

ROTARY-WING AIR VEHICLE AND METHOD AND APPARATUS FOR LAUNCH AND RECOVERY THEREOF

This invention relates generally to a rotary-wing air vehicle and method and apparatus for launch and recovery thereof and, more particularly but not necessarily exclusively, to an unmanned aerial vehicle (UAV) and method and apparatus for launch and recovery thereof.

Unmanned aerial vehicles (UAVs), are well known and used in many different military, as well as civil and commercial, applications, such as search and rescue surveillance, reconnaissance, etc. In general, a UAV is a powered aerial vehicle that does not have a human operator on board, uses aerodynamic forces to provide vehicle lift, and can fly autonomously or be piloted remotely. Although not always a requirement, it is often required for such vehicles to be recoverable and even reusable after a mission.

As with piloted air vehicles, two principal, general types of UAV are known: (i) fixed wing, and (ii) rotary wing.

A fixed wing air vehicle is illustrated schematically in Figure 1A of the drawings. As shown, a fixed wing air vehicle comprises a main body 1 having a pair of wings 2 extending therefrom, and a respective thrust mechanism 3, such as a propeller or jet, mounted on (or in relation to) each wing. Lift is created by the vehicle's forward airspeed and the shape of the wings 2. The principal advantage of a fixed wing UAV is the speed and endurance that can be achieved, making such UAVs particularly suitable for long-distance and/or persistent missions.

A rotary wing air vehicle is illustrated schematically in Figure 1B of the drawings. As shown, a rotary wing UAV typically comprises a main body 4 having a generally central mast 5 mounted at its upper end, with rotor blades 6 rotatably mounted on the mast 5. Lift is generated by high speed rotation of the rotor blades 6 around the mast 5. Another type of rotary-wing air vehicle, known as a multi-copter, comprises a main body and three or more rotor devices, each rotor device being mounted at or near a distal end of a fixed arm extending substantially horizontally from the main body, and configured to generate lift and propulsion in respect of the main body without the rotor blades of the rotor devices ever crossing through the centre of mass (central vertical axis) of the vehicle. The principal advantage of a rotary wing UAV is that it can take

off and land vertically as well as fly forwards, backwards and laterally, and hover, making it particularly suitable for take off and landing where ground space is limited, as well as specific surveillance operations where control is paramount. However, compared with fixed wing air vehicles, rotary winged aircraft have a relatively limited 'endurance'.

There is an ongoing desire to reduce/minimise the ground space required to enable a rotary-wing vehicle to take off and land, particularly in environments where such space is limited. Even though a conventional rotary wing air vehicle is configured to take off and land 'vertically', that is not usually precisely achieved, due, for example, to cross winds and other factors which may affect the vertical stability of the air vehicle and cause it to move laterally before it is safely clear of bystanders and/or infrastructure nearby.

There are also many circumstances in which the speed and endurance capability of a fixed wing UAV, as well as the manoeuvrability of a rotary wing UAV, may be required, whereas there is currently a clear trade-off between the two distinct types of UAV. It would, therefore, be desirable to provide an air vehicle, such as a UAV, that is able to take off and land from a relatively small ground space, fly forward, backward and laterally, as required, and hover, as well as having the speed and endurance characteristics of a fixed wing air vehicle.

Aspects of the present invention seek to address at least some of these issues and, in accordance with a first aspect of the present invention, there is provided a rotary-wing air vehicle comprising a main body, at least two rotor devices arranged and configured to generate propulsion and thrust, in use, to lift and propel said air vehicle, said rotor devices being arranged and configured relative to said main body such that the blades thereof do not cross through a central vertical axis of said main body defining the centre of mass thereof, wherein said main body is provided with an aperture that extends therethrough to define a channel about said central vertical axis, and a pair of opposing wing members extending substantially laterally from the main body, each said wing member defining a longitudinal axis, at least a first propulsion device associated with a first of said wing members arranged and configured to generate a linear thrust relative to the main body in a first direction, and a second propulsion device associated with a second of said wing members arranged and configured to generate linear thrust relative to said main body in a second,

substantially opposite, direction such that said wing members and said main body are caused to rotate, in use.

The air vehicle may be a multicopter comprising a three or more rotor devices, each rotor device being mounted at or near a distal end of a fixed arm extending substantially horizontally from said main body.

The propulsion devices may be fixedly coupled to respective wing members, and at least one of said wing members may be rotatably mounted with respect to said body for rotation about an axis orthogonal to the width of the main body when in an upright orientation, between a first position defining a fixed wing flying mode wherein thrust generated by both said propulsion devices acts in the same direction relative to the main body, and a second position defining a rotary wing flying mode wherein thrust generated by said propulsion devices acts in opposite respective directions relative to said main body.

The at least one wing member may be configured to rotate through substantially 180° about said axis between said first and second positions.

The at least one wing member may be mounted to the main body via a coupling member, said coupling member engaging with an actuation device located in or on said main body, wherein operation of said actuation member is effected by said control signal and causes rotation of said at least one wing member via said coupling member.

The above-mentioned channel may be generally conical in configuration, with the diameter thereof increasing from the upper to the lower edge of the main body, when the vehicle is oriented for use.

In accordance with another aspect of the present invention, there is a system comprising at least one apparatus for launch and recovery of an air vehicle substantially as described above, comprising an elongate pole member configured to extend, in use, through said channel defined by said aperture in said main body of said air vehicle.

Thus, the apparatus of the present invention, and the configuration of the air vehicle according to the present invention enables a launch and recovery process to be achieved, whereby the vehicle is horizontally constrained by the pole member during take off and landing, thereby ensuring that it travels only vertically whilst it is at

an altitude where it might otherwise pose a threat to nearby people and/or infrastructure.

The pole member may be telescopic and moveable between a fully extended and fully contracted configuration. The apparatus may further comprise a base member on which said pole member is mounted or with which said pole member is formed integrally. In this case, the base member may be configured to support said pole member on a surface. The base member may be mounted on a gimbal mechanism configured to maintain said pole member in an upright position.

Alternatively, the base member may comprise a handle to allow manual manipulation of said pole member relative to an air vehicle, in use.

The base member may comprise or include a container arranged such that a portion of said pole member extends substantially centrally therethrough, and configured to house a plurality of said air vehicles in stacked formation, with each said air vehicle being mounted on said pole member via a respective aperture therein. In this case, the container may have an open upper end, and comprises a closure mechanism for selectively opening and closing said open upper end. The closure mechanism may, for example, comprise an iris type closure mechanism comprising a plurality of leaf members arranged around, and pivotally coupled to, the peripheral edge of said open upper end of said container, and further comprising an actuating mechanism for selectively laterally pivoting said leaf members between an open configuration and a closed configuration.

In accordance with another aspect of the present invention, there is provided a method of launching an air vehicle substantially as described above using apparatus substantially as described above, comprising the steps of providing at least one air vehicle on said pole member adjacent to said base member such that said pole member extends through said aperture, and operating said air vehicle such that it is lifted along said pole member toward its distal end until it is clear of said distal end.

In accordance with yet another aspect of the present invention, there is provided a method of recovery of an air vehicle substantially as described above using apparatus substantially as described above, comprising the steps of aligning the distal end of said pole member with said aperture in said main body of said air vehicle, subsequently, capturing said air vehicle on said pole member by causing said distal

end of said pole member to enter said channel, and causing said captured air vehicle to move downwardly along said pole member to a location adjacent to said base member.

The air vehicle may further comprise one or more sensors located in the vicinity of said channel, and said pole member comprises at least one beacon device, and said apparatus may further comprise a guidance control module for monitoring signals emitted by said sensors and said beacon device, determining when said distal end of said pole member is aligned with the aperture of an air vehicle to be recovered, and outputting a control signal indicative thereof to cause said air vehicle to be captured on said pole member.

These and other aspects of the present invention will be apparent from the following specific description in which embodiments of the invention are described, by way of examples only, and with reference to the accompanying drawings, in which:

Figure 1A is a schematic front view of a fixed wing air vehicle according to the prior art;

Figure 1B is a schematic front view of a rotary wing air vehicle according to the prior art;

Figure 2 is a schematic plan view of a hybrid fixed-rotary wing air vehicle according to a first exemplary embodiment of the present invention, illustrated in the fixed wing flying mode configuration;

Figure 3 is a schematic plan view of the hybrid fixed-rotary wing air vehicle of Figure 2, illustrated in the rotary wing flying mode configuration;

Figure 4 is a schematic plan view illustrating the manner of connection of a wing to the main body in a hybrid fixed-rotary wing air vehicle according to an exemplary embodiment of the present invention;

Figure 4A is a schematic diagram illustrating the flight phases of a typical mission undertaken by a hybrid fixed-rotary wing air vehicle according to an exemplary embodiment of the present invention;

Figure 5 is a schematic front view of a launch and recovery apparatus according to an exemplary embodiment of the present invention, when in use to launch an air vehicle according to an exemplary embodiment of the present invention;

Figure 5A is a schematic front view of a launch and recovery apparatus according to another exemplary embodiment of the present invention;

Figure 6 is a schematic front view of the apparatus of Figure 5, when in use to recover an air vehicle according to an exemplary embodiment of the present invention;

Figure 6A is a schematic bottom perspective view of the aperture and channel defined through the main body of an air vehicle according to an exemplary embodiment of the present invention;

Figure 7 is a schematic front view of a launch and recovery apparatus according to another exemplary embodiment of the present invention;

Figure 7A is a schematic plan view of the launch and recovery apparatus of Figure 7, when the canister is open; and

Figure 7B is a schematic plan view of the launch and recovery apparatus of Figure 7, when the canister is closed.

Referring to Figure 2 of the drawings, an air vehicle according to a first exemplary embodiment of the present invention comprises a main body, on which are mounted two opposing wing members such that they extend laterally outward from respective opposing sides of the main body to define a wingspan having a longitudinal axis. In the example shown, the wings have a compound swept back configuration, to aid aerodynamic stability and reduce drag, but it will be appreciated that the present invention is in no way intended to be limited with regard to wing configuration. A respective propulsion device is mounted at the 'leading' edge of each wing and, in the example shown, the propulsion devices are facing in the same direction. Thus, when both propulsion devices are operated to generate thrust in the same direction, they cause the vehicle to move forwards. Referring additionally to Figure 3A of the drawings, the aerofoil cross-sectional shape of the wings produces an aerodynamic force as the vehicle moves forward; and the component of this force perpendicular to the direction of motion is called lift, whereas the component parallel to the direction of motion is called drag. "Turning" of the air in the vicinity of the aerofoil creates curved streamlines, resulting in lower pressure on one side and higher pressure on the other. This pressure difference is accompanied by a velocity difference, via Bernoulli's principle, so the resulting flowfield about the aerofoil has a higher average velocity on

the upper surface than on the lower surface. The lift force is related directly to the average top/bottom velocity difference.

Referring back to Figure 2 and also to Figure 4 of the drawings, at least one of the wings is rotatably mounted on the side of the main body by means of a longitudinal shaft extending from the inner end of the wing. Thus, referring to Figure 3 of the drawings, in the event that it is required to change the mode of flying of the vehicle from fixed wing to rotary wing flying mode, a control signal is generated that causes the wing to rotate about the axis defined by the shaft (which is substantially parallel to the axis defined by the wingspan), such that the leading edge of the wing and the associated propulsion device are facing in the opposite direction. With the thrust from the two propulsion devices now operating in opposite linear directions, the net result is a rotary force that causes the air vehicle as a whole to spin. Lift is maintained because the spinning wings act as a rotary blade forcing air downwardly to overcome the force of gravity and create vertical lift. However, it is envisaged that the effective aerofoil cross-section of the propeller blades may be dynamically altered according to their relative location within a rotary cycle in order to maintain efficient horizontal movement of the vehicle. In the rotary wing mode, the aircraft can be controlled in a manner similar to a conventional rotary wing air vehicle, to control vertical, horizontal and rotational movement of the vehicle, as required.

It can be seen from Figure 4 of the drawings, that the air vehicle described above is provided with an aperture generally centrally on, and extending through, the main body which defines a channel having its longitudinal axis substantially orthogonal to the longitudinal axis of the wing members. Referring additionally to Figure 5 of the drawings, apparatus for launch and recovery of the air vehicle described above is illustrated schematically, in the form of a pole having some sort of base member to enable the pole to be supported on a surface, such as the deck of a ship or the like. In the example shown, the base member is a three dimensional (e.g. conical or cylindrical) base member that is functional to provide a space between the bottom of the pole and the ground. In some exemplary embodiments, as illustrated in Figure 5A of the drawings, the base member may comprise a handle or hand grip to allow it to be held and controlled by a person.

In the case where the apparatus may be required to be used on a moving base, such as a ship, the base member may be mounted on a gimbal arrangement. A gimbal

is defined as a pivoted support that allows the rotation of an object about a single axis. A set of three gimbals, one mounted on the other with orthogonal pivot axes may be used in this case, wherein the base member carrying the pole is mounted on the innermost gimbal such that it remains independent of the rotation of its support. In other words, the pole, when mounted on the gimbaled base member, will remain upright (substantially vertical) irrespective of whether the craft or body on or by which it is carried is pitching forward, left, right, etc.

The pole itself may, advantageously be of telescopic configuration, for ease and safety of storage and transportation. In use, to launch the air vehicle, the vehicle (in the rotary wing mode and configuration described above with reference to Figure 3 of the drawings) is mounted on the pole, adjacent to the base member (or handle), with the pole extending through the aperture in the centre of the main body. The propulsion devices 16a, 16b, which are facing in opposite directions relative to the main body, are started such that the vehicle starts to rotate about the pole. Once the speed of rotation of the vehicle is sufficient, lift is generated and the air vehicle will start to rise, still spinning about the pole. Any instability in the vehicle rotation during this process is compensated by the pole which prevents the vehicle from being deflected or diverted out of the very small launch volume, the radius of which is defined by the distance between the centre of the aperture and the distal end of each wing member.

The pole is of sufficient length, by design, to ensure that the air vehicle has reached a sufficient speed and level of stability by the time it reaches the top and is lifted clear of the distal end of the pole to independently effect substantially stable flight. At this point, the air vehicle can be controlled (remotely or automatically) to move horizontally away from the top of the pole and, if required, then transformed from the rotary wing flying mode to the fixed wing flying mode (described above with reference to Figure 2 of the drawings) by rotation of the wing member, such that the propulsion devices are both located on the leading edge of respective wing members and generating thrust in the same direction relative to the main body of the air vehicle.

Referring to Figure 6 of the drawings, when a flight is complete, and it is required to recover the air vehicle, its flying mode is again changed to the rotary-wing flying mode described above with reference to Figure 3 of the drawings, by rotating one of the wing members (or otherwise changing the direction of thrust of one of the

propulsion devices relative to the main body), such that the whole air vehicle starts to spin. It can then commence its descent back toward the pole of the above-described apparatus (or a similar apparatus). In this case, it is envisaged that sensors (not shown) may be provided on the air vehicle, possibly in the vicinity of the aperture, that cooperate with, for example, a beacon or similar device located at the distal end of the pole to cause a reference or guidance signal to be generated that is configured to guide the air vehicle onto the pole such that the pole enters the aperture. In one exemplary embodiment, guidance control signals may be generated by a plurality of sensors (not shown) located in spaced-apart relation around the lower periphery of the aperture, and the above-mentioned beacon on the distal end of the pole may generate a signal of similar configuration. Thus, in one exemplary embodiment of the invention, a guidance control system may be configured to monitor a phase difference between the sensor and beacon signals to generate the above-mentioned reference or guidance signal, and determine when the phase of all of the guidance control signals matches that of the beacon signal, thereby indicating that the air vehicle is correctly located above the pole for effective recovery thereof.

In another exemplary embodiment, wherein a handle or hand grip is provided at the proximal end of the pole (as shown in Figure 5A of the drawings), an operator may hold and manually control the pole thereby, in order to “spear” or capture the air vehicle, via the aperture, onto the pole.

Either way, and referring to Figure 4B of the drawings, it can be seen that the inner configuration of the aperture through the main body may be generally conical so as to aid capture of the air vehicle during the recovery process. Once the pole tip (and, optionally, a sufficient length of the pole) has passed through the aperture in the main body, the propulsion devices can be automatically switched off to allow the vehicle to progressively slow down and stop spinning and thus slide down the remaining length of the pole until it comes to rest at the top of the base member.

Thus, referring to Figure 4A of the drawings, aspects of the present invention provides an air vehicle concept which is capable of being launched and recovered vertically within a very small volume, hovering flight, and the ability to transition to fixed wing flight, thereby achieving the increased speed and endurance characteristics associated therewith.

In another exemplary embodiment of the invention, as illustrated schematically in Figures 7, 7A and 7B of the drawings, the base member may have a canister mounted thereon (or formed integrally therewith), in which is housed a plurality of stacked air vehicles of the type described above. Each of the stacked air vehicles is housed and aligned with the canister, and mounted on the pole such that the pole extends through the aperture of each of the stacked air vehicles. The canister may be provided with a closure mechanism which is configured to selectively open and close the canister laterally (so as to avoid obstructing the vertical path of the air vehicles up the pole). Such a closure mechanism may comprise an “iris” type mechanism comprising a plurality of ‘leaves’ arranged in overlapping configuration about the periphery of the open end of the canister, and individually pivotally coupled thereto. Each of the leaves is substantially identical in size and shape and configured, in the closed configuration, to extend partially over the open end of the canister, with the net effect of all of the leaves being that they cover the open end of the canister, leaving a central opening to accommodate the pole. Each of the pivotally-coupled leaves is communicably coupled to an actuating mechanism (not shown) which, when in use, causes each of the leaves to pivot about its pivotal axis (substantially laterally relative to the open end of the canister), toward the inner peripheral wall of the canister, so as to expose the open end thereof and allow the air vehicles therein to move, unobstructed, upwardly along the length of the pole.

Thus, when the canister is in the open configuration, each of the air vehicles can be launched in turn, in the manner described above, starting with the air vehicle at the top of the stack, nearest to the open end of the canister. During recovery, each of the air vehicles can, in turn, be recovered in the manner described above, becoming ‘stacked’ within the canister once again. Once all of the vehicles have been recovered as required, the closure mechanism described above is used to seal the open end of the canister to protect the air vehicles housed therein, until required once again for use.

It will be appreciated by a person skilled in the art, from the foregoing description, that modifications and variations can be made to the described embodiments, without departing from the scope of the invention as defined by the appended claims. For example, the principles described above may be applied to a multi-copter vehicle comprising a plurality of rotor devices, whereby each rotor device

is mounted at or near a distal end of a fixed arm extending substantially horizontally from the main body. The central aperture can be provided through the main body of this type of vehicle and the launch and recovery method and apparatus described above can be used because, in this type of device, the rotor blades do not pass through the centre of mass of the vehicle such that they will not interfere with the pole as the vehicle moves up or down along it.

Throughout this specification, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The reference to any prior art in this specification is not, and should not be taken as, an acknowledgment or any form of suggestion that the prior art forms part of the common general knowledge in Singapore.

CLAIMS

1. A rotary-wing air vehicle comprising:

a main body;

at least two rotor devices arranged and configured to generate propulsion and thrust, in use, to lift and propel said air vehicle, said rotor devices being arranged and configured relative to said main body such that the blades thereof do not cross through a central vertical axis of said main body defining the centre of mass thereof, wherein said main body is provided with an aperture that extends therethrough to define a channel about said central vertical axis; and

a pair of opposing wing members extending substantially laterally from the main body, each said wing member defining a longitudinal axis, at least a first propulsion device associated with a first of said wing members arranged and configured to generate a linear thrust relative to the main body in a first direction, and a second propulsion device associated with a second of said wing members arranged and configured to generate linear thrust relative to said main body in a second, substantially opposite, direction such that said wing members and said main body are caused to rotate, in use

2. An air vehicle according to claim 1, wherein said air vehicle is a multi-copter comprising a three or more rotor devices, each rotor device being mounted at or near a distal end of a fixed arm extending substantially horizontally from said main body.

3. An air vehicle according to any one of the preceding claims, wherein said propulsion devices are fixedly coupled to respective wing members, and at least one of said wing members is rotatably mounted with respect to said body for rotation about an axis orthogonal to the width of the main body when in an upright orientation, between a first position defining a fixed flying mode wherein thrust generated by both said propulsion devices acts in the same direction relative to the main body, and a second position defining a rotary wing flying mode wherein thrust generated by said propulsion devices acts in opposite respective directions relative to said main body.

4. An air vehicle according to claim 3, wherein said at least one wing member is configured to rotate through substantially 180° about said axis between said first and second positions.
5. An air vehicle according to claim 3 or claim 4, wherein the at least one wing member is mounted to the main body via a coupling member, said coupling member engaging with an actuation device located in or on said main body, wherein operation of said actuation member is effected by said control signal and causes rotation of said at least one wing member via said coupling member.
6. An air vehicle according to any of the preceding claims, wherein said channel is generally conical in configuration, with the diameter thereof increasing from the upper to the lower edge of the main body, when the vehicle is oriented for use.
7. A system comprising:
at least one air vehicle according any one of the preceding claims; and
apparatus for launch and recovery of the air vehicle, comprising an elongate pole member configured to extend, in use, through said channel defined by said aperture in said main body of said air vehicle.
8. The system according to claim 7, wherein the apparatus for launch and recovery further comprises a base member on which said pole member is mounted or with which said pole member is formed integrally.
9. The system according to claim 8, wherein said base member comprises or includes a container arranged such that a portion of said pole member extends substantially centrally therethrough, and configured to house a plurality of said air vehicles in stacked formation, with each said air vehicle being mounted on said pole member via a respective aperture therein.
10. The system according to claim 9, wherein said container has an open upper end, and comprises a closure mechanism for selectively opening and closing said open upper end.
11. The system according to claim 10, wherein said closure mechanism comprises an iris type closure mechanism comprising a plurality of leaf members arranged around, and pivotally coupled to, the peripheral edge of said open upper end of said container, and further comprising an actuating mechanism for selectively

laterally pivoting said leaf members between an open configuration and a closed configuration.

12. A method of launching an air vehicle according to any of claims 1 to 6 using apparatus comprising an elongate pole member configured to extend, in use, through said channel defined by said aperture in said main body of said air vehicle and a base member on which said pole member is mounted or with which said pole member is formed integrally, the method comprising the steps of providing at least one air vehicle on said pole member adjacent to said base member such that said pole member extends through said aperture, and operating said air vehicle such that it is lifted along said pole member toward its distal end until it is clear of said distal end.
13. A method of recovery of an air vehicle according to any of claims 1 to 6 using apparatus comprising an elongate pole member configured to extend, in use, through said channel defined by said aperture in said main body of said air vehicle and a base member on which said pole member is mounted or with which said pole member is formed integrally, the method comprising the steps of aligning the distal end of said pole member with said aperture in said main body of said air vehicle, subsequently, capturing said air vehicle on said pole member by causing said distal end of said pole member to enter said channel, and causing said captured air vehicle to move downwardly along said pole member to a location adjacent to said base member.
14. A method according to claim 13, wherein said air vehicle further comprises one or more sensors located in the vicinity of said channel, and said pole member comprises at least one beacon device, said apparatus further comprising a guidance control module for monitoring signals emitted by said sensors and said beacon device, determining when said distal end of said pole member is aligned with the aperture of an air vehicle to be recovered, and outputting a control signal indicative thereof to cause said air vehicle to be captured on said pole member.