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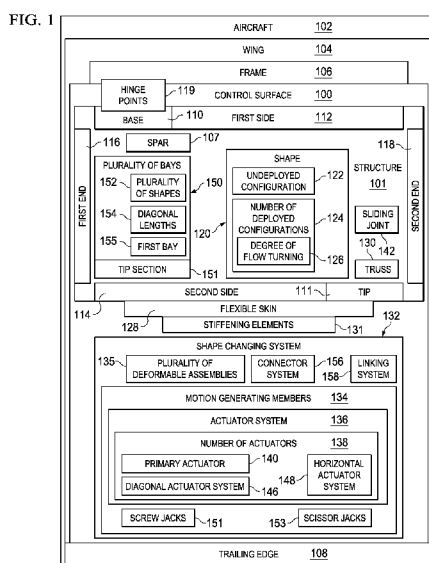
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(54) Title: MECHANISM FOR CHANGING THE SHAPE OF A CONTROL SURFACE



(57) Abstract: An apparatus comprises a structure having a first side, a second side substantially opposite to the first side, a flexible skin, and a plurality of deformable assemblies. The flexible skin is attached to the first side and the second side of the structure. The plurality of deformable assemblies is moveably connected to the structure, in which each deformable assembly in the plurality of deformable assemblies has a vertex and a base. The each deformable assembly in the plurality of deformable assemblies has a height that is capable of changing to change a shape of the structure and a shape of the flexible skin.

MECHANISM FOR CHANGING THE SHAPE OF A CONTROL SURFACE

BACKGROUND INFORMATION

5 **Field:**

The present disclosure relates generally to aircraft and, in particular, to a method and apparatus for controlling aerodynamic performance of an aircraft. Still more particularly, the present disclosure relates to a method and apparatus for changing the shape of a control surface for an aircraft.

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Background:

An aircraft is a type of vehicle capable of flying through the atmosphere. Aircraft may include fixed- wing aircraft and rotor craft. The flight of an aircraft may be controlled by a number of flight control surfaces. A flight control surface is a part of the surface of an aircraft
15 that may control the aerodynamic performance of an aircraft. A flight control surface may be used to adjust or control the attitude of an aircraft. The shape and/or position of flight control surfaces may generate lift, control stability, change direction, change drag, and/or change other suitable aerodynamic parameters for an aircraft.

Flight control surfaces on an aircraft may be used to change the direction of an aircraft
20 around three axes. These axes include a vertical axis, a longitudinal axis, and a lateral axis. A vertical axis passes through an aircraft from top to bottom. Rotation or movement about this axis is called yaw. Yaw changes the direction of the nose of an aircraft pointing it to the left or right. The longitudinal axis passes through the aircraft from the nose to the tail. Rotation about this axis is referred to as bank or roll. The lateral axis passes from one wing tip of an aircraft to
25 another wing tip of an aircraft. Rotation about this axis is referred to as pitch.

Control surfaces may include, for example, an aileron, an elevator, a rotor, a trim, a rudder, a spoiler, a flap, a slat, a thrust reverser, and/or other suitable control surfaces. Different control surfaces may be attached to an airfoil to provide for different axes of motion for the aircraft. An airfoil may be a wing or a blade of an aircraft. These control surfaces may be used
30 to optimize the aerodynamic surfaces of an airfoil.

For example, a flap may be located at a trailing edge of an airfoil in the form of a wing. A flap is an extension to the back of a wing to provide lift augmentation as well as drag augmentation. Further, deployment of a flap may reduce the stalling speed for an aircraft by

altering airflow over the wing. Flap deployment may allow an aircraft to climb and/or descend at a steeper angle without an increase in speed. Movement of this type of control surface, as well as other control surfaces, during flight may be performed to maximize the handling and performance of the aircraft.

5 When deploying a flight control surface, it is desirable to have a control surface that may remain straight in an undeployed configuration but may have a high degree of flow turning in a deployed configuration. The degree of flow turning for a control surface is the degree at which airflow over a wing may be turned or deflected with respect to the original direction of airflow. For example, the deployment of a flap may cause the airflow over a wing during flight to be
10 deflected at some downward angle with respect to the original direction of airflow. Further, it is desirable to have a first side of a control surface that curves in a smooth manner. In other words, the control surface does not have sharp discontinuities in the slope of the first side when in a deployed configuration. It is also desirable to have control surface shape changing systems that do not have protrusions in the mold line of the control surfaces or the aircraft parts to which they
15 are attached.

 Currently, existing control surfaces include extension and/or unfolding mechanisms that have protrusions. For example, currently used flap systems may have fittings which protrude into the airstream on a second side of a wing. Some existing control surfaces may use sliding joints to lengthen the first side of a control surface and shorten the second side of a control
20 surface during deployment of the control surface. Further, some control surfaces may also use a sliding joint at the tip of a control surface. These control surfaces may have inadequate strength, may be heavy, and/or may be expensive.

 The types of changes to the shape of a control surface that may be made with existing flight control surfaces may be limited and may not provide desired aerodynamic performance.
25 For example, existing flap systems do not allow for a high degree of flow turning. A high degree of flow turning may be direction of airflow at the tip of a deployed flap and may be greater than around 50 degrees inclined to the horizontal plane of the aircraft.

 Therefore, it would be advantageous to have a method and apparatus that addresses at least some of the issues discussed above and possibly other issues.

SUMMARY

In one advantageous embodiment, an apparatus comprises a structure having a first side, a second side substantially opposite to the first side, a flexible skin, and a plurality of deformable assemblies. The flexible skin is attached to the first side and the second side of the structure. The plurality of deformable assemblies is moveably connected to the structure, in which each deformable assembly in the plurality of deformable assemblies has a vertex and a base. Each deformable assembly in the plurality of deformable assemblies has a height that is capable of changing to change a shape of the structure and a shape of the flexible skin.

In another advantageous embodiment, an apparatus comprises a structure having a first side, a second side substantially opposite to the first side, a plurality of bays, a flexible skin, a plurality of deformable assemblies, a plurality of connection structures, and an actuator system. The plurality of bays is located within the structure. The flexible skin is attached to the first side and the second side of the structure. The plurality of deformable assemblies is moveably connected to the structure, in which each deformable assembly in the plurality of deformable assemblies has a vertex and a base. Each deformable assembly in the plurality of deformable assemblies has a height that is capable of changing to change a shape of the structure and a shape of the flexible skin. The plurality of connection structures is connected to the plurality of deformable assemblies. Each connection structure in the plurality of connection structures has a vertex and a plurality of members extending from the vertex to an associated deformable assembly in the plurality of deformable assemblies. A first member of the plurality of members is connected to the vertex of each deformable assembly, and a number of other members in the plurality of members is connected to a base of each deformable assembly. The actuator system is connected to a first vertex of a first deformable assembly in a first bay of the plurality of bays and a second vertex of a second deformable assembly in the first bay. A first number of the plurality of deformable assemblies has a first number of vertices linked in series to the first vertex. A second number of the plurality of deformable assemblies has a second number of vertices linked in series to the second vertex. The actuator system is capable of moving the first vertex and the second vertex to change the shape of the structure and the shape of the flexible skin attached to the structure.

In yet another advantageous embodiment, an apparatus comprises a structure, a plurality of bays, a flexible skin, a plurality of deformable assemblies, a plurality of connection structures, a polyhedron structure, and an actuator. The structure has a first side, a second side substantially

opposite to the first side, and a base rotatably connected to a frame. The plurality of bays is located within the structure. The flexible skin is attached to the first side and the second side of the structure. The plurality of deformable assemblies is moveably connected to the structure, in which each deformable assembly in the plurality of deformable assemblies has a vertex and a base. The vertex has a height that is capable of changing to change a shape of the structure and a shape of the flexible skin. The plurality of connection structures is connected to the plurality of deformable assemblies, wherein each connection structure in the plurality of connection structures has a vertex and a plurality of members extending from the vertex to an associated deformable assembly in the plurality of deformable assemblies. A first member of the plurality of members is connected to the vertex of each deformable assembly, and a number of other members in the plurality of members is connected to a base of each deformable assembly. Vertices in a number of connection structures in the plurality of connection structures are connected in series to each other. The polyhedron structure has a first vertex and a second vertex forming an edge of the polyhedron structure; a first elongate member extending from a third vertex of the polyhedron structure to the base of the structure; and a second elongate member extending from a fourth vertex to a first vertex in a first connection structure in the number of connection structures. The actuator is connected to the base of the structure, wherein the actuator is capable of moving the base to rotate the structure. Movement of the base is capable of causing the polyhedron structure to move the first vertex in the first connection structure such that the vertex of each deformable assembly changes height to change the shape of the structure and the shape of the flexible skin attached to the structure.

In still another advantageous embodiment, an apparatus comprises a structure, a flexible skin, an array of bays, and a plurality of diagonal members. The structure has a base rotatably attached to a frame. The flexible skin is attached to the structure. The array of bays is in the structure and has a quadrilateral shape capable of changing shape. The plurality of diagonal members is connected to corners in the array of bays. The plurality of diagonal members is capable of changing a length in connection with each other to change the quadrilateral shape of the array of bays to change a shape of the structure. One of the plurality of diagonal members is capable of rotating the structure with a control surface about the frame.

In a further advantageous embodiment, a method is present for controlling a control surface. A position for the control surface comprising a structure having a first side and a second side substantially opposite to the first side is identified. A flexible skin is attached to the first side and the second side of the structure. A plurality of deformable assemblies is moveably

connected to the structure, in which each deformable assembly in the plurality of deformable assemblies has a vertex, and a base. The vertex has a height that is capable of changing. A motion generation system connected to the vertex is activated to move the vertex to change a height of a number of deformable assemblies in the plurality of deformable assemblies to change a shape of the control surface.

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

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the advantageous embodiments are set forth in the appended claims. The advantageous embodiments, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an advantageous embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a diagram of a control surface for an aircraft in which an advantageous embodiment may be implemented;

Figure 2 is a diagram of an aircraft in which an advantageous embodiment may be implemented;

Figure 3 is a diagram of a flap in accordance with an advantageous embodiment;

Figure 4 is a diagram of a flap in accordance with an advantageous embodiment;

Figure 5 is a diagram of a partially deployed flap in accordance with an advantageous embodiment;

Figure 6 is a diagram of a fully deployed flap in accordance with an advantageous embodiment;

Figure 7 is an exposed top view of a flap in accordance with an advantageous embodiment;

Figure 8 is an exposed cross-sectional view of a flap in accordance with an advantageous embodiment;

Figure 9 is an exposed cross-sectional view of a flap in an undeployed configuration in accordance with an advantageous embodiment;

Figure 10 is an exposed cross-sectional view of a partially deployed flap in accordance with an advantageous embodiment;

Figure 11 is an exposed cross-sectional view of a fully deployed flap in accordance with an advantageous embodiment;

5 **Figure 12** is a diagram of a deformable assembly in accordance with an advantageous embodiment;

Figure 13 is an exposed cross-sectional top view of a flap in an undeployed configuration in accordance with an advantageous embodiment;

10 **Figure 14** is an exposed cross-sectional view of a flap in an undeployed configuration in accordance with an advantageous embodiment;

Figure 15 is an exposed top view of a flap in a partially deployed configuration in accordance with an advantageous embodiment;

Figure 16 is an exposed cross-sectional view of a flap in a deployed configuration in accordance with an advantageous embodiment;

15 **Figure 17** is an exposed top view of a flap in a fully deployed configuration in accordance with an advantageous embodiment;

Figure 18 is an exposed cross-sectional view of a flap in a deployed configuration in accordance with an advantageous embodiment;

20 **Figure 19** is a diagram of a deformable assembly connected to a portion of a connector system in accordance with an advantageous embodiment;

Figure 20 is an exposed top view of a flap in an undeployed configuration in accordance with an advantageous embodiment;

Figure 21 is an exposed cross-sectional view of a flap in an undeployed configuration in accordance with an advantageous embodiment;

25 **Figure 22** is an exposed top view of a flap in a deployed configuration in accordance with an advantageous embodiment;

Figure 23 is a cross-sectional view of a flap in a deployed configuration in accordance with an advantageous embodiment;

30 **Figure 24** is an exposed top view of a flap in a deployed configuration in accordance with an advantageous embodiment;

Figure 25 is a cross-sectional view of a flap in a deployed configuration in accordance with an advantageous embodiment;

Figure 26 is a diagram of a linking system in accordance with an advantageous embodiment;

Figure 27 is a graph illustrating rates of change for a linkage assembly in accordance with an advantageous embodiment;

5 **Figure 28** is a partially exposed top view of a flap with a linking system in an undeployed configuration in accordance with an advantageous embodiment;

Figure 29 is a cross-sectional view of a flap in an undeployed configuration in accordance with an advantageous embodiment;

10 **Figure 30** is an exposed top view of a flap in a deployed configuration in accordance with an advantageous embodiment;

Figure 31 is a cross-sectional view of a flap in a deployed configuration in accordance with an advantageous embodiment;

Figure 32 is an exposed top view of a flap in a deployed configuration in accordance with an advantageous embodiment;

15 **Figure 33** is a cross-sectional view of a flap in a deployed configuration in accordance with an advantageous embodiment;

Figure 34 is a diagram of a portion of a truss of a structure of a flap in accordance with an advantageous embodiment; and

20 **Figure 35** is a flowchart of a method for controlling a control surface in accordance with an advantageous embodiment.

DETAILED DESCRIPTION

25 The different advantageous embodiments recognize that it may be desirable to have a control surface that may quickly change shape. The different advantageous embodiments also recognize that it may be desirable to have a control surface that provides a high degree of flow turning for an aircraft. For example, it may be desirable to have a control surface that is straight in an undeployed configuration but curved in a deployed configuration. The curved shape of the control surface may provide a high degree of flow turning.

30 The different advantageous embodiments recognize that a control surface that curves smoothly such that there are no sharp discontinuities and/or gaps on the first side of the control surface may be desirable. Further, the different advantageous embodiments recognize that a

control surface without protrusions in the mold line of the control surface or the airfoil to which the control surface is attached may be desirable.

Current systems may use sliding joints for both the first side and the second side of a control surface. These systems may also use a sliding joint at the tip of the control surface.

5 However, the different advantageous embodiments recognize that it may be desirable to have a control surface without a sliding joint at the tip to improve the stiffness of the tip section of the control surface. Further, problems with sealing the interior of the control surface from the outside environment may be avoided.

10 With reference now to the figures and, in particular, with reference to **Figure 1**, a diagram of a control surface for an aircraft is depicted in which an advantageous embodiment may be implemented. Control surface **100** may be one example of a control surface that may be implemented in an aircraft such as, for example, aircraft **102**.

15 In this illustrative example, aircraft **102** may have wing **104** with control surface **100** attached to frame **106** of wing **104**. Control surface **100** may be located at trailing edge **108** of wing **104**. Frame **106** may include a number of structural components. These components may include, for example, without limitation, spars, ribs, and/or other structural components. As used herein, “a number of” items refers to one or more items. For example, a number of structural components means one or more structural components.

20 In this illustrative example, control surface **100** may have structure **101**. Structure **101** may be comprised of various members. For example, without limitation, structure **101** may comprise rods, joints, linkage assemblies, and/or various other suitable structural components. Structure **101** may have base **110**, tip **111**, first side **112**, second side **114**, first end **116**, and second end **118**. Structure **101** may also include spar **107**. Spar **107** may be moveably attached to frame **106** of wing **104** at hinge points **119** at first side **112** of structure **101**.

25 Hinge points **119** may allow control surface **100** to be moveably attached to wing **104**. Hinge points **119** may be stationary fixed hinge points connecting spar **107**, first side **112**, and base **110** of structure **101** to frame **106**. Hinge points **119** may allow movement of structure **101** and control surface **100** with respect to hinge points **119**. For example, structure **101** may be capable of rotating about hinge points **119**. Tip **111** may be located near trailing edge **108** of wing **104**.

30 In this illustrative example, structure **101** may have a shape such as, for example, shape **120**. Shape **120** may be a straight shape, a curved shape, and/or some other suitable shape for structure **101**. Shape **120** may change as structure **101** is moved between undeployed

configuration **122** and number of deployed configurations **124**. In undeployed configuration **122**, control surface **100** may have a straight shape. In number of deployed configurations **124**, structure **101** may have curved shapes of varying degrees of curvature.

5 In these examples, number of deployed configurations **124** may allow for a range of degrees of flow turning. For example, number of deployed configurations **124** may provide degree of flow turning **126**. In these examples, degree of flow turning **126** may be the angle at which airflow over wing **104** may be deflected to flow over control surface **100**. In this manner, number of deployed configurations **124** for control surface **100** may be based on the range of degree of flow turning **126**. For example, control surface **100** may allow a 24 degree angle of
10 flow turning with one deployed configuration and a 36 degree angle of flow turning with a second deployed configuration.

Control surface **100** may have a flexible skin such as, for example, flexible skin **128**. Flexible skin **128** may be attached to structure **101** on first side **112** and second side **114** of flexible skin **128**. Flexible skin **128** may be formed from one or more skin panels. Flexible skin
15 **128** may be a thin skin comprised of a material capable of bending. As structure **101** and control surface **100** change shape, flexible skin **128** may also curve to change shape. For example, flexible skin **128** may be a material capable of bending as control surface **100** is moved into number of deployed configurations **124** and may take on a curved shape for shape **120**. Flexible skin **128** may be capable of curving to provide degree of flow turning **126**. In these illustrative
20 examples, flexible skin **128** may be made out of materials such as, for example, without limitation, corrugated metal, ceramic, titanium, composite skin, and/or some other suitable material.

In these examples, control surface **100** may have stiffening elements **131** attached to flexible skin **128**. Stiffening elements **131** may be capable of increasing the stiffness of flexible
25 skin **128** in a spanwise direction in a number of sections in flexible skin **128**, while allowing flexible skin **128** to remain flexible in the chordwise direction. Stiffening elements **131** may be made out of materials such as, for example, without limitation, aluminum, titanium, fiber-reinforced composites, other metals, and/or other suitable materials.

For example, stiffening elements **131** may be metal stiffeners attached to flexible skin
30 **128** along the span of control surface **100** to provide stiffness in the spanwise direction. In these examples, the spanwise direction refers to the direction from first end **116** to second end **118** and vice versa. In some advantageous embodiments, stiffening elements **131** may be embedded

within flexible skin **128** or added to flexible skin **128** during its construction. For example, stiffening elements **131** may be machined as part of flexible skin **128**.

In some advantageous embodiments, structure **101** may include truss **130** attached to flexible skin **128**. Truss **130** may provide load-bearing support for flexible skin **128**. Flexible skin **128** may transfer air loads to truss **130** at points of attachment between flexible skin **128** and structure **101**. Air loads may be the forces on flexible skin **128** and control surface **100** due to air and wind during flight. Truss **130** may be comprised of various elements. These elements may include, for example, without limitation, rods, beams, tubes, joints, linkages, and/or other structural components that may form truss **130** for structure **101**.

In these illustrative examples, control surface **100** may be divided into plurality of bays **150**. In some advantageous embodiments, plurality of bays **150** may be sections of structure **101** that may be delineated by components of structure **101**. For example, plurality of bays **150** may be defined by components. These components may include, for example, without limitation, stiffening elements **131**, components of truss **130**, and/or other suitable components of structure **101**. In yet other advantageous embodiments, plurality of bays **150** may be sections of structure **101** divided in a virtual manner. For example, plurality of bays **150** may be sections of structure **101** without a physical basis or not delineated by structural components.

Plurality of bays **150** may be a number of bays adjacent to each other in the chordwise direction. In these examples, the chordwise direction may be the direction from base **110** to tip **111** and vice versa. Each bay within plurality of bays **150** may extend from first end **116** to second end **118** of structure **101**.

Further, in addition to plurality of bays **150**, structure **101** may include tip section **151**. Tip section **151** may be a portion of structure **101** located between plurality of bays **150** and tip **111**. For example, structure **101** may be divided into plurality of bays **150** and tip section **151** from base **110** to tip **111** of structure **101**. These sections may have varying lengths in the chordwise direction. In these illustrative examples, plurality of bays **150** may have lengths in the chordwise direction that decrease from base **110** to tip **111**.

In these illustrative examples, plurality of bays **150** may have plurality of shapes **152** and diagonal lengths **154**. Plurality of shapes **152** may be, for example, without limitation, hexahedral shapes. In these examples, diagonal lengths **154** may be the lengths of plurality of shapes **152** along the diagonals of plurality of shapes **152**. Plurality of shapes **152** and diagonal lengths **154** for plurality of bays **150** may change as control surface **100** is moved between undeployed configuration **122** and number of deployed configurations **124**. The changing of

plurality of shapes **152** and diagonal lengths **154** may cause shape **120** of control surface **100** to also change.

Plurality of shapes **152** and diagonal lengths **154** may be controlled by a shape changing system such as, for example, without limitation, shape changing system **132**. Shape changing system **132** may use motion generation system **134** and/or plurality of deformable assemblies **135** to change plurality of shapes **152** and diagonal lengths **154** to change shape **120** of structure **101** and control surface **100**.

In these illustrative examples, plurality of deformable assemblies **135** may include one deformable assembly on first end **116** of structure **101** and one deformable assembly on second end **118** of structure **101** for each bay within plurality of bays **150**. Thus, each bay within plurality of bays **150** may have two deformable assemblies. Plurality of deformable assemblies **135** may have points and/or sections capable of moving relative to other points and/or sections in plurality of deformable assemblies **135**.

Further, plurality of deformable assemblies **135** may be moveably connected to structure **101** with points and/or sections that may move with respect to points and/or sections of structure **101**. Motion generation system **134** may be capable of controlling the form of plurality of deformable assemblies **135** to change plurality of shapes **152** and diagonal lengths **154**.

In these examples, motion generation system **134** may include, for example, without limitation, actuator system **136**. Actuator system **136** may include number of actuators **138**. In these illustrative examples, number of actuators **138** may include primary actuator **140**, diagonal actuator system **146**, and/or horizontal actuator system **148**.

Primary actuator **140** may be an actuator attached to spar **107** of structure **101** at second side **114** and base **110** of structure **101** and to frame **106** of wing **104**. Primary actuator **140** may control rotation of structure **101** and control surface **100** about hinge points **119** by lengthening or shortening to rotate spar **107** and thus, structure **101**. Rotation of control surface **100** may provide degree of flow turning **126** for control surface **100**. Further, rotation of control surface **100** in a downward direction about hinge points **119** may cause second side **114** to move in a direction towards wing **104**.

In these advantageous embodiments, second side **114** may be connected to spar **107** and wing **104** by a sliding joint such as, for example, without limitation, sliding joint **142**. Sliding joint **142** may allow second side **114** of control surface **100** to slide into wing **104** during a downward rotation of control surface **100**. In this manner, the interior of control surface **100** may remain sealed from the exterior environment in both undeployed configuration **122** and

number of deployed configurations **124**. Further, sliding joint **142** may make it easier to design a stiff structure for tip section **151** of control surface **100**. In addition, sliding joint **142** may allow for designing tip section **151** to have an optimal size.

In some advantageous embodiments, actuator system **136** may include diagonal actuator system **146** in addition to primary actuator **140**. Diagonal actuator system **146** may include, for example, without limitation, a number of actuators used to change shape **120** of structure **101** by changing diagonal lengths **154** of plurality of bays **150**, and thus, plurality of shapes **152**. These actuators may be connected to structure **101** of control surface **100** on both first end **116** and second end **118**. These actuators may extend across diagonal lengths **154** of plurality of bays **150**.

For example, the actuators within diagonal actuator system **146** may increase in length to increase diagonal lengths **154**. The increase in diagonal lengths **154** may change plurality of shapes **152** for plurality of bays **150** and may change shape **120** of structure **101**. Flexible skin **128** may respond to the change in shape **120** by curving with shape **120**.

Thus, motion generation system **134** may allow control surface **100** to have a curved shape for number of deployed configurations **124**. This curved shape, in addition to the rotation caused by primary actuator **140** to provide degree of flow turning **126**, may form number of deployed configurations **124** for control surface **100**.

In some advantageous embodiments, actuator system **136** may include horizontal actuator system **148** in addition to primary actuator **140**. Horizontal actuator system **148** may include, for example, without limitation, a number of actuators used to change shape **120** of structure **101** by changing diagonal lengths **154** of plurality of bays **150**, and thus, plurality of shapes **152**. In these examples, horizontal actuator system **148** may be connected to plurality of deformable assemblies **135**. Horizontal actuator system **148** may be used to change the form of plurality of deformable assemblies **135** to change diagonal lengths **154**.

In these illustrative examples, for each bay in plurality of bays **150**, a deformable assembly on first end **116** may be connected to a deformable assembly on second end **118** by an actuator within horizontal actuator system **148**. These actuators may lengthen or shorten to change the form of each pair of deformable assemblies in each bay in plurality of bays **150**. In turn, this may change diagonal lengths **154** and plurality of shapes **152** to change shape **120** of structure **101**. Flexible skin **128** may curve in response to the change in shape **120**.

In yet other advantageous embodiments, shape **120** may be changed using a combination of horizontal actuator system **148** and connector system **156**. In these examples, horizontal

actuator system **148** may include a single actuator connecting the pair of deformable assemblies within first bay **155** of plurality of bays **150**. First bay **155** may be the bay located nearest to base **110**. The pair of deformable assemblies within first bay **155** may also each be connected to connector system **156**.

5 Connector system **156** may be a series of vertices and/or members connecting first bay **155** to the other bays within plurality of bays **150**. The vertices may be, for example, without limitation, joints, linkages, and/or some other type of vertex. The members may be, for example, without limitation, rods, tubes, beams, and/or some other type of member. The form changing of the deformable assemblies within first bay **155** may, in turn, lead to the form changing of the
10 other deformable assemblies within plurality of deformable assemblies **135** using connector system **156**. In this manner, the forms of plurality of deformable assemblies **135** may be changed to change diagonal lengths **154**, and thus, shape **120**.

 In still yet other advantageous embodiments, shape **120** may be changed using a combination of primary actuator **140**, connector system **156**, and linking system **158**. Linking
15 system **158** may include a number of polyhedron structures, a number of members, and/or other suitable components. These components may be, for example, without limitation, rods, tubes, beams, and/or some other suitable components.

 In these examples, linking system **158** may relate the rotational movement caused by primary actuator **140** to plurality of deformable assemblies **135**. For example, linking system
20 **158** may be connected to spar **107**. Linking system **158** may also be connected to connector system **156**. Connector system **156** may be moveably connected to plurality of deformable assemblies **135**. In other words, movement of connector system **156** may cause plurality of deformable assemblies **135** to move and change form.

 Linking system **158** may relate the rotation of spar **107** caused by primary actuator **140** to
25 movement of connector system **156**. This movement may, in turn, cause plurality of deformable assemblies **135** to change form and diagonal lengths **154** to change length. In this manner, shape **120** of structure **101** may be changed by the rotational motion caused by a single actuator, such as, for example, primary actuator **140**.

 In other advantageous embodiments, motion generation system **134** may include, for
30 example, without limitation, screw jacks **160**, scissor jacks **153**, and/or some other suitable motion generation system or device capable of changing diagonal lengths **154** and plurality of shapes **152** to change shape **120**. Of course, compared to these other systems, actuators may allow for faster response times for changing shape **120**.

In these examples, the actuators used may be hydraulic linear actuators. However, in other advantageous embodiments, other actuators such as, for example, without limitation, linear motor actuators, electro-mechanical actuators, piezoelectric actuators, and/or other types of actuators may be used.

5 The illustration of control surface **100** in **Figure 1** is not meant to imply physical or architectural limitations to the manner in which control surfaces may be implemented. Other components in addition to, or in place of, the ones illustrated may be used in some advantageous embodiments. Some components illustrated in control surface **100** may be omitted in some advantageous embodiments.

10 For example, control surface **100** may not have truss **130** attached to flexible skin **128**. Plurality of deformable assemblies **135** may be connected to flexible skin **128** in these examples. In other advantageous embodiments, primary actuator **140** may be a system including more than one actuator. In yet other advantageous embodiments, a number of deformable assemblies in plurality of deformable assemblies **135** may be located at the center of plurality of bays **150** in
15 addition to at first end **116** and second end **118**. These deformable assemblies may provide additional support for control surface **100**.

For example, these deformable assemblies may help control surface **100** remain operational under conditions of battle damage, malfunction, and/or some other condition. Further, additional components in addition to the ones described may be used. Other
20 components in addition to, or in place of, the ones illustrated may be used in different advantageous embodiments. Further, in some advantageous embodiments, some of the components illustrated for control surface **100** may be unnecessary.

With reference now to **Figure 2**, a diagram of an aircraft is depicted in which an advantageous embodiment may be implemented. Aircraft **200** is an example of an aircraft in
25 which a control surface such as, for example, without limitation, control surface **100** in **Figure 1** may be implemented.

In this illustrative example, aircraft **200** has wings **202** and **204** attached to body **206**. Aircraft **200** includes wing-mounted engine **208**, wing-mounted engine **210**, and tail **212**. Further, wings **202** and **204** have flaps **214** and **216**, respectively, attached to and/or located on
30 trailing edges **218** and **220** of wings **202** and **204**, respectively. In this illustrative example, flaps **214** and **216** may be examples of control surface **100** in **Figure 1**. In other advantageous embodiments, aircraft **200** may take the form of a different type of aircraft. For example, aircraft

200 may take the form of a stealth aircraft, such as an F-117, F-22, B-2, F-35, or some other suitable type of aircraft.

With reference now to **Figure 3**, a diagram of a flap is depicted in accordance with an advantageous embodiment. In this example, flap **300** may be one example of a control surface, such as, for example, without limitation, control surface **100** in **Figure 1**.

Flap **300** may have undeployed configuration **301**, which may be one example of undeployed configuration **122** in **Figure 1**. Further, flap **300** may have structure **303**, which may be one example of one implementation of structure **101** in **Figure 1**. In undeployed configuration **301**, structure **303** may have a straight shape, which may be one example of shape **120** of structure **101** in **Figure 1**.

In these illustrative examples, structure **303** may have first side **302**, second side **304**, first end **306**, second end **308**, base **310**, and tip **312**. Structure **303** may extend from first end **306** to second end **308** in a spanwise direction such as, for example, spanwise direction **314**. Structure **303** may also extend from base **310** to tip **312** in a chordwise direction such as, for example, chordwise direction **316**. Further, structure **303** may include spar **315**. Spar **315** may be attached to the wing of an aircraft at hinge points **317**.

Flap **300** may have flexible skin **318** attached to structure **303** on first side **302** and second side **304** of structure **303**. In these examples, flexible skin **318** may be one example of flexible skin **128** in **Figure 1**. Further, flexible skin **318** may be attached to stiffeners **320-332**. Stiffeners **320-332** may be examples of stiffening elements such as, for example, without limitation, stiffening elements **131** in **Figure 1**.

In these examples, structure **303** may have truss **333** attached to flexible skin **318**. In these examples, flexible skin **318** may be capable of transferring air loads to truss **333**. For example, first side **302** of structure **303** may encounter an air load of around 2 pounds per square inch, and second side **304** of structure **303** may encounter an air load of around 2 pounds per square inch. Flexible skin **318** may transfer these air loads to the attachment points of truss **333** to flexible skin **318**.

In these illustrative examples, structure **303** may be divided into bays **334-346** and tip section **348**. Bays **334-346** may be examples of bays within plurality of bays **150** in **Figure 1**. Bays **334-346** may be arranged adjacent to each other beginning at base **310** in chordwise direction **316** from base **310** to tip section **348**. In these depicted examples, tip section **348** may be one example of tip section **151** in **Figure 1**.

In this view, bays **334-346** may be defined by stiffeners **320-332**. Bays **334-346** may have hexahedral shapes with at least four faces formed by portions of first end **306**, second end **308**, first side **302**, and second side **304**.

Bay **334** may be a first bay such as, for example, first bay **155** of plurality of bays **150** in **Figure 1**. As one example, bay **334** may have quadrilateral shape **350** on first end **306**. Quadrilateral shape **350** may form one face of a hexahedral shape for bay **334**. Bay **334** may have a similar quadrilateral shape (not shown) on second end **308**.

In these advantageous embodiments, quadrilateral shape **350** may have diagonal length **352**. Diagonal length **352** may also be the diagonal length of the hexahedral shape for bay **334**. By changing diagonal length **352**, quadrilateral shape **350** of bay **334** may also be changed. Similarly, changing the diagonal lengths for bays **336-346** may change the quadrilateral shapes for bays **336-346**. By changing the quadrilateral shapes for bays **334-346**, structure **303** may be reconfigured to have a curved shape for a number of deployed configurations such as, for example, number of deployed configurations **124** in **Figure 1**. Flexible skin **318** may curve with structure **303** in a smooth manner.

With reference now to **Figure 4**, a diagram of a flap is depicted in accordance with an advantageous embodiment. Flap **400** may be one example of one implementation of a control surface such as, for example, flap **300** in **Figure 3**. Flap **400** may be attached to a frame of a wing of an aircraft such as, for example, frame **106** of wing **104** in aircraft **102** in **Figure 1**.

Flap **400** may have structure **401** with first side **404** and second side **406**. Flexible skin **402** may be attached to first side **404** and second side **406** of flap **400**. Flexible skin **402** may be one example of flexible skin **318** in **Figure 3**. Structure **401** may also have base **408**, tip **410**, first end **412**, and second end **414**. Tip section **416** may be located at tip **410** of structure **401**. In this illustrative example, flap **400** may have undeployed configuration **418**.

This configuration may have a zero degree angle for tip **410** with respect to the plane of flap **400**. In other examples, flexible skin **402** may curve in such a way that tip **410** may be at an inclined angle with respect to undeployed configuration **418** of flap **400**. Hinge points **420** may provide attachment points for connecting spar **411** of flap **400** to the frame of the wing of an aircraft. Spar **411** may be located at base **408** and may be part of structure **401**.

Hinge points **420** may be aligned to axis of rotation **421** by which the degree of incline of tip **410** may be measured. The degree of incline of tip **410** may determine the degree of flow turning for flap **400**.

In these illustrative examples, structure **401** may have a truss such as, for example, without limitation, truss **422**. Truss **422** may be one example of truss **333** **Figure 3**. Truss **422** may be attached to flexible skin **402** to provide load-bearing support for flexible skin **402** and flap **400**. In other words, truss **422** may reduce and/or eliminate stress in chordwise direction **415** for flexible skin **402** under air loads.

Without truss **422**, flexible skin **402** may tend to buckle from compression under air loads. Further, stiffening elements **424-436**, attached to flexible skin **402**, may be used to provide stiffness for flexible skin **402** in spanwise direction **417**, while allowing flexible skin **402** to maintain flexibility in chordwise direction **415**. These stiffening elements may be examples of stiffeners **320-332** in **Figure 3**.

The flexibility of flexible skin **402** in chordwise direction **415** may allow flexible skin **402** to curve. Bending of flexible skin **402** may not cause flexible skin **402** to change in length. Flexible skin **402** may be a thin skin in which one dimension of flexible skin **402** may be negligibly small with respect to the other two dimensions. This thinness and the design of flap **400** may result in flexible skin **402** experiencing negligible in-plane stress in three dimensions. This in-plane stress may be a mid-surface stress of flexible skin **402**.

In other words, when flap **400** is deployed, the inner and outer surfaces of flexible skin **402** may experience compression and tension, respectively. In the deployed state, the mid-surface stress between the inner and outer surfaces for flexible skin **402** may be around zero. Further, stresses in the direction perpendicular to the inner and outer surfaces of flexible skin **402** may also be small enough to be considered negligible. Thus, in these examples, the capability of flexible skin **402** to curve may help reduce and/or eliminate in-plane stress for flexible skin **402**.

With reference now to **Figure 5**, a diagram of a partially deployed flap is depicted in accordance with an advantageous embodiment. Flap **400** may be rotated in addition to being changed from a straight shape to a curved shape to form deployed configuration **500**. Deployed configuration **500** may have an angle of around 36 degrees for tip **410** inclined with respect to tip **410** in undeployed configuration **418** in **Figure 4**. At this angle, flap **400** may provide around 36 degrees of flow turning. The bending of flexible skin **402** and flap **400** may provide a smooth surface over which air may flow.

With reference now to **Figure 6**, a diagram of a fully deployed flap is depicted in accordance with an advantageous embodiment. Flap **400** may be further rotated and further curved to form deployed configuration **600**. Deployed configuration **600** may have an angle of around 60 degrees for tip **410** inclined with respect to tip **410** in undeployed configuration **418**.

At this angle, flap **400** may provide around 60 degrees of flow turning. In these illustrative examples, flap **400** may not be capable of bending more than around 60 degrees. In other advantageous embodiments, flap **400** may curve up to around 90 degrees or some other angle.

With reference now to **Figure 7**, an exposed top view of a flap is depicted in accordance with an advantageous embodiment. Flap **700** may be one example of one implementation of a control surface such as, for example, without limitation, control surface **100** in **Figure 1**. Flap **700** may have undeployed configuration **705**, which may be one example of undeployed configuration **122** in **Figure 1**. Further, flap **700** may have a straight shape, which may be one example of shape **120** in **Figure 1**.

In these illustrative examples, flap **700** may have structure **703**. Structure **703** may include structural components such as, for example, without limitation, rods, beams, tubes, joints, screws, bolts, linkage assemblies, and/or other structural components. Flexible skin **702** may be attached to first side **704** and a second side (not shown) of structure **703**. The second side may be substantially opposite to first side **704** of structure **703**. Flexible skin **702** may be one example of flexible skin **128** in **Figure 1**. Structure **703** may also have base **707** and tip **708**. In undeployed configuration **705**, tip **708** may be at a zero degree angle with respect to the plane of flap **700**.

The plane of flap **700** may be an X-Y plane formed by X-axis **750** and Y-axis **752**. Hinge point **709** may be located on end **711** of structure **703**, and hinge point **710** may be located on end **713** of structure **703**.

Hinge points **709** and **710** may be aligned to each other along base **707** of structure **703**. Ends **711** and **713** may be substantially opposite ends of structure **703** and flap **700**. Hinge points **709** and **710** may be stationary hinge points of attachment for connecting spar **701** of structure **703** of flap **700** to the wing of an aircraft. An illustrative depiction of a portion of a wing may be seen in **Figure 8**, below. Hinge points **709** and **710** may also be aligned to axis **719**, which may be an axis of rotation for flap **700**.

In these illustrative examples, flap **700** may rotate about axis **719**. This rotation may cause tip **708** to be at an inclined angle with respect to tip **708** in undeployed configuration **705**. Flap **700** may be rotated by primary actuator **714** connected to the second side opposite to first side **704** of structure **703**.

Primary actuator **714** may rotate flap **700** around hinge points **709** and **710** and axis **719**. This rotation may provide a degree of flow turning for flap **700**. Primary actuator **714** may be attached to spar **701**. Primary actuator **714** may lengthen or shorten to rotate spar **701** in the

direction of arrow 721 around axis 719 and about hinge points 709 and 710. This rotation of spar 701 may pull the second side (not shown) of structure 703 into the wing of an aircraft at sliding joint 744. Sliding joint 744 may be a joint connecting spar 701, base 707, and the second side of structure 703. Sliding joint 744 may allow a portion of structure 703 to slide into the wing of an aircraft. In these examples, primary actuator 714 may be one example of primary actuator 140 in **Figure 1**. Sliding joint 744 may be one example of sliding joint 142 in **Figure 1**.

In these illustrative examples, structure 703 may include a truss such as, for example, truss 712. Truss 712 may be one example of truss 130 in **Figure 1**. Truss 712 may be attached to flexible skin 702 to provide load-bearing support for flexible skin 702 and flap 700. In other words, truss 712 may reduce and/or eliminate stress in chordwise direction 715 for flexible skin 702 under air loads. Without truss 712, flexible skin 702 may tend to buckle from compression under air loads.

Further, stiffening elements 716-728 may be attached to flexible skin 702. Stiffening elements 716-728 may provide stiffness for flexible skin 702 in spanwise direction 717, while allowing flexible skin 702 to maintain flexibility in chordwise direction 715.

In these illustrative examples, structure 703 may be divided up into bays 730-742 and tip section 743. These bays may be defined by stiffening elements 716-728. Bays 730-742 may be arranged adjacent to each other beginning from base 707 in chordwise direction 715. Tip section 743 may be located between tip 708 and bay 742.

With reference now to **Figure 8**, an exposed cross-sectional view of flap 700 is depicted in accordance with an advantageous embodiment. This view of flap 700 may be a view of end 713 of structure 703. Flap 700 may have undeployed configuration 705 and a straight shape. Second side 805 may be visible in this view of flap 700. Second side 805 may be substantially opposite to first side 704.

In this view in **Figure 8**, hinge point 710 may connect spar 701 to frame 806 of wing 808 of an aircraft. Further, primary actuator 714 may be connected to wing 808 at attachment point 810 of frame 806. Frame 806 of wing 808 may be one example of an implementation of frame 106 of wing 104 in **Figure 1**. Sliding joint 744 may allow structure 703 to slide into wing 808 during rotation of spar 701 and structure 703 by primary actuator 714.

In these illustrative examples, when viewed from an end of structure 703, bays 730-742 may have quadrilateral shapes. Further, bays 730-742 may have diagonal lengths, which may be the diagonal lengths of these quadrilateral shapes. These diagonal lengths may not be actual structural elements but may be measurements or dimensions for bays 730-742.

For example, bay **730** may have diagonal length **800** and quadrilateral shape **801** in undeployed configuration **705**. Diagonal length **800** and quadrilateral shape **801** may be substantially the same for both end **711** and end **713** for bay **730** of structure **703**. In these advantageous embodiments, the diagonal lengths of bays **730-742** may be changed to change the quadrilateral shapes of bays **730-742**. These changes may cause a change in the shape of structure **703**, and thus, flap **700**. Flexible skin **702** may curve with the shape of structure **703**.

In these advantageous embodiments, flap **700** may be implemented using at least one of a motion generation system, a plurality of deformable assemblies, and a linking system to change the diagonal lengths and quadrilateral shapes of bays **730-742**. These different implementations may be depicted in the following illustrative examples.

As used herein, the phrase “at least one of”, when used with a list of items, means that different combinations of one or more of the items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, and item C” may include, for example, without limitation, item A or item A and item B. This example also may include item A, item B, and item C, or item B and item C. In other examples, “at least one of” may be, for example, without limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; and/or other suitable combinations.

With reference now to **Figures 9-11**, a flap is depicted in accordance with an advantageous embodiment. In these examples, flap **900** is depicted using a motion generation system having a diagonal actuator system and a primary actuator.

With reference first to **Figure 9**, an exposed cross-sectional view of a flap in an undeployed configuration is depicted in accordance with an advantageous embodiment. Flap **900** may be one example of one implementation of a control surface such as, for example, without limitation, control surface **100** in **Figure 1**. Flap **900** may have undeployed configuration **905**, which may be one example of undeployed configuration **122** in **Figure 1**. Further, flap **900** may have a straight shape, which may be one example of shape **120** in **Figure 1**.

In these illustrative examples, flap **900** may have structure **911**. Structure **911** may include structural components such as, for example, without limitation, rods, beams, tubes, joints, screws, bolts, linkage assemblies, and/or other structural components. Flexible skin **902** may be attached to first side **904** and second side **906** of structure **911**. Flexible skin **902** may be one example of flexible skin **128** in **Figure 1**. Structure **911** may also have base **907**, tip **908**, end **913**, and an end substantially opposite to end **913**, which may not be visible in this view. In

undeployed configuration **905**, tip **908** may be at a zero degree angle with respect to the plane of flap **900**. The plane of flap **900** may be an X-Y plane formed by X-axis **950** and Y-axis **952**.

Hinge point **910** may be located on end **913** of flap **900**. Hinge point **910** may be aligned with a second hinge point (not shown) at the end of structure **911** substantially opposite to end **913**. These hinge points may be aligned along an axis of rotation (not shown) perpendicular to end **913**. Further, these hinge points may be stationary hinge points for attaching spar **901** of structure **911** to the wing of an aircraft. Spar **901** may be one example of spar **107** in **Figure 1**.

In these illustrative examples, structure **911** may rotate in the direction of arrow **903**. This rotation may cause tip **908** to be at an inclined angle with respect to tip **908** in undeployed configuration **905**. Structure **911** may be rotated by a lengthening or shortening of primary actuator **914** connected to second side **906** of structure **911**.

Primary actuator **914** may rotate spar **901** and structure **911** around hinge point **910** and a second hinge point (not shown) at the end of structure **911** substantially opposite to end **913**. This rotation may provide a degree of flow turning for flap **900**. Primary actuator **914** may cause movement of structure **911** in the direction of arrow **903**.

Sliding joint **944** may be a joint connecting spar **901**, second side **906**, and base **907** of flap **900** to a wing. Sliding joint **944** may allow second side **906** of structure **911** to slide into the wing during rotation of spar **901** by primary actuator **914**. In these examples, primary actuator **914** may be one example of primary actuator **140** in **Figure 1**. Sliding joint **944** may be one example of sliding joint **142** in **Figure 1**.

In these illustrative examples, structure **911** may include a truss such as, for example, truss **912**. Truss **912** may be one example of truss **130** in **Figure 1**. Truss **912** may be attached to flexible skin **902** to provide load-bearing support for flexible skin **902** and flap **900**. In other words, truss **912** may reduce and/or eliminate stress in chordwise direction **915** for flexible skin **902** under air loads. Without truss **912**, flexible skin **902** may tend to buckle from compression under air loads.

Further, stiffening elements **916-928** may be attached to flexible skin **902**. Stiffening elements **916-928** may provide stiffness for flexible skin **902** in a spanwise direction (not shown), while allowing flexible skin **902** to maintain flexibility in chordwise direction **915**.

In these illustrative examples, flap **900** may be divided into bays **930-942** and tip section **943**. These bays may be visualized as being divided by stiffening elements **916-928**. Bays **930-942** may be arranged adjacent to each other beginning from base **907** in chordwise direction **915**. Tip section **943** may be located between tip **908** and bay **942**.

In these illustrative examples, bays **930-942** may have quadrilateral shapes. Further, bays **930-942** may have diagonal lengths, which may be the diagonal lengths of these quadrilateral shapes. These diagonal lengths may not be actual structural elements but may be measurements or dimensions for bays **930-942**.

For example, bay **930** may have diagonal length **951** and quadrilateral shape **953** in undeployed configuration **905**. Diagonal length **951** and quadrilateral shape **953** may be the same for both end **913** and the opposite end of structure **911**. In these advantageous embodiments, the diagonal lengths of bays **930-942** may be changed to change the quadrilateral shapes of bays **930-942**. These changes may cause a change in the shape of structure **911** and flap **900**.

In these illustrative examples, flap **900** may use diagonal actuator system **954** in addition to primary actuator **914** to move flap **900** from undeployed configuration **905** to a deployed configuration with a curved shape. Diagonal actuator system **954** may be one example of an implementation of diagonal actuator system **146** in **Figure 1**.

Diagonal actuator system **954** may include diagonal members **956-968**. Diagonal members **956-968** may be attached to structure **911** on end **913**. Further, diagonal members **956-968** may be located in bays **930-942**, respectively.

In these illustrative examples, flap **900** may have a similar set of diagonal members (not shown) attached to structure **911** on an end of structure **911** substantially opposite to end **913** of structure **911**. Thus, each of bays **930-942** may have two diagonal members, one on each end of bays **930-942**. In these examples, flap **900** may have a total of 14 diagonal members for bays **930-942**.

Of course, in other advantageous embodiments, different numbers of diagonal members may be used, depending on the number of bays and the span of flap **900**. For example, in some advantageous embodiments, each bay may have three diagonal members with the third diagonal member positioned in the center of the bay. The additional diagonal member may provide additional support. Further, in other advantageous embodiments, diagonal members **956-968** may be attached to flexible skin **902** directly.

Diagonal members **956-968** may fully extend across the diagonal lengths of bays **930-942** on end **913** of flap **900**. For example, diagonal member **956** may have length **951** of bay **930**. Each of diagonal members **956-968** may change in length. In these examples, diagonal members **956-968** may be actuators such as, for example, without limitation, linear actuators that change in length.

In these illustrative examples, diagonal members **956-968** may change in length to change the diagonal lengths of bays **930-942**. Changing these diagonal lengths may also change the quadrilateral shapes of bays **930-942**. For example, diagonal member **956** may lengthen to increase diagonal length **951** and change quadrilateral shape **953** for bay **930**. The changing of these diagonal lengths and quadrilateral shapes may change the shape of flap **900**. In other words, changing the diagonal lengths may result in a change in the shape of structure **911**. The change in the shape of structure **911** may result in flexible skin **902** curving in this shape in a smooth manner. Structure **911** may bend to move tip **908** to a downward angle. Flexible skin **902** may bend without lengthening and/or shortening in response to the lengthening of diagonal members **956-968**.

With reference now to **Figure 10**, an exposed cross-sectional view of a partially deployed flap is depicted in accordance with an advantageous embodiment. Flap **900** may have deployed configuration **1000** with a curved shape in this depicted example.

In these illustrative examples, deployed configuration **1000** may have tip **908** at an inclined angle of around 36 degrees with respect to tip **908** in undeployed configuration **905** of flap **900**. Further, diagonal members **956-968** in **Figure 10** may be lengthened in deployed configuration **1000** with respect to diagonal members **956-968** in undeployed configuration **905**.

As one example, diagonal member **956**, and thus, bay **930**, may have increased length **1002**, which may be longer than length **951** in **Figure 9**. Increased length **1002** may result in quadrilateral shape **1004**. The lengthening of diagonal members **956-968** may cause structure **911** to change shape and flexible skin **902** to curve with this shape in a smooth manner and without sharp discontinuities and/or gaps in first side **904** or second side **906**.

Primary actuator **914** may allow rotation of spar **901** and structure **911** about hinge point **910** and the hinge point located at the end of structure **911** opposite to end **913**. This rotation may result in a degree of flow turning for flap **900**. The curved shape generated by the lengthening of diagonal members **956-968** and the rotation of flap **900** by primary actuator **914** may form deployed configuration **1000** for flap **900**.

With reference now to **Figure 11**, an exposed cross-sectional view of a fully deployed flap is depicted in accordance with an advantageous embodiment. Flap **900** may have deployed configuration **1100** with a curved shape in this depicted example.

In these illustrative examples, deployed configuration **1100** may have tip **908** at an inclined angle of around 60 degrees with respect to tip **908** in undeployed configuration **905** of flap **900**. Diagonal members **956-968** may be further lengthened in deployed configuration **1100**

with respect to diagonal members **956-968** in undeployed configuration **905** and deployed configuration **1100**. For example, diagonal member **956**, and thus bay **930**, may have increased length **1102**, which may be longer than lengths **951** in **Figure 9** and **1002** in **Figure 10**. Further, bay **930** may have quadrilateral shape **1104**.

5 The illustrations of flap **900** in **Figures 9-11** are not meant to imply physical or architectural limitations to the manner in which a diagonal actuator system for a flap may be implemented. For example, in other advantageous embodiments, the changing of the lengths of diagonal members **956-968** may be implemented using screw jacks, scissor jacks, and/or some other suitable mechanism or device. In yet other advantageous embodiments, diagonal members
10 **956-968** may be positioned across the substantially opposite diagonal lengths of bays **930-942** to cause similar changes to structure **901** and flap **900**.

With reference now to **Figure 12**, a diagram of a deformable assembly is depicted in accordance with an advantageous embodiment. Deformable assembly **1200** may be one example of an implementation of a deformable assembly within a plurality of deformable assemblies such
15 as, for example, plurality of deformable assemblies **135** in **Figure 1**.

In this illustrative example, deformable assembly **1200** may be formed by vertices A **1202**, B **1204**, C **1206**, and D **1208**. Vertices A **1202**, B **1204**, and C **1206** may form base **1210** of deformable assembly **1200**. The vertices depicted in these examples may be a type of joint, bearing, mechanical link, and/or some other suitable connection point.

20 Members A-D **1212**, B-D **1214**, and C-D **1216** may have fixed lengths and may be connected at vertex D **1208**. Member A-B **1218** and member A-C **1220** may also have fixed lengths and may be attached to a structure such as, for example, structure **703** of flap **700** in **Figure 7**. Member A-B **1218** may be attached to structure **703** at vertex A **1202** and vertex B **1204**. Member A-C **1220** may be attached to structure **703** at vertex A **1202** and vertex C **1206**.
25 Each of these members in deformable assembly **1200** may be physical components such as, for example, without limitation, rods, beams, tubes, and/or other physical components.

In this representation of deformable assembly **1200**, base **1210** may be formed by a portion of an end of a structure of a flap. For example, base **1210** may be formed by a portion of end **713** of structure **703** in **Figure 7**. Base **1210** may lie on plane **1211**. Plane **1211** may be the
30 same plane in which an end of a structure of a flap may lie. Length **1224** may be a length from vertex B **1204** to vertex C **1206**.

In these examples, length **1224** may represent the diagonal length of a bay within a flap such as, for example, bay **730** in structure **703** in **Figure 7**. This diagonal length may be a

measured length and/or dimension of bay **730** when flap **700** is in an undeployed configuration with a straight shape.

In these illustrative examples, vertex **D 1208** may be moved to vertex **D' 1226** in the direction of arrow **1228**. This movement may be generated by an actuator such as, for example, an actuator within horizontal actuator system **148** in **Figure 1**. Movement of vertex **D 1208** may cause a change in the form of deformable assembly **1200**.

The fixed lengths of members **A-B 1218**, **A-D 1212**, and **B-D 1214** may cause deformable assembly **1200** to relate movement of vertex **D 1208** to a rotation about member **A-B 1218** in the direction of arrow **1230**. The fixed lengths of members **A-C 1220**, **A-D 1212**, and **C-D 1216** may cause deformable assembly **1200** to also relate movement of vertex **D 1208** to a movement of vertex **C 1206** to vertex **C' 1232**. Vertex **C 1206** may rotate about vertex **A 1202** in the direction of arrow **1235**. In these examples, vertex **C 1206** may be limited to movement in plane **1211**. For example, in flap **700** in **Figure 7**, vertex **C 1206** may only be moved along end **713** of structure **703**.

Movement of vertex **C 1206** to vertex **C' 1232** may lead to an increase in the length from vertex **B 1204** to vertex **C 1206**. In other words, the length may be increased from length **1224** to length **1234**. This increased length may correspond to an increased diagonal length for a bay within a flap. Length **1234** may correspond to a diagonal length of a bay when the flap is in a deployed configuration with a curved shape. In this manner, deformable assembly **1200** may be capable of changing a diagonal length of a bay. The changing of the diagonal length of a bay may result in a change in the shape of the structure of the flap. The change in the shape of the structure may result in the flexible skin of the flap curving with the shape of the structure in a smooth manner.

In these examples, deformable assembly **1200** may have height **1236** from vertex **D 1208** to plane **1211**. Movement of vertex **D 1208** to vertex **D' 1226** in the direction of arrow **1228** may decrease height **1236** to height **1238**. Height **1238** may be the height of deformable assembly **1200** from vertex **D' 1226** to plane **1211**. The change in the height of deformable assembly **1200** may be directly due to an actuator acting at vertex **D 1208**.

With reference now to **Figures 13-18**, a flap is depicted in accordance with an advantageous embodiment. In these examples, flap **1300** is depicted using a plurality of deformable assemblies and a motion generation system having a primary actuator and a horizontal actuator system.

With reference first to **Figure 13**, an exposed cross-sectional top view of a flap in an undeployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may be one example of one implementation of a control surface such as, for example, control surface **100** in **Figure 1**. Flap **1300** may have undeployed configuration **1305**, which
5 may be one example of undeployed configuration **122** in **Figure 1**. Further, flap **1300** may have a straight shape, which may be one example of shape **120** in **Figure 1**.

In these illustrative examples, flap **1300** may have structure **1301**. Structure **1301** may include structural components such as, for example, without limitation, rods, beams, tubes, joints, screws, bolts, linkage assemblies, and/or other structural components. Flexible skin **1302**
10 may be attached to first side **1304** and a second side (not shown) of structure **1301**. The second side may be substantially opposite to first side **1304** of structure **1301**. Flexible skin **1302** may be one example of flexible skin **128** in **Figure 1**. Structure **1301** may also have base **1307**, tip **1308**, end **1311**, and end **1313**. Ends **1311** and **1313** may be substantially opposite ends of structure **1301**. In undeployed configuration **1305**, tip **1308** may be at a zero degree angle with
15 respect to the plane of flap **1300**. The plane of flap **1300** may be an X-Y plane formed by X-axis **1350** and Y-axis **1352**.

Hinge point **1309** may be located on end **1311** of structure **1301**, and hinge point **1310** may be located on end **1313** of structure **1301**. Hinge points **1309** and **1310** may be aligned to each other along base **1307** of structure **1301**. Hinge points **1309** and **1310** may be aligned along
20 axis **1321**. Axis **1321** may be an axis of rotation for flap **1300**.

Hinge points **1309** and **1310** may be stationary hinge points of attachment for connecting spar **1319** of structure **1301** of flap **1300** to the wing of an aircraft. An illustrative depiction of a portion of a wing may be seen in **Figure 14**, below. Hinge points **1309** and **1310** may also be aligned to axis **1321**, which may be an axis of rotation for flap **1300**.

In these illustrative examples, structure **1301** and flap **1300** may rotate about hinge points **1309** and **1310** and axis **1321** in the direction of arrow **1303**. This rotation may cause tip **1308** to be at an inclined angle with respect to tip **1308** in undeployed configuration **1305**. Flap **1300** may be rotated by primary actuator **1314** attached to base **1307** of structure **1301**. Primary actuator **1314** may rotate flap **1300** about axis **1321**. This rotation may provide a degree of flow
25 turning for flap **1300**. Primary actuator **1314** may be attached to spar **1319**.

Primary actuator **1314** may lengthen or shorten to rotate spar **1319** in the direction of arrow **1303** around axis **1321** and about hinge points **1309** and **1310**. This rotation of spar **1319** may pull the second side (not shown) of structure **1301** into the wing of an aircraft at sliding

joint **1344**. Sliding joint **1344** may be a joint connecting spar **1319**, base **1307**, and the second side of structure **1301**. Sliding joint **1344** may allow a portion of structure **1301** to slide into the wing of an aircraft. In these depicted examples, primary actuator **1314** may be one example of primary actuator **140** in **Figure 1**. Sliding joint **1344** may be one example of sliding joint **142** in

Figure 1.

In these illustrative examples, structure **1301** may include a truss such as, for example, truss **1312**. Truss **1312** may be one example of truss **130** in **Figure 1**. Truss **1312** may be attached to flexible skin **1302** to provide load-bearing support for flexible skin **1302** and flap **1300**. In other words, truss **1312** may reduce and/or eliminate stress in chordwise direction **1315** for flexible skin **1302** under air loads. Without truss **1312**, flexible skin **1302** may tend to buckle from compression under air loads.

Further, stiffening elements **1316-1328** may be attached to flexible skin **1302**. Stiffening elements **1316-1328** may stiffen flexible skin **1302** in spanwise direction **1317**, while allowing flexible skin **1302** to maintain flexibility in chordwise direction **1315**.

In these illustrative examples, structure **1301** may be divided up into bays **1330-1342** and tip section **1343**. These bays may be visualized as being defined by stiffening elements **1316-1328**. Bays **1330-1342** may be arranged adjacent to each other beginning from base **1307** in chordwise direction **1315**. Tip section **1343** may be located between tip **1308** and bay **1342**.

In these illustrative examples, flap **1300** may use plurality of deformable assemblies **1354** and horizontal actuator system **1355** to change the diagonal lengths and quadrilateral shapes of bays **1330-1342**. Plurality of deformable assemblies **1354** may include deformable assemblies **1356-1368** in bays **1330-1342**, respectively.

These deformable assemblies may be examples of deformable assembly **1200** in **Figure 12**. Deformable assemblies **1356-1368** may be attached to structure **1301** at end **1313**. In these examples, bays **1330-1342** may have a similar set of deformable assemblies (not shown) attached to structure **1301** at end **1311**. Thus, each bay may have two deformable assemblies. These additional deformable assemblies have not been shown for simplicity and understanding. Deformable assemblies **1356-1368** may be moveably connected to structure **1301**. Deformable assemblies **1356-1368** may move relative to their points of attachment on structure **1301**.

As one example, deformable assembly **1356** may have vertex A **1370**, vertex B **1372**, vertex C **1374**, and vertex D **1376**. Deformable assemblies **1358-1368** may have vertices similar to deformable assembly **1356**. These vertices may correspond to the vertices for deformable assembly **1200** in **Figure 12**. Vertex A **1370** may correspond to vertex A **1202**. Vertex B **1372**

may correspond to vertex B **1204**. Vertex C **1374** may correspond to vertex C **1206**. Vertex D **1376** may correspond to vertex D **1208**. Deformable assemblies **1356-1368** may change form in the same manner as deformable assembly **1200** in **Figure 12**.

In these illustrative examples, horizontal members **1378-1390** may be attached to deformable assemblies **1356-1368** at vertices D at both ends of structure **1301**. For example, horizontal member **1378** may be attached to deformable assembly **1356** at vertex D **1376**. In addition, horizontal member **1378** may also be attached to another deformable assembly (not shown) moveably connected to structure **1301** at end **1311**. Horizontal members **1378-1390** may be actuators in horizontal actuator system **1355**. These actuators may be, for example, without limitation, linear actuators capable of changing length.

Horizontal members **1380-1390** may also be attached to the deformable assemblies attached to structure **1301** in a similar manner as horizontal member **1378**. Thus, each bay of bays **1330-1342** may have one horizontal member connecting two deformable assemblies. In these depicted examples, flap **1300** may have seven horizontal members. As a result, flap **1300** may have seven horizontal members plus primary actuator **1314** for a total of eight actuators for flap **1300**. In this manner, the use of horizontal members and deformable assemblies may reduce the total number of actuators needed as opposed to using diagonal members.

In these illustrative examples, horizontal members **1378-1390** may change lengths in spanwise direction **1317** to affect the form of the deformable assemblies of flap **1300**. For example, deformable assembly **1356** may have height **1392**, which may be measured from end **1313** to vertex D **1376**. Horizontal member **1378** may have length **1393**. Horizontal member **1378** may increase in length to move vertex D **1376** in the direction of arrow **1394**.

Movement of vertex D **1376** may correspond to a similar movement of vertex D **1208** to vertex D' **1226** in **Figure 12**. This movement may cause a decrease in height **1392** of deformable assembly **1356**. In these examples, height **1392** may correspond to height **1236** in **Figure 12**. Changes in deformable assemblies **1356-1368** may relate to changes in the shapes of bays **1330-1342**. These changes may result in a change in the shape of structure **1301** to a curved shape. Flexible skin **1302** may curve with this shape. Such changes may result in a curved shape for flap **1300**.

With reference now to **Figure 14**, an exposed cross-sectional view of flap **1300** in an undeployed configuration is depicted in accordance with an advantageous embodiment. This view of flap **1300** may be a view of end **1313** of structure **1301**. Flap **1300** may have undeployed configuration **1305** with a straight shape. In this view of flap **1300**, second side

1405 of structure **1301** may be seen. Second side **1405** may be substantially opposite to first side **1304** of structure **1301**.

In this view in **Figure 14**, hinge point **1310** may connect spar **1319** to frame **1406** of wing **1408** of an aircraft. Further, primary actuator **1314** may be connected to wing **1408** at attachment point **1410** of frame **1406**. Frame **1406** of wing **1408** may be one example of an implementation of frame **106** of wing **104** in **Figure 1**. Sliding joint **1344** may allow structure **1301** to slide into wing **1408** during rotation of spar **1319** and structure **1301** by primary actuator **1314**.

In these illustrative examples, when viewed from an end of structure **1301**, bays **1330-1342** may have quadrilateral shapes. Further, bays **1330-1342** may have diagonal lengths, which may be the diagonal lengths of these quadrilateral shapes. For example, bay **1330** may have diagonal length **1400** and quadrilateral shape **1401** in undeployed configuration **1305**. Diagonal length **1400** and quadrilateral shape **1401** may be substantially the same for both end **1311** and end **1313** of bay **1330** for flap **1300**. In these advantageous embodiments, the diagonal lengths of bays **1330-1342** may be changed to change the quadrilateral shapes of bays **1330-1342**. These changes may cause a change in the shape of structure **1301**. In response to the change in the shape of structure **1301**, flexible skin **1302** may curve with structure **1301**.

In these examples, diagonal length **1400** may increase in length as horizontal member **1378** in **Figure 13** increases in length and height **1392** (not shown) of deformable assembly **1356** decreases in height. As diagonal length **1400** changes, quadrilateral shape **1401** may also change. As horizontal members **1378-1390** increase in length, the diagonal lengths of bays **1330-1342** increase in length. This increase in length may, in turn, change the quadrilateral shapes of bays **1330-1342**. These changes may result in structure **1301** and flexible skin **1302**, and thus, flap **1300**, having a curved shape.

With reference now to **Figure 15**, an exposed top view of flap **1300** in a partially deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1500**. In deployed configuration **1500**, flap **1300** may have tip **1308** at an inclined angle of around 36 degrees with respect to tip **1308** in undeployed configuration **1305**.

In these illustrative examples, horizontal members **1378-1390** may have increased lengths in deployed configuration **1500** with respect to their lengths in undeployed configuration **1305**. These increased lengths may result in decreased heights for deformable assemblies **1356-1368**. For example, length **1393** of horizontal member **1378** may increase to around length **1502**.

This increase may result in deformable assembly **1356** having height **1504**. Height **1504** may be greater than height **1392** of deformable assembly **1356** in undeployed configuration **1305**. These changes may result in changes in the quadrilateral shapes of bays **1330-1342**.

5 With reference now to **Figure 16**, an exposed cross-sectional view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1500**. In this example, tip **1308** may be at an inclined angle of around 36 degrees with respect to tip **1308** in undeployed configuration **1305**.

10 Bays **1330-1342** may have increased diagonal lengths in deployed configuration **1500** with respect to the diagonal lengths in undeployed configuration **1305**. For example, bay **1330** may have diagonal length **1600** in deployed configuration **1500**, which may be longer than diagonal length **1400** in undeployed configuration **1305**. Further, bay **1330** may have quadrilateral shape **1601** in deployed configuration **1500**.

15 The increase in the diagonal lengths of bays **1330-1342** may result in a change in the shape of structure **1301**. In response to the change in the shape of structure **1301**, flexible skin **1302** may curve with the shape of structure **1301** in a smooth manner. This shape changing of structure **1301** and curving of flexible skin **1302**, in addition to the rotation of flap **1300** by primary actuator **1314**, may form deployed configuration **1500**.

20 With reference now to **Figure 17**, an exposed top view of flap **1300** in a fully deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1700**. In deployed configuration **1700**, tip **1308** may be at an inclined angle of around 60 degrees with respect to tip **1308** in undeployed configuration **1305**.

25 In this illustrative example, horizontal members **1378-1390** may have increased lengths with respect to the lengths of horizontal members **1378-1390** in undeployed configuration **1305** and deployed configuration **1500**. Further, the heights of deformable assemblies **1356-1368** may be decreased with respect to the heights of deformable assemblies **1356-1368** in undeployed configuration **1305** and deployed configuration **1500**. For example, horizontal member **1378** may have length **1702**, which may be longer than lengths **1393** and **1502**. Deformable assembly **1356** may have height **1704**, which may be greater than heights **1392** and **1504**.

30 With reference now to **Figure 18**, an exposed cross-sectional view of flap **1300** in deployed configuration **1700** is depicted in accordance with an advantageous embodiment. In this illustrative example, bays **1330-1342** may have increased diagonal lengths with respect to the diagonal lengths of bays **1330-1342** in undeployed configuration **1305** and deployed configuration **1500**. For example, bay **1330** may have diagonal length **1800**, which may be

longer than diagonal lengths **1400** and **1600**. Further, bay **1330** may have quadrilateral shape **1801**.

With reference now to **Figure 19**, a diagram of a deformable assembly connected to a portion of a connector system is depicted in accordance with an advantageous embodiment. In this depicted example, deformable assembly **1200** in **Figure 12** may be connected to a portion of connector system **1900**. Connector system **1900** may be one example of one implementation for connector system **156** in **Figure 1**.

In these illustrative examples, connector system **1900** may include vertex E **1902**, member A-E **1904**, member B-E **1906**, and member D-E **1908**. Each of these members of connector system **1900** may have a fixed length. Member A-E **1904**, member B-E **1906**, member D-E **1908**, member A-B **1218**, member A-D **1212**, and member B-D **1214** may form connection structure **1910** in **Figure 19**. Connection structure **1910** may be fixed and rigid due to the fixed lengths of its members. However, connection structure **1910** may be capable of rotation and/or movement. Vertex D **1208** of deformable assembly **1200** may be connected to vertex E **1902** of connector system **1900** by member D-E **1908**.

The rigidity of connection structure **1910** and the connection of vertex D **1208** to vertex E **1902** may cause movement of vertex D **1208** to move connection structure **1910**. For example, movement of vertex D **1208** to vertex D' **1226** may cause vertex E **1902** to move to vertex E' **1912**. In other words, vertex E **1902** may be rotated about member A-B **1218** in the direction of arrow **1230**. In this manner, the movement of vertex D **1208** and deformable assembly **1200** may be linked to the movement of vertex E **1902** and connection structure **1910**. In a similar manner, movement of vertex E **1902** may cause vertex D **1208** to move and deformable assembly **1200** to change form. In some advantageous embodiments, connector system **1900** may include a number of connection structures similar to connection structure **1910**.

With reference now to **Figures 20-25**, a flap is depicted in accordance with an advantageous embodiment. Flap **1300** is depicted using a plurality of deformable assemblies, a motion generation system having a horizontal actuator system and a primary actuator, and a connector system.

With reference first to **Figure 20**, an exposed top view of a flap in an undeployed configuration is depicted in accordance with an advantageous embodiment. In these depicted examples, flap **1300** may be implemented using single horizontal member **1378** and connector system **2000**. Horizontal members **1380-1390** in **Figure 13** may not be present in bays **1332-1342**. Connector system **2000** may be one example of one implementation for connector system

156 in **Figure 1**. In these examples, structure **1301** may still have plurality of deformable assemblies **1354**.

In these examples, connector system **2000** may relate changes in deformable assembly **1356** in bay **1330** to changes in deformable assemblies **1358-1368**. In other words, the changes in deformable assembly **1356** generated by horizontal member **1378** may be used to affect similar changes in deformable assemblies **1358-1368**. For example, an increase in length of horizontal member **1378** may cause a change in the form and height of deformable assembly **1356**. This change may result in an increased diagonal length for bay **1330**.

Connector system **2000** may connect deformable assembly **1356** in bay **1330** to deformable assemblies **1358-1368** in bays **1332-1342**. In this manner, the change in the diagonal length of bay **1330** may be translated into changes in the diagonal lengths of bays **1332-1342**.

Connector system **2000** may include vertices E **2002-2014** and connection structures **2016-2028**. Vertices E **2002-2014** may be examples of vertex E **1902** in **Figure 19**. Connection structures **2016-2028** may be examples of connection structure **1910** in **Figure 19**. Vertices E **2002-2014** and connection structures **2016-2028** may relate changes in deformable assembly **1356** to changes in deformable assemblies **1358-1368**.

For example, vertex E **2002** may be connected to vertex D **1376** of deformable assembly **1356** in bay **1330**. Vertex E **2002** may be connected to vertex D **1376** by member **2030** of connection structure **2016**. Member **2030** may be one example of member D-E **1908** in **Figure 19**. Movement of vertex D **1376** in the direction of arrow **1394** by horizontal member **1378** may cause movement of vertex E **2002** and connection structure **2016** in the direction of arrow **2031**.

In these examples, each of bays **1330-1342** may have vertices E **2002-2014** connected to the vertices D of deformable assemblies **1356-1368** by members similar to member **2030**. In these examples, vertices E **2002-2014** may be connected by members **2032-2042**. Members **2032-2042** may connect connection structures **2016-2028** in a series fashion.

Movement of vertex E **2002** and connection structure **2016** in the direction of arrow **2031** may cause movement of vertices E **2004-2014** and connection structures **2018-2028** in a similar direction. Movement of vertices E **2002-2014** and connection structures **2016-2028** may result in movement of the vertices D of deformable assemblies **1356-1368**. Further, movement of these vertices D may result in changes in the heights and forms of deformable assemblies **1356-1368**. In these illustrative examples, a second connector system (not shown) similar to connector system **2000** may be present at end **1311** of structure **1301**. This second connector system may affect changes in deformable assemblies that may also be present at end **1311** of structure **1301**.

With reference now to **Figure 21**, an exposed cross-sectional view of a flap in an undeployed configuration is depicted in accordance with an advantageous embodiment. This view of flap **1300** may be a view of end **1313** of flap **1300**. Flap **1300** may have undeployed configuration **1305** with a straight shape. In this view of flap **1300**, second side **1405** of structure

1301 may be seen.

In these illustrative examples, the diagonal lengths and quadrilateral shapes for bays **1330-1342** may be changed to change the shape of structure **1301** and flap **1300**. For example, movement of vertex D **1376** may change diagonal length **1400** and quadrilateral shape **1401** for bay **1330**.

Movement of the vertices D of deformable assemblies **1356-1368** may result in changes in the diagonal lengths for bays **1330-1342**. Changes in the diagonal lengths for bays **1330-1342** may result in changes in the quadrilateral shapes for bays **1330-1342**. In this manner, changes to these diagonal lengths and quadrilateral shapes may result in a change in the shape of structure **1301**. Flexible skin **1302** may curve in a smooth manner with structure **1301** in response to a change in the shape of structure **1301**.

In this manner, connector system **2000** may connect deformable assembly **1356** in bay **1330** to deformable assemblies **1358-1368** in bays **1332-1342**. The change in the diagonal length of bay **1330** may be translated into changes in the diagonal lengths of bays **1332-1342**.

In these examples, flap **1300** may use a total of two actuators, primary actuator **1314** and horizontal member **1378** (not shown) to change the shape of flap **1300**. Thus, connector system **2000** may reduce the need for additional actuators affecting deformable assemblies **1358-1368** as compared to other advantageous embodiments.

In these examples, this movement may be related to movement of connector system **2000**. Movement of vertex D **1376** may cause movement of vertex E **2002**. This movement may cause connector system **2000** to move. Connector system **2000** may translate the movement of deformable assembly **1356** into movement of deformable assemblies **1358-1368**. In this manner, the change in the form of deformable assembly **1356** will relate to a change in the forms of deformable assemblies **1358-1368**.

With reference now to **Figure 22**, an exposed top view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1500**. In deployed configuration **1500**, tip **1308** may be at an inclined angle of around 36 degrees with respect to tip **1308** in undeployed configuration **1305**.

In deployed configuration **1500**, connector system **2000** may be moved in response to a changing length of horizontal member **1378**. Horizontal member **1378** may change length to move vertex D **1376** and change the form and height of deformable assembly **1356**. The connection of vertex D **1376** to vertex E **2002** by member **2030** may relate movement of vertex D **1376** to movement of connector system **2000**. In this manner, connector system **2000** may allow for the changing of the forms of deformable assemblies **1358-1368** without the need for additional actuators.

With reference now to **Figure 23**, a cross-sectional view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1500**. In this example, tip **1308** may be at an inclined angle of around 36 degrees with respect to tip **1308** in undeployed configuration **1305**. Further, the change in length of horizontal member **1378** (not shown) and the movement of connector system **2000** may change the diagonal lengths and quadrilateral shapes of bays **1330-1342**. These changes may result in a change in the shape of structure **1301**. This change in the shape of structure **1301** lead to flexible skin **1302** curving with structure **1301** in a smooth manner with flap **1300** having a curved shape for deployed configuration **1500** as depicted.

With reference now to **Figure 24**, an exposed top view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1700**. In deployed configuration **1700**, tip **1308** may be at an inclined angle of around 60 degrees with respect to tip **1308** in undeployed configuration **1305**.

In deployed configuration **1700**, horizontal member **1378** may change length to move vertex D **1376**. Movement of vertex D **1376** may lead to movement of connector system **2000**. In this manner, connector system **2000** may move to change the heights and forms of deformable assemblies **1358-1368** in response to the change to height **1704** of deformable assembly **1356**.

With reference now to **Figure 25**, a cross-sectional view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1700**. In this example, tip **1308** may be at an inclined angle of around 60 degrees with respect to tip **1308** in undeployed configuration **1305**. Further, the changing of deformable assemblies **1356-1368** by horizontal member **1378** (not shown) and connector system **2000** may change the diagonal lengths of bays **1330-1342**. In this manner, the shape of structure **1301** may be changed, with flexible skin **1302** curving in a smooth manner to follow the shape of structure **1301**. This curved shape for flap **1300** along with rotation of flap **1300** by primary actuator **1314**, may form deployed configuration **1700** for flap **1300**.

The illustrations of flap **1300** in **Figures 13-18** and **Figures 20-25** are not meant to imply physical or architectural limitations to the manner in which flaps may be implemented. For example, flap **1300** may not have truss **1312** attached to flexible skin **1302**. In other advantageous embodiments, the changing of the lengths of horizontal members **1378-1390** may be implemented using screw jacks, scissor jacks, and/or some other mechanism or device. However, the use of actuators for horizontal members **1378-1390** may allow for faster response rates.

With reference now to **Figure 26**, a diagram of a linking system is depicted in accordance with an advantageous embodiment. Linking system **2600** may be one example of one implementation of a linking system for a control surface such as, for example, linking system **158** for control surface **100** in **Figure 1**. In these examples, linking system **2600** may be viewed from a top view. Linking system **2600** may be connected to connector system **2000** (not shown) and base **1307** of flap **1300** in **Figure 20**. In these examples, linking system **2600** may be used in the place of horizontal member **1378**.

Linking system **2600** may include polyhedron structure **2602**, first member **2604**, and second member **2606**. Second member **2606** may connect polyhedron structure **2602** to a spar at a base of a structure such as, for example, spar **1319** at base **1307** of structure **1301** of flap **1300**. First member **2604** may connect polyhedron structure **2602** to a connector system such as, for example, connector system **2000** (not shown). In these examples, first member **2604** may connect to connector system **2000** (not shown) at vertex E **2002**.

Polyhedron structure **2602** may have members **2608-2612**, vertex F **2614**, vertex G **2616**, and hinge point **2618**. Hinge point **2618** may be stationary and may connect members **2610** and **2612**. Vertex F **2614** may connect member **2610**, member **2608**, and second member **2606**. Vertex G **2616** may connect member **2612**, member **2608**, and first member **2604**. In this illustrative example, polyhedron structure **2602** may have a second hinge point (not shown) and a number of members (not shown) connecting the second hinge point to polyhedron structure **2602**. This second hinge point may be stationary and may be positioned below hinge point **2618** in this view of linking system **2600**.

The vertices and members of linking system **2600** may be designed to have fixed angles and fixed lengths. In this manner, polyhedron structure **2602** may be designed to have a rigid structure of fixed lengths and fixed angles. The different members in linking system **2600** may be, for example, without limitation, rods, beams, tubes, and/or other suitable structural

components. The vertices in linking system **2600** may be, for example, without limitation, joints, mechanical links, and/or other suitable types of connections.

Linking system **2600** may relate motion of spar **1319** caused by primary actuator **1314** (not shown) to movement of vertex E **2002** and thus, vertices E **2004-2014** (not shown). For example, a lengthening or shortening of primary actuator **1314** may cause a rotation of spar **1319**. Member **2606** may connect spar **1319** to polyhedron structure **2602**. This connection may translate rotation of spar **1319** into rotation of polyhedron structure **2602** about hinge point **2618** and the second hinge point. Further, member **2604** may connect polyhedron structure **2602** to vertex E **2002**. This connection may translate rotation of polyhedron structure **2602** into movement of vertex E **2002** and connection structure **2016** (not shown) relative to structure **1301**.

Thus, linking system **2600** may allow vertex E **2002** to move a required amount to achieve a change in the shape of structure **1301** in response to movement generated by primary actuator **1314**. This relation of motion requires that vertex E **2002** be moved a relatively greater distance towards the rear of a wing compared to the forward portion of flap **1300**. This motion may be referred to as a “multiplying” motion. Thus, linkage system **2600** may function as a lever.

Vertex E **2002** may be connected to vertices E **2004-2014** in **Figure 20** in such a way that movement of vertex E **2002** causes movement of vertices E **2004-2014**. The movement of vertices E **2002-2014** causes changes in the forms of the deformable assemblies within flap **1300**. These changes may result in increased diagonal lengths for the bays of flap **1300**. Increased diagonal lengths for the bays may lead to a change in the shape of structure **1301**. In response to this change, flexible skin **1302** may curve to follow the shape of structure **1301**, and flap **1300** may have a curved shape.

The design parameters for linking system **2600** may take into account certain geometric considerations based on the required movement of vertex E **2002** to change the shape of structure **1301** in response to the movement caused by primary actuator **1314**. In this manner, the movement of vertex E **2002** may be controlled to cause flap **1300** to bend to a desired configuration in response to primary actuator **1314**.

In this example, the behavior of linking system **2600** may be governed by the quantities R_1 , R_2 , θ_1 , and θ_2 . As depicted, R_1 may be a length of member **2610**, and R_2 may be a length of member **2612**. Further, θ_1 may be an angle between member **2610** and horizontal axis **2620**, and θ_2 may be an angle between horizontal axis **2620** and member **2612**. Horizontal axis **2620**

may be an axis parallel to spar **1319** when flap **1300** is in undeployed configuration **1305**. The values of R_1 , R_2 , θ_1 , and θ_2 , may be used to tune the rates of change of movement for vertex E **2002**.

If R_2 is greater than R_1 , the motion of vertex E **2002** may be amplified. In other words, the motion Δy_2 of vertex G **2616** in the direction of arrow **2622** may be faster than the motion Δy_1 of vertex F **2614** in the direction of arrow **2624**. In this manner, polyhedron structure **2602** of linking system **2600** may function as a lever.

With reference now to **Figure 27**, a graph illustrating rates of change for a linkage assembly is depicted in accordance with an advantageous embodiment. In this example, the rates of change for motion Δy_1 and motion Δy_2 for a linkage assembly such as, for example, linking system **2600**, may be illustrated.

As illustrated in graph **2700**, depending on the values selected for the design parameters R_1 , R_2 , θ_1 , and θ_2 , the rates of change between motion Δy_1 and motion Δy_2 may be designed to be either linear or nonlinear. In some advantageous embodiments, it may be desirable to specify some degree of linearity for the behavior of linking system **2600**. In other words, it may be desirable to design linking system **2600** to partially and/or approximately linearize the nonlinear behavior of the deformable assemblies in a flap.

As depicted in graph **2700**, the nonlinear behavior of deformable assemblies may be at least partially linearized by selecting a geometry for linking system **2600** that follows a similar behavior to geometry **2702**. Geometry **2702** may have the design parameters R_1 equal to around 2, R_2 equal to around 1, θ_1 equal to around -30 degrees, and θ_2 equal to around 30 degrees.

With reference now to **Figure 28**, a partially exposed top view of flap **1300** with linking system **2600** in **Figure 26** in undeployed configuration **1305** is depicted in accordance with an advantageous embodiment. In this view, bays **1330** and **1332** of structure **1301** may be viewed with deformable assemblies **1356** and **1358** and a portion of connector system **2000**.

In this example, flap **1300** may change its shape using one actuator, primary actuator **1314**, and linking system **2600**. Horizontal member **1378** and horizontal members **1380-1390** may not be present in these advantageous embodiments.

Linking system **2600** may connect to connector system **2000** at vertex E **2002**. Movement of spar **1319** due to rotation caused by primary actuator **1314** may translate into movement of vertex E **2002**. As depicted, movement of vertex E **2002** may cause movement of vertex E **2004**. Movement of vertex E **2002** and vertex E **2004** may cause deformable assemblies **1356** and **1358** to change form and height. For example, height **1392** of deformable

assembly **1356** may be changed in response to movement of vertex E **2002**. These changes may, in turn, lead to changes in the diagonal lengths for bays **1330** and **1332**.

In this manner, linking system **2600** may reduce the number of actuators needed to change the shape of structure **1301** and give flap **1300** a curved shape. In these illustrative examples, flap **1300** may have a second linking system (not shown) connected to a second connector system (not shown) at a vertex E (not shown) at end **1311** of flap **1300**.

Using linking system **2600**, the movement and changing of the deformable assemblies for flap **1300** may be substantially the same as the movement and changing of the deformable assemblies for flap **1300** using horizontal actuators. Linking system **2600** may reduce the number of actuators used to a total of one actuator. Further, linking system **2600** may be connected directly to vertex E **2002** unlike horizontal member **1378**, which may be connected to vertex D **1376**.

With reference now to **Figure 29**, a cross-sectional view of a flap in an undeployed configuration is depicted in accordance with an advantageous embodiment. This view of flap **1300** may be a view of end **1313** of flap **1300**. Flap **1300** may have undeployed configuration **1305** with a straight shape. In this view of flap **1300**, second side **1405** of structure **1301** may be seen. In this example, flap **1300** may have linking system **2600** in **Figure 26**. Further, both hinge point **2618** and hinge point **2900** for polyhedron structure **2602** may be seen.

In these illustrative examples, the diagonal lengths and quadrilateral shapes for the bays of flap **1300** may be changed to change the shape of structure **1301**. For example, primary actuator **1314** may rotate spar **1319** and structure **1301** about hinge point **1310** and hinge point **1309** (not shown). This rotation causes polyhedron structure **2602** of linking system **2600** to rotate about hinge points **2618** and **2900**. This rotation of polyhedron structure **2602** moves vertex E **2002**, which may then cause vertex D **1376** to move. Movement of vertex D **1376** may change the diagonal length and the quadrilateral shape for bay **1330**. Connector system **2000** may relate these changes to the other bays of flap **1300**.

With reference now to **Figure 30**, an exposed top view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1500**. In deployed configuration **1500**, connector system **2000** may be moved in response to rotation of spar **1319** and polyhedron structure **2602** of linking system **2600** caused by primary actuator **1314**.

With reference now to **Figure 31**, a cross-sectional view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1500**.

5 In response to rotation of spar **1319** by primary actuator **1314**, polyhedron structure **2602** of linking system **2600** may rotate about hinge points **2618** and **2900**. This rotation may change the shape of structure **1301** and flap **1300**.

With reference now to **Figure 32**, an exposed top view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1700**.

10 Polyhedron structure **2602** of linking system **2600** may be rotated in response to rotation of spar **1319** by primary actuator **1314**. Rotation of polyhedron structure **2602** may move vertex E **2002**, which may in turn, move vertex D **1376** and connector system **2000**. In this manner, linking system **2600** may be used to change the heights and forms of the deformable assemblies of flap **1300**.

15 With reference now to **Figure 33**, a cross-sectional view of flap **1300** in a deployed configuration is depicted in accordance with an advantageous embodiment. Flap **1300** may have deployed configuration **1700**. Rotation of spar **1319** by primary actuator **1314** may translate into forming deployed configuration **1700** with a curved shape for flap **1300**.

20 The illustrations of flap **900** in **Figures 9-11** and flap **1300** in **Figures 13-18, 20-26, and 28-33** are not meant to imply physical or architectural limitations to the manner in which a flap may be implemented. Other components in addition to, or in place of, the ones illustrated may be used in some advantageous embodiments. Some components illustrated in flap **900** may be omitted in some advantageous embodiments.

25 For example, in other advantageous embodiments, flap **900** and flap **1300** may have a different number of bays than shown. In some advantageous embodiments, flap **900** and flap **1300** may have more than one bay in the spanwise direction. Further, flap **900** may have additional diagonal members in the center of its bays to provide additional support. This additional support may help flap **900** operate even under conditions of damage that may be sustained due to battle, malfunction, or some other condition. In the same manner, flap **1300**
30 may have additional deformable assemblies positioned in the center of its bays to provide additional support.

In other advantageous embodiments, deformable assemblies **1356-1368** may be attached to structure **1301** in a manner to cause movement of vertex D **1376** in an opposite direction.

With reference now to **Figure 34**, a diagram of a portion of a truss of a structure of a flap is depicted in accordance with an advantageous embodiment. In these illustrative examples, truss **3400** may be one example of one implementation of a truss such as, for example, truss **130** in **Figure 1** and truss **912** in **Figure 9**. Truss **3400** may be a part of structure **3401** of a flap. Structure **3401** may be one example of a structure for a flap such as, for example, structure **911** for flap **900** in **Figure 9**.

The portion of truss **3400** depicted in **Figure 34** may show a portion of a flexible skin, such as flexible skin **3402** attached to truss **3400**. In this view, flexible skin **3402** may be attached to truss **3400** by link **3404** and link **3406**. When the shape of structure **3401** changes in response to one of the mechanisms described above, flexible skin **3402** may be restrained by links **3404** and **3406** in the directions of axis **3408**. Axis **3408** may be axis normal to flexible skin **3402**.

Further, links **3404** and **3406** may allow flexible skin **3402** to slide along truss **3400** and structure **3401** in chordwise direction **3410** in a manner that does not lengthen or shorten flexible skin **3402**. For example, flexible skin **3402** may slide from position **3412** to position **3414** using links **3404** and **3406** without lengthening or shortening. In other advantageous embodiments, mechanisms other than links, such as links **3404** and **3406**, may be used.

With reference now to **Figure 35**, a flowchart of a method for controlling a control surface is depicted in accordance with an advantageous embodiment. In these examples, the process illustrated in **Figure 35** may be performed for a control surface such as, for example, without limitation, control surface **100** in **Figure 1**.

The process may begin by identifying a desired shape for the control surface (operation **3500**). The control surface may comprise a structure having a first side and a second side substantially opposite to the first side. A flexible skin may be attached to the first side and the second side of the structure. Further, a plurality of deformable assemblies may be moveably connected to the structure. Each deformable assembly in the plurality of deformable assemblies may have a vertex, a base, and a height that is capable of changing to change a shape of the control surface.

The process then activates a motion generation system to change the shape of the control surface to the desired shape (operation **3502**). The motion generation system may be connected to the vertex of a deformable assembly to move the vertex to change the height of a number of deformable assemblies in the plurality of deformable assemblies to change the shape of the control surface. Thereafter, the process may terminate.

Although the different advantageous embodiments in the illustrative examples are described with respect to an aircraft, one or more of the different advantageous embodiments may be applied to other vehicles other than aircraft such as, for example, without limitation, a submarine, a personnel carrier, a tank, a train, an automobile, a bus, a spacecraft, a surface ship, and other suitable vehicles.

The description of the different advantageous embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous embodiments.

The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

CLAIMS:

What is claimed is:

- 5 1. An apparatus comprising:
a structure having a first side and a second side substantially opposite to the first side;
a flexible skin attached to the first side and the second side of the structure; and
a plurality of deformable assemblies moveably connected to the structure, in which each
deformable assembly in the plurality of deformable assemblies has a vertex and a base, wherein
10 the each deformable assembly in the plurality of deformable assemblies has a height that is
capable of changing to change a shape of the structure and a shape of the flexible skin.
2. The apparatus of claim 1 further comprising:
a motion generation system capable of moving the vertex of the each deformable
assembly in the plurality of deformable assemblies to change the height of the each deformable
15 assembly in the plurality of deformable assemblies to change the shape of the structure and the
shape of the flexible skin attached to the structure.
3. The apparatus of claim 2, wherein the structure has a plurality of bays and a tip
section and wherein a number of deformable assemblies in the plurality of deformable
assemblies are located in each of the plurality of bays.
- 20 4. The apparatus of claim 1, further comprising:
a number of stiffening elements at a number of locations on the flexible skin, wherein the
number of stiffening elements is capable of stiffening the flexible skin in a spanwise direction at
the number of locations.
5. The apparatus of claim 3, wherein the motion generation system is connected to a
25 first vertex of a first deformable assembly in a first bay of the plurality of bays and a second
vertex of a second deformable assembly in the first bay and wherein a first number of the
plurality of deformable assemblies has a first number of vertices linked in series to the first
vertex and wherein a second number of the plurality of deformable assemblies has a second
number of vertices linked in series to the second vertex.
- 30 6. An apparatus comprising:
a structure having a first side and a second side substantially opposite to the first side;
a plurality of bays located within the structure;
a flexible skin attached to the first side and the second side of the structure;

a plurality of deformable assemblies moveably connected to the structure, in which each deformable assembly in the plurality of deformable assemblies has a vertex and a base, wherein the each deformable assembly in the plurality of deformable assemblies has a height that is capable of changing to change a shape of the structure and a shape of the flexible skin;

5 a plurality of connection structures connected to the plurality of deformable assemblies, wherein each connection structure in the plurality of connection structures has a vertex and a plurality of members extending from the vertex to an associated deformable assembly in the plurality of deformable assemblies, and wherein a first member of the plurality of members is connected to the vertex of the associated deformable assembly and a number of other members
10 in the plurality of members are connected to a base of the associated deformable assembly; and

an actuator system connected to a first vertex of a first deformable assembly in a first bay of the plurality of bays and a second vertex of a second deformable assembly in the first bay, wherein a first number of the plurality of deformable assemblies has a first number of vertices linked in series to the first vertex, wherein a second number of the plurality of deformable
15 assemblies has a second number of vertices linked in series to the second vertex, and wherein the actuator system is capable of moving the first vertex and the second vertex to change the shape of the structure and the shape of the flexible skin attached to the structure.

7. A method for controlling a control surface, the method comprising:

identifying a desired shape for the control surface comprising a structure having a
20 first side and a second side substantially opposite to the first side; a flexible skin attached to the first side and the second side of the structure; and a plurality of deformable assemblies moveably connected to the structure, wherein each deformable assembly in the plurality of deformable assemblies has a vertex and a base, and wherein the each deformable assembly in the plurality of deformable assemblies has a height that is capable of changing to change a shape of the control
25 surface; and

activating a motion generation system connected to the vertex to move the vertex to change the height of a number of deformable assemblies in the plurality of deformable assemblies to change the shape of the control surface to the desired shape.

8. The method of claim 7, wherein the structure has a plurality of bays and a tip
30 section and wherein a number of deformable assemblies in the plurality of deformable assemblies are located in each of the plurality of bays.

9. The method of claim 8, wherein the each of the plurality of bays has a diagonal length, wherein the diagonal length changes as the height of the each deformable assembly in the plurality of deformable assemblies changes.

5 10. The method of claim 8, wherein the each of the plurality of bays has a quadrilateral shape, wherein the quadrilateral shape changes as a diagonal length for the quadrilateral shape changes.

11. The method of claim 7, wherein the plurality of deformable assemblies is moveably connected to the structure.

12. The method of claim 7, wherein the structure includes a truss.

10 13. The method of claim 7, wherein a base of the structure is moveably attached to a frame of a part.

14. The method of claim 7, wherein the part is selected from one of a wing, a horizontal stabilizer, and a vertical stabilizer.

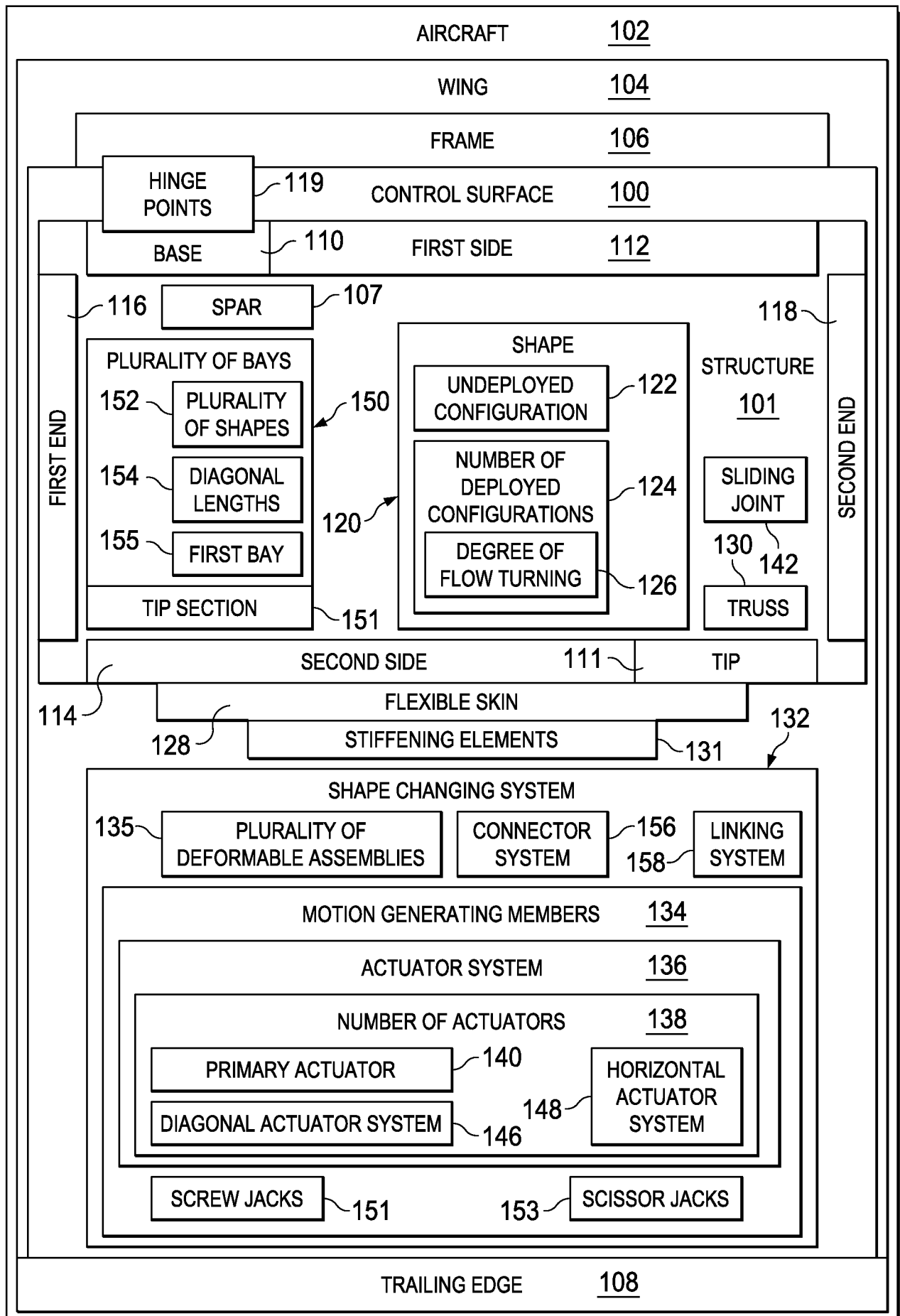
15 15. The method of claim 13, wherein the structure further comprises:
a spar, wherein the spar is moveably connected to the frame of the part.

16. The method of claim 7, further comprising:
a number of stiffening elements at a number of locations on the flexible skin,
wherein the number of stiffening elements is capable of stiffening the flexible skin in a spanwise
direction at the number of locations.

20 17. The method of claim 7, wherein the activating step further comprises:
rotating the control surface.

FIG. 1

1/34



2/34

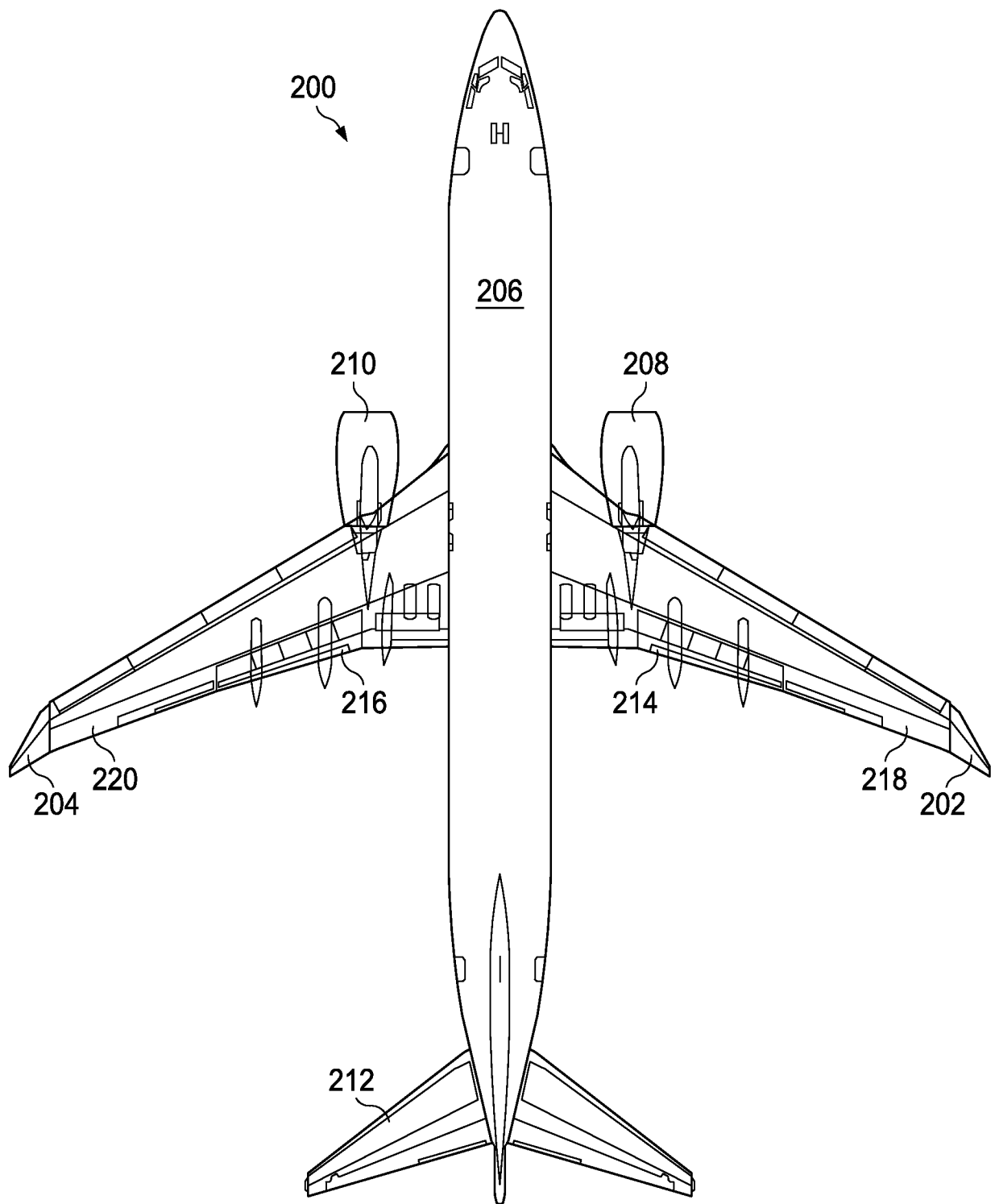


FIG. 2

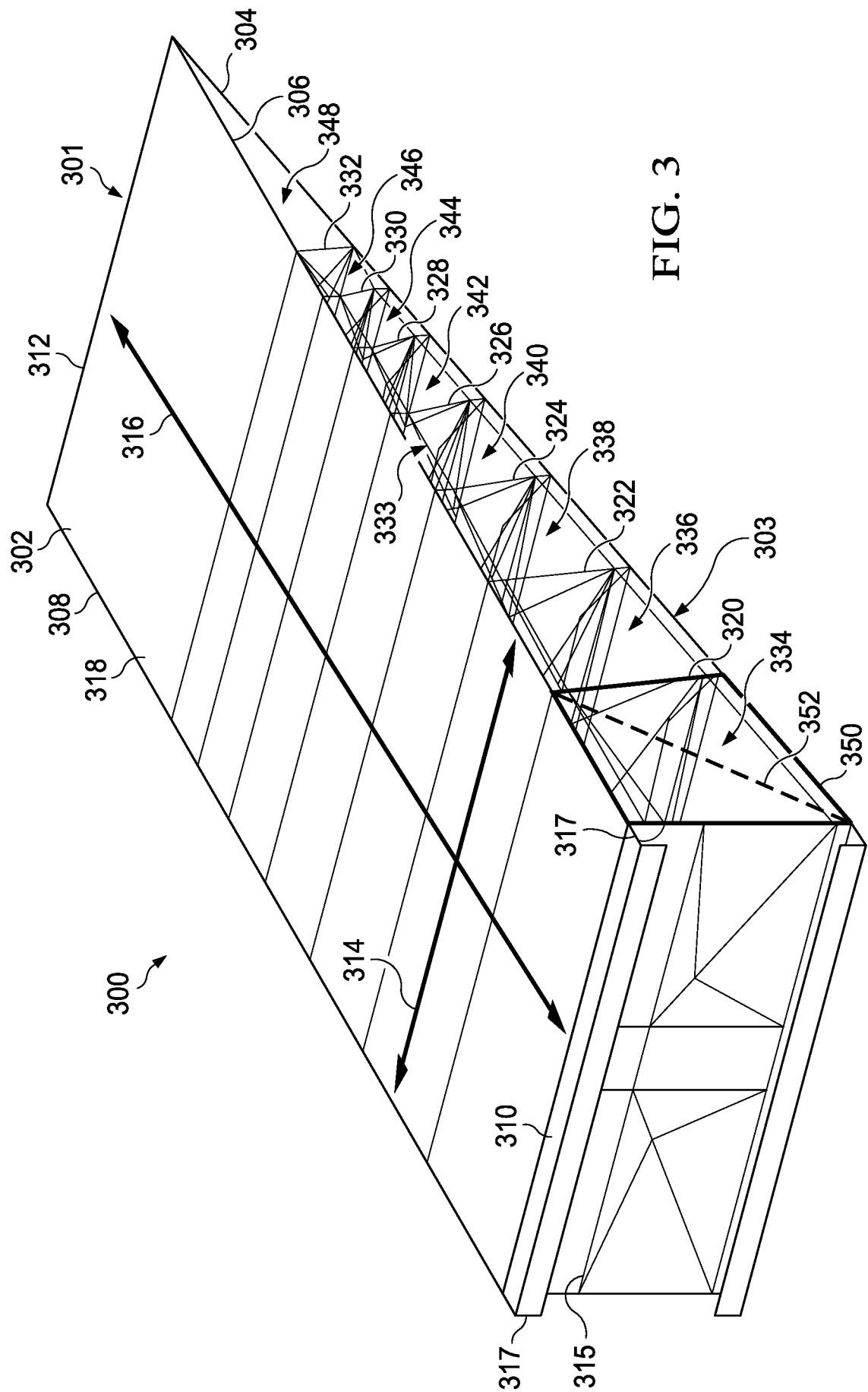


FIG. 3

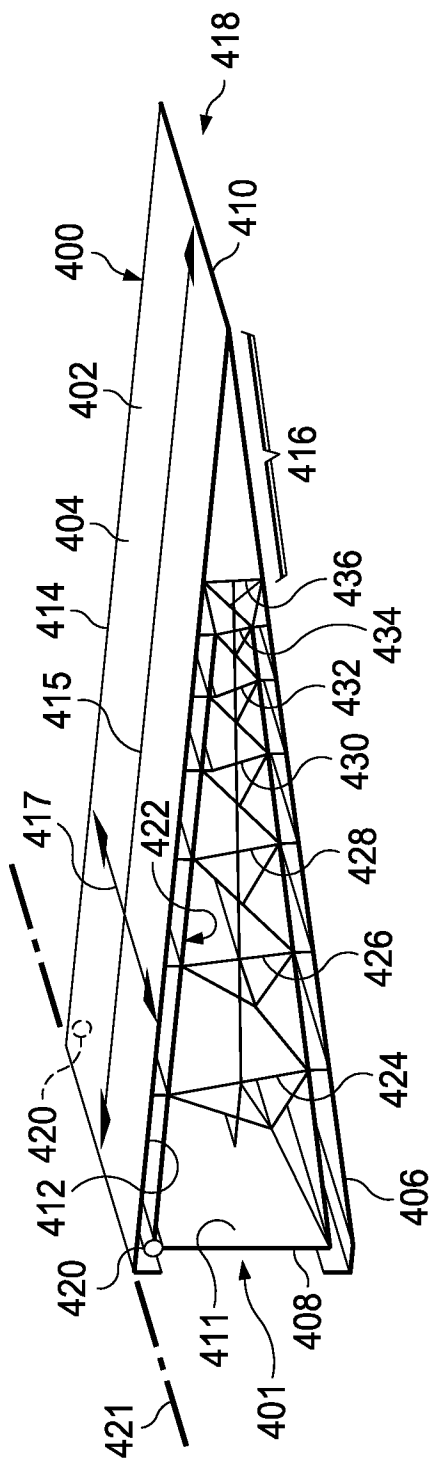
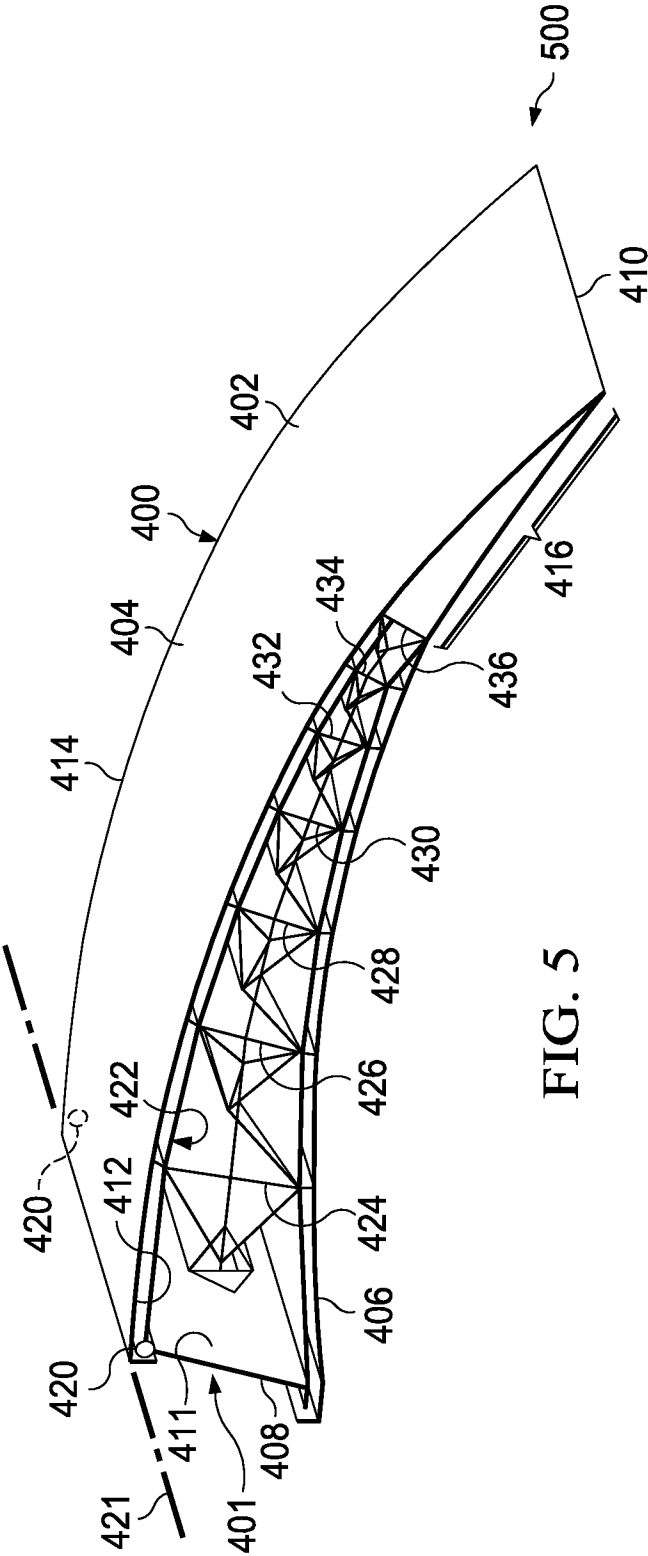


FIG. 4



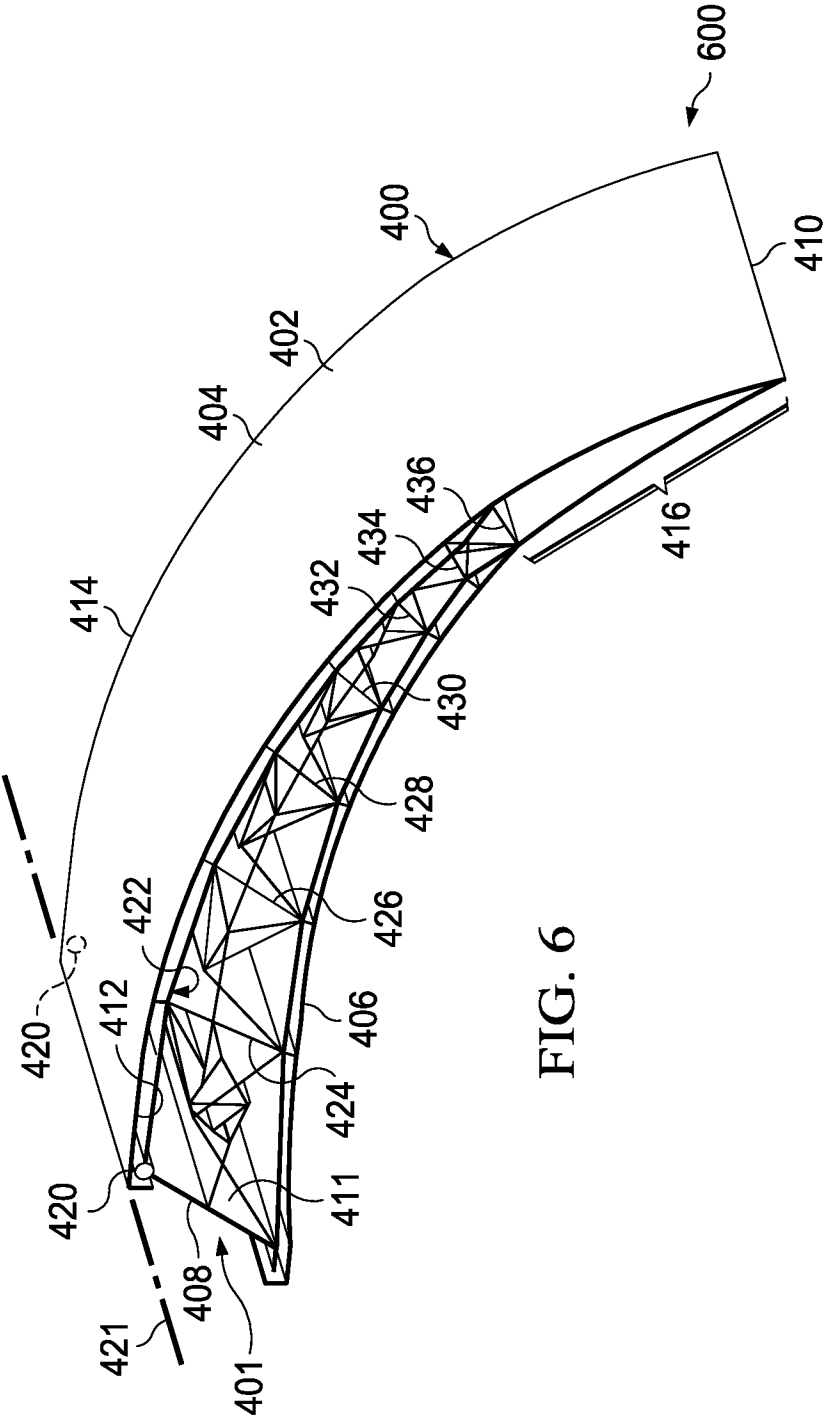
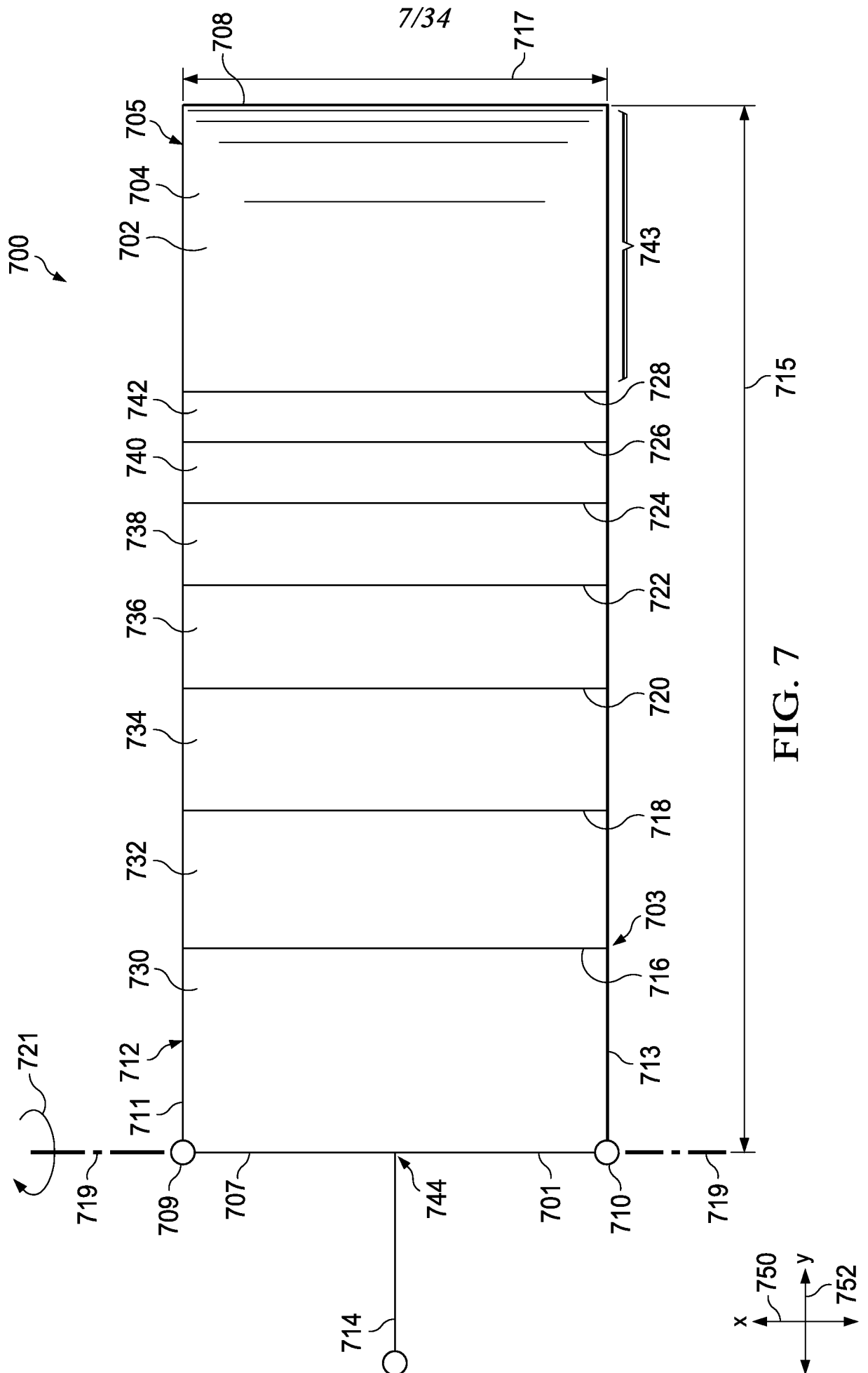


FIG. 6



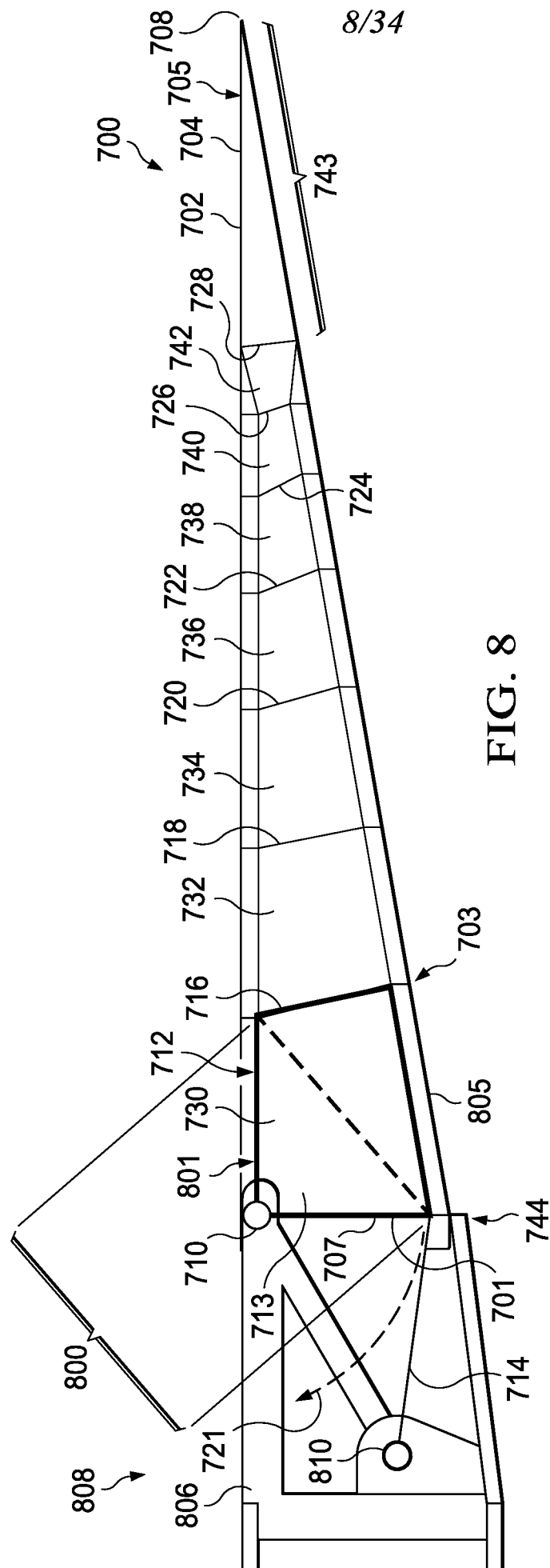


FIG. 8

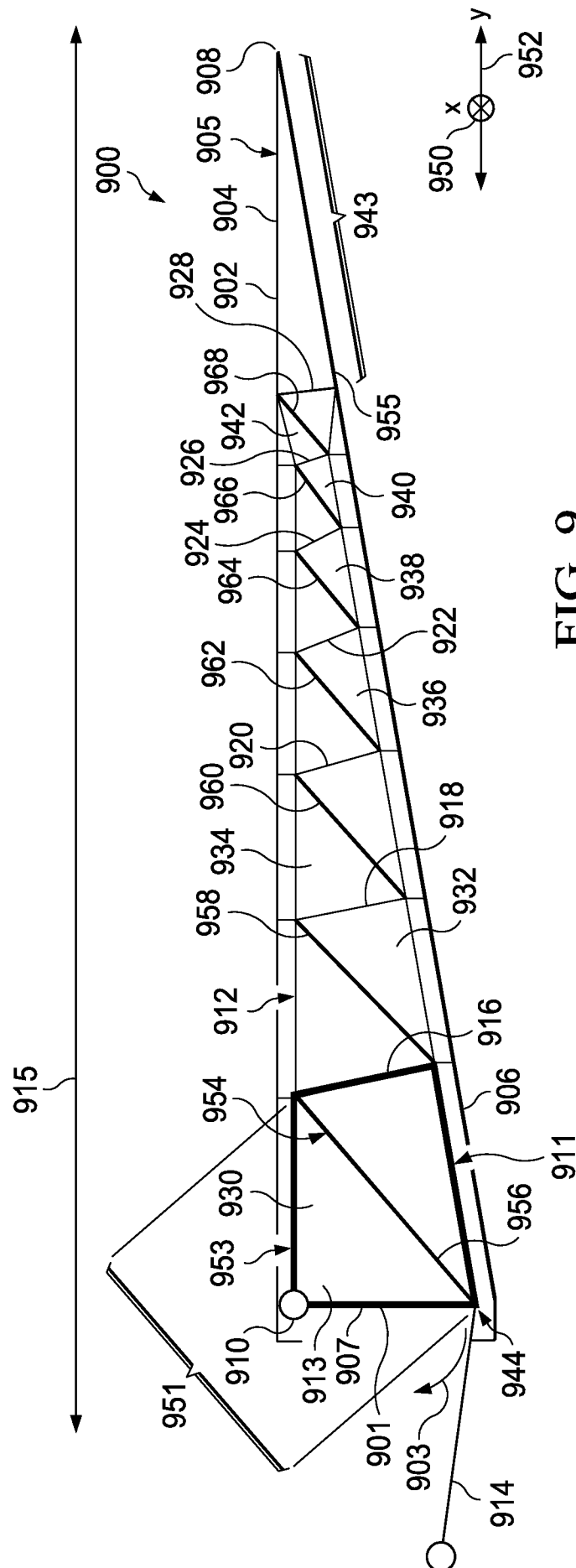


FIG. 9

10/34

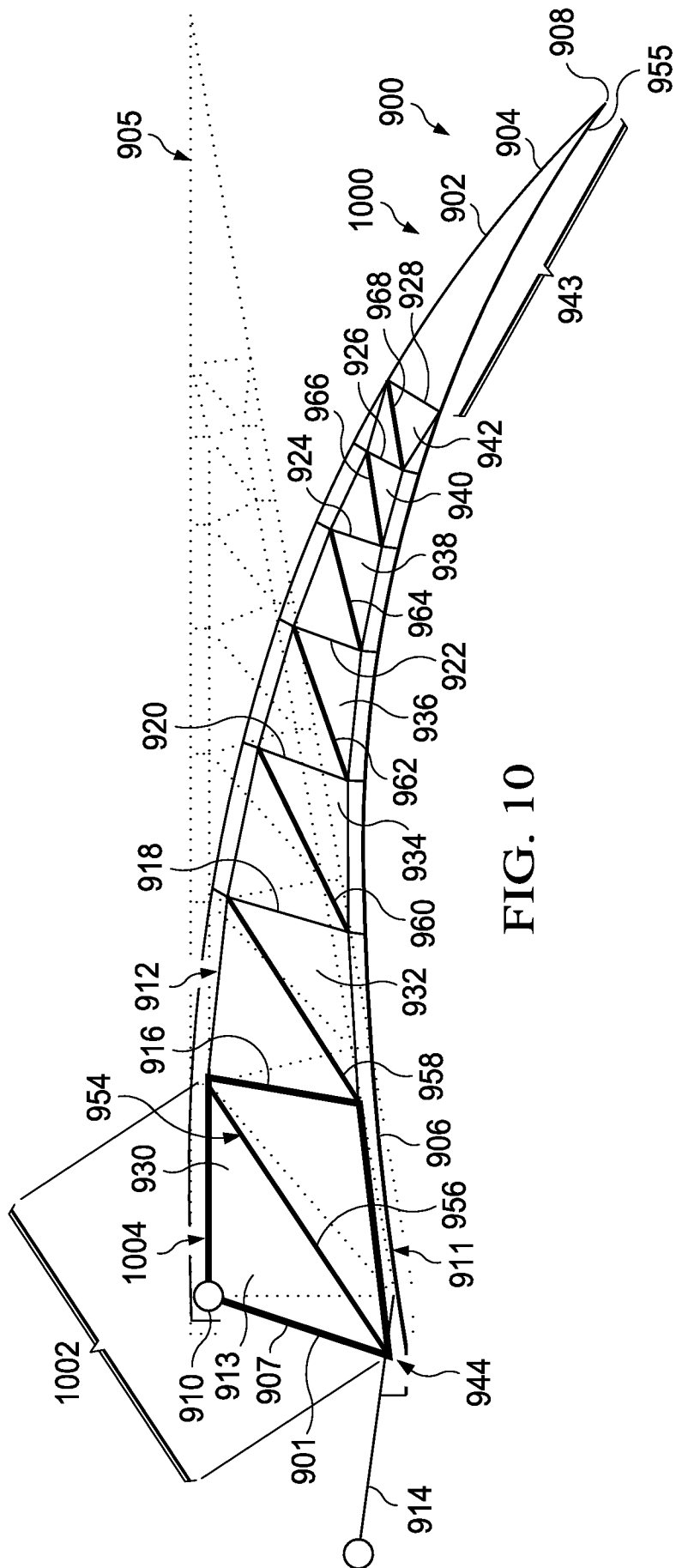


FIG. 10

11/34

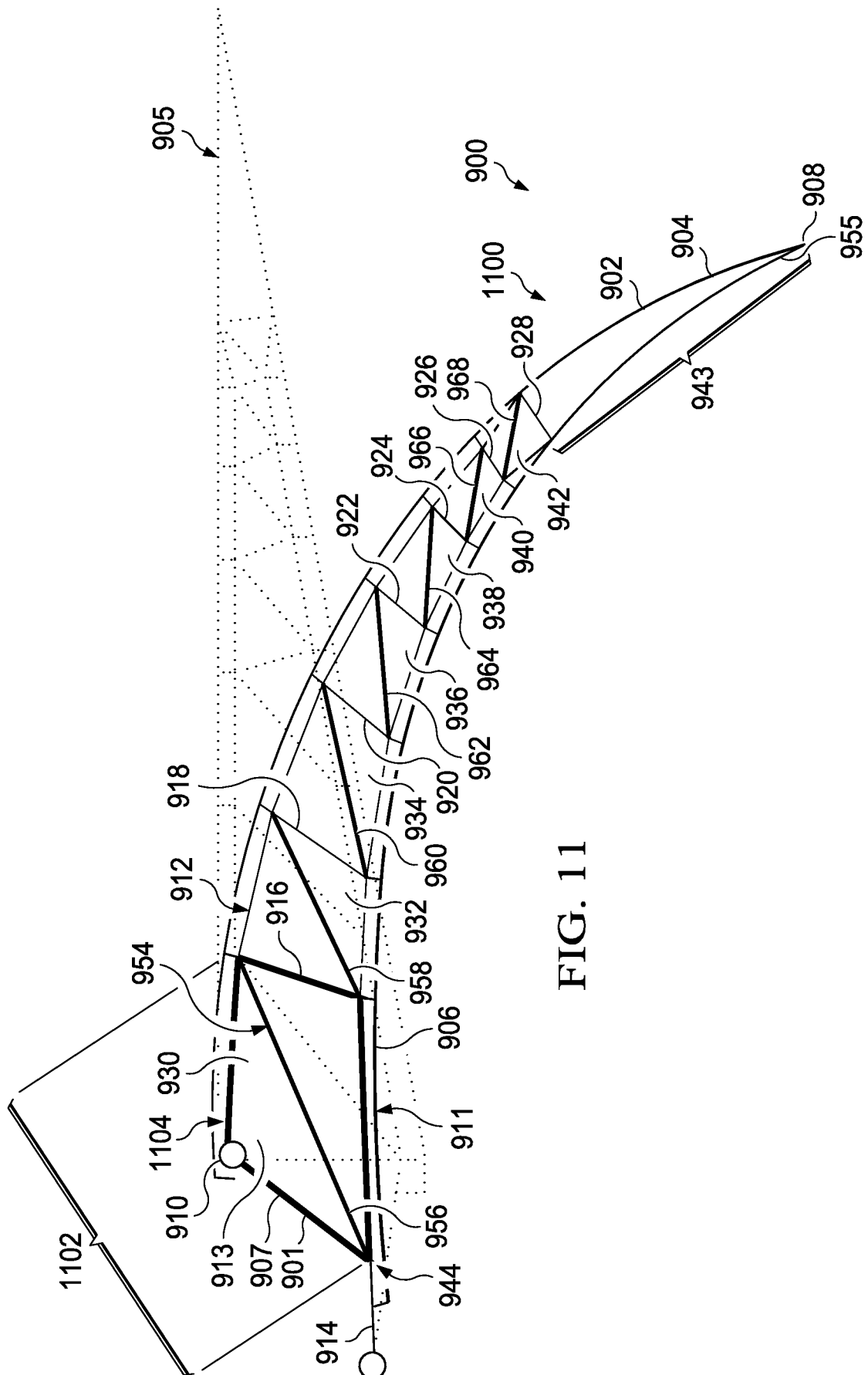


FIG. 11

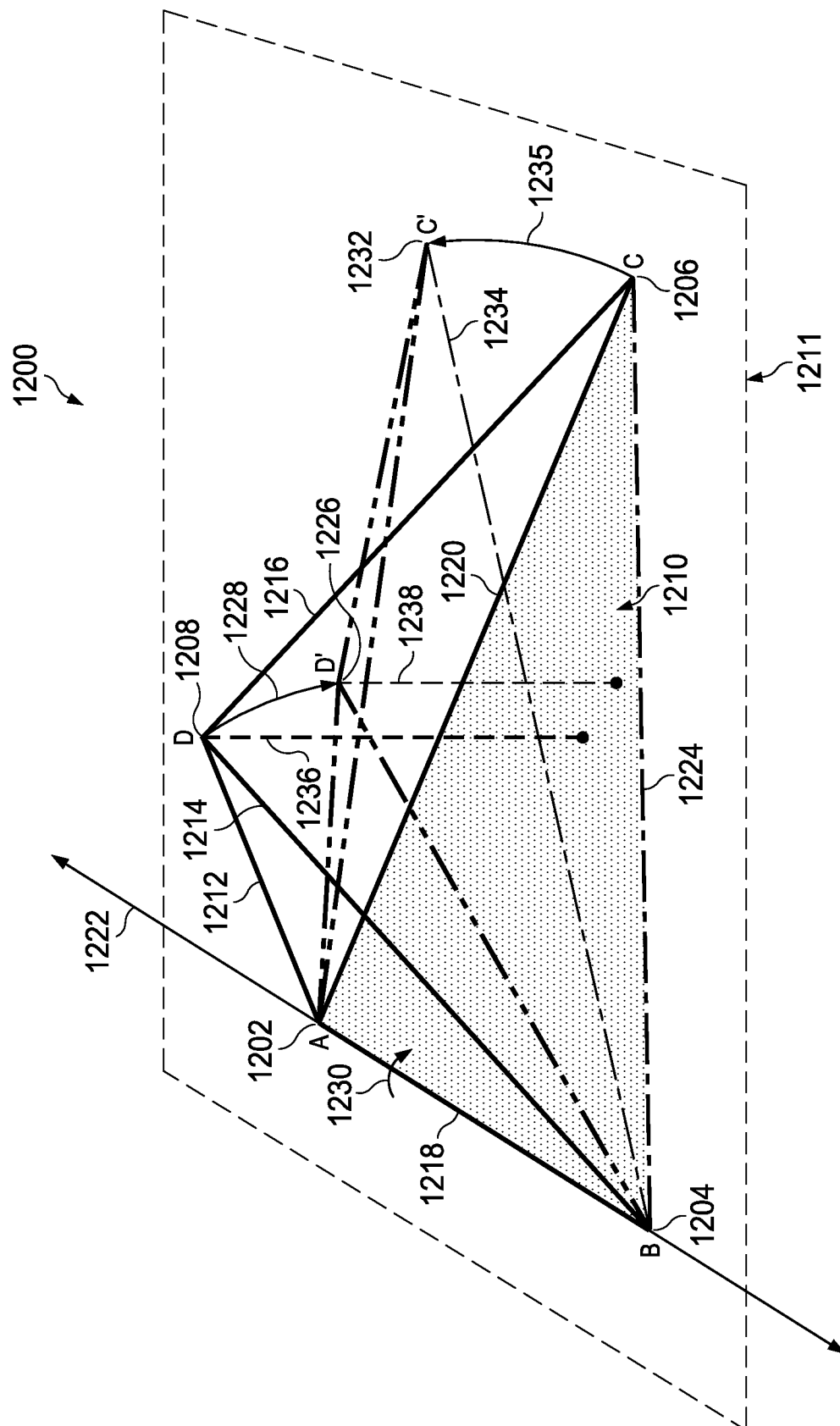
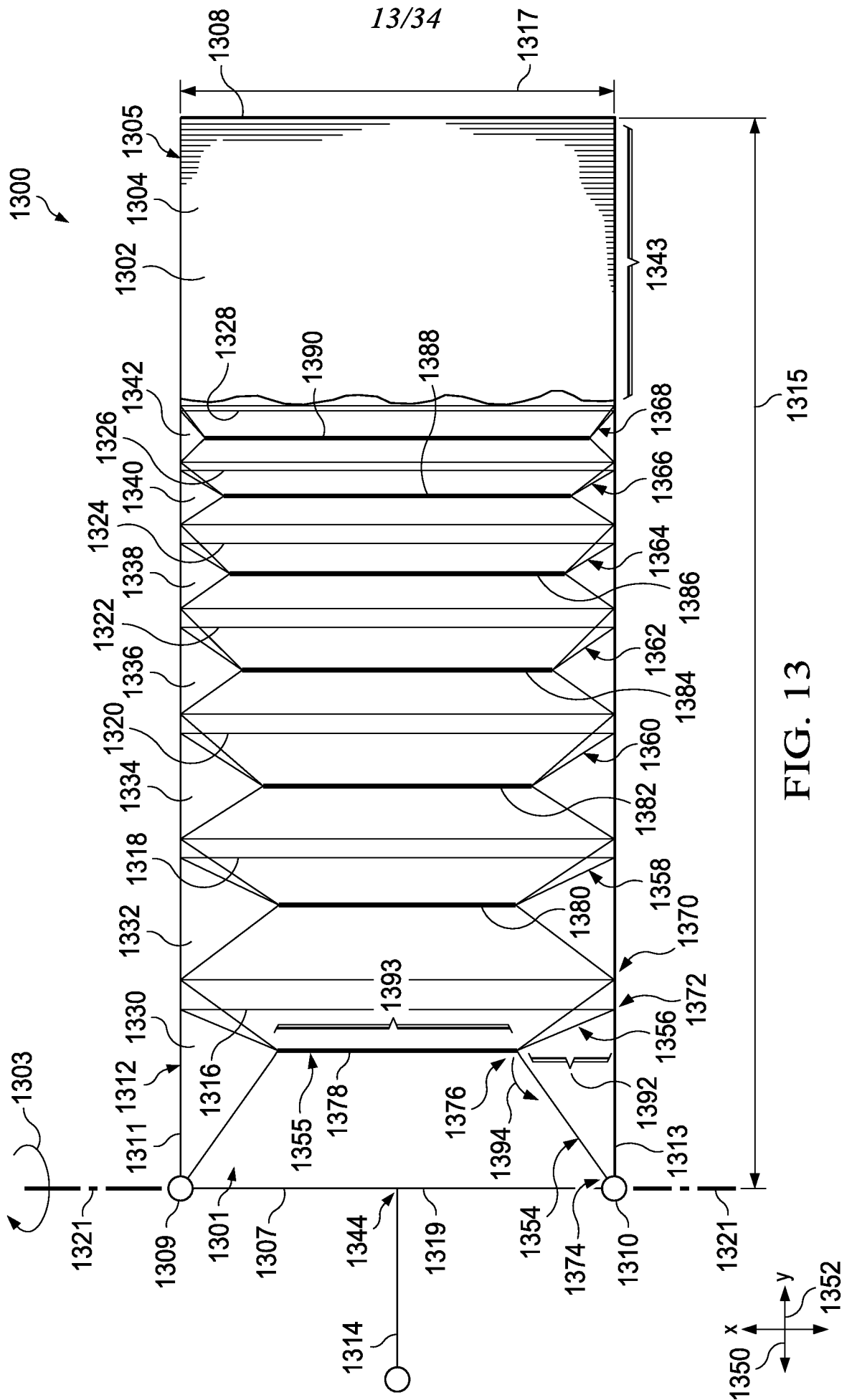
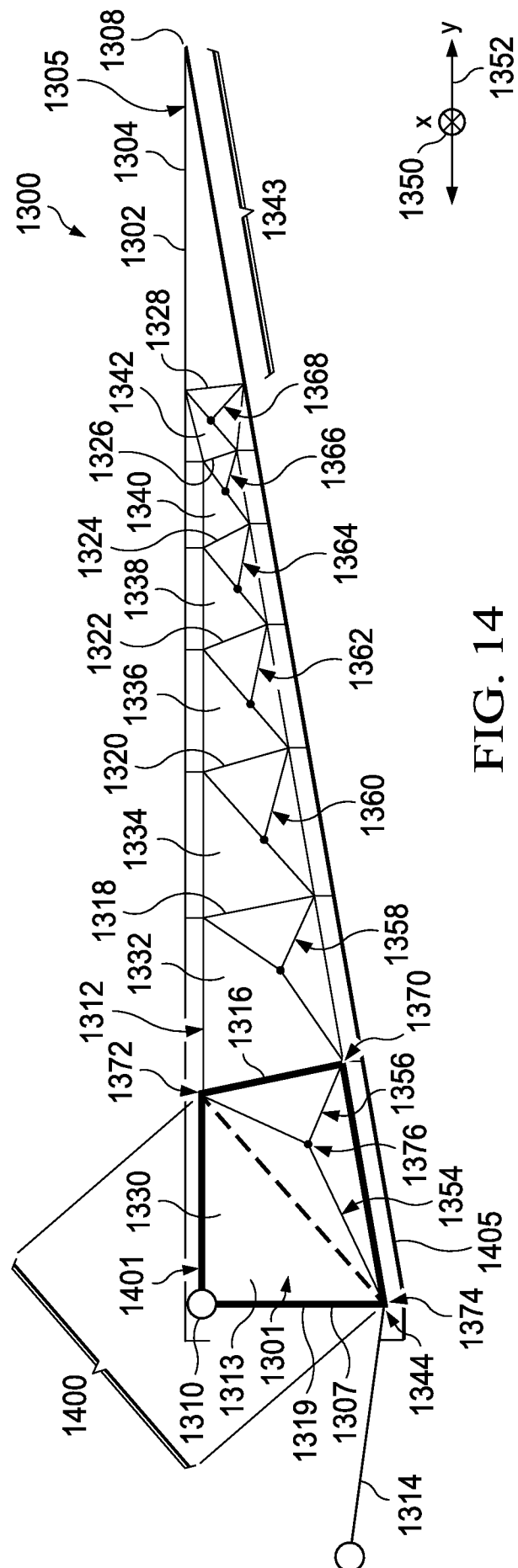
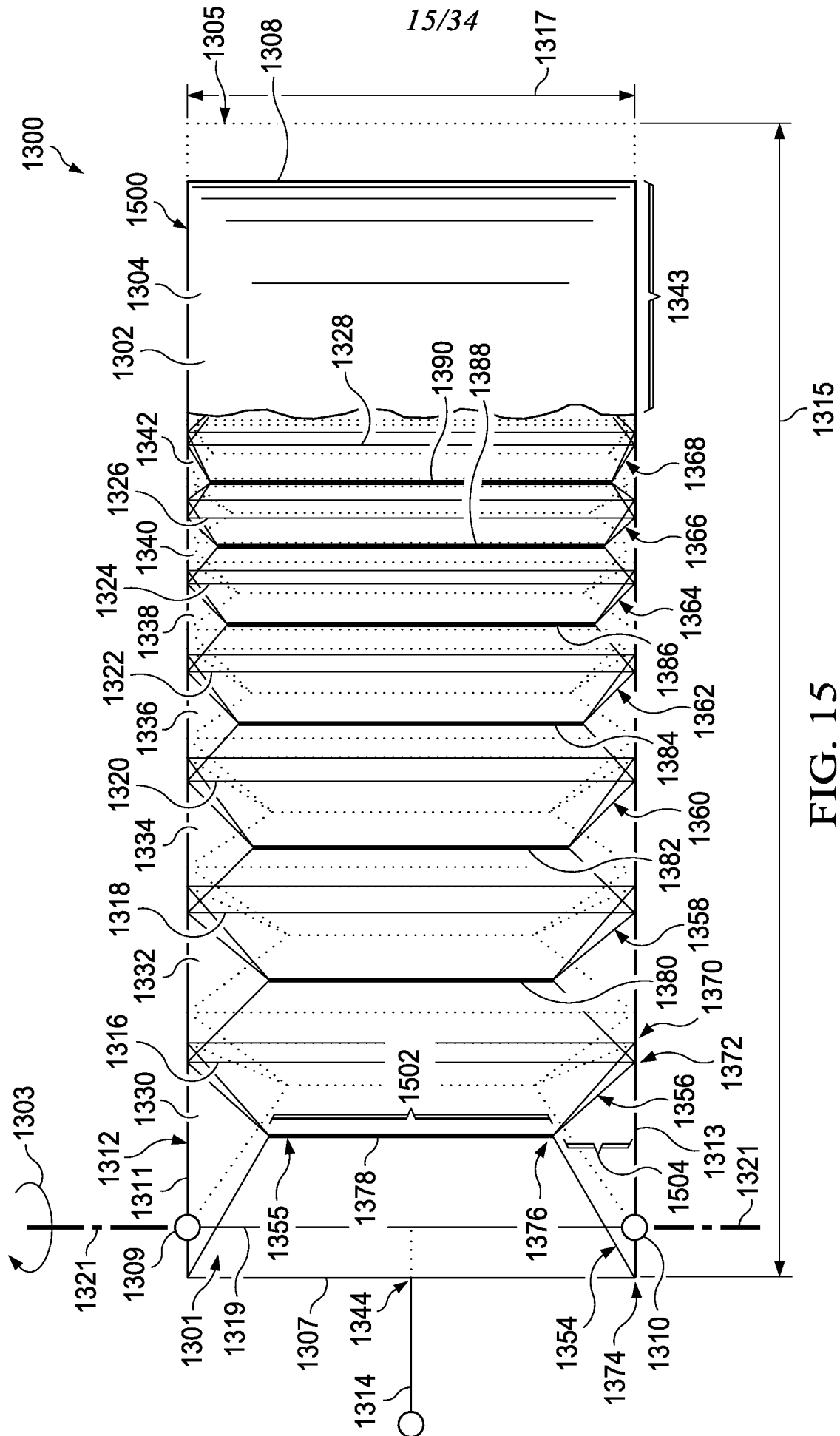


FIG. 12







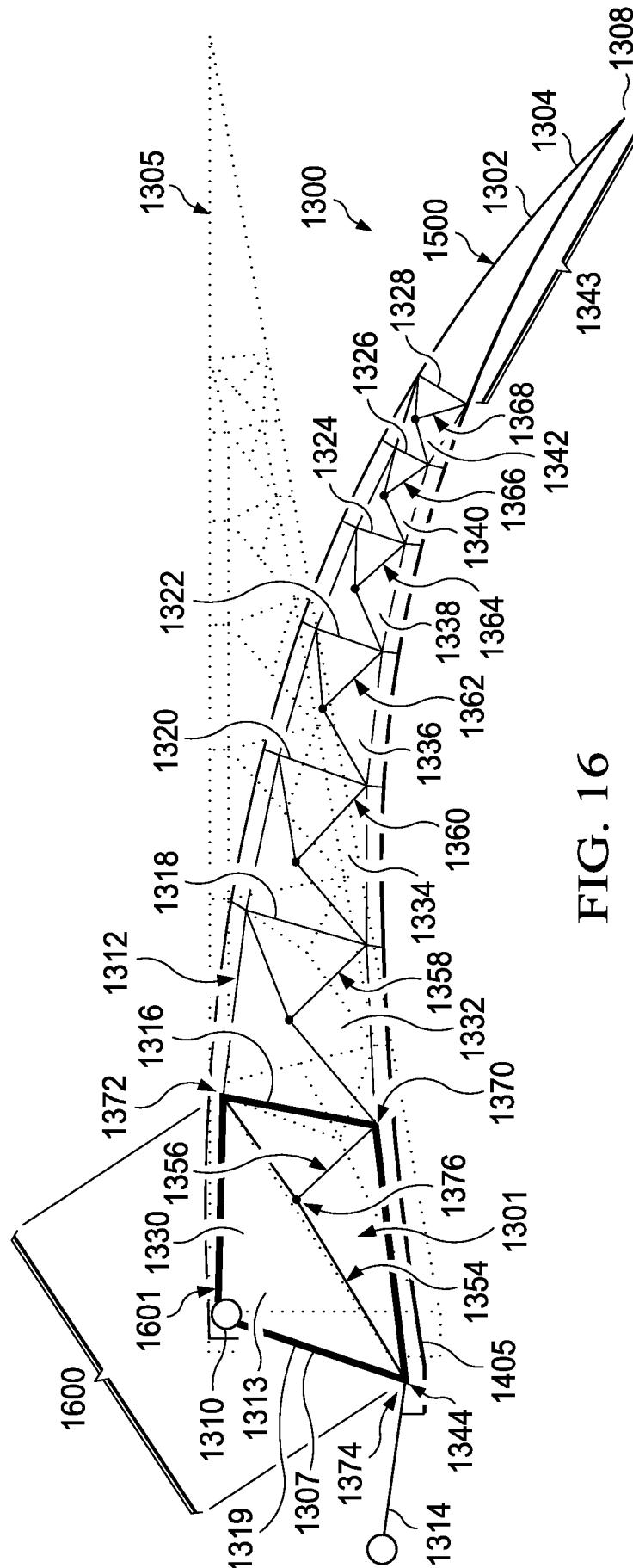
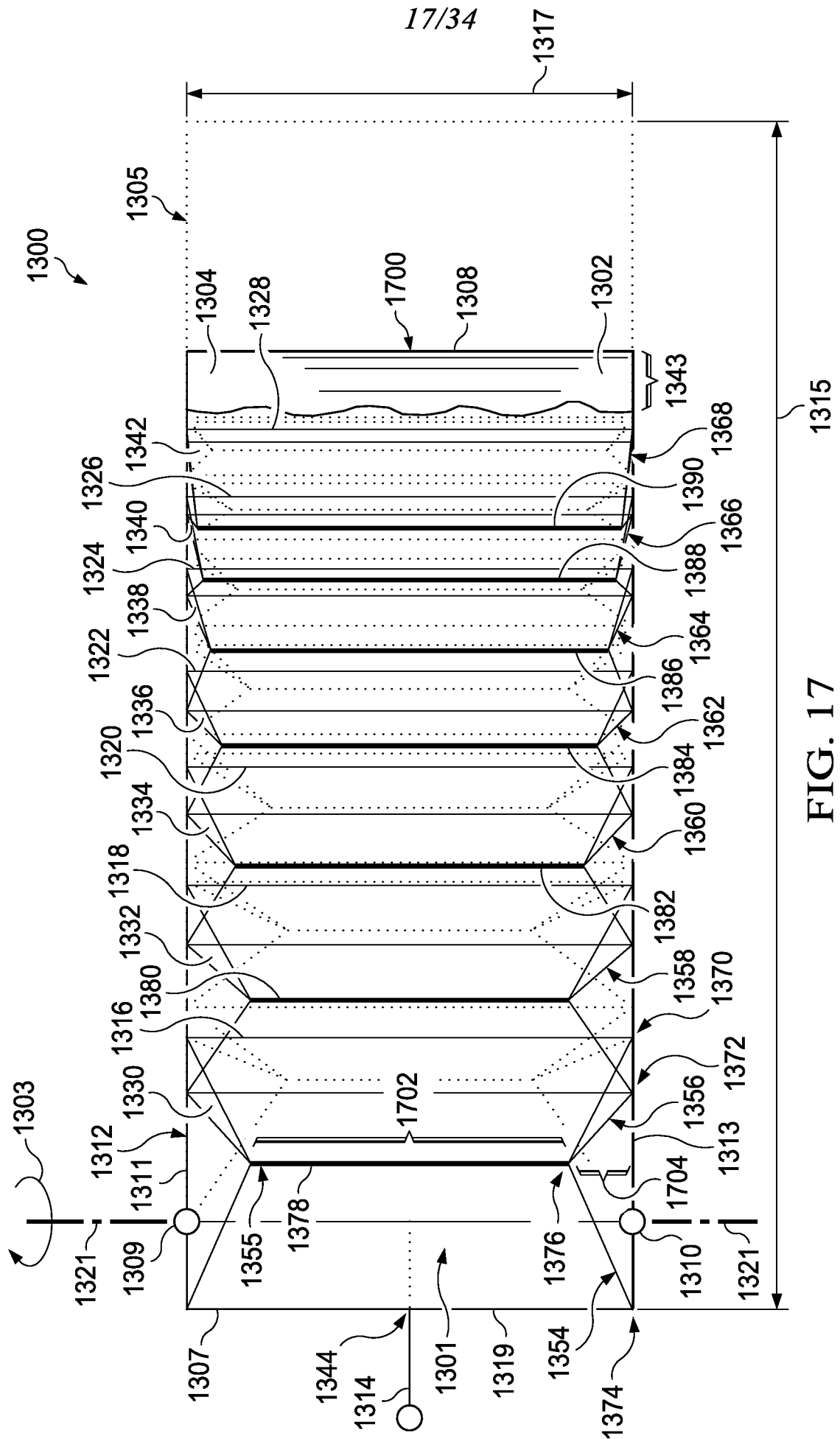


FIG. 16



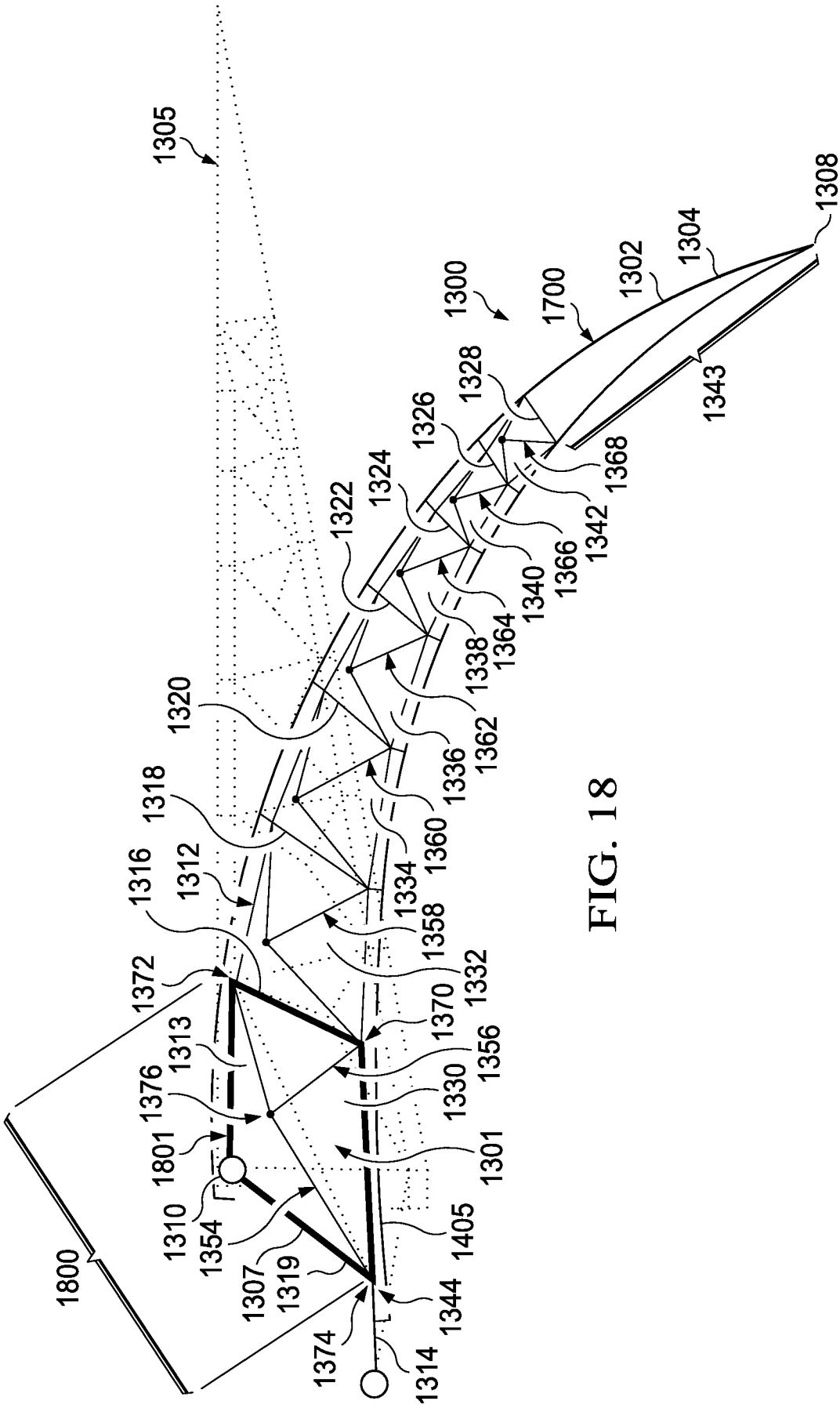


FIG. 18

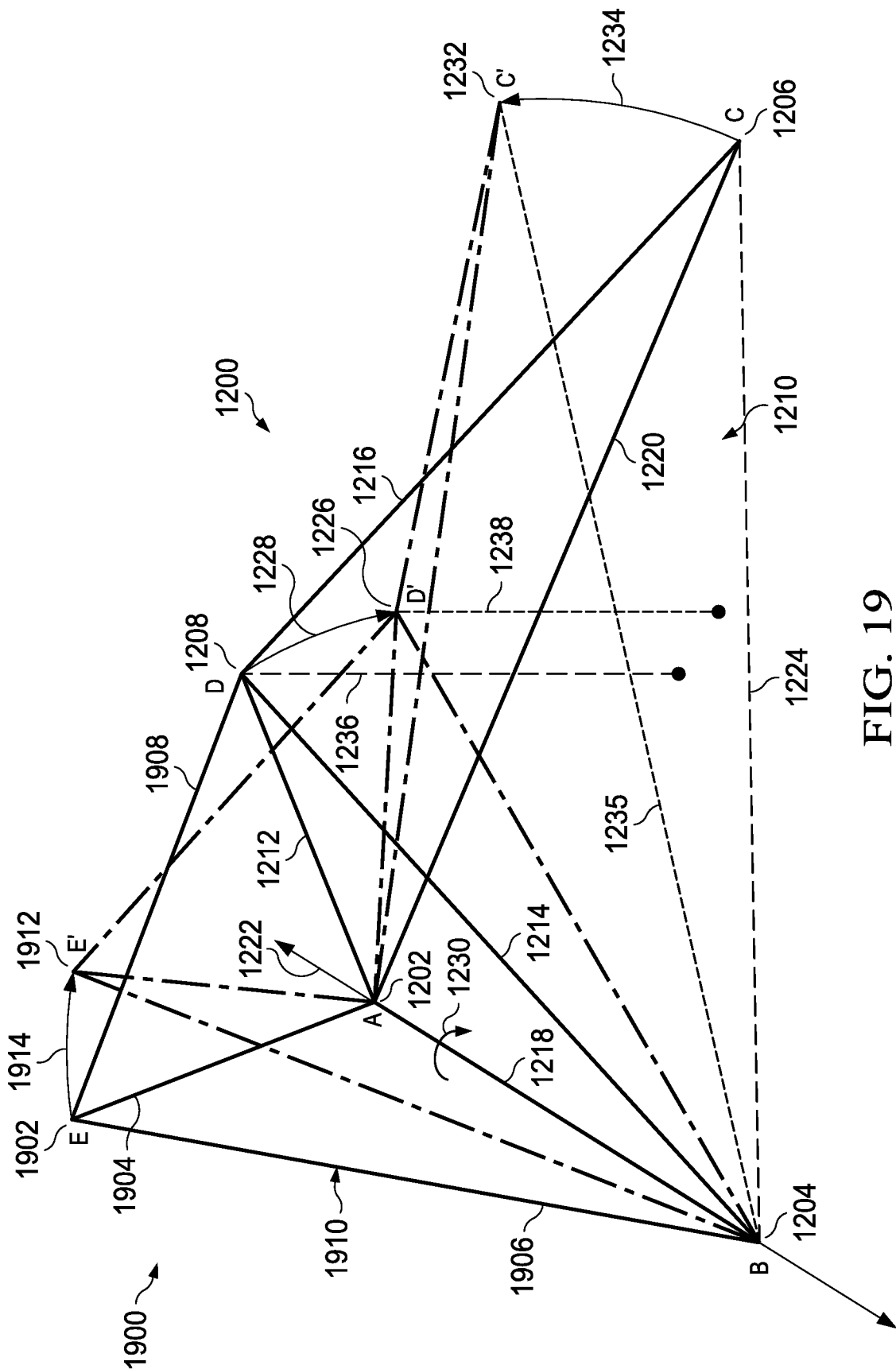
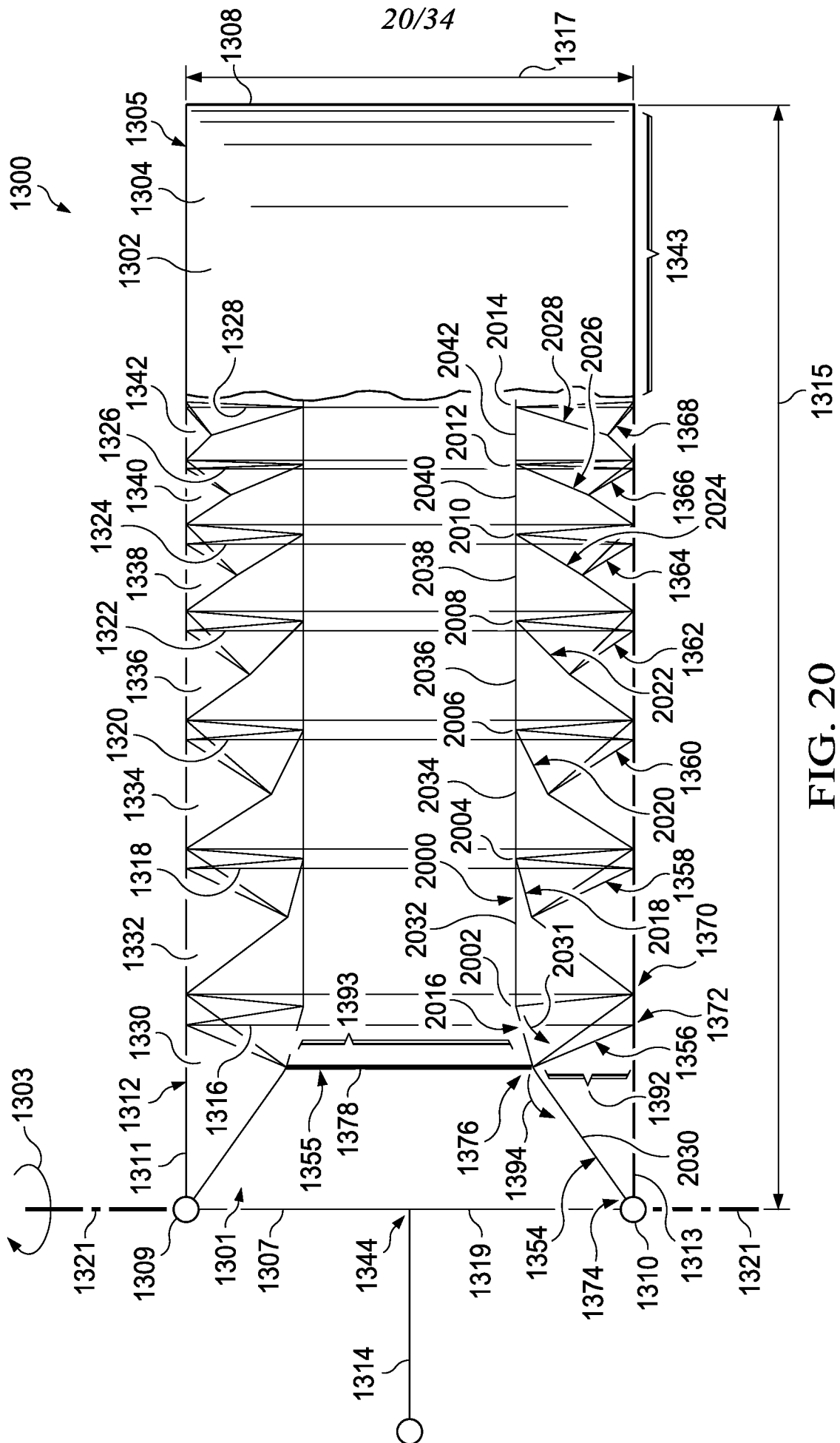


FIG. 19



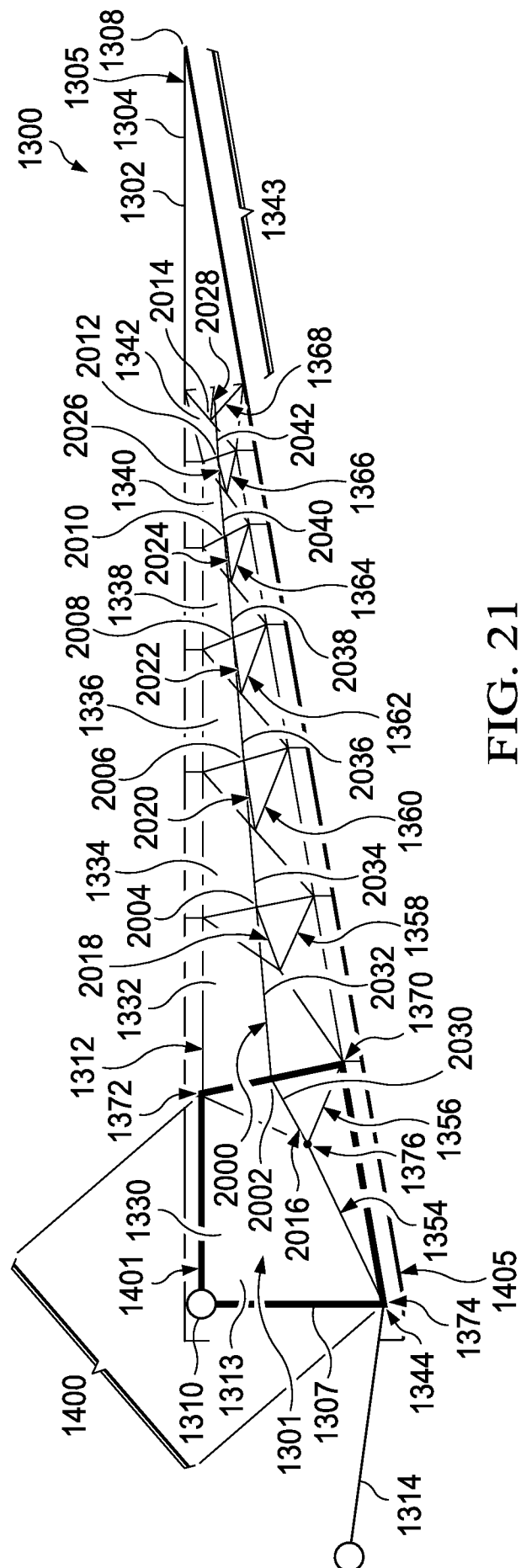
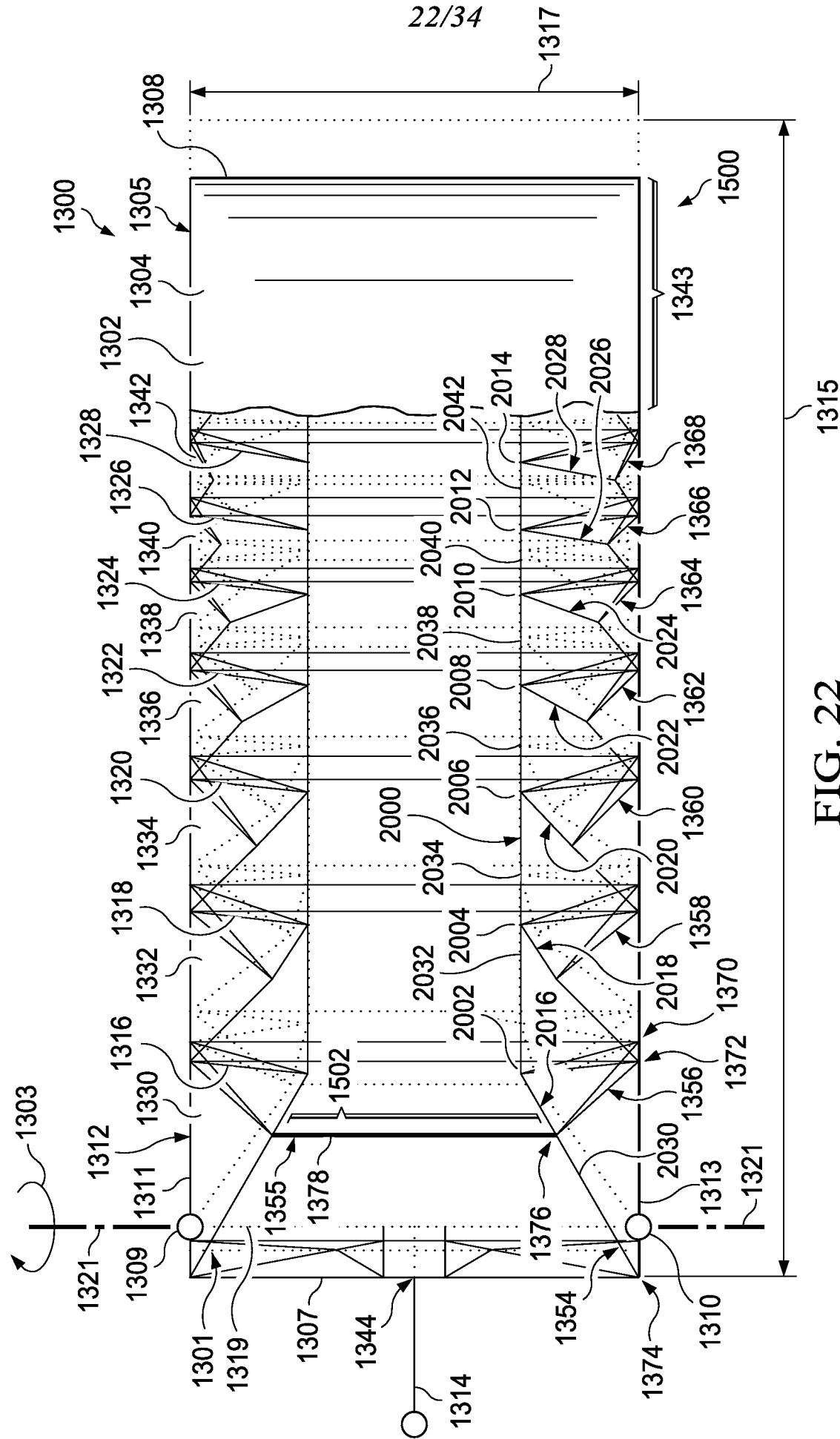


FIG. 21



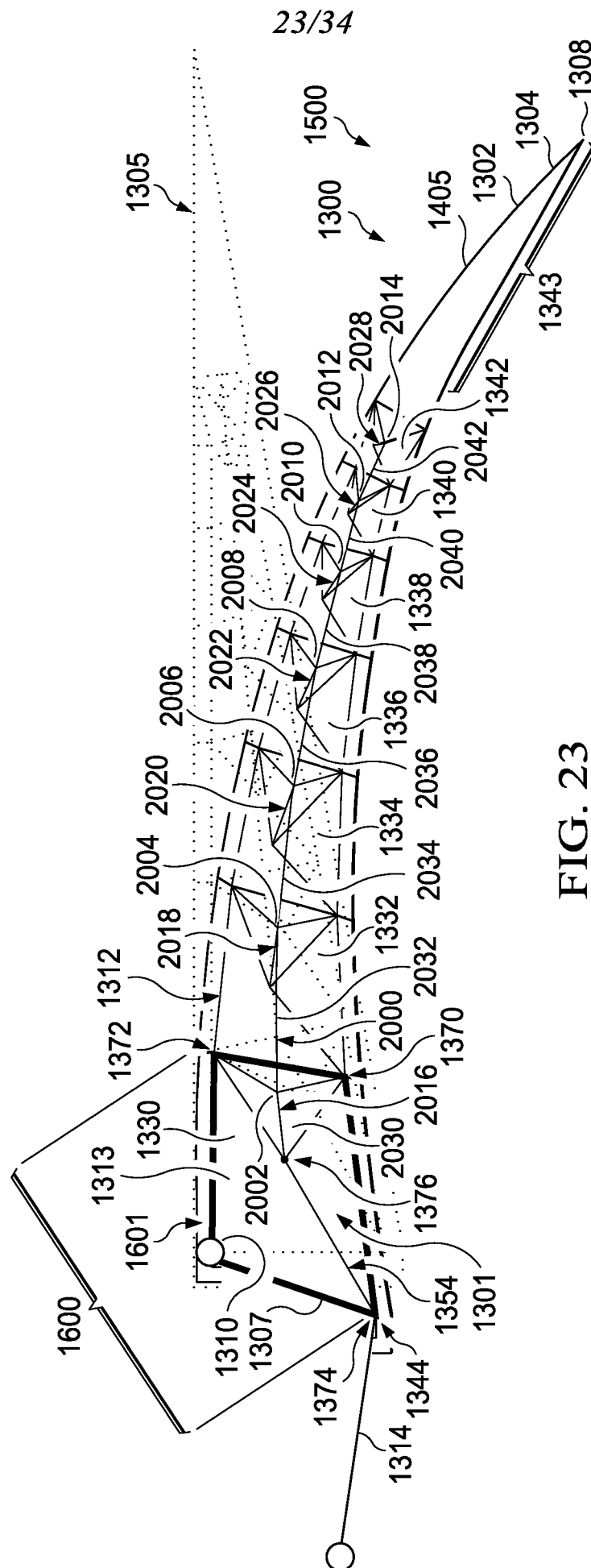
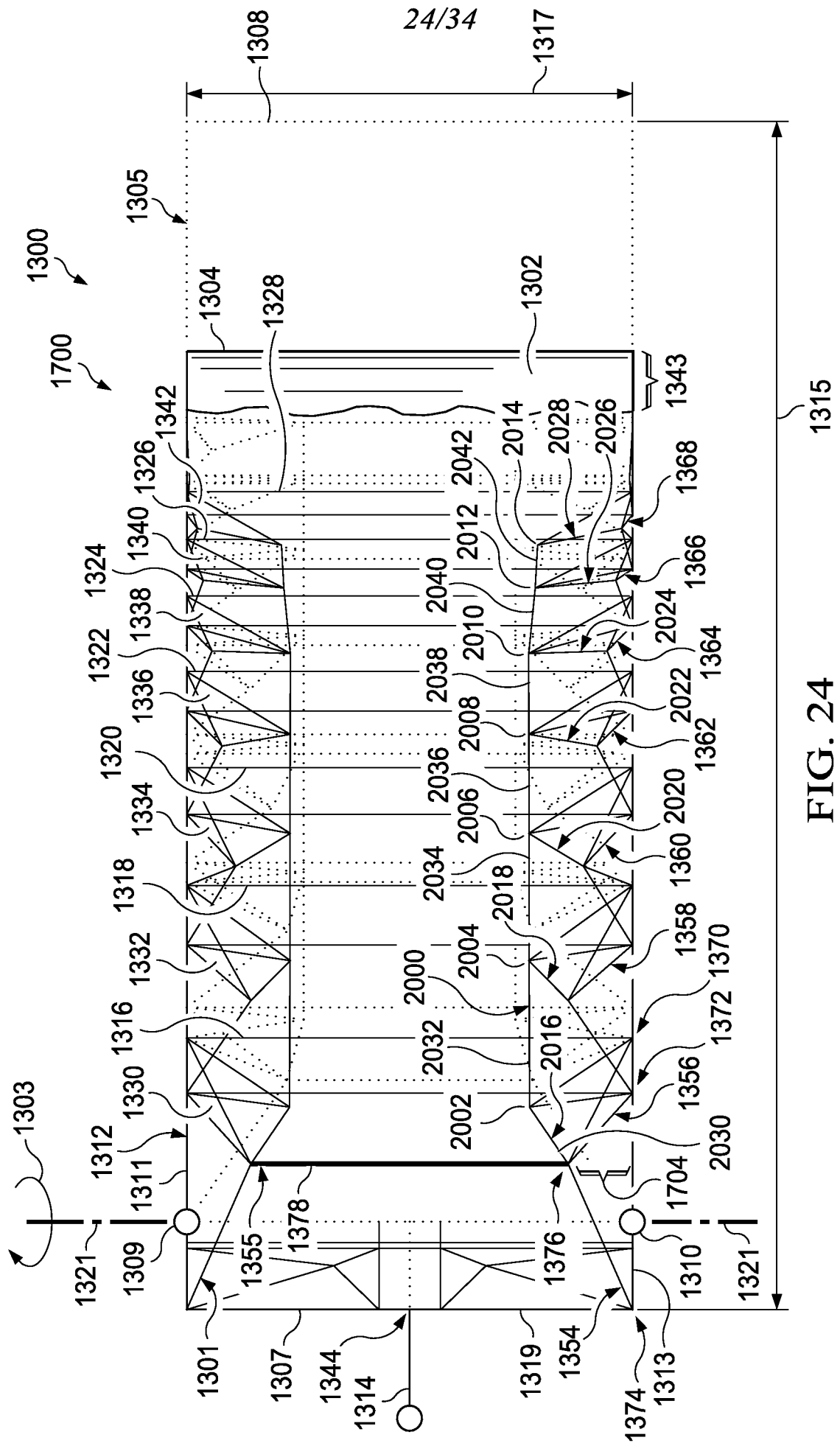


FIG. 23



25/34

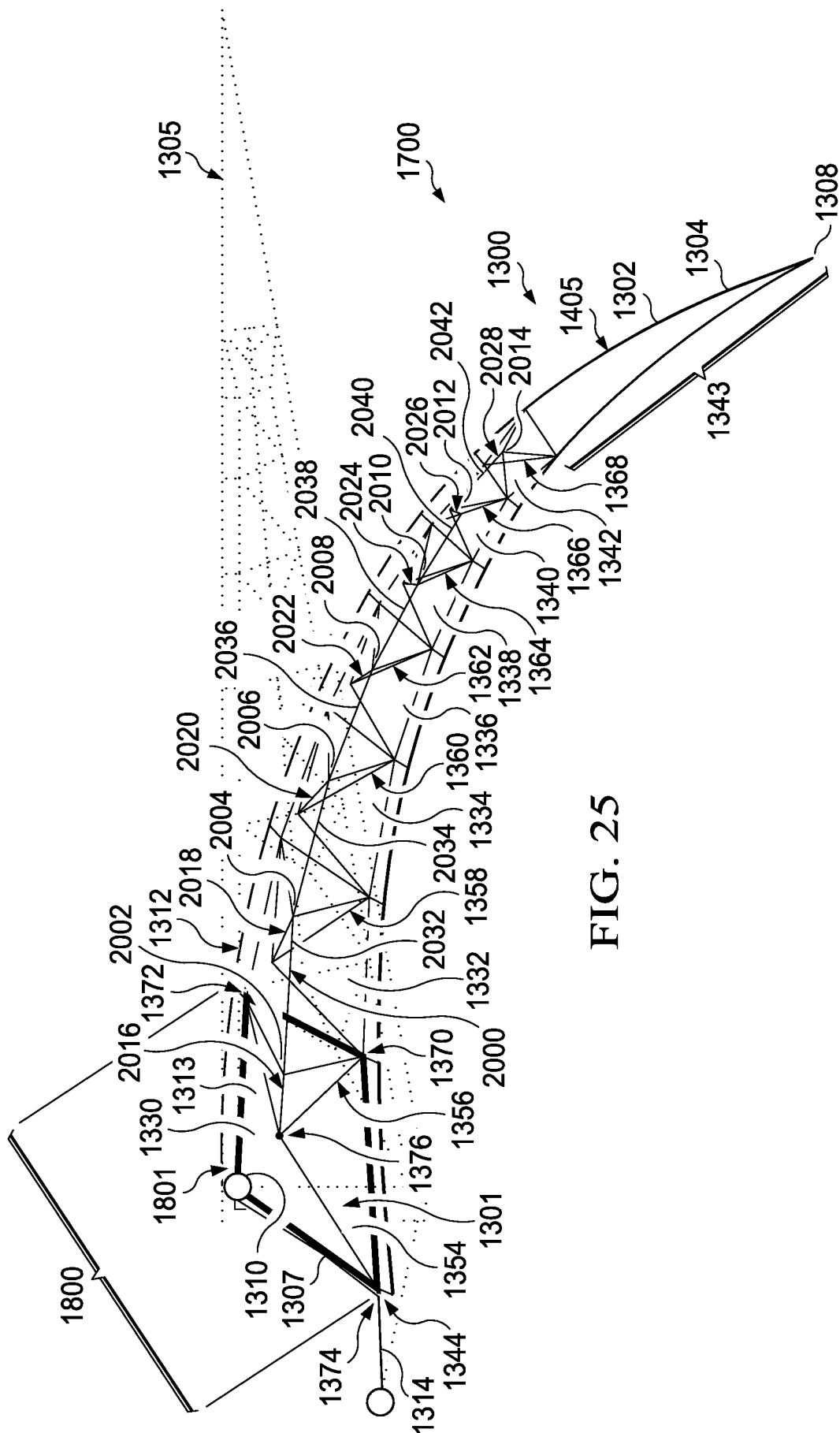


FIG. 25

26/34

FIG. 26

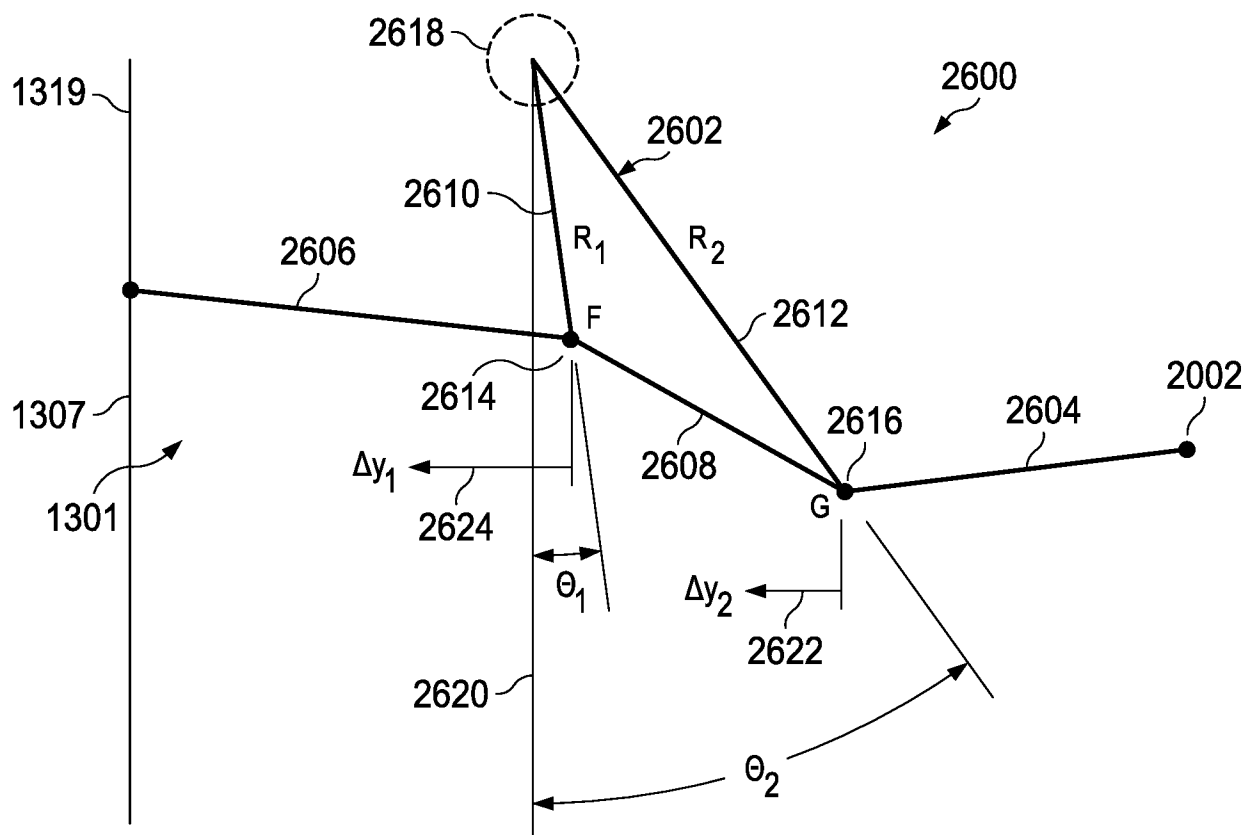
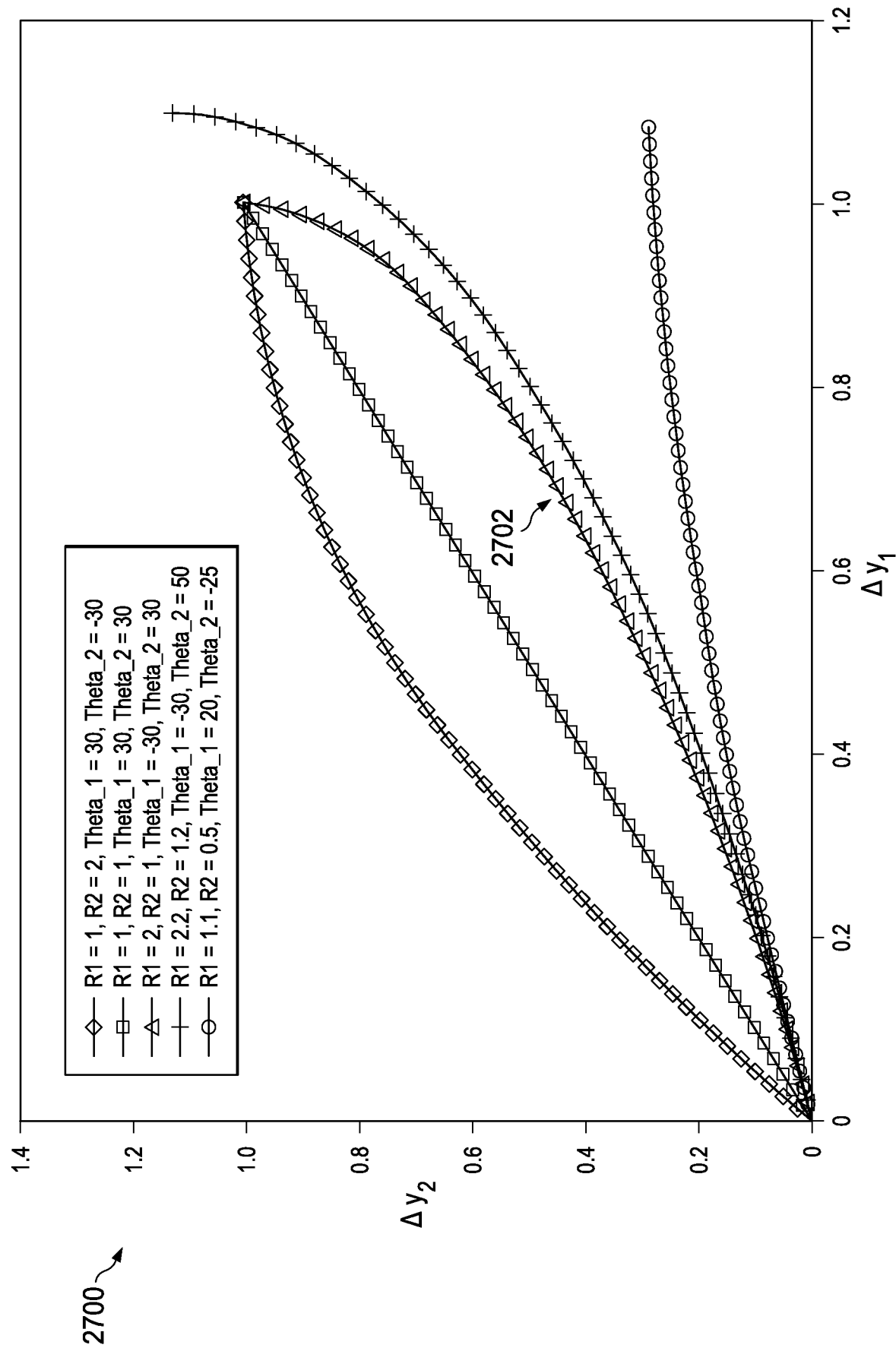


FIG. 27



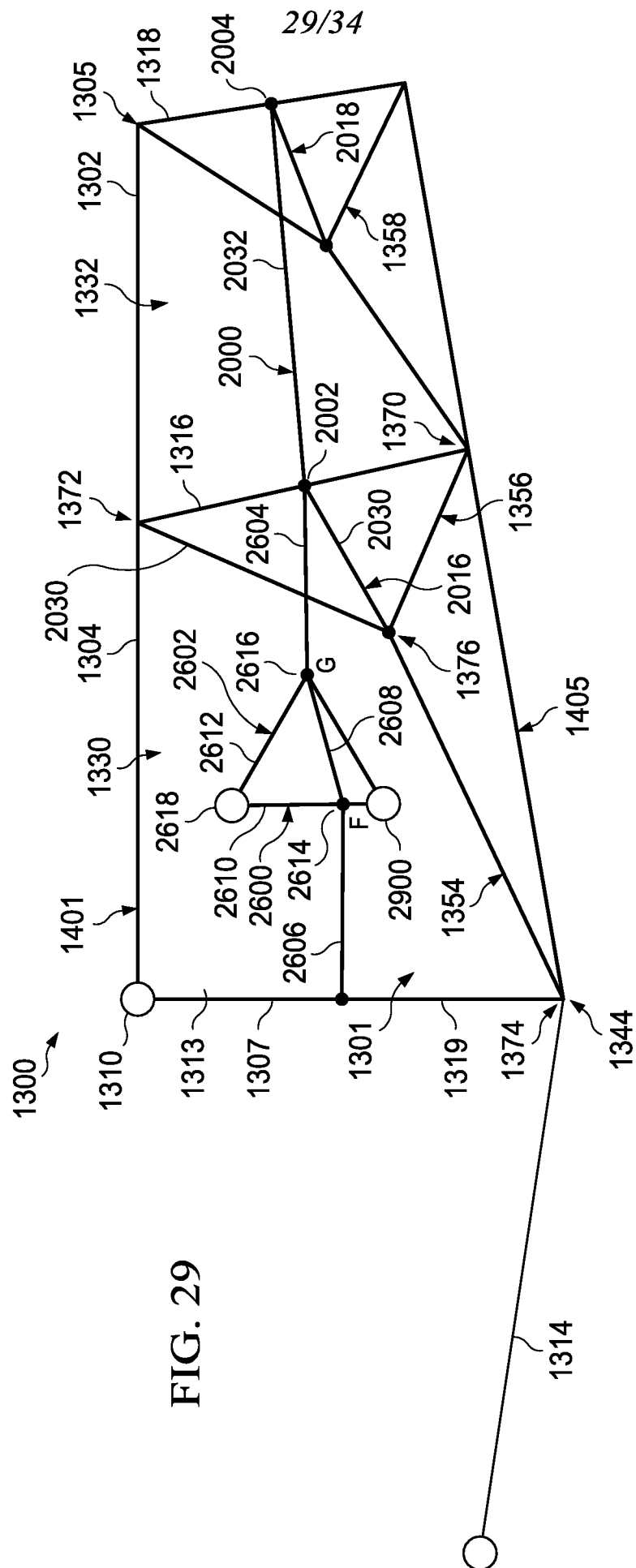


FIG. 29

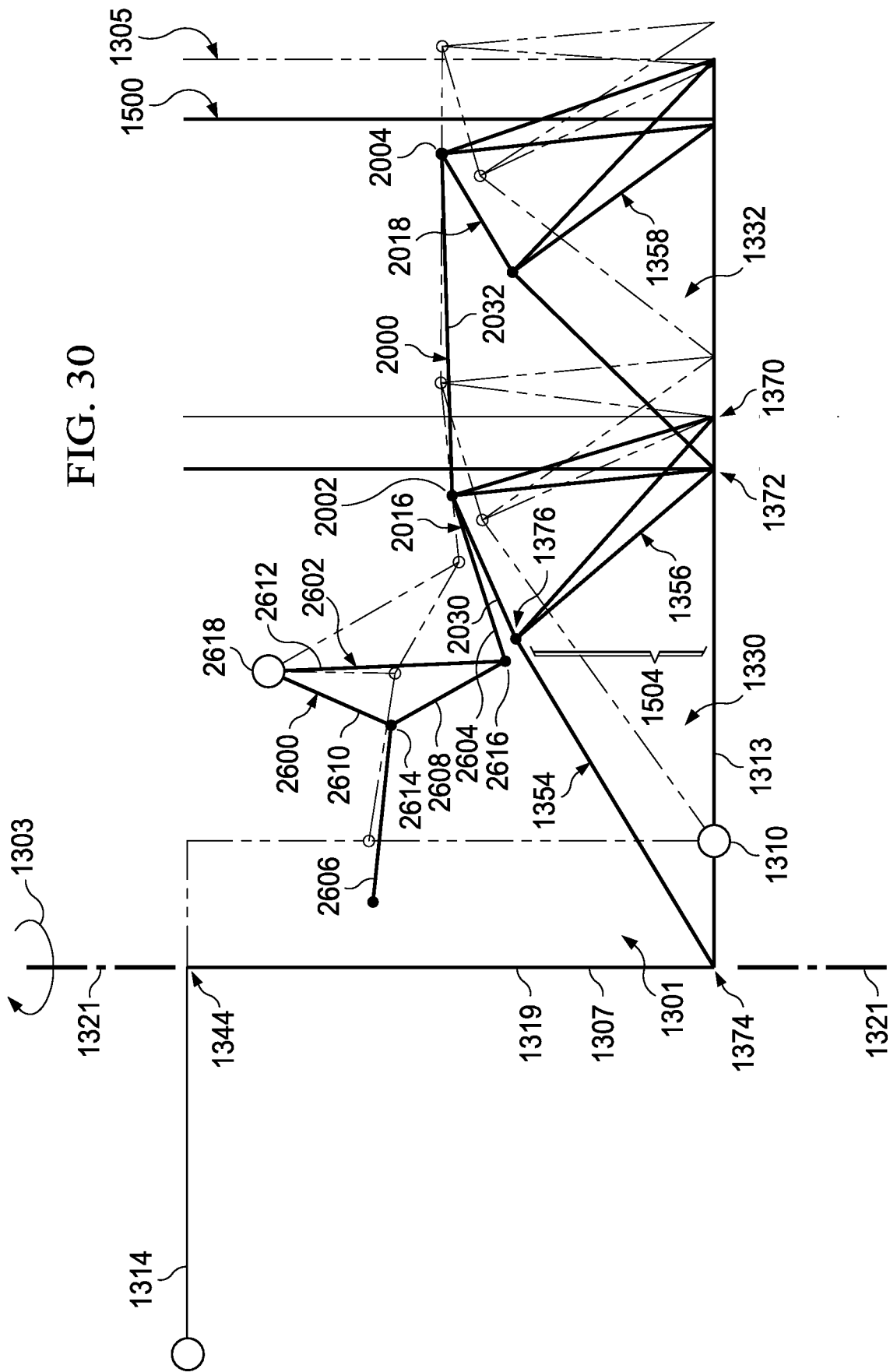


FIG. 30

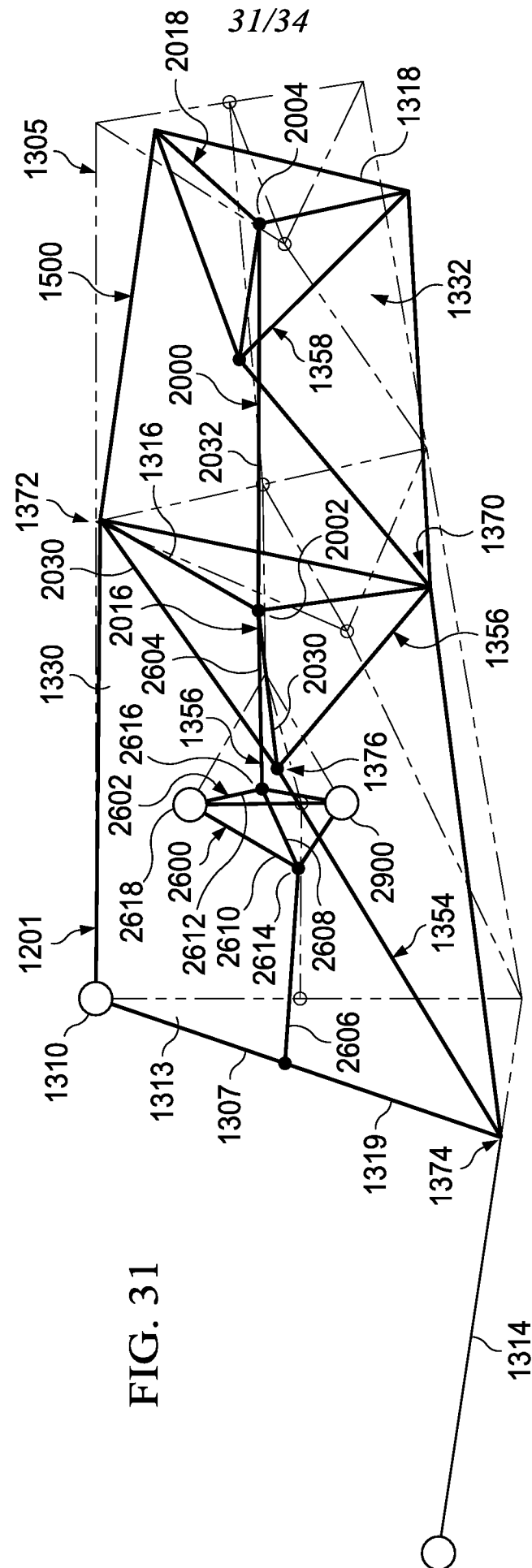


FIG. 31

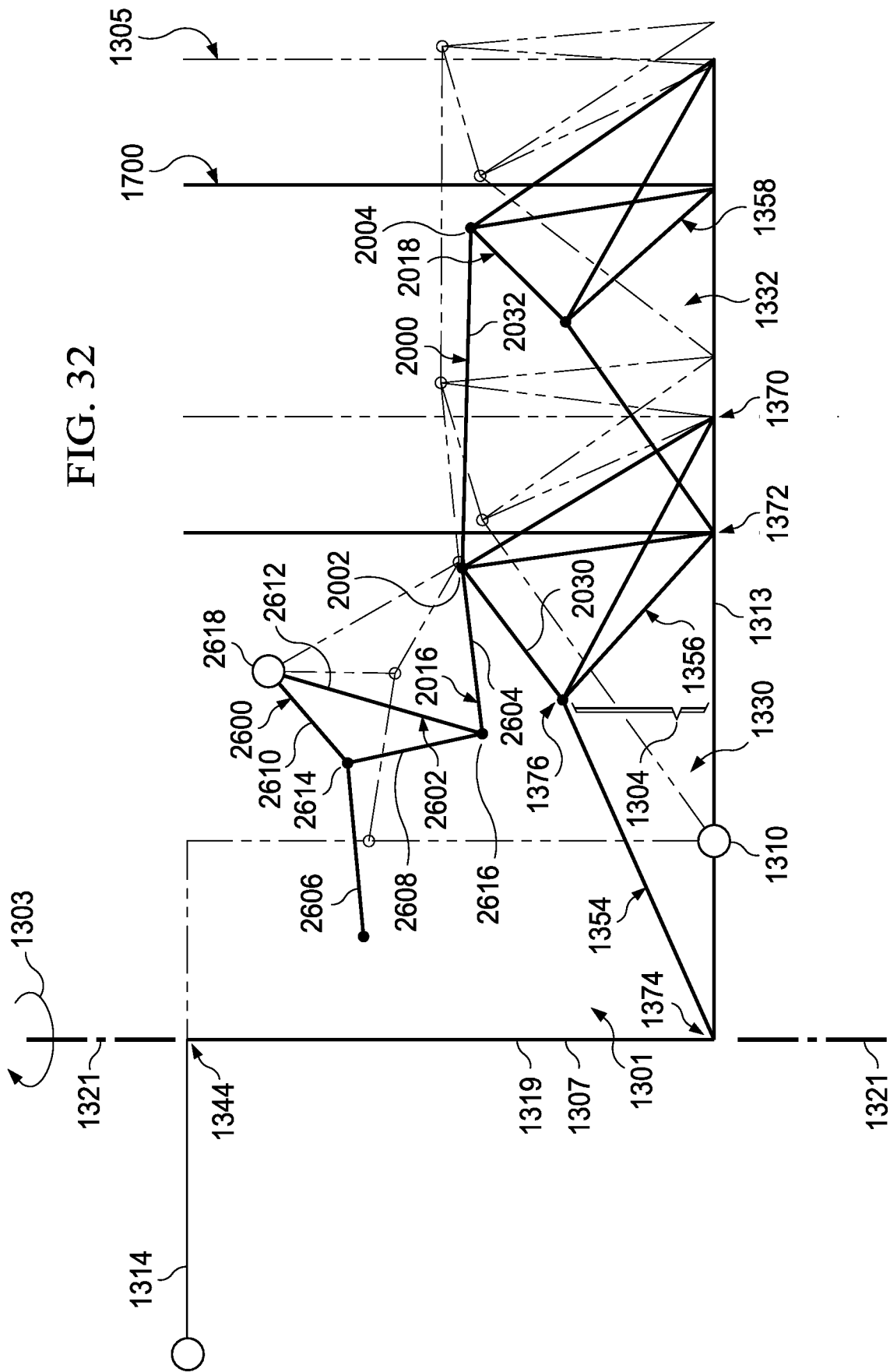


FIG. 32

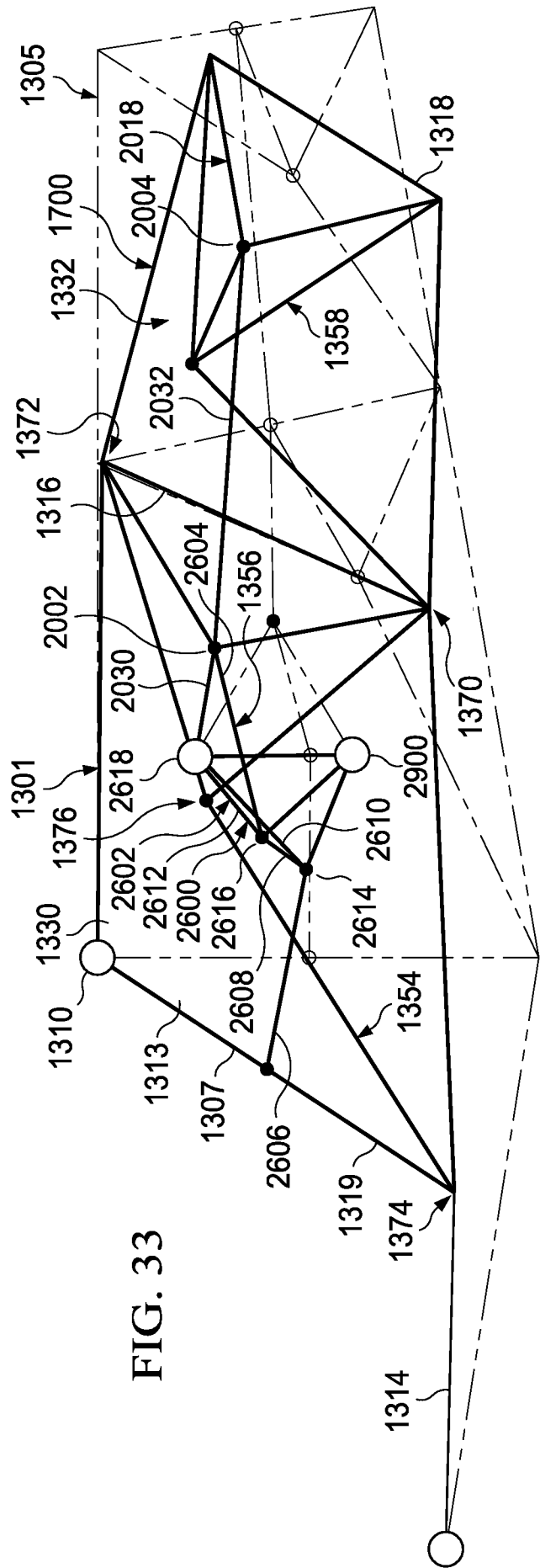


FIG. 33

34/34

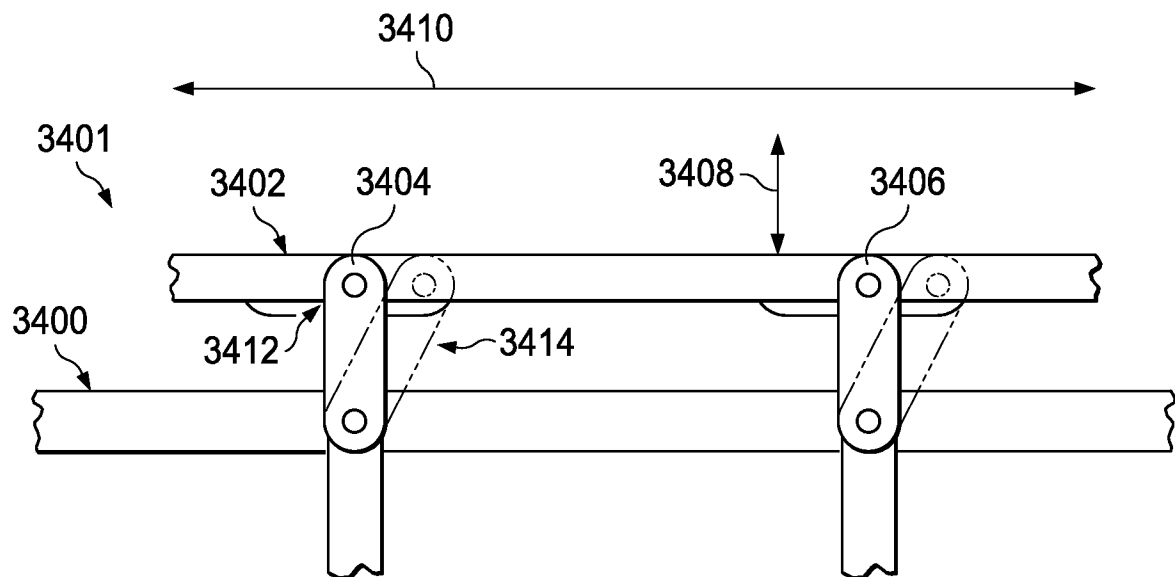


FIG. 34

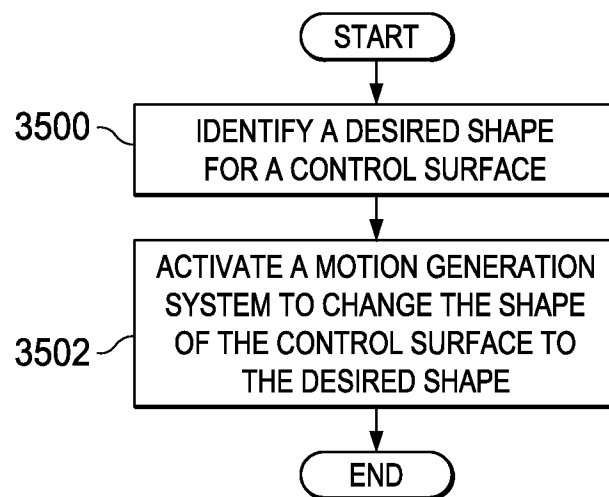


FIG. 35