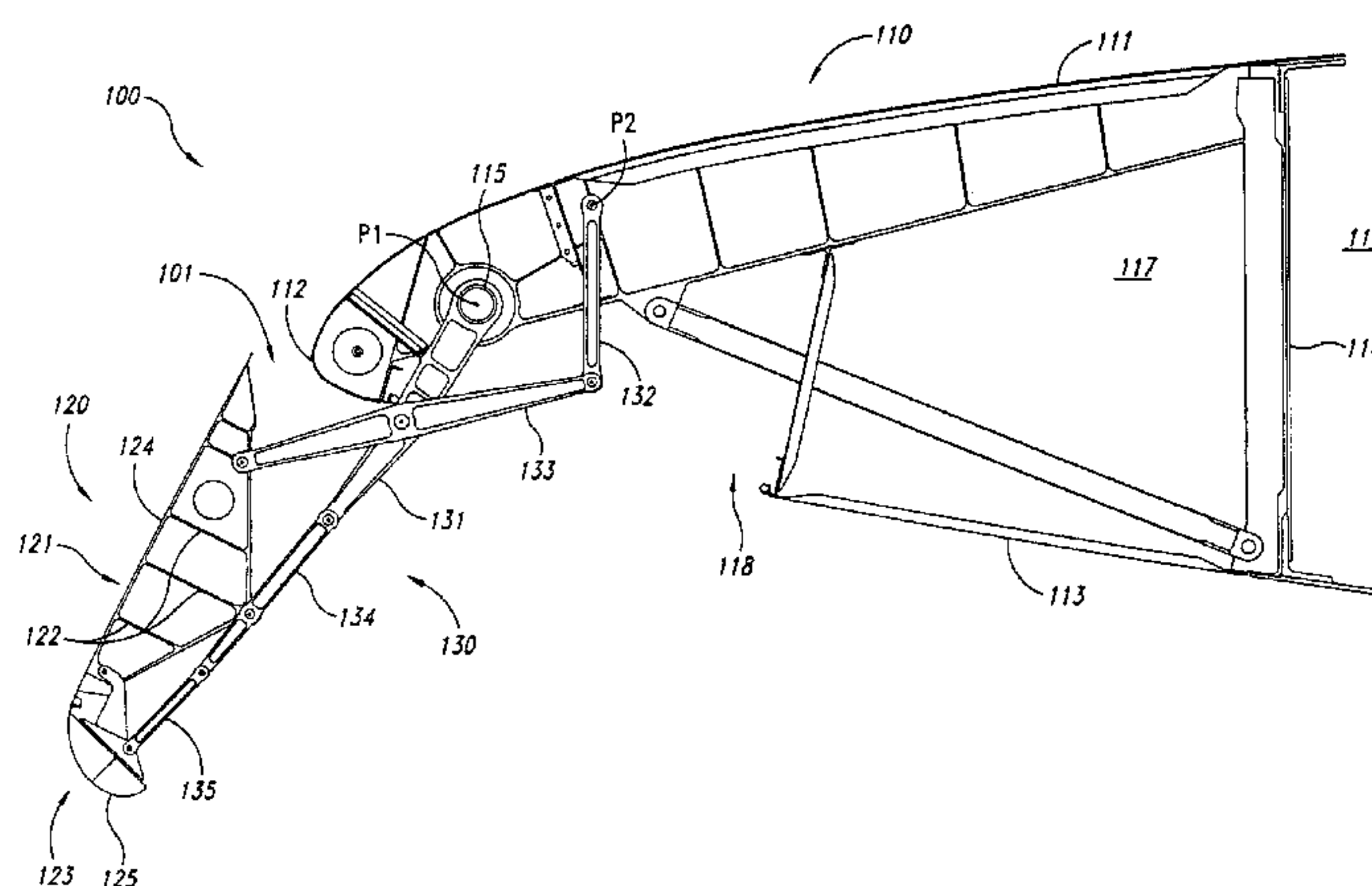
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(57) Abstract: Link mechanisms for gapped rigid Krueger flaps, and associated methods and systems are disclosed. A system in accordance with one embodiment includes a deployable leading edge assembly (120) that in turn includes a deployable leading edge panel (121) having a generally fixed-shape flow surface, a bullnose (123) coupled to the panel, and a link mechanism (130) coupled to the panel and the bullnose to move the panel between a stowed position and a deployed position. The mechanism includes a first support link (131), a second support link (132), and first (133), second (134), and third (135) positioning links. The positioning links are pivotably connected among the leading edge panel, the bullnose, the first support link and the second support link so that the leading edge panel forms a gap (101) with the airfoil when in the deployed position. The positioning links are the only positioning links coupled between the support links, the leading edge panel, and the bullnose at a particular wing span location.

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LINK MECHANISMS FOR GAPPED RIGID KRUEGER FLAPS, AND ASSOCIATED SYSTEMS AND METHODS

TECHNICAL FIELD

The present disclosure is directed generally to link mechanisms for gapped, rigid
5 Krueger flaps, and associated systems and methods.

BACKGROUND

Modern aircraft often use a variety of high lift leading and trailing edge devices to improve high angle of attack performance during various phases of flight, including takeoff and landing. Existing leading edge devices include leading edge slats and
10 Krueger flaps. Current leading edge slats generally have a stowed position in which the slat forms a portion of the leading edge of the wing, and one or more deployed positions in which the slat extends forward and down to increase the camber and/or planform area of the wing. The stowed position is generally associated with low drag at low angles of attack and can be suitable for cruise and other low angle of attack
15 operations. The extended position(s) is/are generally associated with improved airflow characteristics over the aircraft's wing at higher angles of attack. Typical leading edge slat designs include arrangements in which the leading edge device retracts in an aft direction to form the leading edge of the wing when stowed. Krueger flaps have generally the same function as leading edge slats, but rather than retracting aft to form
20 the leading edge of the wing, Krueger flaps typically fold into the lower surface of the wing when stowed.

In some cases, a slot or gap is created between the leading edge device and the wing as the device extends. During certain operating conditions, air can flow through this slot to energize the airflow over the upper surface of the wing, and improve overall
25 airflow characteristics over the wing. A drawback with current systems is that it can be difficult to properly form and/or properly place the gap to achieve the desired flow characteristics proximate to the leading edge device. Another drawback associated with Krueger flap arrangements is that it may be difficult to form a gap that is large

enough to achieve the desired airflow characteristics, without requiring complex and/or structurally inefficient linkage mechanisms.

SUMMARY

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The following summary is provided for the benefit of the reader only, and is not intended to limit in any way the invention as set forth by the claims. The present invention is directed generally toward link mechanisms for gapped, rigid Krueger flaps, and associated systems and methods. An aircraft system in accordance with one aspect of the invention includes a deployable leading edge assembly that in turn includes a deployable leading edge panel having a generally fixed-shape flow surface, a bullnose pivotably coupled to the leading edge panel, and a link mechanism coupled to the leading edge panel and the bullnose to move the leading edge panel between a stowed position and a deployed position. The link mechanism can have first and second spaced apart support links that are pivotably coupleable to an airfoil. First, second, and third positioning links are pivotably connected among the leading edge panel, the bullnose, and the first and second support links. The leading edge panel forms a gap with the airfoil when in the deployed position, and the positioning links are the only positioning links coupled between the support links, the leading edge panel, and the bullnose at a particular wing span location. Accordingly, in at least some embodiments, the leading edge assembly can include a five-link arrangement that provides a suitable aerodynamic gap between the airfoil and the rigid deployable leading edge panel, while also providing a bullnose to guide the flow of air over the airfoil.

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In further particular aspects, the first positioning link has a first end, a second end, and an intermediate portion between its first and second ends. The first positioning link is pivotably connected to the second support link toward its first end, to the leading edge panel toward its second end, and to the first support link at its intermediate portion to form a scissors arrangement with the first support link. The second positioning link has a first end, a second end, and an intermediate portion between its first and second ends, and is pivotably connected to the first support link toward its

first end, to the third positioning link toward its second end, and to the leading edge panel at its intermediate portion. The gap formed by deploying the leading edge assembly with the link mechanism can be at least 2% of the chord length of the airfoil to which the leading edge assembly is attached. In further particular embodiments, each of the links can be generally straight. In other embodiments, the opposite ends of the links can be offset by 40° or less, and in still further particular embodiments, by 20° or less.

In accordance with one aspect of the invention, there is provided an aircraft system. The system includes a deployable leading edge assembly that includes a deployable leading edge panel having a generally fixed-shape flow surface, a bullnose pivotably coupled to the leading edge panel, and a first link mechanism coupled to the leading edge panel and the bullnose at a first wing span location to move the leading edge panel between a stowed position and a deployed position. The first link mechanism has a first support link pivotably coupleable to an airfoil, a second support link pivotably coupleable to the airfoil and spaced apart from the first support link, and first, second, and third positioning links pivotably connected among the leading edge panel, the bullnose, the first support link and the second support link. The leading edge panel forms a gap with the airfoil when in the deployed position, and the first, second, and third positioning links are the only positioning links coupled between the first and second support links, the leading edge panel, and the bullnose at the first wing span location. The deployable leading edge assembly also includes a second link mechanism coupled to the leading edge panel and the bullnose at a second wing span location spaced apart in spanwise direction from the first wingspan location to move the leading edge panel between the stowed position and the deployed position. The second link mechanism has a third support link pivotably coupleable to the airfoil, a fourth support link pivotably coupleable to the airfoil and spaced apart from the third support link, and fourth, fifth, and sixth positioning links pivotably connected among the leading edge panel, the bullnose, the third support link, and the fourth support link. The leading edge panel forms a gap with the airfoil when in the deployed position, and the fourth, fifth, and sixth positioning links are

the only positioning links coupled between the third and fourth support links, the leading edge panel, and the bullnose at the second wing span location.

5 The system of claim may further include the airfoil. The first and second support links may be pivotably coupled to the airfoil, and the first positioning link may be pivotably connected to the first support link, the second support link and the leading edge panel. The second positioning link may be pivotably connected to the first support link, the leading edge panel and the third positioning link, and the third positioning link may be pivotably connected
10 between the second positioning link and the bullnose.

The first positioning link may have a first end, a second end, and an intermediate portion between its first and second ends, the first positioning link being pivotably connected to the second support link toward its first end, pivotably connected to the leading edge panel toward its second end, and
15 pivotably connected to the first support link at its intermediate portion to form a scissors arrangement with the first support link. The second positioning link may have a first end, a second end, and an intermediate portion between its first and second ends, the second positioning link being pivotably connected to the first support link toward its first end, pivotably connected to the third
20 positioning link toward its second end, and pivotably connected to the leading edge panel at its intermediate portion.

The first support link and the first positioning link may each have three pivot joints coupled to adjacent elements, the three pivot joints of the first support link may be at least approximately co-linear, and the three pivot joints of the first positioning link may be at least approximately co-linear.
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The system of may further include the airfoil, and the first and second support links may be pivotably coupled to the airfoil.
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The airfoil may have an airfoil chord length and the leading edge panel may form a gap that is at least 2% of the airfoil chord length when in the deployed position.

The system may further include the airfoil, and the first and second support links may be pivotably coupled to the airfoil. The airfoil may have an airfoil chord length, and the leading edge panel may form a gap that is at least 2% of the airfoil chord length when in the deployed position.

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The first support link may be coupled to an actuator.

The leading edge panel may have a streamwise flow surface that is exposed to freestream airflow when in both the stowed and the deployed positions.

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Each of the links may be generally straight.

The first support link may have three pivot locations positioned along a generally straight line.

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The first positioning link may have three pivot locations positioned along a generally straight line.

The second positioning link may have three pivot locations positioned along a generally straight line.

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For each link, opposite ends of the link may be offset by 20 degrees or less.

For each link, opposite ends of the link may be offset by 40 degrees or less.

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Both the leading edge panel and the bullnose may have generally fixed-shape, streamwise flow surfaces.

The first support link and the first positioning link may form a first scissors configuration, and the leading edge panel and the second positioning link may form a second scissors configuration.

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In accordance with another aspect of the invention, there is provided an aircraft wing system. The system includes an airfoil and a deployable leading edge assembly. The deployable leading edge assembly includes: a deployable leading edge panel having a generally rigid, fixed-shape flow

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surface; a bullnose pivotably coupled to the leading edge panel and having a generally rigid, fixed-shape flow surface; and a first link mechanism coupled to the leading edge panel, the bullnose and the airfoil at a first wing span location to move the leading edge panel between a stowed position and a deployed position. The first link mechanism has: a first support link pivotably coupled to the airfoil; a second support link pivotably coupled to the airfoil and positioned aft of the first support link; a first positioning link pivotably connected to the first support link, the second support link and the leading edge panel; a second positioning link pivotably connected to the second support link and the leading edge panel; and a third positioning link pivotably connected between the second positioning link and the bullnose. The leading edge panel forms a gap with the airfoil when in the deployed position, and the first, second, and third positioning links are the only positioning links coupled between the first and second support links, the leading edge panel, and the bullnose at the first wing span location. The deployable leading edge assembly also includes a second link mechanism coupled to the leading edge panel, the bullnose and the airfoil at a second wing span location spaced apart in a spanwise direction from the first wing span location to move the leading edge panel between the stowed position and the deployed position. The second link mechanism has: a third support link pivotably coupled to the airfoil; a fourth support link pivotably coupled to the airfoil and positioned aft of the second support link; a fourth positioning link pivotably connected to the third support link, the fourth support link and the leading edge panel; a fifth positioning link pivotably connected to the fourth support link, and the leading edge panel; and a sixth positioning link pivotably connected between the second positioning link and the bullnose. The leading edge panel forms a gap with the airfoil when in the deployed position, and the fourth, fifth, and sixth positioning links are the only positioning links coupled between the third and fourth support links, the leading edge panel, and the bullnose at the second wing span location.

Each of the links may be generally straight.

For each link, opposite ends of the link may be offset by **20** degrees or less.

For each link, opposite ends of the link may be offset by **40** degrees or less.

5 In accordance with another aspect of the invention, there is provided a method for operating an aircraft wing system. The method involves deploying a leading edge panel and a bullnose relative to an airfoil by: rotating a first support link pivotably coupled to the airfoil at a first wing span location; rotating a second support link pivotably coupled to the airfoil and positioned
10 aft of the first support link; rotating a third support link pivotably coupled to the airfoil at a second wingspan location spaced apart in a spanwise direction from the first wing span location; rotating a fourth support link pivotably coupled to the airfoil and positioned aft of the third support link; rotating first, second, and third positioning links pivotably connected among the leading
15 edge panel, the bullnose, the first support link and the second support link, wherein the first, second, and third positioning links are the only positioning links coupled between the first and second support links, the leading edge panel and the bullnose at the first wing span location; rotating fourth, fifth, and sixth positioning links pivotably connected among the leading edge panel, the
20 bullnose, the third support link and the fourth support link, wherein the fourth, fifth, and sixth positioning links are the only positioning links coupled between the third and fourth support links, the leading edge panel and the bullnose at the second wing span location; forming a gap between the airfoil and a generally fixed-shape streamwise flow surface of the leading edge panel; and
25 rotating the bullnose relative to the leading edge panel.

Deploying the leading edge panel may involve moving the leading edge panel from a stowed position in which the panel forms a part of a lower surface of the airfoil, to a deployed position in which at least part of the panel is located
30 forward of a leading edge of the airfoil.

Forming a gap may involve forming a gap that is at least **2%** of a chord length of the airfoil.

Rotating the first, second, and third positioning links may involve rotating the first positioning link and the first support link relative to each other in a scissors manner, and rotating the second positioning link and the leading edge relative to each other in a scissors manner.

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Further aspects are directed toward methods for operating an aircraft system. One method includes deploying a rigid leading edge panel and a rigid bullnose relative to an airfoil by rotating a first support link pivotably coupled to the airfoil at a wingspan location, rotating a second support link pivotably coupled to the airfoil and spaced apart from the first support link, and rotating first, second, and third positioning links. The first, second, and third positioning links are pivotably connected among the leading edge panel, the bullnose, the first support link, and the second support link, and are the only positioning links coupled between the support links, the leading edge panel, and the bullnose at the wingspan location. The method can still further include forming a gap between the leading edge panel and the airfoil, and rotating the bullnose relative to the leading edge panel.

20 BRIEF DESCRIPTION OF THE DRAWINGS

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Figure 1 is a partially schematic, cross-sectional elevation view of a system that includes a deployable leading edge assembly and link mechanism configured in accordance with an embodiment of the invention, and shown in a deployed position.

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Figure 2 illustrates the system shown in Figure 1 in another deployed position. Figure 3 illustrates the system shown in Figure 1 in a partially retracted position. Figure 4 illustrates the system shown in Figure 1 in a fully retracted position.

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Figure 5 illustrates a system having a leading edge assembly and link mechanism configured in accordance with another embodiment of the invention.

Figure 6 illustrates a system that includes a leading edge assembly installed on an aircraft in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

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The present disclosure describes link mechanisms for gapped rigid Krueger flaps, and associated systems and methods. Certain specific details are set forth in the following description and in Figures 1-6 to provide a thorough understanding of various

embodiments of the invention. Well-known structures, systems and methods often associated with such systems have not been shown or described in detail to avoid unnecessarily obscuring the description of the various embodiments of the invention. In addition, those of ordinary skill in the relevant art will understand that additional
5 embodiments of the invention may be practiced without several of the details described below.

Figure 1 is a partially schematic, cross-sectional side elevation view of an aircraft system 100 having a deployable leading edge assembly 120 and an associated link mechanism 130 configured in accordance with an embodiment of the invention. The
10 leading edge assembly 120 is configured to provide enhanced high lift characteristics for an airfoil 110 on which it is installed. General attributes of the airfoil 110 and more detailed attributes of the leading edge assembly 120 and the link mechanism 130 are described below.

The airfoil 110 can be configured for operation over any of a variety of flight conditions.
15 The particular airfoil 110 shown in Figure 1 is configured for cruise at high subsonic Mach numbers representative of typical commercial transport airliners. Accordingly, the airfoil 110 can include a wing upper surface 111, a wing lower surface 113, and a relatively blunt leading edge 112 that is faired smoothly into both the upper surface 111 and the lower surface 113. The lower surface 113 of the airfoil 110 can include an
20 opening 118. When the leading edge assembly 120 is in its stowed position (described later with reference to Figure 4), it seals the opening 118 to provide for a generally continuous, aerodynamically smooth lower surface 113. When the leading edge assembly 120 is moved to its deployed position, as shown in Figure 1, the opening 118 is exposed.

25 A forward bulkhead 114 separates an aft fuel bay 116 from a leading edge dry bay 117. The leading edge dry bay 117 houses the link mechanism 130. The link mechanism 130 can be powered by any number of actuator arrangements, including a torque tube 115 that extends generally transverse to the plane of Figure 1 along the leading edge 112, and can be coupled to multiple link mechanisms 130 along the span of the airfoil
30 110. For purposes of illustration, one link mechanism 130 at a particular spanwise location is shown in Figure 1. As described later with reference to Figure 6, multiple link

mechanisms 130 may be positioned in a spanwise direction to control the motion of one or more deployable leading edge assemblies 120.

The leading edge assembly 120 can include a leading edge panel 121 and a bullnose 123 that is pivotably connected to the rigid leading edge panel 121. The leading edge panel 121 can include a streamwise flow surface 124 that has a generally rigid, fixed shape. A panel support structure 122 can be positioned to support the streamwise flow surface 124 and maintain its shape. Accordingly, the streamwise flow surface 124 may undergo small deflections due to aerodynamic loading, but has generally the same shape shown in Figure 1 when in any of its deployed positions, and when in its stowed position. The bullnose 123 can also include a generally rigid, fixed-shape bullnose flow surface 125. Unlike variable camber Krueger flap arrangements, an embodiment of the leading edge assembly 120 shown in Figure 1 uses the functionality of the generally fixed-shape flow surfaces 124, 125, and the link mechanism 130 (rather than flexibility of the streamwise flow surface 124), to produce the desired airflow characteristics at a variety of positions.

The leading edge assembly 120 is shown in its fully deployed position in Figure 1. In this position, the leading edge panel 121 is positioned downwardly and forwardly of the airfoil leading edge 112, and forms a gap 101 with the leading edge 112. The bullnose 123 is positioned slightly forwardly and downwardly of the leading edge panel 121. In this configuration, the leading edge assembly 120 effectively forms a much blunter (through reasonably aerodynamically efficient) leading edge for the airfoil 110, which allows the airfoil 110 to operate efficiently at high angles of attack. Such angles of attack are typically encountered during approach, landing, and takeoff.

The gap 101 formed between the leading edge panel 121 and the leading edge 112 can further improve the aerodynamic performance of the overall system 100. In many cases, it may be desirable to have a relatively large gap when the leading edge assembly 120 is in its fully deployed position. For example, it may be desirable to have a gap 101 that is up to and in some cases greater than 2% of the overall chord length of the airfoil 110 (e.g., the distance between the airfoil leading edge 112 and the airfoil trailing edge, which not visible in Figure 1). Accordingly, it may be desirable to have a gap between the leading edge 112 and the leading edge panel 121 of up to 8 inches on an airfoil having a local chord length of 400 inches. However, it has been challenging to

develop a system that is structurally efficient, creates the large desired gap 101, and moves the leading edge assembly 120 between its deployed position (shown in Figure 1) and its stowed position (described below with reference to Figure 4). Embodiments of the link mechanism 130 described below can address these issues.

5 The link mechanism 130 can include support links that are connected to the airfoil 110, and positioning links that are connected between the support links and the leading edge assembly 120. For example, in an embodiment shown in Figure 1, the link mechanism 130 can include a first support link 131 attached to the torque tube 115 at a pivot joint P1. A second support link 132 can be positioned aft of the first support link 131 and
10 can be pivotably attached to the airfoil structure at another pivot joint P2. A first positioning link 133 can be pivotably connected to the first support link 131, the second support link 132, and the leading edge panel 121. A second positioning link 134 can be pivotably connected to the first support link 131, the leading edge panel 121, and a third positioning link 135. The third positioning link 135 can be pivotably connected between
15 the second positioning link 134 and the bullnose 123. This five-link arrangement can efficiently move the leading edge assembly 120 (e.g., the leading edge panel 121 and the bullnose 123) between the fully deployed position shown in Figure 1 and other positions described below with reference to Figures 2-4.

Referring now to Figure 2, the torque tube 115 has rotated counterclockwise as
20 indicated by arrow C to move the leading edge panel 121 and the bullnose 123 toward the opening 118. In this position, the leading edge assembly 120 can form a very blunt "barn door" configuration which slows the aircraft down, for example, during landing rollout. In this position, and in other deployed positions, the leading edge panel 121 and therefore the link mechanism 130 can be subject to high loads generated by
25 aerodynamic forces acting on the forwardly-facing leading edge panel 121. The arrangement of the link mechanism 130 can be organized to efficiently transmit the aerodynamic loads to the airfoil 110. For example, each of the links can be generally straight, so as to transmit loads generally in compression or tension, without incurring significant bending loads. In a particular example, the first positioning link 133 can have
30 a first end 133a, a second end 133b, and an intermediate portion 133c. The first positioning link 133 can be pivotably connected toward its first end 133a to the second support link 132 at a pivot joint P3. The first positioning link 133 can be connected toward its second end 133b to the leading edge panel 121 at another pivot joint P4, and

can be connected toward its intermediate portion 133c to the first support link 131 at still another pivot joint P5. As shown by phantom lines in Figure 2, the pivot joints P3, P5, and P4 can be aligned along a generally straight line, and the first end 133a, second end 133b, and intermediate portion 133c, can also be aligned along a generally straight line. Accordingly, the first positioning link 133 can efficiently transmit compression loads from the leading edge panel 121 to the first support link 131 and the second support link 132. These loads are then transmitted to the structure of the airfoil 110.

Other links of the link mechanism 130 can have a generally similar arrangement. For example, the second positioning link 134 can include a first end 134a, a second end 134b, and an intermediate portion 134c. Each of these portions can be aligned along a generally straight line, as can a corresponding pivot point P6 between the second positioning link 134 and the first support link 131, a pivot point P7 between the second positioning link 134 and the third positioning link 135, and a pivot point P8 between the second positioning link 134 and the leading edge panel 121. The third positioning link 135 can be aligned along a generally straight axis between its two pivot points P7 and P9, and both the first support link 131 and the second support link 132 can also be aligned along generally straight axes (e.g., pivot points P1, P5 and P6 can be aligned along a generally straight axis for the first support link 131, and pivot points P2 and P3 can be aligned along a generally straight axis for the second support link 132). In particular embodiments, the ends of any of the links can be offset from each other by relatively small angular amounts (e.g., less than 20°, or less than 10°) without significantly detracting from the structural efficiency of the links. For example, as shown in Figure 2, both the first support link 131 and the first positioning link 133 have relatively small angular offsets between oppositely located pivot points P1, P6 and P3, P4, respectively.

Figure 3 illustrates the leading edge assembly 120 as it approaches its stowed position. The leading edge panel 121 is rotated toward the opening 118 and the bullnose 123 is folded about its pivot point P10 relative to the leading edge panel 121. As is clearly visible in Figure 3, the first positioning link 133 and the first support link 131 form a "scissors" configuration relative to each other, and the second positioning link 134 forms a scissors configuration relative to the leading edge panel 121. This double scissors configuration is one characteristic of an embodiment of the link mechanism

130 that allows it to move the leading edge panel 121 over a significant distance between the deployed position shown in Figure 1 and the fully stowed position described below with reference to Figure 4.

Figure 4 illustrates the leading edge assembly 120 in its fully stowed position. In this configuration, the leading edge panel 121 has been folded toward the airfoil 110 so as to be flush with the leading edge 112 and the lower surface 113, with the bullnose 123 and the link mechanism 130 housed completely within the dry bay 117. In this configuration, the airfoil 110 is typically flown at conditions not requiring enhanced lift performance, for example, sustained cruise conditions.

One feature of embodiments of the system described above with reference to Figures 1-4 is that the link mechanism 130 can have five links (e.g., two support links and three positioning links). An advantage of this arrangement when compared with other link arrangements having more than five links is that it can be simpler to manufacture, install, and maintain. Another advantage when compared to link mechanisms having fewer than five links is that it can position the leading edge panel 121 significantly forward of the airfoil leading edge 112 to form a large or relatively large gap 101. This is expected to improve the aerodynamic performance of the overall system when the leading edge assembly 120 is in its deployed configuration.

Another feature of at least some embodiments of the system described above with reference to Figures 1-4 is that the links in the link mechanism 130 can be generally straight. This is unlike some Krueger flap link arrangements which include significantly offset or "gooseneck" links. An advantage of the relatively straight links is that they are structurally efficient. For example, they can efficiently carry loads in tension and compression, without being subjected to significant bending loads. As a result, each of the links can be relatively small in size (as a result of not having to sustain significant bending loads), which can in turn reduce the overall weight of the link mechanism 130. Reduced weight increases the fuel efficiency of the aircraft on which the link mechanism 130 is installed, and/or the ability of the aircraft to carry a large payload.

Still another feature of embodiments of the system described above is that the flow surfaces of the leading edge assembly can have a generally fixed shape. For example, the streamwise flow surface 124 of the leading edge panel 121, and the streamwise bullnose flow surface 125 can both have generally fixed shapes. An advantage of this

arrangement is that it can be simpler than existing variable camber Krueger flaps to install and maintain. In particular, existing variable geometric flow surfaces typically require a significantly more complex arrangement of links (to adequately control the shapes of the flexible flow surfaces) than are included in at least some of the
5 embodiments described above.

Figure 5 is a partially schematic, cross-sectional side view of a system 500 having a link mechanism 530 configured in accordance with another embodiment of the invention. The link mechanism 530 is shown in solid lines in its deployed position, and in dashed lines in its stowed position. The system 500 can include an airfoil 110, leading edge
10 panel 121, and a bullnose 123 that are generally similar to the corresponding elements shown in Figures 1-4. The link mechanism 530 can include five links (as does the link mechanism 130 shown in Figure 1) that are configured and arranged in a different manner than that shown in Figure 1. For example, the link mechanism 530 can include a first support link 531 positioned aft of a second support link 532. This is unlike the
15 arrangement shown in Figure 1, in which the first support link (e.g., the driven support link 131, with three pivot points) is positioned forward of the second support link. The link mechanism 530 can also include first, second and third positioning links 533, 534, and 535, with the first and second positioning links 533, 534 having increased angular offsets when compared with the corresponding links shown in Figure 1. For example,
20 the first positioning link 533 can have an angular offset angle A of about 10° , as compared with a corresponding offset angle of less than 5° for the first positioning link 133 shown in Figure 2. The second positioning link 534 shown in Figure 5 can have an offset angle B of about 30° as compared with a corresponding offset angle for the second positioning link 134 shown in Figure 2 of less than 5° . The offset angles shown
25 in Figure 5 may allow for a potentially more compact arrangement, without significantly impacting structural efficiency. For example, while the offset angle B for the second positioning link 534 may be larger than that for the second positioning link 134 shown in Figure 2, the load placed on the second positioning link 534 by the bullnose 123 may be low enough so as not to require a significant increase in size for the second
30 positioning link 534.

Figure 6 is a schematic illustration of a system 600 that includes an aircraft 604 having leading edge assemblies with multiple link mechanisms configured in accordance with another embodiment of the invention. The aircraft 604 can include a fuselage 602,

wings 610 and an empennage 603. Each wing 610 can include one or more leading edge assemblies 620 (three are shown on each wing in Figure 6). Each leading edge assembly 620 can include a leading edge panel 621 carried by multiple link mechanisms 630. For example, in an embodiment shown in Figure 6, each leading edge panel 621 is carried by two link mechanisms 630, each located at a different spanwise location. In other embodiments, each leading edge panel 621 can be carried by more than two link mechanisms. Each of the link mechanisms 630 can include a five-link arrangement generally similar to any of the arrangements described above with reference to Figures 1-5.

From the foregoing, it will be appreciated that the specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the invention. For example, in some embodiments, the linkages may have different shapes or arrangements than are shown in the Figures. In still further embodiments, the actuator may be coupled to different links than are shown in the illustrated embodiments, and/or may have a different arrangement than a torque tube arrangement. Aspects of the invention described in the context of particular embodiments may be combined or eliminated in other embodiments. For example, features of the link mechanism shown in Figure 5 may be combined with features of the link mechanism shown in Figure 1. Further, while advantages associated with certain embodiments of the invention 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 invention. Accordingly, the invention is not limited except as by the appended claims.

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. An aircraft system, comprising:

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a deployable leading edge assembly that includes:

a deployable leading edge panel having a generally
fixed-shape flow surface;

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a bullnose pivotably coupled to the leading edge
panel;

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a first link mechanism coupled to the leading edge
panel and the bullnose at a first wing span location
to move the leading edge panel between a stowed
position and a deployed position, the first link
mechanism having:

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a first support link pivotably coupleable to an
airfoil;

25

a second support link pivotably coupleable to
the airfoil and spaced apart from the first
support link; and

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first, second, and third positioning links
pivotably connected among the leading edge
panel, the bullnose, the first support link and
the second support link, wherein the leading
edge panel forms a gap with the airfoil when
in the deployed position, and wherein the first,
second, and third positioning links are the
only positioning links coupled between the

first and second support links, the leading edge panel and the bullnose at the first wing span location; and

5 a second link mechanism coupled to the leading edge panel and the bullnose at a second wing span location spaced apart in spanwise direction from the first wingspan location to move the leading edge panel between the stowed position and the deployed position,
10 the second link mechanism having:

a third support link pivotably coupleable to the airfoil;

15 a fourth support link pivotably coupleable to the airfoil and spaced apart from the third support link; and

20 fourth, fifth, and sixth positioning links pivotably connected among the leading edge panel, the bullnose, the third support link and the fourth support link, wherein the leading edge panel forms a gap with the airfoil when in the deployed position, and wherein the
25 fourth, fifth, and sixth positioning links are the only positioning links coupled between the third and fourth support links, the leading edge panel and the bullnose at the second wing span location.

2. The system of claim 1, further comprising the airfoil, and wherein:

the first and second support links are pivotably coupled to
the airfoil;

the first positioning link is pivotably connected to the first
support link, the second support link and the leading edge
panel;

the second positioning link is pivotably connected to the
first support link, the leading edge panel and the third
positioning link; and

the third positioning link is pivotably connected between the
second positioning link and the bullnose.

3. The system of claim 1 or 2 wherein:

the first positioning link has a first end, a second end, and
an intermediate portion between its first and second ends,
the first positioning link being pivotably connected to the
second support link toward its first end, pivotably
connected to the leading edge panel toward its second
end, and pivotably connected to the first support link at its
intermediate portion to form a scissors arrangement with
the first support link; and

the second positioning link has a first end, a second end,
and an intermediate portion between its first and second
ends, the second positioning link being pivotably connected
to the first support link toward its first end, pivotably
connected to the third positioning link toward its second
end, and pivotably connected to the leading edge panel at
its intermediate portion.

4. The system of any one of claims 1 to 3 wherein the first support link and the first positioning link each have three pivot joints coupled to adjacent elements, and wherein the three pivot joints of the first support link are at least approximately co-linear, and wherein the three pivot joints of the first positioning link are at least approximately co-linear.
5. The system of claim 1, further comprising the airfoil, and wherein the first and second support links are pivotably coupled to the airfoil.
6. The system of claim 5 wherein the airfoil has an airfoil chord length, wherein the leading edge panel forms a gap that is at least 2% of the airfoil chord length when in the deployed position.
7. The system of any one of claims 1 to 4 further comprising the airfoil, wherein:
- the first and second support links are pivotably coupled to the airfoil;
- the airfoil has an airfoil chord length; and
- the leading edge panel forms a gap that is at least 2% of the airfoil chord length when in the deployed position.
8. The system of claim 1 wherein the first support link is coupled to an actuator.
9. The system of claim 1 wherein the leading edge panel has a streamwise flow surface that is exposed to freestream airflow when in both the stowed and the deployed positions.

10. The system of claim 1 wherein each of the links is generally straight.
- 5 11. The system of any one of claims 1 to 5 wherein the first support link has three pivot locations positioned along a generally straight line.
- 10 12. The system of claim 1 wherein the first positioning link has three pivot locations positioned along a generally straight line.
13. The system of claim 1 wherein the second positioning link has three pivot locations positioned along a generally straight line.
- 15 14. The system of claim 1 wherein for each link, opposite ends of the link are offset by 20 degrees or less.
15. The system of claim 1 wherein for each link, opposite ends of the link are offset by 40 degrees or less.
- 20 16. The system of claim 1 wherein both the leading edge panel and the bullnose have generally fixed-shape, streamwise flow surfaces.
- 25 17. The system of claim 1 wherein the first support link and the first positioning link form a first scissors configuration, and wherein the leading edge panel and the second positioning link form a second scissors configuration.
- 30 18. An aircraft wing system, comprising:
an airfoil;
a deployable leading edge assembly that includes:

a deployable leading edge panel having a generally rigid, fixed-shape flow surface;

5

a bullnose pivotably coupled to the leading edge panel and having a generally rigid, fixed-shape flow surface;

10

a first link mechanism coupled to the leading edge panel, the bullnose and the airfoil at a first wing span location to move the leading edge panel between a stowed position and a deployed position, the first link mechanism having:

15

a first support link pivotably coupled to the airfoil;

20

a second support link pivotably coupled to the airfoil and positioned aft of the first support link;

25

a first positioning link pivotably connected to the first support link, the second support link and the leading edge panel;

30

a second positioning link pivotably connected to the second support link, and the leading edge panel; and

35

a third positioning link pivotably connected between the second positioning link and the bullnose, wherein the leading edge panel forms a gap with the airfoil when in the deployed position, and wherein the first, second, and third positioning links are the only positioning links coupled between the

first and second support links, the leading edge panel and the bullnose at the first wing span location; and

5 a second link mechanism coupled to the leading edge panel, the bullnose and the airfoil at a second wing span location spaced apart in a spanwise direction from the first wing span location to move the leading edge panel between the stowed position and the deployed position, the second link mechanism having:

10 a third support link pivotably coupled to the airfoil;

15 a fourth support link pivotably coupled to the airfoil and positioned aft of the second support link;

20 a fourth positioning link pivotably connected to the third support link, the fourth support link and the leading edge panel;

25 a fifth positioning link pivotably connected to the fourth support link, and the leading edge panel; and

30 a sixth positioning link pivotably connected between the second positioning link and the bullnose, wherein the leading edge panel forms a gap with the airfoil when in the deployed position, and wherein the fourth, fifth, and sixth positioning links are the only positioning links coupled between the third and fourth support links, the leading edge

35

panel and the bullnose at the second wing span location.

5 **19.** The system of claim **18** wherein each of the links is generally straight.

20. The system of claim **18** wherein for each link, opposite ends of the link are offset by **20** degrees or less.

10 **21.** The system of claim **18** wherein for each link, opposite ends of the link are offset by **40** degrees or less.

22. A method for operating an aircraft wing system, comprising:

15 deploying a leading edge panel and a bullnose relative to an airfoil by:

 rotating a first support link pivotably coupled to the airfoil at a first wing span location;

20 rotating a second support link pivotably coupled to the airfoil and positioned aft of the first support link;

 rotating a third support link pivotably coupled to the airfoil at a second wingspan location spaced apart in a spanwise direction from the first wing span location;

 rotating a fourth support link pivotably coupled to the airfoil and positioned aft of the third support link;

30 rotating first, second, and third positioning links pivotably connected among the leading edge panel, the bullnose, the first support link and the second support link, wherein the first, second, and third positioning links are the only positioning links

35

coupled between the first and second support links,
the leading edge panel and the bullnose at the first
wing span location;

5

rotating fourth, fifth, and sixth positioning links
pivotably connected among the leading edge panel,
the bullnose, the third support link and the fourth
support link, wherein the fourth, fifth, and sixth
positioning links are the only positioning links
coupled between the third and fourth support links,
the leading edge panel and the bullnose at the
second wing span location;

10

15

forming a gap between the airfoil and a generally
fixed-shape streamwise flow surface of the leading
edge panel; and

rotating the bullnose relative to the leading edge
panel.

20

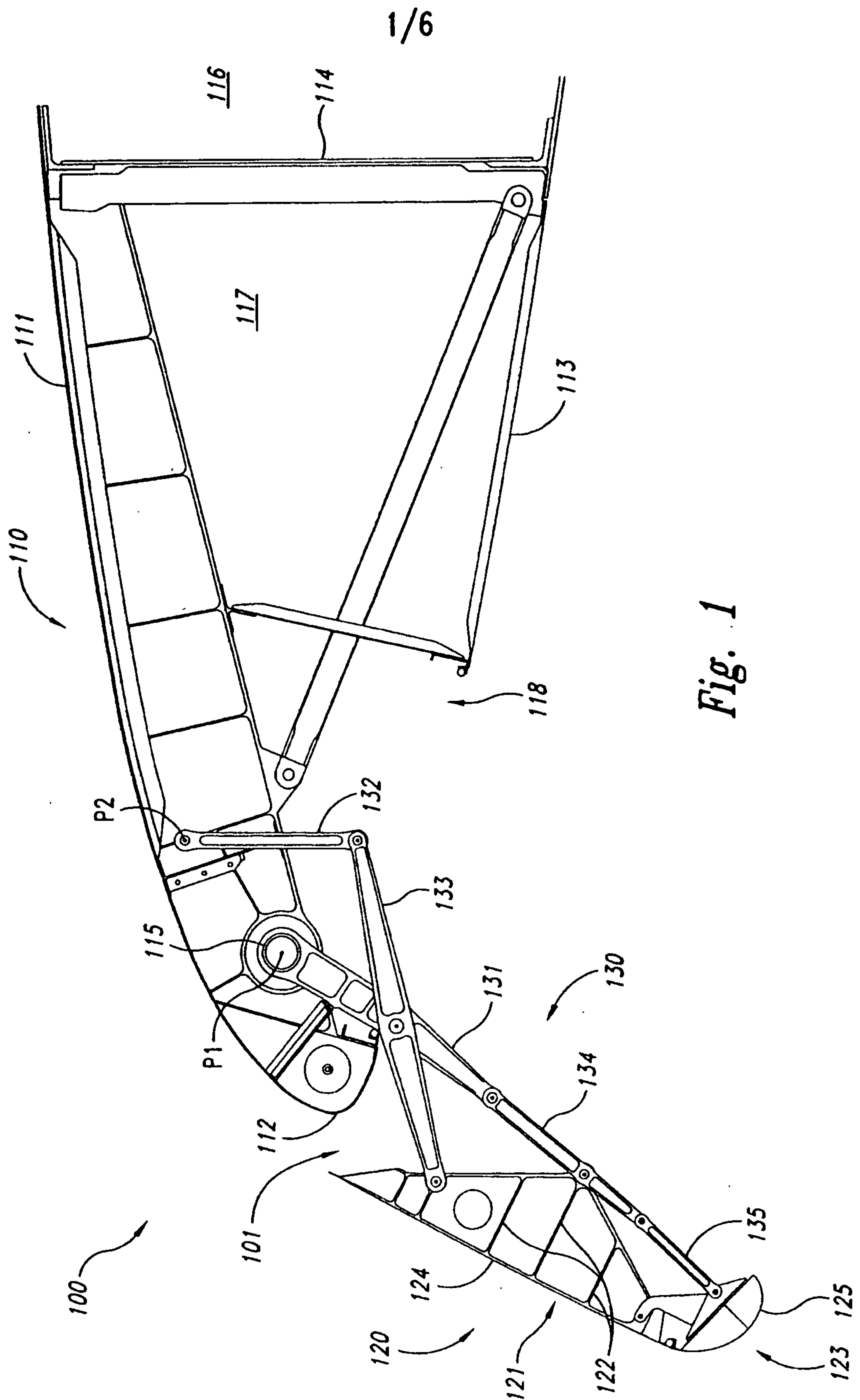
23. The method of claim **22** wherein deploying the leading edge panel
includes moving the leading edge panel from a stowed position in
which the panel forms a part of a lower surface of the airfoil, to a
deployed position in which at least part of the panel is located
forward of a leading edge of the airfoil.

25

24. The method of claims **22** or **23** wherein forming a gap includes
forming a gap that is at least **2%** of a chord length of the airfoil.

30

25. The method of any one of claims **22** to **24** wherein rotating the
first, second, and third positioning links includes rotating the first
positioning link and the first support link relative to each other in a
scissors manner, and rotating the second positioning link and the
leading edge relative to each other in a scissors manner.



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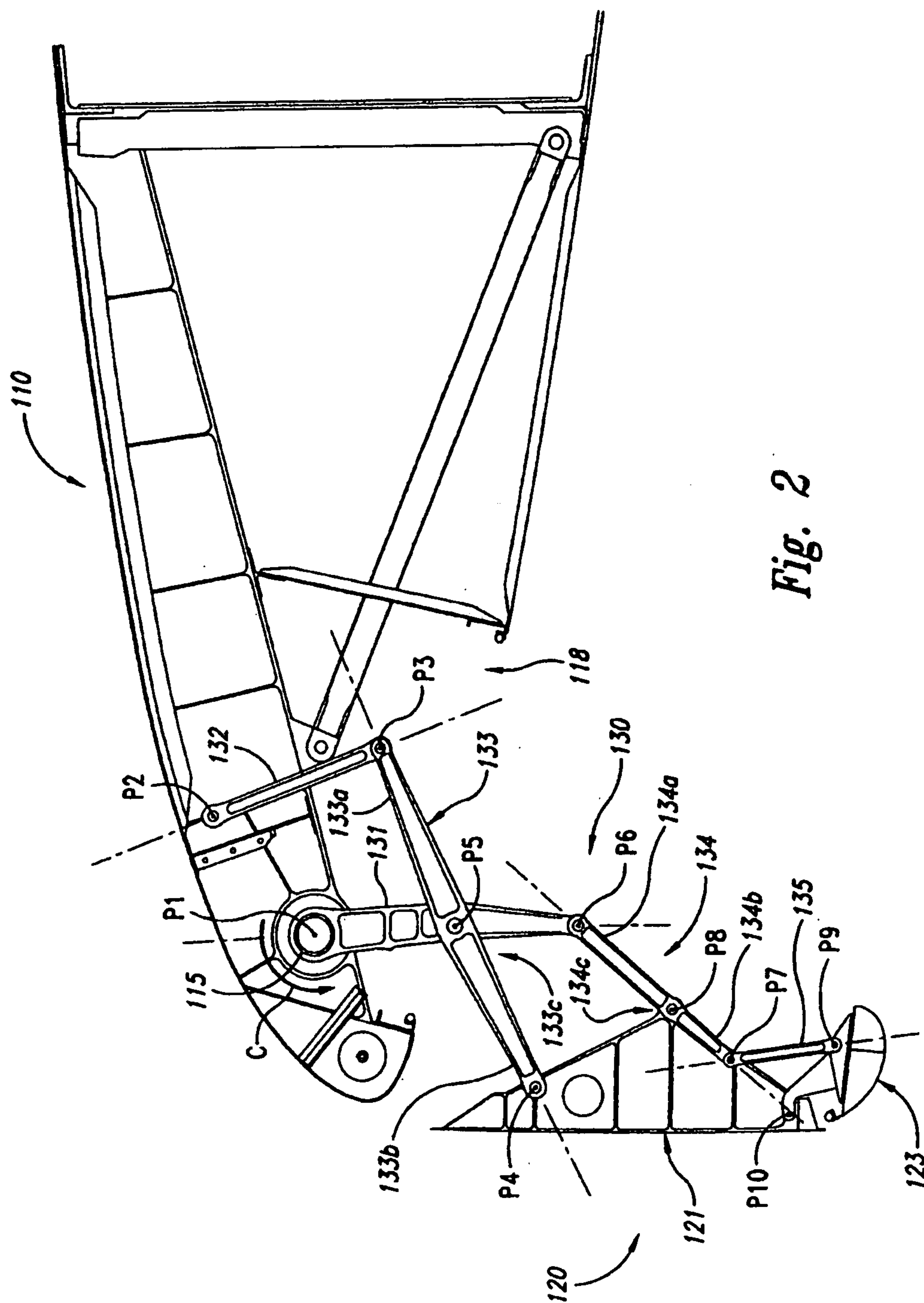
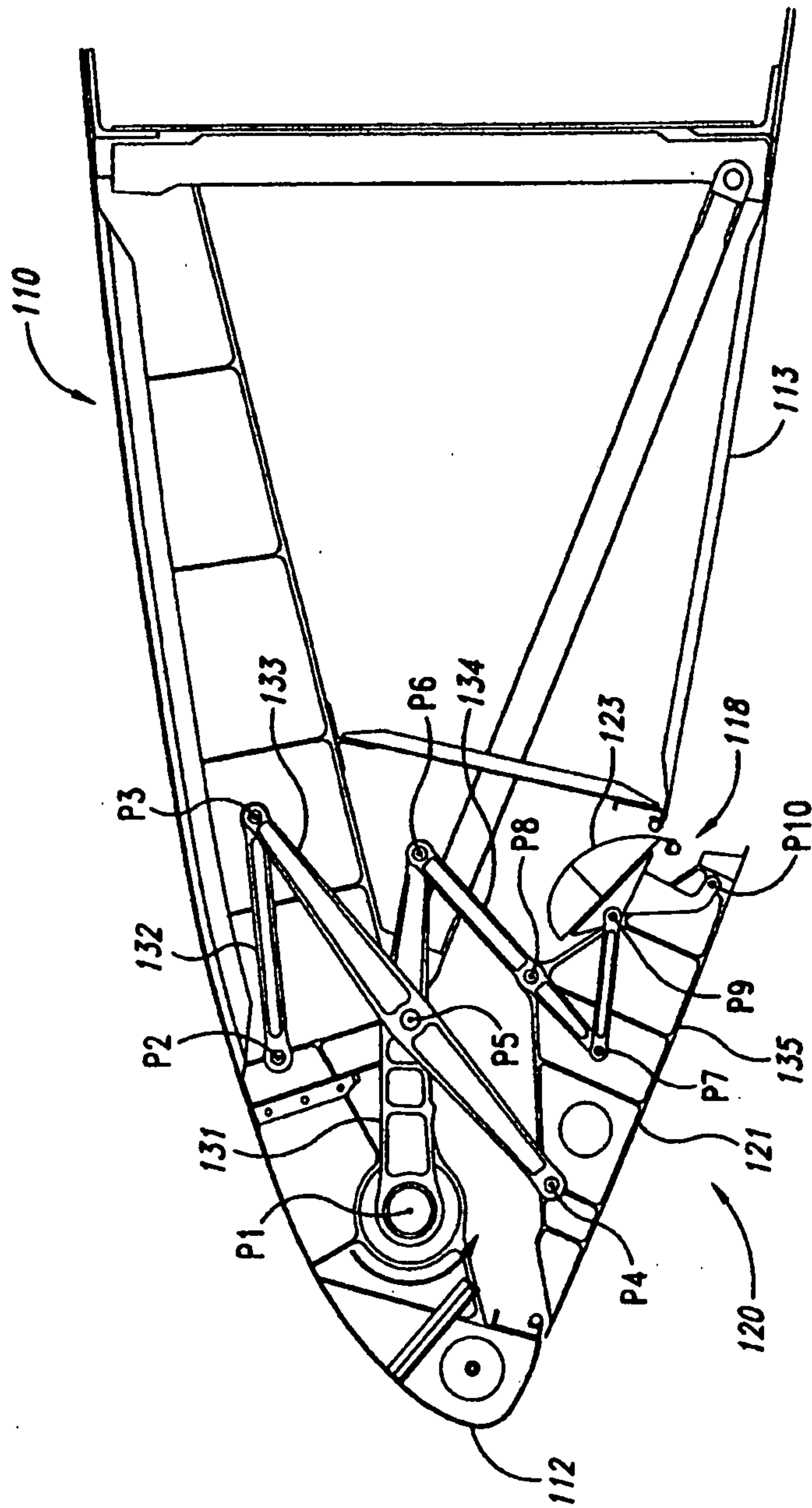


Fig. 2

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*Fig. 3*

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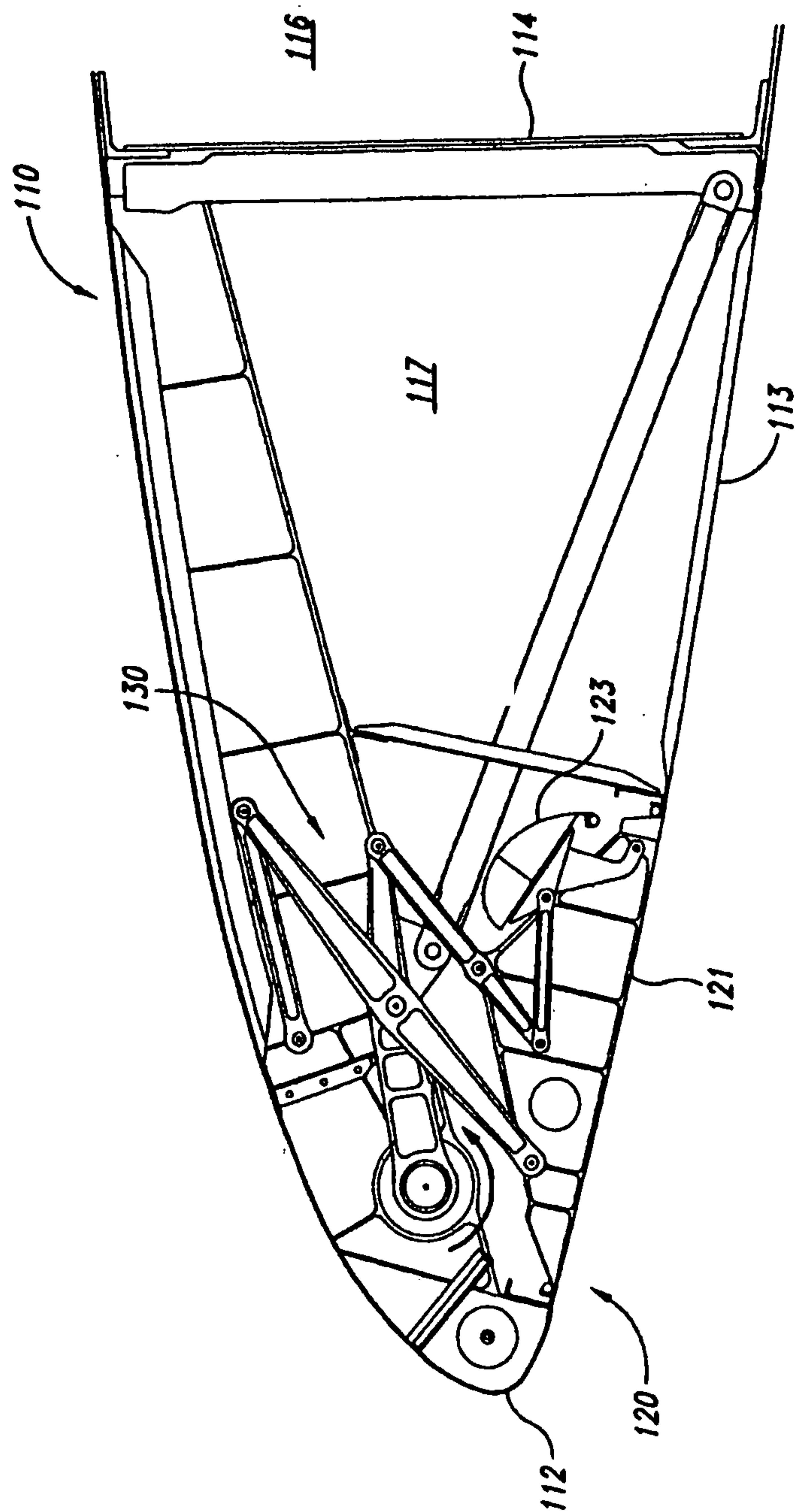


Fig. 4

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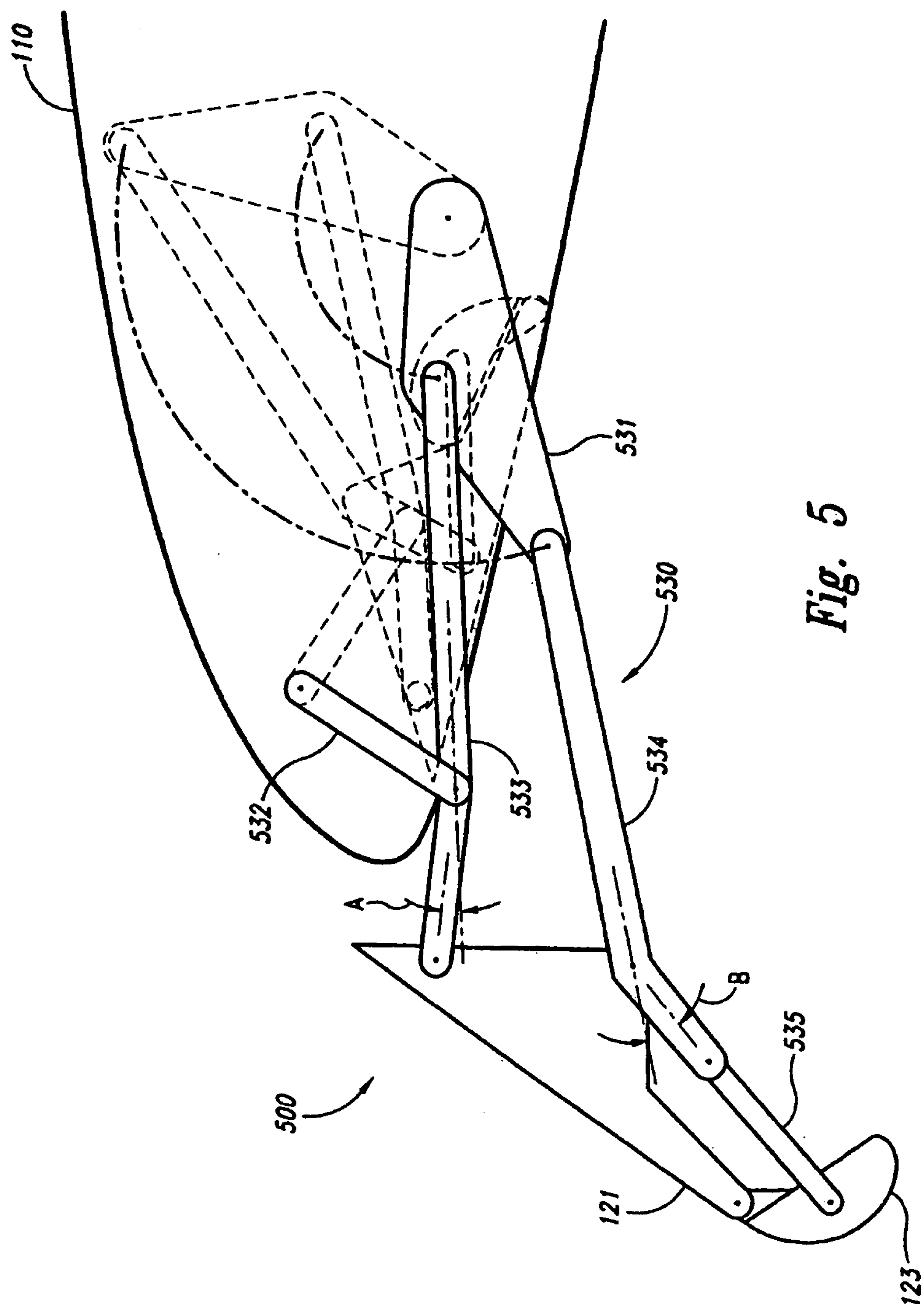
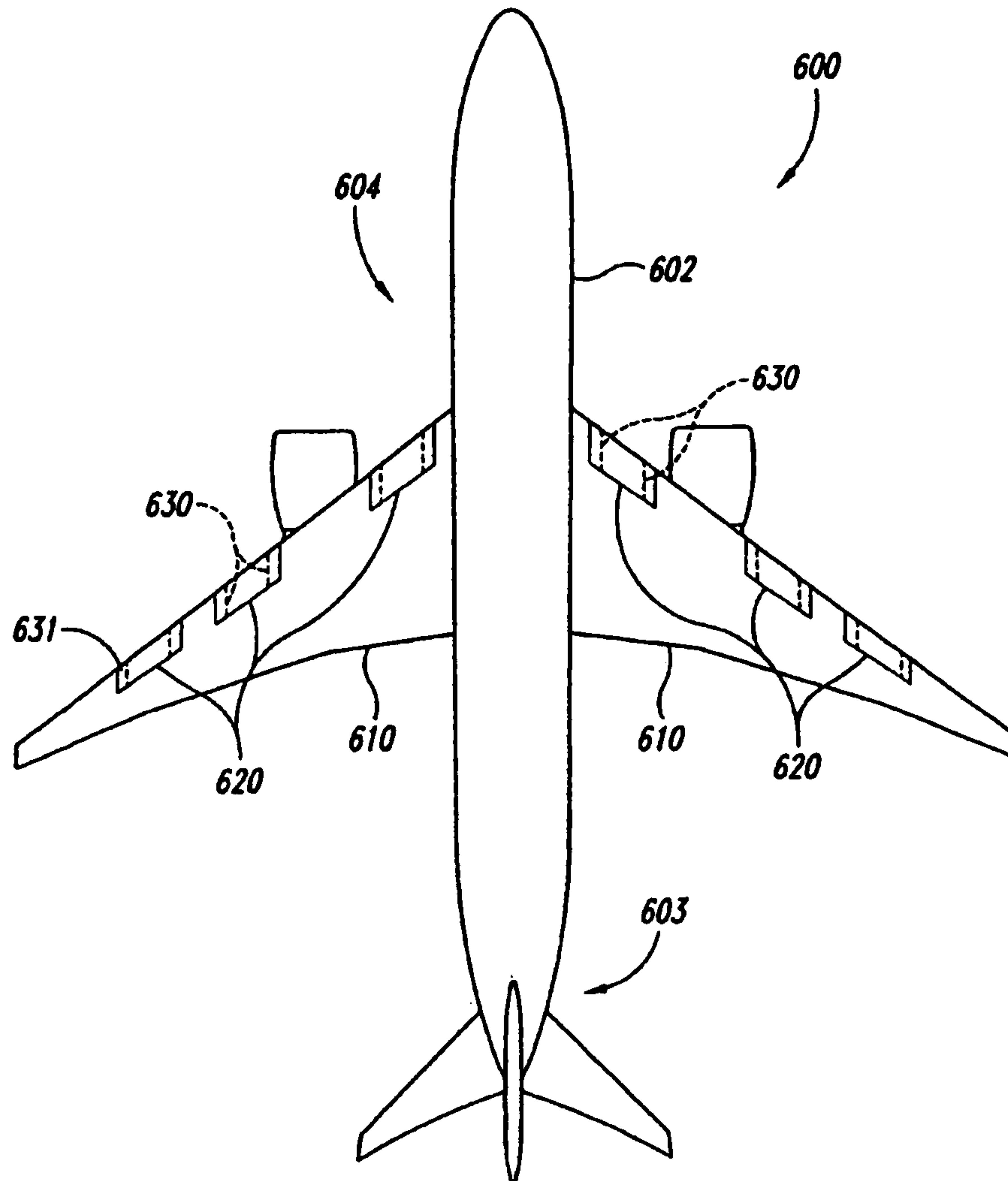


Fig. 5

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*Fig. 6*

