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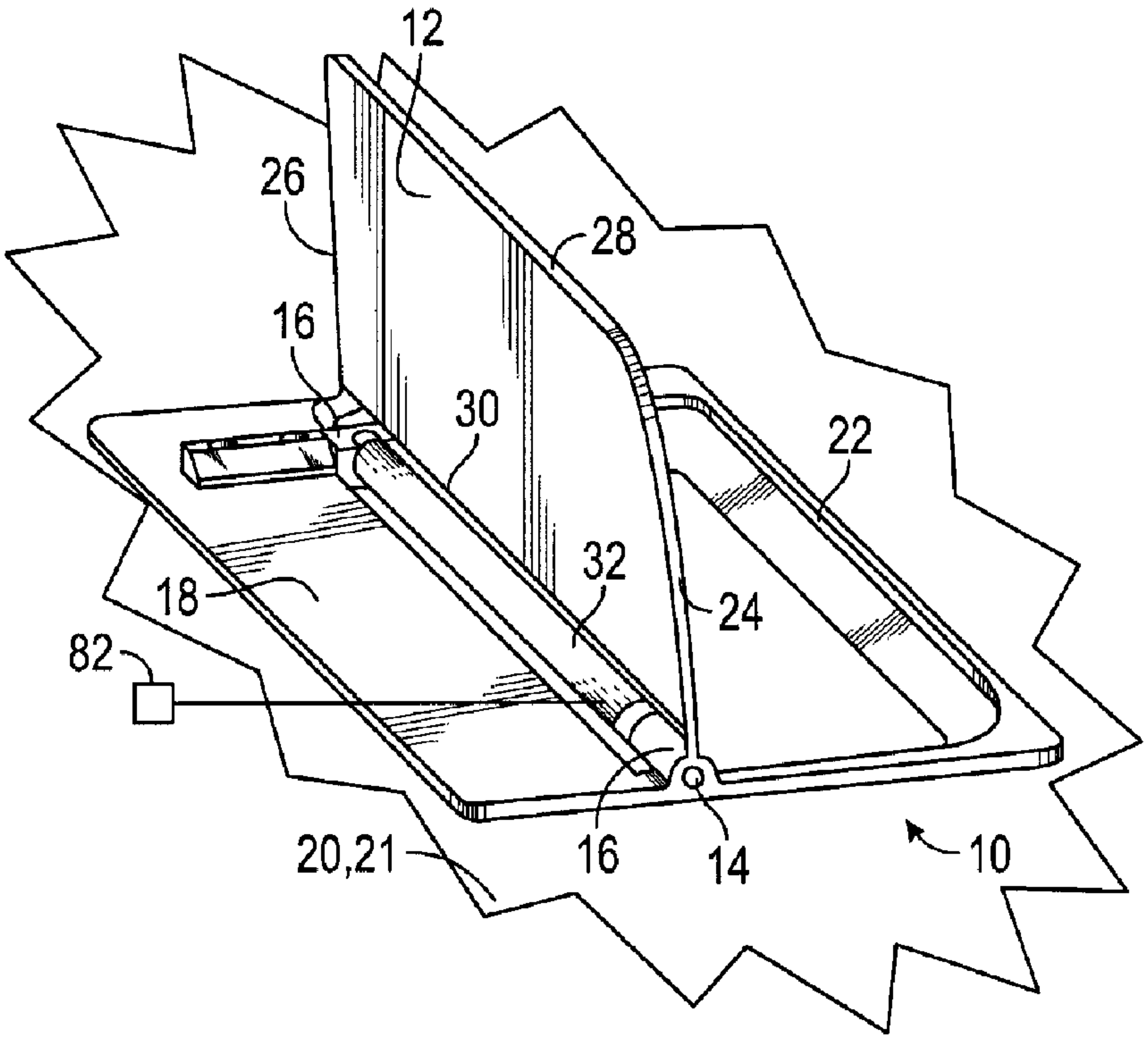
(54) **Titre : GENERATEUR DE TOURBILLONS UTILISANT DES ALLIAGES A MEMOIRE DE FORME**
(54) **Title: VORTEX GENERATOR USING SHAPE MEMORY ALLOYS**



(57) **Abrégé/Abstract:**
In one embodiment, the disclosed vortex generator may include a flap, a bearing configured to be mounted on a surface, an axle retained in the bearing, the flap attached to the axle such that the flap rotates relative to the bearing about the axle, and an actuator made of a shape memory alloy attached to the flap and to a support, the actuator shaped to receive the axle therethrough, such that a change in temperature of the actuator causes the actuator to rotate the flap relative to the bearing.

ABSTRACT

In one embodiment, the disclosed vortex generator may include a flap, a bearing configured to be mounted on a surface, an axle retained in the bearing, the flap attached to the axle such that the flap rotates relative to the bearing about the axle, and an actuator made of a shape memory alloy attached to the flap and to a support, the actuator shaped to receive the axle therethrough, such that a change in temperature of the actuator causes the actuator to rotate the flap relative to the bearing.

VORTEX GENERATOR USING SHAPE MEMORY ALLOYS

FIELD

This disclosure relates to vortex generators and, more particularly, to deployable vortex generators mounted on aerodynamic surfaces.

BACKGROUND

A vortex generator typically consists of a small vane or flap that may be mounted on an aerodynamic surface to create a vortex in air flowing over the surface. Vortex generators may be used on many devices, but are used most commonly on the nacelles, fuselages, and aerodynamic wing surfaces of aircraft. When so placed on an aerodynamic surface, vortex generators delay flow separation and aerodynamic stalling, thereby improving the effectiveness of wings and control surfaces. In one particular application, vortex generators may be spaced along the front third of a wing surface in order to maintain steady airflow over the control surfaces at the trailing edge of the wing.

Vortex generators may be generally rectangular or triangular in shape and are mounted to extend substantially perpendicular to the surface on which they are mounted. Typically, vortex generators may be shaped to extend from the aerodynamic surface to about **80%** as high as the boundary layer of air passing over the surface and extend span-wise near the thickest part of an aircraft wing. When mounted on an aircraft wing, vortex generators typically are positioned obliquely relative to the span of the wing so that they have an angle of attack with respect to local air flow.

Vortex generators typically are most needed during low speed, low-altitude flight, such as during take-off and landing. In other applications, they may be needed only during high-speed, high-altitude cruise. Since vortex generators typically are fixed vane devices, they remain deployed at all times during flight. This may result in unnecessary extra drag and resultant increase in fuel consumption.

In response to the negative effects of vortex generators during cruise, deployable vortex generators have been developed in which the aerodynamic surface or flap of the generator is deployed only during take-off, landing and other low speed operation, and is otherwise stowed and removed from exposure to air flow during cruise. Accordingly, there is a need for a vortex generator that may be actuated between stowed and deployed positions with a minimum of cost and structure.

SUMMARY

In one embodiment, the disclosed vortex generator may include a flap, a bearing configured to be mounted on a surface, an axle retained in the bearing, the flap attached to the axle such that the flap rotates relative to the bearing about the axle, and an actuator made of a shape memory alloy attached to the flap and to a support, the actuator shaped to receive the axle therethrough, such that a change in temperature of the actuator causes the actuator to rotate the flap relative to the bearing.

In another embodiment, a vortex generator may include a frame configured to be mounted on an aerodynamic surface, a forward bearing mounted on the frame, a rearward bearing mounted on the frame, an axle rotatably attached to the forward and rearward bearings, a flap having a leading edge and a trailing edge, the flap including a forward sleeve attached to the axle and a rearward sleeve attached to the axle such that the flap rotates relative to the forward and rearward bearings, and an actuator made of a shape memory alloy and configured to receive the axle therethrough, the actuator being attached to the axle and to the rearward bearing, such that a change in temperature of the actuator causes the actuator to rotate the flap about the axle from a stowed position, wherein the flap is parallel to the frame, to a deployed position, wherein the flap is not parallel to the frame, and an opposite change in temperature of the actuator causes the actuator to rotate the flap from the deployed position to the stowed position.

In yet another embodiment, a method for deploying a vortex generator including a flap may include mounting a bearing on an aerodynamic surface, attaching an axle to the bearing and to the flap such that the flap rotates relative to the bearing about the axle, attaching an actuator made of a shape memory alloy to the flap and to the bearing, and elevating the aerodynamic surface to an altitude wherein a temperature of the actuator decreases so that the actuator rotates the flap to one of a parallel position relative to the aerodynamic surface and a non-parallel position relative to the aerodynamic surface.

Other objects and advantages of the disclosed vortex generator will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. **1** is a perspective view of the disclosed vortex generator using shape memory alloys, in which the vortex generator is in a deployed position;

Fig. **2** is a perspective view of the vortex generator of Fig. **1**, in which the vortex generator is shown in a stowed position;

Fig. **3** is a perspective view of the vortex generator of Fig. **1**, in which the vortex generator is shown partially deployed;

Fig. **4** is a detail of the vortex generator of Fig. **2**, showing the forward bearing;

Fig. **5** is a detail of the vortex generator of Fig. **1**, showing the rearward bearing; and

Fig. **6** is a detail of the vortex generator of Fig. **1**, showing the forward bearing.

DETAILED DESCRIPTION

As shown in Figs. **1-3**, the disclosed vortex generator, generally designated **10**, may include a flap **12** that is attached to an axle **14**. The axle **14** may be retained in a bearing, generally designated **16**, that, in turn, may be mounted on a surface, which in the embodiment of Figs. **1-3** may be a frame **18**. The flap **12** may rotate relative to the bearing **16** about the axle **14**. The frame **18** may be mounted on an aerodynamic surface **20** of a vehicle **21**. The frame **18** may include an opening **22** shaped to receive the flap **12**. In an embodiment, the frame **18** may be unitary with, and consist of a portion of, the aerodynamic surface **20** of the vehicle **21**. In embodiments, the vehicle **21** may be an aircraft, a spacecraft reentry vehicle, a marine vehicle and/or a land vehicle.

The flap **12** may include a leading edge **24**, a trailing edge **26**, an outer edge **28**, and an inner edge **30**. The flap may be made of the same material, such as aircraft aluminum alloy, and have the same thickness as the frame **18**. In an embodiment, the flap **12** may be shaped such that the distance between the outer edge **28** and inner edge **30** approximates the height of a boundary layer of air passing over the surface **20**. In other embodiments, the flap **12** may be shaped such that the distance between the outer edge **28** and the inner edge **30** may be less than a height of a boundary layer flowing over the surface **20**, for example **80%** of that height, or greater than a height of a boundary layer flowing over the surface **20**. The flap **12** may be oriented on the vehicle **21** such that the leading edge **24** encounters air flowing over the surface **20** in forward vehicle motion and is upstream of the trailing edge **24**. The flap **12** may be positioned obliquely to airflow on the surface **20**.

The flap **12** may be generally planar in shape, and rectangular. In embodiments, the flap may be arcuate in shape, such as to conform to the curvature of the adjacent surface **20**. The leading edge **24** may be substantially straight, or in the embodiment shown may extend perpendicularly from the axle **14** and gradually curve rearward to the outer edge **26**. The flap **12** may be shaped to pivot about axle **14** between a deployed position shown in Fig. **1**, in which the flap is perpendicular, or substantially perpendicular, to the frame **18** and aerodynamic surface **20**, and a stowed position shown in Fig. **2**, in which the flap rests within the opening **22** of the frame and is parallel, or substantially parallel, to the frame.

The vortex generator **10** may include an actuator, generally designated **32**, made of shape memory alloy ("SMA"). The shape memory alloy may be alloys of copper-aluminum-nickel, nickel-titanium, and zinc-copper-gold-iron. As shown in Fig. **4**, the actuator **32** may be in the form of a tube or sleeve having a central bore **34** shaped to receive the cylindrical axle **14** therethrough. The bore **34** may be cylindrical in shape, or in embodiments may have a polygonal shape in cross section, such as a hexagonal shape. In an embodiment, the portion of the axle **14** that extends through the bore **34** may have a complementary polygonal shape in cross section. The actuator also may include set screws **36** that fix the actuator **32** relative to the axle **14**, so that rotation of the actuator **32** may cause the axle **14** to rotate relative to the bearing **16**.

In an embodiment, the flap **12** may include a forward sleeve **38** extending from the inner edge **30**. The forward sleeve may have a bore **40** therethrough shaped to receive the axle **14**. The forward sleeve **38** may include set screws **42** that attach and fix the forward sleeve to the axle, so that rotation of the axle **14** causes the forward sleeve **38**, and hence the flap **12**, to rotate relative to the bearing **16** and frame **18**.

Also as shown in Fig. **4**, the bearing **16** may include a first or forward journal bearing **44**, which in an embodiment may be formed integrally with the frame **18**. Bearing **44** may have a bore **46** therethrough that receives a forward portion **48** of the axle **14**. The forward bearing **44** may include a first bearing surface in the form of a flat **50** that is shaped and positioned to engage a correspondingly shaped second bearing surface in the form of a flat **52** formed on the forward sleeve **38**. The flats **50, 52** may cooperate to act as a stop **54** that limits rotation of the flap **12** relative to the frame **18** and aerodynamic surface **20** (Figs. **1-3**) to a preset deployed position.

As shown in Fig. **5**, the bearing **16** may include a second or rearward journal bearing **55** that rotatably receives a rearward portion **56** of the axle **14**. The flap **12** may include a rearward sleeve **58** extending from the inner edge **30**. The sleeve **58** may have a bore **60** shaped to receive the rearward portion **56** of the axle **14**. The rearward sleeve **58** may include set screws **62** that attach and fix the rearward sleeve to the rearward portion **56** of the axle **14**, so that the flap **12** rotates with rotation of the axle **14** at the trailing edge **26**. The rearward bearing **55** may be attached to the frame **18** by screws **64**, or in embodiments, may be formed integrally with the frame **18**, or may be attached by other means such as adhesives, welding and brazing. In the embodiment shown, axle **14** may be a continuous rod. In other embodiments, axle **14** may be segmented and consist of only a forward component or portion **48** (Fig. 4) and a rearward component or portion **56**. In such an embodiment, the forward and rearward components **48, 56** may be of sufficient length to extend through at least the forward and rearward sleeves **38, 58,** and the forward and rearward bearings **44, 54,** respectively. In still other embodiments, the components **48, 56** may be of sufficient length to extend into the ends of the bore **34** of the actuator **32.**

The rearward bearing **55** may include bosses **66** that receive and engage a complementarily shaped end **68** of the actuator **32.** The end **68** of the actuator **32** may be secured to the bosses **66** by adhesive, or may be attached by screws or brazed or welded. In an embodiment, the engagement of the actuator **32** with the rearward bearing **55** may be effected by capturing the actuator on the axle **14** between the rearward bearing and the forward sleeve **38**, or as shown in Fig. **4**, by fixing the actuator on the axle at a forward end by set screws **36.** The actuator **32** thus may be fixed relative to the rearward bearing **55** so that rotation of the actuator **32** may be constrained to rotate and apply torque to the axle **14** when actuated, because of the attachment of the actuator to the axle **14** by way of set screws **36** (Fig. **4**).

As shown in Fig. **6**, the forward end of the actuator **32** may include an adapter sleeve **70** that may not be made of shape memory alloy. The adapter sleeve **70** may be made of aluminum or other metal, or of a polymer, or of carbon fiber. In one embodiment, the adapter sleeve **70** may have an eccentrically shaped end **72** that engages a complementarily shaped end **74** of the shape memory alloy component **76** of the actuator **32** and thus may prevent relative rotation of the shape memory component and adapter sleeve. This engagement may be fixed by adhesives, welding or other well-known means. Similarly, the forward end **78** of the actuator sleeve **70** may be eccentrically shaped and engage a correspondingly shaped surface **80** formed on the forward sleeve **38** of the flap **12.** Thus, rotational motion of the actuator **76** may be transmitted directly to the flap **12** through the forward sleeve **38.** In embodiments, such a direct connection may not be necessary because both the actuator **32** and the forward sleeve **38** of the flap **12** may be attached and fixed to the forward portion **48** of the axle **14** such that rotational motion of the actuator may be transmitted to the forward sleeve **38** of the flap through the forward portion of the axle.

The operation of the vortex generator may be as follows. As shown in Fig. **1**, the frame **18** may be mounted on an aerodynamic surface **20** of a vehicle **21**, which surface may be the wing surface of an aircraft, or other aerodynamic surface, such as the surface of a nacelle, fuselage or vertical stabilizer. Alternatively, the aerodynamic surface may be on a land vehicle, such as an automobile, a marine vehicle, or a spacecraft re-entry vehicle that is part of a spacecraft. The frame **18** may be attached to the surface **20** by rivets (not shown), by an adhesive, or by brazing or welding. The frame **18** also may be unitary with the surface **20**.

The shape memory alloy component **76** (Fig. **6**) of the actuator **32** may be selected and configured, as by annealing and/or selection of metal composition of the SMA, such that at ambient temperature at or near sea level, or at relatively low altitudes (e.g., under **10,000** feet), the SMA actuator **32** may be heated by ambient air so that its temperature increases. This increase in temperature of the SMA actuator **32** may cause the actuator to twist against the rearward bearing **55**, thereby twisting the axle **14** relative to the bearing **16** and frame **18**. This torsional force may cause the flap **12** to rotate counterclockwise to a deployed position, as shown in Fig. **1**, from a stowed position as shown in Fig. **2**. The flap **12** thus may be rotated relative to the bearing **16** to the deployed position to act as a vortex generator for the vehicle **21** during takeoff and landing, and during low altitude climb and descent. In an embodiment, the SMA actuator **32** may be selected to rotate the flap **12** to a preset orientation, and in an embodiment, this preset orientation may be determined by the geometry of the stop **54**.

In an alternate embodiment, the shape memory alloy component **76** of the actuator **32** may be selected and configured, as by annealing and/or selection of metal composition of the SMA, such that a relatively high altitude (e.g., at or above **10,000** feet) the SMA actuator **32** may be cooled by ambient air so that its temperature decreases relative to its temperature in ambient air at a relatively low altitude (e.g., below **10,000** feet). This decrease in temperature of the SMA actuator **32** may cause the actuator to twist against the rearward bearing **55**, thereby twisting the axle **14** relative to the bearing **16** and frame **18**, which torsional force may cause the flap **12** to rotate counterclockwise from the stowed position shown in Fig. **2** to the deployed position shown in Fig. **1**. In an embodiment, this deployed position may be a preset position determined by selection and configuration of the SMA actuator **32**, and in other embodiments may be determined by the geometry of the stop **54**. Thus, by material selection and/or configuration of the SMA of the component **76**, the flap **12** may be rotated from the stowed position to the deployed position either when temperature decreases, as with an increase in altitude of the vehicle **21**, or when the temperature increases, as with a decrease in altitude of the vehicle.

In an embodiment, the flap **12** may be perpendicular, or substantially perpendicular, to the frame **18** and/or aerodynamic surface **20** when rotated to the preset deployed position. As shown in Fig. **6**, in this position the stop **54** (see also Figs. **4** and **6**) may prevent further rotational movement of the flap **12** relative to the frame **18**, so that the flap **12** is at a preset deployed position determined by the position of the stop.

In an embodiment, as shown in Fig. **3**, the actuator **32** and/or stop **54** may be selected and/or configured such that the shape memory alloy component **76** rotates the flap **12** to a preset deployed position that is a non-parallel, non-perpendicular angle, such as **45** degrees, relative to the frame **18**.

In an embodiment, as shown in Fig. **1**, rather than rely on heating of the shape memory alloy component **76** from ambient air to increase the temperature of the actuator **32**, the vehicle **21** may include a heating device, generally designated **82** (Fig. **1**), that may be connected to heat the shape memory alloy component **76** electrically by Joule heat. In another embodiment, the heating device **82** may constitute a blower or duct from an engine (not shown) of the vehicle **21** for directing heated air upon the shape memory alloy component **76**.

When the vehicle **21** and surface **20** are elevated to a pre-set altitude, for example above **10,000** feet above sea level, the decrease in ambient temperature may cause a decrease in the temperature of the actuator **32**, causing the actuator to rotate in a clockwise direction as shown in Figs. **1** and **3**. In an embodiment, this decrease in temperature of the actuator **32** may result from deactivating the heating device **82**. This counter-rotation, which may result from cooling or a reduction in temperature of the shape memory alloy component **76** (Fig. **6**) of the actuator **32**, may cause the actuator to rotate the axle **14**, and thus the flap **12**, to the stowed position shown in Fig. **2**. In this stowed position, the flap **12** may be within the opening **22** of the frame **18**, and is parallel, or substantially parallel, to the frame and/or aerodynamic surface **20**.

When in the stowed position, the flap **12** may be substantially within the opening **22** and therefore present a low profile and minimal drag to the surface **20** of the associated aircraft or vehicle **21**. In an alternate embodiment, as described previously, the SMA actuator **32** may be configured or composed to rotate the flap **12** clockwise to the stowed position when heated, and to rotate the flap counterclockwise to the deployed position when cooled. The configuration may depend upon the aerodynamic requirements of the vehicle **21**. Thus, the actuator **32** may be attached to the axle **14** and to the rearward bearing **55** such that a change in temperature of the actuator may cause the actuator to rotate the flap **12** about the axle from a stowed position, wherein the flap is parallel to the frame **18**, to a deployed position, wherein the flap is not parallel to the frame, and an opposite change in temperature of the actuator may cause the actuator to rotate the flap from the deployed position to the stowed position.

While the forms of apparatus and methods herein described constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise forms of apparatus and methods, and that changes may be made therein without departing from the scope of the invention.

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

1. A vortex generator comprising:

a flap;

a bearing configured to be mounted on a surface;

an axle retained in the bearing, the flap attached to the axle such that the flap rotates relative to the bearing about the axle; and

an actuator made of a shape memory alloy attached to the flap and to a support, the actuator shaped to receive the axle therethrough, such that a change in temperature of the actuator causes the actuator to rotate the flap relative to the bearing.

2. The vortex generator of claim **1**, wherein the actuator is configured to rotate the flap relative to the bearing from a stowed position, wherein the flap is parallel to the surface, to a deployed position, in which the flap is not parallel to the surface, in response to one of an increase in a temperature of the actuator and a decrease in the temperature of the actuator, and from the deployed position to the stowed position in response to one of a decrease in the temperature of the actuator and an increase in the temperature of the actuator, respectively.

3. The vortex generator of claim **1** or **2**, wherein the flap includes a forward sleeve shaped to receive a forward portion of the axle, and a rearward sleeve shaped to receive a rearward portion of the axle.

4. The vortex generator of claim **3**, wherein the actuator is configured to engage the forward sleeve such that rotational motion of the actuator is transmitted to the flap through the forward sleeve.

5. The vortex generator of claim **3** or **4**, wherein the actuator and the forward sleeve are fixed to the forward portion of the axle such that rotational motion of the actuator is transmitted to the forward sleeve through the forward portion of the axle.

6. The vortex generator of any of claims **3-5**, wherein the rearward sleeve is fixed to the rearward portion of the axle.

7. The vortex generator of any of claims **3-6**, wherein the bearing is the support, and the actuator is attached to the bearing.

8. The vortex generator of claim **7**, further comprising a stop configured to prevent rotation of the flap past a preset position relative to the surface.

9. The vortex generator of claim **8**, wherein the stop is formed by engagement of the forward sleeve with the bearing.

10. The vortex generator of claim **9**, wherein the stop incudes a first bearing surface formed on the forward sleeve, and a second bearing surface formed on the bearing, such that engagement of the first bearing surface and second bearing surface prevents rotation of the flap past the preset position.

11. The vortex generator of any of claims **8-10**, wherein the preset position positions the flap perpendicular to the surface.

12. The vortex generator of any of claims **8-11**, wherein the actuator is configured to rotate the flap between a stowed position, in which the flap is parallel to the surface, and the preset position in response to an increase in temperature of the actuator from one of ambient temperature and a heating device, and to rotate the flap between the preset position to the stowed position in response to a decrease in temperature of the actuator.

13. The vortex generator of any preceding claim, wherein the actuator is a sleeve having a central bore shaped to receive the axle therethrough.

14. The vortex generator of any preceding claim, wherein the bearing includes a forward bearing and a rearward bearing, and the rearward bearing includes the support.

15. The vortex generator of claim **14**, wherein the actuator extends between the forward bearing and the rearward bearing.

16. The vortex generator of claim **15**, wherein the frame includes a forward bearing, and the rearward bearing is attached to the frame.

17. The vortex generator of any preceding claim, wherein the surface includes a frame adapted to be attached to a vehicle.

18. The vortex generator of claim **17**, wherein the vehicle is one of an aircraft, a spacecraft, a land vehicle, and a marine vehicle.

19. A vortex generator comprising:

a frame configured to be mounted on an aerodynamic surface;

a forward bearing mounted on the frame;

a rearward bearing mounted on the frame;

an axle rotatably attached to the forward and rearward bearings;

a flap having a leading edge and a trailing edge, the flap including a forward sleeve attached to the axle and a rearward sleeve attached to the axle such that the flap rotates relative to the forward and rearward bearings; and

an actuator made of a shape memory alloy and configured to receive the axle therethrough, the actuator being attached to the axle and to the rearward bearing, such that a change in temperature of the actuator causes the actuator to rotate the flap about the axle from a stowed position, wherein the flap is parallel to the frame, to a deployed position, wherein the flap is not parallel to the frame, and an opposite change in temperature of the actuator causes the actuator to rotate the flap from the deployed position to the stowed position.

20. A method for deploying a vortex generator including a flap, the method comprising:

mounting a bearing on an aerodynamic surface;

attaching an axle to the bearing and to the flap such that the flap rotates relative to the bearing about the axle;

attaching an actuator made of a shape memory alloy to the flap and to the bearing; and elevating the aerodynamic surface to an altitude wherein a temperature of the actuator decreases so that the actuator rotates the flap to one of a parallel position relative to the aerodynamic surface and a non-parallel position relative to the aerodynamic surface.

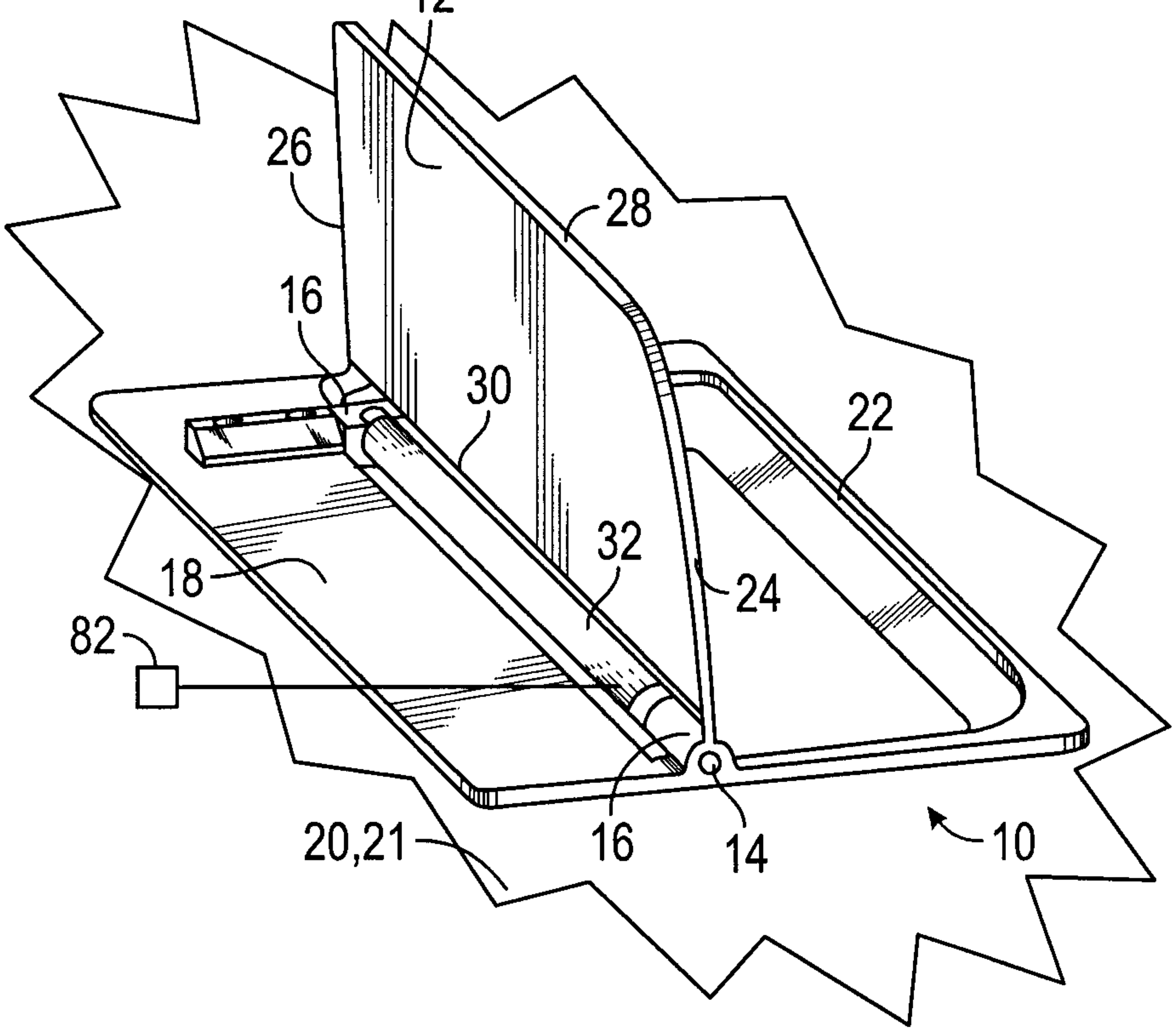

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FIG. 1

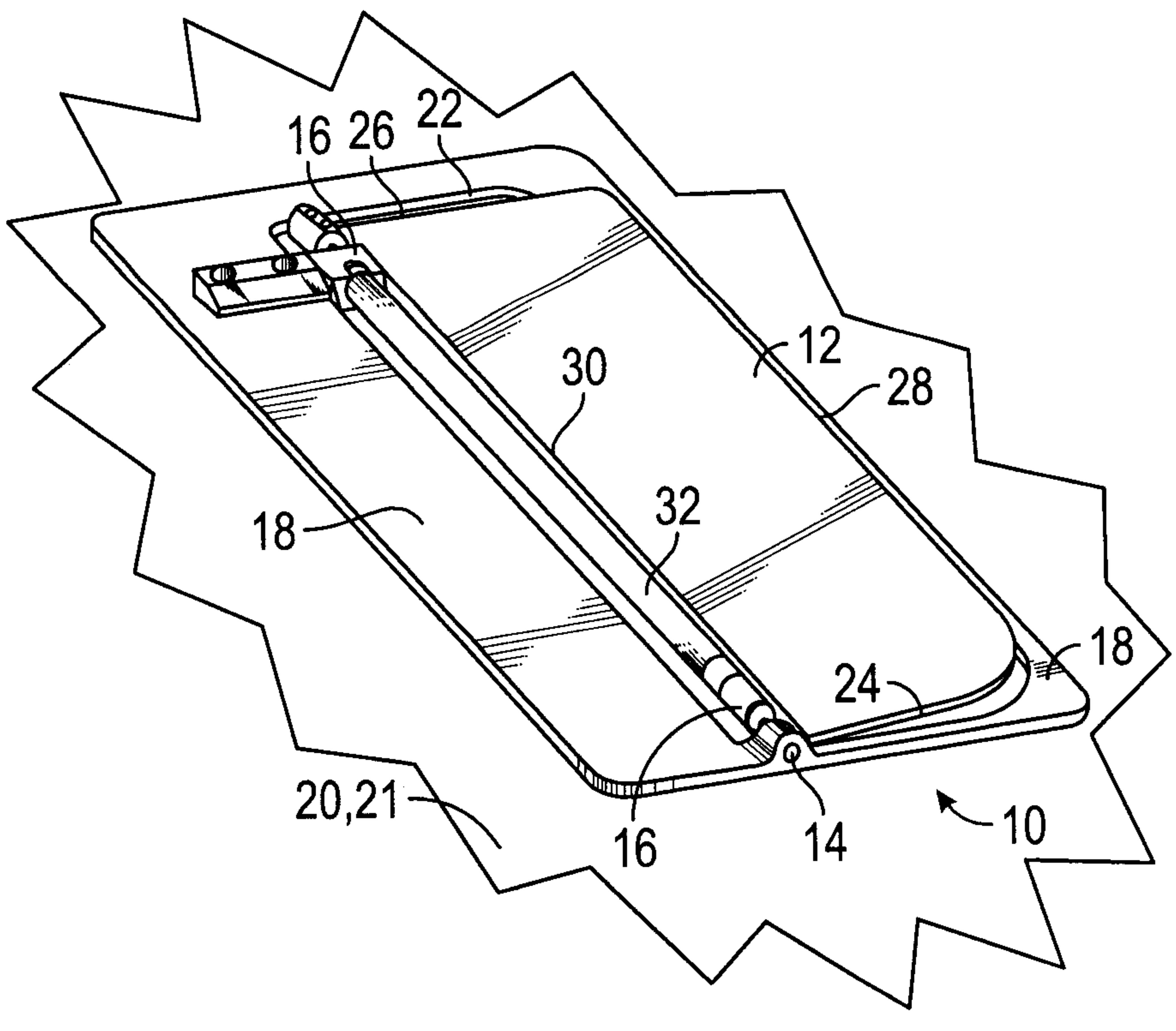
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FIG. 2

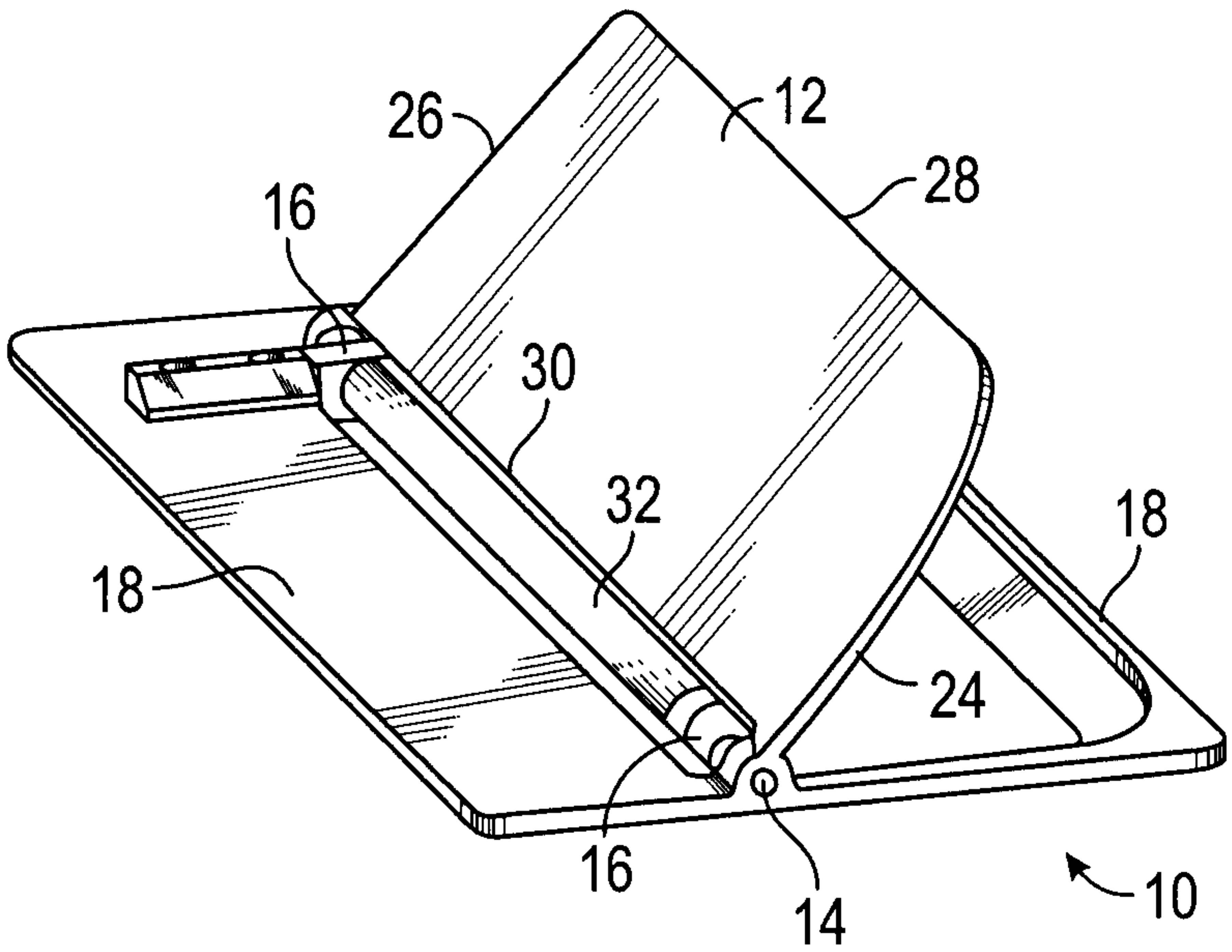
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FIG. 3

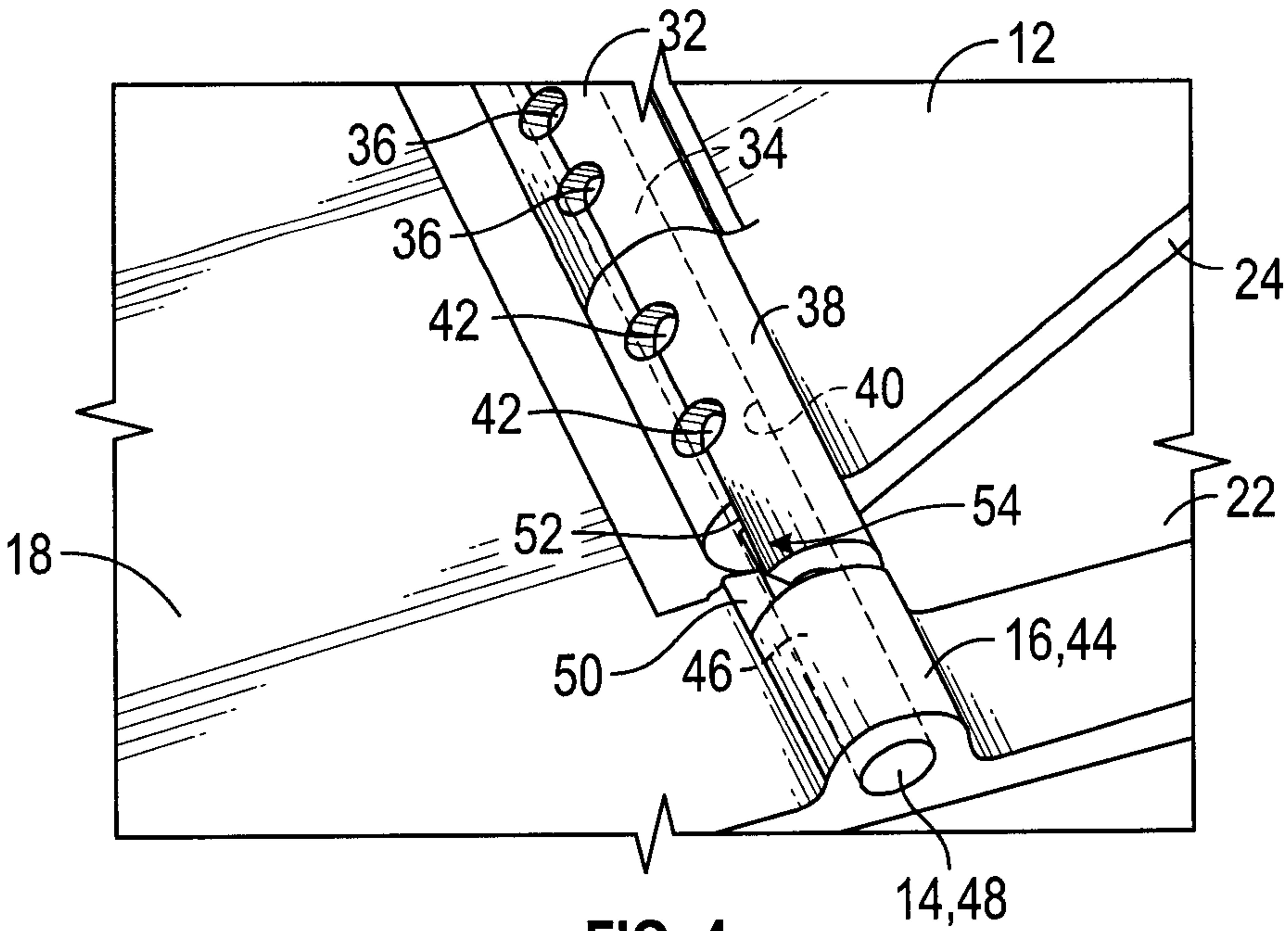
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FIG. 4

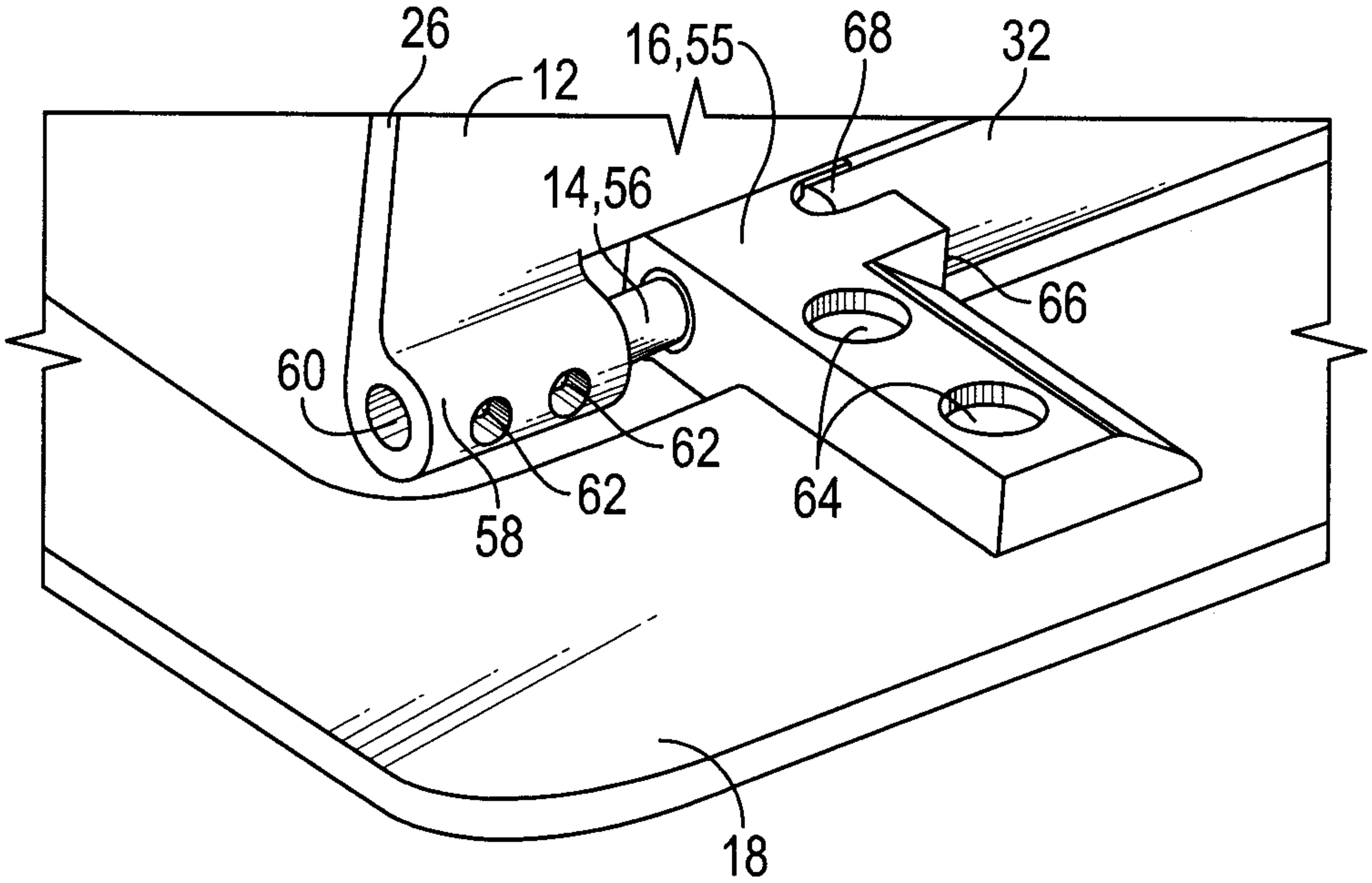
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FIG. 5

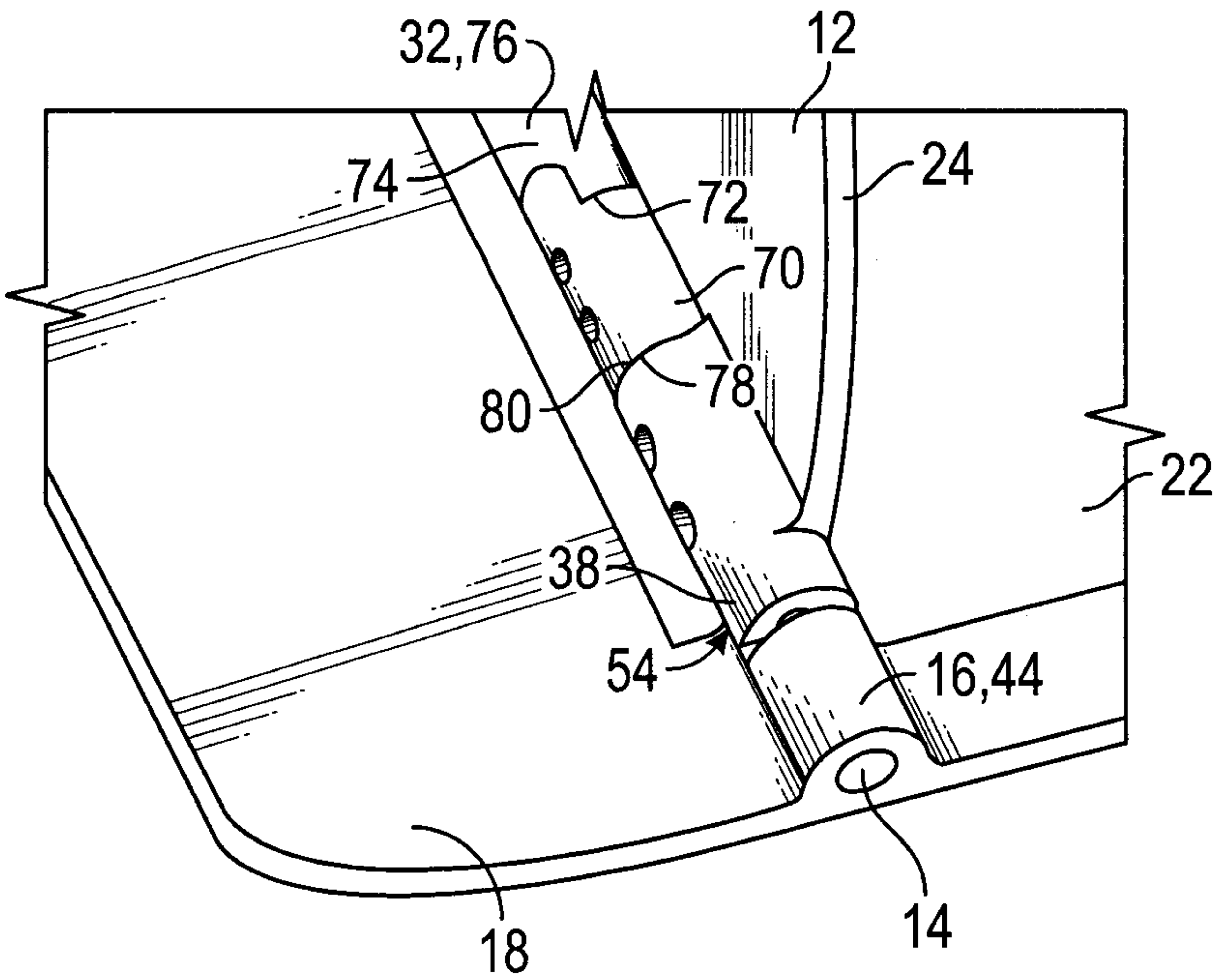
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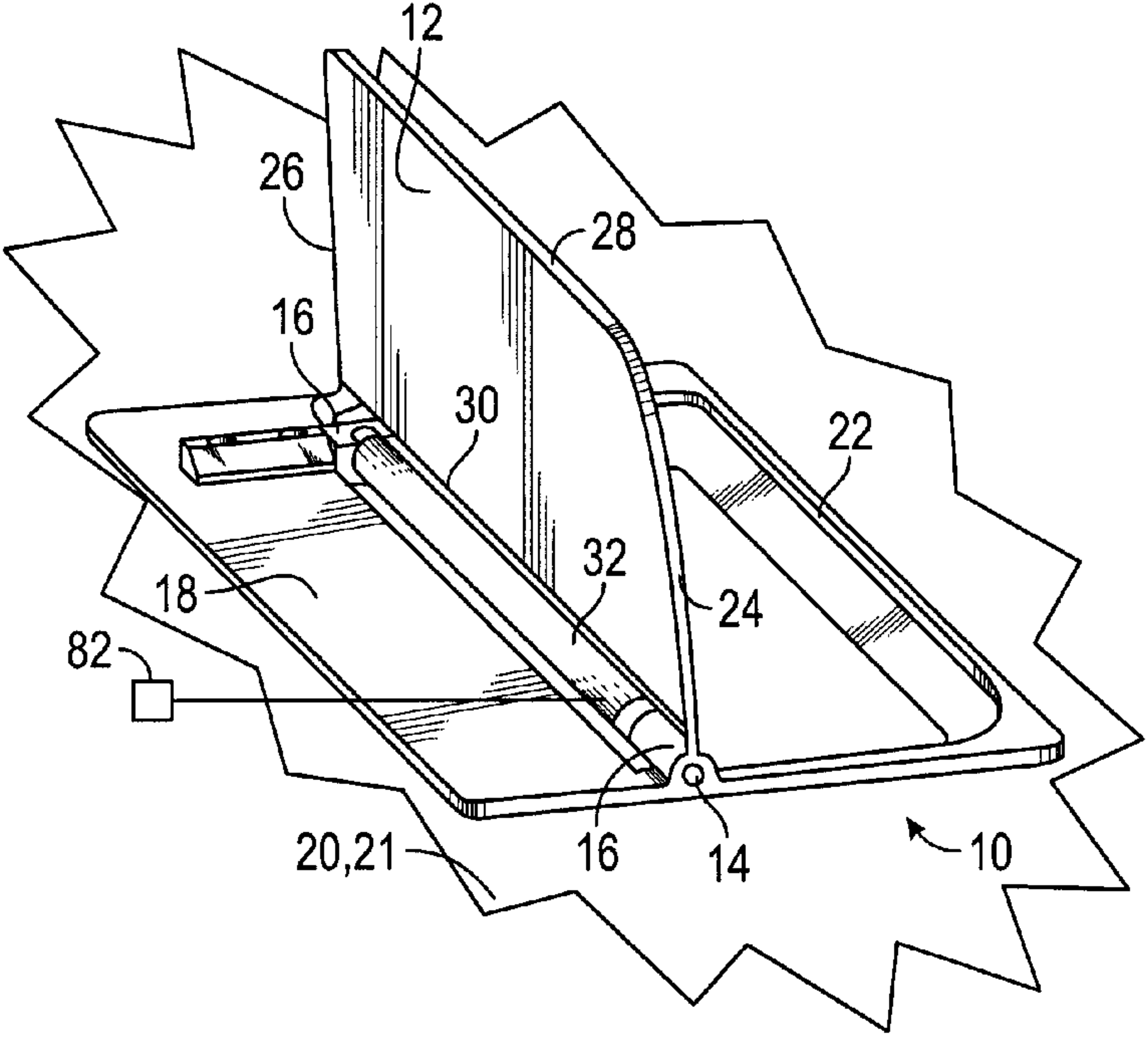
FIG. 6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