United States Patent Application Publication	20250263164
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	Uskert; Richard C. et al.

EXTENDABLE WING

Abstract

An aircraft wing apparatus includes a plurality of wing-skin sections, an extendable spar assembly, and a controller. The plurality of wing-skin sections includes a first wing-skin section and a second wing-skin section. The extendable spar assembly includes a first spar member coupled with the first wing-skin section and a second spar member coupled with the second wing-skin section. The controller is constructed and arranged to move the second spar member to predefined positions relative to the first spar member to place the plurality of wing-skin sections into predefined configurations. The predefined configurations including a stowed configuration, a first deployed configuration, and a second deployed position that is different from the first deployed position.

Inventors: **Uskert; Richard C. (Monkton, MD), McClelland; Donovan Ray (Baltimore, MD), Ruck; Joshua Stephen (Baltimore, MD), Otradovec; Daniel Thomas (Forest Hill, MD)**

Applicant: **Textron Systems Corporation** (Hunt Valley, MD)

Family ID: **1000008561723**

Appl. No.: **19/058439**

Filed: **February 20, 2025**

Related U.S. Application Data

us-provisional-application US 63555994 20240221

Publication Classification

Int. Cl.: **B64C3/56** (20060101); **B64C3/18** (20060101); **B64C3/26** (20060101)

U.S. Cl.:

CPC **B64C3/56** (20130101); **B64C3/185** (20130101); **B64C3/26** (20130101);

Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application claims priority to and the benefit of earlier-filed U.S. Application No. 63/555,994, filed on Feb. 21, 2024, and entitled “Extendable Wing”, the contents and teachings of which are hereby incorporated by reference in their entirety.

BACKGROUND

[0002] Some conventional drones include rotors that provide vertical thrust for vertical takeoff and landing (VTOL). On a first type of conventional drone, the rotors are fixed to static wings that remain in the same orientation for both VTOL and forward flight. On a second type of conventional drone, the rotors are fixed to pivotable wings that rotate to position the rotors in different directions.

[0003] To transition to forward flight, these drones operate separate horizontal thrusters or rotate the VTOL rotors horizontally to provide forward thrust. For example, on the drones with pivotable wings, the wings are initially positioned vertically to orient the rotors for takeoff. Once airborne, the pivotable wings are rotated horizontally to orient the rotors for forward flight, enabling the wings to provide vertical lift.

SUMMARY

[0004] Unfortunately, there are deficiencies to the above-described conventional drones. Along these lines, these drones have rigid, fixed-length wings that limit their suitability to satisfy certain types of mission requirements. For example, a conventional drone with short wings may not have suitable aerodynamic efficiency for long distance flights. In contrast, a conventional drone with long wings may not have suitable maneuverability or speed.

[0005] Further, such fixed-length wings suffer from a constant drag profile which necessitates varying amounts of forward thrust to fly at different speeds. Propulsive units generally are not optimized around multiple thrust requirements, and thus introduce inefficiencies during operation.

[0006] Even further, some conventional drones present deficiencies while landing. For example, when landing conventional drones with pivotable wings, the wings rotate to face perpendicularly to wind directions (e.g., aftward to face the sides the drone's body, upwards, or a combination of both). Orienting the wings in this manner increases surface areas exposed to crosswinds, increasing destabilizing forces on the drone and decreasing positional accuracy and control over the drone. As a result, the drone may drift excessively when landing, presenting safety risks to equipment and personnel.

[0007] In contrast to the above-described conventional drones having fixed-length wings, improved techniques are directed to utilizing a wing apparatus having an extendable (or adjustable) spar. The extendable spar may be extended, in part or in whole, to increase wing surfaces that contribute to lift, increasing aerodynamic performance of an aircraft. Additionally, the extendable spar may be retracted (or consolidated) to minimize crosswind forces against the aircraft and to reduce a footprint of the aircraft for landing and/or takeoff in locations where space is limited (e.g., ship decks, etc.). Accordingly, the wing surfaces are modifiable to provide a variety of wing profiles for different mission requirements.

[0008] One embodiment is directed to an aircraft wing apparatus. The aircraft wing apparatus includes a plurality of wing-skin sections having a first wing-skin section and a second wing-skin section. The aircraft wing apparatus further includes an extendable spar assembly including a first spar member coupled with the first wing-skin section and a second spar member coupled with the second wing-skin section. The aircraft wing apparatus further includes a controller constructed and arranged to move the second spar member to predefined positions relative to the first spar member to place the plurality of wing-skin sections into predefined configurations. The predefined configurations include a stowed configuration, a first deployed configuration, and a second deployed position that is different from the first deployed position.

[0009] Another embodiment is directed to an aircraft including an aircraft body, an engine, and an aircraft wing apparatus. The engine is coupled with the aircraft body and is constructed and arranged to provide power for forward flight. The aircraft wing apparatus is coupled with the aircraft body. The aircraft wing apparatus includes a plurality of wing-skin sections having a first wing-skin section and a second wing-skin section. The aircraft wing apparatus further includes an extendable spar assembly including a first spar member coupled with the first wing-skin section and a second spar member coupled with the second wing-skin section. The aircraft wing apparatus further includes a controller constructed and arranged to move the second spar member to predefined positions relative to the first spar member to place the plurality of wing-skin sections into predefined configurations. The predefined configurations include a stowed configuration, a first deployed configuration, and a second deployed position that is different from the first deployed position.

[0010] Yet another embodiment is directed to a method of controlling an aircraft wing apparatus coupled with an aircraft. The method includes accessing a controller constructed and arranged to operate an extendable spar assembly of the aircraft wing apparatus. The extendable spar assembly includes a first spar member and a second spar member. The first spar member is coupled with a first wing-skin section of a plurality of wing-skin sections. The second spar member is coupled with a second wing-skin section of the plurality of wing-skin sections. The method further includes moving the second spar member to a first predefined position relative to the first spar member to place the plurality of wing-skin sections from a stowed configuration into a first deployed configuration. The method further includes moving the second spar member to a second predefined position relative to the first spar member to place the plurality of wing-skin sections into a second deployed configuration, the first deployed configuration being different from the second deployed configuration.

[0011] In some arrangements, the first spar member defines a channel, at least part of the second spar member being constructed and arranged to slide within the channel when moving relative to the first spar member.

[0012] In some arrangements, an outer end of the second wing-skin section in the first deployed configuration laterally extends a first predefined distance away from an outer end of the first wing-skin section. Further, the outer end of the second wing-skin section in the second deployed configuration laterally extends a second predefined distance away from the outer end of the first wing-skin section. The first predefined distance is different from the second predefined distance.

[0013] In some arrangements, the controller includes an actuation assembly including a pulley wheel and a pulley cable, the pulley wheel being disposed at an outer portion of the first spar member. The pulley cable interfaces with the pulley wheel and has an end coupled with an inner portion of the second spar member. The controller further includes a set of motors constructed and arranged to actuate the pulley cable to extend the second spar member relative to the first spar member.

[0014] In some arrangements, the extendable spar further includes a third spar member coupled with a third wing-span section of the plurality of wing-span sections. Further, the actuation assembly includes a second pulley wheel and a second pulley cable. The second pulley wheel is disposed on an outer portion of the second spar member. The second pulley cable interfaces with the second pulley wheel and is coupled between the first spar member and the third spar member. The second pulley cable is constructed and arranged to extend the third spar member relative to the first spar member based on extension of the second spar member by the set of motors.

[0015] In some arrangements, the set of motors are further constructed and arranged to retract the

second spar member relative to the first spar member.
[0016] In some arrangements, the extendable spar further includes a third spar member coupled with a third wing-span section of the plurality of wing-span sections. Further, the controller includes a retraction assembly including a retraction pulley wheel and a retraction pulley cable. The retraction pulley wheel is disposed at an inner portion of the second spar member. A retraction pulley cable interfaces with the retraction pulley wheel and is coupled with the first spar member and the third spar member. The retraction pulley cable is constructed and arranged to retract the third spar member relative to the first spar member based on retraction of the second spar member by the set of motors.
[0017] In some arrangements, the first wing-skin section and the second wing-skin section include respective forward ends and respective aft ends. A first distance between the respective forward ends is less than a second distance between the respective aft ends.
[0018] In some arrangements, the aircraft wing apparatus further includes a plurality of wing ribs disposed between the plurality of wing-skin sections and the extendable spar. The plurality of wing ribs includes a first group of wing ribs which supports the first wing-skin section and a second group of wing ribs which supports the second wing-skin section.
[0019] In some arrangements, wing ribs of the plurality of wing ribs are coupled together via a scissor linkage assembly. The scissor linkage assembly is constructed and arranged to extend and retract the wing ribs of the plurality of wing ribs relative to each other.
[0020] In some arrangements, the plurality of wing ribs includes a first wing rib, a second wing rib, and a set of wing ribs disposed between the first wing rib and the second wing rib. The first wing rib is fixedly attached to the first spar member. The second wing rib is fixedly attached to the second spar member. The set of wing ribs is constructed and arranged to move relative to both the first wing rib and the second wing rib based on movement of the second spar member relative to the first spar member.
[0021] This Summary is provided merely for purposes of summarizing some example embodiments so as to provide a basic understanding of some aspects of the disclosure. Accordingly, it will be appreciated that the above-described example embodiments are merely examples and should not be construed to narrow the scope or spirit of the disclosure in any way. Other embodiments, aspects, and advantages will become apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the described embodiments.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS
[0022] The foregoing and other features and advantages will be apparent from the following description of particular embodiments, as illustrated in the accompanying drawings, in which like reference characters refer to the same or similar parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of various embodiments.
[0023] FIGS. **1-2** illustrate perspective views of an example aircraft wing apparatus, according to some embodiments of the present disclosure.
[0024] FIGS. **3-8** illustrate perspective views of another example aircraft wing apparatus, according to some embodiments of the present disclosure.
[0025] FIGS. **9-10** illustrate perspective views of yet another example aircraft wing apparatus, according to some embodiments of the present disclosure.
[0026] FIGS. **11-13** illustrate perspective views of yet another example aircraft wing apparatus having a swept-wing planform, according to some embodiments of the present disclosure.

[0027] FIG. **14** illustrates a perspective view of yet another example aircraft wing apparatus having an offset wing-skin arrangement, according to some embodiments of the present disclosure.
[0028] FIG. **15** illustrates a perspective view of yet another example aircraft wing apparatus having a centralized wing-skin arrangement, according to some embodiments of the present disclosure.
[0029] FIG. **16** is a block diagram of a controller for actuating an aircraft wing apparatus, according to some embodiments of the present disclosure.
[0030] FIGS. **17-18** illustrate perspective views of yet another example aircraft wing apparatus having a scissor linkage assembly, according to some embodiments of the present disclosure.
[0031] FIG. **19** is a block diagram of an aircraft having an aircraft wing apparatus, according to some embodiments of the present disclosure.
[0032] FIG. **20** is a flowchart of a method of controlling an aircraft, such as the aircraft shown in FIG. **19**, according to some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0033] An improved technique is directed to a wing apparatus having an extendable (or adjustable) spar. The extendable spar may be extended, in part or in whole, to increase wing surfaces that contribute to lift, increasing aerodynamic performance of an aircraft. Additionally, the extendable spar may be retracted (or consolidated) to minimize crosswind forces against the aircraft and to reduce a footprint of the aircraft, e.g., for landing and/or takeoff in locations where space is limited. In this manner, the wing apparatus provides a variety of wing profiles for different mission requirements.
[0034] The various individual features of the particular arrangements, configurations, and embodiments disclosed herein can be combined in any desired manner that makes technological sense. Additionally, such features are hereby combined in this manner to form all possible combinations, variants and permutations except to the extent that such combinations, variants and/or permutations have been expressly excluded or are impractical. Support for such combinations, variants and permutations is considered to exist in this document.
[0035] FIGS. **1** and **2** show various views of an example aircraft wing apparatus **100** that extends and retracts to provide different wing profiles for an aircraft. FIG. **1** shows the aircraft wing apparatus **100** in a fully extended (deployed) configuration. FIG. **2** shows the aircraft wing apparatus **100** in a retracted (stowed) configuration. As described in greater detail below, one or more features are hidden from view in FIG. **2** to highlight certain aspects of the aircraft wing apparatus **100**. Additionally, one or more features are shown as transparent to show internal details of the aircraft wing apparatus **100**.
[0036] The aircraft wing apparatus **100** includes wing-skin sections **102***a*, **102***b*, and **102***c* (collectively, wing-skin sections **102**) and an extendable spar assembly **104**. The wing-skin sections **102** are constructed and arranged to provide an airfoil that generates vertical lift during forward flight. As best shown in FIG. **2**, the wing-skin sections **102** may be nested within each other to reduce a lateral length of the aircraft wing apparatus **100**. Along these lines, the wing-skin section **102***b* defines a space for stowing the wing-skin section **102***c*, and the wing-skin section **102***a* defines a space for stowing both the wing-skin section **102***b* and the wing-skin section **102***c*. In some embodiments, the wing-skin sections **102** include various flight control surfaces, such as ailerons, elevators, flaps, and so forth, to adjust aircraft positioning during flight.
[0037] As shown in FIG. **2**, the extendable spar assembly **104** includes spar members **104***b* and **104***c*. The spar member **104***b* is fixedly attached to the wing-skin section **102***b*, and the spar member **104***b* is fixedly attached to the wing-skin section **102***c*. It should be understood that portions of the spar members **104***b* and **104***c* may extend into their respective wing-skin sections **102***b* and **102***c*. These portions are hidden from view for simplicity. Further, one or more additional spar members may be provided, e.g., another spar member may be fixedly attached to the wing-skin section **102***a*. In some embodiments, part of extendable spar **104** extends into and couples with an aircraft body (e.g., a fuselage).

[0038] The spar member **104***b* defines a lateral channel within which the spar member **104***c* may be wholly or partially contained. The spar member **104***c* is constructed and arranged to slide within the channel when extending or retracting the wing-skin section **102***c* relative to the wing-skin section **102***b*. The spar members **104***b* and **104***c* may be maintained (or held) different positions to place the wing-skin sections **102** into predefined configurations, e.g., fully stowed, fully extended, partially extended, and so forth.

[0039] During example operation, the spar members **104***b* and **104***c* slide relative to the wing-skin section **102***a* to extend and retract the wing-skin sections **102***b* and **102***c*. When the spar members **104***a* and **104***b* are in a stowed (e.g., fully retracted) configuration (e.g., as shown in FIG. **2**), the wing-skin sections **102***b* and **102***c* are housed within the wing-skin section **102***a*. Advantageously, while the aircraft wing apparatus **100** is in the stowed configuration, crosswind forces acting on the aircraft wing apparatus **100** may be minimized. As a result, the aircraft wing apparatus **100** provides improved positional accuracy and stability during vertical takeoff and landing (VTOL).

[0040] Further, the spar members **104***b* and **104***c* may be moved to predefined positions to place the wing-skin sections **102** into various deployed configurations. For example, in a first deployed configuration, the wing-skin sections **102** may be fully extended to provide a first wing profile. In a second deployed configuration, the wing-skin sections **102** may be partially extended to provide a second wing profile.

[0041] Advantageously, the variable wing profiles enable the aircraft wing apparatus **100** to dynamically adjust flight characteristics (e.g., maneuverability, aerodynamic efficiency, and so forth) before or during flight. In this manner, the aircraft wing apparatus **100** may be adapted to best suit a variety of mission parameters and flight modes (e.g., dash to target, loiter to target, combinations thereof, etc.). For example, in the embodiments discussed above, the first deployed configuration may be directed to providing higher endurance and fuel efficiency for longer flight and/or increased payload delivery. In contrast, the second deployed configuration may be directed to providing increased aircraft maneuverability and reducing parasitic drag on the aircraft for faster travel.

[0042] Further, while in the stowed configuration (e.g., by fully retracting the spar), the aircraft wing apparatus may reduce the surface area of exposed to crosswind forces, e.g., to improving positional accuracy when vertically landing and reducing an overhead footprint of the aircraft. In this manner, the aircraft may land on smaller landing areas (e.g., certain ship decks, etc.). Further details will now be provided with reference to FIGS. **3** through **8**.

[0043] FIGS. **3** through **8** show various views of an example aircraft wing apparatus **300**. FIGS. **3** and **4** show various views of the aircraft wing apparatus **300** in an extended (deployed) configuration. FIGS. **5** and **6** show various view of the aircraft wing apparatus **300** in a retracted (stowed) configuration. FIG. **7** shows a side view of the aircraft wing apparatus **300**. FIG. **8** shows a cross-sectional view of an extendable spar assembly **304**. As described in greater detail below, one or more features are hidden from view in some figures to highlight certain aspects of the aircraft wing apparatus **300**. Additionally, certain features are shown as transparent to show internal details of the aircraft wing apparatus **300**.

[0044] The aircraft wing apparatus **300** includes wing-skin sections **302***a* through **302***d* (collectively, wing-skin sections **302**), the extendable spar assembly **304**, and a plurality of wing ribs **306**. As shown in FIG. **3**, the wing-skin sections **302***a* through **302***d* provide respective airfoil surfaces spanning respective lateral distances **308***a* through **308***d* (collectively, lateral distances **308**). It should be appreciated that the lateral distances **308** may differ from each other. For example, as shown, the lateral distance **308***d* is less than the other lateral distances **308***a* through **308***c*. Further, the lateral distances **308** may be adjusted via the extendable spar assembly **304**, e.g., to better suit flight requirements of individual missions. In some embodiments, the wing-skin sections **302** are made of a non-rigid or collapsible material, e.g., fabric or thin composite.

[0045] The extendable spar assembly **304** include spar members **304***a* through **304***d*. Similar to the extendable spar assembly **104** (FIG. **1**), the extendable spar assembly **304** may define one or more channels for stowing the spar members **304***a* through **304***d*. As shown, the spar member **304***a* define a channel for stowing the spar member **304***b*, the spar member defines a channel for stowing the spar member **304***c*, and the spar member **304***c* defines a channel for stowing the spar member **304***d*.

[0046] As best seen in FIG. **8**, the spar members **304***a* though **304***b* are coupled together via respective sets of roller bearings **310**. These sets of roller bearings **310** are constructed and arranged to reduce friction between individual spar members and case extension and retraction of the extendable spar **304** when acted upon by wind forces, e.g., while airborne. Further, the sets of roller bearings **310** are constructed and arranged to withstand forces acting on the aircraft wing apparatus **300** during flight. Although the sets of roller bearings **310** are provided, it should be understood that alternative couplings may be used instead, such as plain bearings, fluid bearings, and so forth.

[0047] The plurality of wing ribs **306** provides internal structural support to the wing-skin sections **302**, e.g., to maintain an airfoil shape during operation. One or more wing ribs of the plurality of wing ribs **306** are fixedly attached to the extendable spar assembly **304**. For example, in some embodiments, a respective wing rib is fixedly attached to an outer end of each of the spar members **304***a* through **304***d*. These wing ribs are constructed and arranged to move based on action of the extendable spar assembly **304**. Additional wing ribs are interspersed between the fixedly attached wing ribs and are constructed and arranged to slide along individual spar members, e.g., to separate from each other during extension or converge toward each other during retraction.

[0048] During example operation, the aircraft wing apparatus **300** is initially in a stowed configuration, e.g., as shown in FIG. **6**. When the aircraft wing apparatus **300** enters a deployed configuration, the extendable spar assembly **304** extends to a predefined position, e.g., fully extended or partially extended. As the extendable spar assembly **304** moves, the plurality of wing ribs **306** likewise extends laterally outwards. When the extendable spar assembly **304** extends, the wing ribs of the plurality of wing ribs **306** separate from each other to span a length of the aircraft wing assembly **300**, e.g., as shown in FIG. **3**. In this manner, the plurality of wing ribs **306** provides support for the wing-skin sections **302**.

[0049] Conversely, when the extendable spar assembly **304** retracts, the wing ribs **306** converge together to reduce a lateral length of the aircraft wing assembly **300**, e.g., as shown in FIG. **6**. In some embodiments, the wing-skin sections **302** are made of non-rigid material (e.g., fabric) which folds or otherwise consolidates when the extendable spar assembly **304** retracts. Alternatively or in addition, one or more wing-skin sections **302** may be partially or wholly housed within another wing-skin section **302**, e.g., the wing-skin section **302***a*. In this manner, the aircraft wing apparatus **300** may adjust a wingspan of an aircraft to best suit given mission parameters. Further details will now be provided with reference to FIGS. **9** through **10**.

[0050] FIGS. **9** and **10** show cross-sectional views of an example aircraft wing apparatus **900**. Similar to the aircraft wing apparatus **300** (FIG. **3**), the aircraft wing apparatus **900** includes a wing-skin section **902**, an extendable spar **904**, and wing ribs **906**.

[0051] FIG. **9** shows a single spar member **904***a* of the extendable spar **904** coupled with the wing-skin section **902** via the wing ribs **906**. FIG. **10** shows additional spar members **904***b* through **904***d* nested within the spar member **904***a*. It should be understood that additional wing-skin sections and wing ribs may be coupled with the additional spar members **904***b* through **904***d* in a manner similar to the wing-skin section **902** and the wing ribs **906**. Further details will now be provided with reference to FIGS. **11** through **13**.

[0052] FIGS. **11** through **13** show various views of an example aircraft wing apparatus **1100**. FIG. **11** shows a top-down view of the aircraft wing apparatus **1100** in a fully extended (deployed) configuration. FIG. **12** shows a top-down view of the aircraft wing apparatus **1100** in a retracted (stowed) configuration. FIG. **13** shows a perspective view of internal components of the aircraft wing apparatus **1100**.

[0053] The aircraft wing apparatus **1100** includes wing-skin sections **1102**_a_, **1102**_b_, (collectively, wing-skin sections **1102**) and an extendable spar assembly **1104**. The wing-skin section **1102**_a_ is constructed and arranged to provide a swept-wing planform and couple with an aircraft body (e.g., a fuselage). Further, as best shown in FIG. **11**, the wing-skin sections **1102** taper as the wing-skin sections **1102** extend away from the aircraft body. For example, the wing-skin section **1102**_a_ spans a length **1120**_a_ in an axial (forward-aft) direction, and the wing-skin section **1102**_b_ spans a smaller length **1120**_b_ in the axial direction. Based on the difference in axial lengths, the wing-skin sections **302** that are further from the aircraft body may nest within the wing-skin sections **302** that are closer to the aircraft body, e.g., as shown in FIG. **12**.

[0054] The extendable spar assembly **1104** is shown in FIG. **13** and is housed within the wing-skin sections **1102**. Similar to the extendable spar assembly **304** (FIG. **3**), the extendable spar assembly **1104** is constructed and arranged to selectively position the wing-skin sections **1102**. Further details will now be provided with reference to FIG. **14**.

[0055] FIG. **14** shows a top-down view of an example aircraft wing apparatus **1400**.

[0056] The aircraft wing apparatus **1400** includes wing-skin sections **1402**_a_ through **1402**_d_ (collectively, wing-skin sections **1402**). One or more of the wing-skin sections **1402** are constructed and arranged to slide relative to the other wing-skin sections **1402** to extend and retract the aircraft wing apparatus **1400**, e.g., to the left and right as shown in FIG. **14**. Further, the wing-skin sections **1402** are constructed and arranged to nest with each other. For example, the wing-skin section **1402**_d_ fits within the wing-skin section **1402**_c_, the wing-skin section **1402**_c_ fits within the wing-skin section **1402**_b_, and so forth.

[0057] It should be appreciated that the wing-skin sections **1402** are different sizes from each other. For example, where the wing-skin section **1402**_a_ and **1402**_b_ meet, the wing-skin section **1402**_a_ is longer than wing-skin section **1402**_b_ in an axial (forward-aft) direction, which enables the wing-skin section **1402**_b_ to fit within the wing-skin section **1402**_a_. As a result, steps **1440** and **1442** exist between the wing-skin sections **1402**_a_ and **1402**_b_.

[0058] To minimize the impact on aerodynamic efficiency, the wing-skin sections **1402** are offset closer to a leading edge of aircraft wing apparatus **1400**, rather than a trailing edge of the aircraft wing apparatus **1400**. As a result, the steps between individual wing-skin sections are smaller at the leading edge compared to the trailing edge, e.g., step **1440** at the leading edge is less than step **1442** at the trailing edge. Advantageously, with this arrangement, aerodynamic efficiency may be improved. Further details will now be provided with reference to FIG. **15**.

[0059] FIG. **15** shows a top-down view of an example aircraft wing apparatus **1500**, which provides an alternative arrangement compared to the aircraft wing apparatus **1400** (FIG. **14**). Similar to the aircraft wing apparatus **1400**, the aircraft wing apparatus **1500** includes nesting wing-skin sections **1502**_a_ through **1502**_d_ (collectively, wing-skin sections **1502**. Additionally, similar to the wing-skin sections **1402** (FIG. **14**), the wing-skin sections **1502** decrease in length between individual wing-skin sections **1502**, e.g., as indicated by steps **1540** and **1542**.

[0060] In contrast to the wing-skin sections **1402** (FIG. **14**), the wing-skin sections **1502** are centrally disposed between the trailing edge to the leading edge. That is, the steps **1540** and **1542** may be equal to each other. Advantageously, under this arrangement, construction may be simplified. Further details will now be provided with reference to FIG. **16**.

[0061] FIG. **16** shows an example controller **1600** constructed and arranged to selectively extend and retract an extendable spar assembly, e.g., any of the extendable spar assemblies **104** (FIG. **2**), **304** (FIG. **3**), **904** (FIG. **9**), **1104** (FIG. **13**). As will be explained in further detailed below, the controller **1600** may be coupled with an aircraft body (e.g., a fuselage) and extends laterally outwards from the aircraft body. As used herein, the term “inner” refers to an end closer to the aircraft body and the term “outer” refers to an end further from the aircraft body.

[0062] The controller **1600** includes a first actuation assembly **1602** for extension, and a second actuation assembly **1604** for retraction. The first actuation assembly **1602** includes pulley wheels **1610***a* through **1610***c* (collectively, pulley wheels **1610**), cables **1612***a* through **1612***c* (collectively, cables **1612**), and lateral members **1614***a* through **1614***d* (collectively, lateral members **1614**). The pulley wheels **1610** are coupled to respective outer portions of lateral members **1614***a* through **1614***c*. As provided in FIG. **16**, the outer portions of the lateral members **1614** are positioned towards the right side of the figure and the inner portions of the lateral members **1614** are positioned towards the left side of the figure.

[0063] The cables **1612** interface with the pulley wheels **1610** and have one or more ends coupled with inner portions of the lateral members **1614**. As shown, the first cable **1612***a* wraps around the first pulley wheel **1610***a* and has an end coupled with an inner portion of the second lateral member **1614***b*. The second cable **1612***b* wraps around the second pulley wheel **1610***b* and has one end coupled with an inner portion of the first lateral member **1614***a* and a second end coupled with an inner portion of the third lateral member **1614***c*. Similarly, the third cable **1612***c* wraps around the third pulley wheel **1610***c* and has one end coupled with an inner portion of the second lateral member **1614***b* and another end coupled with an inner portion of the fourth lateral member **1614***d*.

[0064] The lateral member **1614***a* may be fixed relative to the aircraft body. The remaining lateral members **1614***b* through **1614***d* are constructed and arranged to selectively slide relative to the fixed lateral member **1614***a* in a lateral direction (e.g., left and right as shown in FIG. **16**). In some embodiments, the lateral members **1614** are coupled with respective spar members of the extendable spar assembly (e.g., spar members **304***a* through **304***d* as shown in FIG. **3**). For example, the lateral member **1614***a* may be coupled with the spar member **304***a*, the lateral member **1614***b* may be coupled with the spar member **304***b*, and so forth. Alternatively, the lateral members **1614** may represent portions of the spar members themselves.

[0065] The second actuation assembly **1604** includes pulley wheels **1620***a* and **1620***b* (collectively, pulley wheels **1620**), cables **1622***a* through **1622***c* (collectively, cables **1622**), and lateral members **1624***a* through **1624***d* (collectively, lateral members **1624**). The pulley wheels **1620** are coupled to respective inner portions of lateral members **1624***b* and **1624***c*.

[0066] The first cable **1622***a* is coupled with the second lateral member **1624**. The remaining cables **1622***b* and **1622***c* interface with the pulley wheels **1620** and have one or more ends coupled with outer portions of the lateral members **1624**. As shown, the second cable **1622***b* wraps around the first pulley wheel **1620***a* and has one end coupled with an outer portion of the first lateral member **1624***a* and another end coupled with the third lateral member **1624***c*. The third cable **1622***c* wraps around the second pulley wheel **1620***b* and has one end coupled with an outer portion of the second lateral member **1624***b* and an outer portion of the fourth lateral member **1624***d*.

[0067] The lateral member **1624***a* may be fixed relative to the aircraft body. The remaining lateral members **1624***b* through **1624***d* are constructed and arranged to selectively slide relative to the fixed lateral member **1624***a* in a lateral direction (e.g., left and right as shown in FIG. **16**). In some embodiments, the lateral members **1624** are coupled with respective spar members of the extendable spar assembly (e.g., spar members **304***a* through **304***d* as shown in FIG. **3**). For example, the lateral member **1624***a* may be coupled with the spar member **304***a*, the lateral member **1624***b* may be coupled with the spar member **304***b*, and so forth. Alternatively, the lateral members **1624** may represent portions of the spar members themselves.

[0068] During example operation, the controller **1600** actuates the cables **1612***a* and **1622***a* to extend and retract the extendable spar assembly. To extend the extendable spar assembly, the controller **1600** pulls a free end of the cable **1612***a* inward (e.g., to the left as shown in FIG. **16**). As a result, the other end of the cable **1612***a*, which is coupled with the inner portion of the second lateral member **1614***b*, pulls the inner portion of the second lateral member **1614***b* toward the outer portion of the first lateral member **1614***a*, which moves the second lateral member **1614***b* outward relative to the first lateral member **1614***a*.

[0069] Further, as the second lateral member **1614***b* moves outward, the second lateral member

1614*b* carries the pulley wheel **1610***b* with it. The change in position of the pulley wheel **1610***b* increases a length of the cable **1612***b* on one side of the pulley wheel **1610***b*, which pulls the inner portion of the third lateral member **1614***c* towards an outer portion of the second lateral member **1614***b*. In this manner, the third lateral member **1614***c* move outward based on the extension of the second lateral member **1614***b*. Along the same lines, the fourth lateral member **1614***d* moves outward via the pulley wheel **1610***c* and cable **1612***c*. Accordingly, the controller **1600** extends the spar members of the extendable spar assembly.

[0070] To retract the extendable spar assembly, the controller **1600** pulls a free end of the cable **1622***a* inward (e.g., to the left as shown in FIG. **16**), which pulls the second lateral member **1624***b* inward. As the second lateral member **1624***b* moves inward, the second lateral member **1624***b* carries the pulley wheel **1620***a* with it. The change in position of the pulley wheel **1620***a* increases a length of the cable **1622***b* on one side of the pulley wheel **1620***a*, which pulls the outer portion of the third lateral member **1614***c* towards an inner end of the second lateral member **1614***b*. In this manner, the third lateral member **1624***c* moves inward based on the retraction of the second lateral member **1624***b*. Along the same lines, the fourth lateral member **1624***d* moves inward via the pulley wheel **1620***b* and cable **1612***b*. Accordingly, the controller **1600** retracts the extendable spar assembly.

[0071] Advantageously, the above-described arrangement enables the controller **1600** to extend the spar members of the extendable spar assembly based on actuation of the single cable **1612***a*. Likewise, the controller **1600** may retract the individual spar members of the extendable spar assembly based on actuation of the single cable **1622***a*. In this manner, extension and retraction by the controller **1600** may be simplified. Additionally, this arrangement enables the controller **1600** to hold different predefined positions for different wing profiles, such as a fully stowed profile, a fully deployed profile, and a partially deployed profile.

[0072] Further, it should be appreciated that the individual lateral members **1614** and **1624** may move different lengths and/or draw distances from each other during actuation. For example, the second lateral member **1614***b* may extend a first distance relative to the first lateral member **1614***a*, and the third lateral member **1614***c* may extend a second distance relative to the second lateral member **1614***b*. Advantageously, this arrangement enables the aircraft to assume particular wing profiles during operation. Further details will now be provided with reference to FIGS. **17** and **18**.

[0073] FIGS. **17** and **18** show various view of an example aircraft wing apparatus **1700** having a scissor linkage assembly **1710**. FIG. **17** shows a side view of the aircraft wing apparatus **1700**. FIG. **18** shows a top-down view of the scissor linkage assembly **1710**. Certain features are hidden from view in FIG. **18** to highlight features of the scissor linkage assembly **1710**.

[0074] The aircraft wing apparatus **1700** includes wing-skin sections **1702**, an extendable spar assembly **1704**, wing ribs **1706***a*, **1706***b*, . . . (collectively, a plurality of wing ribs **1706**), and the scissor linkage assembly **1710**. The wing-skin sections **1702**, the extendable spar assembly **1704**, and the plurality of wing ribs **1706** may be similar to, e.g., the wing-skin sections **302**, the extendable spar assembly **304**, and the plurality of wing ribs **306** described above in relation to FIG. **3**.

[0075] In some embodiments, the plurality of wing ribs **1706** includes a first wing rib fixedly attached with a first spar member of the extendable spar assembly **1704**, and a second wing rib fixedly attached to a second spar member of the extendable spar assembly **1704**. Further, the plurality of wing ribs **1706** includes a set of wing ribs disposed between the first wing rib and the second wing rib. The set of wing ribs is sidable along one or more of the spar members of the extendable spar assembly **1704**.

[0076] As shown best in FIG. **18**, the scissor linkage assembly **1700** is coupled with the wing ribs **1706** and is constructed and arranged to extend and retract the wing ribs **1706** relative to each other.

[0077] During example operation, the spar members of the extendable spar assembly **1704** move outwards to deploy the wing-skin sections **1702**. At the same time, the first wing rib and the second wing rib of the plurality of wing ribs **1706** separate from each other, as these wing ribs are fixedly attached to different spar members of the extendable spar assembly **1704**. Further, based on the separation of the first wing rib and the second wing rib, the scissor linkage assembly **1710** causes the set of wing ribs disposed between the first wing rib and the second wing rib to likewise separate. Accordingly, the wing ribs **1706** provide support to the wing-skin sections **1702** during flight. Similar action may occur in reverse to stow the wing-skin sections **1702**. Further details will now be provided with reference to FIG. **19**.

[0078] FIG. **19** shows a block diagram of an example aircraft **1900**. The aircraft **1900** includes an aircraft body **1902**, a propeller **1904**, and aircraft wing apparatus **1906***a* and **1906***b* (collectively, aircraft wing apparatus **1906**). Although the aircraft **1900** is provided as a propeller airplane, it should be understood that the aircraft **1900** is provided for example purposes. Alternative arrangements are possible, such as a helicopter, rotorcraft, and so forth. Further, in some embodiments, the aircraft **1900** includes additional componentry, such as sensors, flight controls, rotors for vertical takeoff and landing (VTOL), and so forth.

[0079] The aircraft wing apparatus **1906** may be, e.g., any of the aircraft wing apparatus **100** (FIG. **1**), **300** (FIG. **3**), **900** (FIG. **9**), **1100** (FIG. **11**), **1400** (FIG. **14**), **1500** (FIG. **15**), **1700** (FIG. **17**).

[0080] The aircraft body **1902** is constructed and arranged to house various componentry, including an engine **1910**, a set of motors **1912**, and control circuitry **1914**. The engine **1910** is constructed and arranged to provide power to the propeller **1904** for forward flight. The set of motors **1912** are constructed and arranged to selectively extend and retract the aircraft wing apparatus **1906** based on control by the control circuitry **1914**. In some embodiments, the set of motors **1912** and the control circuitry **1914** form a part of the controller **1600** (FIG. **16**). For example, the set of motors **1912** may operate to actuate the cables **1612***a* and **1622***a* of the controller **1600**.

[0081] In certain embodiments, the set of motors **1912** includes different motors for actuating the cables **1612***a* and **1622***a*, respectively. The control circuitry **1914** coordinate operation of the motors to extend and retract the aircraft wing apparatus **1906**. Along these lines, when the control circuitry **1914** instructs one motor to pull a respective cable (e.g., to extend or retract the aircraft wing apparatus **1906**), the control circuitry **1914** further instructs the other motor to allow its respective cable to unwind.

[0082] During example operation, the set of motors **1912** extend the aircraft wing apparatus **1906** to different positions to assume different configurations. For example, the aircraft wing apparatus **1906** may assume a stowed configuration, a first deployed configuration, and a second deployed configuration that is different from the first deployed configuration. In this manner, the aircraft **1900** may assume different wing profiles to best suit parameters of a given mission. Further details will now be provided with reference to FIG. **20**.

[0083] FIG. **20** shows an example method **2000** for controlling an aircraft wing apparatus coupled with an aircraft, e.g., the aircraft wing apparatus **1906** coupled with aircraft **1900**, as shown in FIG. **19**.

[0084] At **2002**, access is obtained to a controller constructed and arranged to operate an extendable spar assembly of the aircraft wing apparatus. The extendable spar assembly includes a first spar member and a second spar member. The first spar member is coupled with a first wing-skin section of a plurality of wing-skin sections. The second spar member is coupled with a second wing-skin section of the plurality of wing-skin sections.

[0085] At **2004**, the controller moves the second spar member to a first predefined position relative to the first spar member. As a result, the plurality of wing-skin sections is placed from a stowed configuration into a first deployed configuration (e.g., a fully deployed configuration).

[0086] At **2006**, the controller moves the second spar member to a second predefined position relative to the first spar member. As a result, the plurality of wing-skin sections is placed into a second deployed configuration (e.g., a partially deployed configuration), the first deployed configuration being different from the second deployed configuration. In this manner, the aircraft wing apparatus may be positioned to best satisfy the mission requirements.

[0087] As described above, improved techniques are directed to an aircraft wing apparatus having an extendable (or adjustable) spar. The extendable spar may be extended, in part or in whole, to increase wing surfaces that contribute to lift, increasing aerodynamic performance of an aircraft. Additionally, the extendable spar may be retracted (or consolidated) to minimize crosswind forces against the aircraft and to reduce a footprint of the aircraft, e.g., for landing and/or takeoff in locations where space is limited. In this manner, the wing apparatus provides a variety of wing profiles for different mission requirements.

[0088] While various embodiments of the present disclosure have been particularly shown and described, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present disclosure as defined by the appended claims.

[0089] It should be appreciated that the extendable spar assemblies described herein serve as internal beam structures which may translate within travel ranges. Such a travel range may include a position of maximum retraction (or minimum extension) and a position of maximum extension (or minimum retraction). Advantageously, in accordance with one or more embodiments, the controller **1600** (FIG. **16**) is constructed and arranged to move an extendable spar assembly to a position (or particular amount of retraction/extension) within the travel range and maintain (e.g., indefinitely hold or lock) the extendable spar assembly at that position to enable an aircraft to enjoy certain aerodynamic features during flight. In this manner, the aircraft may be adapted to best suit a variety of mission parameters and flight modes (e.g., dash to target, loiter to target, combinations thereof, etc.).

[0090] It should be further understood that the controller **1600** (FIG. **16**) was described above as including pulley wheels and cables for actuating an extendable spar assembly by way of example only. In accordance with certain embodiments, the extendable spar assembly may be actuated in other ways, such as using gears, actuators, pressure control, combinations thereof, and so forth. Along these lines, various apparatus such as actuators or tubes supplying fluid pressure may move one wing-skin section relative to another, and the aggregated operation of multiple actuators or multiple tubes supplying different fluid pressures, etc. may operate to control movement of the spar members relative to each other to provide certain desired wing extensions.

[0091] The scope of this disclosure should be determined by the appended claims and their legal equivalents. Therefore, it will be appreciated that the scope of the present disclosure fully encompasses other embodiments which may become obvious to those skilled in the art, and that the scope of the present disclosure is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean “one and only one” unless explicitly so stated, but rather “one or more.” All structural, chemical, and functional equivalents to the elements of the above-described preferred embodiment that are known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. Moreover, it is not necessary for a device or method to address each and every problem sought to be solved by the present disclosure, for it to be encompassed by the present claims. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims.

[0092] The foregoing description of various preferred embodiments of the disclosure have been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise embodiments, and obviously many modifications and variations are possible in light of the above teaching. The example embodiments, as described above, were chosen and described in order to best explain the principles of the disclosure and its practical application to thereby enable others skilled in the art to best utilize the disclosure in various embodiments and with various modifications as are suited to the particular use contemplated. It is

intended that the scope of the disclosure be defined by the claims appended hereto.
[0093] Various examples have been described. These and other examples are within the scope of the following claims.

Claims

1. An aircraft wing apparatus, comprising: a plurality of wing-skin sections including a first wing-skin section and a second wing-skin section; an extendable spar assembly including a first spar member coupled with the first wing-skin section and a second spar member coupled with the second wing-skin section; and a controller constructed and arranged to move the second spar member to predefined positions relative to the first spar member to place the plurality of wing-skin sections into predefined configurations, the predefined configurations including a stowed configuration, a first deployed configuration, and a second deployed position that is different from the first deployed position.
2. The aircraft wing apparatus of claim 1, wherein the first spar member defines a channel, at least part of the second spar member being constructed and arranged to slide within the channel when moving relative to the first spar member.
3. The aircraft wing apparatus of claim 1, wherein an outer end of the second wing-skin section in the first deployed configuration laterally extends a first predefined distance away from an outer end of the first wing-skin section, and wherein the outer end of the second wing-skin section in the second deployed configuration laterally extends a second predefined distance away from the outer end of the first wing-skin section, the first predefined distance being different from the second predefined distance.
4. The aircraft wing apparatus of claim 1, wherein the controller includes: an actuation assembly including a pulley wheel and a pulley cable, the pulley wheel being disposed at an outer portion of the first spar member, the pulley cable interfacing with the pulley wheel and having an end coupled with an inner portion of the second spar member; and a set of motors constructed and arranged to actuate the pulley cable to extend the second spar member relative to the first spar member.
5. The aircraft wing apparatus of claim 4, wherein the extendable spar further includes a third spar member coupled with a third wing-span section of the plurality of wing-span sections; and wherein the actuation assembly further includes a second pulley wheel and a second pulley cable, the second pulley wheel being disposed on an outer portion of the second spar member, the second pulley cable interfacing with the second pulley wheel and being coupled between the first spar member and the third spar member, the second pulley cable being constructed and arranged to extend the third spar member relative to the first spar member based on extension of the second spar member by the set of motors.
6. The aircraft wing apparatus of claim 4, wherein the set of motors are further constructed and arranged to retract the second spar member relative to the first spar member.
7. The aircraft wing apparatus of claim 6, wherein the extendable spar further includes a third spar member coupled with a third wing-span section of the plurality of wing-span sections; and wherein the controller further includes: a retraction assembly including a retraction pulley wheel and a retraction pulley cable, the retraction pulley wheel being disposed at an inner portion of the second spar member, a retraction pulley cable interfacing with the retraction pulley wheel and being coupled with the first spar member and the third spar member, the retraction pulley cable being constructed and arranged to retract the third spar member relative to the first spar member based on retraction of the second spar member by the set of motors.
8. The aircraft wing apparatus of claim 1, wherein the first wing-skin section and the second wing-skin section include respective forward ends and respective aft ends, a first distance between the respective forward ends being less than a second distance between the respective aft ends.
9. The aircraft wing apparatus of claim 1, further comprising: a plurality of wing ribs disposed

between the plurality of wing-skin sections and the extendable spar, the plurality of wing ribs including a first group of wing ribs which supports the first wing-skin section and a second group of wing ribs which supports the second wing-skin section.

10. The aircraft wing apparatus of claim 9, wherein wing ribs of the plurality of wing ribs are coupled together via a scissor linkage assembly, the scissor linkage assembly being constructed and arranged to extend and retract the wing ribs of the plurality of wing ribs relative to each other.

11. The aircraft wing apparatus of claim 9, wherein the plurality of wing ribs includes a first wing rib, a second wing rib, and a set of wing ribs disposed between the first wing rib and the second wing rib, the first wing rib being fixedly attached to the first spar member, the second wing rib being fixedly attached to the second spar member, the set of wing ribs being constructed and arranged to move relative to both the first wing rib and the second wing rib based on movement of the second spar member relative to the first spar member.

12. An aircraft, comprising: an aircraft body; an engine coupled with the aircraft body, the engine being constructed and arranged to provide power for forward flight; and an aircraft wing apparatus coupled with the aircraft body, the aircraft wing apparatus including: a plurality of wing-skin sections including a first wing-skin section and a second wing-skin section; an extendable spar assembly including a first spar member coupled with the first wing-skin section and a second spar member coupled with the second wing-skin section; and a controller constructed and arranged to move the second spar member to predefined positions relative to the first spar member to place the plurality of wing-skin sections into predefined configurations, the predefined configurations including a stowed configuration, a first deployed configuration, and a second deployed position that is different from the first deployed position.

13. The aircraft of claim 12, wherein the first spar member defines a channel, at least part of the second spar member being constructed and arranged to slide within the channel when moving relative to the first spar member.

14. The aircraft of claim 12, wherein an outer end of the second wing-skin section in the first deployed position extends a first predefined distance away from an outer end of the first wing-skin section, and wherein the outer end of the second wing-skin section in the second deployed position extends a second predefined distance away from the outer end of the first wing-skin section, the first predefined distance being different from the second predefined distance.

15. The aircraft of claim 12, wherein the controller includes: an actuation assembly including a pulley wheel and a pulley cable, the pulley wheel being disposed at an outer portion of the first spar member, the pulley cable interfacing with the pulley wheel and having an end coupled with an inner portion of the second spar member; and a set of motors constructed and arranged to actuate the pulley cable to extend the second spar member relative to the first spar member.

16. The aircraft of claim 15, wherein the extendable spar further includes a third spar member coupled with a third wing-span section of the plurality of wing-span sections; and wherein the actuation assembly further includes a second pulley wheel and a second pulley cable, the second pulley wheel being disposed on an outer portion of the second spar member, the second pulley cable interfacing with the second pulley wheel and being coupled between the first spar member and the third spar member, the second pulley cable being constructed and arranged to extend the third spar member relative to the first spar member based on extension of the second spar member by the set of motors.

17. The aircraft of claim 12, wherein the aircraft wing apparatus further includes: a plurality of wing ribs disposed between the plurality of wing-skin sections and the extendable spar, the plurality of wing ribs including a first group of wing ribs which supports the first wing-skin section and a second group of wing ribs which supports the second wing-skin section.

18. The aircraft of claim 17, wherein wing ribs of the plurality of wing ribs are coupled together via a scissor linkage assembly, the scissor linkage assembly being constructed and arranged to extend and retract the wing ribs of the plurality of wing ribs relative to each other.

19. The aircraft of claim 17, wherein the plurality of wing ribs includes a first wing rib, a second wing rib, and a set of wing ribs disposed between the first wing rib and the second wing rib, the first wing rib being fixedly attached to the first spar member, the second wing rib being fixedly attached to the second spar member, the set of wing ribs being constructed and arranged to move relative to both the first wing rib and the second wing rib based on movement of the second spar member relative to the first spar member.

20. A method of controlling an aircraft wing apparatus coupled with an aircraft, the method comprising: accessing a controller constructed and arranged to operate an extendable spar assembly of the aircraft wing apparatus, the extendable spar assembly including a first spar member and a second spar member, the first spar member being coupled with a first wing-skin section of a plurality of wing-skin sections, the second spar member being coupled with a second wing-skin section of the plurality of wing-skin sections; moving the second spar member to a first predefined position relative to the first spar member to place the plurality of wing-skin sections from a stowed configuration into a first deployed configuration; and moving the second spar member to a second predefined position relative to the first spar member to place the plurality of wing-skin sections into a second deployed configuration, the first deployed configuration being different from the second deployed configuration.