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### Wing deployment apparatus and methods for aircraft

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#### Abstract

Wing deployment apparatus and methods are disclosed herein. An example wing deployment apparatus includes a rotary actuator coupled to a torque coupler having a locking key disposed in an opening. The locking key moves between an outer radial position and an inner radial position. A lead screw is rotationally coupled to the torque coupler. The lead screw has a first recess to accept the locking key when the locking key is in the inner radial position. A nut is threadably engaged to the lead screw and includes a second recess to accept the locking key when the locking key is in the outer radial position. The locking key prevents movement of the nut along the axis of rotation when the locking key is in the outer radial position. A wing is operatively coupled to the nut to move the wing to a deployed position.

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## Background/Summary

RELATED APPLICATION (1) This patent claims the benefit of U.S. Provisional Patent Application No. 63/589,535, which was filed on Oct. 11, 2023. U.S. Provisional Patent Application No. 63/589,535 is hereby incorporated herein by reference in its entirety. Priority to U.S. Provisional Patent Application No. 63/589,535 is hereby claimed.

### FIELD

(1) This disclosure relates generally to aircraft and, more particularly, to wing deployment apparatus and methods for aircraft.

### BACKGROUND

(2) Air launched vehicles are aircraft that are carried on or outside of a host aircraft. The host aircraft carries the air launched vehicle from the ground to an operating altitude and speed. Once at operating altitude and speed, the air launched vehicle is launched and begins flight as an aircraft. Thus, the air launched vehicle does not require the thrust and high lift control surfaces required for traditional take-off. However, the wings of air launched vehicles occupy a significant volume of space and can interfere with the host aircraft. Therefore, the wings of air launched vehicles should be stowed or otherwise aerodynamically hidden until launched. Once launched, the wings of the air launched vehicle can be deployed and used to enable flight of the air launched vehicle.

### SUMMARY

(3) An example wing deployment apparatus disclosed herein includes a rotary actuator, having an axis of rotation, coupled to a torque coupler. The torque coupler includes an opening and a locking key disposed in the opening. The locking key moves in a radial direction relative to the axis of rotation between an outer radial position and an inner radial position. A lead screw is rotationally coupled to the torque coupler and moves along the axis of rotation relative to the torque coupler between a first axial position and a second axial position. The lead screw has a first recess to align with the opening when the lead screw is in the second axial position, the first recess to accept the locking key when the locking key is in the inner radial position. A nut is threadably engaged to the lead screw and rotationally fixed. The nut includes a second recess to accept the locking key when the locking key is in the outer radial position and the lead screw is in the first axial position. The locking key prevents movement of the nut along the axis of rotation relative to the torque coupler when the locking key is in the outer radial position and the lead screw is in the first axial position. A wing is operatively coupled to the nut to move the wing between a stowed and a deployed position in response to movement of the nut.

(4) An example aircraft disclosed herein includes a fuselage, a wing movable between a stowed position and a deployed position, and a rotary actuator. The rotary actuator has an axis of rotation and is coupled to a torque coupler. The torque coupler includes an opening and a locking key disposed in the opening. The locking key moves in a radial direction relative to the axis of rotation between an outer radial position and an inner radial position. A lead screw is rotationally coupled to the torque coupler and moves along the axis of rotation relative to the torque coupler between a first axial position and a second axial position. The lead screw has a first recess to align with the opening when the lead screw is in the second axial position, to accept the locking key when the locking key is in the inner radial position. A nut is threadably engaged to the lead screw and rotationally fixed. The nut includes a second recess to accept the locking key when the locking key is in the outer radial position and the lead screw is in the first axial position. The locking key prevents movement of the nut along the axis of rotation relative to the torque coupler when the locking key is in the outer radial position and the lead screw is in the first axial position. The nut is

operatively coupled to the wing to move the wing from the stowed position to the deployed position.

(5) An example method of deploying a wing on an aircraft disclosed herein includes rotating a torque coupler about an axis of rotation, the torque coupler including a locking key disposed in an opening of the torque coupler. The method continues by translating a lead screw, the lead screw rotationally coupled to the torque coupler, toward the torque coupler from a first position to a second position along the axis of rotation. The lead screw is threadably engaged to a nut. The method continues by unlocking the nut from the torque coupler by disengaging the locking key from the nut. The method further includes translating the nut away from the torque coupler along the axis of rotation. The method concludes by deploying a wing in response to the translating of the nut.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is an illustration of an example aircraft with example wings in an example stowed position.
- (2) FIG. 2 illustrates the example wing deployment apparatus of the example aircraft of FIG. 1.
- (3) FIG. 3 illustrates an enlarged view of the example wing deployment apparatus of FIG. 2 showing the wings biased towards an example stowed position.
- (4) FIG. 4A illustrates a cross-section of the example wing deployment apparatus of FIG. 3.
- (5) FIG. 4B illustrates the cross-sectioned wing deployment apparatus of FIG. 4A with an example lead screw and an example torque coupler removed for clarity.
- (6) FIGS. 5A and 5B illustrate the example wing deployment apparatus of FIG. 4A as the example lead screw translates from an example first axial position as shown in FIG. 4A to an example second axial position as shown in FIG. 5B.
- (7) FIG. 6 illustrates the example wing deployment apparatus of FIG. 2 with the wings in an example deployed position.
- (8) FIGS. 7A and 7B illustrate the example wing deployment apparatus of FIG. 6 with an example locking pin to engage with the example wing.
- (9) FIG. 8 is a flowchart representative of an example method for deploying an example wing of an example aircraft.
- (10) In general, the same reference numbers will be used throughout the drawing(s) and accompanying written description to refer to the same or like parts. The figures are not necessarily to scale.
- (11) As used herein, unless otherwise stated, the term “above” describes the relationship of two parts relative to Earth. A first part is above a second part, if the second part has at least one part between Earth and the first part. Likewise, as used herein, a first part is “below” a second part when the first part is closer to the Earth than the second part. As noted above, a first part can be above or below a second part with one or more of: other parts therebetween, without other parts therebetween, with the first and second parts touching, or without the first and second parts being in direct contact with one another.
- (12) As used in this patent, stating that any part (e.g., a layer, film, area, region, or plate) is in any way on (e.g., positioned on, located on, disposed on, or formed on, etc.) another part, indicates that the referenced part is either in contact with the other part, or that the referenced part is above the other part with one or more intermediate part(s) located therebetween.
- (13) As used herein, connection references (e.g., attached, coupled, connected, and joined) may include intermediate members between the elements referenced by the connection reference and/or relative movement between those elements unless otherwise indicated. As such, connection

references do not necessarily infer that two elements are directly connected and/or in fixed relation to each other. As used herein, stating that any part is in “contact” with another part is defined to mean that there is no intermediate part between the two parts.

(14) Unless specifically stated otherwise, descriptors such as “first,” “second,” “third,” etc., are used herein without imputing or otherwise indicating any meaning of priority, physical order, arrangement in a list, and/or ordering in any way, but are merely used as labels and/or arbitrary names to distinguish elements for ease of understanding the disclosed examples. In some examples, the descriptor “first” may be used to refer to an element in the detailed description, while the same element may be referred to in a claim with a different descriptor such as “second” or “third.” In such instances, it should be understood that such descriptors are used merely for identifying those elements distinctly within the context of the discussion (e.g., within a claim) in which the elements might, for example, otherwise share a same name.

#### DETAILED DESCRIPTION

(15) Many air launched vehicles have stowable wings that rotate, extend, or otherwise deploy after being released from the host aircraft. The stowable wings allow the air launched vehicle to be carried by the host aircraft while reducing the aerodynamic effects of the air launched vehicle on the host aircraft. Thus, known air launched vehicles have apparatus to deploy stowed wings, as well as apparatus to secure the stowed wings in place while carried by the host aircraft. If stowed wings are not adequately secured, flight conditions of the host aircraft can cause the wings to partially or fully deploy and disadvantageously affect the aerodynamics of the host aircraft. This could make the host aircraft less efficient and more difficult to control.

(16) Example wing deployment apparatus described herein combine a deploying function with a holding/locking function. Thus, the stowable wings are securely held in place and later deployed using the same apparatus. The holding/locking function prevents undesired or premature deployment of the wings (e.g., while the aircraft is attached to the host). This consolidation of functions reduces the size and weight of the wing deployment apparatus relative to known wing deployment and wing securing apparatus of air launched vehicles. In some example wing deployment apparatus, the components and hardware that deploy the stowable wings are the same components that secure the stowable wings, further reducing the size, weight, complexity, and cost of the wing deployment apparatus. Thus, the air launched vehicle is made more efficient while also allowing the host aircraft to operate more efficiently.

(17) FIG. 1 is an illustration of an example aircraft **100** with example wings **102** and **103** in an example stowed position **104**. The wings **102** and **103** are coupled to a fuselage **105** and a wing deployment apparatus **106**. In some examples, the aircraft **100** is an air launched vehicle. In other examples, the aircraft **100** is a drone (e.g., a manned or unmanned drone). The wing deployment apparatus **106** is shown with an example covering. In other examples, the wing deployment apparatus **106** can have other coverings (e.g., a shell, a fairing, etc.) at least partially above (e.g., covering, surrounding, shielding, etc.) the wing deployment apparatus **106**. The wings **102** and **103** are shown with an example size and shape, but in other examples the wings **102** and **103** can be different sizes (e.g., different length and width) and shapes (e.g., contours).

(18) FIG. 2 illustrates the example wing deployment apparatus **106** of the example aircraft **100** of FIG. 1. The wings **102** and **103** are coupled to an example nut **200** via example cables **202**. The example wings **102** and **103** move from the stowed position **104** to a deployed position **600** (detailed in FIG. 6) in response to the nut **200** moving (e.g., in a linear or longitudinal direction along a longitudinal axis of the nut **200**). In some examples, the wings **102** and **103** rotate between the stowed position **104** and the deployed position **600** in response to the cables **202** pulling the wings **102** and **103** about a rotational coupling (e.g., pin, pivot, bearing, etc.). In other examples, the wings **102** and **103** are coupled to the nut **200** by different means (e.g., rods, linkages, fasteners, rack and pinion, gears, transmissions, etc.). In some examples, the wings **102** and **103** rotate between the stowed position **104** and the deployed position **600**. In other examples, the wings **102**

and **103** move between the stowed position **104** and the deployed position **600** through a complex motion (e.g., translation, rotation about multiple axes, a series of motions, stepped motions, etc.). (19) The nut **200** of FIG. 2 is threadably engaged to an example lead screw **204**. For example, the nut **200** and the lead screw **204** provide a lead-screw assembly. The lead screw **204** is rotatably coupled to an example rotary actuator **206** on a first end and an example first bearing block **208** on a second end opposite the first end. In this way, an axis of rotation **210** is defined by the rotary actuator **206** and the first bearing block **208**. The nut **200** translates (e.g., linearly) along the axis of rotation **210** as it is threadably engaged to the lead screw **204**. In other words, the translational motion of the nut **200** is defined by the axis of rotation **210** of the lead screw **204**. The example nut **200** of the illustrated example can be a tensioning nut, a ball lock, a follower, a ball nut, a ball lock follower, a sleeve, a slider and/or any other structure, fastener, or follower to convert rotational movement of the lead screw **204** into translational movement.

(20) An example torque coupler **212** (further detailed in FIGS. 4A and 4B), rotatably couples the rotary actuator **206** and the lead screw **204**. An example set screw **214** fixes the torque coupler **212** so that it cannot translate along the axis of rotation **210**. The set screw **214** is threadably engaged to an example second bearing block **216**. The rotary actuator **206** is fixed to the second bearing block **216**. In other examples, the rotary actuator **206** is fixed at a different location and coupled to the torque coupler **212** through a transmission (e.g., gearbox, belt, or other coupling). In some examples, the first bearing block **208**, the second bearing block **216**, and the lead screw **204** are substantially coplanar with the wings **102** and **103** in the stowed position **104**. In other examples, the first bearing block **208** and the lead screw **204** may have other orientations relative to the wings **102** and **103** (e.g., parallel, askew, orthogonal, etc.). In some examples, the lead screw **204** is located between the wings **102** and **103**. In other examples, the lead screw **204** can be located in other positions relative to the wings **102** and **103**.

(21) FIG. 3 illustrates an enlarged view of the example wing deployment apparatus **106** of FIG. 2 showing the wings **102** and **103** biased towards the example stowed position **104**. The wing **102** has an example first stop surface **300** and an example second stop surface **302**. The first stop surface **300** contacts the nut **200**. The second stop surface **302** contacts the second bearing block **216**. In this way, the wing **102** is fixed in place in the stowed position **104**. In some examples, the first stop surface **300** and the second stop surface **302** are opposite each other, perpendicular to the axis of rotation **210**. In other examples, the first and second stop surfaces **300** and **302** can have different locations, relative orientations, and/or contacting surfaces. The set screw **214** is coupled to the nut **200** through the torque coupler **212** (further detailed in FIGS. 4A and 4B). The set screw **214** can be rotated into the second bearing block **216**, to which it is threadably engaged, to apply a force to move the nut **200** towards the second bearing block **216**. Thus, the wing **102** is biased toward the stowed position **104** by the set screw **214**. In other words, the set screw **214** causes compression in the wing **102** between the first stop surface **300** and the second stop surface **302**. The compression of wing **102** between the first stop surface **300** and the second stop surface **302** biases the wing **102** to rotate towards the stowed position **104**. While wing **102** is discussed in the above examples, example wing **103** can have similar first and second stop surfaces **300** and **302**. In some examples, wings **102** and **103** have first and second stop surfaces **300** and **302** that are symmetric relative to the axis of rotation **210**. The first and second stop surfaces **300** and **302** of wing **103** interact similarly with the nut **200** and the second bearing block **216** to bias the wing **103** toward the stowed position **104**.

(22) FIG. 4A illustrates a cross-section of the example wing deployment apparatus **106** of FIG. 3. The example rotary actuator **206** is rotatably coupled to the example torque coupler **212**. The torque coupler **212** is rotatably coupled to the example lead screw **204**. The lead screw **204** has a first recess **400** disposed within the torque coupler **212**. The first recess **400** is formed on an outer surface (e.g., a neck or non-threaded outer surface) of the lead screw **204** (e.g., positioned in a cavity of the torque coupler **212**). In some examples, the rotary actuator **206** is positioned opposite

the lead screw **204**. Thus, the rotary actuator **206**, the torque coupler **212**, and the lead screw **204** are rotatably coupled and coaxial on the axis of rotation **210**. In other examples, the rotary actuator **206** has a different axis of rotation than the lead screw **204** and the torque coupler **212**, and is coupled through a transmission (e.g., gearbox, belt, or other coupling). The torque coupler **212** is translationally fixed by the set screw **214**. In other words, the torque coupler **212** cannot translate along the axis of rotation **210** because it is translationally fixed by the set screw **214**. The torque coupler **212** has an example opening **402** (or recess) to contain an example locking key **404**. In some examples, the locking key **404** has a spherical shape (e.g., ball bearing shape). In other examples, the locking key **404** can have a different shape (e.g., disc shape, cuboid shape, cylindrical shape, etc.). The opening **402** limits motion of the locking key **404**. For example, the opening **402** of the torque coupler **212** traps the locking key **404** to limit or prevent translational movement of the nut **200**. In some examples, the locking key **404** can move in a radial direction relative to the axis of rotation **210**. In other examples, the locking key **404** can move in the radial direction and rotate around the axis of rotation **210**. In some examples, the locking key **404** moves along a path defined by the opening **402**.

(23) As shown in FIG. 4A, the locking key **404** is in an example outer radial position **406**. The locking key **404** is disposed in an example second recess **408** of the nut **200** while the locking key **404** is in the outer radial position **406**. In the example wing deployment apparatus **106** of FIG. 4A, the locking key **404** is radially fixed in the outer radial position between the second recess **408** and the lead screw **204** (e.g., a portion of the outer surface not including the first recess **400**). The locking key **404** is translationally fixed along the axis of rotation **210** by contacting the opening **402** of the torque coupler **212**. Thus, locking key **404** can rotate freely around the axis of rotation **210**, while fixed at a radial and translational position relative to the axis of rotation **210**. The nut **200** is translationally fixed along the axis of rotation **210** by the locking key **404**. In other words, the nut **200** cannot move (e.g., linearly, or longitudinally) along the axis of rotation **210** while the locking key **404** is in the outer radial position **406** and the locking key **404** is contacting the second recess **408**. As described above, the nut **200** is in contact with the wing (e.g., in contact with the wing **102** at the first stop surface **300**, as shown in FIG. 3). Thus, the wing **102** is fixed in position by the nut **200**, and the nut **200** is fixed in position by the locking key **404**. In other words, the wing **102** is locked in a stowed position (e.g., the stowed position **104** of FIG. 1) when the locking key **404** is in the outer radial position **406**. Furthermore, as the locking key **404** is translationally fixed by the opening **402** and the torque coupler **212**, the wing **102** can be biased towards the stowed position by moving the torque coupler **212** translationally along the axis of rotation **210** in the direction of the first stop surface of the wing (e.g., first stop surface **300**) via the set screw **214**. In other words, set screw **214** can be used to bias the wings (e.g., the wings **102** and **103** of FIG. 1) towards the stowed position (e.g., the stowed position **104** of FIG. 1).

(24) FIG. 4B illustrates the cross-sectioned wing deployment apparatus **106** of FIG. 4A with parts removed for clarity. The torque coupler **212**, the locking key **404**, and lead screw **204** have been removed to provide a clearer view. The example nut **200** is shown with the second recess **408** (e.g., an annular recess). In some examples, the second recess **408** is an axially symmetric groove along an inner surface of the nut **200**. In some examples, the second recess **408** is shaped to urge the locking key **404** (not shown) away from the second recess **408** as the nut **200** is moved away from the torque coupler **212** (not shown). In some examples, there are a plurality of first recesses in the lead screw **204**, a plurality of locking keys **404**, and a plurality of openings **402** in the torque coupler **212**. The plurality of locking keys **404** supports the forces of fixing the nut **200** more evenly, reducing friction and improving performance of the wing deployment apparatus **106**. In some examples, the torque coupler **212** is supported by bearings **410** (e.g., roller bearings, ball bearings, pin bearings, etc.) and thrust bearings **412** (e.g., thrust roller bearings, thrust ball bearings, thrust pin bearings, etc.). The bearings **410** and thrust bearings **412** allow the torque coupler **212** to rotate freely while supporting loads from the nut **200** and the lead screw **204**.



(25) In some examples, the first recess **400** is an annular recess or channel formed on the outer surface of the lead screw **204**. In some examples, the first recess **400** is a plurality of recesses or channels formed on the outer surface (e.g., radially spaced about 45 degrees, 30 degrees, etc.) of the lead screw **204**. In some examples, the second recess **408** is an annular recess or channel formed on an inner surface or wall of the nut **200**. In some examples, the second recess **408** is a plurality of recesses or channels formed on the inner surface (e.g., radially spaced about 45 degrees, 30 degrees, etc.) of the nut **200**. In some examples, a number of first recesses **400** corresponds to (e.g., equals to) a number of second recesses **408**. In some examples, the locking key **404** is a plurality of ball bearings radially spaced (e.g., 45 degrees, 30 degrees, etc.) about the outer surface of the lead screw **204**.

(26) FIGS. 5A and 5B illustrate the example wing deployment apparatus **106** of FIG. 4A as the example lead screw **204** translates from an example first axial position as shown in FIG. 4A to an example second axial position **500** as shown in FIG. 5B (e.g., an intermediate position between the stowed position and the deployment position). The example locking key **404**, as shown in FIG. 5A, is leaving the example outer radial position **406** and moving away from the example second recess **408**. The example nut **200** begins to change position relative to the example torque coupler **212**. The lead screw **204** is rotationally coupled to torque coupler **212** and the rotary actuator **206**. The rotary actuator **206** rotates the lead screw **204**, which is threadably engaged to nut **200**, and causes the lead screw **204** to translate along the axis of rotation **210**. In some examples the lead screw **204** is a ball screw and is threadably engaged with a ball nut of the nut **200**. In some examples, the lead screw **204** is shaped (e.g., square shaped, splined, keyed, etc.) to fit inside the torque coupler **212** and transfer torque. The lead screw **204** is rotatably coupled to the torque coupler **212** and can slide freely (e.g., translate in the axial direction freely) when the locking key **404** is in the outer radial position **406**.

(27) FIG. 5B shows the example lead screw **204** in an example second axial position **500** and the example locking key **404** in an example inner radial position **502**. The first recess **400** of the lead screw **204** aligns with the opening **402** (e.g., the center of the first recess **400** has substantially the same position along the axis of rotation **210** as the center of the opening **402**) when the lead screw **204** is in the second axial position **500**. In contrast, the first recess **400** does not align with the opening **402** (e.g., distance between the first recess **400** and the rotary actuator **206** is greater than the distance between the opening **402** and the rotary actuator **206**) when the lead screw **204** is in first axial position (as shown in FIG. 4A). The locking key **404** contacts the first recess **400** of the lead screw **204** when the locking key **404** is in the inner radial position **502** and the lead screw **204** is in the second axial position **500**. When the lead screw **204** approaches the second axial position **500** (e.g., part or all of the first recess **400** aligns with the opening **402** along the axis of rotation **210**), the locking key **404** is no longer fixed radially relative to the axis of rotation **210**. In other words, the locking key **404** is fixed in the outer radial position **406** until the lead screw **204** approaches the second axial position **500** (e.g., part or all of the first recess **400** aligns with the opening **402** along the axis of rotation **210**). When the locking key **404** is no longer fixed in the outer radial position **406**, the nut **200** is no longer translationally fixed and can move along the axis of rotation **210**. In other words, when the lead screw **204** approaches the second axial position **500**, the nut **200** is unlocked.

(28) FIG. 5A illustrates that the locking key **404** begins to move from the outer radial position **406** towards the inner radial position **502** (shown in FIG. 5B) once the lead screw **204** approaches the second axial position **500** (shown in FIG. 5B). The locking key **404** no longer fixes any component (e.g., the nut **200** and/or the lead screw **204**) along the axis of rotation **210** as it leaves the outer radial position **406**. Thus, as the rotary actuator **206** continues to rotate, the lead screw **204** translates towards the torque coupler **212** and the nut **200** translates away from the torque coupler **212** along the axis of rotation **210**. In other words, once the lead screw **204** approaches the second axial position **500** (e.g., part or all of the first recess **400** aligns with the opening **402** along the axis

of rotation **210**), the nut **200** begins to translate away from the torque coupler **212**. As the tensioning nut **200** begins to translate, the second recess **408** of the nut **200** urges the locking key **404** towards the inner radial position **502**. The nut **200** continues to translate away from the torque coupler **212**, which forces the locking key **404** to be in the inner radial position **502**. In this way, the locking key **404** is in the inner radial position **502**, contacting the first recess **400** while the lead screw **204** is in the second axial position **500**. In some examples, the locking key **404** is fixed in the radial direction between the nut **200** and the lead screw **204** while the lead screw **204** is in the second axial position **500**. In other examples, the locking key **404** is urged towards the inner radial position **502** while the lead screw **204** is in the second axial position **500** but not fixed (e.g., loosely held, released, unfixed, etc.) after the second recess **408** translates fully past the opening **402**. In some examples, the lead screw **204** stops translating once the locking key **404** enters the inner radial position **502**. In some examples, the lead screw **204** stops translating once the threaded portion of lead screw **204** contacts the torque coupler **212**.

(29) FIG. 6 illustrates the example wing deployment apparatus **106** of FIG. 2 with the wings **102** and **103** in the example deployed position **600**. The wings **102** and **103** contact the second bearing block **216** on an example third stop surface **602**. The nut **200** is coupled to the wing **102** through the cable **202**. In the deployed position **600**, the nut **200** is translated towards first bearing block **208** until the third stop surface **602** makes contact with the wing **102**. In other words, the third stop surfaces **602** stop the motion of the wings **102** and **103**. The rotary actuator **206** no longer rotates the lead screw **204** as the nut **200** reaches the end of its travel. The cables **202** are tensioned by the nut **200**, thereby biasing the wings **102** and **103** towards the deployed position **600**.

(30) FIGS. 7A and 7B illustrate the example wing deployment apparatus **106** of FIG. 6 with an example locking pin **700** to engage with the example wing **102**. The wing **102** has an example pin recess **702** to receive the locking pin **700**. In some examples, the pin recess **702** and the locking pin **700** have a cylindrical shape. In other examples, the locking pin **700** can have other shapes or cross sections (e.g., rectangular, semicircle, etc.). When the wing **102** is in the stowed position **104**, as shown in FIG. 7A, the locking pin **700** does not align with the pin recess **702**. When the wing **102** is in the deployed position **600**, as shown in FIG. 7B, the locking pin **700** and the pin recess **702** align. FIGS. 7A and 7B show the locking pin **700** and the pin recess **702** in one example orientation. In other examples, the locking pin **700** and the pin recess **702** can have other orientations relative to the wing (e.g., above the wings, on the side of the wings, etc.). The locking pin **700** enters the pin recess **702** to fix the wing **102** in the deployed position **600**. In some examples, when the locking pin **700** fixes the wing **102** in the deployed position **600**, the rotary actuator **206** becomes unpowered and the tension in the cable **202** is released. Thus, the aircraft **100** maintains the wing **102** in the deployed position **600** without sending power (e.g., electricity) to the rotary actuator **206** by engaging the locking pin **700** in the pin recess **702** of the wing **102**. This lowers the power requirement and allows the aircraft **100** to have smaller power supplies (e.g., batteries), lowering the weight and related inefficiencies of the aircraft **100**.

(31) FIG. 8 is a flowchart representative of an example method **800** for deploying an example wing of an example aircraft. The method **800** begins with rotating a torque coupler (e.g., torque coupler **212**) about an axis of rotation (e.g., the axis of rotation **210**) (block **802**). In some examples, the torque coupler is rotated directly by a rotary actuator (e.g., rotary actuator **206**). In other examples, the torque coupler is rotated by the rotary actuator through another component (e.g., transmission, gear box, torque multiplier, etc.). The rotary actuator is, in some examples, an electric motor. In other examples, the rotary actuator can have other power sources (e.g., hydraulic, pneumatic, etc.). The method **800** continues with translating a lead screw (e.g., lead screw **204**) towards the torque coupler from a first position to a second position along the axis of rotation (block **804**). The lead screw is coupled to the torque coupler and threadably engaged to a tensioning nut (e.g., nut **200**). The tensioning nut is translationally locked to the torque coupler by locking key (e.g., locking key **404**), so rotating the torque coupler results in the lead screw translating towards or away from the

torque coupler based on the direction of the rotation. The method **800** continues with unlocking a tensioning nut (e.g., nut **200**) from the torque coupler (block **806**). The locking key moves away from the nut (e.g., disengages from the nut) and towards a recess (e.g., first recess **400**) in the lead screw when the lead screw is in the second axial position. Thus, the locking key leaves contact with the nut and unlocks the nut, allowing it to translate freely along the axis of rotation. In some examples, the locking key moves towards the lead screw when unlocking the nut and translationally locks the lead screw to the torque coupler. In other examples, the locking key moves into the recess of the lead screw without affecting the motion of the lead screw. The method continues by translating the nut away from the torque coupler along the axis of rotation (block **808**). The nut is threadably engaged to the lead screw. As the lead screw continues to rotate, the nut begins to translate due to the threaded coupling with the lead screw. The method finishes by deploying a wing (e.g., wing **102**) in response to the translating of the nut (block **810**). The wing is coupled to the nut, thus translating the nut causes the wing to move from a stowed position (e.g., stowed position **104**) to a deployed position (e.g., deployed position **600**).

(32) “Including” and “comprising” (and all forms and tenses thereof) are used herein to be open ended terms. Thus, whenever a claim employs any form of “include” or “comprise” (e.g., comprises, includes, comprising, including, having, etc.) as a preamble or within a claim recitation of any kind, it is to be understood that additional elements, terms, etc., may be present without falling outside the scope of the corresponding claim or recitation. As used herein, when the phrase “at least” is used as the transition term in, for example, a preamble of a claim, it is open-ended in the same manner as the term “comprising” and “including” are open ended. The term “and/or” when used, for example, in a form such as A, B, and/or C refers to any combination or subset of A, B, C such as (1) A alone, (2) B alone, (3) C alone, (4) A with B, (5) A with C, (6) B with C, or (7) A with B and with C. As used herein in the context of describing structures, components, items, objects and/or things, the phrase “at least one of A and B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B. Similarly, as used herein in the context of describing structures, components, items, objects and/or things, the phrase “at least one of A or B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B. As used herein in the context of describing the performance or execution of processes, instructions, actions, activities, etc., the phrase “at least one of A and B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B. Similarly, as used herein in the context of describing the performance or execution of processes, instructions, actions, activities, etc., the phrase “at least one of A or B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B.

(33) As used herein, singular references (e.g., “a”, “an”, “first”, “second”, etc.) do not exclude a plurality. The term “a” or “an” object, as used herein, refers to one or more of that object. The terms “a” (or “an”), “one or more”, and “at least one” are used interchangeably herein. Furthermore, although individually listed, a plurality of means, elements, or actions may be implemented by, e.g., the same entity or object. Additionally, although individual features may be included in different examples or claims, these may possibly be combined, and the inclusion in different examples or claims does not imply that a combination of features is not feasible and/or advantageous.

(34) The following paragraphs provide various examples of wing deployment apparatus and methods for aircraft disclosed herein:

(35) Example 1 is a wing deployment apparatus including a rotary actuator having an axis of rotation coupled to a torque coupler. The torque coupler includes an opening with a locking key disposed in the opening. The locking key is movable in a radial direction relative to the axis of rotation between an outer radial position and an inner radial position. A lead screw is rotationally coupled to the torque coupler and moves along the axis of rotation relative to the torque coupler

between a first axial position and a second axial position. The lead screw has a first recess to align with the opening when the lead screw is in the second axial position to accept the locking key when the locking key is in the inner radial position. A nut is threadably engaged to the lead screw and rotationally fixed. The nut includes a second recess to accept the locking key when the locking key is in the outer radial position and the lead screw is in the first axial position. The locking key prevents movement of the nut along the axis of rotation relative to the torque coupler when the locking key is in the outer radial position and the lead screw is in the first axial position. A wing is operatively coupled to the nut to move the wing between a stowed and a deployed position in response to the movement of the nut.

(36) Example 2 includes the wing deployment apparatus of example 1, where the wing contacts the nut when the wing is in the stowed position and the lead screw is in the first axial position. The nut prevents movement of the wing towards the deployed position.

(37) Example 3 includes the wing deployment apparatus of example 2, further including a set screw coupled to the torque coupler. The set screw applies a force to the torque coupler along the axis of rotation. The force moves the nut and biases the wing towards the stowed position while the lead screw is in the first axial position.

(38) Example 4 includes the wing deployment apparatus of example 1, where the second recess is shaped to urge the locking key towards the inner radial position as the nut moves away from the torque coupler along the axis of rotation.

(39) Example 5 includes the wing deployment apparatus of example 1, where the locking key has a spherical shape.

(40) Example 6 includes the wing deployment apparatus of example 1, where the second recess is an axially symmetric groove along an inner surface of the nut.

(41) Example 7 includes the wing deployment apparatus of example 6, including a plurality of first recesses, a plurality of openings, and a plurality of locking keys.

(42) Example 8 includes the wing deployment apparatus of example 1, where the lead screw is a ball screw, and the nut includes a ball nut.

(43) Example 9 includes the wing deployment apparatus of example 1, where the rotary actuator is an electric motor.

(44) Example 10 includes the wing deployment apparatus, including a locking pin to engage with the wing when the wing is in the deployed position. The locking pin prevents movement of the wing.

(45) Example 11 is an aircraft including a fuselage and a wing that moves between a stowed position and a deployed position. The aircraft includes a rotary actuator that has an axis of rotation and is coupled to a torque coupler. The torque coupler includes an opening. A locking key is disposed in the opening and moves in a radial direction, relative to the axis of rotation, between an outer radial position and an inner radial position. A lead screw is rotationally coupled to the torque coupler and moves along the axis of rotation relative to the torque coupler between a first axial position and a second axial position. The lead screw has a first recess that aligns with the opening when the lead screw is in the second axial position. The first recess accepts the locking key when the locking key is in the inner radial position. A nut is threadably engaged to the lead screw and rotationally fixed. The nut includes a second recess to accept the locking key when the locking key is in the outer radial position and the lead screw is in the first axial position. The locking key prevents movement of the nut along the axis of rotation relative to the torque coupler when the locking key is in the outer radial position and the lead screw is in the first axial position. The nut is operatively coupled to the wing to move the wing from the stowed position to the deployed position.

(46) Example 12 includes the aircraft of example 11, where the wing contacts the nut when the wing is in the stowed position and the lead screw is in the first axial position. The nut prevents movement of the wing towards the deployed position.

- (47) Example 13 includes the aircraft of example 12, further including a set screw coupled to the torque coupler. The set screw applies a force to the torque coupler along the axis of rotation. The force moves the nut and biases the wing towards the stowed position while the lead screw is in the first axial position.
- (48) Example 14 includes the aircraft of example 11, where the locking key has a spherical shape.
- (49) Example 15 includes the aircraft of example 11, further including a plurality of first recesses, a plurality of openings, and a plurality of locking keys.
- (50) Example 16 includes the aircraft of example 11, where the lead screw is a ball screw, and the nut includes a ball nut.
- (51) Example 17 includes the aircraft of claim **11**, where the rotary actuator is an electric motor.
- (52) Example 18 includes the aircraft of example 11, including a locking pin to engage with the wing when the wing is in the deployed position. The locking pin prevents movement of the wing.
- (53) Example 19 is a method of deploying a wing on an aircraft including rotating a torque coupler about an axis of rotation. The torque coupler includes a locking key disposed in an opening of the torque coupler. The method continues with translating a lead screw rotationally coupled to the torque coupler toward the torque coupler, from a first position to a second position along the axis of rotation. The lead screw is threadably engaged to a nut. The method continues with unlocking the nut from the torque coupler by disengaging the locking key from the nut. The method continues by translating the nut away from the torque coupler along the axis of rotation and deploying a wing in response to the translating of the nut.
- (54) Example 20 includes the method of example 19, further including locking the wing with a locking pin after deploying the wing. The locking pin prevents motion of the wing.
- (55) The following claims are hereby incorporated into this Detailed Description by this reference. Although certain example systems, apparatus, articles of manufacture, and methods have been disclosed herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all systems, apparatus, articles of manufacture, and methods fairly falling within the scope of the claims of this patent.

## Claims

1. A wing deployment apparatus comprising: a rotary actuator having an axis of rotation and coupled to a torque coupler, the torque coupler including an opening; a locking key disposed in the opening, the locking key movable in a radial direction relative to the axis of rotation between an outer radial position and an inner radial position; a lead screw rotationally coupled to the torque coupler and movable along the axis of rotation relative to the torque coupler between a first axial position and a second axial position, the lead screw having a first recess to align with the opening when the lead screw is in the second axial position to accept the locking key when the locking key is in the inner radial position; a nut threadably engaged to the lead screw and rotationally fixed, the nut including a second recess to accept the locking key when the locking key is in the outer radial position and the lead screw is in the first axial position, the locking key to prevent movement of the nut along the axis of rotation relative to the torque coupler when the locking key is in the outer radial position and the lead screw is in the first axial position; and a wing operatively coupled to the nut to move the wing between a stowed and a deployed position in response to movement of the nut.
2. The apparatus as recited in claim 1, wherein the wing contacts the nut when the wing is in the stowed position and the lead screw is in the first axial position, the nut to prevent movement of the wing towards the deployed position.
3. The apparatus as recited in claim 2, further including a set screw coupled to the torque coupler, the set screw to apply a force to the torque coupler along the axis of rotation, the force to move the nut and to bias the wing towards the stowed position while the lead screw is in the first axial

position.

4. The apparatus as recited in claim 1, wherein the second recess is shaped to urge the locking key toward the inner radial position as the nut moves away from the torque coupler along the axis of rotation.

5. The apparatus as recited in claim 1, wherein the locking key has a spherical shape.

6. The apparatus as recited in claim 1, wherein the second recess is an axially symmetric groove along an inner surface of the nut.

7. The apparatus as recited in claim 6, further including a plurality of first recesses, a plurality of openings, and a plurality of locking keys.

8. The apparatus as recited in claim 1, wherein the lead screw is a ball screw and the nut includes a ball nut.

9. The apparatus as recited in claim 1, wherein the rotary actuator is an electric motor.

10. The apparatus as recited in claim 1, further including a locking pin to engage with the wing when the wing is in the deployed position, the locking pin to prevent movement of the wing.

11. An aircraft comprising: a fuselage; a wing movable between a stowed position and a deployed position; a rotary actuator having an axis of rotation and coupled to a torque coupler, the torque coupler including an opening; a locking key disposed in the opening, the locking key movable in a radial direction relative to the axis of rotation between an outer radial position and an inner radial position; a lead screw rotationally coupled to the torque coupler and movable along the axis of rotation relative to the torque coupler between a first axial position and a second axial position, the lead screw having a first recess to align with the opening when the lead screw is in the second axial position to accept the locking key when the locking key is in the inner radial position; and a nut threadably engaged to the lead screw and rotationally fixed, the nut including a second recess to accept the locking key when the locking key is in the outer radial position and the lead screw is in the first axial position, the locking key to prevent movement of the nut along the axis of rotation relative to the torque coupler when the locking key is in the outer radial position and the lead screw is in the first axial position, the nut operatively coupled to the wing to move the wing from the stowed position to the deployed position.

12. The aircraft as recited in claim 11, wherein the wing contacts the nut when the wing is in the stowed position and the lead screw is in the first axial position, the nut to prevent movement of the wing towards the deployed position.

13. The aircraft as recited in claim 12, further including a set screw coupled to the torque coupler, the set screw to apply a force to the torque coupler along the axis of rotation, the force to move the nut and bias the wing towards the stowed position while the lead screw is in the first axial position.

14. The aircraft as recited in claim 11, wherein the locking key has a spherical shape.

15. The aircraft as recited in claim 11, further including a plurality of first recesses, a plurality of openings, and a plurality of locking keys.

16. The aircraft as recited in claim 11, wherein the lead screw is a ball screw and the nut includes a ball nut.

17. The aircraft as recited in claim 11, wherein the rotary actuator is an electric motor.

18. The aircraft as recited in claim 11, further including a locking pin to engage with the wing when the wing is in the deployed position, the locking pin to prevent movement of the wing.

19. The method of deploying a wing on an aircraft comprising: rotating a torque coupler about an axis of rotation, the torque coupler including a locking key disposed in an opening of the torque coupler; translating a lead screw rotationally coupled to the torque coupler toward the torque coupler from a first position to a second position along the axis of rotation, the lead screw threadably engaged to a nut; unlocking the nut from the torque coupler by disengaging the locking key from the nut; translating the nut away from the torque coupler along the axis of rotation; and deploying a wing in response to the translating of the nut.

20. A method as recited in claim 19, further including locking the wing with a locking pin after deploying the wing, the locking pin to prevent motion of the wing.

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