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Karem

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(54) **MULTI-ROLE AIRCRAFT WITH INTERCHANGEABLE MISSION MODULES**

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B64C 3/56 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B64C 1/0009*** (2013.01); ***B64C 1/061*** (2013.01); ***B64C 1/26*** (2013.01); ***B64C 3/56*** (2013.01); ***B64C 39/024*** (2013.01); ***B64C 39/10*** (2013.01); ***B64D 37/00*** (2013.01); *B64C 2001/0072* (2013.01); *B64C 2039/105* (2013.01);
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USPC 244/36, 45, 118.2, 119, 120, 129.1
See application file for complete search history.

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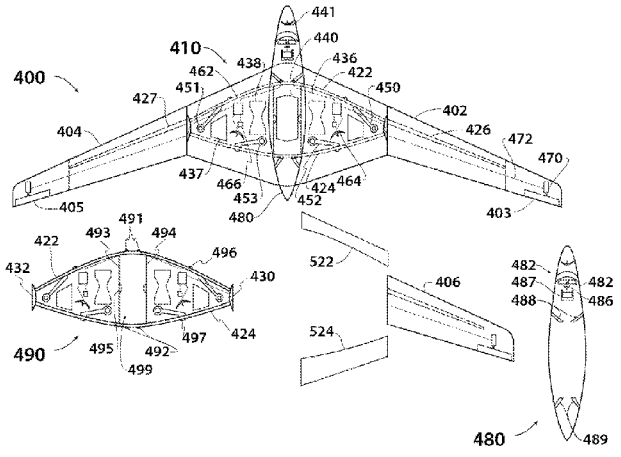
(57) **ABSTRACT**

A flight-operable, truly modular aircraft has an aircraft core to which one or more of outer wings members, fuselage, cockpit, leading and trailing edge couplings, and empennage and tail sections can be removably coupled and/or replaced during the operating life span of the aircraft. In preferred embodiments the aircraft core houses the propulsive engines, avionics, at least 80% of the fuel, and all of the landing gear. The aircraft core is preferably constructed with curved forward and aft composite spars, that transfer loads across the center section, while accommodating a mid-wing configuration. The aircraft core preferably has a large central cavity dimensioned to interchangeably carry an ordnance launcher, a surveillance payload, electronic countermeasures, and other types of cargo. Contemplated aircraft can be quite large, for example having a wing span of at least 80 ft.

19 Claims, 5 Drawing Sheets



(51) **Int. Cl.**

B64C 1/06	(2006.01)
B64C 39/10	(2006.01)
B64C 39/02	(2006.01)
B64D 37/00	(2006.01)
B64C 1/26	(2006.01)

(52) **U.S. Cl.**

CPC *B64C2211/00* (2013.01); *Y02T 50/12* (2013.01); *Y02T 50/145* (2013.01); *Y02T 50/433* (2013.01)

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Figure 1A (Prior Art)

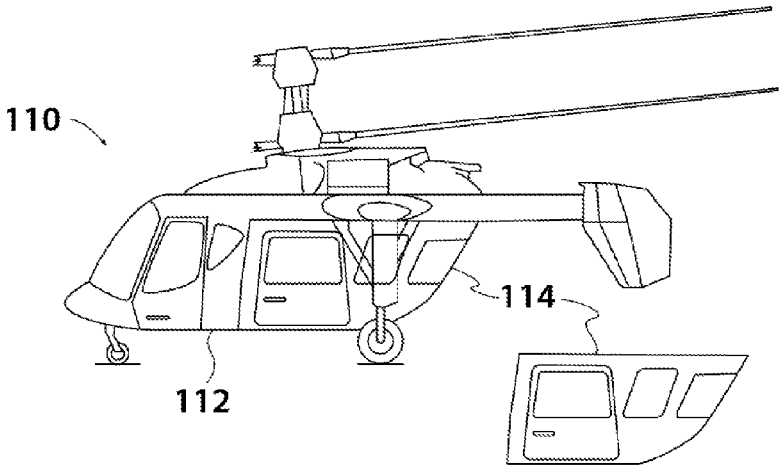

Figure 1B (Prior Art)

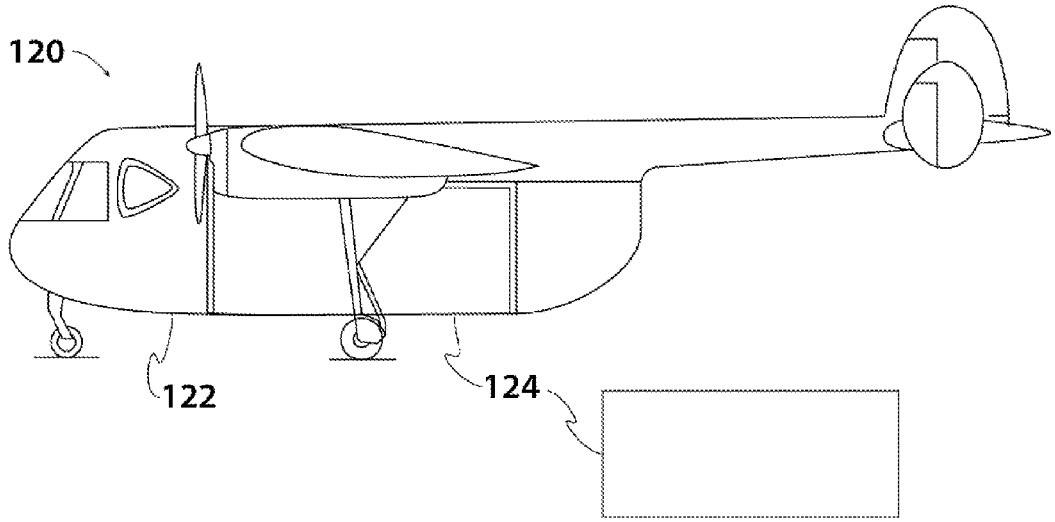

Figure 2

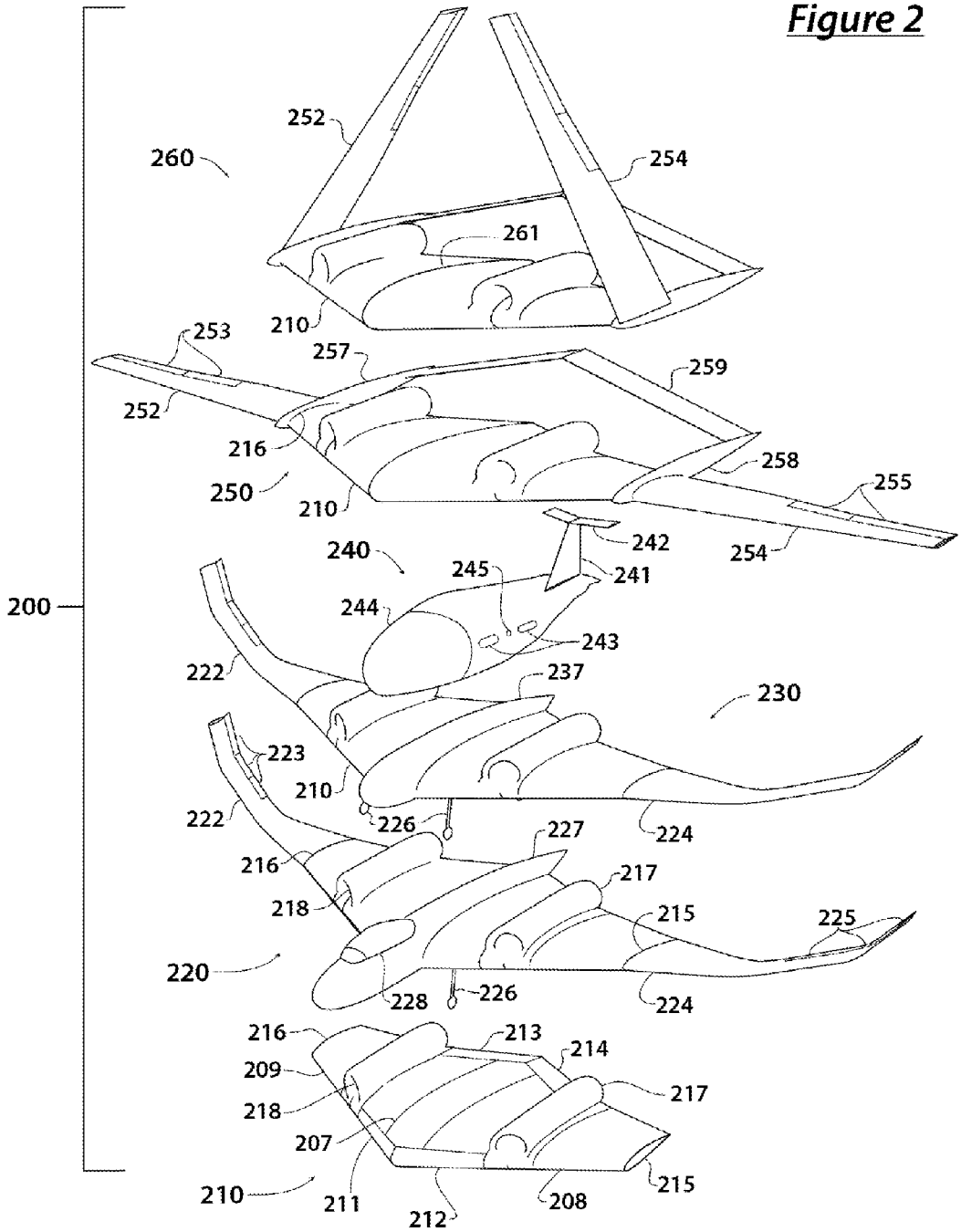
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Figure 3

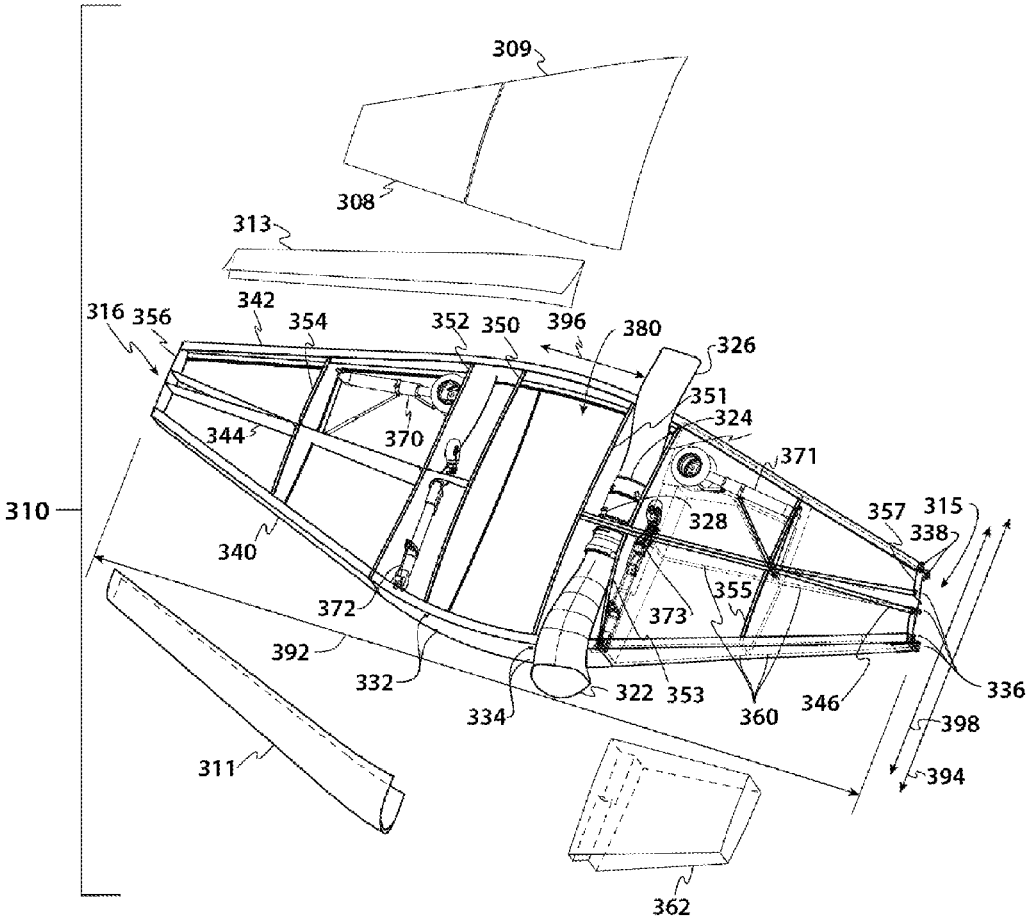
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Figure 4

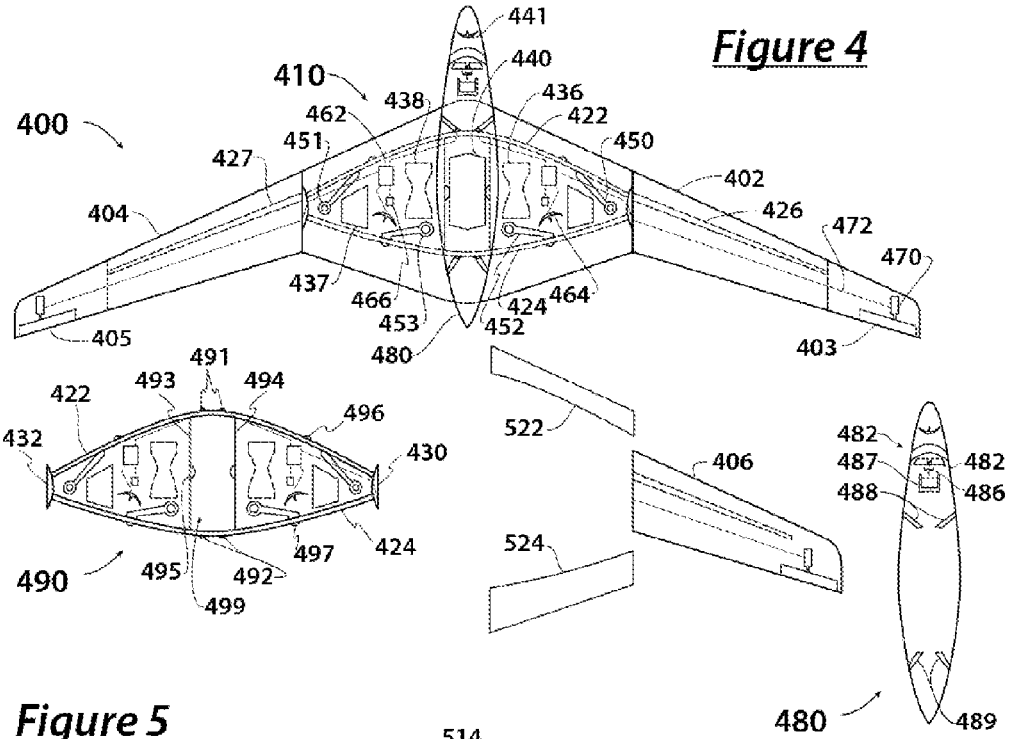


Figure 5

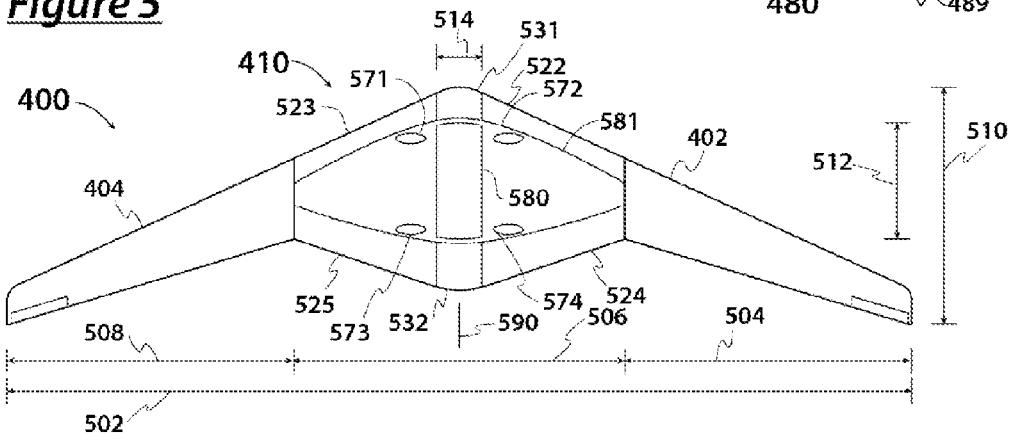
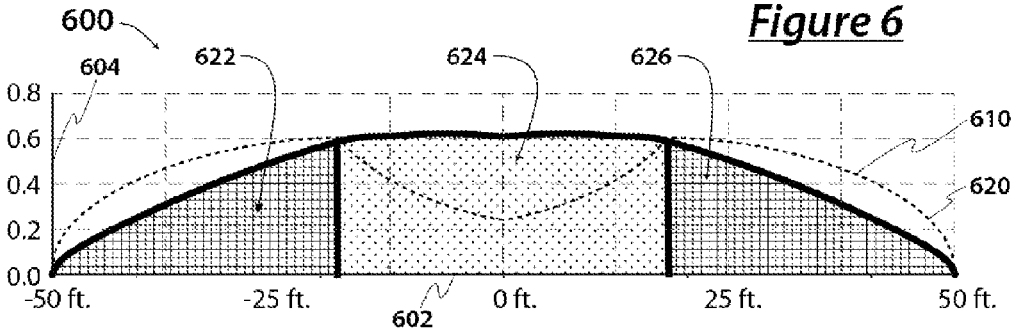


Figure 6



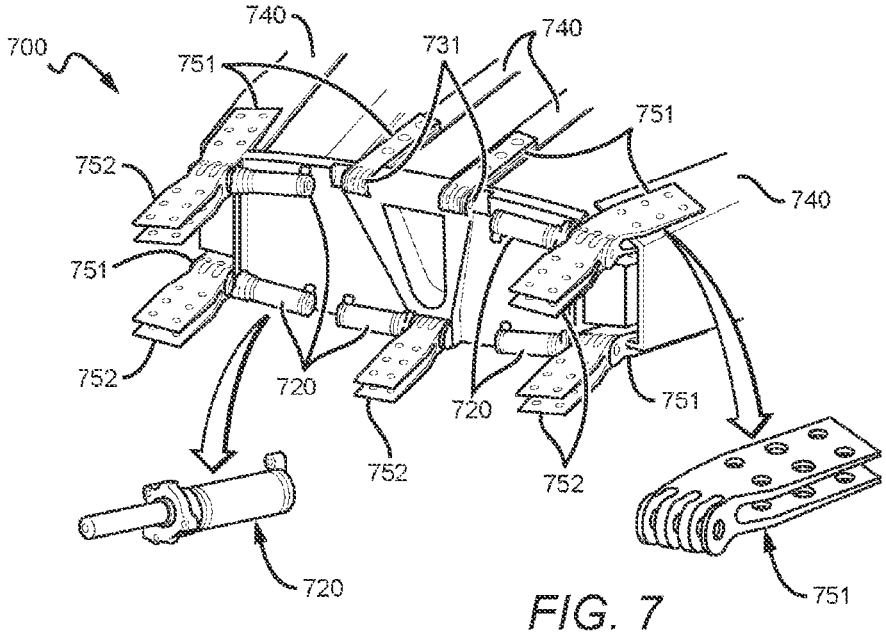

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FIG. 7

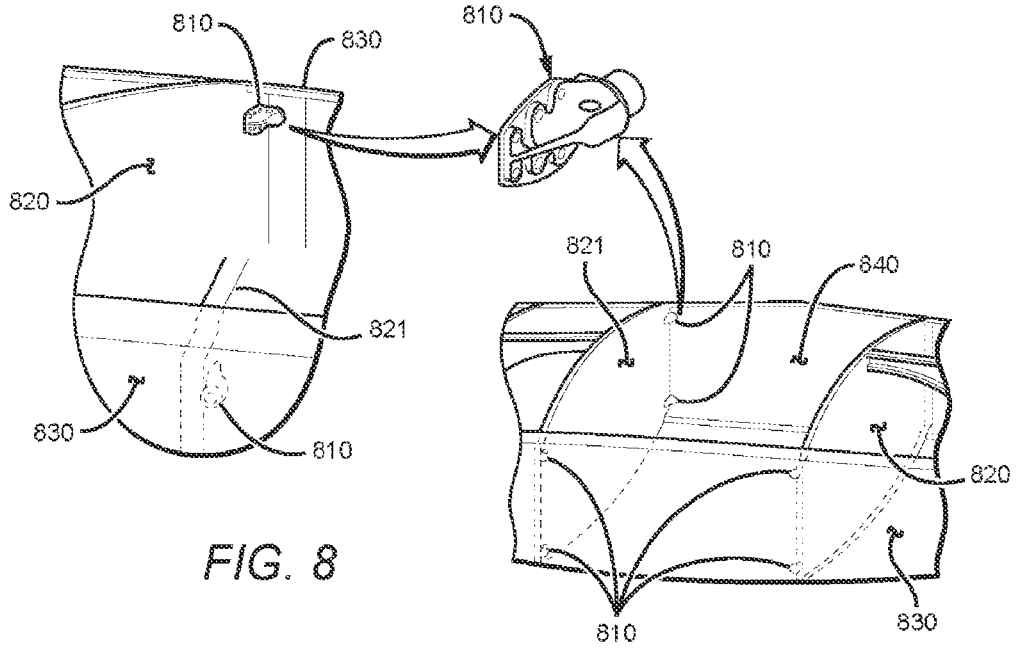
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FIG. 8

MULTI-ROLE AIRCRAFT WITH INTERCHANGEABLE MISSION MODULES

This application claims priority to U.S. Provisional Application No. 61/372,941 filed Aug. 12, 2010, and U.S. Utility application Ser. No. 13/205,870, filed Aug. 9, 2011, each of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The field of the invention is aircraft.

BACKGROUND

Aircraft development is a capital-intensive and usually lengthy process. Further, because the viability of aircraft depends largely on their weight, conservatism in design can have powerful consequences on the viability of an aircraft. As a result of these two factors and other considerations, any given aircraft tends to be specialized for one role or mission during the design process.

At the same time, aircraft are used on and needed for a variety of missions and roles. Aircraft carry different payloads, including for example, passengers, cargo, sensors, and munitions. Beyond payload, other requirements can shape an aircraft design; for example, some missions require flight in a certain speed regime, while other missions require high fuel efficiency.

Prior art approaches to providing aircraft suitable for conducting specific missions tend to either (i) design a distinct aircraft for a specific mission, (ii) adapt an existing aircraft design for another mission through modifications (iii) attempt to bridge multiple missions in the design stage through an a priori requirement.

Each of these three prior art approaches has weaknesses. The first approach, to design a distinct aircraft for a specific mission, is extremely expensive and often impractical. In general, it has the least potential to meet multiple diverse requirements, therefore limiting its market. The second approach, post-hoc adaptation, is often used in adapting aircraft to new missions similar to the original design mission. Even this approach is expensive and time consuming, however. These difficulties arise in part because of formidable certification and qualification requirements. An example of aircraft post-hoc modification is the transformation of the Lockheed L-188 Electra civilian passenger transport into the Lockheed P-3 Orion naval maritime surveillance aircraft. The original mission (passenger transport) and the new mission (maritime surveillance) have similar flight envelope requirements, in terms of speed and altitude.

The third general approach, attempting bridge multiple missions in the design stage through an a priori requirement, often entails extraordinary costs and engineering effort. An example of this approach would be the Lockheed Martin F-35 family of supersonic fighter aircraft, attempting commonality between the F-35B short takeoff and vertical landing (STOVL) platform, the F-35C carrier based fighter platform, and the F-35A land-based conventional takeoff supersonic fighter platform. The F-35 program is renowned for being billions of dollars over budget and years behind schedule; this results at least in part from attempts to achieve high degrees of commonality among the aircraft in the family. The Boeing competitor to the F-35, as described in U.S. Pat. No. 5,897,078 struggled with similar issues in attempting to bridge diverse mission requirements, while still retaining some degree of parts-commonality among variants.

The '078 patent and all other extrinsic materials discussed herein are incorporated by reference in their entirety. Where a definition or use of a term in an incorporated reference is inconsistent or contrary to the definition of that term provided herein, the definition of that term provided herein applies and the definition of that term in the reference does not apply.

In summary, aircraft are sometimes designed to be flexible, yet this by-design flexibility can only go so far. Alternatively, different versions of aircraft are designed for specific needs, users, and missions. Only a few prior art aircraft and aircraft related developments known to the inventor have had elements of modularity, and no known prior art aircraft have achieved complete or even extensive modularity.

A few cargo aircraft have carried their cargo in removable cargo containers. Notably, the Fairchild XC-120 Packplane, Miles M.68 Boxcar, and Kamov KA-226 are the instances known to the inventor. FIG. **1**A illustrates the Kamov KA-226 helicopter **110**, which features a main portion **112** of the aircraft and a removable cargo container **114**, which can be configured to carry passengers. FIG. **1**B is a side view illustration of the Miles M.68 Boxcar **120**, which is a fixed-wing transport aircraft having a main portion **114** of the aircraft, and configured to carry cargo in a removable cargo container **124**.

While these prior art aircraft carry their cargo payload in removable containers, they cannot be said to be truly modular aircraft, because they do not change containers to change missions or roles. These prior art aircraft are really predominantly single-role transport aircraft that happen to carry their cargo in an external container that forms part of the aerodynamic fairing of the aircraft, rather than carrying their cargo in containers internal to the aerodynamic fairing of the aircraft like most air freighters.

Aircraft designed to have large cargo bays also do not lend themselves to modularity because the wings need to have structural support across the fuselage. Such structural supports are either positioned above the fuselage (in a high wing configuration) or below the fuselage (in a low wing configuration). In either of those configurations it is not practical to provide readily replaceable wings.

In a similar vein, but for a different kind of aircraft, U.S. Pat. No. 4,736,910 to O'Quinn is directed to a light fighter aircraft with interchangeable nose and tail sections. U.S. Pat. No. 3,640,492 is directed to aircraft having electronics or avionics equipment in removable portions of the aircraft structure or aerodynamic fairing. U.S. Pat. No. 7,234,667 to Talmage describes the division of an aircraft into sections, any of which could be recovered by parachute following an in-flight incident. U.S. Pat. No. 6,098,927 describes an aircraft with a removable fuselage section to increase or decrease the payload capacity of the aircraft. Related to this idea, the practice of extending or contracting fuselage sections by the addition or removal of fuselage plugs is known in the art, and is commonplace in stretched families of transports, including for example, the Airbus A318, A319, A320, and A321, which are substantially just stretched versions of the same aircraft accommodating 107-220 passengers. Unless the context dictates the contrary, all ranges set forth herein should be interpreted as being inclusive of their endpoints, and open-ended ranges should be interpreted to include only commercially practical values. Similarly, all lists of values should be considered as inclusive of intermediate values unless the context indicates the contrary.

US Patent Application 2008/0017426 describes a somewhat modular ground vehicle, wherein a core vehicle can attach to a variety of interchangeable elements to serve different roles or missions. However, it should be noted that the

field of ground vehicles is substantially different from the field of aircraft, and that aircraft are subject to stricter design constraints. For example, aircraft are highly weight sensitive and aerodynamic drag sensitive and poorly tolerate structural and powerplant inefficiencies, such as those built into the ground vehicle of 2008/0017426 for modularity. A person of ordinary skill in the art would not expect systems and methods that work on ground vehicles to also work on aircraft without significant additional inventive subject matter.

It should be noted that a key constraint for adapting aircraft to serve different roles and missions is the operator interface. As an example, consider the vastly different pilot interfaces found among helicopters, transport aircraft, fighter aircraft, and the ground stations of unmanned aircraft. If an aircraft is to serve multiple roles and missions, it must have a suitable and adaptable interface. This is a formidable challenge, and relatively little known prior art addresses this challenge.

U.S. Pat. No. 5,626,030 to Watson describes a ground-based flight simulator that uses parts of an actual aircraft. However, this reference does not provide a ground control station for an aircraft that is common to a cockpit of an aircraft. U.S. Pat. No. 5,880,669 to Romanoff, et al. also describes an aircraft simulator system, but does not disclose a ground control station for an unmanned aircraft that is substantially identical to a cockpit for a manned aircraft.

Thus, there is still a need for aircraft that are quickly and economically adaptable to different roles and missions, not simply adaptable to different payloads—aircraft that are both modular and multirole.

SUMMARY OF THE INVENTION

The inventive subject matter provides apparatus, systems and methods of a flight-operable, truly modular aircraft.

In a first aspect, a modular aircraft combines an originally deployed wing member that provides at least 15% of the lift during at least some portion of cruise flight, a center section that provides at least 25% of the aircraft during such flight, and has one or both of (a) a forward coupling adapted to couple or decouple a fuselage to the center section during the operational life, and (b) a wing coupling adapted to couple or decouple the wing member during the operational life. Detachable leading and trailing edge couplings can be applied to the center section, and preferably assist in providing lift.

In this first aspect, the fuselage is optional, and where the fuselage is present, it may or may not include a cockpit. Although the aircraft may be shaped as a flying wing, having substantially no empennage, no horizontal tail, and no vertical tail, the optional fuselage may include an empennage, a horizontal tail, and/or a vertical tail.

Modularity can be achieved to a large extent by incorporating many components into the center section. For example, the center section can advantageously contain a propulsive engine, disposed so that it does not extend above or below the center section. In some contemplated embodiments, there are first and second engines disposed on opposite sides of the central cavity. The center section preferably houses at least 80% of all of the fuel, and the aircraft may have a fuel capacity greater than maximum takeoff weight.

The center section can also advantageously include avionics sufficient to operate the aircraft without receiving controls from outside the center section. In some embodiments, it is contemplated that the avionics can operate the aircraft through either or both of ground control and an on-board pilot control. Additionally or alternatively, the center section can include an on-board pilot interface. The center section can also advantageously receive one or more, and preferably all of the retracted landing gear for the aircraft.

In preferred embodiments, the center section is constructed in a manner that produces a centerline central cavity. This can advantageously be accomplished using forward and aft curved composite spars, and right and left inboard ribs. the central cavity can be quite large, for example having a width dimension at least 3% of the span of the aircraft, and a length dimension at least 20% of the length of the aircraft. Not only is the central cavity large horizontally, but it can be large vertically, preferably extending all vertically all the way to the upper skin and lower skins of the aircraft. The central cavity can also advantageously have a cargo dimensioned to interchangeably carry an ordnance launcher, a surveillance payload, and electronic countermeasures.

By placing so much of the flight-critical components in the center section, the wings (or outer wing sections) can be detachable. For example, a detachable wing member having a composite wing spar can couple to the forward and aft spars of the center section using a wing coupling with one or more hardpoints. The wing coupling can carry electrical connections between the center section and the wing member, and in some contemplated embodiments the wings can be hingedly coupled to the center section. Whether or not the wings are detachable, it is contemplated that they can be quite large. For example, aircraft contemplated herein can have a wing span of at least 80 ft, with left and right outer wing members having sufficient stiffness to produce a natural frequency of no less than 6 Hz when airborne.

Other hardpoints are contemplated that removably couple a cockpit module to the center section during an operational life of the aircraft, and that removably couple a tail section to the center section during an operational life of the aircraft.

Various kits are contemplated with one or more of the features discussed above. For example, kits are contemplated that comprise a fuselage, that include a replacement wing member that is not fungible with the originally deployed wing member, that include replacement leading and/or trailing edge portions, and that include center sections having horizontally curved forward and aft composite spars.

In a second aspect, a modular aircraft having originally deployed wing member that provides at least 20% of the lift of the aircraft during at least some portion of cruise flight has (a) center section that includes a centerline cavity, and avionics sufficient to operate the aircraft; (b) a forward coupling adapted to couple or decouple a forward component to the center section during the operational life; and (c) a wing coupling adapted to couple or decouple the wing member during the operational life. The aircraft can have any one or more of the features discussed above.

In a third aspect, a modular aircraft has a center section with a large cargo bay, and left and right wings that are structurally coupled together at least predominantly using supports positioned fore and aft of the cargo bay, rather than above or below the cargo bay. This allows the wings to be coupled to the center section in a mid wing configuration, without adding undue weight to the aircraft. In a preferred mid wing aircraft described below, the cargo bay is at least 6 feet wide, at least 14 feet long, and at least 10 feet high. More preferably, the cargo bay is at least 8, or at least 10 feet wide, independently at least 16, at least 18, or at least 20 feet long, and independently at least 12, at least 14, or at least 16 feet high.

Various objects, features, aspects and advantages of the inventive subject matter will become more apparent from the following detailed description of preferred embodiments,

along with the accompanying drawing figures in which like numerals represent like components.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1**A is a side view drawing of a prior art rotorcraft with a removable cargo container, while FIG. **1**B is a side view drawing of a prior art fixed-wing airplane with a removable cargo container.

FIG. **2** is a schematic perspective illustration of a preferred modular aircraft kit comprising a center section, various outer wing portions, and various mission modules.

FIG. **3** is a perspective exploded view illustration of an alternate preferred aircraft center section showing the supporting structure and key mechanical systems.

FIG. **4** is a schematic top-view illustration of a preferred modular aircraft.

FIG. **5** is a schematic top-view illustration of an alternate configuration of the preferred modular aircraft of FIG. **4**.

FIG. **6** is plot of the lift distribution of the preferred modular aircraft of FIG. **5**.

FIG. **7** is a perspective view illustration of an exceptionally preferred aircraft left interface assembly.

FIG. **8** is a perspective view illustration of an exceptionally preferred forward and aft center section hardpoints.

DETAILED DESCRIPTION

Along with the drawing, the following detailed description serves to elucidate various aspects of the present inventive subject matter.

FIG. **2** is a schematic perspective illustration of a preferred modular aircraft kit comprising a center section, various outer wing portions, and various mission modules.

The modular aircraft kit **200** comprises a center section **210**. The center section **210** advantageously features a left interface **215** for a left outer wing member and a right interface **216** for a right outer wing member. In especially preferred embodiments, the left and right interfaces **215**, **216** are hardpoints configured to allow folding or removal of the outer wing members for compact stowage. The center section **210** is preferably equipped with provisions for propulsive means. A right engine housing **218** and a left engine housing **217** each fair over an inlet, turbofan engine, and exhaust. When coupled to electric power, a flight control system, and a fuel supply, the engine is capable of producing thrust for sustained flight of the modular aircraft. The center section **210** also has a substructure consisting of one or more spars and ribs (not shown). In preferred embodiments, removable aerodynamic or structural elements are attached to this substructure. Center section **210** is equipped with a right leading edge portion **211**, a left leading edge portion **212**, a right trailing edge portion **213**, a left trailing edge portion, and one or more center panels **207**. By removing or replacing the center panels **207** and other interchangeable elements, other mission modules or fuselages can be accommodated. The center section **210** also comprises a right wing member **209** and a left wing member **208** for generating lift. Internal to the center section **210** are a number of aircraft systems essential to flight.

A preferred manned aircraft **220** is advantageously composed of elements of the modular aircraft kit **200**. A center section **210** is configured to support a fuselage **227** featuring a cockpit **228**. The cockpit **228** advantageously includes provisions for a human pilot including an ejection seat, flight controls, an environmental control system, avionics, a clear windscreen or canopy, and instrumentation. The center section **210** supports a right outer wing member **222** comprising right control surfaces **223** attached at the right interface **216** for an outer wing in a manner that supports folding of the right outer wing member **222**. Similarly, the left outer wing portion **224** has left control surfaces **225** and is attached at the left interface **215** with the center section. The preferred manned aircraft **220** has no tail surfaces, empennage, horizontal tail, or vertical tail. All aircraft control is affected via control surfaces **223**, **225** located on the right and left outer wing members **222**,**224**. Also shown is landing gear **226** in an extended position, which advantageously retracts into the center section. To install the fuselage **227**, which can be viewed as a mission module, the center panel **207** and other parts of the center section are removed (or alternately, are never installed) from the center section **210**. The fuselage **227** is structurally attached at hardpoints (not shown) and electrical connections are made facilitate power and data signals between the fuselage **227** and center section **210**. Similarly, electrical connections are made between the outer wing members **222**, **224** and the center section **210**. In preferred aircraft, control surfaces **223**, **225** are electrically actuated, but other actuation means such as hydraulic, mechanical, and pneumatic are also contemplated.

A preferred unmanned aircraft **230** is also composed of elements of the modular aircraft kit **200**. In this case, the center section **210** is configured to support a mission module **237** advantageously containing payload and mission equipment, including, for example, elements selected from the list containing sensors, cameras, cargo, munitions, fire suppressant, datalinks, antennas, and radio communications equipment. The same outer wing portions **222**, **224** are attached to the center section **210** as for the manned aircraft **220**. Indeed, the only difference between unmanned aircraft **230** and manned aircraft **220** is the selection and installation of mission module **237** and fuselage **227**, respectively. Unmanned aircraft **230** features the same landing gear **226**, engines, control surfaces, and systems as manned aircraft **220**. Unmanned aircraft **230** is advantageously equipped with a flight control computer containing flight control laws allow autonomous flight without human intervention. Unmanned aircraft **230** is also advantageously equipped with one or more datalinks (not shown) mounted in the mission module **237** or center section **210** allowing control via remote ground control station (not shown). Some preferred aircraft may comprise elements of U.S. application Ser. No. 11/506,571.

In preferred modular aircraft kits, other (not originally deployed) mission modules would also be installable in the center section **210**. For example, a cargo module **240** would interface with center section **210** via structural hardpoints **243** and an electrical interface **245**. The cargo module **240** could comprise a hatch portion **244** for loading or unloading cargo, and an empennage comprising a vertical tail **241** and a horizontal tail **242**. Other cargo modules are also contemplated with no empennage wherein all flight control and stability assurance are obtained via control surfaces located on outboard wing portions.

An alternate unmanned aircraft **250** is also composed of elements of the modular aircraft kit **200**. In this case, the center section **210** has no fuselage or mission module attached or mounted to it. Instead, all mission equipment is stowed internal to the center section **210**, accessible via removable panels or hatches. In this manner, the drag of the central portion of the aircraft is reduced because there is no fuselage or mission module creating additional frontal area. Alternate unmanned aircraft **250** comprises a different right outboard wing portion **252** and a different left outboard wing portion **254** from corresponding components of aircraft **220** and **230**. These wing portions **252**, **254** can be seen to be

substantially entirely flat, not having dihedral or curvature out of plane. Right control surfaces **253** are mounted on the right outboard wing portion **252**, while left control surfaces **255** are mounted on the left outboard wing portion. Additionally, a right boom **257** is also attached at the right interface **216** with the center section. The right boom **257** cooperates with a left boom **258** to support an optional empennage **259** for providing pitch and directional stability and control to the aircraft **250**. The outboard wing portions **252**, **254** are attached to center section **210** by means of folding mechanisms.

The folded alternate unmanned aircraft **260** allows for compact stowage. Here, the right wing portion **252** and left wing portion **254** are rotated up over the center section **210** such that the wing tips approach the aircraft centerline **261**.

Whether manned, unmanned, with folding wings or without folding wings, preferred aircraft have a mid-wing configuration, which is used herein to mean that the wings are other than in a high or low position on a fuselage (in our case the center section). As used herein, a low-wing configuration has the left and right wing sections structurally coupled at the bottom of or below the fuselage, and a high-wing configuration has the left and right wing sections structurally coupled at the top of or above the fuselage.

Thus, it is seen that any manner of workable variations can be achieved by substituting various elements of the modular aircraft kit **200**. Outer wing portions of different spans, taper ratios, sweeps, airfoils, and planforms can be substituted to tailor aircraft performance to intended missions. It is contemplated that some outer wing portions can have different control surface configurations, with any suitable number of slats, plain flaps, slotted flaps, or split flaps. Some outer wing portions could advantageously be equipped with large embedded antennas as needed for certain missions. Similarly, any number of various fuselages or mission modules could be coupled to the center section **210**. Such fuselages or mission modules could accommodate varied payloads with different sizes and packing requirements, including, for example, passengers, pallets, munitions, radars, and RF jamming equipment. In especially preferred modular aircraft kits, the essential systems for aircraft functioning are contained in the center section **210** to allow for rapid reconfiguration. In this manner, the flight control computer, standard communications equipment, navigation sensors, fuel tanks, fuel pumps, generators, electric power system, and engines are located within the center section **210**. With contemplated mode of modular operation, an aircraft could begin its operational life with one set of originally deployed outer wing members, and then exchange them for another, non-fungible set of outer wing members selected from an aircraft kit **200**.

One list of contemplated missions for a single aircraft with interchangeable mission modules includes: aerial mapping, maritime patrol, police surveillance, aerial spraying, air ambulance, air interdiction, close air support, ground strike, light water bomber for firefighting, refrigerated cargo, cargo accommodations with a roller floor and tie downs, combination cargo and passenger transport, air drop cargo, standard passenger transport, luxury passenger transport, communications relay, radio frequency signal jamming or interception, missile launch, and small vehicle launch.

FIG. **3** is a perspective exploded view illustration of an alternate preferred aircraft center section **310** showing the supporting structure and key mechanical systems. The alternate preferred aircraft center section **310** comprises a supporting substructure, including a forward spar **340**, an aft spar **342**, a right center spar **344**, a left center spar **346**, right and left inboard ribs **350**, **351**, right and left second ribs **352**, **353**, right and left third ribs **354**, **355**, and right and left outboard ribs **356**, **357**. In this preferred embodiment, both the forward spar **340** and aft spar **342** are curved and run between a left interface **315** of the center section **310** and a right interface **316**. These spars serve as the primary structural members to react forces generated by lifting surfaces on the center section **310** and from outboard wing members (not shown).

The forward spar **340**, aft spar **342**, right inboard rib **350**, and left inboard rib **351** define a central cavity **380** that can accommodate payloads or cargo, and has unobstructed access both upward and downward in a conventional flight orientation (when no skin panels, mission modules, or fuselage modules block this access). This upward and downward access is useful for sensor range of sight, launching munitions, maintenance access, air drop of cargo, and installation of fuselage modules or payloads that require a depth dimension greater than the maximum depth of forward and aft spars **340**, **342**. The central cavity **380** has a centerline cavity length **398** and a maximum cavity width **396**. Notably, to achieve the open central cavity **380**, the right center spar **344** must terminate at the right inboard rib **350** while the left center spar **346** terminates at the left inboard rib **351**. One of ordinary skill in the art would not contemplate a discontinuous center spar, because the highest bending moments and stresses occur near the center of a wing structure. Normally, structural members have the greatest dimensions (height, depth, and thickness) where bending moments and stresses are highest because this yields a more efficient and lower weight structure. Termination of major structural member (such as the left and right center spars **344**, **346**) at the point of greatest bending moment does not follow from best engineering practices. At its outer extent, near the right interface **316** of the center section **310**, the right center spar **344** splits into a y-shape to better support a right outer wing portion.

Overall, the center section has a center span **392** between the left interface **315** and right interface **316**. Depending on the nature of the outer wing portions (not shown) selected for attachment to the center section **310**, the assembled aircraft can have a total span that is substantially greater than the center span **392** of the center section **310**, including, in preferred embodiments, an overall span that is 2×, 2.5×, 3×, 3.5×, or even 4× the span **392** of the center section **310**. The substructure of the center section **310** also has a substructure length **394** between the aftmost portion of the aft spar **342** and the foremost portion of the forward spar **340**. In preferred embodiments, the substructure length **394** is greater than the cavity length **398** and between 1.25×, 1.5×, 1.75×, 2×, 2.5×, and 3× the cavity width **396**. In this instance, and where other upper limits are not expressly stated, the reader should infer a reasonable upper limit. In this instance, for example, a commercially reasonable upper limit is about 5× the cavity width.

The substructure of the center section **310** advantageously supports aerodynamic fairing elements including a right leading edge portion **311**, a right trailing edge portion **313**, and upper surface skin panels **308**, **309**. These fairing elements cooperate to serve as a portion of the center section **310** for generating lift, having a total area (left and right sides) at least equal to the product of the cavity length **398** and cavity width **396**.

The center section **310** and its substructure also carry a variety of systems essential to the functioning of an aircraft. In preferred embodiments, the center section **310** supports at least one engine inlet **322**, a left side engine **324**, a generator **328**, and an exhaust duct **326**. For clarity, in FIG. **3**, only the left side engine **324** is shown. Cooperatively, the left side engine **324** and right side engine (not shown) provide adequate thrust to sustain level flight of an assembled aircraft. In some preferred embodiments, the left and right engines

cooperate to provide a maximum thrust that is not greater than 20%, 30%, 40% or 50% of the maximum takeoff weight of the aircraft. In some preferred embodiments, the engine **324** is installed in such a manner that it does not extend above or below the center section **310**, even if portions of an inlet or exhaust might extend above the center section. Additionally, a set of left fuel tanks **360** and right fuel tanks (not shown) provide fuel supply to the aircraft engines. An exemplary fuel tank **362** is supported by a combination of spars, ribs, and skin panels when installed in the center section **310**. In some preferred embodiments, the total fuel capacity of the aircraft in pounds is greater than the maximum takeoff weight of the aircraft in pounds. Preferred aircraft are also equipped with a four leg landing gear system entirely housed in the center section **310** when retracted, and comprising a right main leg **370**, a left main leg **371**, a right nose leg **372**, and a left nose leg **373**. The left and right nose legs **372**, **373** provide a steering capability.

For modularity, the center section **310** is advantageously constructed to support interchangeable mission modules, fuselages, and outer wing portions. In preferred embodiments, a left outer wing portion (not shown) is supported by a folding system including a set of right forward folding attachments **336** and right aft folding attachments **338** that rotatably support an outer wing portion, and react the considerable flight bending moments generated by an outer wing portion into the forward spar **340**, aft spar **342**, and left center spar **346**. The center section **310** also supports a variety of mission modules or fuselages by means of hardpoints **332**, **334** that allow mission modules to be mechanically fastened in a manner that facilitates quick disconnection and reconnection while still reacting loads.

In especially preferred embodiments, the aft spar **342**, forward spar **340**, and center spars **344**, **346** are of carbon-epoxy composite construction. The caps of the forward spar **340** and aft spar may comprise high modulus carbon fibers in pultruded form. Hardpoints **332**, **334** and folding attachments **336**, **338** are preferably constructed of high strength metal including for example titanium or steel.

FIG. **4** is a schematic top-view illustration of a flight-operable, modular aircraft **400** having an operational life. Some contemplated operational lives include 2000 hours 3000 hours, 5000 hours, 10000 hours 20000 hours, 30000 hours, 50000 hours, of flight time. An aircraft center section **410** couples to a right outer wing member **402** and a left outer wing member **404**. The outer wing members installed at the start of the aircraft's operational life are said to be originally deployed. The left and right outer wing members are advantageously each sized and configured to provide at least 12, 15, 20, 25, 30, or 35% of the total lift of the aircraft during at least some portion of substantially straight and level cruise flight. In preferred embodiments, the center section **410** is shaped and configured to produce at least 20, 25, 30, 35, 40, and 50% of the total lift of the aircraft during the same portion of the cruise flight. An aircraft flight will typically comprise takeoff, climb, cruise, an optional loiter, cruise, descent, and landing in sequence. A cruise flight condition means sustained self-powered flight at a given cruise altitude and cruise speed. Contemplated cruise altitudes include 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, and 65 thousand feet above sea level. Contemplated cruise speeds correspond to Mach numbers of 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, and 0.9.

The right outer wing member **402** comprises a spar **426** for structural support, a control surface **403** to assist in trim and control of the modular aircraft **400**, an actuator **470** to drive the control surface **403**, and wiring **472** to carry power and command signals from a flight control computer **462** located in the aircraft center section **410**. In some preferred embodiments, the originally deployed left outer wing member **404** is substantially a mirror image of the originally deployed right outer wing member **402**, and also comprises a left control surface **405** and left spar **427**. It is contemplated that preferred modular aircraft **400** could exchange an originally deployed right outer wing member **402** a replacement right outer wing member **406** that is not fungible with the originally deployed right outer wing member **402**. At the same time, flight control laws, as codified and executed in the flight control computer **462**, would adapt to this change of wing members as necessary.

The center section **410** is built around an aircraft core **490**, an element advantageously configured to enable aircraft system modularity. The aircraft core **490** comprises a forward curved spar member **422**, an aft curved spar member **424**, and left and right hardpoints **432**, **430** that accommodate attachment of outer wing members, folding of outer wing members, and are located in the immediate vicinity of connections for electrical power or signals for powering the outer wing members. The hardpoints **430**, **432** serve as wing couplings adapted to couple or decouple outer wing members **402**, **404** during the operational life of the aircraft. The right wing hardpoint **430** can be viewed as a coupling that carries load between a composite spar **426** of the detachable right outer wing member **402**, and the fore and aft curved spars **422**, **424**, respectively. The hardpoints **430**, **432** can also be advantageously configured as hinges to allow folding of the outer wing members **402**, **404** for compact stowage. The aircraft core **490** is also advantageously equipped with forward hardpoints **491** that serve a forward coupling adapted to couple or decouple a fuselage or mission module to the center section **410** during the operational life. In preferred embodiments, the forward hardpoints **491** are attached to the curved forward spar **422**. Aft hardpoints **492** may cooperate with forward hardpoints **491** in supporting or coupling a fuselage **480**, mission module, or payload to the aircraft core **490** and center section **410**.

The preferred modular aircraft **400** is optionally equipped with a fuselage **480**. Preferred fuselages **480** are optional and can be coupled or decoupled from the aircraft during the operational life. Fuselage **480** is equipped with a cockpit **482** comprising an on-board pilot interface and means for on-board pilot control, including instrumentation and display screens **482**, inceptors **486**, and an ejection seat **487**. Fuselage **480** is equipped with forward mounts **488** and aft mounts **489** which couple to aircraft forward hardpoints **491** and aft hardpoints **492** to support the optional/removable fuselage **480**, and allow the installation or removal of the fuselage in less than two hours. Other fuselages or mission modules are contemplated, including those without cockpits or means for on-board pilot control, which can couple to the aircraft **400** using the same forward and aft hardpoints **491**, **492** such that fuselages can be changed out during the operational life of the aircraft **400**. In preferred embodiments, the fuselage coupling or the wing coupling that attaches the right outer wing member **402** to the center section **410** also carries electrical connections. In especially preferred embodiments, a quick disconnect connector is located within two feet of a structural hardpoint. Some preferred fuselages **480** or mission modules are equipped with a targeting system **441** such as a radar that is operable by each of a pilot in the cockpit and also by a ground controller.

It is further contemplated that in some especially preferred embodiments, mission modules need not be a single-piece fuselage. The modular nature of the aircraft core **490** having

a series of couplings and hardpoints allows it to be viewed as a multi-way receptacle for accessories, including a nose portion of a mission module that could attach to forward hardpoints **491** or other couplings, a tail portion of a mission module that could attach to aft hardpoints **492** or other couplings, optionally a central portion of a mission module, skin panels, a first outer wing portion, a second outer wing portion, and various leading edge and trailing edge pieces. In this manner, mission equipment and mission modules can be rapidly tailored to meet emerging needs, without the requirement of having to change an entire fuselage. In some instances, only the nose portion of a fuselage or mission module might be interchanged, for example to accommodate an alternate targeting system **441**.

The aircraft core **490** also has a leading edge coupling **496** to support attachment of a removable leading edge **522**, and a trailing edge coupling **497** to support attachment of a removable trailing edge **524**. This enables coupling or decoupling right and left leading edge portions during the operational life of the aircraft, where the leading edge portions are configured to assist in providing lift to the aircraft during the at least some portion of cruise flight. The center section **410** of the aircraft **400** comprises an aircraft core **490** as well as a leading edge fairing **522** and trailing edge fairing **524**. The aircraft core **490** comprises a right engine **436** and a left engine **438** which cooperate to provide a propulsive force for the aircraft. In preferred embodiments, the engines **436**, **438** are installed such that they do not extend above or below the center section **410** skin surfaces. A preferred installation of the right engine **436** involves support from a right inboard rib **494** or from an upper surface extension of a right center spar that does not extend across the central cavity **499** such that the engine that is not structurally supported from directly below the engine.

It is thus seen that, in some preferred embodiments, the central cavity **499** of the aircraft core **490** can be viewed as an open bay entirely inside the aircraft, and supported on only four sides by a fore and aft spar and left and right inboard ribs. In such instances, the central cavity **499** is free from supporting structural members such as spars running laterally across, through, above, or below the central cavity **499**. While many such aircraft could benefit from such structural supporting members to provide strength and stiffness near the centerline of the aircraft where bending moments are high, the present inventive subject matter contemplates eliminating all such supporting members in order to create a flexible and modular central cavity **499** which can accommodate any manner of payloads. In preferred embodiments, even skin or door surfaces which may be installed above or below the central cavity **499** to provide an aerodynamic fairing for reduced drag, are non-structural, and carry no more than 2% or 5% of the total bending moment across the centerline of the aircraft.

The aircraft core **490** also contains one or more flight control computers **462**, and one or more sensors **466**, and communications that cooperate to serve as avionics sufficient to operate the aircraft without receiving controls from outside the center section **410**. Preferred aircraft **400** have center sections **410** that contain substantially all of the avionics functionality and are advantageously equipped with fault-tolerant flight control computers and redundant sensors that communicate via an aircraft network bus. Preferred aircraft are also advantageously equipped with one or more communications devices **464**, including for example, line-of-sight datalinks, voice radios, beyond-line-of-sight datalanks, transponders, satellite communications radios, and other data radios. In preferred embodiments, the communications devices **464** allows for receiving communications and commands from off-board persons or devices as well as the transmission of flight data and sensor data to off-board persons or devices. In some contemplated aircraft, the flight control computers **462** are capable of receiving inputs or commands from either or both on-board pilot control and ground control such as a ground station. In instances where the flight control computers **462** receive input from both off-board and on-board pilots, the flight control computers **462** advantageously act as an arbiter to determine which set of inputs drive the vehicle core flight control. In especially preferred embodiments, the aircraft core **490** is equipped with substantially all of the systems content required to fly the aircraft **400** except for flight control surfaces and their actuation. This segregation of systems content helps enable overall aircraft modularity.

The aircraft core **490** is further advantageously equipped with left and right forward landing gear **451**, **450** and left and right aft landing gear **453**, **452** that attach to ribs or spars **422**, **424** via hardpoints. These four landing gear members are preferably retractable and are advantageously configured to retract into the center section **410** such that they do not extend further forward of the forward curved spar **422** or further aft of the aft spar **424**, and are entirely bounded by the structural elements and skins of the center section **410** when in the fully retracted position. Some preferred aircraft cores **490** resemble a trapezoid, resulting from the cooperation of the forward curved spar **422**, aft curved spar **424**, right hardpoint **430**, left hardpoint **432**, and left and right inboard ribs **493**, **494** in providing structural support for the aircraft's operations.

The aircraft core **490** is advantageously equipped with a fuel supply **437** such as one or more fuel tanks operationally coupled to the propulsive engines **436**, **438**. The total fuel supply is preferably distributed both to the right and the left of the central cavity **499**, and the engines **436**, **438** are preferably disposed on either side of the central cavity **499**. It is contemplated that the fuel supply **437** can be sized and configured to house at least 80% or at least 90% of the aircraft total fuel and be housed entirely within the bounds of the aircraft center section.

In preferred embodiments, the horizontally curved forward spar **422** and horizontally curved aft spar **424** are major structural elements bridging the loads generated by left and right outboard wing members **404**, **402**. Each of the two carries at least 30% and at most 70% of the bending load during at least some portion of substantially straight and level cruise flight. In especially preferred embodiments, the spars **422**, **424** are made of carbon-epoxy composite and are constructed in pre-curved molds and run continuously and laterally between a right wing coupling **430** and a left wing coupling **432**. A right inboard rib **494** and left inboard rib **493** run longitudinally between the forward spar **422** and the aft spar **424**. The aircraft core **490** thus comprises forward and aft curved composite spars **422**, **424**, and right and left inboard ribs **493**, **494**, the spars and ribs operatively coupled to provide the centerline central cavity **499**.

With reference to both FIG. **4** and FIG. **5**, which depict different configurations of the same flight-operable modular aircraft **400**, the central cavity **499** has a width dimension **514** and a length dimension **512** as well as a depth and an internal volume. In preferred embodiments, the width dimension **514** is at least 3%, 4%, 5%, 7%, or 9% of the total span **502** of the flight-operable modular aircraft **400**, and at most 10%, 15%, or 20% of the span **502**. The length dimension **512** is at least 15%, 20%, 25%, 30%, 40%, 50% or 60% of the total length **510** of the aircraft **400** and at least 70% of the length of the aircraft core **490**. In preferred embodiments, the central cavity has a cargo coupling **495** that is configured and dimen-

sioned to carry an interchangeable payload **440**. Contemplated interchangeable payloads include an ordnance launcher, a surveillance payload, electronic countermeasures, and other sensors, RF equipment, and munitions.

FIG. **5** is a schematic top-view illustration of an alternate configuration of the preferred modular aircraft of FIG. **4**, without the optional fuselage **480** installed and without showing many of the internal systems contained in the aircraft core **490**. In this view, the aircraft **400** is equipped with no fuselage, a right outer wing member **402**, a left outer wing member **404** removable leading edges **522**, **523** and removable trailing edges **524**, **525**. A payload is carried in the internal central cavity **499**. The internal central cavity **499** is preferably covered by one or more non-structural skin panels **580** such that the central cavity **499** has no overhead structural support. In preferred embodiments, there is no structural support above or below the central cavity **499**. In some embodiments, the bottom of the internal cavity may be covered by moving payload doors. Preferred central cavities **499** extend vertically to an upper skin and a lower skin or non-structural payload doors. Other portions of the aircraft core **490** may be covered by one or more skin panels **581**. The skin panels **581** may have provisions for engine inlets **571**, **572** and engine exhausts **573**, **574** that cooperate to allow air to flow through engines **436**, **438** even if the engines **436**, **438** have a buried installation and are housed between the upper and lower skins of the center section **410**.

The aircraft **400** has a total span **502** that is the sum of a center span **506** associated with the center section **410**, a right span **504** associated with the right outer wing member **402** and a left span **508** associated with the left outer wing member **404**. The center section extends laterally between the left and right attachments for the outer wing members **402**, **404**. Left and right are defined relative to a centerline **590** of the aircraft **400**. Preferred total spans of the aircraft are between 30 and 180 feet, between 50 and 160 feet, between 70 and 140 feet, and between 90 and 130 feet, or least 80 feet, or at least 100 feet. Due to the modular nature of the aircraft **400**, the total span **502** of the aircraft **400** can change during its operational life.

It is contemplated that, despite the considerable total span as described above, some preferred aircraft **400** can be constructed in such a way that the overall vehicle, comprising forward and aft curved composite spars **422**, **424** and right and left outboard wing members **402**, **404** has sufficient stiffness to produce a natural frequency of no less than 5 Hz or no less than 6 Hz when airborne. This high structural stiffness can advantageously delay or prevent aeroelastic flutter from occurring.

As shown, the aircraft **400** of FIG. **5** is shaped as a flying wing, having substantially no empennage, no horizontal tail, and no vertical tail. Some preferred aircraft are substantially flat, having a dihedral or anhedral of no more than ten degrees, and a maximum thickness-to-chord ratio of no more than thirty percent. Elements of FIG. **4** and FIG. **5** could be combined to form a kit. One exemplary kit could comprise a flight-operable modular aircraft **400** without an originally deployed fuselage, as well as an optional/removable fuselage **480**, a right outer wing member **406** that is non-fungible with an originally deployed right outer wing member **404**, and a leading edge portion **522**.

In preferred embodiments, the wing coupling that attaches the right outer wing member **402** to the center section **410** also carries electrical connections. In especially preferred embodiments, a quick disconnect connector is located within two feet of a structural hardpoint.

FIG. **6** is plot of the lift distribution of the preferred modular aircraft of FIG. **5** at a cruise flight condition. The horizontal axis **602** extends from the left semi-span of the aircraft **400** to the right semi-span of the aircraft **400**. The vertical axis **604** is non-dimensional and represents the local lift coefficient for curve **610** and the product of local chord and local lift coefficient divided by the chord at the right extent of the center section ($c \times c_l / c_{ref}$) for curve **620**. Curve **620** is proportional to dimensional local lift at a wing section. Thus, shaded area **622** represents the total lift generated by the left outer wing member **404**, shaded area **626** represents the total lift generated by the right outer wing member **402**, and shaded area **624** represents the total lift generated by the center section **410**. In preferred embodiments where the aircraft **400** is a flying wing, substantially all of the lift is generated by these three sections together. In especially preferred embodiments, the center section generates between 30% and 70% or between 40% and 60% of the total lift of the aircraft during sustained flight at a substantially straight and level cruise condition.

FIG. **7** is a perspective view illustration of an exceptionally preferred aircraft left interface assembly **700**, **215** or **315** of center section **210**, **310** or **410** and a modular outer wing section **224**, **254** or **404**. The multi-shear, steel or titanium fittings **751**, **752**, shown as hardpoints and folding attachments **336**, **338** or **432** carry loads from the outboard modular outer left wing to the center section. The inboard fittings **751** are permanently fastened to the inboard spars **740** and the outboard fittings **752** are permanently fastened to the outboard spars. The inboard fittings **751** and outboard fittings **752** are mechanically fastened via reusable attachment hardware. Each inboard and outboard fitting pair is joined via a pin which is rapidly inserted to or extracted from the fittings **751**, **752** via a hydraulic actuator **720**. Extraction of the hydraulic pins **720** from the fittings **751**, **752** allows the especially preferred outer left wing module **224**, **254** or **404** to fold. Removal of two additional pins **731** allows complete removal or replacement of the outer left wing module. All hardware used to fold, remove and assemble the outer left wing is reused for the continued operation of the aircraft; no hardware is modified, repaired or discarded as part of the folding, removal of replacement.

FIG. **8** is a perspective view illustration of an exceptionally preferred embodiment of forward and aft hardpoints **810**, **332**, **334**, **491** or **492** of center section **210**, **310** or **410**. Four of the aluminum or titanium hardpoints **810** are located on the forward curved spar **830**, **340** or **422** and four (preferably identical hardware) are located on the aft curved spar **840**, **342** or **424**. Each attachment is permanently fastened to the primary structure via the forward **830** or aft **840** spar and the left inboard rib **820**, **351** or **493** or the right inboard rib **821**, **350** or **494**. The front and aft hardpoints provide for attachment and removable of fuselage **480** and provide for attachment and removable of an interchangeable payload **440** in the aircraft open central cavity **380** or **499** via reusable attachment hardware. All hardware used to remove and assemble the fuselage is reused for the continued operation of the aircraft; no hardware is modified, repaired or discarded as part of the removal of replacement.

At a nominal, non-accelerating cruise flight condition, the aircraft lift is approximately equal to its weight. If the aircraft is not refueled or resupplied in flight, the weight in cruise is less than the weight at takeoff. Aircraft conventionally have a maximum takeoff weight, which is the greatest weight at which the aircraft can safely takeoff. Under normal operation, without refueling or resupply, the aircraft weight will continuously decrease until landing as fuel is burned. Powered aircraft are conventionally equipped with a fuel supply

capable of holding a maximum quantity of fuel. It is contemplated that some preferred aircraft **400** without provisions for aerial refueling could be equipped with a fuel supply **437** sized and dimensioned with fuel capacity greater than maximum takeoff weight. In this manner, the aircraft would be not be able to takeoff with its fuel supply **437** filled to capacity. One of ordinary skill in the art simply would not think of over-sizing the fuel supply to such a degree, because there is no perceptible benefit. The present inventive subject matter, however, contemplates that an aircraft core **490** could accommodate future growth of an aircraft **400** in this manner.

It should be apparent to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the appended claims. Moreover, in interpreting both the specification and the claims, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "comprises" and "comprising" should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Where the specification claims refers to at least one of something selected from the group consisting of A, B, C . . . and N, the text should be interpreted as requiring only one element from the group, not A plus N, or B plus N, etc.

What is claimed is:

1. A flight-operable, modular aircraft comprising:

a center section having a cargo bay, and fore and aft spars positioned fore and aft of the cargo bay, respectively; and

left and right wings that are structurally coupled together at least predominantly through the fore and aft spars;

wherein the center section provides a least 25% of the lift of the aircraft during at least some portion of cruise flight the aircraft has a wing span of at least 80 ft, and has left and right wings having sufficient stiffness to produce a natural frequency of no less than 6 Hz.

2. The aircraft of claim **1**, wherein the wings are coupled to the center section in a mid-wing configuration.

3. The aircraft of claim **1**, wherein the wings are coupled to the fore and aft spars using reusable attachment hardware comprising at least one of pins and bolts.

4. The aircraft of claim **3**, wherein the wings are folding wings.

5. The aircraft of claim **1**, wherein the center section having a cargo bay that is structurally open to top and bottom, and is bounded forward and aftward by the fore and aft spars, respectively.

6. The aircraft of claim **1**, further comprising left and right ribs structurally coupled to the fore and aft spars, and wherein the cargo bay is bounded by the fore and aft spars, and the left and right ribs.

7. The aircraft of claim **1**, wherein the fore spar has hard points for connecting a nose section, and the aft spar has hard points for connecting a tail section, and each of the hard points uses at least one of pins and bolts.

8. The aircraft of claim **7**, wherein bending loads resulting from the nose and tail section are structurally carried by left and right ribs.

9. The aircraft of claim **1**, wherein the fore spar extends across an entire first width of the center section.

10. The aircraft of claim **9**, wherein the fore spar is curved across the entire first width, and comprises a composite material.

11. The aircraft of claim **9**, further comprising an aft support that includes comprises a second curved spar that extends across an entire second width of the center section.

12. The aircraft of claim **1**, further comprising right and left inboard ribs, and wherein the center section has a trapezoidal shape defined by the right and left inboard ribs and the fore and aft spars.

13. The aircraft of claim **1**, wherein the fore spar is curved across an entire first width of the center section, the aft spar is are curved across an entire second section.

14. The aircraft of claim **1**, wherein the aircraft is shaped as a flying wing, having substantially no empennage, no horizontal tail, and no vertical tail.

15. The aircraft of claim **1**, wherein the center section includes an engine that provides a propulsive force for the aircraft, and wherein the engine does not extend above or below the center section.

16. The aircraft of claim **1**, wherein center section includes avionics capable of operating the aircraft through both ground control and on-board pilot control, and fault-tolerant flight control computers and redundant sensors that communicate via an aircraft network bus.

17. The aircraft of claim **1**, further comprising first, second, and third landing gear that retract into the center section.

18. The aircraft of claim **1**, further comprising a cockpit, and a targeting system operable by each of a pilot in the cockpit and a ground controller.

19. The aircraft of claim **1**, further comprising a supply of fuel, wherein the center section is an interchangeable mission module that houses at least 80% of onboard fuel.

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