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Barrett et al.

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(54) **AERIAL VEHICLES AND METHODS OF USE**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 14/120,446, filed on Jun. 10, 2014, now abandoned, and a
(Continued)

(51) **Int. Cl.**

A63H 27/00	(2006.01)
B64C 25/06	(2006.01)

(Continued)

(52) **U.S. Cl.**
CPC ***A63H 27/12*** (2013.01); ***A63H 27/02*** (2013.01); ***A63H 33/003*** (2013.01); ***B64C 25/06*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B64C 29/02; B64C 29/0025; B64C 2201/088; B64C 2201/108; A63H 17/00;
(Continued)

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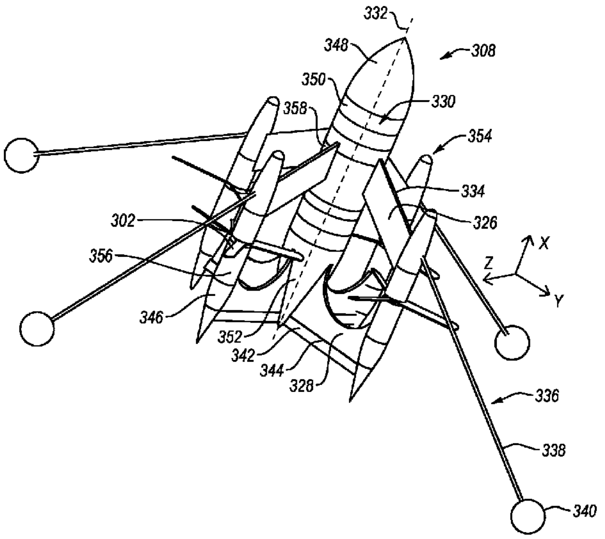
(57) **ABSTRACT**

An aerial vehicle capable of convertible flight from hover to linear flight includes a body having a longitudinal body axis, a plurality of forward wings, a plurality of aft wings, at least one motor, and at least three aerodynamic propulsors driven by the at least one motor. Each forward wing extends a forward wing plane. Each aft wing extends from an aft wing plane. The aerodynamic propulsors are mounted longitudinally between the plurality of forward wings and plurality of aft wings.

18 Claims, 14 Drawing Sheets



Related U.S. Application Data

continuation-in-part of application No. 14/120,447, filed on Jun. 20, 2014, now abandoned.

(51) **Int. Cl.**

B64D 27/02	(2006.01)
A63H 33/00	(2006.01)
B64C 29/02	(2006.01)
B64C 39/02	(2006.01)

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

CPC ***B64C 29/02*** (2013.01); ***B64C 39/024*** (2013.01); ***B64D 27/02*** (2013.01); *B64C 2201/021* (2013.01); *B64C 2201/104* (2013.01); *B64C 2201/108* (2013.01); *B64C 2201/128* (2013.01); *B64C 2203/00* (2013.01)

(58) **Field of Classification Search**

CPC A63H 17/26; A63H 27/00; A63H 27/02; A63H 27/12

See application file for complete search history.

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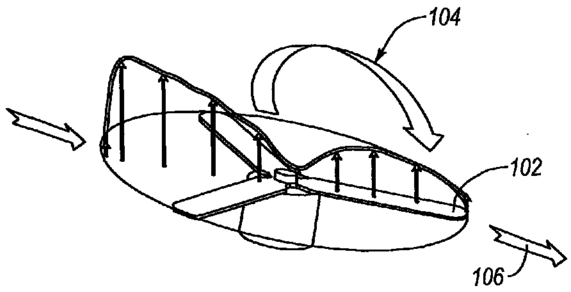

FIG. 1
PRIOR ART

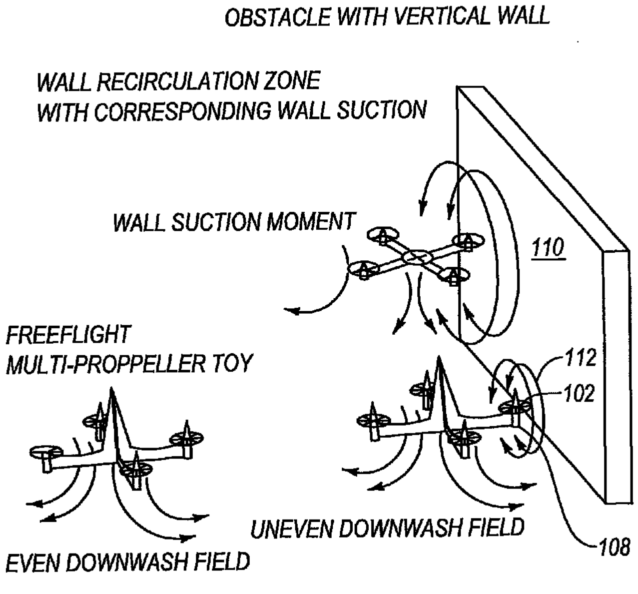

FIG. 2
PRIOR ART

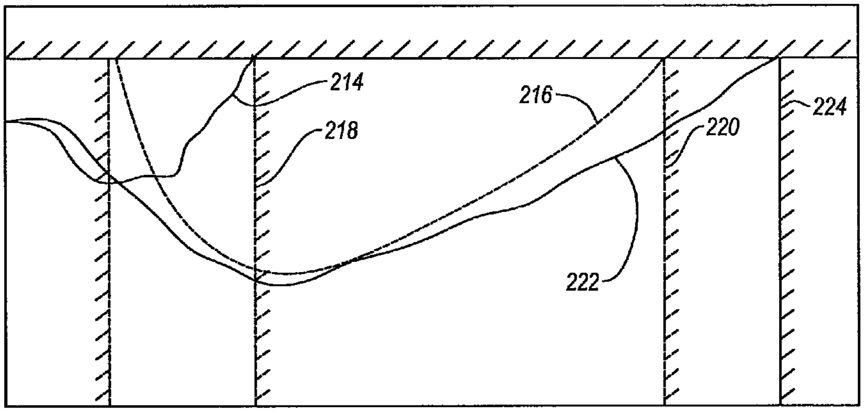

FIG. 3
PRIOR ART

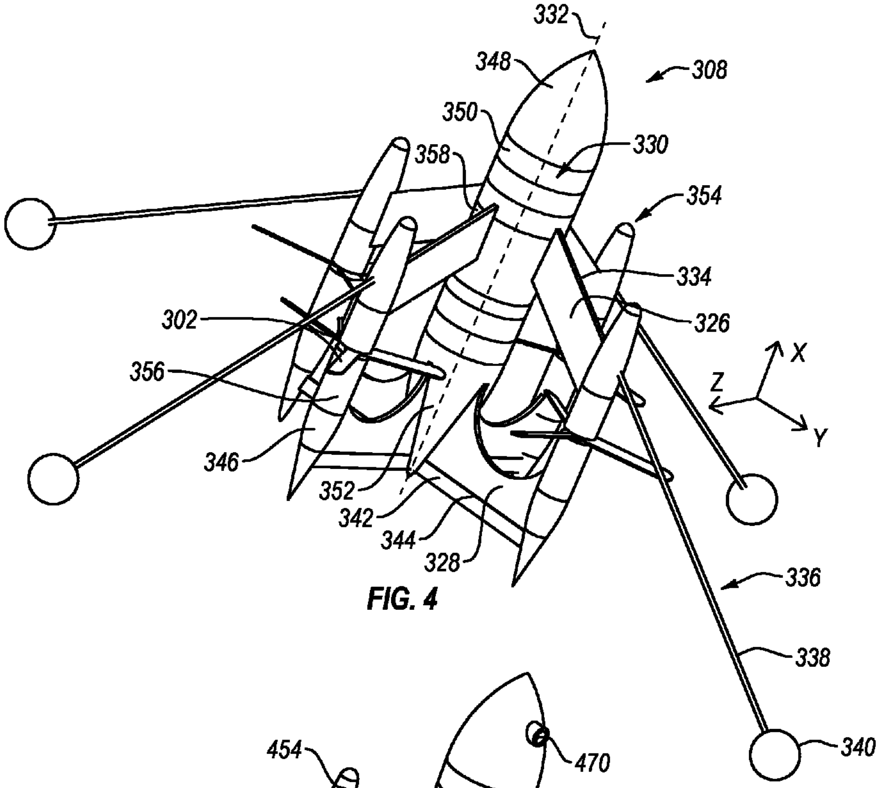
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FIG. 4

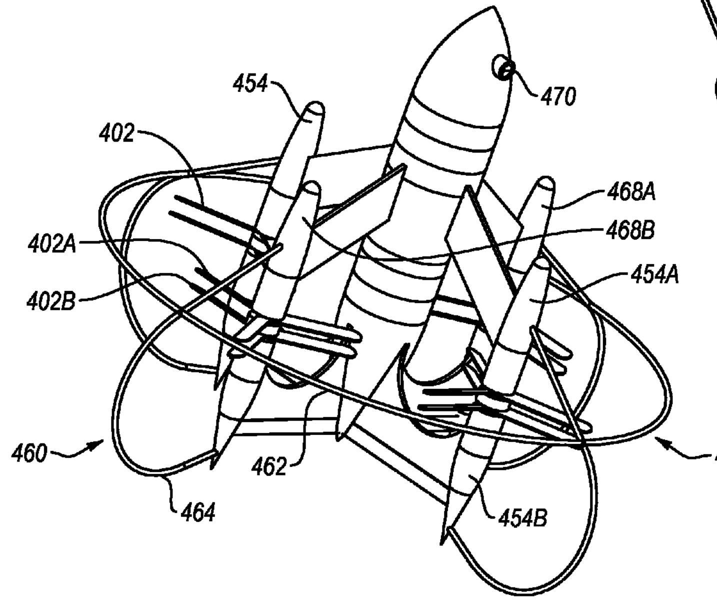
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FIG. 5

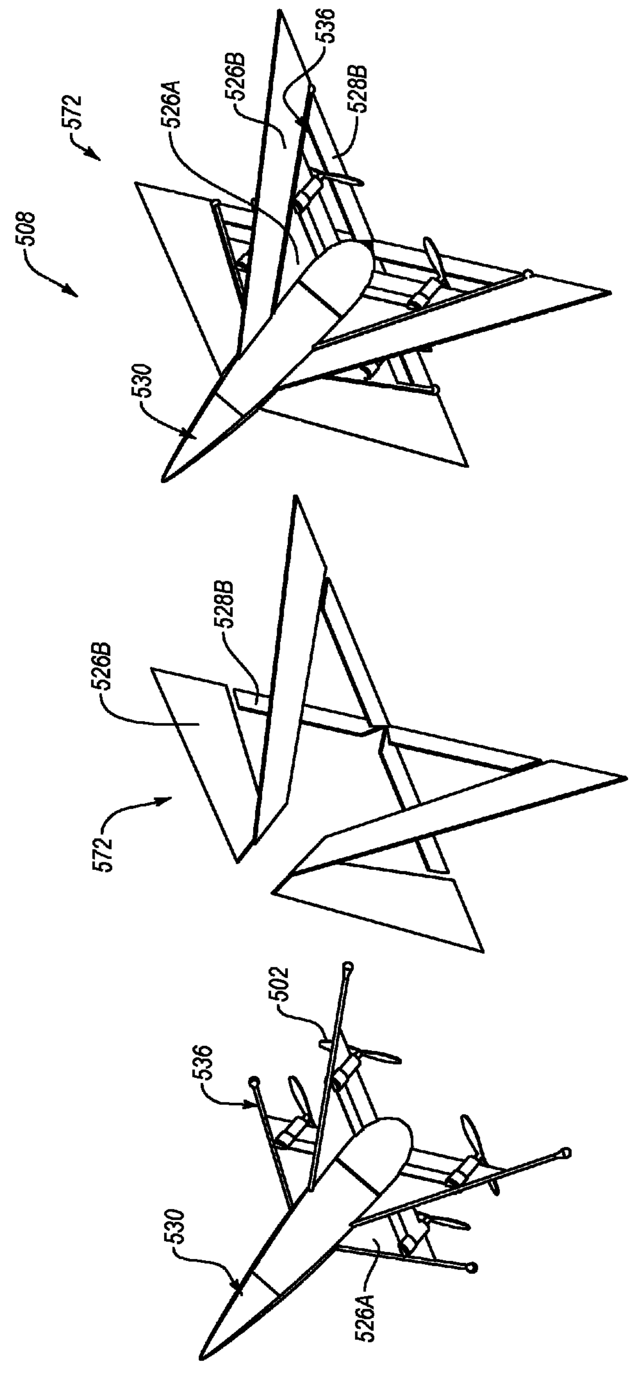

FIG. 6

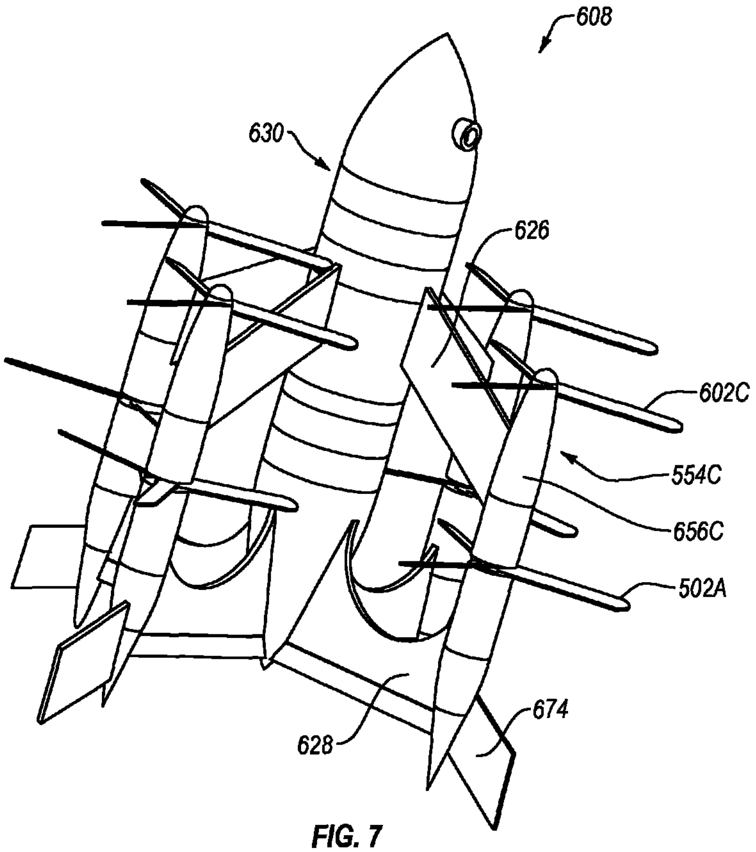

FIG. 7

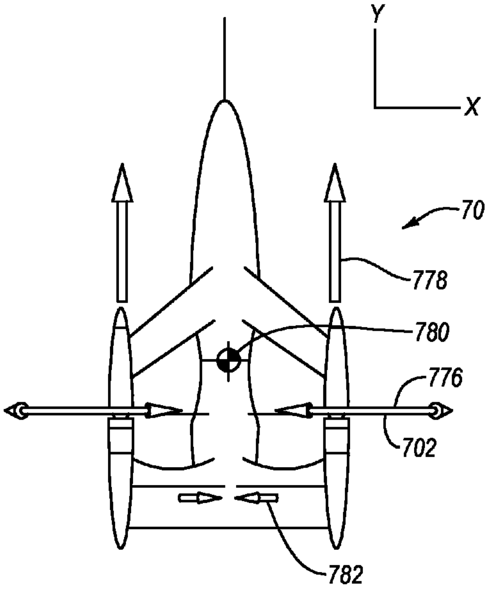

FIG. 8

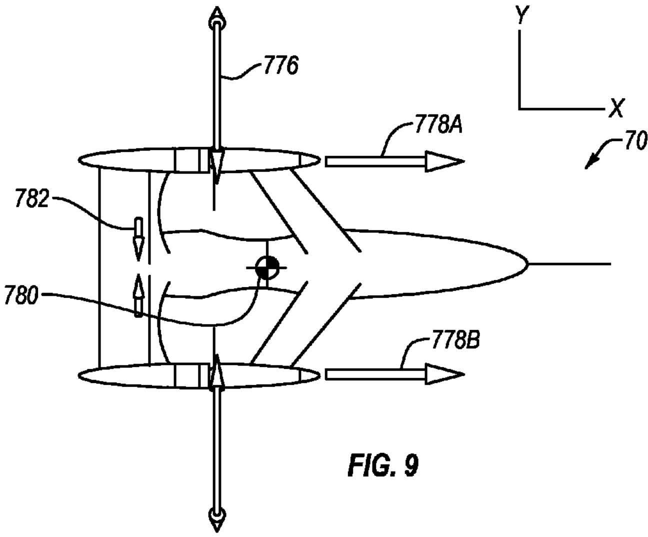

FIG. 9

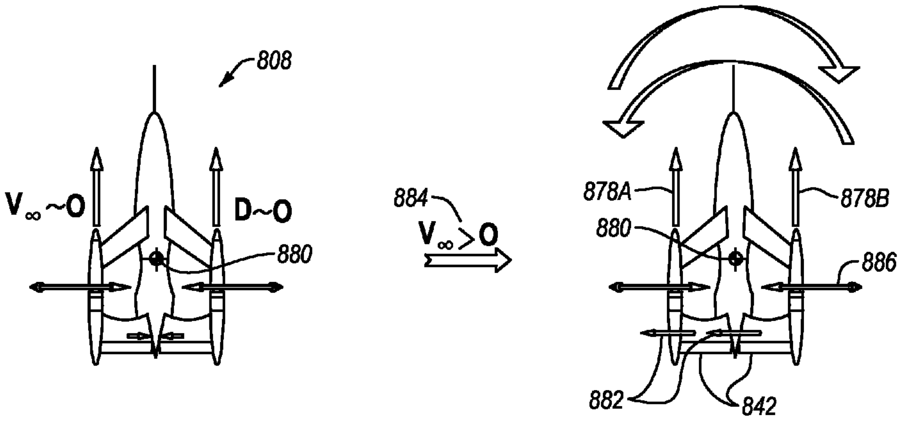

FIG. 10

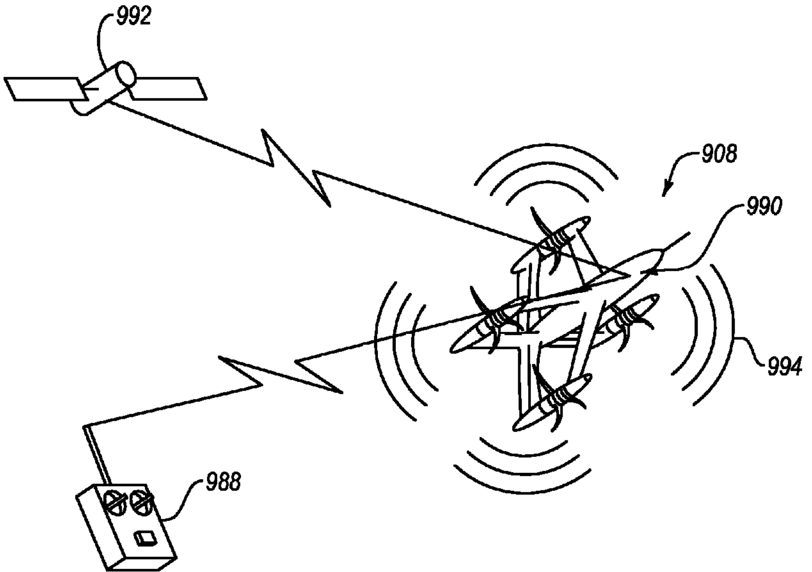
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FIG. 11

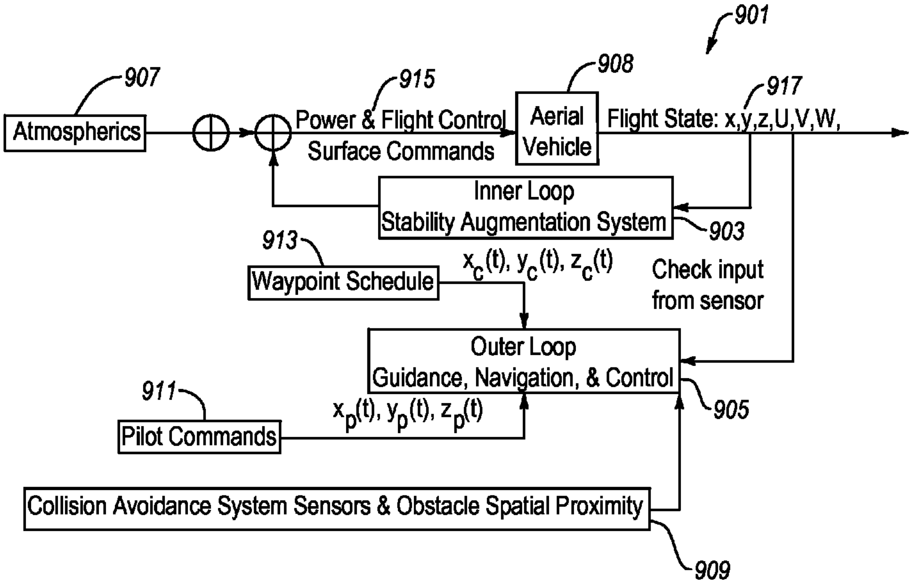
901
907
Atmospherics
915
Power & Flight Control
Surface Commands
908
Aerial
Vehicle
917
Flight State: x,y,z,U,V,W,
Inner Loop
Stability Augmentation System
903
913
Waypoint Schedule
$x_c(t), y_c(t), z_c(t)$
Check input
from sensor
Outer Loop
Guidance, Navigation, & Control
905
911
Pilot Commands
$x_p(t), y_p(t), z_p(t)$
Collision Avoidance System Sensors & Obstacle Spatial Proximity
909

FIG. 12

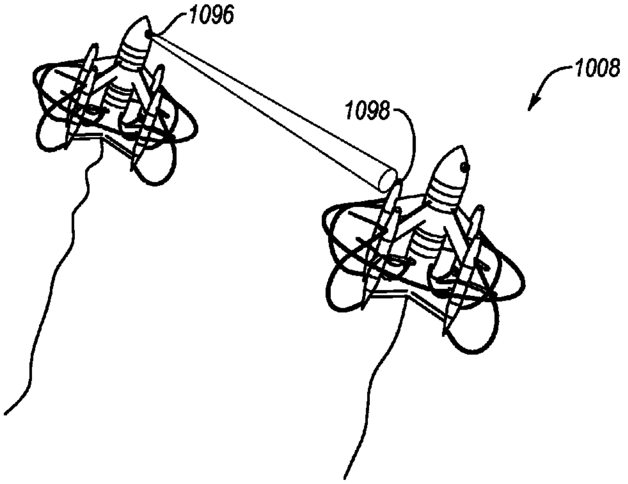

FIG. 13

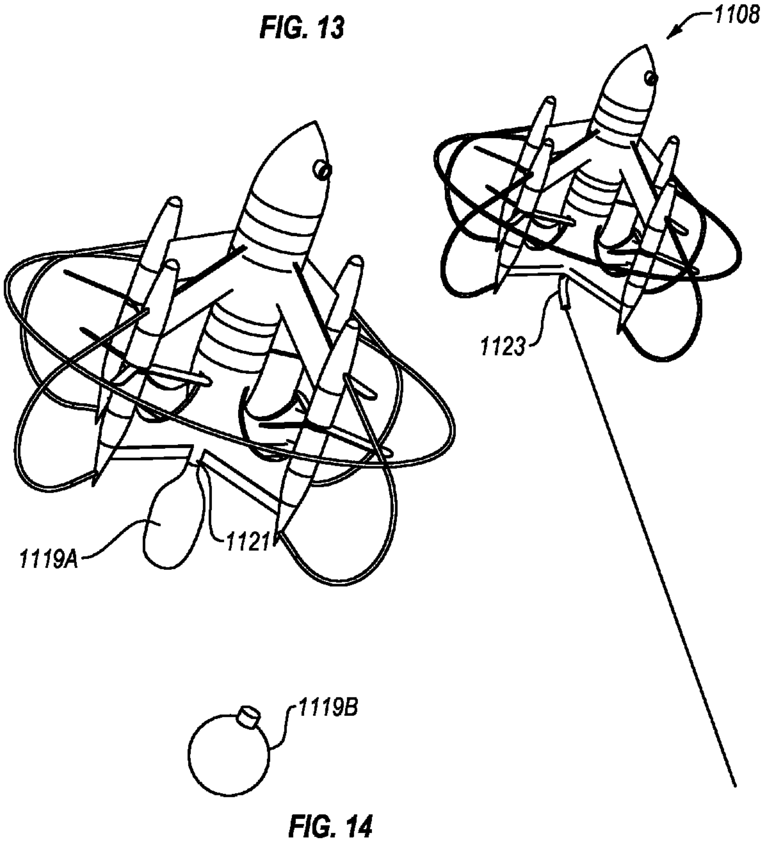

FIG. 14

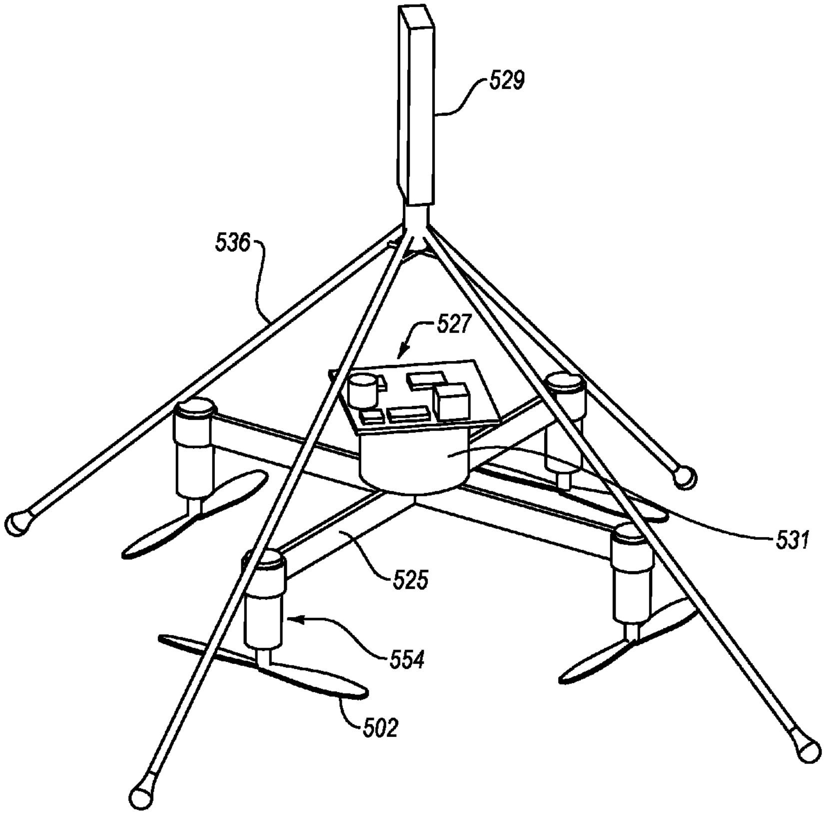

FIG. 15

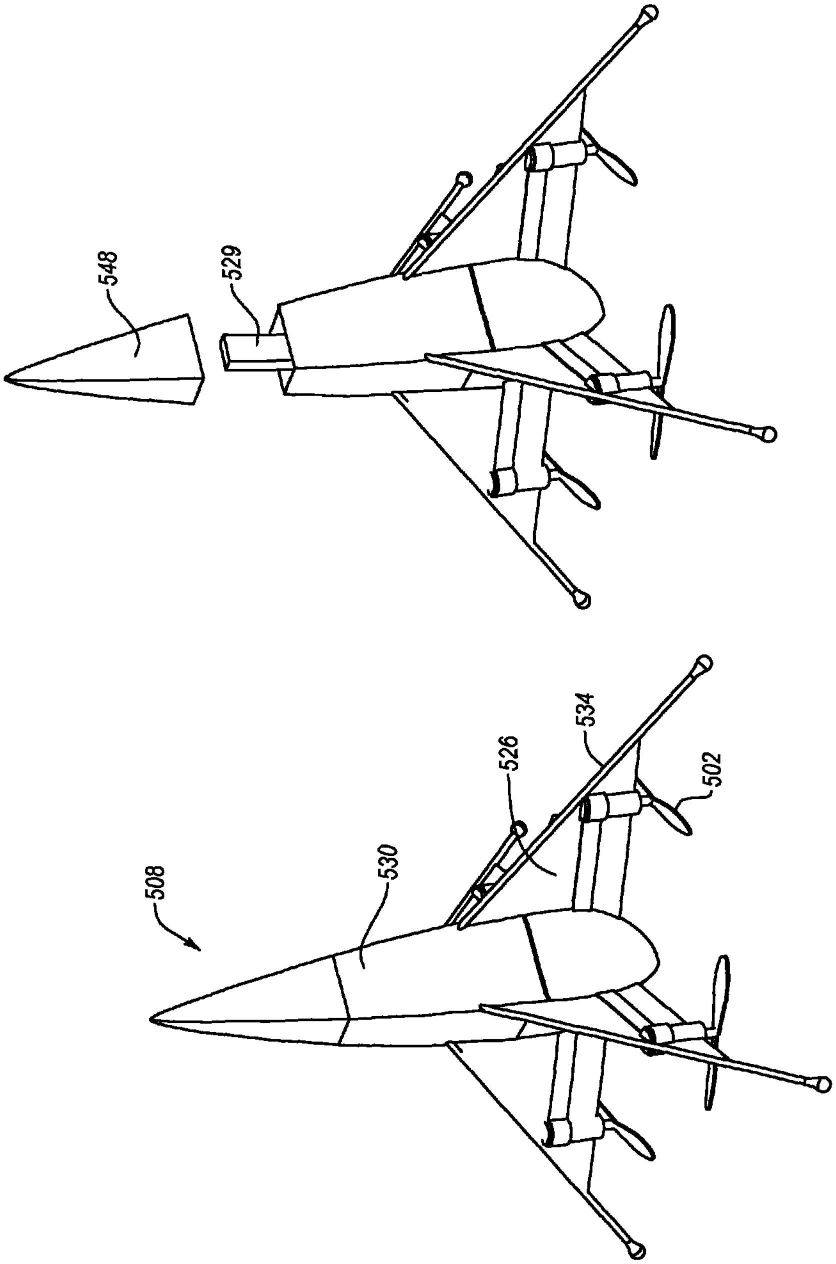

FIG. 16

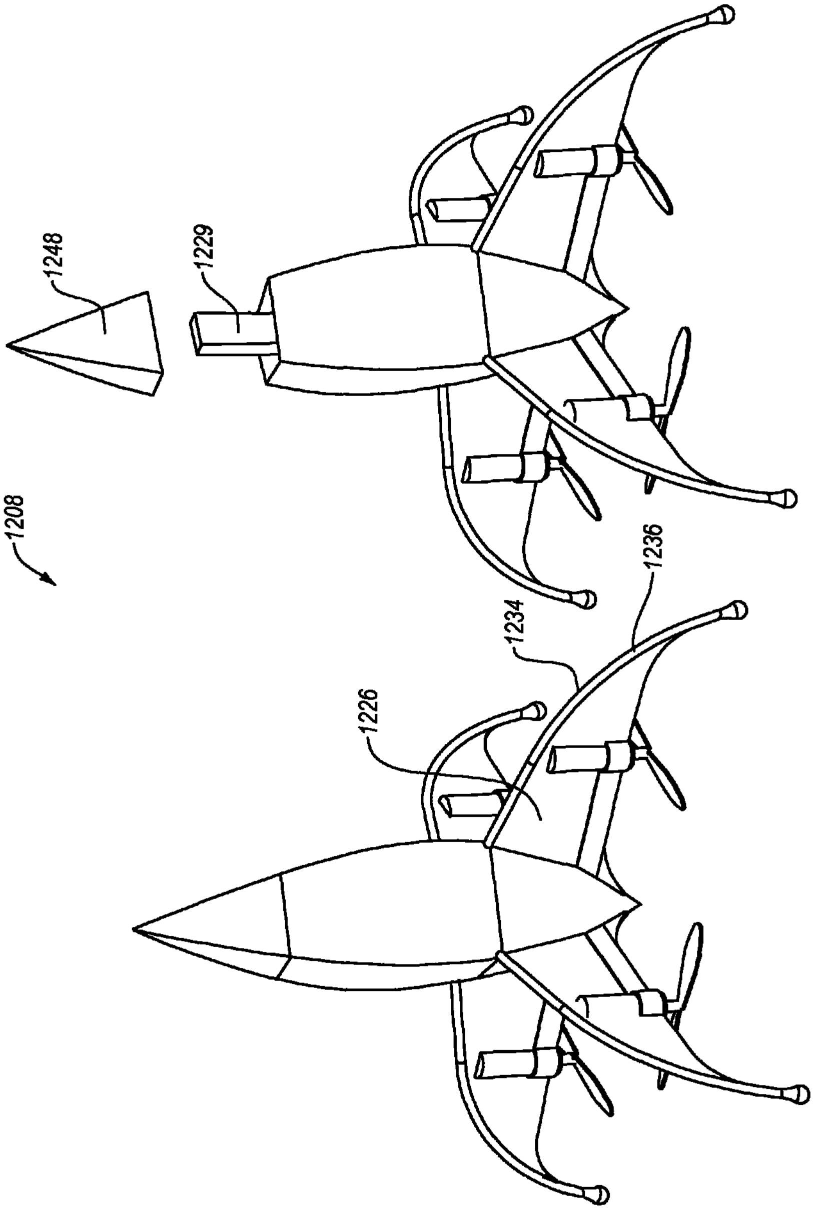

FIG. 17

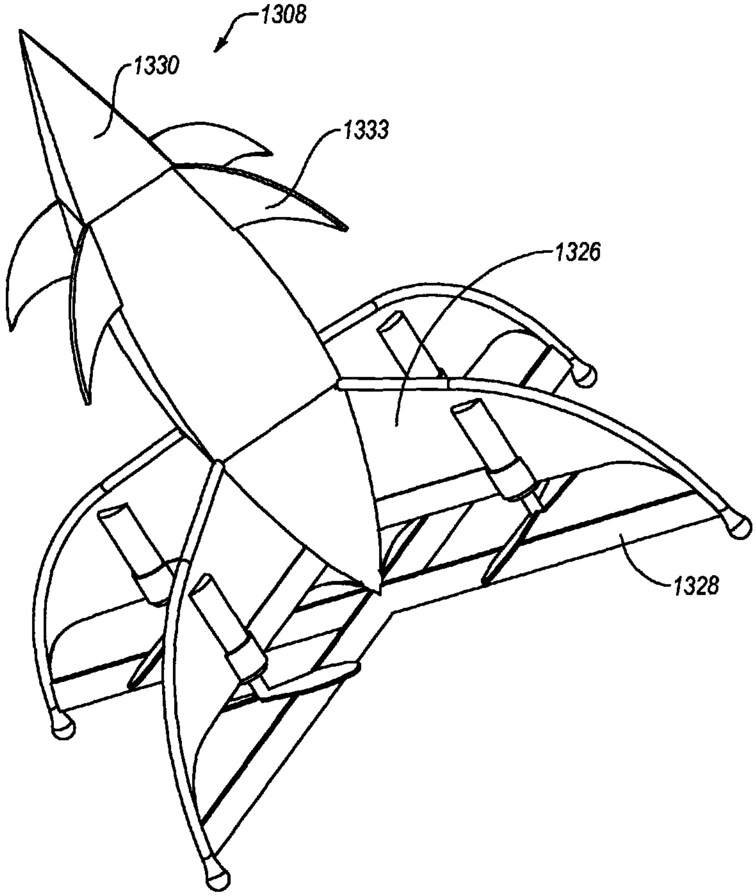

FIG. 18

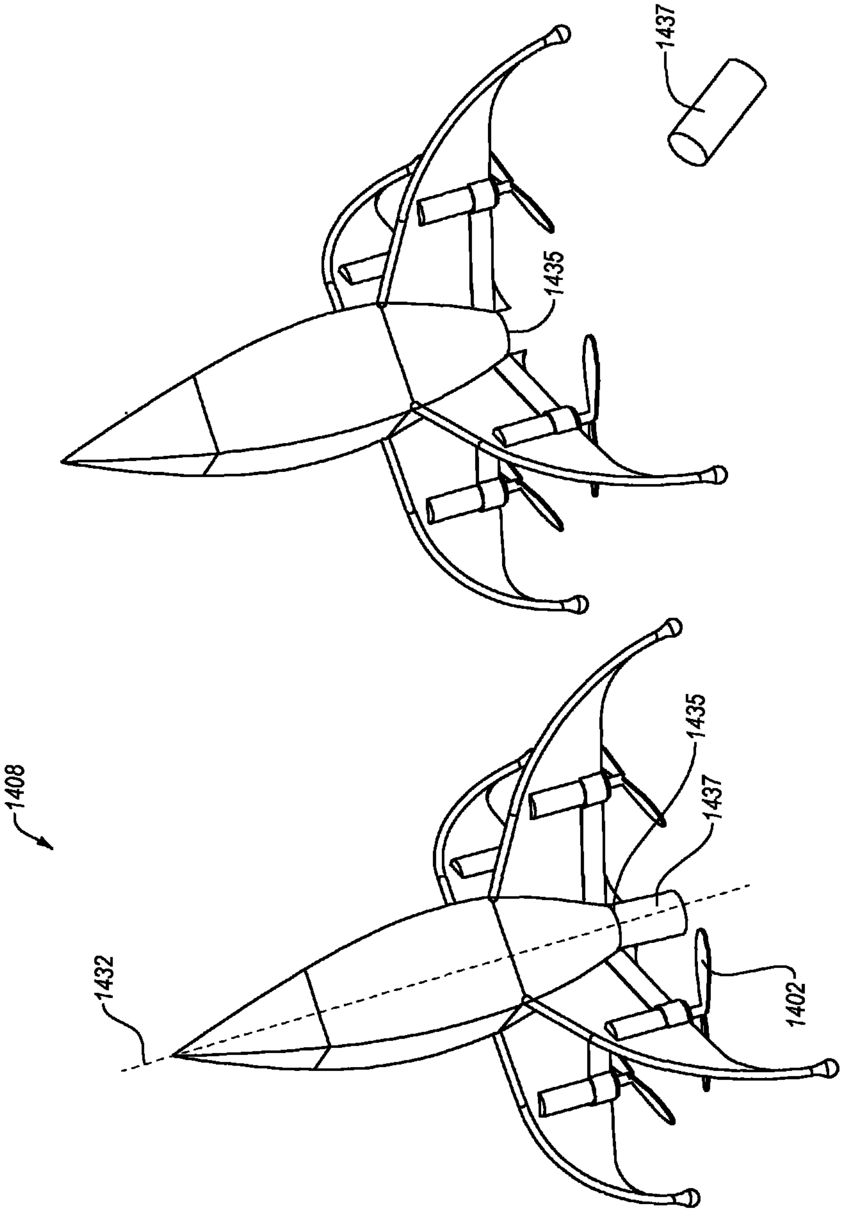

FIG. 19

AERIAL VEHICLES AND METHODS OF USE

This application is a continuation in part of U.S. patent application Ser. No. 14/120,446, filed Jun. 10, 2014, and entitled "REMOTE-CONTROLLED CONVERTIBLE MULTI-PROPELLER TOY" This application is a continuation in part of U.S. patent application Ser No. 14/120,447, filed Jun. 20, 2014, and entitled "AERIAL VEHICLES AND METHODS OF USE" the disclosures of which are incorporated herein by reference.

BACKGROUND

1. Field of the Disclosure (Technical Field)

The disclosure is concerned with aerial vehicles. More particularly, pertains to a class of flying toys which are able to hover like helicopters, then convert and fly like airplanes using a plurality of propellers and wings for lift and flight control.

2. Background Art

For more than two centuries, multi-propeller aircraft have been experimented with, starting with the fabled toy of Launoy and Bienvenu of 1783. These devices were and are limited mostly to hover-type flight modes, flying at low speeds for limited endurances and distances. Airplanes and gliders have similarly been in existence for many hundreds of years, flying much faster with greater endurances and range.

SUMMARY OF THE DISCLOSURE

This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

In an embodiment, an aerial vehicle includes a body, at least one motor supported by the body, and at least three aerodynamic propulsors driven by the at least one motor. The body includes a plurality of forward wings and a plurality of aft wings extending away from a longitudinal axis of the body. The plurality of forward wings extends in a forward wing plane that contains the longitudinal body axis and is tilted no more than 15 degrees from the longitudinal body axis. The plurality of aft wings extends in a forward wing plane that contains the longitudinal body axis and is tilted no more than 15 degrees from the longitudinal body axis. The at least three aerodynamic propulsors are positioned longitudinally between the plurality of forward wings and plurality of aft wings.

In another embodiment, an aerial vehicle includes a body, at least three aerodynamic propulsors each driven by a motor, a communication module, and a flight director. The body includes a plurality of forward wings and a plurality of aft wings extending away from a longitudinal axis of the body. The plurality of forward wings extends in a forward wing plane that contains the longitudinal body axis and is tilted no more than 15 degrees from the longitudinal body axis. The plurality of aft wings extends in a forward wing plane that contains the longitudinal body axis and is tilted no more than 15 degrees from the longitudinal body axis. The at least three aerodynamic propulsors are positioned longitudinally between the plurality of forward wings and plurality of aft wings. The flight director is in data communication with at least one of the motors associated with the at least three aerodynamic propulsors and has a stability augmentation system configured to receive flight state information and pilot commands and to output flight control commands based at least partially upon the flight state information and pilot commands.

In yet another embodiment, an aerial vehicle includes a body, at least three aerodynamic propulsors each driven by a motor, a communication module, and a flight director. The body includes a plurality of forward wings and a plurality of aft wings extending away from a longitudinal axis of the body. The plurality of forward wings extends in a forward wing plane that contains the longitudinal body axis and is tilted no more than 15 degrees from the longitudinal body axis. The plurality of forward wings includes a structural leading edge that is configured to structurally support landing gear and extends through a radially outwardmost point of the aerial vehicle. The plurality of aft wings extends in a forward wing plane that contains the longitudinal body axis and is tilted no more than 15 degrees from the longitudinal body axis. The at least three aerodynamic propulsors are positioned longitudinally between the plurality of forward wings and plurality of aft wings and within the radially outwardmost point such that the structural leading edge forms a propulsor cage that provides protection for the aerodynamic propulsors from impact. The flight director is in data communication with at least one of the motors associated with the at least three aerodynamic propulsors and has a stability augmentation system configured to receive flight state information and pilot commands and to output flight control commands based at least partially upon the flight state information and pilot commands.

Additional features of embodiments of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by the practice of such embodiments. The features of such embodiments may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features will become more fully apparent from the following description and appended claims, or may be learned by the practice of such embodiments as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to describe the manner in which the above-recited and other advantages and features of the disclosure can be obtained, a more particular description will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. For better understanding, like elements have been designated by like reference numbers throughout the various accompanying figures. Though some elements in some figures have the same reference number as elements in other figures, these elements may be the same or may differ. While some of the drawings are schematic representations of concepts, at least some of the drawings may be drawn to scale. Understanding that these drawings depict only typical embodiments of the disclosure and are not therefore to be considered limiting of its scope, the embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates an example of the physics of the pitchback instability coupled with cross-flow drag problems which plague open-propeller and shrouded-propeller aerial vehicle designs.

FIG. **2** illustrates the wall recirculation zone with resulting wall suction moments.

FIG. **3** is a comparison of energy requirements of a convertible aerial vehicle versus conventional helicopter and airplane designs.

FIG. **4** is a perspective view of an embodiment of a convertible aerial vehicle, according to the present disclosure.

FIG. **5** is a perspective view of an embodiment of a convertible aerial vehicle having a propeller cage, according to the present disclosure.

FIG. **6** is a perspective view of an embodiment of a convertible aerial vehicle with removable training wings in an assembled and disassembled form, according to the present disclosure.

FIG. **7** is a perspective view of an embodiment of a convertible aerial vehicle with multiple sets of propellers and without an undercarriage, according to the present disclosure.

FIG. **8** is a side view of an embodiment of a convertible aerial vehicle along the body in a hover flight configuration illustrating pitch, roll and yaw moments and longitudinal body axis and transverse body axis translational force vectors, according to the present disclosure.

FIG. **9** is a side view of an embodiment of a convertible aerial vehicle in an airplane-mode illustrating pitch, yaw and roll moments and longitudinal body axis and transverse body axis translational force vectors, according to the present disclosure.

FIG. **10** illustrates an embodiment of a convertible aerial vehicle in quiescent hover flight and the physics of deck-level hovering flight during transition and/or when exposed to a lateral gust field.

FIG. **11** schematically illustrates communication of pilot commands and/or other flight commands to an embodiment of a convertible aerial vehicle, according to the present disclosure.

FIG. **12** illustrates a schematic drawing of an embodiment of stability and control loop architecture, according to the present disclosure.

FIG. **13** illustrates a pair of embodiments of aerial vehicle toys engaged in ribbon-cutting and laser-tag dogfight flight, according to the present disclosure.

FIG. **14** is a perspective view of a pair of embodiments of convertible aerial vehicles engaging in lofting and deploying a cargo, according to the present disclosure.

FIG. **15** is a perspective view of an embodiment of a core of a convertible aerial vehicle with structural leading wing edges, according to the present disclosure.

FIG. **16** is a perspective view of an embodiment of a convertible aerial vehicle including the core of FIG. **15** in an assembled and partially disassembled form, according to the present disclosure.

FIG. **17** is a perspective view of an embodiment of a convertible aerial vehicle with a curved leading wing edge in an assembled and partially disassembled form, according to the present disclosure.

FIG. **18** is a perspective view of an embodiment of a convertible aerial vehicle with a canard wing set, according to the present disclosure.

FIG. **19** is a perspective view of an embodiment of a convertible aerial vehicle with a rocket propulsor mounted in the body, according to the present disclosure.

DETAILED DESCRIPTION

One or more specific embodiments of the present disclosure will be described below. These described embodiments are examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, not all features of an actual implementation may be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions will be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. It should be understood that any directions or reference frames in the preceding description are merely relative directions or movements. For example, any references to "up" and "down" or "above" and "below" or "forward" and "aft" are merely descriptive of the relative position or movement of the related elements. Any element described in relation to an embodiment or a figure herein may be combinable with any element of any other embodiment or figure described herein.

This disclosure generally relates to aerial vehicles. This disclosure relates to aerial vehicles with multiple aerodynamic propulsors that are capable of flight convertible from a hover flight to an airplane-type or translational flight mode. Multi-propeller aerial vehicles are susceptible to being disturbed by gust fields via pitchback instabilities and large cross-flow drag levels when in hovering flight. This tendency for instability increases the probability of a crash, which, in turn, often leads to vehicle breakage and/or harm to bystanders.

A more debilitating crash mode which is not readily apparent is related to wall-suction. As a hovering aerial vehicle approaches a vertical surface, especially one which is close to the ground, a toroidal vortex is established in the form of a recirculation donut. This recirculation zone generates a strong downwash field on the wall-side of the propellers, thereby reducing lift and pitching the propeller-craft towards the wall. This almost always leads to a crash. One solution to catastrophic propeller breakage is to install propeller guards. However, propeller guards lead to high weight increments and even greater pitchback instabilities and crossflow drag when in freeflight, when exposed to a gust and close to walls. The translational problem is weakly dealt with by pitching the aircraft into the local gust field. While sometimes effective, the response time is often slow and leads to gross body rotations which disturb camera views which are often used for piloting via First Person View (FPV) systems.

While aerial vehicles which can fly like helicopters are accepted by the market and toys that can fly like airplanes are similarly desirable, it is clear that an aerial vehicle which possesses the best of both flight modes can be more desirable than either one individually. At least one embodiment described herein is capable of both hovering and airplane-like translational flight (i.e., applying thrust in a direction that is generally parallel to the ground for an extended period of time). In at least one embodiment described herein, an aerial vehicle achieves improved hover performance like a helicopter and yet maintains the ability to execute fully acrobatic maneuvers like a high performance airplane. In general, aircraft that are good at airplane-type flight have very limited hover maneuverability and are susceptible to lateral gusts when in a hover, are often flipped over when in hover modes and are unable to land without catastrophic wing, empennage, fuselage and/or propeller strike. Aerial vehicles which are good at hovering and low-speed flight often have such tremendous levels of drag when in high speed flight that they cannot even begin to reach conventional airplane or toy airplane speeds.

There are five main challenges of conventional multi-propeller aircraft which may feed into each other, including aerodynamic instabilities due to propeller pitchback and/or crossflow drag; flight near hard surfaces and/or objects; toroidal recirculation near vertical surfaces and/or objects; exacerbation of instability by thrust-based navigation; and wall suction leading to body rotations. For example, as shown in FIG. **1**, a propeller **102** may experience pitchback instabilities **104** and crossflow drag **106** that induce large body rotational and spatial excursions (i.e., deviations from intended flight pattern or direction) in the propeller **102** or in hovering vehicles that employ the propeller **102** when flying in real atmospheric conditions. These excursions often lead to crashes unto themselves against hard objects, the ceiling, the ground, or people, resulting in harm to individuals and/or damage to the vehicle and surrounding environment.

Further, as shown in FIG. **2**, the excursions may place a vehicle **108** employing the propeller **102** in the proximity of a vertical surface **110** (like the side of a house or wall) where a toroidal recirculation zone **112**, induces a high level of downwash on the propeller **102** or vehicle **108** propeller-side closest to the vertical surface **110**, which in turn sucks the vehicle **108** towards the vertical surface **110** or wall. The toroidal recirculation zone **112** may lead to vehicle **108** instabilities, which may be exacerbated by attempts to stabilize the vehicle **108**. For example, if a hovering vehicle **108** relies only upon thrust to escape the wall suction, then often, as wall-side thrust is increased (either by the pilot or a flight controller), the strength of the toroidal recirculation zone **112** and its suction correspondingly increases as adverse downwash velocities grow. Such toroidal recirculation zone **112** suction at or near vertical surfaces **110** may induce both wall-side rotation and translation, which may in turn frequently induce crashes, disturb camera angles via body rotations, lead to mechanical breakage, and, in flight close to people, can even harm individuals.

The most common design feature on aerial vehicles that is used to prevent catastrophic propeller damage is the addition of a propeller guard. While effective in preventing some damage, propeller guards are heavy and, through their very geometry, may induce even greater levels of the cross-flow drag and pitchback instability described in relation to FIG. **1**. Occasionally, large training cross-arms are added to the landing gear at the bottom of the aircraft, thereby allowing the user to learn how to fly the aircraft. While protecting the aircraft from downward strikes, the aircraft can be easily flipped over when close to the ground, inducing propeller damage. Cross-arms are exceedingly heavy and draggy as they lie directly in the propwash close to the ground, which compromises maneuverability. As used herein, "draggy" should be understood to describe one or more features of a vehicle that increase the aerodynamic drag of the vehicle. The comparatively high weight of cross-arms also leads to a net downward shift in center of gravity which exacerbates pendulum instabilities.

FIG. **3** illustrates that if a given aircraft with a fixed amount of maximum power is flown in a helicopter-like (hover) configuration, it will have a reasonable hover required-power but will have a comparatively low helicopter maximum translational flight speed **218**, which is determined when the helicopter required-power line **214** intersects the available power line. Similarly, the airplane required-power line **216** is dominated by stall-related effects at low speeds leading to an airplane minimum speed. Like helicopters, the airplane required-power line will intersect at a given available power line, which determines the airplane maximum translational flight speed **220**, which is much higher than the helicopter maximum translational flight speed **218**.

At least one embodiment of a convertible aerial vehicle described herein displays a convertible required-power line **222** that lacks the stall speed constraint of an airplane which sets wing areas to high levels. Instead, the wings of the convertible aircraft can be significantly smaller. This, in turn, leads to a dramatic reduction in wetted area (i.e., the area of atmosphere through which the vehicle moves) which decreases total flat plate equivalent drag, f. Because f of the convertible aerial vehicle is much lower than that of a similarly powered airplane, a simple relationship governing the convertible maximum translational flight speed **224** of the aircraft makes the relationship clear. Given two otherwise identical designs, the one with a lower value of equivalent flat plate area will be faster:

$$\sqrt[3]{\frac{2\eta_p P_{sav}}{\rho\left(f+\frac{C_L^2}{\pi Ae}\right)}}=V_{max} \qquad \text{(eq. 1)}$$

Wherein: η_p is the propeller efficiency, P_{sav} is the shaft power available, ρ is the density of air, f is the parasite area of the aircraft, C_L is the lift coefficient of the lifting surface, A is the aspect ratio of the lifting surface, and e is the Oswald's efficiency of the lifting surface.

If one assumes that the design will fly at the maximum value of lift-to-drag for greatest efficiency, via tailoring wing areas for maximum efficiency cruise speed then equation 1 becomes:

$$\sqrt[3]{\frac{\eta_p P_{sav}}{\rho f}}=V_{max} \qquad \text{(eq. 2)}$$

Accordingly, as wing areas are reduced because of the relaxation or elimination of stall constraints, the convertible aerial vehicle will be able to either go faster with the same size powerplant and/or achieve the same top speed with a smaller motor.

FIG. **3** illustrates a potential opportunity presented by a synergistically designed convertible aerial vehicle. An embodiment of a synergistically designed convertible aerial vehicle may hover with system-level Figure of Merit (FOM) similar to or greater than that of a helicopter and then convert to a translational flight mode for high speed flight (which is typically two to five times greater than the highest speeds that can be achieved by a conventional helicopter), then convert back to hover flight for, in one example, landing. In another example, the translational flight may include flight generated by one or more propulsors that lies mostly in a horizontal plane and is close to the primary direction of flight. In conventional, commercial aircraft, jet engines are typically tilted less than 15° from the body longitudinal axis, which in turn is typically oriented within 15° of a horizontal plane for most of the flight and principally in the direction of flight, which coincides with the direction stability axis. Other examples of airplane mode flight include that which is achieved by gliders as noted by the direction of flight as coinciding with the x-direction stability axis in still-air conditions with no propulsors present. Aircraft which possess translational flight capability typically have one or more thrust generating mechanisms which generate propulsive thrust principally parallel to the aircraft longitudinal axis, which possesses the lowest levels of cross-flow drag in a given flight mode, which for conventional aircraft is the body x-axis.

Convertible aerial vehicle have historically been able to achieve higher speeds than helicopters while maintaining some form of hover flight capability. At least one embodiment of an aerial vehicle disclosed herein, however, promises to have even greater hover efficiency by boosting system-level Figures of Merit by 2% to 5% over a helicopter. At least one embodiment of a convertible aircraft described herein generates strong airflows along its body-x axis in hovering flight, which is tilted approximately 90° to the horizontal, and the body-x axis is the axis of lowest drag presentation. The total crossflow drag is, therefore, mitigated with respect to helicopters. Another pair of features reducing drag along the body longitudinal axis are the comparatively low wetted area and the form factor. This low wetted area is an artifact of the relaxation of stall constraints which allows lifting surfaces to shrink with respect to the sizes required for takeoff and landing required by airplanes. With shrunken lifting surfaces, the low wetted areas present much lower drag than that caused by much larger wings which are typically found on conventional aircraft of the same weight.

Although the present disclosure may describe embodiments in terms of toy embodiments, the present disclosure is not so limited. Rather, principles and elements of the disclosure apply to aerial vehicles generally. For example, at least one aerial vehicle herein may be used in a larger-scale aerial vehicle, such as an unmanned aerial vehicle. These unmanned aerial vehicles may include the following ranges of size: from 2 centimeters (cm) to 5 meters (m) in main propeller diameters. Furthermore, although most embodiments are described in terms of having propellers, other aerodynamic propulsors may be used. For example, in some embodiments a ducted fan, small jet engine, rocket engine, other aerodynamic propulsor, or combinations thereof may be used.

Referring now to FIG. **4**, an aerial vehicle **308** according to the present disclosure may include propellers **302** that may be mounted between a forward wing set **326** and an aft wing set **328**; neither at the front, nor at the back of the aircraft. The forward wing set **326** and aft wing set **328** may be mounted to a central body **330** having a longitudinal body axis **332** extending therethrough. The central body **330** may include at least one bay which may be of any cross-sectional geometry or size and may house things like batteries, receiver and/or transmitter electronics, sensors, general cargo, or combinations thereof.

The mounting position of the propellers **302** may allow the vehicle **308** to shield the propellers **302** from objects above (i.e., in the longitudinal axis **332** of the body **302**—including tree branches or light fixtures as the aircraft is caught in a ceiling suction toroid) or below. In some embodiments, the leading edge **334** of the forward wing set **326** may be both structural and load-bearing to the point that they accommodate a protective undercarriage assembly **336** which both ties into and/or forms the vehicle **308** primary structure. The undercarriage assembly **336** may be positioned in and/or attached to the forward portion of the vehicle **308** rather than the aft portion of the vehicle **308**, which may reduce or remove any destabilizing shift in center of gravity.

Legs **338** of the undercarriage assembly **336** and/or propeller cages may extend beyond the radial outermost point of the propellers **302**, thereby shielding the propellers **302** from damage in the event of a rough landing or crash. Similarly, should the vehicle **308** fly into a person or other object, shielding the propellers **302** may reduce or eliminate the probability of striking an individual with the propellers **302** and/or the probability of an injury in the event of a strike may be reduced.

Unlike a propeller guard surrounding a propeller, which may generate pitchback instabilities and crossflow drag increments as described in relation to FIG. **1**, an undercarriage assembly **336** may generate a pitchforward stabilizing increment as the aerodynamic center lies below the propeller **302** planes and center of gravity of the vehicle **308**. When combined with a plurality of landing pads **340** located on the undercarriage assembly **336** radially and distally away from the body **330**, the crossflow drag of the landing pads **340** may further accentuate stabilizing pitchforward moments. The landing pads **340** may be connected to the undercarriage assembly **336** using a connection of variable compliance to allow tunable damping, compliance, and energy absorption upon landing or obstacle strike.

In embodiments with an undercarriage assembly **336**, the aerial vehicle **308** may be increased in structural strength by fixing the undercarriage assembly **336** directly into the forward wing set **326** primary structure while possessing extremely low levels of wetted area and form drag as it presents a low-drag aerodynamic profile. Because of the low wetted area increments, the crossflow drag may be between one to three orders of magnitude less than a propeller guard in hover. In forward flight, the geometry of the undercarriage assembly **336** is such that the low wetted area increments mean that the corresponding equivalent flat plate drag increment may also be an order of magnitude lower than that of a propeller guard. In embodiments where the undercarriage assembly **336** is positioned far upstream of the propeller **302**, the translational flight drag may be further reduced as the dynamic pressure ratio at that location is approximately 1.0. Propeller guards of conventional aircraft generally operate at substantially higher dynamic pressure ratios which drives up their drag increments (typically due to scrubbing drag) even further relative to an undercarriage assembly **336** arrangement, especially considering that their form drag is high as well as wetted area.

In some embodiments, the aerial vehicle **308** may include turning vane flaps **342** movable relative to the aft wing set **328** by a hinge **344** or other pivoting connection. The turning vane flaps **342** may lie below the propellers **302** and firmly in the propeller slipstreams. This orientation may facilitate execution of full pitch, roll and yaw control moments about the center of gravity. In some embodiments, when the control deflections and associated degrees of freedom of the turning vane flaps **342** are combined with motor control degrees of freedom, at least one of the embodiments of an aerial vehicle **308** may easily execute rotation-free translations and execute body-level stationkeeping even in the presence of high gust fields. The aircraft may be kept in moment equilibrium with the deck level in hovering flight while turning vanes apply net forces along the transverse body axes in either direction. Longitudinal body axis **332** position control may be maintained via propeller thrust manipulation coming from speed and/or blade feathering angle variations.

In embodiments with propeller shielding and/or translational control aspects of the design (i.e., turning vane flaps **342**), at least one embodiment of an aerial vehicle **308** will maintain extremely high levels of pitch control authority useful for conversion between hover and translational flight modes and maintenance of flight stability in the transition corridor. Specifically, pitch control may be executed independently and collectively via variations of the thrust between the propellers **302** which are displaced from each other in the transverse direction relative to the body **330** (i.e. fuselage) as well as turning vane flap **342** deflections, which generate elevator-equivalent pitching moments.

Movement of the aerial vehicle **308** may be defined relative to an x-, y-, and z-axis reference frame as depicted in FIG. **4**. The x-direction may be parallel to the longitudinal axis **332** of the vehicle **308** and the x- and y-directions may be transverse directions perpendicular to one another. Roll control about the x-axis may be established in at least one embodiment by differential speed control of propellers **302** and/or turning vane flap **342** deflections. Yaw control about the body **330** z-axis may be similarly controlled by differential speed control of the propellers **302** displaced laterally along the body **330** y-axis and/or turning vane flap **342** deflections which generate rudder-equivalent moments about the body **330** z-axis.

Translational control along y- and z-axes of the aerial vehicle **308** may be provided by maintaining moment equilibrium about the two axes via thrust manipulation from the propellers **302** while simultaneously executing rudder-equivalent and/or elevator-equivalent turning vane flap **342** deflections. Translational control along the x-axis may be obtained by direct thrust variations via speed control of the propellers **302**. In at least one embodiment of an aerial vehicle **308** disclosed herein, the control aspects may include as many as eleven degrees of freedom. Embodiments with higher number of wing pairs in the forward wing set **326** and the aft wing set **328** and/or propellers **302** may possess even higher numbers of degrees of freedom.

At least one embodiment of an aerial vehicle **308** incorporates an overall configuration which is extremely low drag in converted, translational flight, which synergistically lends efficient hover properties as well. Multi-propeller aerial vehicles typically use truss or round-bar arm designs to support the propellers **302**. The support arms create non-trivial crossflow blockage drag, as the support arms sit directly below the propeller in the high dynamic pressure region of the flow. At least one embodiment of an aerial vehicle according to the present disclosure excludes support arms and/or may include aerodynamic fairings **346** immediate behind the propellers **302**, where the fairings **346** may be fixed to the aft wing set **328**. The drag associated with support arms may be unacceptable in convertible flight (i.e., flight from hover to translational flight). Accordingly, the total blockage drag of the design may be one to two orders of magnitude lower in a hover and at certain boattail heights above the ground may actually produce lifting thrust. Embodiments of aerial vehicles **308** without truss or round-bar support arms directly below the propeller may lead to overall hover efficiencies which are significantly greater than conventional multi-propeller toys and even conventional helicopter toys. As a result, in these embodiments, the total power required to hover will be reduced, which in turn, may shrink battery sizes relative to the other designs, which lowers weight, component, and manufacturing costs.

Because the takeoff weight to empty weight sensitivities of multi-propeller toys is typically high when dimensions are small, at least one embodiment of an aerial vehicle toy includes this beneficial property, which shrinks gross weights. Because the weights of the embodiments having this design will be lower than a conventionally configured aerial vehicle, it will not only cost less, but it will tend to be much more robust as inertial loads during object strike will be lower and product safety will be similarly enhanced beyond just those levels which are provided by the unique undercarriage assembly **336**. Relative to a conventionally configured helicopter, propeller torque is exactingly countered, not by a tail rotor which consumes 10% 15% of the main rotor power, but by balancing lifting propellers **302**, which counter torque with no parasitic losses such as seen in a conventionally configured helicopter.

As shown in FIG. **4**, the aerial vehicle **308** may include a nose **348** that can be of an aerodynamically faired configuration allowing smooth passage of air in both hover and translational flight modes and may have holes or slots allowing for induction of an internal airflow to cool internal electronics and batteries. A number of storage bays **350** may be included, that may hold a variety of devices from stability augmentation systems to sensors to general cargo to energy storage devices. The aerial vehicle **308** may include an aft body portion **352**. In some embodiments, the aft body portion **352** can house a variety of mission packages and/or cargo. In other embodiments, the aft body portion **352** can be substantially empty to maintain proper weight and balance distributions of the aerial vehicle **308** as a whole.

The aerial vehicle **308** may include one or more powerpods **354**. In some embodiments, the one or more powerpods **354** may have a comparatively high aspect ratio configuration (i.e., ratio of a longitudinal dimension to a transverse dimension) and may support propellers **302** structurally from the front and back while passing structural loads through the motor shaft via, for example, bearing assemblies. The propellers **302** may be foldable, flexible, frangible and/or deformable for packaging, flight safety and robustness. At least one motor **356** may provide shaft power to the propellers **302** to turn them in a variety of directions and speeds depending on the number of wings and associated powerpod **354** assemblies. The aerial vehicle **308** may include the fairings **346**. In some embodiments, the fairings **346** may act as structural supports for the at least one motor **356** and/or termina of the aft wing set **328**, undercarriage assembly **336**, alighting assemblies, other structural or shielding components, or combinations thereof. The aerial vehicle **308** may include forward wing set **326** that may support the forward sections of the powerpods **354** structurally by passing structural loads directly to a forward body portion **358**.

As described herein, the aerial vehicle **308** may include landing gear, such as the undercarriage assembly **336** with legs **338** and landing pads **340**. The forward wing set **326** may integrate the landing gear and pass landing loads from the undercarriage assembly **336** directly to the forward wing set **326** primary structures. The aerial vehicle **308** may include an aft wing set **328** that may structurally connect the powerpods **354** to the aft body portion **352**. The forward wing set **326** and the aft wing set **328** may contain a variety of structural members and/or electrical lines to sustain and/or control flight. The aft wing set **328** may structurally support turning vane flaps **342**.

FIG. **5** illustrates another embodiment of an aerial vehicle **408** having a configuration with more than one set of propellers **402** per powerpod **454** which may be rotated in the same or opposite directions. The propellers **402**A, **402**B may be driven by motors in both the forward and aft portions of the powerpods **454**A, **454**B. The undercarriage assembly **436** may be amenable to the formation of a propeller cage **460** or protective basket which may allow for safe flight to protect the propellers **402** from obstacles and similarly protect the object or people from the propellers **402**. The vertical basket arches **462** may connect to a basket hoop **464** which may fully enclose the propellers **402** in a low-drag configuration. The aerial vehicle **408** can also be equipped with binocular sensors like pinhole cameras **468**A, **468**B which may be laterally displaced to offer an operator both parallax and depth perception via displacement along the body y-axis. The aerial vehicle **408** can also be equipped with monocular sensors **470** mounted on pan-tilt-zoom assemblies in any portion of the aerial vehicle **408**. Antennae of a variety of configurations may be mounted on any portion of the aerial vehicle **408** and/or incorporated into the body **430** or undercarriage assembly **436**. In some embodiments, an aerial vehicle may be flown in first person via a vision aided system, leading to a first-person view (FPV) piloting scheme. An aerial vehicle may be flown by waypoint navigation scheme, third-person flight modes, arcade or a hybrid of any of the above.

FIG. **6** illustrates an embodiment of an aerial vehicle **508** that is a conversion training variant which may include a number of features which assist in stabilizing conversions between hover flight and translational flight. The aerial vehicle **508** may include a removable training wing set **572** configured to supplement the wing sets of the aerial vehicle **508**. In some embodiments, the aerial vehicle **508** may have a forward wing set **526**A connected to the body **530** and mounted forward of the propellers **502**. The forward wing set **526**A may be structurally supported by an undercarriage assembly **536** that extends radially and aftwardly, at least partially defining the leading edge of the forward wing set **526**A. The removable training wing set **572** may include a relatively large training forward wing set **526**B that is configured to connect to the body **530** and/or the leading edge of the forward wing set **526**A and supplement the forward wing set **526**A. The removable training wing set **572** may include a relatively large training aft wing set **528**B that is configured to connect to the body **530** and/or the training forward wing set **526**B. The size, and hence drag, of the training aft wing set **528**B may be so great that they may induce a large aftward shift along the body x-axis of the aerodynamic center of the aerial vehicle **508**. Such a shift of the aerodynamic center of the aerial vehicle **508** may lead to such high static margin that as the aerial vehicle **508** is exposed to increasing flight speeds, the aerial vehicle **508** attitude is forced ever further into the local freestream velocity vectors. Embodiments including an oversized training aft wing set **528**B may aid pilots, such as novice pilots who are learning how to convert flight modes. However, because the removable training wing set **572** can more than double the wetted area, the removable training wing set **572** is not generally suitable for high speed flight. Thus, in some embodiments, the removable training wing set **572** may be removed, for example, once the pilot gains experience and confidence with conversion. In some embodiments, the removable training wing set **572** may be a single structural component that is selectively connectable to the aerial vehicle **508** as a whole. In other embodiments, the removable training wing set **572** may have discrete components that a user may selectively apply to the aerial vehicle **508** for different training purposes and/or flight characteristics. For example, the training forward wing set **526**B and the training aft wing set **528**B may be applied and/or removed from the aerial vehicle **508** independently from one another. As with many training schemes, the training forward wing set **526**B and the training aft wing set **528**B may come in a variety of chords and spans so that the level of stability may be gradually reduced with increasing levels of pilot skill and confidence.

FIG. **7** illustrates yet another embodiment of an aerial vehicle **608** with the undercarriage assembly removed and a set of forward propellers **602**C mounted forward of the forward wing set **626** and forward of the propellers **602**A mounted between the forward wing set **626** and aft wing set **628**. Forward propellers **602**C, and associated motor assemblies **656**C can be mounted to the body **630** and/or forward powerpods **654**C and used to boost maximum flight speeds, both in hover flight and translational flight modes; however because the propellers lie outside of the protection of the space between the forward wing set **626** and aft wing set **628**, this configuration may be reserved for more experienced pilots. The position of the forward propellers **602**C may induce a power-on forward shift in effective aerodynamic center position and accordingly reduce the total static margin. In some embodiments, fixed or movable stabilizers **674** may be included for both stabilization and control.

The embodiments of aerial vehicles described herein will have a high number of independent and dependent degrees of freedom with respect to a conventionally configured multi-propeller aircraft, helicopter, or airplane. FIG. **8** is a lateral view of an embodiment of an aerial vehicle **708** along the body y-axis illustrating the aerial vehicle **708** in hover flight. The aerial vehicle **708** may include a plurality of propellers **702** which may each generate a yawing moment **776**. These yawing moments **776** are a function of propeller types, pitch angles, rotational speeds and directions which may be varied, from flight to flight or in-flight. As the propellers **702** are spun at different speeds relative to each other or their blade angles are pitched more or less relative to each other, the thrust vector **778** of each propeller **702** may be manipulated for control of moments about the center of mass **780** of the aerial vehicle **708**. Turning vane flaps may generate elevator forces **782** in elevator-equivalent and rudder-equivalent directions.

These force vectors may be varied with respect to each other to generate pitching moments about the center of mass **780**, either positive or negative. If the sum of the thrust vectors **778** from the propellers **702** on a first lateral side of the aerial vehicle **708** is greater than the sum of the thrust vectors **778** from the propellers **702** on a second lateral side of the aerial vehicle **708**, then the aerial vehicle **708** pitches around the center of mass **780**, providing all other force vectors remain unchanged. The elevator forces **782** are represented by the two visible components of those vectors. The elevator forces **782** may manipulate the aerial vehicle **708** in z-axis translational motions as well as generate pitching moments about the aircraft center of mass **780**.

FIG. **9** is a top-view of the aerial vehicle **708** of FIG. **8** in fully-converted translational flight. As the sum of the thrust vectors **778**A from the propellers **702** on the first lateral side of the aerial vehicle **708** becomes greater than the sum of the thrust vectors **778**B from the propellers **702** on the second lateral side of the aerial vehicle **708**, the aerial vehicle **708** will yaw clockwise as seen in this view about the aircraft center of mass **780**. The elevator forces **782** may manipulate the aerial vehicle **708** in y-axis translational motions as well as generate yawing moments about the aircraft center of mass **780**. These force differentials (i.e., pitch, roll, yaw) may be accomplished by, for example, varying propeller speeds and/or turning vane orientations as described herein.

FIG. **10** illustrates how an embodiment of an aerial vehicle **808** may maintain deck-level translations and equilibrium during relative movement of the aerial vehicle **808** and the surrounding air. The aerial vehicle **808** in a quiescent flight condition with a farfield freestream velocity near zero exhibits essentially no cross-flow drag, D~0. As the aircraft is exposed to a lateral flow speed induced by direct translation of the aerial vehicle **808** or a gust of air **884**, a crossflow-drag component **886** will go to a non-zero value. To counter this crossflow drag component **886** the pilot and/or flight director may command the turning vane flaps **842** to generate countering lateral elevator forces **882**. To maintain moment equilibrium about the center of mass **880**, the thrust force of the windward propellers **878**A may be reduced with respect to the thrust force of the leeward propellers **878**B while the sum of thrust force of the windward propellers **878**A and thrust force of the leeward propellers **878**B is at the same level as when the aerial vehicle **808** was in hover flight with zero cross-flow. This differential in thrust force **878**A, **878**B may generate a counterclockwise moment about the center of mass **880** which may be used to exactly counter a clockwise moment generated by the elevator force **882** generated by the turning vane flaps **842**. Accordingly, the aerial vehicle **808** may be kept in exact force and moment equilibrium with a level deck.

FIG. **11** illustrates a plurality of guidance, navigation, and flight command signals that may be transmitted to an aerial vehicle **908**. In some embodiments, a conventional radio controller **988** may be used to directly and/or indirectly communication pilot commands to the aerial vehicle **908** via a signal in the electromagnetic spectrum. The pilot commands may be transmitted to a receiver unit **990** within the aerial vehicle **908** which may be attached to one or more antennae. In other embodiments, one or more satellites **992** can send a number of electromagnetic signals to the aerial vehicle **908** so as to provide spatial orientation to the receiver unit **990**. The aerial vehicle **908** may also be fitted with a plurality of proximity sensors **994** operating in acoustic and/or radio frequencies using electromagnetic waves or optical or infrared signals. These signals may be used to increase situational awareness for pilot-commanded flight and/or used as part of an automatic or semi-automatic flight control system.

FIG. **12** illustrates an embodiment of a data flowchart **901** depicting data flow through a flight director with inner loop stability augmentation system (SAS) **903** and an outer loop guidance, navigation, and control (GNC) system **905**. A plurality of sensors may be used to determine atmospherics information **907** and provide the atmospherics information **907** to the flight director. One or more onboard sensors in a collision avoidance and obstacle spatial proximity system may also provide collision avoidance information **909** and aid in establishing aircraft and operator situational awareness. Collision avoidance information **909** may be supplied with pilot commands **911** to the outer GNC system **905** which feeds data to the aerial vehicle only upon mixing within an inner SAS **903**. The outer GNC system **905** may receive a waypoint schedule **913** that is at least partially provided by communication with one or more satellites **992**, described in relation to FIG. **11**. The outer GNC system **905** and inner SAS **903** may provide power and flight control surface commands **915** to the aerial vehicle **908** to move the aerial vehicle **908** according to the pilot commands **911** in light of the atmospherics information **907**, collision avoidance information **909**, and the necessary modifications to maintain stability according to the inner SAS **903**. The aerial vehicle **908** may move in the intended direction and relay back flight state information **917** to the inner SAS **903** and the outer GNC system **905**. In some embodiments, the flight state information may include pitch, orientation, speed, acceleration, inertial moments, altitude, position, other values, or combinations thereof.

At least one embodiment of an aerial vehicle toy may be used in a number of aerial games in addition to simple acrobatics which can be commanded. FIG. **13** shows a pair of aerial vehicles **1008** engaging in combat using a form of radio frequency, optical, infrared, UV, or other electromagnetic beam targeting an opposing aircraft. As the beam originates from an emitter **1096** from the pursuing aerial vehicle **1008**, travels through space and hits the opposing aerial vehicle **1008** on a receiver **1098**. The result of a beam strike could be the emission of a sound signaling a hit, a loss of power, a prescribed aircraft maneuver and/or loss of power or complete motor shut-down.

Other activities may include using an embodiment of an aerial vehicle **1108** to loft a given payload **1119**A as shown in FIG. **14**. Such a payload may be any form of harmless game-related substance and under current FAA rules may be flown indoors. The payload **1119**B in freefall may be safe to humans upon impact, such as a water-balloon, a shaving-cream filled balloon or a bag of flour. When mounted to the aircraft, the payload **1119**A may be released by a remotely controlled release mechanism **1121**. Other payloads may include liquids held in a reservoir which may be ejected from a nozzle **1123** a given distance like shaving cream or other effluents, such as SILLY STRING. In some embodiments, such a reservoir may be located within a body **1130** of the aerial vehicle **1108** and may be ejected from the nozzle **1123** upon receiving a command from the pilot or other operator.

FIG. **15** illustrates the internal core of the aerial vehicle **508** described in relation to FIG. **6**. The internal core may include an undercarriage assembly **536** and a support member **525**. The undercarriage assembly **536** and support member **525** may provide a structural framework upon with the plurality of powerpods **554** and propellers **502** may be mounted. The core may include a flight director **527** in electrical communication with a plurality of sensors and/or communication modules to convert pilot commands and flight state information into flight commands, as described in relation to FIG. **12**. The core may include an energy storage device **529** in electrical communication with the flight director **527**, the plurality of sensors, emitters, the communication module, the plurality of powerpods **554**, any other devices described herein, or combinations thereof.

In other embodiments, the flight director **527** may include an inertial measuring unit (IMU) which will send signals to a comparator which will mix motor command signals which will be amplified by the power electronics assembly. The power electronics assembly will be used to drive indicator sound generators and/or lights to demonstrate to the operator different states of readiness and/or flight command levels. The power electronics assembly will also send power to the powerpods **554**.

The flight director **527** may be shock mounted on a piece of mounting material **531** which is designed so as to provide both equivalent spring stiffness and damping so as to induce stable, controllable flight. The undercarriage assembly **536** forms a straight structural triangle stretching between the energy storage device **529** and the support member **525**. The mounting material **531** may interface with the support member **525**. The support member **525** may have a light fill center or closed center. In the case of a closed center, powerpods **554** are connected at some distance from the center of the support member **525**. The support member **525** may include or be made of any comparatively stiff material like cast nylon or graphite-epoxy composite, which may surround softer material like foam, balsa or honeycomb or no material at all for an open configuration.

FIG. **16** shows the aerial vehicle **508** with a forward wing set **526** and body **530** affixed to the core of FIG. **15** and the aerial vehicle **508** with a nose **548** removed to provide access to the energy storage device **529**. The nose **548** may be polygonal, oval, irregular, or circular in cross section and may be composed of materials which are capable of accepting multiple impact loads from crashing into surfaces soft and hard. The nose **548** may be filled with energy absorbing foam and may be made from sheet stock. The nose **548** may be designed to aerodynamically shield the energy storage device **529** and seat over the forward portion of the body **530**, which, in turn may have a polygonal, oval, irregular or circular cross section. The body **530** transfers forward body structural loads, air, and D'Alembert's forces aft towards the forward sections of the undercarriage assembly **536**.

Because the undercarriage assembly **536** may be stiffer, stronger and heavier per unit volume than the lifting surfaces (i.e., forward wing set **526**) which may be made from materials like polymer or metal honeycomb, foam, foil, paper or balsa, they have several effects on the section and whole surface aeroelastic stability. Because the lifting surfaces can be made from comparatively lightweight materials, a longitudinal section across the wing would be composed of a stiff, strong, comparatively heavy leading edge **534** component as the undercarriage assembly **536** also forms the leading edge **534** of the forward wing set **526**.

While in some embodiments, the undercarriage assembly **536** may be removable, the undercarriage assembly **536** may be integrated into the primary structure of the aerial vehicle **508**. Accordingly, the undercarriage assembly **536** may be a load-bearing member through which landing, takeoff, flight, other loads, or combinations thereof are passed. Because a given longitudinal section of the forward wing set **526** and undercarriage assembly **536** shows a leading edge **534** reinforced by the undercarriage assembly **536**, and the density of the undercarriage assembly **536** may be as much as two orders of magnitude greater than the density of the rest of the forward wing set **526**, the section center of gravity is shifted forward in front of the section aerodynamic center, which, sub-sonically, will be close to the quarter-chord. Similarly, the torsional and flexural stiffnesses of the undercarriage assembly **536** may be greater than the torsional and flexural stiffnesses of the rest of the forward wing set **526**, which trails the undercarriage assembly **536** in the longitudinal direction. The effect of this geometric arrangement on sectional elastic axis is similar to that of the effect on the section center of gravity. Because the undercarriage assembly **536** is often two to five orders of magnitude greater in flexural and torsional stiffness than the rest of the forward wing set **526** which trails it, the elastic axis position quite often is far in front of the quarter-chord of the section, which is approximately the position of the section aerodynamic center. At least partially due to this structural arrangement, both the section center of gravity and the elastic axis may be positioned in front of the section aerodynamic center.

While the undercarriage assembly and leading edge of the wing set have been described as being substantially straight, the leading edge of the wing set may be or include curved elements as shown in FIG. **17**. An embodiment of an aerial vehicle **1208** having a curvilinear undercarriage assembly **1236** may shrink the total aft body length by as much as a factor of two while maintaining an equivalent surface area of a forward wing set **1226**. The leading edge **1234** may include a curve in a range having upper and lower values including any of 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, or any values therebetween. For example, the leading edge **1234** may curve between 10° and 90°. In other examples, the leading edge **1234** may curve between 20° and 50°. In yet other examples, the leading edge **1234** may curve about 30°. Similarly to FIG. **16**, FIG. **17** depicts the aerial vehicle **1208** with a removable nose **1248** removed to allow access to an energy storage device **1229** and/or other electronics.

FIG. **18** depicts an embodiment of an aerial vehicle **1308** including a canard wing set **1333** mounted to a body **1330** of the aerial vehicle **1308**. An aerial vehicle **1308** including curvilinear forward surfaces and/or empennage pieces such as the canard wing set **1333** in addition to the forward wing set **1326** and aft wing set **1328**, the aerodynamic center may be positioned precisely for maintenance of proper stability and maneuverability when converted from hover flight to translational flight.

FIG. **19** depicts an embodiment of an aerial vehicle **1408** including a plurality of types of propulsors. The aerial vehicle **1408** may include at least three aerodynamic propulsors of a first type, such as the propellers **1402** described herein, in combination with a propulsor of a second type. In some embodiments, the aerial vehicle **1408** may include at least three propellers **1402** located equidistant from a longitudinal axis **1432** of the aerial vehicle **1408** with a central mounting channel **1435** that may house a rocket propulsor **1437**. The rocket propulsor **1437** may be a solid fuel rocket, a liquid fuel rocket, staged rocket, other type of rocket, or combinations thereof. In some embodiments, the rocket propulsor **1437** may be mounted forward of the at least three propellers **1402**. In other embodiments, the rocket propulsor **1437** may be positioned such that an exhaust path of the rocket propulsor **1437** may not overlap with the at least three propellers **1402**.

The central mounting channel **1435** may be constructed of heat-resistant materials so as to resist the effects of ejection charges of the rocket propulsor **1437** at the conclusion of core burn. This configuration of rocket propulsor **1437** may be initiated by on-board or ground-based electronics and/or power and/or may be fired by a fuse type assembly. After the rocket propulsor **1437** is consumed, a recoil charge may or may not be used to eject the entire rocket propulsor **1437** or it may be retained for the rest of the flight. The central mounting channel **1435** may place the rocket thrust vector straight through the aircraft center of mass and along the longitudinal axis **1432** for maintenance of flight stability upon motor firing.

The articles "a," "an," and "the" are intended to mean that there are one or more of the elements in the preceding descriptions. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Numbers, percentages, ratios, or other values stated herein are intended to include that value, and also other values that are "about" or "approximately" the stated value, as would be appreciated by one of ordinary skill in the art encompassed by embodiments of the present disclosure. A stated value should therefore be interpreted broadly enough to encompass values that are at least close enough to the stated value to perform a desired function or achieve a desired result. The stated values include at least the variation to be expected in a suitable manufacturing or production process, and may include values that are within 5%, within 1%, within 0.1%, or within 0.01% of a stated value.

A person having ordinary skill in the art should realize in view of the present disclosure that equivalent constructions do not depart from the spirit and scope of the present disclosure, and that various changes, substitutions, and alterations may be made to embodiments disclosed herein without departing from the spirit and scope of the present disclosure. Equivalent constructions, including functional "means-plus-function" clauses are intended to cover the structures described herein as performing the recited function, including both structural equivalents that operate in the same manner, and equivalent structures that provide the same function. It is the express intention of the applicant not to invoke means-plus-function or other functional claiming for any claim except for those in which the words 'means for' appear together with an associated function. Each addition, deletion, and modification to the embodiments that falls within the meaning and scope of the claims is to be embraced by the claims.

The terms "approximately," "about," and "substantially" as used herein represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, the terms "approximately," "about," and "substantially" may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of a stated amount. Further, it should be understood that any directions or reference frames in the preceding description are merely relative directions or movements. For example, any references to "up" and "down" or "above" or "below" are merely descriptive of the relative position or movement of the related elements.

Although the preceding description has been described herein with reference to particular means, materials and embodiments, it is not intended to be limited to the particulars disclosed herein; rather it extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims.

What is claimed is:

1. An aerial vehicle, comprising:

a body having a central longitudinal body axis, the body including:

a plurality of forward wings, each forward wing of the plurality of forward wings extending in a forward wing plane that includes the central longitudinal body axis, and

a plurality of aft wings, each aft wing of the plurality of aft wings extending in an aft wing plane that contains the central longitudinal body axis;

at least one motor supported by the body; and

at least three aerodynamic propulsors driven by the at least one motor, the at least three aerodynamic propulsors being located between the plurality of forward wings and the plurality of aft wings and lying in a horizontal plane that is perpendicular to the central longitudinal body axis, the at least three aerodynamic propulsors being configured to provide translational control about the central longitudinal body axis, and pitch, yaw, and roll control.

2. The aerial vehicle of claim **1**, the body further comprising a longitudinally forward, transversely central nose section that terminates in an aerodynamically shaped nose.

3. The aerial vehicle of claim **1**, further comprising a removable undercarriage assembly attached to the body such that major structural loads are delivered to the plurality of forward wings, and which extends beyond a radially outermost point of the at least three aerodynamic propulsors from the central longitudinal body axis.

4. The aerial vehicle of claim **3**, further comprising landing pads on a radially outwardmost end of the undercarriage assembly from the central longitudinal body axis.

5. The aerial vehicle of claim **1**, further comprising a plurality of turning vane flaps to provide pitch, yaw, and roll control and translational flight control along transverse and rotational body axes relative to the central longitudinal body axis.

6. The aerial vehicle of claim **1**, wherein the plurality of forward wings are structurally connected to the body and the plurality of aft wings are structurally connected to the body, and wherein structural loads are transferred from the plurality of forward wings to the body and structural loads are transferred from the plurality of aft wings to the body.

7. The aerial vehicle of claim **1**, further comprising a communication module capable of receiving a command signal from a human-operated transmitter or satellite and providing the command signal to the at least one motor.

8. The aerial vehicle of claim **1**, further comprising an undercarriage defining a propulsor cage between the plurality of forward wings and the plurality of aft wings to mitigate object strikes against at least one of the aerodynamic propulsors.

9. The aerial vehicle of claim **1**, further comprising a flight director including an inner loop stability augmentation system and outer loop guidance, navigation, and control system which senses both spatial orientation and location and issues flight control commands to counter deviations from commanded flight paths.

10. The aerial vehicle of claim **1**, further comprising an emitter configured to emit beams operating in any radio frequency, infrared, ultraviolet or visible wavelength and a sensor configured to sense the beams.

11. An aerial vehicle, comprising:

a body having a central longitudinal body axis, the body including:

a plurality of forward wings, each forward wing of the plurality of forward wings extending in a forward wing plane that includes the central longitudinal body axis, and

a plurality of aft wings, each aft wing of the plurality of aft wings extending in an aft wing plane that contains the central longitudinal body axis;

at least three aerodynamic propulsors, each of the aerodynamic propulsors having a motor associated therewith and driving the aerodynamic propulsor, the at least three aerodynamic propulsors being located between the plurality of forward wings and the plurality of aft wings and lying in a horizontal plane that is perpendicular to the central longitudinal body axis, the at least three aerodynamic propulsors being configured to provide translational control about the central longitudinal body axis and pitch, yaw, and roll control;

a communication module capable of receiving a command signal from a human-operated transmitter or satellite and providing the command signal to at least one of the motors; and

a flight director in data communication with at least one of the motors associated with the at least three aerodynamic propulsors, the flight director having a stability augmentation system configured to receive flight state information and pilot commands and to output flight control commands based at least partially upon the flight state information and pilot commands.

12. The aerial vehicle of claim **11**, further comprising a plurality of turning vane flaps to provide pitch, yaw, and roll control and translational flight control along transverse and rotational body axes, the plurality of turning vane flaps operably connected to vane motors, wherein the vane motors are in data communication with the flight director.

13. The aerial vehicle of claim **12**, further comprising orientation and acceleration sensors in data communication with the flight director, the orientation and acceleration sensors configured to provide flight state information to the stability augmentation system.

14. The aerial vehicle of claim **12**, further comprising a proximity sensor in data communication with the flight director, the proximity sensor configured to detect a direction of and a distance to an object relative to the body.

15. An aerial vehicle, comprising:

a body having a central longitudinal body axis and a forward end and an aft end, the body including:

a plurality of forward wings, each forward wing of the plurality of forward wings extending in a forward wing plane that includes the central longitudinal body axis, wherein each wing of the plurality of forward wings have a structural leading edge that is configured to structurally support landing gear and extends through a radially outwardmost point of the aerial vehicle, and

a plurality of aft wings, each aft wing of the plurality of aft wings extending in an aft wing plane that contains the central longitudinal body axis;

at least three aerodynamic propulsors, each of the aerodynamic propulsors having a motor associated therewith and driving the aerodynamic propulsor, the at least three aerodynamic propulsors being located longitudinally between the plurality of forward wings and the plurality of aft wings, lying in a horizontal plane that is perpendicular to the central longitudinal body axis, and located within the radially outwardmost point such that the structural leading edge forms a propulsor cage that provides protection for the aerodynamic propulsors from impact, the at least three aerodynamic propulsors being configured to provide translational control about the central longitudinal body axis and pitch, yaw, and roll control; and

a flight director in data communication with each of the motors associated with the at least three aerodynamic propulsors, the flight director having a stability augmentation system configured to receive flight state information and pilot commands and to output flight control commands based at least partially upon the flight state information and pilot commands.

16. The aerial vehicle of claim **15**, wherein at least a portion of the structural leading edge is curved.

17. The aerial vehicle of claim **15**, wherein the body further includes a cargo volume, the cargo volume configured to deploy at least part of a cargo contained therein during flight.

18. The aerial vehicle of claim **15**, wherein the plurality of forward wings and the plurality of aft wings comprise removable training wings.

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