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United States Patent Application Publication

20250263167

Kind Code

A1

Publication Date

August 21, 2025

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Tilting Hexrotor Aircraft

Abstract

One embodiment is an aircraft including a fuselage; a wing connected to the fuselage; first and second booms connected to the wing on opposite sides of the fuselage; first and second forward propulsion systems attached to forward ends of the first and second booms; first and second aft propulsion systems fixedly attached proximate aft ends of the first and second booms; first and second wing-mounted propulsion systems connected to outboard ends of wings; and first and second wing tips fixedly connected to outboard sides of the first and second wing-mounted propulsion systems; wherein the first and second wing-mounted propulsion systems and the first and second wing tips are collectively tiltable between a first position when the aircraft is in a hover mode and a second position when the aircraft is in a cruise mode.

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Appl. No.: 18/933072

Filed: October 31, 2024

Related U.S. Application Data

parent US continuation 17216591 20210329 parent-grant-document US 12168508 child US 18933072

Publication Classification

Int. Cl.: B64C29/00 (20060101); **B64C39/04** (20060101); **B64C39/08** (20060101); **B64D27/31** (20240101); **B64D27/32** (20240101); **B64D31/16** (20240101)

U.S. Cl.:

CPC B64C29/0033 (20130101); **B64C29/00** (20130101); **B64C39/04** (20130101); **B64C39/08** (20130101); **B64D27/24** (20130101);

Background/Summary

CROSS-REFERENCE OF PRIORITY APPLICATION [0001] This application is a continuation of (and claims the benefit of priority to) U.S. patent application Ser. No. 17/216,591, filed Mar. 29, 2021, entitled “TILTING HEXROTOR AIRCRAFT,” which is incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates in general to the field of tiltrotor aircraft and, more particularly, though not exclusively, to tilting hexrotor arrangements for such aircraft.

BACKGROUND

[0003] An electric vertical takeoff and landing (eVTOL) is a type of aircraft that uses electric power to supply rotational energy through electric motor(s) to props, rotors, or fans in an aircraft propulsion system for enabling the aircraft to hover, take off, and land vertically. Because of their versatility and lack of a need for a runway, eVTOLs are particularly useful for providing urban air mobility. As used herein, the term eVTOL also includes VTOLs that use hybrid electric (with an engine running a generator producing electricity and battery stored power) or turbo electric (an engine running a generator providing all power required) propulsion systems. One particular type of eVTOL is an electric tiltrotor aircraft.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] To provide a more complete understanding of the present disclosure and features and advantages thereof, reference is made to the following description, taken in conjunction with the accompanying figures, in which like reference numerals represent like elements:

[0005] FIGS. 1A-1B illustrate a tiltrotor aircraft having a tilting hexrotor configuration in accordance with embodiments described herein;

[0006] FIG. 2 illustrates a hexrotor arc arrangement of rotors of the tiltrotor aircraft of FIGS. 1A and 1B;

[0007] FIGS. 3A-3B illustrate another tiltrotor aircraft having a tilting hexrotor configuration in accordance with alternative embodiments described herein;

[0008] FIGS. 4A-4B illustrate another tiltrotor aircraft having a tilting hexrotor configuration in accordance with alternative embodiments described herein;

[0009] FIGS. 5A-5B illustrate another tiltrotor aircraft having a tilting hexrotor configuration in accordance with alternative embodiments described herein;

[0010] FIGS. 6A-6B illustrate another tiltrotor aircraft having a tilting hexrotor configuration in accordance with alternative embodiments described herein;

[0011] FIGS. 7A-7B illustrate another tiltrotor aircraft having a tilting hexrotor configuration in accordance with alternative embodiments described herein;

[0012] FIGS. 8A-8B illustrate another tiltrotor aircraft having a tilting hexrotor configuration in

accordance with alternative embodiments described herein; and

[0013] FIGS. **9A-9B** illustrate another tiltrotor aircraft having a tilting hexrotor configuration in accordance with alternative embodiments described herein;

[0014] FIG. **10** illustrates other tiltrotor aircraft tilting hexrotor configurations in accordance with alternative embodiments described herein; and

[0015] FIG. **11** illustrates an alternative arrangement for a boom-mounted propulsion system for an aircraft in accordance with embodiments described herein.

DETAILED DESCRIPTION

[0016] The following disclosure describes various illustrative embodiments and examples for implementing the features and functionality of the present disclosure. While particular components, arrangements, and/or features are described below in connection with various example embodiments, these are merely examples used to simplify the present disclosure and are not intended to be limiting. It will of course be appreciated that in the development of any actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, including compliance with system, business, and/or legal constraints, which may vary from one implementation to another. Moreover, it will be appreciated that, while such a development effort might be complex and time-consuming; it would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

[0017] In the Specification, reference may be made to the spatial relationships between various components and to the spatial orientation of various aspects of components as depicted in the attached drawings. However, as will be recognized by those skilled in the art after a complete reading of the present disclosure, the devices, components, members, apparatuses, etc. described herein may be positioned in any desired orientation. Thus, the use of terms such as “above”, “below”, “upper”, “lower”, “top”, “bottom”, or other similar 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 components described herein may be oriented in any desired direction. When used to describe a range of dimensions or other characteristics (e.g., time, pressure, temperature, length, width, etc.) of an element, operations, and/or conditions, the phrase “between X and Y” represents a range that includes X and Y.

[0018] Additionally, as referred to herein in this Specification, the terms “forward”, “aft”, “inboard”, and “outboard” may be used to describe relative relationship(s) between components and/or spatial orientation of aspect(s) of a component or components. The term “forward” may refer to a spatial direction that is closer to a front of an aircraft relative to another component or component aspect(s). The term “aft” may refer to a spatial direction that is closer to a rear of an aircraft relative to another component or component aspect(s). The term “inboard” may refer to a location of a component that is within the fuselage of an aircraft and/or a spatial direction that is closer to or along a centerline of the aircraft (wherein the centerline runs between the front and the rear of the aircraft) or other point of reference relative to another component or component aspect. The term “outboard” may refer to a location of a component that is outside the fuselage of an aircraft and/or a spatial direction that farther from the centerline of the aircraft or other point of reference relative to another component or component aspect.

[0019] Further, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Example embodiments that may be used to implement the features and functionality of this disclosure will now be described with more particular reference to the accompanying FIGURES.

[0020] Described herein are various configurations for hexrotor aircraft. In accordance with features of embodiments described herein, the drive system includes one or more fixed electric motors coupled to an off-axis tilting gearbox. The tilting configuration may have a motor attached

to a drive system for reduction of rpm or the motor itself may be direct drive directly turning the prop at the desired speed. Tilting of the rotor assemblies can take place with respect to the stationary motors and wing or other stationary structure of the aircraft. The motors or motors with drive may tilt with the rotors/props or the motor may remain stationary with the prop and a portion of the drive rotating. Tilting may occur with a portion of the attached wing or boom or the wing or boom may stay fixed with only the pylon tilting.

[0021] The tilting pylons in certain ones of the following illustrative example include forward tilting pylon on a boom and typically aft rotors above or below the boom. In some cases, the aft rotor are tiltable on a tail surface or below the boom. The wing tip rotor may either tilt independently of the wing (as shown in FIGS. 3A, 4A, and 5A) or tilt with a portion of the wing rotating with it (as shown in FIG. 1A). In either case, the portion of the wing outboard of the pylon may tilt with the pylon or remain stationary. When rotating with the rotating pylon, all of the wing or any percentage of the wing may rotate. No or minimal wing rotating with the pylon improves drag during transition from hover mode to cruise mode, as the flow on the wing remains largely attached as opposed to stalled, which can create large drag and lift issues. Allowing the wing to rotate minimizes download in hover mode due to impingement of the rotor stream on exposed airframe/wing surfaces, reducing net rotor lift and power required in hover. The tail may be independent of the propulsive boom or attached as a primary load path.

[0022] FIGS. 1A and 1B illustrate an example tiltrotor aircraft **100** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. 1A), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. 1B), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **100** includes a fuselage **102**, wing **104**, and booms **106a**, **106b**, connected to the wing on opposite sides of the fuselage **102**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including forward propulsion systems **108a**, **108b**, adjacent to the forward end of the fuselage **102**, aft propulsion systems **110a**, **110b**, adjacent to the aft end of the fuselage **102**, and a pair of wing-mounted propulsion systems **112a**, **112b**, proximate opposite tips of wing **104**. In the illustrated embodiment, forward propulsion systems **108a**, **108b**, are attached to forward ends of booms **106a**, **106b**, respectively, and aft propulsion systems **110a**, **110b**, are attached to booms **106a**, **106b**, respectively, proximate aft ends thereof. Aircraft **100** further includes a tail assembly **113** at an aft end thereof.

[0023] In the illustrated embodiment, each forward propulsion system **108a**, **108b**, includes a drive system housing comprising a pylon **120a**, **120b**, and a rotatable open rotor assembly **122a**, **122b**, comprising a plurality of rotor blades **124a**, **124b**, connected to a rotor mast and configured to rotate about a rotor axis **126a**, **126b**. As shown in FIGS. 1A and 1B, each rotor assembly **122a**, **122b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor blades **124a**, **124b**, about rotor axis **126a**, **126b**, generates lift while operating in helicopter mode and thrust while operating in airplane mode. Each pylon **120a**, **120b**, may house one or more electric motors therein configured to produce rotational energy that drives the rotation of rotor assembly **122a**, **122b**. Alternatively, each pylon **120a**, **120b**, may house a gearbox therein that drives the rotation of rotor assembly **122a**, **122b**, wherein the gearbox receives rotational energy from a driveshaft.

[0024] In the illustrated embodiment, each wing-mounted propulsion system **112a**, **112b**, includes a drive system housing comprising a pylon **130a**, **130b**, and a rotatable open rotor assembly **132a**, **132b**, comprising a plurality of rotor blades **134a**, **134b**, connected to a rotor mast and configured to rotate about a rotor axis **136a**, **136b**. As shown in FIGS. 1A and 1B, each rotor assembly **132a**, **132b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described.

It should also be recognized that rotor assemblies **132a**, **132b**, may include a different number of rotor blades than rotor assemblies **122a**, **122b**. Rotation of rotor blades **134a**, **134b**, about rotor axis **136a**, **136b**, generates lift while operating in helicopter mode and thrust while operating in airplane mode. Each pylon **130a**, **130b**, may house one or more electric motors therein configured to produce rotational energy that drives the rotation of rotor assembly **132a**, **132b**. Alternatively, each pylon **130a**, **130b**, may house a gearbox therein that drives the rotation of rotor assembly **132a**, **132b**, wherein the gearbox receives rotational energy from a driveshaft.

[0025] In the illustrated embodiment, each aft propulsion system **110a**, **110b**, includes a drive system housing comprising a pylon **140a**, **140b**, and a rotatable open rotor assembly **142a**, **142b**, comprising a plurality of rotor blades **144a**, **144b**, connected to a rotor mast and configured to rotate about a rotor axis **146a**, **146b**. As shown in FIGS. 1A and 1B, each rotor assembly **142a**, **142b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades on a single or stacked rotor may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor blades **144a**, **144b**, about rotor axis **146a**, **146b**, generates lift while operating in helicopter mode. Each pylon **140a**, **140b**, may house one or more electric motors therein configured to produce rotational energy that drives the rotation of rotor assembly **142a**, **142b**. Alternatively, each pylon **140a**, **140b**, may house a gearbox therein that drives the rotation of rotor assembly **142a**, **142b**, wherein the gearbox receives rotational energy from a driveshaft. It will be recognized that while rotor assemblies **142a**, **142b**, are illustrated as being disposed above (i.e., on top of) booms **104a**, **104b**, they may alternatively be disposed below (i.e., on the underside of) booms and the distance from rotor to boom may vary or there may be rotor above and below the pylon as yet another alternative.

[0026] The fairings of pylons **140a**, **140b**, are designed to reduce the rotor-boom noise. In particular, there are two parameters that influence the acoustics of rotors over booms, including the relative width W of the boom surface (narrow is better than wide) and the ratio of the height of the rotor h to the rotor radius R (the higher the better). The fairings function to elevate the rotor above the boom, thereby to increase h/R and lower the acoustic impact of the rotor over the boom, and to cover the mast to prevent the elevated rotor from being overly penalizing in drag, as the fairing has lower drag than an exposed mast. The fairing is also much narrower (lower relative W) than original boom as well, which provides additional acoustic advantages.

[0027] In accordance with features of embodiments described herein, and as illustrated in FIGS. 1A and 1B, wing-mounted propulsion systems **112a**, **112b**, are connected to inboard ends of wing tips **114a**, **114b**, attached to outboard ends of wing **104**. Wing tips **114a**, **114b**, together with wing-mounted propulsion systems **112a**, **112b**, tilt relative to wing **104** between a first position (FIG. 1A), in which propulsion systems **112a**, **112b**, and wing tips **114a**, **114b**, are configured in a hover mode, and a second position (FIG. 1B), in which propulsion systems **112a**, **112b**, and wing tips **114a**, **114b**, are configured in a cruise mode. Similarly, forward propulsion systems **108a**, **108b**, (and more specifically, pylons **120a**, **120b**) are tiltably connected to forward ends of booms **106a**, **106b**, such that they may be tilted between a first position (FIG. 1A), in which propulsion systems **108a**, **108b**, are configured in a hover mode, and a second position (FIG. 1B), in which propulsion systems **108a**, **108b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **110a**, **110b**, are fixedly attached to booms **106a**, **106b**, proximate aft ends thereof and do not convert between hover mode (FIG. 1A) and cruise mode (FIG. 1B).

[0028] The position of rotor assemblies **122a**, **122b**, **132a**, **132b**, as well as the pitch of individual rotor blades **124a**, **124b**, **134a**, **134b**, **144a**, **144b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **100**. As previously noted, propulsion systems **108a**, **108b**, **112a**, **112b**, are each convertible, relative to fuselage **102**, between a vertical position, as shown in FIG. 1A, and a horizontal position, as shown in FIG. 1B. Propulsion systems **108a**, **108b**, **112a**, **112b**, are in the vertical position during vertical takeoff and landing mode.

Vertical takeoff and landing mode may be considered to include hover operations of aircraft **100**. Propulsion systems **108a**, **108b**, **112a**, **112b**, are in the horizontal position during forward flight mode, in which aircraft **100** is in forward flight. In forward flight mode, propulsion systems **108a**, **108b**, **112a**, **112b**, direct their respective thrusts in the aft direction to propel aircraft **100** forward. Aircraft **100** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. **1A**, although faster forward flight is achievable while in the forward flight mode configuration of FIG. **1B**. Propulsion systems **108a**, **108b**, **112a**, **112b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system. Each of the propulsion systems **108a**, **108b**, **110a**, **110b**, **112a**, **112b**, may utilize an electric motor and gearbox unit disposed within a respective pylon **120a**, **120b**, **130a**, **130b**, **140a**, **140b** or a direct drive motor of group of motors on the same shaft as a power source to rotate the respective rotor assembly **122a**, **122b**, **132a**, **132b**, **142a**, **142b**, about rotor axis **126a**, **126b**, **136a**, **136b**, **146a**, **146b**, via a rotor mast.

[0029] It should be noted that, although propulsion systems **108a**, **108b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **110a**, **110b**. Additionally and/or alternatively, propulsion systems **112a**, **112b**, may be connected to opposite ends of wing **104** such that only pylons **130a**, **130b**, or a portion thereof, are tiltable relative to wing **104**. The tiltable pylons **130a**, **130b** and **108a** and **108b** may also be differentially tiltable and may vary in power to control yaw of the aircraft whereas different thrust for roll and pitch is controlled through differential blade pitch, rpm, and motor power.

[0030] In accordance with features of embodiments described herein, when aircraft **100** is in cruise mode, rotor assemblies **142a**, **142b**, may cease rotation. In embodiments in which propulsion systems **108a**, **108b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies **122a**, **122b**, may also cease rotation when aircraft **100** is in cruise mode. Fewer active rotor assemblies in cruise mode improves blade loading and propulsive efficiency of the props. In addition, stopping the aft rotors avoids ingestion of the wakes from the forward rotors, which would make the aft rotors less efficient. With six rotor assemblies, a rotor assembly can be lost while still allowing aircraft **100** to hover even without motor redundancy per rotor assembly. In the event of a rotor failure, the rotor on the opposite side of the aircraft would be powered down, allowing the aircraft to hover as a quad copter with the four remaining rotors operating at elevated power levels. In accordance with features of embodiments described herein, if the aft left rotor were to fail, the forward right rotor would also be powered down, allowing the thrust on the remaining rotors to balance. Electric power to the motors allows the distributed nature of the aircraft **100** to stay weight efficient without requiring extensive cross-connects.

[0031] Because the aircraft **100** includes six (6) rotor assemblies, the aircraft may be referred to as a “hexrotor aircraft.” FIG. **2** illustrates a hexrotor arc arrangement **200** when aircraft **100** is in hover mode. In particular, to allow the minimum number of rotors and still allow loss of a rotor as a recoverable failure mechanism in a hover, the rotors are arranged in an arc arrangement both side-to-side and forward-to-aft. As a result, when one rotor is lost and a second rotor is powered down, the aircraft can still be balanced as a quad arrangement on the remaining rotors. If a linear arrangement were used, the power and balance requirements would prevent recovery on just four rotors. Multi-copters with more than six rotors may recover by offsetting opposing rotors, but six in the illustrated arc arrangement is the minimum to allow a recovery after failure and result in significant weight savings due to fewer redundant motors and rotors.

[0032] FIGS. **3A** and **3B** illustrate an example tiltrotor aircraft **300** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. **3A**), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. **3B**), which allows for forward flight as

well as horizontal takeoff and landing. Aircraft **300** includes a fuselage **302**, wing **304**, and booms **306a**, **306b**, connected to the wing on opposite sides of the fuselage **302**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a first pair of boom-mounted propulsion systems **308a**, **308b**, a second pair of boom-mounted propulsion systems **310a**, **310b**, and a pair of wing-mounted propulsion systems **312a**, **312b**. In the illustrated embodiment, propulsion systems **312a**, **312b**, are tiltably connected to the forward edge of wing **304** at outboard ends thereof, while propulsion systems **308a**, **308b**, are tiltably connected to the forward end of booms **306a**, **306b** inboard of propulsion systems **312a**, **312b**. Alternatively, propulsion systems **308a**, **308b**, may be tiltably connected to the forward edge of wing **304** inboard of propulsion systems **312a**, **312b**. Propulsion systems **310a**, **310b**, are mounted to upper surfaces of booms **304a**, **304b**, proximate the aft end or aft of the fuselage **302**. Aircraft **300** further includes a tail assembly **313** at an aft end thereof.

[0033] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **308a**, **308b**, **310a**, **310b**, **312a**, and **312b** may include a drive system housing comprising a pylon, and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. 3A and 3B, the rotor assembly of each of propulsion systems **308a**, **308b**, **312a**, **312b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **308a**, **308b**, may include a different number of rotor blades than rotor assemblies of propulsion systems **312a**, **312b**. Rotation of rotor assemblies of propulsion systems **308a**, **308b**, **312a**, and **312b** generates lift while the aircraft **300** is operating in helicopter mode and thrust while the aircraft **300** is operating in airplane mode.

[0034] In the illustrated embodiment, each boom-mounted propulsion system **310a**, **310b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. 3A and 3B, each rotor assembly of propulsion systems **310a**, **310b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor assemblies of propulsion systems **310a**, **310b**, generates lift while the aircraft **300** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **310a**, **310b**, are illustrated as being disposed above (i.e., on top of) booms **304a**, **304b**, they may alternatively be disposed below (i.e., on the underside of) booms.

[0035] In accordance with features of embodiments described herein, and as illustrated in FIGS. 3A and 3B, propulsion systems **308a**, **308b**, **312a**, **312b**, are tiltably connected to the wing **304** and tilt relative to wing between a first position (FIG. 3A), in which propulsion systems **308a**, **308b**, **312a**, **312b**, are configured in a hover mode, and a second position (FIG. 3B), in which propulsion systems **308a**, **308b**, **312a**, **312b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **310a**, **310b**, are fixedly attached to booms **306a**, **306b**, aft of the wing **304** in hover mode and do not convert between hover mode (FIG. 3A) and cruise mode (FIG. 3B).

[0036] The position of rotor assemblies of propulsion systems **308a**, **308b**, **312a**, **312b**, as well as the pitch of individual rotor blades of all of the propulsion systems **308a**, **308b**, **310a**, **310b**, **312a**, **312b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **300**. As previously noted, propulsion systems **308a**, **308b**, **312a**, **312b**, are each convertible, relative to fuselage **302**, between a vertical position, as shown in FIG. 3A, and a horizontal position, as shown in FIG. 3B. Propulsion systems **308a**, **308b**, **312a**, **312b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **300**. Propulsion systems **308a**, **308b**, **312a**, **312b**, are in the horizontal position during forward flight mode, in which aircraft **300** is in forward flight.

In forward flight mode, propulsion systems **308a**, **308b**, **312a**, **312b**, direct their respective thrusts in the aft direction to propel aircraft **300** forward. Aircraft **300** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. **3A**, although faster forward flight is achievable while in the forward flight mode configuration of FIG. **3B**. Propulsion systems **308a**, **308b**, **312a**, **312b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0037] It should be noted that, although propulsion systems **308a**, **308b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **310a**, **310b**.

[0038] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **300** is in cruise mode, rotor assemblies of propulsion systems **310a**, **310b**, may cease rotation. In embodiments in which propulsion systems **308a**, **308b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **300** is in cruise mode. For rotors fixed in a hover or horizontal position, stopping the rotor when in transition to cruise flight on the wing reduces power requirements not contributing to forward flight. Drag is reduced by stopping the rotor such that only the tip presents frontal area. Propulsive efficiency of the remaining rotors is increased as the remaining rotors blade loading increases in cruise in comparison to power lost as a function of rotating the blade.

[0039] FIGS. **4A** and **4B** illustrate an example tiltrotor aircraft **400** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. **4A**), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. **4B**), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **400** includes a fuselage **402**, wing **404**, and booms **406a**, **406b**, connected to the wing on opposite sides of the fuselage **402**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a forward pair of boom-mounted propulsion systems **408a**, **408b**, an aft pair of boom-mounted propulsion systems **410a**, **410b**, and a pair of wing-mounted propulsion systems **412a**, **412b**. In the illustrated embodiment, propulsion systems **412a**, **412b**, are tiltable connected to the wing **404** proximate outboard ends thereof, while propulsion systems **408a**, **408b**, are tiltable connected to the forward end of wing booms **404a**, **404b**. Propulsion systems **410a**, **410b**, are mounted to bottom surfaces of booms **404a**, **404b**, proximate the aft end of the fuselage **402**. Aircraft **400** further includes a tail assembly **413** at an aft end thereof.

[0040] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **408a**, **408b**, **410a**, **410b**, **412a**, and **412b** may include a drive system housing comprising a pylon, and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **4A** and **4B**, the rotor assembly of each of propulsion systems **408a**, **408b**, **412a**, **412b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **408a**, **408b**, may include a different number of rotor blades than rotor assemblies of propulsion systems **412a**, **412b**. Rotation of rotor assemblies of propulsion systems **408a**, **408b**, **412a**, and **412b** generates lift while the aircraft **400** is operating in helicopter mode and thrust while the aircraft **400** is operating in airplane mode.

[0041] In the illustrated embodiment, each boom-mounted propulsion system **410a**, **410b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **4A** and **4B**, each rotor assembly of propulsion systems **410a**, **410b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor

assemblies of propulsion systems **410a**, **410b**, generates lift while the aircraft **400** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **410a**, **410b**, are illustrated as being disposed below (i.e., on the underside of) booms **404a**, **404b**, they may alternatively be disposed above (i.e., on top of) booms.

[0042] In accordance with features of embodiments described herein, and as illustrated in FIGS. **4A** and **4B**, propulsion systems **412a**, **412b**, are connected to inboard ends of wing tips **414a**, **414b**, disposed on outboard ends of wing **404**. Wing tips **414a**, **414b**, together with wing-mounted propulsion systems **412a**, **412b**, tilt relative to wing **404** between a first position (FIG. **4A**), in which propulsion systems **412a**, **412b**, and wing tips **414a**, **414b**, are configured in a hover mode, and a second position (FIG. **4B**), in which propulsion systems **412a**, **412b**, and wing tips **414a**, **414b**, are configured in a cruise mode.

[0043] Similarly, forward propulsion systems **408a**, **408b**, are tiltably connected to forward ends of booms and tiltable between a first position (FIG. **4A**), in which propulsion systems **408a**, **408b**, **412a**, **412b**, are configured in a hover mode, and a second position (FIG. **4B**), in which propulsion systems **408a**, **408b**, **412a**, **412b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **410a**, **410b**, are fixedly attached to booms **406a**, **406b**, aft of the wing **404** in hover mode and do not convert between hover mode (FIG. **4A**) and cruise mode (FIG. **4B**).

[0044] The position of rotor assemblies of propulsion systems **408a**, **408b**, **412a**, **412b**, as well as the pitch of individual rotor blades of all of the propulsion systems **408a**, **408b**, **410a**, **410b**, **412a**, **412b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **400**. As previously noted, propulsion systems **408a**, **408b**, **412a**, **412b**, are each convertible, relative to fuselage **402**, between a vertical position, as shown in FIG. **4A**, and a horizontal position, as shown in FIG. **4B**. Propulsion systems **408a**, **408b**, **412a**, **412b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **400**. Propulsion systems **408a**, **408b**, **412a**, **412b**, are in the horizontal position during forward flight mode, in which aircraft **400** is in forward flight. In forward flight mode, propulsion systems **408a**, **408b**, **412a**, **412b**, direct their respective thrusts in the aft direction to propel aircraft **400** forward. Aircraft **400** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. **4A**, although faster forward flight is achievable while in the forward flight mode configuration of FIG. **4B**. Propulsion systems **408a**, **408b**, **412a**, **412b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0045] It should be noted that, although propulsion systems **408a**, **408b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **410a**, **410b**.

[0046] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **400** is in cruise mode, rotor assemblies of propulsion systems **410a**, **410b**, may cease rotation. In embodiments in which propulsion systems **408a**, **408b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **400** is in cruise mode. Aircraft **400** functions similarly to aircraft **300**, with the primary benefit being a wing extension outboard of the rotor pylon that allows greater efficiency in cruise than a wing with less span. The wing extension rotor with rotor pylon to minimize download in hover due the impingement of the rotor downwash on its exposed surfaces.

[0047] FIGS. **5A** and **5B** illustrate an example tiltrotor aircraft **500** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. **5A**), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. **5B**), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **500** includes a fuselage **502**, aft wing **504**, forward

wing **505**, and booms **506a**, **506b**, connected to the wing **504** on opposite sides of the fuselage **502**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a first pair of wing-mounted propulsion systems **508a**, **508b**, a pair of boom-mounted propulsion systems **510a**, **510b**, and a second pair of wing-mounted propulsion systems **512a**, **512b**. In the illustrated embodiment, propulsion systems **512a**, **512b**, are tiltably connected to wing **504** proximate outboard ends thereof, while propulsion systems **508a**, **508b**, are tiltably connected to wing **505** proximate outboard ends thereof and are disposed inboard of propulsion systems **512a**, **512b**. Propulsion systems **510a**, **510b**, are mounted to upper surfaces of booms **505A**, **505B**, proximate aft ends thereof. Aircraft **500** further includes a tail assembly **513** at an aft end thereof.

[0048] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **508a**, **508b**, **510a**, **510b**, **512a**, and **512b** may include a drive system housing comprising a pylon, and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. 5A and 5B, the rotor assembly of each of propulsion systems **508a**, **508b**, **512a**, **512b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **508a**, **508b**, may include a different number of rotor blades than rotor assemblies of propulsion systems **512a**, **512b**. Rotation of rotor assemblies of propulsion systems **508a**, **508b**, **512a**, and **512b** generates lift while the aircraft **500** is operating in helicopter mode and thrust while the aircraft **500** is operating in airplane mode.

[0049] In the illustrated embodiment, each boom-mounted propulsion system **510a**, **510b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. 5A and 5B, each rotor assembly of propulsion systems **510a**, **510b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor assemblies of propulsion systems **510a**, **510b**, generates lift while the aircraft **500** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **510a**, **510b**, are illustrated as being disposed above (i.e., on top of) booms **505A**, **505B**, they may alternatively be disposed below (i.e., on the underside of) booms.

[0050] In accordance with features of embodiments described herein, and as illustrated in FIGS. 5A and 5B, propulsion systems **512a**, **512b**, are connected to inboard ends of wing tips **514a**, **514b**, disposed on outboard ends of wing **504**. Wing tips **514a**, **514b**, together with wing-mounted propulsion systems **512a**, **512b**, tilt relative to wing **504** between a first position (FIG. 5A), in which propulsion systems **512a**, **512b**, and wing tips **514a**, **514b**, are configured in a hover mode, and a second position (FIG. 5B), in which propulsion systems **512a**, **512b**, and wing tips **514a**, **514b**, are configured in a cruise mode.

[0051] Similarly, in accordance with features of embodiments described herein, and as illustrated in FIGS. 5A and 5B, propulsion systems **508a**, **508b**, are connected to inboard ends of wing tips **515a**, **515b**, disposed on outboard ends of wing **505**. Wing tips **515a**, **515b**, together with wing-mounted propulsion systems **508a**, **508b**, tilt relative to wing **505** between a first position (FIG. 5A), in which propulsion systems **508a**, **508b**, and wing tips **515a**, **515b**, are configured in a hover mode, and a second position (FIG. 5B), in which propulsion systems **508a**, **508b**, and wing tips **515a**, **515b**, are configured in a cruise mode.

[0052] In accordance with features of embodiments described herein, aft propulsion systems **510a**, **510b**, are fixedly attached to booms **506a**, **506b**, aft of the wing **504** in hover mode and do not convert between hover mode (FIG. 5A) and cruise mode (FIG. 5B).

[0053] The position of rotor assemblies of propulsion systems **508a**, **508b**, **512a**, **512b**, as well as the pitch of individual rotor blades of all of the propulsion systems **508a**, **508b**, **510a**, **510b**, **512a**,

512b, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **500**. As previously noted, propulsion systems **508a**, **508b**, **512a**, **512b**, are each convertible, relative to fuselage **502**, between a vertical position, as shown in FIG. 5A, and a horizontal position, as shown in FIG. 5B. Propulsion systems **508a**, **508b**, **512a**, **512b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **500**. Propulsion systems **508a**, **508b**, **512a**, **512b**, are in the horizontal position during forward flight mode, in which aircraft **500** is in forward flight. In forward flight mode, propulsion systems **508a**, **508b**, **512a**, **512b**, direct their respective thrusts in the aft direction to propel aircraft **500** forward. Aircraft **500** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. 5A, although faster forward flight is achievable while in the forward flight mode configuration of FIG. 5B. Propulsion systems **508a**, **508b**, **512a**, **512b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0054] It should be noted that, although propulsion systems **508a**, **508b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **510a**, **510b**.

[0055] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **500** is in cruise mode, rotor assemblies of propulsion systems **510a**, **510b**, may cease rotation. In embodiments in which propulsion systems **508a**, **508b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **500** is in cruise mode. The significant features of the aircraft **500** is that a boom arrangement is avoided while the hexrotor arc arrangement in hover is maintained. The propulsion assemblies **508a**, **508b**, are supported by canard-like forward lifting surfaces. The propulsion assemblies **510a**, **510b**, are supported by extensions off the trailing edge of the wing. The tail arrangement is free to be any usual configuration such as t-tail, cruciform, v-tail or other. The propulsion assemblies **510a**, **510b**, could be converted into a pusher arrangement, in which case all six rotors would continue to function in cruise mode.

[0056] FIGS. 6A and 6B illustrate an example tiltrotor aircraft **600** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. 6A), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. 6B), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **600** includes a fuselage **602**, wing **604**, and an X-shaped boom assembly **606** connected to the wing **604** and comprising boom segments **606a**, **606b**, **607a**, **607b**, that extend outboard of the fuselage **602**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a first pair of boom-mounted propulsion systems **608a**, **608b**, a second pair of boom-mounted propulsion systems **610a**, **610b**, and a pair of wing-mounted propulsion systems **612a**, **612b**. Aircraft **600** further includes a tail assembly **613** at an aft end thereof.

[0057] In the illustrated embodiment, propulsion systems **612a**, **612b**, are tiltably connected to wing **604** proximate outboard ends thereof, while propulsion systems **608a**, **608b**, are tiltably connected to outboard ends of booms **606a**, **606b**, inboard of propulsion systems **612a**, **612b**. Propulsion systems **610a**, **610b**, are mounted to upper surfaces of outboard ends of booms **607a**, **607b**, aft of the wing **604**.

[0058] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **608a**, **608b**, **610a**, **610b**, **612a**, and **612b** may include a drive system housing comprising a pylon, and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. 6A and 6B, the rotor assembly of each of propulsion systems **608a**, **608b**, **612a**, **612b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and

the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **608a**, **608b**, may include a different number of rotor blades than rotor assemblies of propulsion systems **612a**, **612b**. Rotation of rotor assemblies of propulsion systems **608a**, **608b**, **612a**, and **612b** generates lift while the aircraft **600** is operating in helicopter mode and thrust while the aircraft **600** is operating in airplane mode.

[0059] In the illustrated embodiment, each boom-mounted propulsion system **610a**, **610b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **6A** and **6B**, each rotor assembly of propulsion systems **610a**, **610b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor assemblies of propulsion systems **610a**, **610b**, generates lift while the aircraft **600** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **610a**, **610b**, are illustrated as being disposed above (i.e., on top of) booms **607a**, **607b**, they may alternatively be disposed below (i.e., on the underside of) booms.

[0060] In accordance with features of embodiments described herein, and as illustrated in FIGS. **6A** and **6B**, propulsion systems **612a**, **612b**, are connected to inboard ends of wing tips **614a**, **614b**, disposed on outboard ends of wing **604**. Wing tips **614a**, **614b**, together with wing-mounted propulsion systems **612a**, **612b**, tilt relative to wing between a first position (FIG. **6A**), in which propulsion systems **612a**, **612b**, and wing tips **614a**, **614b**, are configured in a hover mode, and a second position (FIG. **6B**), in which propulsion systems **612a**, **612b**, and wing tips **614a**, **614b**, are configured in a cruise mode.

[0061] Similarly, forward propulsion systems **608a**, **608b**, are tiltably connected to forward ends of booms **606a**, **606b**, and tiltable between a first position (FIG. **6A**), in which propulsion systems **608a**, **608b**, are configured in a hover mode, and a second position (FIG. **6B**), in which propulsion systems **608a**, **608b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **610a**, **610b**, are fixedly attached proximate aft ends of booms **607a**, **607b**, aft of the wing **604** in hover mode and do not convert between hover mode (FIG. **6A**) and cruise mode (FIG. **6B**).

[0062] The position of rotor assemblies of propulsion systems **608a**, **608b**, **612a**, **612b**, as well as the pitch of individual rotor blades of all of the propulsion systems **608a**, **608b**, **610a**, **610b**, **612a**, **612b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **600**. As previously noted, propulsion systems **608a**, **608b**, **612a**, **612b**, are each convertible, relative to fuselage **602**, between a vertical position, as shown in FIG. **6A**, and a horizontal position, as shown in FIG. **6B**. Propulsion systems **608a**, **608b**, **612a**, **612b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **600**. Propulsion systems **608a**, **608b**, **612a**, **612b**, are in the horizontal position during forward flight mode, in which aircraft **600** is in forward flight. In forward flight mode, propulsion systems **608a**, **608b**, **612a**, **612b**, direct their respective thrusts in the aft direction to propel aircraft **600** forward. Aircraft **600** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. **6A**, although faster forward flight is achievable while in the forward flight mode configuration of FIG. **6B**. Propulsion systems **608a**, **608b**, **612a**, **612b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0063] It should be noted that, although propulsion systems **608a**, **608b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **610a**, **610b**.

[0064] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **600** is in cruise mode, rotor assemblies of propulsion systems **610a**, **610b**, may cease

rotation. In embodiments in which propulsion systems **608a**, **608b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **600** is in cruise mode. Aircraft **600** is yet another configuration in which the hexrotor arc arrangement in hover is enabled without the use of boom supports. In this case, as shown in FIGS. **6A** and **6B**, supports extend radially from the wing centerline supporting the propulsion systems **608a**, **608b**, **610a**, **610b**. The central wing **604** adds on wing capability and rotor redundancy. [0065] FIGS. **7A** and **7B** illustrate an example tiltrotor aircraft **700** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. **7A**), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. **7B**), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **700** includes a fuselage **702**, wing **704**, a V-shaped boom assembly **706** comprising boom segments **706a**, **706b**, connected above the wing **704**, and aft wing extensions **707A**, **707B**, connected to the wing on opposite sides of the fuselage **702**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a first pair of boom-mounted propulsion systems **708a**, **708b**, a pair of extension-mounted propulsion systems **710a**, **710b**, and a pair of wing-mounted propulsion systems **712a**, **712b**. Aircraft **700** further includes a tail assembly **713** at an aft end thereof. [0066] In the illustrated embodiment, propulsion systems **712a**, **712b**, are tiltably connected to wing **704** proximate outboard ends thereof, while propulsion systems **708a**, **708b**, are tiltably connected to outboard ends of boom segments **706a**, **706b**, inboard of propulsion systems **712a**, **712b**. Propulsion systems **710a**, **710b**, are mounted to upper surfaces of outboard ends of wing extensions **707a**, **707b**.

[0067] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **708a**, **708b**, **710a**, **710b**, **712a**, and **712b** may include a drive system housing comprising a pylon, and a tiltable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **7A** and **7B**, the rotor assembly of each of propulsion systems **708a**, **708b**, **712a**, **712b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **708a**, **708b**, may include a different number of rotor blades than rotor assemblies of propulsion systems **712a**, **712b**. Rotation of rotor assemblies of propulsion systems **708a**, **708b**, **712a**, and **712b** generates lift while the aircraft **700** is operating in helicopter mode and thrust while the aircraft **700** is operating in airplane mode.

[0068] In the illustrated embodiment, each extension-mounted propulsion system **710a**, **710b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **7A** and **7B**, each rotor assembly of propulsion systems **710a**, **710b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor assemblies of propulsion systems **710a**, **710b**, generates lift while the aircraft **700** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **710a**, **710b**, are illustrated as being disposed above (i.e., on top of) wing extensions **707A**, **707B**, they may alternatively be disposed below (i.e., on the underside of) wing extensions.

[0069] In accordance with features of embodiments described herein, and as illustrated in FIGS. **7A** and **7B**, propulsion systems **712a**, **712b**, are connected to inboard ends of wing tips **714a**, **714b**, disposed on outboard ends of wing **704**. Wing tips **714a**, **714b**, together with wing-mounted propulsion systems **712a**, **712b**, tilt relative to wing between a first position (FIG. **7A**), in which propulsion systems **712a**, **712b**, and wing tips **714a**, **714b**, are configured in a hover mode, and a second position (FIG. **7B**), in which propulsion systems **712a**, **712b**, and wing tips **714a**, **714b**, are configured in a cruise mode.

[0070] Similarly, propulsion systems **708a**, **708b**, are connected to boom tips **716a**, **716b**, disposed on outboard ends of boom segments **706a**, **706b**. Boom tips **716a**, **716b**, together with propulsion systems **708a**, **708b**, are tiltable relative to boom extensions **706a**, **706b**, between a first position (FIG. 7A), in which propulsion systems **708a**, **708b**, and boom tips **716a**, **716b**, are configured in a hover mode, and a second position (FIG. 7B), in which propulsion systems **708a**, **708b**, and boom tips **716a**, **716b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **710a**, **710b**, are fixedly attached proximate aft ends of wing extensions **707a**, **707b**, aft of the wing **704** in hover mode and do not convert between hover mode (FIG. 7A) and cruise mode (FIG. 7B).

[0071] The position of rotor assemblies of propulsion systems **708a**, **708b**, **712a**, **712b**, as well as the pitch of individual rotor blades of all of the propulsion systems **708a**, **708b**, **710a**, **710b**, **712a**, **712b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **700**. As previously noted, propulsion systems **708a**, **708b**, **712a**, **712b**, are each convertible, relative to fuselage **702**, between a vertical position, as shown in FIG. 7A, and a horizontal position, as shown in FIG. 7B. Propulsion systems **708a**, **708b**, **712a**, **712b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **700**. Propulsion systems **708a**, **708b**, **712a**, **712b**, are in the horizontal position during forward flight mode, in which aircraft **700** is in forward flight. In forward flight mode, propulsion systems **708a**, **708b**, **712a**, **712b**, direct their respective thrusts in the aft direction to propel aircraft **700** forward. Aircraft **700** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. 7A, although faster forward flight is achievable while in the forward flight mode configuration of FIG. 7B. Propulsion systems **708a**, **708b**, **712a**, **712b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0072] It should be noted that, although propulsion systems **708a**, **708b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **710a**, **710b**.

[0073] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **700** is in cruise mode, rotor assemblies of propulsion systems **710a**, **710b**, may cease rotation. In embodiments in which propulsion systems **708a**, **708b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **700** is in cruise mode. Aircraft **700** is a hybrid of aircraft **500** (FIG. 5A-5B) and aircraft **600** (FIG. 6A-6B) in which propulsion assemblies **708a**, **708b**, are supported by airfoil shaped struts from the center of the wing (in a manner similar to aircraft **600**), while the propulsion assemblies **710a**, **710b**, are supported by wing extensions aft (in a manner similar to aircraft **500**).

[0074] FIGS. 8A and 8B illustrate an example tiltrotor aircraft **800** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. 8A), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. 8B), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **800** includes a fuselage **802**, wing **804**, and booms **806a**, **806b**, connected to the wing on opposite sides of the fuselage **802**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a first pair of wing-mounted propulsion systems **808a**, **808b**, a pair of boom-mounted propulsion systems **810a**, **810b**, and a second pair of wing-mounted propulsion systems **812a**, **812b**. Aircraft **800** further includes a tail assembly **813** at an aft end thereof.

[0075] In the illustrated embodiment, propulsion systems **812a**, **812b**, are tiltably connected to wing **804** proximate outboard ends thereof, while propulsion systems **808a**, **808b**, are tiltably connected to forward ends of booms **806a**, **806b**, inboard of propulsion systems **812a**, **812b**. Propulsion systems **810a**, **810b**, are mounted to upper surfaces proximate aft ends of booms **806a**,

806b.

[0076] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **808a**, **808b**, **810a**, **810b**, **812a**, and **812b** may include a drive system housing comprising a pylon, and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **8A** and **8B**, the rotor assembly of each of propulsion systems **808a**, **808b**, **812a**, **812b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **808a**, **808b**, may include a different number of rotor blades than rotor assemblies of propulsion systems **812a**, **812b**. Rotation of rotor assemblies of propulsion systems **808a**, **808b**, **812a**, and **812b** generates lift while the aircraft **800** is operating in helicopter mode and thrust while the aircraft **800** is operating in airplane mode.

[0077] In the illustrated embodiment, each propulsion system **810a**, **810b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **8A** and **8B**, each rotor assembly of propulsion systems **810a**, **810b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor assemblies of propulsion systems **810a**, **810b**, generates lift while the aircraft **800** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **810a**, **810b**, are illustrated as being disposed above (i.e., on top of) booms **808A**, **808B**, they may alternatively be disposed below (i.e., on the underside of) booms.

[0078] In accordance with features of embodiments described herein, and as illustrated in FIGS. **8A** and **8B**, propulsion systems **812a**, **812b**, are connected to inboard ends of wing tips **814a**, **814b**, disposed on outboard ends of wing **804**. Wing tips **814a**, **814b**, together with wing-mounted propulsion systems **812a**, **812b**, tilt relative to wing between a first position (FIG. **8A**), in which propulsion systems **812a**, **812b**, and wing tips **814a**, **814b**, are configured in a hover mode, and a second position (FIG. **8B**), in which propulsion systems **812a**, **812b**, and wing tips **814a**, **814b**, are configured in a cruise mode.

[0079] Similarly, propulsion systems **808a**, **808b**, are connected to forward ends of booms **806a**, **806b**. Propulsion systems **808a**, **808b**, are tiltable relative to booms **806a**, **806b**, between a first position (FIG. **8A**), in which propulsion systems **808a**, **808b**, are configured in a hover mode, and a second position (FIG. **8B**), in which propulsion systems **808a**, **808b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **810a**, **810b**, are fixedly attached to booms **806a**, **806b**, proximate aft ends thereof in hover mode and do not convert between hover mode (FIG. **8A**) and cruise mode (FIG. **8B**).

[0080] The position of rotor assemblies of propulsion systems **808a**, **808b**, **812a**, **812b**, as well as the pitch of individual rotor blades of all of the propulsion systems **808a**, **808b**, **810a**, **810b**, **812a**, **812b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **800**. As previously noted, propulsion systems **808a**, **808b**, **812a**, **812b**, are each convertible, relative to fuselage **802**, between a vertical position, as shown in FIG. **8A**, and a horizontal position, as shown in FIG. **8B**. Propulsion systems **808a**, **808b**, **812a**, **812b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **800**. Propulsion systems **808a**, **808b**, **812a**, **812b**, are in the horizontal position during forward flight mode, in which aircraft **800** is in forward flight. In forward flight mode, propulsion systems **808a**, **808b**, **812a**, **812b**, direct their respective thrusts in the aft direction to propel aircraft **800** forward. Aircraft **800** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. **8A**, although faster forward flight is achievable while in the forward flight mode configuration of FIG. **8B**. Propulsion systems **808a**, **808b**, **812a**, **812b**, may be tiltable between the vertical and horizontal positions by actuators

(not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0081] It should be noted that, although propulsion systems **808a**, **808b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **810a**, **810b**.

[0082] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **800** is in cruise mode, rotor assemblies of propulsion systems **810a**, **810b**, may cease rotation. In embodiments in which propulsion systems **808a**, **808b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **800** is in cruise mode. Aircraft **800** incorporates a twin boom option in which the boom terminates with forming the tail, thereby reducing tail complexity while increasing tail options.

[0083] FIGS. **9A** and **9B** illustrate an example tiltrotor aircraft **900** that is convertible between a VTOL or hover (also commonly referred to as helicopter) mode (shown in FIG. **9A**), which allows for vertical takeoff and landing, hovering, and low speed directional movement, and a cruise (also commonly referred to as airplane) mode (shown in FIG. **9B**), which allows for forward flight as well as horizontal takeoff and landing. Aircraft **900** includes a fuselage **902**, wing **904**, and booms **906a**, **906b**, connected to the wing on opposite sides of the fuselage **902**. In accordance with features of embodiments described herein, aircraft further includes three pairs of propulsion systems, including a pair of forward propulsion systems **908a**, **908b**, a pair of aft propulsion systems **910a**, **910b**, and a pair of wing-mounted propulsion systems **912a**, **912b**. In the illustrated embodiment, propulsion systems **912a**, **912b**, are tiltable connected to the outboard ends of wing **904**, while propulsion systems **908a**, **908b**, are tiltable connected to the forward ends of booms **906a**, **906b**, inboard of propulsion systems **912a**, **912b**. Propulsion systems **910a**, **910b**, are mounted to upper surfaces of aft ends of booms **906a**, **906b**. Aircraft **900** further includes a tail assembly **913** at an aft end thereof.

[0084] Similar to the propulsion systems of aircraft **100**, each of propulsion systems **908a**, **908b**, **910a**, **910b**, **912a**, and **912b** may include a drive system housing comprising a pylon, and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **9A** and **9B**, the rotor assembly of each of propulsion systems **908a**, **908b**, **912a**, **912b**, includes five (5) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. It should also be recognized that rotor assemblies of propulsion systems **909A**, **909B**, may include a different number of rotor blades than rotor assemblies of propulsion systems **912a**, **912b**. Rotation of rotor assemblies of propulsion systems **908a**, **908b**, **912a**, and **912b** generates lift while the aircraft **900** is operating in helicopter mode and thrust while the aircraft **900** is operating in airplane mode.

[0085] In the illustrated embodiment, each aft propulsion system **910a**, **910b**, includes a drive system housing comprising a pylon and a rotatable open rotor assembly comprising a plurality of rotor blades connected to a rotor mast and configured to rotate about a rotor axis. As shown in FIGS. **9A** and **9B**, each rotor assembly of propulsion systems **910a**, **910b**, includes two (2) rotor blades; however, it should be recognized that more or fewer blades may be implemented without departing from the spirit and the scope of the embodiments described. Rotation of rotor assemblies of propulsion systems **910a**, **910b**, generates lift while the aircraft **900** is operating in helicopter mode. It will be recognized that while rotor assemblies of propulsion systems **910a**, **910b**, are illustrated as being disposed above (i.e., on top of) booms **906a**, **906b**, they may alternatively be disposed below (i.e., on the underside of) booms.

[0086] In accordance with features of embodiments described herein, and as illustrated in FIGS. **9A** and **9B**, propulsion systems **908a**, **908b**, **909B**, **912a**, **912b**, are tiltable connected to the wing **904** and tilt relative to wing between a first position (FIG. **9A**), in which propulsion systems **908a**, **908b**, **912a**, **912b**, are configured in a hover mode, and a second position (FIG. **9B**), in which

propulsion systems **908a**, **908b**, **912a**, **912b**, are configured in a cruise mode. In accordance with features of embodiments described herein, aft propulsion systems **910a**, **910b**, are fixedly attached to booms **906a**, **906b**, aft of the wing **904** in hover mode and do not convert between hover mode (FIG. **9A**) and cruise mode (FIG. **9B**).

[0087] The position of rotor assemblies of propulsion systems **908a**, **908b**, **912a**, **912b**, as well as the pitch of individual rotor blades of all of the propulsion systems **908a**, **908b**, **910a**, **910b**, **912a**, **912b**, can be selectively controlled in order to selectively control direction, thrust, and lift of aircraft **900**. As previously noted, propulsion systems **908a**, **908b**, **912a**, **912b**, are each convertible, relative to fuselage **902**, between a vertical position, as shown in FIG. **9A**, and a horizontal position, as shown in FIG. **9B**. Propulsion systems **908a**, **908b**, **912a**, **912b**, are in the vertical position during vertical takeoff and landing mode. Vertical takeoff and landing mode may be considered to include hover operations of aircraft **900**. Propulsion systems **908a**, **908b**, **912a**, **912b**, are in the horizontal position during forward flight mode, in which aircraft **900** is in forward flight. In forward flight mode, propulsion systems **908a**, **908b**, **912a**, **912b**, direct their respective thrusts in the aft direction to propel aircraft **900** forward. Aircraft **900** is operable to fly in all directions during the vertical takeoff and landing mode configuration of FIG. **9A**, although faster forward flight is achievable while in the forward flight mode configuration of FIG. **9B**. Propulsion systems **908a**, **908b**, **912a**, **912b**, may be tiltable between the vertical and horizontal positions by actuators (not shown) that are tiltable in response to commands originating from a pilot and/or a flight control system.

[0088] It should be noted that, although propulsion systems **908a**, **908b**, are shown and described as being tiltable between cruise and hover positions, those propulsion systems may be fixed in the hover positions, similarly to propulsion systems **910a**, **910b**.

[0089] In accordance with features of embodiments described herein, in certain embodiments, when aircraft **900** is in cruise mode, rotor assemblies of propulsion systems **910a**, **910b**, may cease rotation. In embodiments in which propulsion systems **908a**, **908b**, are also fixed (i.e., do not convert between hover and cruise modes), rotor assemblies thereof may also cease rotation when aircraft **900** is in cruise mode. Aircraft **900** is a simpler unmanned aerial vehicle (UAV) version of aircraft **400** and aircraft **800** suitable for unmanned logistics. Rotor complexity or propulsion assemblies is reduced and the booms are truncated, allowing the tail assembly **913b** to also function as part of the landing gear. A nosewheel **920** is also provided under the fuselage **902**.

[0090] FIG. **10** illustrates other tiltrotor aircraft tilting hexrotor configurations in accordance with alternative embodiments described herein. In particular, FIG. **10** illustrates embodiments in which the aft rotors rotate down for hover **1004** and **1008** and up into a pusher configuration for cruise **1002** and **1006**. FIG. **10** further illustrates a configuration in which a rotating aft rotor is part of a v-tail arrangement **1010** and **1012**. All of the configurations shown in FIG. **10** represent variations of achieving a hexrotor arc arrangement in hover while allowing six rotors to provide propulsion in cruise.

[0091] FIG. **11** illustrates an alternative arrangement for a boom-mounted propulsion system for an aircraft in accordance with embodiments described herein. As shown in FIG. **11**, a boom-mounted propulsion system **1100** including a rotor assembly **1101** may be embedded within a boom **1102** between an upper boom portion **1104** and a lower boom portion **1106** connected by a boom closeout portion **1108**. In the illustrated embodiment, the propulsion system **1100** is an aft propulsion system mounted proximate a tail assembly **1110**. As shown in FIG. **11**, a motor/drive fairing **1112** for the propulsion system **1100** is associated with the upper boom portion **1104** and a bearing **1114** is provided on an inside surface of the lower boom portion **1106** below the rotor assembly **1101** of the propulsion system **1100**. Advantages of the configuration shown in FIG. **11** include reducing the drag of the stopped rotor assembly over configurations in which the rotor blades are exposed. It will be noted that in alternative embodiments, the motor/drive fairing **1112** may be associated with the lower boom portion **1106**, in which case the bearing **1116** would be

disposed on a lower surface of the upper boom portion **1104**.

[0092] It should be appreciated that aircraft illustrated herein, such as aircraft **100**, is merely illustrative of a variety of aircraft that can implement the embodiments disclosed herein. Indeed, the various embodiments of the electric drive system line replaceable unit described herein may be used on any aircraft that utilizes motors. Other aircraft implementations can include hybrid aircraft, tiltrotor aircraft, quad tiltrotor aircraft, unmanned aircraft, gyrocopters, airplanes, helicopters, commuter aircraft, electric aircraft, hybrid-electric aircraft, and the like. As such, those skilled in the art will recognize that the embodiments described herein for an electric drive system line replaceable unit can be integrated into a variety of aircraft configurations. It should be appreciated that even though aircraft are particularly well-suited to implement the embodiments of the present disclosure, non-aircraft vehicles and devices can also implement the embodiments.

[0093] The components of rotor assemblies described herein may comprise any materials suitable for use with an aircraft rotor. For example, rotor blades and other components may comprise carbon fiber, fiberglass, or aluminum; and rotor masts and other components may comprise steel or titanium.

[0094] Example 1 provides an aircraft including a fuselage; a wing connected to the fuselage; a tail assembly at an aft end of the aircraft; a first boom connected to a first side of the fuselage and a first side of the tail assembly; a second boom connected to a second, opposite side of the fuselage and a second, opposite side of the tail assembly; and no more than six propulsion systems, the propulsion systems including: first and second forward propulsion systems tiltably connected to forward ends of the first and second booms such that the first and second forward propulsion systems are tiltable between a first position when the aircraft is in a hover mode in which the first and second forward propulsion systems rotate in a horizontal plane and a second position when the aircraft is in a cruise mode in which the first and second forward propulsion systems rotate in a vertical plane; first and second aft propulsion systems fixedly attached proximate aft ends of the first and second booms, in which each of the aft propulsion systems is angled outboard from a top surface of the one of the booms to which it is attached such that an axis of rotation of the aft propulsion system forms a non-zero angle outboard from a vertical axis; and a first wing-mounted propulsion system connected to a first side of the wing and having a first wing tip at a first outboard end of the wing; and a second wing-mounted propulsion system connected to a second, opposite side of the wing and having a second wing tip at a second, opposite outboard end of the wing, in which the first and second wing-mounted propulsion systems including the first and second wing tips are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode, and in which each of the propulsion systems includes a rotor assembly including a plurality of rotor blades.

[0095] Example 2 provides the aircraft of example 1, in which the rotor assemblies of the first and second aft propulsion systems rotate when the aircraft is in the hover mode and cease to rotate when the aircraft is in the cruise mode.

[0096] Example 3 provides the aircraft of example 1 or 2, in which the rotor assemblies of the first and second forward propulsion systems rotate when the aircraft is in the hover mode and cease to rotate when the aircraft is in the cruise mode.

[0097] Example 4 provides the aircraft of any one of examples 1-3, in which the rotor assemblies of the forward propulsion systems and the wing-mounted propulsion systems include an identical number of blades.

[0098] Example 5 provides the aircraft of example 4, in which the rotor assemblies of the aft rotor propulsion systems include fewer blades than the rotor assemblies of the forward propulsion systems and the wing-mounted propulsion systems.

[0099] Example 6 provides the aircraft of any one of examples 1-5, in which the rotor assemblies of the forward propulsion systems and the wing-mounted propulsion systems include five blades each and the rotor assemblies of the aft rotor propulsion systems include two blades each.

[0100] Example 7 provides the aircraft of any one of examples 1-6, in which the wing is disposed on a top surface of the fuselage.

[0101] Example 8 provides the aircraft of any one of examples 1-7, in which a portion of each of the booms is integrated into the wing.

[0102] Example 9 provides the aircraft of any one of examples 1-8, in which the propulsion systems collectively include a hexrotor arc when the aircraft is in the hover mode.

[0103] Example 10 provides the aircraft of any one of examples 1-9, in which the first and second forward propulsion systems are located forward of the first and second wing-mounted propulsion systems.

[0104] Example 11 provides the aircraft of any one of examples 1-10, in which the first and second wing-mounted propulsion systems are located outboard of the first and second forward propulsion systems.

[0105] Example 12 provides the aircraft of any one of examples 1-11, in which the first and second aft propulsion systems are attached to a top surface of the first and second booms such that the rotor assemblies rotate above the first and second booms.

[0106] Example 13 provides an electric vertical takeoff and landing aircraft (eVTOL) selectively convertible between a hover mode and a cruise mode, the eVTOL including a fuselage; a wing connected to the fuselage; a tail assembly at an aft end of the aircraft; a first boom connected to a first side of the fuselage and a first side of the tail assembly; a second boom connected to a second, opposite side of the fuselage and a second, opposite side of the tail assembly; and a propulsion arrangement for propelling the aircraft, the propulsion arrangement including no more than six propulsion systems, the no more than six propulsion systems including first and second forward propulsion systems attached to the forward ends of the first and second booms; first and second aft propulsion systems fixedly attached proximate the aft ends of the first and second booms; and a first wing-mounted propulsion system connected to a first side of the wing and having a first wing tip at a first outboard end of the wing; and a second wing-mounted propulsion system connected to a second, opposite side of the wing and having a second wing tip at a second, opposite outboard end of the wing, in which the first and second wing-mounted propulsion systems including the first and second wing tips are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode.

[0107] Example 14 provides the eVTOL of example 13, in which the first and second aft propulsion systems are operable when the aircraft is in the hover mode and inoperable when the aircraft is in the cruise mode.

[0108] Example 15 provides the eVTOL of example 13 or 14, in which the first and second forward propulsion systems are tiltable connected to forward ends of the first and second booms such that the first and second forward propulsion systems are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode.

[0109] Example 16 provides the eVTOL of any one of examples 13-15, in which the first and second forward propulsion systems are fixedly attached to the forward ends of the first and second booms and in which the first and second forward propulsion systems are operable when the aircraft is in the hover mode and inoperable when the aircraft is in the cruise mode.

[0110] Example 17 provides the eVTOL of any one of examples 13-16, in which the propulsion systems collectively include a hexrotor arc when the aircraft is in the hover mode.

[0111] Example 18 provides an electric vertical takeoff and landing aircraft (eVTOL) selectively convertible between a hover mode and a cruise mode, the eVTOL including a fuselage; a wing connected to a top surface of the fuselage and having opposite outboard ends; first and second booms connected to the wing on opposite sides of the fuselage and including forward ends disposed forward of the wing and aft ends disposed aft of the wing; first and second forward propulsion systems attached to the forward ends of the first and second booms; first and second aft propulsion systems fixedly attached proximate the aft ends of the first and second booms, in which

each of the aft propulsion systems is angled outboard from a top surface of the one of the booms to which it is attached such that an axis of rotation of the aft propulsion system forms a non-zero angle outboard from a vertical axis; and a first wing-mounted propulsion system connected to a first side of the wing and having a first wing tip at a first outboard end of the wing; and a second wing-mounted propulsion system connected to a second, opposite side of the wing and having a second wing tip at a second, opposite outboard end of the wing, in which the first and second wing-mounted propulsion systems including the first and second wing tips are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode, and in which each of the propulsion systems includes a rotor assembly including a plurality of rotor blades.

[0112] Example 19 provides the eVTOL of example 18, in which the first and second aft propulsion systems are attached to a bottom surface of the first and second booms such that rotor assemblies of the first and second aft propulsion systems rotate below the first and second booms.

[0113] Example 20 provides the eVTOL of example 18 or 19, in which the rotor assemblies of the first and second aft propulsion systems and the first and second forward propulsion systems rotate when the aircraft is in the hover mode and cease to rotate when the aircraft is in the cruise mode.

[0114] At least one embodiment is disclosed, and variations, combinations, and/or modifications of the embodiment(s) and/or features of the embodiment(s) made by a person having ordinary skill in the art are within the scope of the disclosure. Alternative embodiments that result from combining, integrating, and/or omitting features of the embodiment(s) are also within the scope of the disclosure. Where numerical ranges or limitations are expressly stated, such express ranges or limitations should be understood to include iterative ranges or limitations of like magnitude falling within the expressly stated ranges or limitations (e.g., from about 1 to about 10 includes, 2, 3, 4, etc.; greater than 0.10 includes 0.11, 0.12, 0.13, etc.). For example, whenever a numerical range with a lower limit, R_l , and an upper limit, R_u , is disclosed, any number falling within the range is specifically disclosed. In particular, the following numbers within the range are specifically disclosed: $R = R_l + k * (R_u - R_l)$, wherein k is a variable ranging from 1 percent to 100 percent with a 1 percent increment, i.e., k is 1 percent, 2 percent, 3 percent, 4 percent, 5 percent, . . . 50 percent, 51 percent, 52 percent, . . . , 95 percent, 96 percent, 97 percent, 98 percent, 99 percent, or 100 percent. Moreover, any numerical range defined by two R numbers as defined in the above is also specifically disclosed. Use of the term “optionally” with respect to any element of a claim means that the element is required, or alternatively, the element is not required, both alternatives being within the scope of the claim. Use of broader terms such as comprises, includes, and having should be understood to provide support for narrower terms such as consisting of, consisting essentially of, and comprised substantially of. Accordingly, the scope of protection is not limited by the description set out above but is defined by the claims that follow, that scope including all equivalents of the subject matter of the claims. Each and every claim is incorporated as further disclosure into the specification and the claims are embodiment(s) of the present invention. Also, the phrases “at least one of A, B, and C” and “A and/or B and/or C” should each be interpreted to include only A, only B, only C, or any combination of A, B, and C.

[0115] The diagrams in the FIGURES illustrate the architecture, functionality, and/or operation of possible implementations of various embodiments of the present disclosure. Although several embodiments have been illustrated and described in detail, numerous other changes, substitutions, variations, alterations, and/or modifications are possible without departing from the spirit and scope of the present disclosure, as defined by the appended claims. The particular embodiments described herein are illustrative only and may be modified and practiced in different but equivalent manners, as would be apparent to those of ordinary skill in the art having the benefit of the teachings herein. Those of ordinary skill in the art would appreciate that the present disclosure may be readily used as a basis for designing or modifying other embodiments for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. For

example, certain embodiments may be implemented using more, less, and/or other components than those described herein. Moreover, in certain embodiments, some components may be implemented separately, consolidated into one or more integrated components, and/or omitted. Similarly, methods associated with certain embodiments may be implemented using more, less, and/or other steps than those described herein, and their steps may be performed in any suitable order.

[0116] Numerous other changes, substitutions, variations, alterations, and modifications may be ascertained to one of ordinary skill in the art and it is intended that the present disclosure encompass all such changes, substitutions, variations, alterations, and modifications as falling within the scope of the appended claims.

[0117] One or more advantages mentioned herein do not in any way suggest that any one of the embodiments described herein necessarily provides all the described advantages or that all the embodiments of the present disclosure necessarily provide any one of the described advantages. Note that in this Specification, references to various features included in “one embodiment”, “example embodiment”, “an embodiment”, “another embodiment”, “certain embodiments”, “some embodiments”, “various embodiments”, “other embodiments”, “alternative embodiment”, and the like are intended to mean that any such features are included in one or more embodiments of the present disclosure but may or may not necessarily be combined in the same embodiments.

[0118] As used herein, unless expressly stated to the contrary, use of the phrase “at least one of”, “one or more of” and “and/or” are open ended expressions that are both conjunctive and disjunctive in operation for any combination of named elements, conditions, or activities. For example, each of the expressions “at least one of X, Y and Z”, “at least one of X, Y or Z”, “one or more of X, Y and Z”, “one or more of X, Y or Z” and “A, B and/or C” can mean any of the following: 1) X, but not Y and not Z; 2) Y, but not X and not Z; 3) Z, but not X and not Y; 4) X and Y, but not Z; 5) X and Z, but not Y; 6) Y and Z, but not X; or 7) X, Y, and Z. Additionally, unless expressly stated to the contrary, the terms “first”, “second”, “third”, etc., are intended to distinguish the particular nouns (e.g., blade, rotor, element, device, condition, module, activity, operation, etc.) they modify. Unless expressly stated to the contrary, the use of these terms is not intended to indicate any type of order, rank, importance, temporal sequence, or hierarchy of the modified noun. For example, “first X” and “second X” are intended to designate two X elements that are not necessarily limited by any order, rank, importance, temporal sequence, or hierarchy of the two elements. As referred to herein, “at least one of”, “one or more of”, and the like can be represented using the “(s)” nomenclature (e.g., one or more element(s)).

[0119] In order to assist the United States Patent and Trademark Office (USPTO) and, additionally, any readers of any patent issued on this application in interpreting the claims appended hereto, Applicant wishes to note that the Applicant: (a) does not intend any of the appended claims to invoke paragraph (f) of 35 U.S.C. Section 112 as it exists on the date of the filing hereof unless the words “means for” or “step for” are specifically used in the particular claims; and (b) does not intend, by any statement in the Specification, to limit this disclosure in any way that is not otherwise reflected in the appended claims.

Claims

1. An aircraft comprising: a fuselage; a wing connected to the fuselage; a tail assembly at an aft end of the aircraft; a first boom connected to a first side of the fuselage and a first side of the tail assembly; a second boom connected to a second, opposite side of the fuselage and a second, opposite side of the tail assembly; and no more than six propulsion systems, the propulsion systems including: first and second forward propulsion systems tiltably connected to forward ends of the first and second booms such that the first and second forward propulsion systems are tiltable between a first position when the aircraft is in a hover mode in which the first and second forward

propulsion systems rotate in a horizontal plane and a second position when the aircraft is in a cruise mode in which the first and second forward propulsion systems rotate in a vertical plane; first and second aft propulsion systems fixedly attached proximate aft ends of the first and second booms, wherein each of the aft propulsion systems is angled outboard from a top surface of the one of the booms to which it is attached such that an axis of rotation of the aft propulsion system forms a non-zero angle outboard from a vertical axis; and a first wing-mounted propulsion system connected to a first side of the wing and having a first wing tip at a first outboard end of the wing; and a second wing-mounted propulsion system connected to a second, opposite side of the wing and having a second wing tip at a second, opposite outboard end of the wing, wherein the first and second wing-mounted propulsion systems including the first and second wing tips are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode, and wherein each of the propulsion systems includes a rotor assembly comprising a plurality of rotor blades.

2. The aircraft of claim 1, wherein the rotor assemblies of the first and second aft propulsion systems rotate when the aircraft is in the hover mode and cease to rotate when the aircraft is in the cruise mode.

3. The aircraft of claim 1, wherein the rotor assemblies of the first and second forward propulsion systems rotate when the aircraft is in the hover mode and cease to rotate when the aircraft is in the cruise mode.

4. The aircraft of claim 1, wherein the rotor assemblies of the forward propulsion systems and the wing-mounted propulsion systems include an identical number of blades.

5. The aircraft of claim 4, wherein the rotor assemblies of the aft rotor propulsion systems include fewer blades than the rotor assemblies of the forward propulsion systems and the wing-mounted propulsion systems.

6. The aircraft of claim 1, wherein the rotor assemblies of the forward propulsion systems and the wing-mounted propulsion systems include five blades each and the rotor assemblies of the aft rotor propulsion systems include two blades each.

7. The aircraft of claim 1, wherein the wing is disposed on a top surface of the fuselage.

8. The aircraft of claim 1, wherein a portion of each of the booms is integrated into the wing.

9. The aircraft of claim 1, wherein the propulsion systems collectively comprise a hexrotor arc when the aircraft is in the hover mode.

10. The aircraft of claim 1, wherein the first and second forward propulsion systems are located forward of the first and second wing-mounted propulsion systems.

11. The aircraft of claim 1, wherein the first and second wing-mounted propulsion systems are located outboard of the first and second forward propulsion systems.

12. The aircraft of claim 1, wherein the first and second aft propulsion systems are attached to a top surface of the first and second booms such that the rotor assemblies rotate above the first and second booms.

13. An electric vertical takeoff and landing aircraft (eVTOL) selectively convertible between a hover mode and a cruise mode, the eVTOL comprising: a fuselage; a wing connected to the fuselage; a tail assembly at an aft end of the aircraft; a first boom connected to a first side of the fuselage and a first side of the tail assembly; a second boom connected to a second, opposite side of the fuselage and a second, opposite side of the tail assembly; and a propulsion arrangement for propelling the aircraft, the propulsion arrangement comprising no more than six propulsion systems, the no more than six propulsion systems comprising: first and second forward propulsion systems attached to the forward ends of the first and second booms; first and second aft propulsion systems fixedly attached proximate the aft ends of the first and second booms; and a first wing-mounted propulsion system connected to a first side of the wing and having a first wing tip at a first outboard end of the wing; and a second wing-mounted propulsion system connected to a second, opposite side of the wing and having a second wing tip at a second, opposite outboard end of the

wing, wherein the first and second wing-mounted propulsion systems including the first and second wing tips are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode.

14. The eVTOL of claim 13, wherein the first and second aft propulsion systems are operable when the aircraft is in the hover mode and inoperable when the aircraft is in the cruise mode.

15. The eVTOL of claim 13, wherein the first and second forward propulsion systems are tiltably connected to forward ends of the first and second booms such that the first and second forward propulsion systems are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode.

16. The eVTOL of claim 13, wherein the first and second forward propulsion systems are fixedly attached to the forward ends of the first and second booms and wherein the first and second forward propulsion systems are operable when the aircraft is in the hover mode and inoperable when the aircraft is in the cruise mode.

17. The eVTOL of claim 13, wherein the propulsion systems collectively comprise a hexrotor arc when the aircraft is in the hover mode.

18. An electric vertical takeoff and landing aircraft (eVTOL) selectively convertible between a hover mode and a cruise mode, the eVTOL comprising: a fuselage; a wing connected to a top surface of the fuselage and having opposite outboard ends; first and second booms connected to the wing on opposite sides of the fuselage and including forward ends disposed forward of the wing and aft ends disposed aft of the wing; first and second forward propulsion systems attached to the forward ends of the first and second booms; first and second aft propulsion systems fixedly attached proximate the aft ends of the first and second booms, wherein each of the aft propulsion systems is angled outboard from a top surface of the one of the booms to which it is attached such that an axis of rotation of the aft propulsion system forms a non-zero angle outboard from a vertical axis; and a first wing-mounted propulsion system connected to a first side of the wing and having a first wing tip at a first outboard end of the wing; and a second wing-mounted propulsion system connected to a second, opposite side of the wing and having a second wing tip at a second, opposite outboard end of the wing, wherein the first and second wing-mounted propulsion systems including the first and second wing tips are tiltable between a first position when the aircraft is in the hover mode and a second position when the aircraft is in the cruise mode, and wherein each of the propulsion systems includes a rotor assembly comprising a plurality of rotor blades.

19. The eVTOL of claim 18, wherein the first and second aft propulsion systems are attached to a bottom surface of the first and second booms such that rotor assemblies of the first and second aft propulsion systems rotate below the first and second booms.

20. The eVTOL of claim 18, wherein the rotor assemblies of the first and second aft propulsion systems and the first and second forward propulsion systems rotate when the aircraft is in the hover mode and cease to rotate when the aircraft is in the cruise mode.
