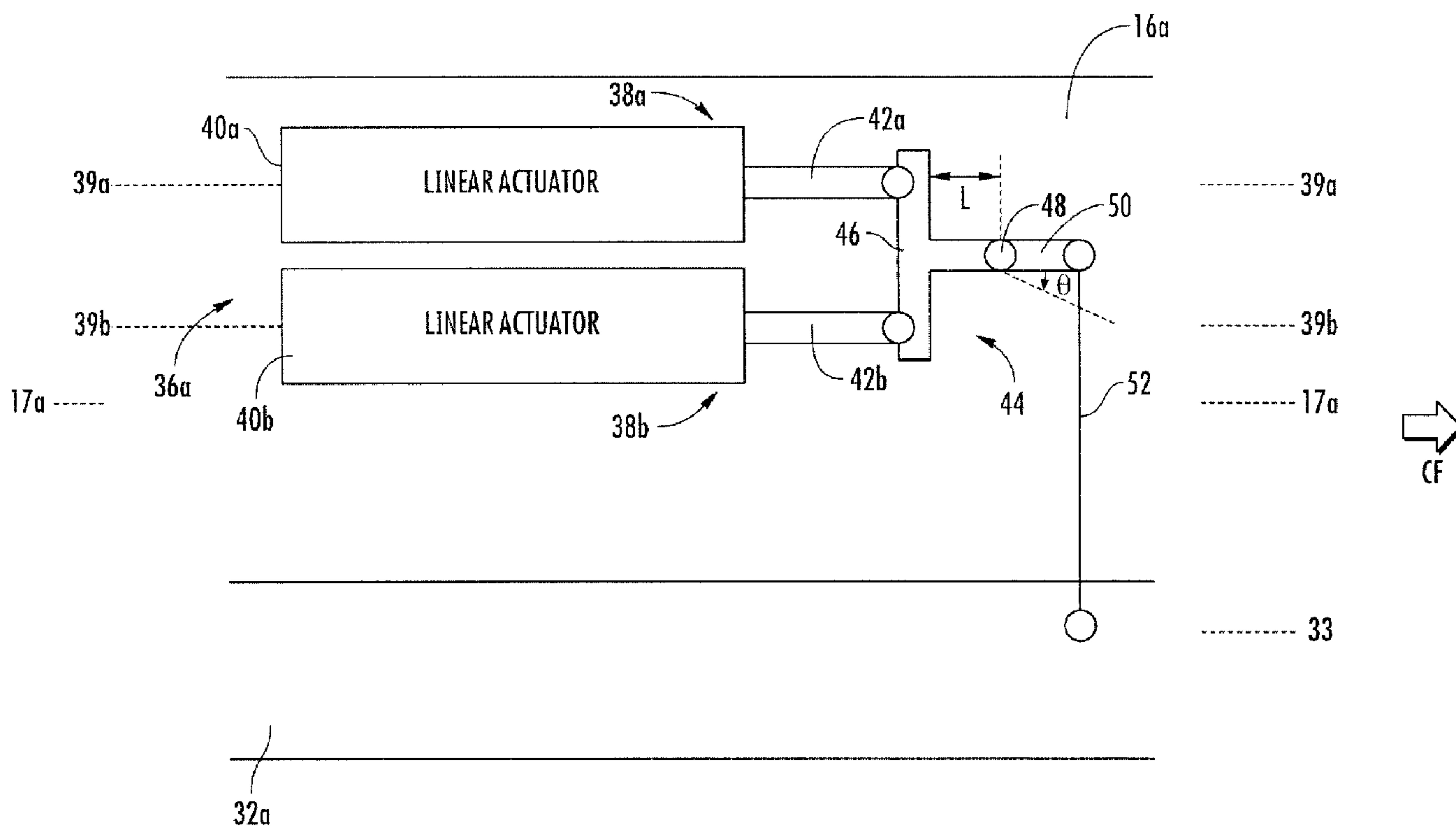




(22) Date de dépôt/Filing Date: 2010/11/01  
(41) Mise à la disp. pub./Open to Public Insp.: 2012/05/10  
(62) Demande originale/Original Application: 2 813 952

(51) Cl.Int./Int.Cl. *B64C 27/615* (2006.01),  
*B64C 13/24* (2006.01), *B64C 13/30* (2006.01),  
*F16H 21/44* (2006.01)  
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(54) Titre : PROCÉDE ET APPAREIL POUR LA MANIPULATION ACTIVE DE SURFACES AERODYNAMIQUES  
(54) Title: METHOD AND APPARATUS FOR ACTIVELY MANIPULATING AERODYNAMIC SURFACES



(57) **Abrégé/Abstract:**

A method and apparatus is provided, including an actuator system that may be connected to a wing frame for controlling an active element. The actuator system may include sliding elements movable along an axis parallel to the span-wise axis of the wing. The sliding elements may be connected to fixed elements and a crank element, the crank element generally comprising a beam element and a pivot element. The beam element may be offset from the pivot element so that the crank element is rotatable about the pivot element with a negative stiffness under an external force that tends to pull the sliding elements away from the fixed elements.

## Abstract

A method and apparatus is provided, including an actuator system that may be connected to a wing frame for controlling an active element. The actuator system may include sliding elements movable along an axis parallel to the span-wise axis of the wing. The sliding elements may be connected to fixed elements and a crank element, the crank element generally comprising a beam element and a pivot element. The beam element may be offset from the pivot element so that the crank element is rotatable about the pivot element with a negative stiffness under an external force that tends to pull the sliding elements away from the fixed elements.

## METHOD AND APPARATUS FOR ACTIVELY MANIPULATING AERODYNAMIC SURFACES

### Technical Field

This disclosure relates in general to the field of heavier-than-air aircraft, and  
5 more particularly to a method and apparatus for actively manipulating aerodynamic  
surfaces.

### Description of the Prior Art

Emerging and future generations of rotary-wing and tilt-rotor aircraft have active  
elements on the blade or wing, such as trailing edge flaps and leading edge droops,  
10 which can provide a number of enhancements over passive designs. For example,  
active elements can be used for vibration reduction, noise reduction, and performance  
improvements. Actuator systems are needed to operate active elements, but actuator  
systems also add weight and complexity to the aircraft. Accordingly, the design of  
powerful, light-weight actuator systems presents significant challenges to engineers and  
15 manufacturers.

### Summary

In one aspect, there is provided an apparatus, comprising: a first linear actuator  
having a first fixed element and a first sliding element; a second linear actuator having a  
second fixed element and a second sliding element; a beam element connected on a  
20 first end to the first sliding element and connected on a second end to the second  
sliding element; a pivot element connected to the beam element between the first  
sliding element and the second sliding element; and an arm element having a first end  
connected to the beam element. In a particular embodiment, the first linear actuator is  
aligned in series with the second linear actuator.

25 In another aspect, there is provided an aircraft, comprising: a fuselage; a wing  
having span-wise axis, a frame connected to the fuselage, and an active element; a first

linear actuator having a first stator element and a first sliding element; a second linear actuator having a second stator element and a second sliding element; a beam element connected on a first end to the first sliding element and connected on a second end to the second sliding element; a pivot element connected to the beam element between  
5 the first sliding element and the second sliding element; and an arm element having a first end connected to the beam element and a second end connected to the active element; wherein the first stator element and the second stator element are rigidly connected to the wing frame. In a particular embodiment, the first linear actuator is aligned in series with the second linear actuator.

10 In another aspect, there is provided an aircraft, comprising: a fuselage; a wing having span-wise axis, a frame connected to the fuselage, and an active element; and an actuator system connected to the frame and the active element, the actuator system having sliding elements movable along an axis parallel to the span-wise axis of the wing and counterbalanced by each other through a pivot element.

15 In another aspect, there is provided an apparatus, comprising: a first linear actuator having a first fixed element and a first sliding element; a second linear actuator having a second fixed element and a second sliding element; a first tension belt portion fastened on a first end to the first sliding element and routed around a first pivot element for fastening on a second end to an active element; and a second tension belt portion  
20 fastened on a first end to the second sliding element and routed around a second pivot element for fastening on a second end to the active element.

In another aspect, there is provided an apparatus for manipulating an aerodynamic surface, comprising: a first linear actuator having a first fixed element and a first sliding element; a second linear actuator having a second fixed element and a  
25 second sliding element; a beam element connected on a first end to the first sliding element and connected on a second end to the second sliding element; a pivot element connected to the beam element between the first sliding element and the second sliding element; and an arm element coupled to the aerodynamic surface and having a first end

connected to the beam element; wherein the pivot element is offset from the beam element.

In another aspect, there is provided an aircraft, comprising: a fuselage; a wing having span-wise axis, a frame connected to the fuselage, and an active element; and  
5 an actuator system connected to the frame and the active element, the actuator system having sliding elements movable along an axis parallel to the span-wise axis of the wing and counterbalanced by each other through a pivot element; wherein the sliding elements are movably disposed within fixed elements and connected to a crank element, the crank element comprising a beam element offset from the pivot element so  
10 that the crank element is rotatable about the pivot element with a negative stiffness under an external force that tends to pull the sliding elements away from the fixed elements.

In a further aspect, there is provided an aircraft, comprising: a fuselage; a wing having span-wise axis, a frame connected to the fuselage, and an active element; a first  
15 linear actuator having a first stator element and a first sliding element; a second linear actuator having a second stator element and a second sliding element; a beam element connected on a first end to the first sliding element and connected on a second end to the second sliding element; a pivot element connected to the beam element between the first sliding element and the second sliding element the pivot element being offset  
20 from the beam element; and an arm element having a first end connected to the beam element and a second end connected to the active element; wherein the first stator element and the second stator element are rigidly connected to the wing frame.

#### Brief Description of the Drawings

The method and apparatus (collectively, the system) for active manipulation of  
25 aerodynamic surfaces, as well as a preferred mode of use, and further objectives and advantages thereof, will best be understood by reference to the following detailed description when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a perspective view of an example embodiment of a helicopter according to the present specification;

Figure 2 is a partial top view of an example embodiment of a helicopter having an active blade element and actuator system according to the present specification;

5 Figure 3 is a simple top-view schematic of an example embodiment of an actuator system according to the present specification having a span-wise orientation and a parallel configuration of linear actuators in a rotor blade;

10 Figure 4 is a simple side-view schematic of an example embodiment of an actuator system according to the present specification having a span-wise orientation and a parallel configuration of linear actuators in a rotor blade;

Figure 5 is a cut-away view of an example embodiment of a linear motor actuator according to the present specification;

15 Figure 6 is a simple top-view schematic of another example embodiment of an actuator system according to the present specification having a span-wise orientation and a serial configuration of linear actuators in a rotor blade; and

Figure 7 is a perspective view of another example embodiment of an actuator system according to the present specification having a span-wise orientation and a parallel configuration of linear actuators in a rotor blade.

20 While the system and apparatus for active manipulation of aerodynamic forces is susceptible to various modifications and alternative forms, the novel features thereof are shown and described below through specific example embodiments. It should be understood, however, that the description herein of specific example embodiments is not intended to limit the system or apparatus to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives  
25 falling within the scope of the disclosure.

### Description of the Preferred Embodiment

Illustrative embodiments of the novel system are described below. In the interest of clarity, not all features of such embodiments may be described. It should be appreciated that in the development of any such system, numerous implementation-specific decisions must be made to achieve specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it should be appreciated that such decisions might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

Reference may be made to the spatial relationships between various components and to the spatial orientation of various aspects of components as the system is depicted in the attached drawings. However, as should be recognized by those skilled in the art, the elements, members, components, *etc.* described herein may be positioned in any desired orientation. Thus, the use of terms such as “above,” “below,” “upper,” “lower,” or other like terms to describe a spatial relationship between various components or to describe the spatial orientation of aspects of such components should be understood to describe a relative relationship between the components or a spatial orientation of aspects of such components, respectively, as the example embodiments described herein may be oriented in any desired direction.

Referring to the appended drawings, Figure 1 is a perspective view of an example embodiment of a helicopter 10 according to the present specification. In general, helicopter 10 has a fuselage 12 and a main rotor assembly 14, which includes main rotor blades 16a-c and a main rotor shaft 18. Helicopter 10 may also include a tail rotor assembly 20, which generally includes tail rotor blades 22 and a tail rotor shaft 24. Main rotor blades 16a-c may rotate about a longitudinal axis 26 of main rotor shaft 18. Tail rotor blades may rotate about a longitudinal axis 28 of tail rotor shaft 24. Also illustrated in Figure 1 are flaps 32a-b and actuator systems 36a-b on main rotor blades

16a-b, respectively. Not visible in Figure 1 are flap 32c and actuator system 36c on main rotor blade 16c.

Figure 2 is a partial top view of helicopter 10, including main rotor blade 16a, connected to a hub 30 on main rotor shaft 18. In the example embodiment of helicopter 5 10, main rotor blade 16a may include additional active elements that may be used to manipulate aerodynamic surfaces, such as flap 32a. Flap 32a in the example embodiment of helicopter 10 is placed outboard along the trailing edge 34a, but may be placed in other positions according to particular design criteria. And while flap 32a is illustrated and described herein as a distinct component of main rotor blade 16a, it may 10 also be any movable or flexible portion of main rotor blade 16a. An example embodiment of actuator system 36a is also depicted in the cut-away section Figure 2, generally oriented parallel to a span-wise axis 17a of main rotor blade 16a. During operation, main rotor blade 16a may rotate about hub 30, while actuator system manipulates flap 32a. The rotation causes a number of reactive forces, including lift and 15 centrifugal forces (CF).

Figure 3 is a simple top-view schematic of actuator system 36a in main rotor blade 16a. Actuator system 36a may include linear actuators 38a-b. Each linear actuator 38a-b typically includes a fixed or stationary element, such as stators 40a-b, and a moving or sliding element, such as sliders 42a-b. Stators 40a-b in the example 20 embodiment are rigidly connected to the frame of main rotor blade 16a, and they may be identical elements or may have distinct properties for certain applications. Likewise, sliders 42a-b may be identical or have distinct properties for certain applications. Linear actuators 38a-b each has an elongated shape with a lengthwise axis 39a-b that is generally oriented parallel with span-wise axis 17a of main rotor blade 16a. In the 25 example embodiment of Figure 3, linear actuators 38a-b are also generally oriented parallel to each other along the span of main rotor blade 16a. Such a span-wise orientation is generally preferable to other orientations as it generally provides larger space in the blade for larger, more powerful motors with longer strokes, and better mass placement.

In actuator system 36a, a crank 44 is connected to sliders 42a-b. Crank 44 includes a beam element 46, a pivot element 48, and an arm element 50. Examples of pivot element 48 include a conventional bearing with rolling elements, an elastomeric element, a sleeve bushing, or a structural flexure. Pivot element 48 may be positioned coincident with beam element 46, or may be offset a distance L relative to beam element 46, as shown in Figure 3. By adjusting distance L, the large centrifugal force acting on sliders 42a-b may be used advantageously to create a negative stiffness spring effect, wherein the negative spring constant, k, is proportional to the centrifugal force CF, distance L, and angular displacement  $\theta$  ( $-k = CF \cdot L \cdot \sin(\theta) / \theta$ ). The negative spring effect may counteract aerodynamic forces and reduce actuator power requirements, thereby also potentially reducing the mass of actuator system 36a. Arm element 50 may be rigidly attached to beam element 46, or beam element 46 and arm element may 50 be fabricated as a single element.

Figure 4 is a simple side-view schematic of actuator system 36a. Stators 40a-b are preferably placed within the frame of main rotor blade 16a in parallel. Connecting rod 52 connects actuator system 36a to flap 32a through crank 44 (see Figure 3) and sliders 42a-b (see Figure 3). Flap 32a may rotate about an axis 33 in response to force from connecting rod 52. Alternate positions of flap 32a as it rotates about axis 33 are illustrated in phantom as flaps 32a-1 and 32a-2.

Figure 5 is a cut-away view of an example embodiment of a linear actuator 60. In this embodiment, linear actuator 60 is an electromagnetic linear motor having a fixed element, stator 62, having electric coils, and an elongated, high-power permanent magnetic slider 64. The slider 64 moves and converts electrical power to useful work. The motion, position, and retention of slider 64 are controlled with electromagnetic force generated with the electric coils of stator 62. Such an actuator may provide benefits in certain applications where high bandwidth and large stroke with a small footprint are desirable. For example, an electromagnetic motor such as linear actuator 60 may be advantageous in a helicopter rotor blade where vibrations and noise are counteracted

with relatively small flap deflections at high frequency, but performance is enhanced with larger deflections at a lower frequency.

During rotation of main rotor blade 16a, the centrifugal forces are carried across beam element 46 and reacted by pivot 48, effectively canceling the tendency of sliders 5 42a-b to sling outward because of the centrifugal forces. Crank 44 is similar to a common bell crank, and as it rotates it converts the span-wise motion of sliders 42a-b into chord-wise motion that may be used to manipulate an active element, such as flap 32a, which is connected to arm element 50 through a connecting rod 52 or similar linkage.

10 In operation, sliders 42a-b are actuated such that each reciprocates generally parallel to axis 17a and slider 42a moves opposite to slider 42b. Thus, as slider 42a moves in the outboard direction of main rotor blade 16a, slider 42b moves inboard. And as slider 42a moves outboard and slider 42b moves inboard, crank 44 rotates about pivot element 48, causing arm element 50 to advance toward trailing edge 34a of main 15 rotor blade 16a. The movement of arm element 50 toward trailing edge 34a in turn causes connecting rod 52 to act on flap 32a, which may rotate about axis 33 to position 32a-1.

Conversely, as slider 42a moves inboard and slider 42b moves outboard, crank 44 rotates in the opposite direction about pivot element 48, causing arm element 50 to 20 retreat from trailing edge 34a. The movement of arm element 50 away from trailing edge 34b in turn causes connecting rod 52 to act on flap 32a, which may rotate about axis 33 to another position, such as 32a-2.

Figure 6 is a simple top-view schematic of another example embodiment of an actuator system 70 in a main rotor blade 72 according to the present specification. 25 Actuator system 70 may include linear actuators 74a-b. Each linear actuator 74a-b typically includes a fixed or stationary element, such as stators 76a-b, and a moving element or sliding element, such as sliders 78a-b. Stators 76a-b in the example embodiment are rigidly connected to the frame of main rotor blade 72, and they may be

identical elements or may have distinct properties for certain applications. Likewise, sliders 78a-b may be identical or have distinct properties for certain applications. Linear actuators 74a-b each has an elongated shape with a lengthwise axis 75a-b that is generally oriented parallel with span-wise axis 73 of main rotor blade 72. In contrast to  
5 linear actuators 38a-b in Figure 3, linear actuators 74a-b are generally oriented in series along the span of main rotor blade 72.

In actuator system 70, a crank 80 is connected to sliders 78a-b. Crank 80 includes a beam element 82, a pivot element 84, and an arm element 86. Extension elements 79a-b may be used to connect sliders 78a-b to beam element 82. Examples  
10 of pivot element 84 include a conventional bearing with rolling elements, an elastomeric element, a sleeve bushing, or a structural flexure. Pivot element 84 may be positioned coincident with beam element 82, or may be positioned a distance L relative to beam element 82, as shown in Figure 6. By adjusting distance L, the large centrifugal force acting on sliders 78a-b may be used advantageously to create a negative stiffness  
15 spring effect, wherein the negative spring constant, k, is proportional to the centrifugal force CF, distance L, and angular displacement  $\theta$  ( $-k = CF \cdot L \cdot \sin(\theta) / \theta$ ). The negative spring effect may counteract aerodynamic forces and reduce actuator power requirements, thereby also potentially reducing the mass of actuator system 70. Arm element 86 may be rigidly attached to beam element 82, or beam element 82 and arm  
20 element 86 may be fabricated as a single element.

During rotation of main rotor blade 72, the centrifugal forces are carried across beam element 82 and reacted by pivot element 84, effectively canceling the tendency of sliders 78a-b to sling outward because of the centrifugal forces. Crank 80 is similar to a common bell crank, and as it rotates it converts the span-wise motion of sliders 78a-b  
25 into chord-wise motion that may be used to manipulate an active element, such as flap 88, which is connected to arm element 86 through a connecting rod 90 or similar linkage.

In operation, sliders 78a-b are actuated such that each reciprocates generally parallel to axis 73 and slider 78a moves opposite to slider 78b. Thus, as slider 78a moves in the outboard direction of main rotor blade 72, slider 78b moves inboard. And as slider 78a moves outboard and slider 78b moves inboard, crank 80 rotates about pivot element 84, causing arm element 86 to advance toward trailing edge 92 of main rotor blade 72. The movement of arm element 86 toward trailing edge 92 in turn causes connecting rod 90 to act on flap 88, which may rotate about axis 89.

Conversely, as slider 78a moves inboard and slider 78b moves outboard, crank 80 rotates in the opposite direction about pivot element 84, causing arm element 86 to retreat from trailing edge 92. The movement of arm element 86 away from trailing edge 92 in turn causes connecting rod 90 to act on flap 88, which may rotate about axis 89.

Figure 7 is a perspective view of another example embodiment of an actuator system 100 in a main rotor blade 102 according to the present specification. Actuator system 100 may include linear actuators 104a-b. Each linear actuator 104a-b typically includes a fixed or stationary element and a moving or sliding element, such as sliders 106a-b. The fixed element may be rigidly connected to the frame of main rotor blade 102, and they may be identical elements or may have distinct properties for certain applications. Likewise, sliders 106a-b may be identical or have distinct properties for certain applications. Linear actuators 104a-b each has an elongated shape with a lengthwise axis that is generally oriented parallel with a span-wise axis of main rotor blade 102. In the example embodiment of Figure 7, linear actuators 102a-b are also generally oriented parallel to each other along the span of main rotor blade 16a. Such a span-wise orientation is generally preferable to other orientations as it generally provides larger space in the blade for larger, more powerful motors with longer strokes, and better mass placement.

In actuator system 100, tension belts 108a-b may be connected to sliders 106a-b, respectively. Tension belts 108a-b are routed around pivot elements 110a-b, respectively, and then fastened to an active element 112, such as a flap.

In operation, sliders 106a-b are actuated such that each reciprocates generally parallel to the span-wise axis of main rotor blade 102 and slider 106a moves opposite to slider 106b. Thus, as slider 106a moves in the outboard direction of main rotor blade 102, slider 106b moves inboard. And as slider 106a moves outboard and slider 106b moves inboard, tension belt 108b is pulled inboard about pivot element 110b, causing active element 112 to rotate. Conversely, as slider 106a moves inboard and slider 106b moves outboard, tension belt 108a is pulled inboard about pivot element 110a, causing active element 112 to rotate in the opposite direction.

Alternatively or additionally, an actuator system may include hydraulic, piezoelectric, or electromechanical components. For example, a linear actuator may have a fixed element such as a hydraulic cylinder and a moving element such as a hydraulic ram.

The system and apparatus described herein provides significant advantages, including: (1) reducing or eliminating the adverse effects of centrifugal forces on linear actuators in a span-wise orientation; (2) more powerful motors; (3) longer stroke and greater bandwidth than other systems; and (4) improved mass distribution characteristics.

Certain example embodiments have been shown in the drawings and described above, but variations in these embodiments will be apparent to those skilled in the art. The principles disclosed herein are readily applicable to a variety of aircraft, including many types of rotary wing, tilt-rotor, and fixed wing aircraft, as well as a variety of other active wing elements, including leading edge droops. The preceding description is for illustration purposes only, and the claims below should not be construed as limited to the specific embodiments shown and described.

Claims

1. An apparatus for manipulating an aerodynamic surface, comprising:  
a first linear actuator having a first fixed element and a first sliding element;  
a second linear actuator having a second fixed element and a second sliding  
5 element;  
a beam element connected on a first end to the first sliding element and  
connected on a second end to the second sliding element;  
a pivot element connected to the beam element between the first sliding element  
and the second sliding element; and  
10 an arm element coupled to the aerodynamic surface and having a first end  
connected to the beam element;  
wherein the pivot element is offset from the beam element.
2. The apparatus of claim 1, wherein the first linear actuator and the second linear  
15 actuator are electromagnetic actuators.
3. The apparatus of claim 1 or 2, wherein the first linear actuator is aligned parallel  
to the second linear actuator.
- 20 4. The apparatus of claim 1 or 2, wherein the first linear actuator is aligned in series  
with the second linear actuator.
5. An aircraft, comprising:  
a fuselage;  
25 a wing having span-wise axis, a frame connected to the fuselage, and an active  
element; and  
an actuator system connected to the frame and the active element, the actuator  
system having sliding elements movable along an axis parallel to the span-wise axis of  
the wing and counterbalanced by each other through a pivot element;

wherein the sliding elements are movably disposed within fixed elements and connected to a crank element, the crank element comprising a beam element offset from the pivot element so that the crank element is rotatable about the pivot element with a negative stiffness under an external force that tends to pull the sliding elements  
5 away from the fixed elements.

6. An aircraft, comprising:  
a fuselage;  
a wing having span-wise axis, a frame connected to the fuselage, and an active  
10 element;  
a first linear actuator having a first stator element and a first sliding element;  
a second linear actuator having a second stator element and a second sliding  
element;  
a beam element connected on a first end to the first sliding element and  
15 connected on a second end to the second sliding element;  
a pivot element connected to the beam element between the first sliding element  
and the second sliding element the pivot element being offset from the beam element;  
and  
an arm element having a first end connected to the beam element and a second  
20 end connected to the active element;  
wherein the first stator element and the second stator element are rigidly  
connected to the wing frame.

7. The aircraft of claim 5 or 6, wherein the first sliding element and the second  
25 sliding element are aligned to be movable along an axis parallel to the span-wise axis of  
the wing.

8. The aircraft of any one of claims 5 to 7, wherein the wing is rotatable about a hub  
connected to the fuselage.

9. The aircraft of any one of claims 6 to 8, wherein the first linear actuator and the second linear actuator are electromagnetic motors.
10. The apparatus of any one of claims 6 to 9, wherein the first linear actuator is  
5 aligned parallel to the second linear actuator.
11. The aircraft of any one of claims 6 to 9, wherein the first linear actuator is aligned in series with the second linear actuator.
- 10 12. The aircraft of claim 6, wherein:  
the wing is rotatable about a hub connected to the fuselage;  
the first sliding element and the second sliding element are aligned to be  
movable along an axis parallel to the span-wise axis of the wing; and  
the first linear actuator is aligned parallel to the second linear actuator.  
15
13. The aircraft of claim 6, wherein:  
the wing is rotatable about a hub connected to the fuselage;  
the first sliding element and the second sliding element are aligned to be  
movable along an axis parallel to the span-wise axis of the wing; and  
20 the first linear actuator is aligned in series with the second linear actuator.

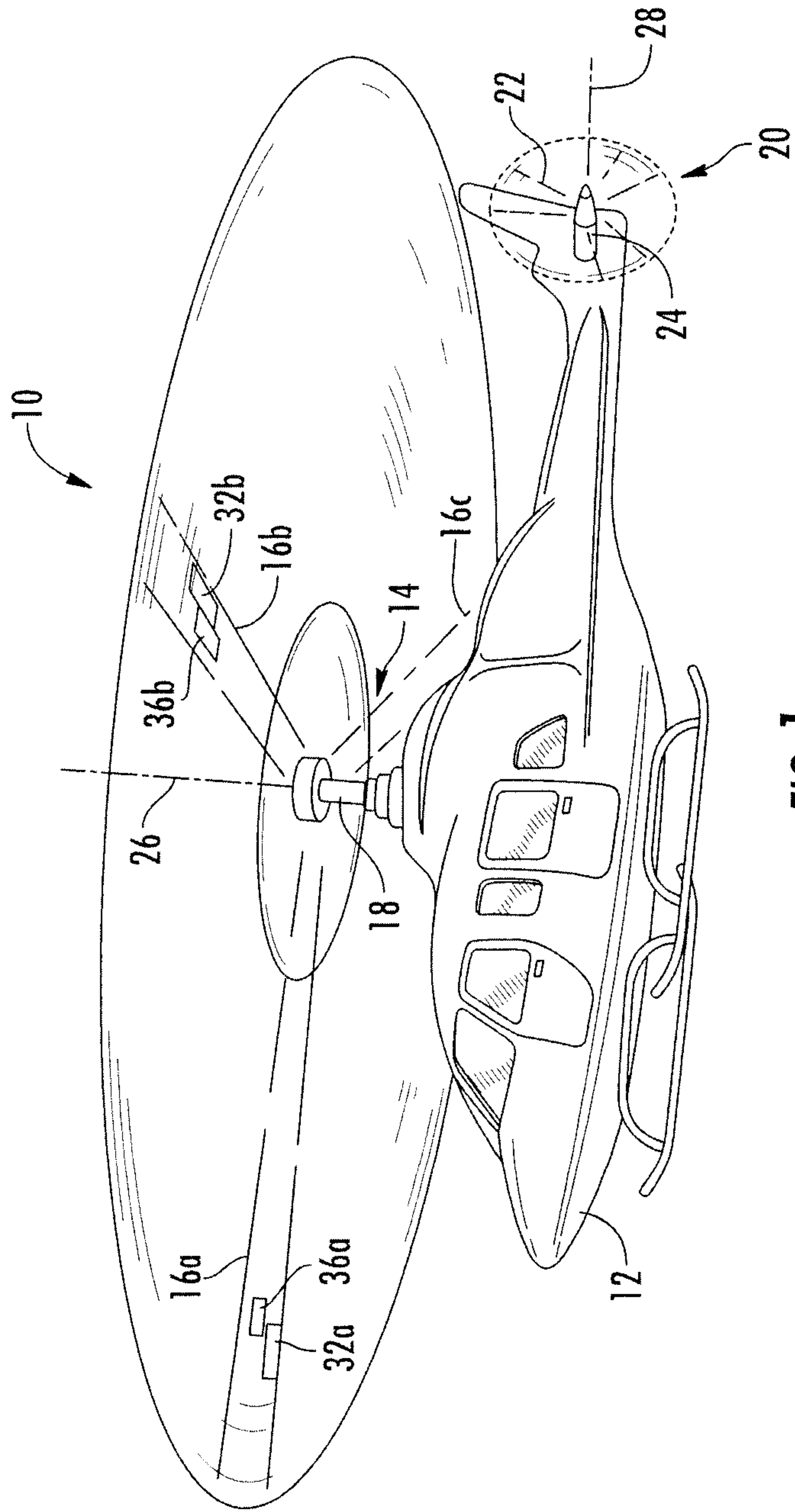


FIG. 1

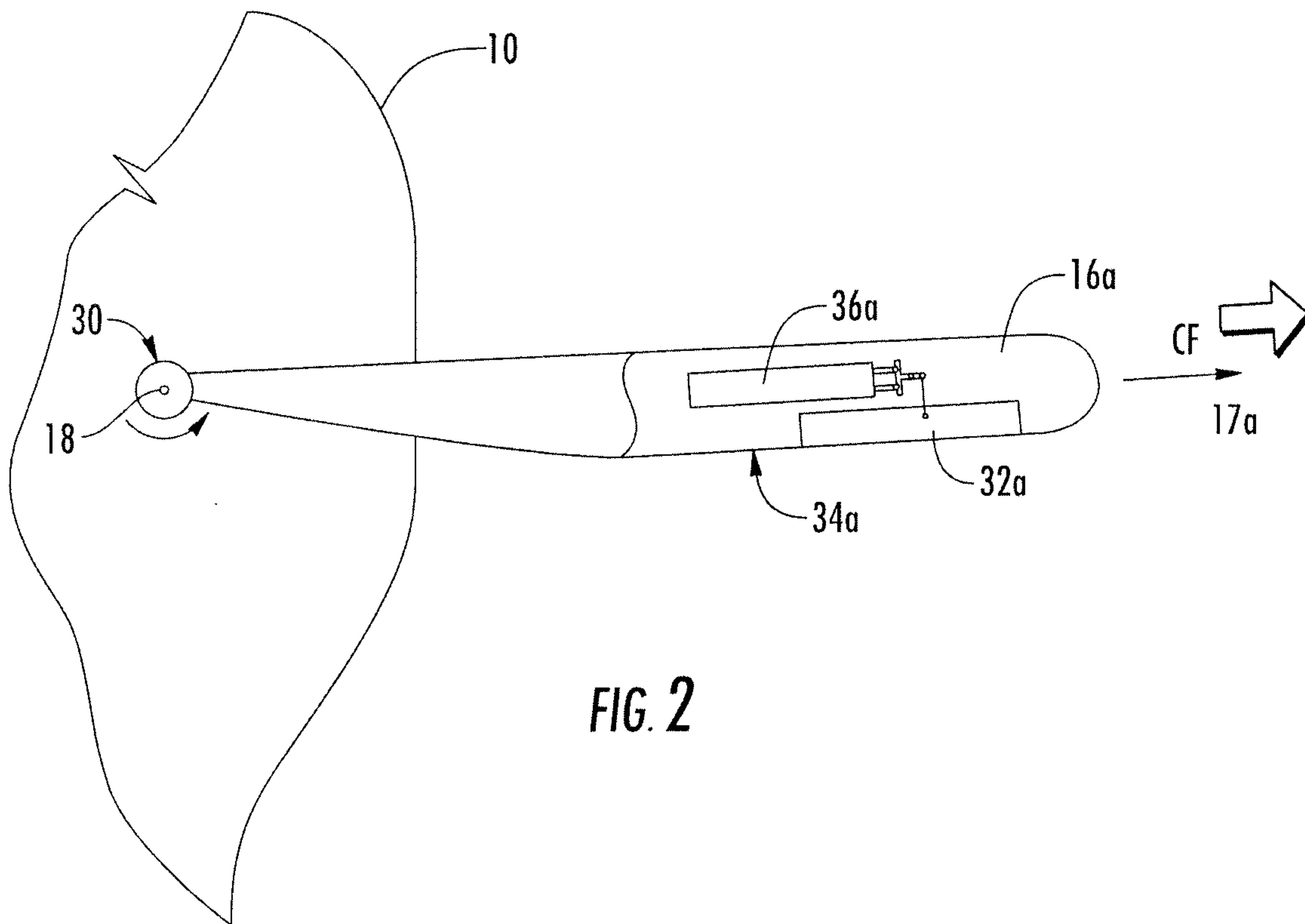


FIG. 2

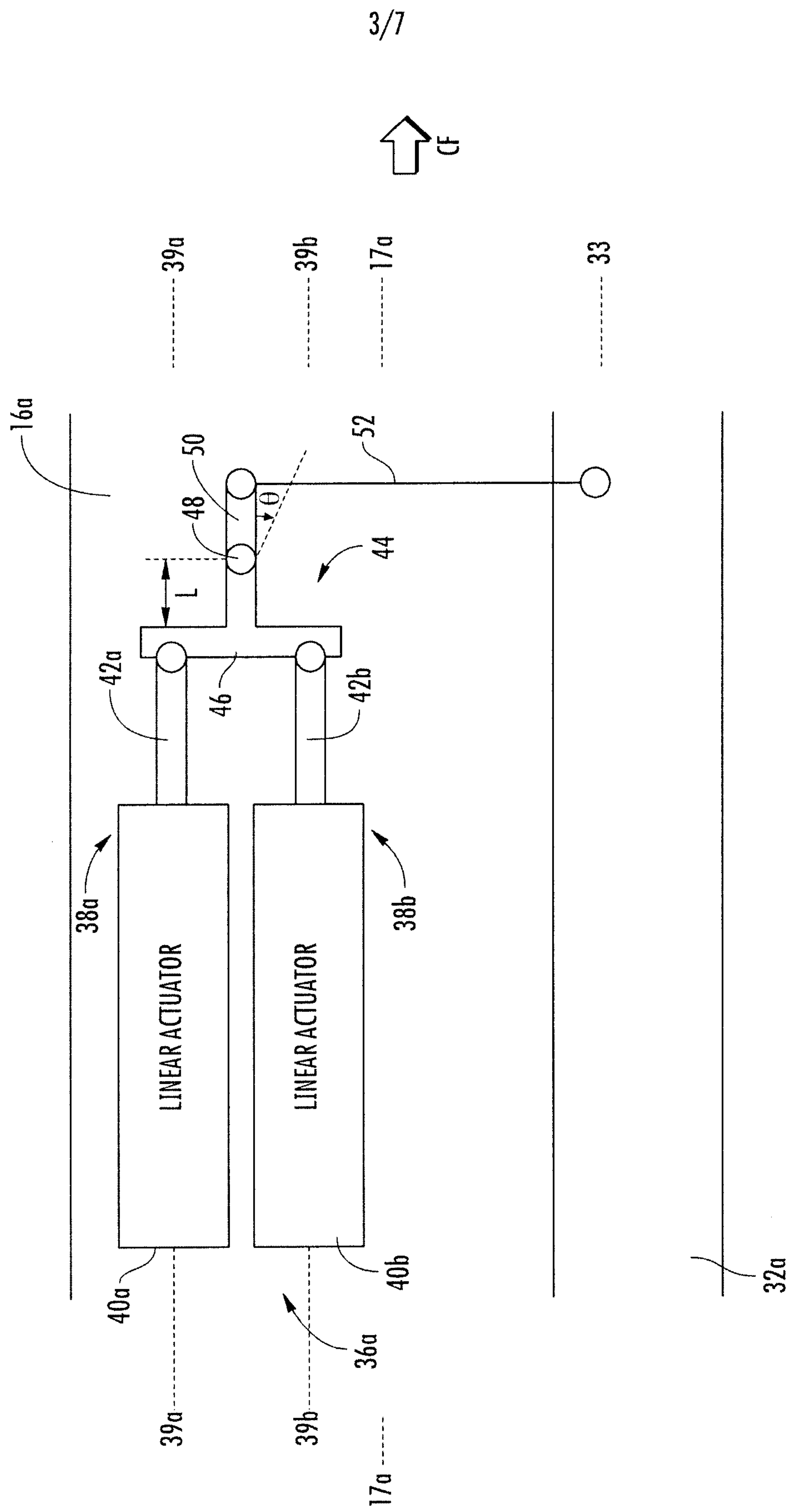


FIG. 3

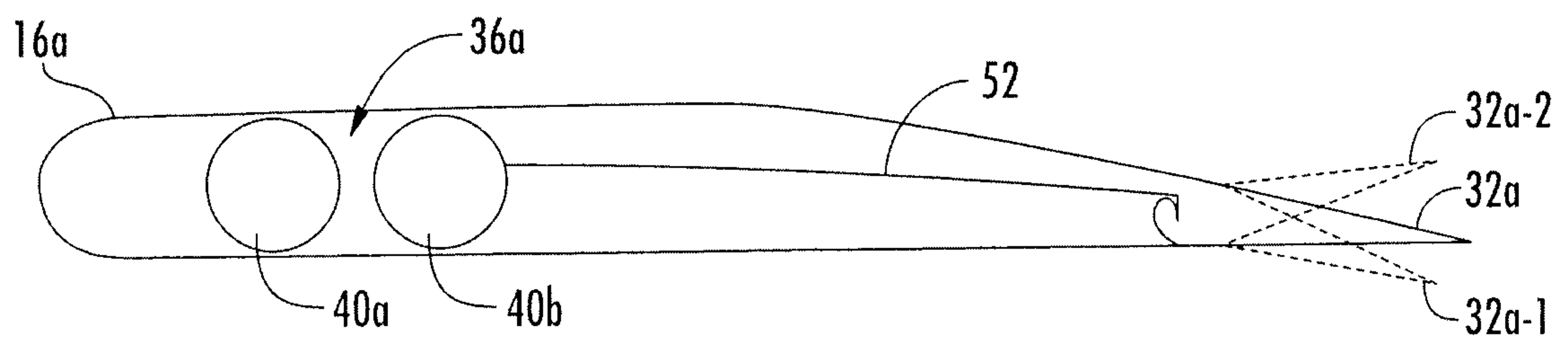


FIG. 4

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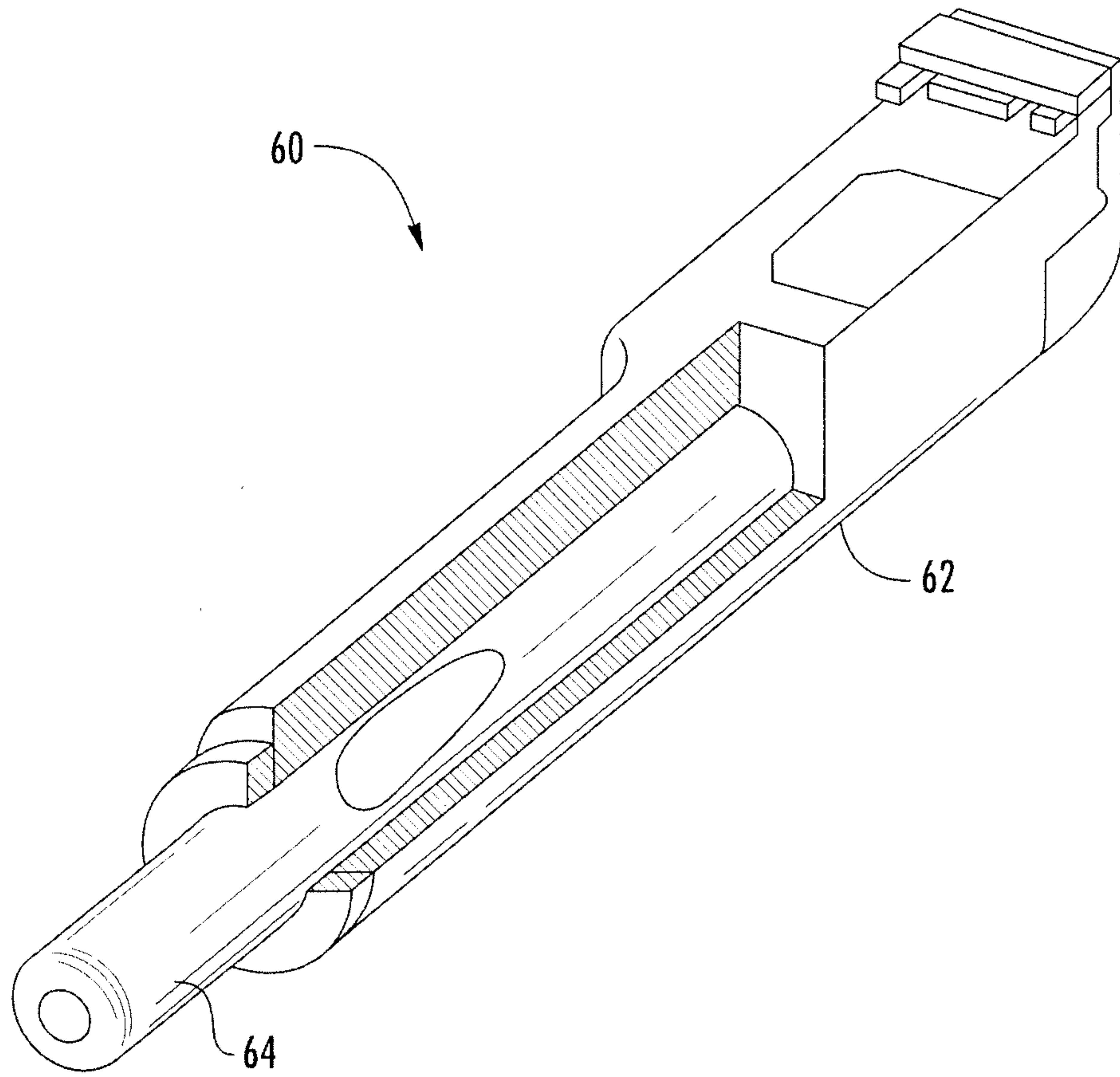


FIG. 5

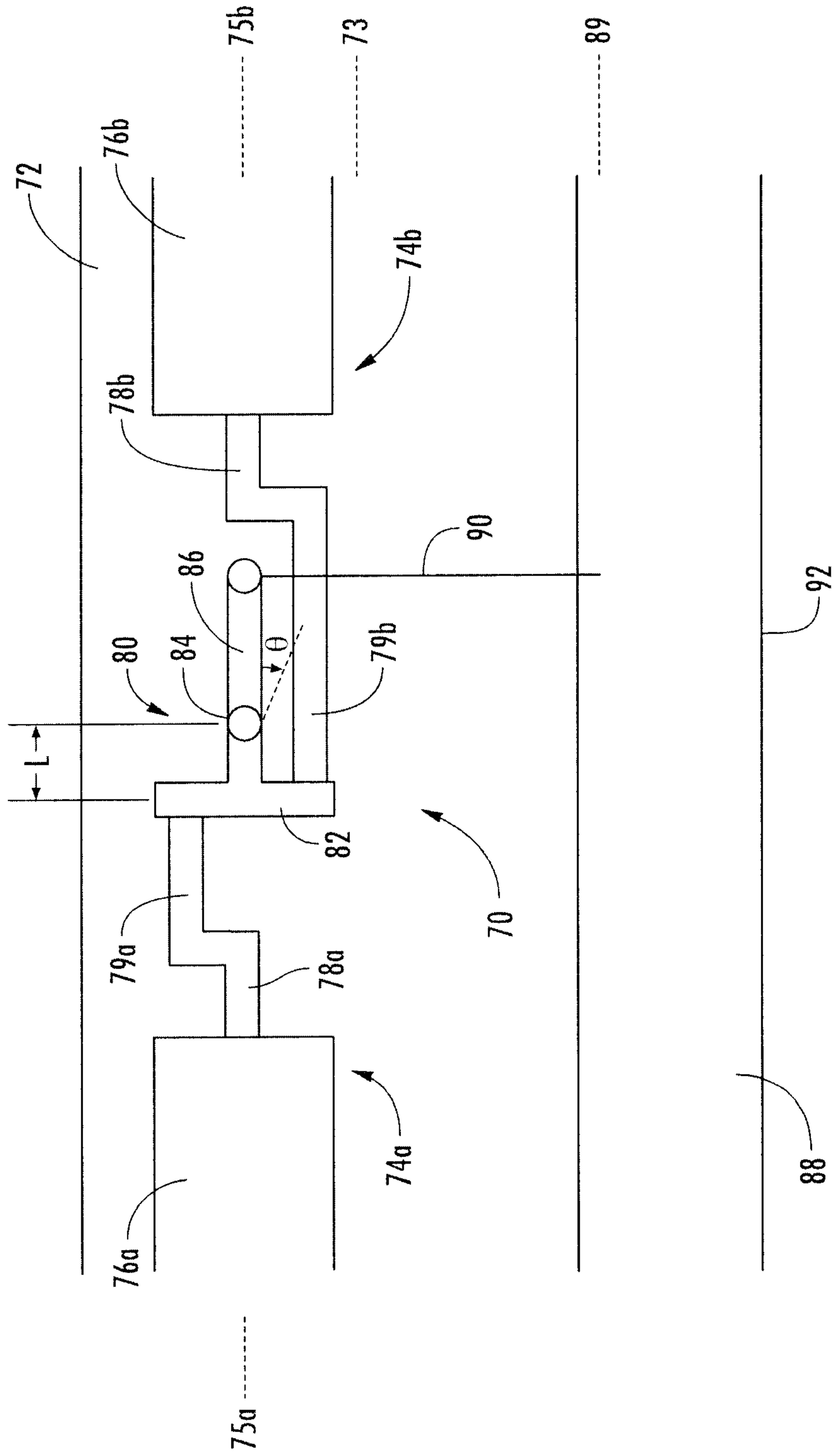


FIG. 6

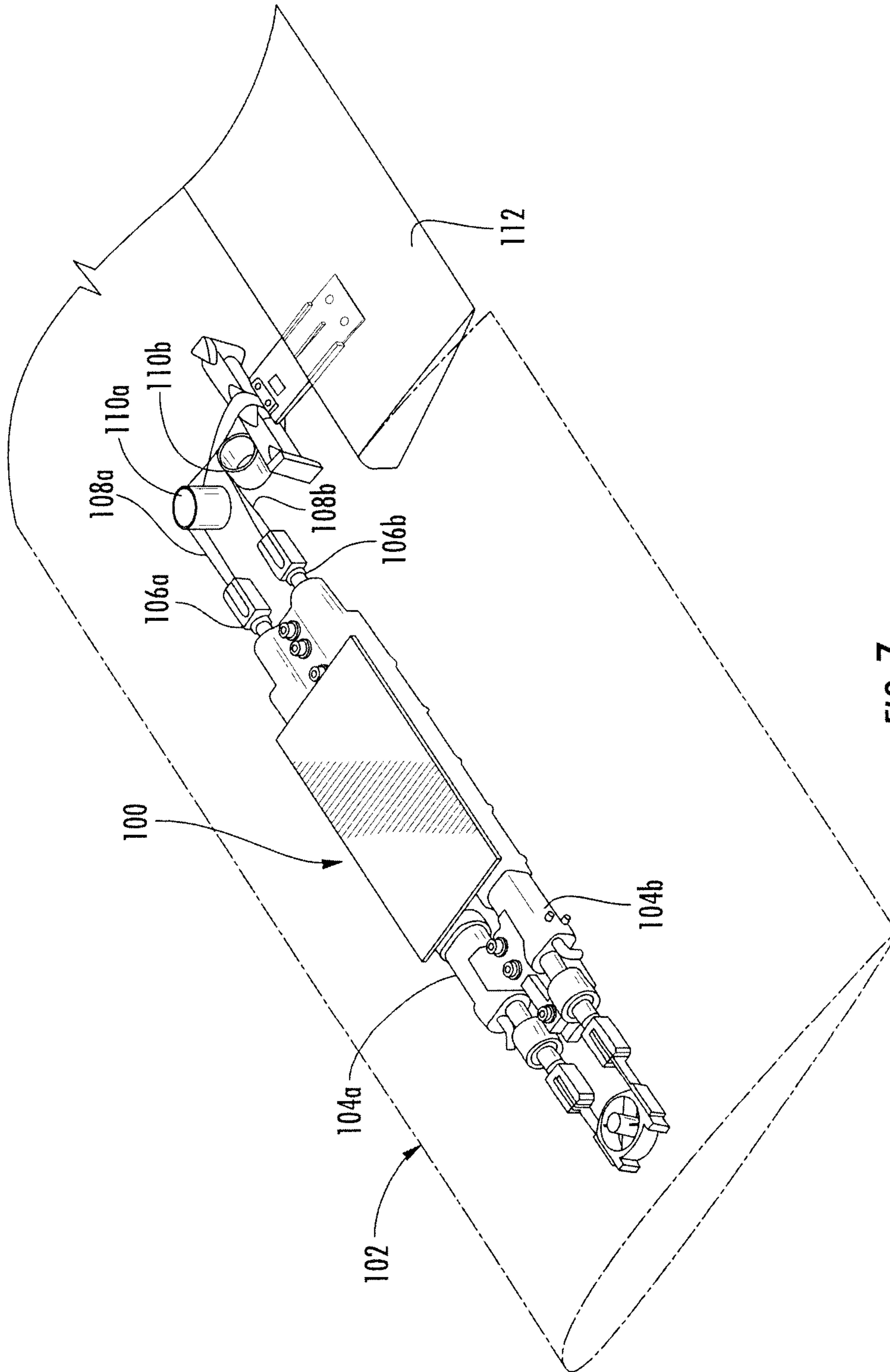


FIG. 7