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DEPLOYABLE WING SYSTEM FOR AIR VEHICLE

TECHNOLOGICAL FIELD

This invention relates to wing systems for an air vehicle, in particular wing systems having deployable wings for providing aerodynamic flight capability to air vehicles.

BACKGROUND

Some types of air vehicles, for example some types of unmanned air vehicles (UAVs), are configured as subsonic air vehicles. In some cases, the air vehicle is launched with the lift-generating wings folded in close proximity to the fuselage, and the wings are subsequently deployed to enable aerodynamic flight.

Some examples of existing air vehicles having a deployable appendage include: Lockheed Martin Outrider; Area-I ALTIUS family; Green Dragon (IAI); UVision Hero 120; SkyStriker; VXAerospace Dash X; AeroVironment Switchblade; MBDA Viper Strike.

By way of non-limiting example, US 2012/138727 discloses a sonar buoy that includes a fuselage having a tube-like shape, one or more wings coupled to the fuselage, an engine coupled to the fuselage and operable to propel the sonar buoy through flight, and a guidance computer operable to direct the sonar buoy to a predetermined location. The sonar buoy further includes a sonar detachably coupled to the fuselage and forming at least a part of the fuselage, and a rocket motor detachably coupled to the fuselage. The one or more wings are operable to be folded into a position to allow the sonar buoy to be disposed within a launch tube coupled to a vehicle and to automatically deploy to an appropriate position for flight after the sonar buoy is launched from the launch tube. The rocket motor propels the sonar buoy from the launch tube and detaches from the fuselage after launch.

Further by way of non-limiting example, US 2012/280080 discloses a folding wing for an aircraft comprises first and second inboard wing sections, and first and second

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outboard wing sections. The first and second inboard wing sections rotate about a centerline hinge, and a centerline spring applies force to the first and second inboard wing sections to rotate the first and second inboard wing sections from a stowed position to a deployed position. At least one of the first and second inboard wing sections translates along the axis of rotation of the first and second inboard wing sections as they move from the stowed to the deployed positions. The first and second outboard wing sections rotate between the stowed and the deployed positions about first and second outboard hinges.

Further by way of non-limiting example, US 2017/369150 discloses a wing for an unmanned aerial vehicle, which includes a first body of the wing with a first end proximate a body of the vehicle. A second end is opposite the first end. A first joint is on the first end of the first main body of the wing. The joint rotatably couples the wing to the vehicle. A second joint is on the second end of the vehicle. A second body of the wing is rotatably coupled to the first body via the second joint.

Further by way of non-limiting example, US 2016/355250 discloses a deployment or hinge mechanism and, more particularly, a compact unmanned aerial vehicle (UAV) wing deployment mechanism. The deployment mechanism includes a hinged mechanism that stows in a stacked configuration and deploys in a level configuration.

Further by way of non-limiting example, WO 2002/2972 relates to a wing folding mechanism for a pair of wings comprising a lower wing and a co-operative upper wing extending opposite to each other in a deployment position and approach each other when rotated from respective remote ends to a resting position.

Further by way of non-limiting example, CN108177783A discloses a training type unmanned aerial vehicle, comprising a head, a body, a main wing mechanism, a tail wing mechanism, a power device and a parachute.

Further by way of non-limiting example, CN107745800A discloses an unmanned aerial vehicle for architectural municipal gardens. The unmanned aerial vehicle comprises a fuselage and two wing devices respectively arranged at two sides of the fuselage.

Further by way of non-limiting example, CN107380402 relates to an unmanned aerial vehicle with folding wings. The unmanned aerial vehicle with the folding wings comprises a fuselage, the wings, horizontal tails, vertical tails, a folding wing releasing

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mechanism and a fixing base, and positioning holes are formed in the wings, the horizontal tails and the vertical tails; and positioning clamp columns are arranged on the fixing base, and the positioning clamp columns are matched with the positioning holes.

Further by way of non-limiting example, CN107284651 relates to a folding type wing. The folding type wing is mainly formed by parts of a wing supporting framework, a sliding rail, skin-covered supporting ribs, a covering skin, a wing motion device and the like.

Further by way of non-limiting example, CN106741847A discloses a launching type unmanned aerial vehicle (UAV) and a system and an implementing method thereof.

GENERAL DESCRIPTION

According to a first aspect of the presently disclosed subject matter there is provided a wing system for an air vehicle, the air vehicle having a fuselage including a fuselage longitudinal axis, the wing system comprising:

- a set of wings, configured for transitioning between a stowed configuration and a deployed configuration, the set of wings including:

- a first said wing having a first wing tip, a first wing longitudinal axis, and a first pivot axis;

- a second said wing having a second wing tip, a second wing longitudinal axis, and a second pivot axis;

- wherein said first pivot axis and said second pivot axis are non-coaxial;

- wherein in the stowed configuration, the first wing and the second wing are in overlying relationship such that at least a majority of a pressure surface of one of said first wing and said second wing is facing a suction surface of the other one of said one of said first wing and said second wing, and said first wing tip is spaced from said second wing tip by a first lateral spacing; and

- wherein in the deployed configuration, the first wing is oriented with respect to the second wing such that said first wing tip is spaced from said second wing tip by a second lateral spacing greater than said first lateral spacing;

- and wherein said transitioning comprises a pivoting operation, comprising:

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pivoting said first wing about said first pivot axis between the stowed configuration and the deployed configuration;

pivoting said second wing about said second pivot axis between the stowed configuration and the deployed configuration.

For example, the wing system is configured for providing a levelling operation configured for levelling the first wing and the second wing with respect to one another from the overlying relationship in the stowed configuration, to a leveled relationship in the deployed configuration. For example, the wing system is configured for providing said levelling operation concurrent with said transitioning between said stowed configuration and said deployed configuration.

Additionally or alternatively, for example, the wing system is configured for synchronizing said levelling operation with said pivoting operation.

Additionally or alternatively, for example, the wing system is configured for providing a translation operation configured for selectively translating the first wing and the second wing along a stroke direction through a stroke length, between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration. For example, the wing system is configured for providing said translation operation concurrent with said transitioning between said stowed configuration and said deployed configuration.

Additionally or alternatively, for example, the wing system is configured for synchronizing said translation operation with said pivoting operation.

Additionally or alternatively, for example, in the stowed configuration, the first wing and the second wing are configured in said overlying relationship for being oriented with respect to the fuselage section such that the first wing longitudinal axis and the second wing longitudinal axis are each nominally parallel with the fuselage longitudinal axis.

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Additionally or alternatively, for example, in the deployed configuration, the first wing is oriented with respect to the fuselage section such that the first wing longitudinal axis is non-parallel with respect to the fuselage longitudinal axis.

Additionally or alternatively, for example, said first pivot axis is parallel with respect to said second pivot axis.

Additionally or alternatively, for example, said first pivot axis is laterally spaced with respect to said second pivot axis by a lateral spacing.

Additionally or alternatively, for example, the wing system comprises a deployment mechanism configured for selectively transitioning the first wing and the second wing between said stowed configuration and said deployed configuration. For example, said deployment mechanism comprises an actuator configured for selectively driving operation of the deployment mechanism. Additionally or alternatively, for example, said deployment mechanism is configured for self locking. Additionally or alternatively, for example, said first wing comprises a first pivot shaft coaxial with the first pivot axis, and wherein said second wing comprises a second pivot shaft coaxial with the second pivot axis; for example, said deployment mechanism comprises a load bearing bulkhead, wherein said first wing is pivotably mounted to said load bearing bulkhead via said first pivot shaft, and said second wing is pivotably mounted to said load bearing bulkhead via said second pivot shaft. Additionally or alternatively, for example, said deployment mechanism is configured for providing in said pivoting operation a pivoting synchronization operation comprising synchronizing pivoting of said first wing about said first pivot axis in a first rotational direction with pivoting of said second wing about said second pivot axis in a second rotational direction, opposite to said first rotational direction. For example, said deployment mechanism comprises a meshed gear arrangement for providing said synchronization operation. For example, said meshed gear arrangement comprises a first gear wheel fixedly mounted to said first pivot shaft and co-axial with said first pivot axis, and a second gear wheel fixedly mounted to said second pivot shaft and co-axial with said second pivot axis, wherein said first gear wheel is meshed with respect to said second gear wheel. For example, said actuator comprises a motor operatively coupled to said meshed gear arrangement and configured for

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selectively providing a torque to at least one of said first gear wheel and said second gear wheel to drive said meshed gear arrangement to thereby provide said synchronization operation. For example, said actuator comprises a motor gear wheel meshed with at least one of said first gear and said second gear to drive said meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, said deployment mechanism comprises a leveling arrangement for providing and for synchronizing said levelling operation with said pivoting operation. For example, the deployment mechanism includes one of the following:

- wherein at least one of said first wing and said second wing is movably mounted to the respective said first shaft or said second shaft with respect to one degree of freedom in translation parallel to the respective said first pivot axis or said second pivot axis;
- wherein said first wing is fixedly mounted to said first shaft, and wherein said second wing is movably mounted to said second shaft with respect to one degree of freedom in translation parallel to said second pivot axis;
- wherein said first wing is fixedly mounted to said first shaft, and wherein said second wing is movably mounted to said second shaft with respect to one degree of freedom in translation parallel to said second pivot axis, and, wherein said second shaft is in the form of a male spline shaft, and wherein the said second wing is movably mounted to said second shaft via a female spline coupling complementary to said male spline shaft.

Additionally or alternatively, for example, said leveling arrangement comprises a cam arrangement operatively coupled to the second wing.

For example, said cam arrangement comprises a cam follower and a cam rail. For example, said cam rail comprises at least one helical cam rail, fixedly mounted with respect to said load-bearing bracket and having a helical axis co-axial with said second pivot axis, and wherein said cam follower fixedly mounted to the second wing, such that movement of the cam follower along said cam rail causes the second wing to translate

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along said degree of freedom with respect to said second pivot shaft in said levelling operation.

Additionally or alternatively, for example, said deployment mechanism comprises a translation arrangement configured for synchronizing said translation operation with said pivoting operation. For example, said translation arrangement comprises a rail system configured to be fixedly mounted to the air vehicle, and wherein said bracket is moveably mounted to said rail system to enable said bracket to be translated along said stroke direction through said stroke length. For example, said translation arrangement comprises a rack and pinion arrangement, comprising a pinion gear rotatably mounted to said bracket, and a rack gear mounted in fixed spatial relationship with respect to said rail system, wherein said pinion gear is coupled with said meshed gear arrangement, such that actuation of said meshed gear system causes rotation of said pinion gear, which in turn turns with respect to the rack gear causing translation of the load-bearing bracket along said stroke direction. For example, said translation arrangement comprises at least two said pinion gears of different diameter one from the other, each said pinion gear being alternately rotatably mounted to said bracket to correspondingly provide a different said stroke length.

Additionally or alternatively, for example, said first wing comprises a first wing root and wherein said first pivot shaft is located at or near said first wing root, and wherein said second wing comprises a second wing root and wherein said second pivot shaft is located at or near said second wing root.

According to the first aspect of the presently disclosed subject matter there is also provided an air vehicle comprising the wing system according to the first aspect of the presently disclosed subject matter.

For example, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to a lower side of the fuselage. Alternatively, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to an upper side of the fuselage.

Additionally or alternatively, for example, the air vehicle is a UAV.

According to a second aspect of the presently disclosed subject matter there is provided a deployment mechanism for a wing system for an air vehicle, the wing system comprising a set of wings including a first wing and a second wing, the deployment mechanism being configured for enabling transitioning the wing system between a stowed configuration and a deployed configuration, and comprising:

a first shaft configured for enabling the first wing to be mounted thereto, the first shaft having a first pivot axis, a second shaft configured for enabling the second wing to be mounted thereto, the second shaft having a second pivot axis, wherein said first pivot axis and said second pivot axis are non-coaxial, and wherein in the stowed configuration the first shaft and the second shaft are configured for mounting the first wing and the second wing, respectively, in overlying arrangement;

a pivoting arrangement configured for providing and synchronizing a pivoting operation comprising pivoting of said first shaft about said first pivot axis in a first rotational direction with pivoting of said second shaft about said second pivot axis in a second rotational direction, opposite to said first rotational direction;

a leveling arrangement for providing and for synchronizing a levelling operation with said pivoting operation, wherein in operation of the deployment arrangement the leveling arrangement is, in said levelling operation, configured for transitioning the first wing and the second wing with respect to one another from a non-leveled relationship in the stowed configuration, to a leveled relationship in the deployed configuration.

For example, the deployment mechanism is configured for synchronizing said levelling operation with said pivoting operation.

Additionally or alternatively, for example, the wing system is further configured for providing a translation operation configured for selectively translating the first wing and the second wing along a stroke direction through a stroke length, between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration.

Additionally or alternatively, for example, said deployment mechanism comprises a translation arrangement configured for synchronizing a translation operation with said pivoting operation, wherein said translation operation is configured for selectively translating, in operation of the deployment system, the first wing and the second wing along a stroke direction through a stroke length, between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration.

Additionally or alternatively, for example, the deployment mechanism is configured for synchronizing said translation operation with said pivoting operation.

Additionally or alternatively, for example, said translation arrangement comprises a rail system configured to be fixedly mounted to the air vehicle, and wherein said bracket is moveably mounted to said rail system to enable said bracket to be translated along said stroke direction through said stroke length.

Additionally or alternatively, for example, said first pivot axis is parallel with respect to said second pivot axis, and wherein said first pivot axis is laterally spaced with respect to said second pivot axis by a lateral spacing.

Additionally or alternatively, for example, said deployment mechanism comprises an actuator configured for selectively driving operation of the deployment mechanism, and wherein optionally said deployment mechanism is configured for self locking.

Additionally or alternatively, for example, said first wing comprises a first pivot shaft coaxial with the first pivot axis, and wherein said second wing comprises a second pivot shaft coaxial with the second pivot axis.

Additionally or alternatively, for example, said deployment mechanism comprises a load bearing bulkhead, wherein said first wing is pivotably mounted to said load bearing bulkhead via said first pivot shaft, and said second wing is pivotably mounted to said load bearing bulkhead via said second pivot shaft.

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Additionally or alternatively, for example, said deployment mechanism is configured for providing in said pivoting operation a pivoting synchronization operation comprising synchronizing pivoting of said first wing about said first pivot axis in a first rotational direction with pivoting of said second wing about said second pivot axis in a second rotational direction, opposite to said first rotational direction.

Additionally or alternatively, for example, said deployment mechanism comprises a meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, said meshed gear arrangement comprises a first gear wheel fixedly mounted to said first pivot shaft and co-axial with said first pivot axis, and a second gear wheel fixedly mounted to said second pivot shaft and co-axial with said second pivot axis, wherein said first gear wheel is meshed with respect to said second gear wheel.

Additionally or alternatively, for example, said actuator comprises a motor operatively coupled to said meshed gear arrangement and configured for selectively providing a torque to at least one of said first gear wheel and said second gear wheel to drive said meshed gear arrangement to thereby provide said synchronization operation.

Additionally or alternatively, for example, said actuator comprises a motor gear wheel meshed with at least one of said first gear and said second gear to drive said meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, at least one of said first wing and said second wing is movably mounted to the respective said first shaft or said second shaft with respect to one degree of freedom in translation parallel to the respective said first pivot axis or said second pivot axis.

Additionally or alternatively, for example, said first wing is fixedly mounted to said first shaft, and wherein said second wing is movably mounted to said second shaft with respect to one degree of freedom in translation parallel to said second pivot axis.

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Additionally or alternatively, for example, said second shaft is in the form of a male spline shaft, and wherein the said second wing is movably mounted to said second shaft via a female spline coupling complementary to said male spline shaft.

Additionally or alternatively, for example, said leveling arrangement comprises a cam arrangement operatively coupled to the second wing.

Additionally or alternatively, for example, said cam arrangement comprises a cam follower and a cam rail.

Additionally or alternatively, for example, said cam rail is a helical cam rail, fixedly mounted with respect to said load-bearing bracket and having a helical axis co-axial with said second pivot axis, and wherein said cam follower fixedly mounted to the second wing, such that movement of the cam follower along said helical cam rail causes the second wing to translate along said degree of freedom with respect to said second pivot shaft in said levelling operation.

Additionally or alternatively, for example, said translation arrangement comprises a rail system configured to be fixedly mounted to the air vehicle, and wherein said bracket is moveably mounted to said rail system to enable said bracket to be translated along said stroke direction through said stroke length.

Additionally or alternatively, for example, said translation arrangement comprises a rack and pinion arrangement, comprising a pinion gear rotatably mounted to said bracket, and a rack gear mounted in fixed spatial relationship with respect to said rail system, wherein said pinion gear is coupled with said meshed gear arrangement, such that actuation of said meshed gear system causes rotation of said pinion gear, which in turn turns with respect to the rack gear causing translation of the load-bearing bracket along said stroke direction.

Additionally or alternatively, for example, said translation arrangement comprises at least two said pinion gears of different diameter one from the other, each said pinion gear being alternately rotatably mounted to said bracket to correspondingly provide a different said stroke length.

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According to the second aspect of the presently disclosed subject matter there is also provided a wing system comprising the deployment mechanism according to the second aspect of the presently disclosed subject matter.

According to the second aspect of the presently disclosed subject matter there is also provided an air vehicle comprising the wing system according to the second aspect of the presently disclosed subject matter.

For example, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to a lower side of the fuselage. Alternatively, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to an upper side of the fuselage.

Additionally or alternatively, for example, the air vehicle is a UAV.

According to a third aspect of the presently disclosed subject matter there is provided a deployment mechanism for a wing system for an air vehicle, the wing system comprising a set of wings including a first wing and a second wing, the deployment mechanism being configured for enabling transitioning the wing system between a stowed configuration and a deployed configuration, and comprising:

- a first shaft configured for enabling the first wing to be mounted thereto, the first shaft having a first pivot axis, a second shaft configured for enabling the second wing to be mounted thereto, the second shaft having a second pivot axis, wherein said first pivot axis and said second pivot axis are non-coaxial, and wherein in the stowed configuration the first shaft and the second shaft are configured for mounting the first wing and the second wing, respectively, in overlying arrangement;
- a pivoting arrangement configured for providing and synchronizing a pivoting operation comprising pivoting of said first shaft about said first pivot axis in a first rotational direction with pivoting of said second shaft about said second pivot axis in a second rotational direction, opposite to said first rotational direction;
- a translation arrangement configured for synchronizing a translation operation with said pivoting operation, wherein said translation operation is configured for selectively translating, in operation of the deployment system, the first wing and the second wing along a stroke direction through a stroke length, between a first

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axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration.

For example, the deployment mechanism is configured for synchronizing said translation operation with said pivoting operation.

Additionally or alternatively, for example, said deployment mechanism comprises a leveling arrangement for providing and for synchronizing a levelling operation with said pivoting operation, wherein in operation of the deployment arrangement the leveling arrangement is, in said levelling operation, configured for transitioning the first wing and the second wing with respect to one another from a non-leveled relationship in the stowed configuration, to a leveled relationship in the deployed configurations. For example, the deployment mechanism is configured for synchronizing said levelling operation with said pivoting operation.

Additionally or alternatively, for example, said first pivot axis is parallel with respect to said second pivot axis, and wherein said first pivot axis is laterally spaced with respect to said second pivot axis by a lateral spacing.

Additionally or alternatively, for example, said deployment mechanism comprises an actuator configured for selectively driving operation of the deployment mechanism, and wherein optionally said deployment mechanism is configured for self locking.

Additionally or alternatively, for example, said first wing comprises a first pivot shaft coaxial with the first pivot axis, and wherein said second wing comprises a second pivot shaft coaxial with the second pivot axis.

Additionally or alternatively, for example, said deployment mechanism comprises a load bearing bulkhead, wherein said first wing is pivotably mounted to said load bearing bulkhead via said first pivot shaft, and said second wing is pivotably mounted to said load bearing bulkhead via said second pivot shaft.

Additionally or alternatively, for example, said deployment mechanism is configured for providing in said pivoting operation a pivoting synchronization operation comprising synchronizing pivoting of said first wing about said first pivot axis in a first

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rotational direction with pivoting of said second wing about said second pivot axis in a second rotational direction, opposite to said first rotational direction.

Additionally or alternatively, for example, said deployment mechanism comprises a meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, said meshed gear arrangement comprises a first gear wheel fixedly mounted to said first pivot shaft and co-axial with said first pivot axis, and a second gear wheel fixedly mounted to said second pivot shaft and co-axial with said second pivot axis, wherein said first gear wheel is meshed with respect to said second gear wheel.

Additionally or alternatively, for example, said actuator comprises a motor operatively coupled to said meshed gear arrangement and configured for selectively providing a torque to at least one of said first gear wheel and said second gear wheel to drive said meshed gear arrangement to thereby provide said synchronization operation.

Additionally or alternatively, for example, said actuator comprises a motor gear wheel meshed with at least one of said first gear and said second gear to drive said meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, at least one of said first wing and said second wing is movably mounted to the respective said first shaft or said second shaft with respect to one degree of freedom in translation parallel to the respective said first pivot axis or said second pivot axis.

Additionally or alternatively, for example, said first wing is fixedly mounted to said first shaft, and wherein said second wing is movably mounted to said second shaft with respect to one degree of freedom in translation parallel to said second pivot axis.

Additionally or alternatively, for example, said second shaft is in the form of a male spline shaft, and wherein the said second wing is movably mounted to said second shaft via a female spline coupling complementary to said male spline shaft.

Additionally or alternatively, for example, said leveling arrangement comprises a cam arrangement operatively coupled to the second wing.

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Additionally or alternatively, for example, said cam arrangement comprises a cam follower and a cam rail.

Additionally or alternatively, for example, said cam rail is a helical cam rail, fixedly mounted with respect to said load-bearing bracket and having a helical axis co-axial with said second pivot axis, and wherein said cam follower fixedly mounted to the second wing, such that movement of the cam follower along said helical cam rail causes the second wing to translate along said degree of freedom with respect to said second pivot shaft in said levelling operation.

Additionally or alternatively, for example, said deployment mechanism comprises a translation arrangement configured for synchronizing said translation operation with said pivoting operation.

Additionally or alternatively, for example, said translation arrangement comprises a rail system configured to be fixedly mounted to the air vehicle, and wherein said bracket is moveably mounted to said rail system to enable said bracket to be translated along said stroke direction through said stroke length.

Additionally or alternatively, for example, said translation arrangement comprises a rack and pinion arrangement, comprising a pinion gear rotatably mounted to said bracket, and a rack gear mounted in fixed spatial relationship with respect to said rail system, wherein said pinion gear is coupled with said meshed gear arrangement, such that actuation of said meshed gear system causes rotation of said pinion gear, which in turn turns with respect to the rack gear causing translation of the load-bearing bracket along said stroke direction.

Additionally or alternatively, for example, said translation arrangement comprises at least two said pinion gears of different diameter one from the other, each said pinion gear being alternately rotatably mounted to said bracket to correspondingly provide a different said stroke length.

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According to the third aspect of the presently disclosed subject matter there is also provided a wing system comprising the deployment mechanism according to the third aspect of the presently disclosed subject matter.

According to the third aspect of the presently disclosed subject matter there is also provided an air vehicle comprising the wing system according to the third aspect of the presently disclosed subject matter.

For example, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to a lower side of the fuselage. Alternatively, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to an upper side of the fuselage.

Additionally or alternatively, for example, the air vehicle is a UAV.

According to a fourth aspect of the presently disclosed subject matter there is provided a wing system for an air vehicle, the air vehicle having a fuselage including a fuselage section and a fuselage longitudinal axis, the wing system comprising:

- a set of wings, including a first said wing having a first wing longitudinal axis, and a second said wing having a second wing longitudinal axis, and configured for transitioning between a stowed configuration and a deployed configuration;

- wherein in the stowed configuration, the first wing and the second wing are generally aligned with the fuselage longitudinal axis; and

- wherein in the deployed configuration, the first wing is oriented with respect to the second wing such that the wings tips are more spaced from one another than in the stowed configuration;

- and further comprising a deployment mechanism configured for selectively providing a wing pivoting operation, comprising:

- pivoting said first wing about a first pivot axis between the stowed configuration and the deployed configuration;

- pivoting said second wing about a second pivot axis between the stowed configuration and the deployed configuration;

- wherein said first pivot axis and said second pivot axis are non-coaxial;

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the deployment mechanism being further configured for selectively providing a displacement operation concurrent with the wing pivoting operation, said displacement operation comprising translating the first wing and the second wing through a stroke length concurrent with said pivoting, between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration;

wherein said deployment mechanism is configured for enabling changing a magnitude of said stroke length while unaffected said wing pivoting operation.

For example, said deployment mechanism comprises a translation arrangement configured for synchronizing said translation operation with said pivoting operation, wherein said translation operation is configured for selectively translating, in operation of the deployment system, the first wing and the second wing along a stroke direction through a stroke length, between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration.

Additionally or alternatively, for example, the deployment mechanism is configured for synchronizing said translation operation with said pivoting operation.

Additionally or alternatively, for example, said translation arrangement comprises a rail system configured to be fixedly mounted to the air vehicle, and wherein said bracket is moveably mounted to said rail system to enable said bracket to be translated along said stroke direction through said stroke length.

Additionally or alternatively, for example, said translation arrangement comprises a rack and pinion arrangement, comprising a pinion gear rotatably mounted to said bracket, and a rack gear mounted in fixed spatial relationship with respect to said rail system, wherein said pinion gear is coupled with said meshed gear arrangement, such that actuation of said meshed gear system causes rotation of said pinion gear, which in turn turns with respect to the rack gear causing translation of the load-bearing bracket along said stroke direction.

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Additionally or alternatively, for example, said translation arrangement comprises at least two said pinion gears of different diameter one from the other, each said pinion gear being alternately rotatably mounted to said bracket to correspondingly provide a different said stroke length.

Additionally or alternatively, for example, said first pivot axis is parallel with respect to said second pivot axis, and wherein said first pivot axis is laterally spaced with respect to said second pivot axis by a lateral spacing.

Additionally or alternatively, for example, said deployment mechanism comprises an actuator configured for selectively driving operation of the deployment mechanism, and wherein optionally said deployment mechanism is configured for self locking.

Additionally or alternatively, for example, said first wing comprises a first pivot shaft coaxial with the first pivot axis, and wherein said second wing comprises a second pivot shaft coaxial with the second pivot axis.

Additionally or alternatively, for example, said deployment mechanism comprises a load bearing bulkhead, wherein said first wing is pivotably mounted to said load bearing bulkhead via said first pivot shaft, and said second wing is pivotably mounted to said load bearing bulkhead via said second pivot shaft.

Additionally or alternatively, for example, said deployment mechanism is configured for providing in said pivoting operation a pivoting synchronization operation comprising synchronizing pivoting of said first wing about said first pivot axis in a first rotational direction with pivoting of said second wing about said second pivot axis in a second rotational direction, opposite to said first rotational direction.

Additionally or alternatively, for example, said deployment mechanism comprises a meshed gear arrangement for providing said synchronization operation.

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Additionally or alternatively, for example, said meshed gear arrangement comprises a first gear wheel fixedly mounted to said first pivot shaft and co-axial with said first pivot axis, and a second gear wheel fixedly mounted to said second pivot shaft and co-axial with said second pivot axis, wherein said first gear wheel is meshed with respect to said second gear wheel.

Additionally or alternatively, for example, said actuator comprises a motor operatively coupled to said meshed gear arrangement and configured for selectively providing a torque to at least one of said first gear wheel and said second gear wheel to drive said meshed gear arrangement to thereby provide said synchronization operation.

Additionally or alternatively, for example, said actuator comprises a motor gear wheel meshed with at least one of said first gear and said second gear to drive said meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, said deployment mechanism is comprises a leveling arrangement for providing and for synchronizing a levelling operation with said pivoting operation, wherein in operation of the deployment arrangement the leveling arrangement is, in said levelling operation, configured for transitioning the first wing and the second wing with respect to one another from a non-leveled relationship in the stowed configuration, to a leveled relationship in the deployed configuration.

For example, the deployment mechanism is configured for synchronizing said levelling operation with said pivoting operation.

Additionally or alternatively, for example, at least one of said first wing and said second wing is movably mounted to the respective said first shaft or said second shaft with respect to one degree of freedom in translation parallel to the respective said first pivot axis or said second pivot axis.

Additionally or alternatively, for example, said first wing is fixedly mounted to said first shaft, and wherein said second wing is movably mounted to said second shaft with respect to one degree of freedom in translation parallel to said second pivot axis.

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Additionally or alternatively, for example, said second shaft is in the form of a male spline shaft, and wherein the said second wing is movably mounted to said second shaft via a female spline coupling complementary to said male spline shaft.

Additionally or alternatively, for example, said leveling arrangement comprises a cam arrangement operatively coupled to the second wing.

Additionally or alternatively, for example, said cam arrangement comprises a cam follower and a cam rail.

Additionally or alternatively, for example, said cam rail is a helical cam rail, fixedly mounted with respect to said load-bearing bracket and having a helical axis co-axial with said second pivot axis, and wherein said cam follower fixedly mounted to the second wing, such that movement of the cam follower along said helical cam rail causes the second wing to translate along said degree of freedom with respect to said second pivot shaft in said levelling operation.

According to a fourth aspect of the presently disclosed subject matter there is also provided a deployment mechanism for a wing system for an air vehicle, the wing system comprising a set of wings including a first wing and a second wing, the deployment mechanism being configured for enabling transitioning the wing system between a stowed configuration and a deployed configuration, and comprising:

- a deployment mechanism configured for selectively providing a wing pivoting operation, comprising:

- pivoting said first wing about a first pivot axis between the stowed configuration and the deployed configuration;

- pivoting said second wing about a second pivot axis between the stowed configuration and the deployed configuration;

- wherein said first pivot axis and said second pivot axis are non-coaxial;

- the deployment mechanism being further configured for selectively providing a displacement operation concurrent with the wing pivoting operation, said displacement operation comprising translating the first wing and the second wing through a stroke length concurrent with said pivoting, between a first axial

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position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration;

wherein said deployment mechanism is configured for enabling changing a magnitude of said stroke length while unaffected said wing pivoting operation.

For example, said deployment mechanism comprises a translation arrangement configured for synchronizing said translation operation with said pivoting operation, wherein said translation operation is configured for selectively translating, in operation of the deployment system, the first wing and the second wing along a stroke direction through a stroke length, between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration.

Additionally or alternatively, for example, the deployment mechanism is configured for synchronizing said translation operation with said pivoting operation.

Additionally or alternatively, for example, said translation arrangement comprises a rail system configured to be fixedly mounted to the air vehicle, and wherein said bracket is moveably mounted to said rail system to enable said bracket to be translated along said stroke direction through said stroke length.

Additionally or alternatively, for example, said translation arrangement comprises a rack and pinion arrangement, comprising a pinion gear rotatably mounted to said bracket, and a rack gear mounted in fixed spatial relationship with respect to said rail system, wherein said pinion gear is coupled with said meshed gear arrangement, such that actuation of said meshed gear system causes rotation of said pinion gear, which in turn turns with respect to the rack gear causing translation of the load-bearing bracket along said stroke direction.

Additionally or alternatively, for example, said translation arrangement comprises at least two said pinion gears of different diameter one from the other, each said pinion gear being alternately rotatably mounted to said bracket to correspondingly provide a different said stroke length.

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Additionally or alternatively, for example, said first pivot axis is parallel with respect to said second pivot axis, and wherein said first pivot axis is laterally spaced with respect to said second pivot axis by a lateral spacing.

Additionally or alternatively, for example, said deployment mechanism comprises an actuator configured for selectively driving operation of the deployment mechanism, and wherein optionally said deployment mechanism is configured for self locking.

Additionally or alternatively, for example, said first wing comprises a first pivot shaft coaxial with the first pivot axis, and wherein said second wing comprises a second pivot shaft coaxial with the second pivot axis.

Additionally or alternatively, for example, said deployment mechanism comprises a load bearing bulkhead, wherein said first wing is pivotably mounted to said load bearing bulkhead via said first pivot shaft, and said second wing is pivotably mounted to said load bearing bulkhead via said second pivot shaft.

Additionally or alternatively, for example, said deployment mechanism is configured for providing in said pivoting operation a pivoting synchronization operation comprising synchronizing pivoting of said first wing about said first pivot axis in a first rotational direction with pivoting of said second wing about said second pivot axis in a second rotational direction, opposite to said first rotational direction.

Additionally or alternatively, for example, said deployment mechanism comprises a meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, said meshed gear arrangement comprises a first gear wheel fixedly mounted to said first pivot shaft and co-axial with said first pivot axis, and a second gear wheel fixedly mounted to said second pivot shaft and co-axial with said second pivot axis, wherein said first gear wheel is meshed with respect to said second gear wheel.

Additionally or alternatively, for example, said actuator comprises a motor operatively coupled to said meshed gear arrangement and configured for selectively providing a torque to at least one of said first gear wheel and said second gear wheel to drive said meshed gear arrangement to thereby provide said synchronization operation.

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Additionally or alternatively, for example, said actuator comprises a motor gear wheel meshed with at least one of said first gear and said second gear to drive said meshed gear arrangement for providing said synchronization operation.

Additionally or alternatively, for example, said deployment mechanism is comprises a leveling arrangement for providing and for synchronizing a levelling operation with said pivoting operation, wherein in operation of the deployment arrangement the leveling arrangement is, in said levelling operation, configured for transitioning the first wing and the second wing with respect to one another from a non-leveled relationship in the stowed configuration, to a leveled relationship in the deployed configuration.

For example, the deployment mechanism is configured for synchronizing said levelling operation with said pivoting operation.

Additionally or alternatively, for example, at least one of said first wing and said second wing is movably mounted to the respective said first shaft or said second shaft with respect to one degree of freedom in translation parallel to the respective said first pivot axis or said second pivot axis.

Additionally or alternatively, for example, said first wing is fixedly mounted to said first shaft, and wherein said second wing is movably mounted to said second shaft with respect to one degree of freedom in translation parallel to said second pivot axis.

Additionally or alternatively, for example, said second shaft is in the form of a male spline shaft, and wherein the said second wing is movably mounted to said second shaft via a female spline coupling complementary to said male spline shaft.

Additionally or alternatively, for example, said leveling arrangement comprises a cam arrangement operatively coupled to the second wing.

Additionally or alternatively, for example, said cam arrangement comprises a cam follower and a cam rail.

Additionally or alternatively, for example, said cam rail is a helical cam rail, fixedly mounted with respect to said load-bearing bracket and having a helical axis co-axial with said second pivot axis, and wherein said cam follower fixedly mounted to the

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second wing, such that movement of the cam follower along said helical cam rail causes the second wing to translate along said degree of freedom with respect to said second pivot shaft in said levelling operation.

According to the fourth aspect of the presently disclosed subject matter there is also provided a wing system comprising the deployment mechanism according to the fourth aspect of the presently disclosed subject matter.

According to the fourth aspect of the presently disclosed subject matter there is also provided an air vehicle comprising the wing system according to the fourth aspect of the presently disclosed subject matter.

For example, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to a lower side of the fuselage. Alternatively, the air vehicle comprises a fuselage, and wherein the at least one wing system is mounted to an upper side of the fuselage.

Additionally or alternatively, for example, the air vehicle is a UAV.

According to the fourth aspect of the presently disclosed subject matter there is also provided a method of operating an air vehicle, comprising:

- providing an air vehicle as defined according to the fourth aspect of the presently disclosed subject matter;
- providing a said magnitude of said stroke length while unaffected said wing pivoting operation

According to a fifth aspect of the presently disclosed subject matter there is also provided a method of operating an air vehicle, comprising:

- providing an air vehicle as defined herein with respect to any one of the first, second third or fourth aspect of the presently disclosed subject matter;
- selectively operating the respective wing system to transition the wing system from the stowed configuration to the deployed configuration.

For example, the method further comprises:

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- selectively operating the respective wing system to transition the wing system from the deployed configuration to the stowed configuration.

According to a sixth aspect of the presently disclosed subject matter there is also provided a method of operating an air vehicle, comprising:

- (a) providing an air vehicle as defined herein with respect to any one of the first, second third or fourth aspect of the presently disclosed subject matter, the air vehicle in the stowed configuration encapsulated in a fairing;
- (b) launching the encapsulated air vehicles;
- (c) separating the air vehicle from the fairing;
- (d) selectively operating the respective wing system to transition the wing system from the stowed configuration to the deployed configuration.

For example, step (b) comprises any one of:

- launching the encapsulated air vehicle via a launch barrel;
- launching the encapsulated air vehicle using a booster rocket;
- launching the encapsulated air vehicle from a carrier aircraft.

Additionally or alternatively, for example, step (b) comprises launching the encapsulated air vehicle to a predetermined altitude and a predetermined forward speed.

A feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which in said stowed configuration, the respective first wing and second wing of each wing set is compactly folded over one another with respect to the fuselage lateral sides while enabling maximizing wing span in the deployed configuration.

Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which in said stowed configuration, the respective first wing and second wing of each wing set is compactly folded over one another with respect to the fuselage lateral sides while enabling providing long endurance and/or enhanced aerodynamic efficiency and/or minimize energy consumption with respect to the air vehicle in the deployed configuration.

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Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which in said stowed configuration, the respective first wing and second wing of each wing set is compactly folded over one another with respect to the fuselage lateral sides while enabling low speed flight for the air vehicle in the deployed configuration.

Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which in said stowed configuration, the respective first wing and second wing of each wing set is compactly folded over one another with respect to the fuselage lateral sides while providing stability to the air vehicle during deployment and at the deployed configuration.

Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which in said stowed configuration, the respective first wing and second wing of each wing set can be maximized while still remaining within the "footprint" of the fuselage.

Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which the respective first wing and second wing of each wing set can have long spans while enabling the air vehicle to be packed into a small packaging volume, for example within an aerodynamic fairing.

Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which the length of the wings can be chosen for the particular air vehicles while maintain the ability to position the wings, in the deployed configuration, with the desired proximity to air vehicle center of mass.

Another feature of at least one example of the presently disclosed subject matter is that a wing system is provided for an air vehicle, in which the respective deployment mechanism can be adapted to provide a variety of different magnitudes for the stroke length, while essentially unchanging the magnitude of the angular displacements of the wings about the respective pivot axes, enabling the same deployment mechanism to be easily adapted for installation in a variety of air vehicles, in which the required stroke length can be different in each air vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, examples will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1(a) shows in side view an air vehicle comprising a wing system according to a first example of the presently disclosed subject matter, wherein the wing system is in the stowed configuration; **Fig. 1(b)** shows in side view the example of the air vehicle of Fig. 1(a) in the deployed configuration.

Fig. 2(a) schematically illustrates in top view the example of the wing system of Fig. 1(a) in the stowed configuration; **Fig. 2(b)** schematically illustrates in top view the example of the wing system of Fig. 1(a) in a position intermediate the stowed configuration and the deployed configuration; **Fig. 2(c)** schematically illustrates in top view the example of the wing system of Fig. 1(a) in the deployed configuration; **Fig. 2(d)** schematically illustrates in composite top view the example of the wing system of Fig. 2(a), Fig. 2(b) and Fig. 2(c).

Fig. 3(a) schematically illustrates in composite top view the pivoting operation of the example of the air vehicle of Fig. 2(d); **Fig. 3(b)** schematically illustrates in composite top view the translation operation of the example of the air vehicle of Fig. 2(d).

Fig. 4(a) shows in isometric top-front-side view, a deployment mechanism for a wing system according to a first example of the presently disclosed subject matter, wherein the wing system is in the stowed configuration; **Fig. 4(b)** shows in top view the example of the deployment mechanism of Fig. 4(a) in the stowed configuration; **Fig. 4(c)** shows in isometric top-front-side view, the example of the deployment mechanism of Fig. 4(a) in the deployed configuration; **Fig. 4(d)** shows in top view the example of the air vehicle of Fig. 4(c) in the deployed configuration.

Fig. 5 shows in isometric top-front-side view, part of the deployment mechanism and part of the wings of the example of Figs. 4(a) to 4(d), in the deployed configuration.

Fig. 6(a) shows in isometric top-aft-side view, part of the deployment mechanism of the example of Figs. 4(a) to 4(d); **Fig. 6(b)** shows in isometric top-front-side view, part of the deployment mechanism of the example of Figs. 4(a) to 4(d).

Fig. 7(a) shows in top view, part of the deployment mechanism and part of the wings of the example of Figs. 4(a) to 4(d), in the stowed configuration; **Fig. 7(b)** shows in top view, part of the deployment mechanism and part of the wings of the example of Figs. 4(a) to 4(d), in the deployed configuration.

Fig. 8(a) shows in partial isometric top-aft-side view, part of the deployment mechanism, including part of the leveling mechanism, and part of the wings of the example of Figs. 4(a) to 4(d), in the stowed configuration; **Fig. 8(b)** shows in partial isometric top-aft-side view, the example of Fig. 8(a) in a position intermediate the stowed configuration and the deployed configuration; **Fig. 8(c)** shows in partial isometric top-aft-side view, the example of Fig. 8(a) in the deployed configuration.

Fig. 9(a) shows in partial isometric bottom-aft-side view, the deployment mechanism, including the leveling mechanism, and part of the wings of the example of Figs. 4(a) to 4(d), in the stowed configuration; **Fig. 9(b)** shows in partial isometric bottom-aft-side view, the example of Fig. 9(a) in a first position intermediate the stowed configuration and the deployed configuration; **Fig. 9(c)** shows in partial isometric bottom-aft-side view, the example of Fig. 9(a) in a second position intermediate the stowed configuration and the deployed configuration; **Fig. 9(d)** shows in partial isometric bottom-aft-side view, the example of Fig. 9(a) in the deployed configuration.

Fig. 10(a) shows in partial isometric bottom-aft-side view, the deployment mechanism, including the translation arrangement, and part of the wings of the example of Figs. 4(a) to 4(d), in the stowed configuration; **Fig. 10(b)** shows in partial isometric bottom-aft-side view, the example of Fig. 10(a) in a first position intermediate the stowed configuration and the deployed configuration; **Fig. 10(c)** shows in partial isometric bottom-aft-side view, the example of Fig. 10(a) in a second position intermediate the stowed configuration and the deployed configuration; **Fig. 10(d)** shows in partial isometric bottom-aft-side view, the example of Fig. 10(a) in the deployed configuration.

DETAILED DESCRIPTION

Referring to Figs. 1(a) and 1(b), an air vehicle according to a first example of the presently disclosed subject matter, generally designated **100**, comprises a wing system **200**, which is *per se* novel.

In at least this example, the air vehicle **100** is a powered, fixed-wing type air vehicle, comprising a subsonic configuration, having a fuselage section **110** (also referred to herein as the fuselage **110**), said wing system **200**, a suitable propulsion system (not shown), and an empennage **300** – for example (but not limited to) including a tailplane and vertical stabilizers. Furthermore, while the presently disclosed subject matter finds particular application in UAV aircraft, the presently disclosed subject matter can also be applied to manned aircraft, *mutatis mutandis*, in particular to general aviation, subsonic transport, naval aviation, and so on, for example. In alternative variations of this example, and in other examples, the air vehicle **100** can instead be configured as an un-powered, fixed-wing type subsonic/transonic air vehicle. In yet other alternative variations of this example, and in other examples, the air vehicle **100** can instead be configured as a powered, fixed-wing type transonic or supersonic air vehicle, manned or unmanned.

The air vehicle **100** further comprises a control system comprising a controller (not shown) configured for operating the air vehicle **100** at least within the flight envelope thereof.

As will become clearer herein, the wing system **200** has a stowed configuration **SC**, and a deployed configuration **DC**. Furthermore, the wing system **200** is deployable between the stowed configuration **SC**, and the deployed configuration **DC**.

While the wing system **200** in the illustrated example is disclosed herein in relation to the main lift-generating wings of the air vehicle, in other implementations of the presently disclosed subject matter the concept and operation of the wing system **200** can instead be applied to an empennage, for example the vertical stabilizer or horizontal stabilizes, or to a canard arrangement for example, *mutatis mutandis*.

While the air vehicle in the illustrated example is disclosed herein as having a wing system with one set of wings, in alternative variations of this example the wing system can have more than one set of wings, for example two wing sets. In such a case, for example, a

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first wing set deploys the wings in a forward direction, while the second wing set deploys its wings in an aft direction, thereby providing a tandem wing arrangement. The two sets of wings can be mounted together to the underside of the fuselage, or can be mounted together to the upper side of the fuselage, or one set can be mounted to the underside of the fuselage while the other set can be mounted to the upper side of the fuselage.

The wing system **200** comprises a set of wings **210**, configured for transitioning between the stowed configuration and the deployed configuration, the set of wings **210** comprising two wings **220**, in particular a first wing **221** and a second wing **222**. In the illustrated examples, the first wing **221** is provided on the port side, and is therefore also referred to herein as the port wing, while the second wing **222** is provided on the starboard side, and is therefore also referred to herein as the starboard wing. However, in other alternative variations of this example, the first wing **221** can refer to the starboard wing, while the second wing **222** can refer to the port wing, *mutatis mutandis*.

Thus, unless otherwise specified herein, the reference numeral **220** shall also refer to each one of the first wing **221** and the second wing **222**.

Referring in particular to Figs. 2(a), 2(b), 2(c) and 2(d), each said wing **220** is pivotably mounted with respect to the fuselage **110** about a respective pivot axis **PA**, thereby enabling the wings **220** to each pivot about its respective axis **PA** between the stowed configuration **SC** and the deployed configuration **DC**.

Thus, the first wing **221** is pivotably mounted with respect to the fuselage **110** about a respective first pivot axis **PA1**, thereby enabling the first wing **221** to pivot about its respective first pivot axis **PA1** between the stowed configuration **SC** and the deployed configuration **DC**. Similarly, the second wing **222** is pivotably mounted with respect to the fuselage **110** about a respective second pivot axis **PA2**, thereby enabling the second wing **222** to pivot about its respective second pivot axis **PA2** between the stowed configuration **SC** and the deployed configuration **DC**.

According to an aspect of the presently disclosed subject matter, the first pivot axis **PA1** and the second pivot axis **PA1** are non-coaxial. In at least this example, the first pivot axis **PA1** and the second pivot axis **PA2** are parallel to one another, and spaced by pivot spacing **PS**.

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However, in alternative variations of this example, and in other examples, respective pivot axes **PA** of the two wings **220** are not parallel, for example non-parallel and spaced. In such cases, the respective pivot axes **PA** of the two wings **220** can intersect at a location above or below the wings **220**, such that at the vertical location of the wings **220** (i.e., along a direction parallel to the yaw axis **Y**), the pivot axes are also spaced from one another.

In at least this example, the first pivot axis **PA1** and the second pivot axis **PA2** are each parallel to the yaw axis **Y** of the air vehicle **100**. However, in alternative variations of this example, the first pivot axis **PA1** and the second pivot axis **PA2** are each inclined to the yaw axis **Y**, for example along a plane parallel to the yaw-roll plane of the air vehicle.

In at least this example, the first pivot axis **PA1** and the second pivot axis **PA2** are each orthogonal to the longitudinal axis **LA** of the air vehicle **100**.

In at least this example, the first pivot axis **PA1** and the second pivot axis **PA2** are each parallel to, or set at a small angle with respect to, the thickness of each wing **220** of the air vehicle **100**.

In at least this example, the first pivot axis **PA1** and the second pivot axis **PA2** are each orthogonal to the chord of each wing **220** of the air vehicle **100**.

The first wing **221** and the second wing **222** are essentially mirror images of one another, and are otherwise substantially identical with the exception that at least in this example, a portion of each wing **220** in the vicinity of the respective pivot axis **PA** can be different to one another.

In at least this example, the air vehicle **100** is configured for being accommodated or otherwise encapsulated in a fairing (not shown), while the wing system **200** is in the stowed configuration **SC**. For example, such a fairing enables the air vehicle **100** to be isolated from aerodynamic forces as the air vehicle **100** is accelerated to required speed and altitude, and/or such a fairing can protect the air vehicle while in storage or while being transported. For example the air vehicle **100** can be accelerated to required speed and altitude via an external launch system, for example a launch barrel, or for example via a booster rocket (as a payload thereof for example), or for example can be delivered

to required altitude and required speed via a carrier air vehicle, which can be manned or unmanned.

In at least the example of Figs. 1(a) and 1(b), the wings **220** are below the fuselage **110**, that is, the suction surface of the uppermost wing **220** (for example the first wing **221**) of the wing system **200** is facing a bottom portion **115** of the fuselage **110**. However, in at least one alternative variation of the example of Fig. 1, the wings **220** can be above the fuselage, that is, the pressure surface of the lowermost wing **220** (for example the second wing **222**) of the wing system **200** is facing an upper portion of the fuselage **110**.

Each wing **220** is based on (i.e., the wing **220** comprises a plurality of aerofoil sections each corresponding to) suitable aerofoils according to the configuration of the air vehicle and other factors – for example whether the air vehicle is optimized for subsonic flight, transonic flight, or supersonic flight, and so on.

In particular, in at least this example and other examples, the wings **220** are configured as lift-generating wings capable of providing sufficient lift to enable aerodynamic flight for the air vehicle **100**. Furthermore, the wings **220** can include control surfaces, for example, flaps, ailerons and so on, for providing stability and control to the air vehicle.

While in this example the wings **220** are in plan form generally trapezoidal (i.e., having a taper) or any other shape, in alternative variations of this example, the wings can have a generally rectangular plan form, or any other suitable plan form.

While in this example the wings **220** are zero swept (i.e., having zero sweep angle) in the deployed configuration, in alternative variations of this example, the wings can have a positive sweep angle or a negative sweep angle in the deployed configuration. For example, such swept wings can be of particular use in transonic and/or supersonic air vehicles. In other examples, such swept wings can be of particular use in subsonic/transonic air vehicles due to center of gravity position and related static margin and stability considerations.

Referring in particular to Fig. 1(a) and Fig. 2(d), the first wing **221** comprises a first wing tip **221T**, a first wing root **221R**, a first wing leading edge **221L**, a first wing trailing edge **221E**, a first wing suction surface **221S** and a first wing pressure surface

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221P, and a first wing longitudinal axis **221LA1**. The first wing **221** also has a first longitudinal length **LL1**, root to tip, in a direction parallel to first wing longitudinal axis **221LA1**.

The second wing **222** comprises a second wing tip **222T**, a second wing root **222R**, a second wing leading edge **222L**, a second wing trailing edge **222E**, a second wing suction surface **222S** and a second wing pressure surface **222P**, and a second wing longitudinal axis **222LA2**. The second wing **222** also has a second longitudinal length **LL2**, root to tip, in a direction parallel to second wing longitudinal axis **222LA2**.

In at least this example, in the stowed configuration **SC**, the first wing **221** and the second wing **222** are in an overlying relationship such as to provide a compact arrangement with respect to the fuselage and minimize the overall dimensions of the air vehicle **100** in the stowed configuration. For example, such a compact form can be useful when the air vehicle **100** is to be accommodated in a fairing and/or when packaging the air vehicle for transport or storage.

In at least this example, in the deployed configuration **DC**, the first wing **221** and the second wing **222** are in a spatial relationship with respect to one another and to the fuselage **110** such as to enable the wings to interact with an airflow such as to thereby generate aerodynamic lift to enable aerodynamic flight for the air vehicle **100**.

Referring again to Figs. 1(a) to 2(d), in the stowed configuration **SC**, the first wing **221** and the second wing **222** are in overlying relationship, i.e., with respect to one another.

In such overlying relationship, and referring in particular to Fig. 1(a) and Fig. 2(a), at least a majority of a pressure surface **221P** of the first wing **221** is facing the suction surface **222S** of the second wing **222**, and said first wing tip is spaced from said second wing tip by a first lateral spacing.

In such overlying relationship the first wing longitudinal axis **221LA1** and the second wing longitudinal axis **222LA2** are nominally parallel with one another – either actually parallel to one another, or close thereto, for example within $\pm 10^\circ$ to one another, or within $\pm 15^\circ$ to one another, or within $\pm 20^\circ$ to one another.

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At least in this example, in the stowed configuration **SC**, the first wing **221** and the second wing **222** are configured in the aforesaid overlying relationship for being oriented with respect to the fuselage **110** such that the first wing longitudinal axis **221LA1** and the second wing longitudinal axis **222LA2** are each nominally parallel with the fuselage longitudinal axis **LA**.

Also as will become clearer herein, in the deployed configuration **DC**, the first wing **221** is oriented with respect to the fuselage **110** such that the first wing longitudinal axis **221LA1** is non-parallel, for example depending on the sweep angle orthogonal or at another suitable angle between 0° and 90° , with respect to the fuselage longitudinal axis **LA**. Furthermore, in the deployed configuration **DC**, the second wing **222** is oriented with respect to the fuselage **110** such that the second wing longitudinal axis **222LA2** is non-parallel, for example depending on the sweep angle orthogonal or at another suitable angle between 0° and 90° , with respect to the fuselage longitudinal axis **LA**.

For example, and referring for example to Fig. 2(d), in the stowed configuration **SC**, the first wing **221** and the second wing **222** are oriented with respect to the fuselage **110** such that the first wing longitudinal axis **221LA1** and the second wing longitudinal axis **222LA2** are each nominally parallel with the longitudinal axis **LA** of the fuselage **110**.

In at least this example, in the deployed configuration **DC**, the first wing longitudinal axis **240LA1** and the second wing longitudinal axis **222LA2** are each nominally parallel with the pitch axis **P** of the air vehicle **100**. However, in alternative variations of this example, in which the wings **220** can be anhedral or dihedral, and/or have non-zero sweep, the first wing longitudinal axis **240LA1** and the second wing longitudinal axis **222LA2** can each be non-parallel with the pitch axis **P**.

Referring in particular to Fig. 2(a) and Fig. 2(c), at least in this example, in the stowed configuration **SC**, the first wing **221** and the second wing **222** are configured in the aforesaid overlying relationship for being oriented with respect to the fuselage **110** such that the first wing tip **221T** is spaced from the second wing tip **222T** by a first spacing **S1**, while in the deployed configuration **DC** the wings are pivoted away from one another such that the first wing tip **221T** is spaced from the second wing tip **222T** by a second spacing **S2**, wherein the second spacing **S2** is greater than the first spacing **S1**. In at least

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this example, the first spacing **S1** is nominally zero, i.e., the first wing tip **221T** is generally overlying the second wing tip **222T**; furthermore, in at least in this example, the second spacing **S2** corresponds to the span of the wings.

As mentioned above, the wing system **200** is configured for transitioning set of wings **210** between the stowed configuration **SC** and the deployed configuration **DC**. According to an aspect of the presently disclosed subject matter, the aforesaid transitioning comprises a pivoting operation, comprising:

- pivoting the first wing **221** about the first pivot axis **PA1** between the stowed configuration **SC** and the deployed configuration **DC**;
- pivoting the second wing **222** about the second pivot axis **PA2** between the stowed configuration **SC** and the deployed configuration **DC**.

In at least this example, and referring to Fig. 3, the wing system **200** is configured for pivoting the first wing **221** about the first pivot axis **PA1**, concurrently with pivoting the second wing **222** about the second pivot axis **PA2**. Furthermore, in transitioning between the stowed configuration **SC** and the deployed configuration **DC** via the pivoting operation:

- the first wing **221** is pivoted about the first pivot axis **PA1** by a non-zero first angular displacement θ_1 ; and
- the second wing **222** is pivoted about the second pivot axis **PA2** by a non-zero second angular displacement θ_2 .

It is to be noted that pivoting the first wing **221** about the first pivot axis **PA1** by a non-zero first angular displacement θ_1 essentially rotates the first wing **221** to project generally laterally from the fuselage **110**, thereby orienting the first leading edge **221L** towards the forward end of the air vehicle **100** and the first trailing edge **221E** towards the aft end of the air vehicle **100**, and concurrently essentially increases the spacing of the first wing tip **221T** with respect to the fuselage **110**, while concurrently the spacing of the first wing root **221R** with respect to the fuselage **110** can remain unchanged, or changed by a much smaller amount.

Similarly, pivoting the second wing **222** about the second pivot axis **PA2** by a non-zero second angular displacement θ_2 essentially rotates the second wing **222** to

project generally laterally from the fuselage **110**, thereby orienting the second leading edge **222L** towards the forward end of the air vehicle **100** and the second trailing edge **222E** towards the aft end of the air vehicle **100**, and concurrently essentially increases the spacing of the second wing tip **222T** with respect to the fuselage **110**, while concurrently the spacing of the second wing root **222R** with respect to the fuselage **110** can remain unchanged, or changed by a much smaller amount.

In at least this example, the non-zero first angular displacement θ_1 and the non-zero second angular displacement θ_2 are equal in magnitude to one another, though they are in opposite rotational directions. For example, each one of the non-zero first angular displacement θ_1 and the non-zero second angular displacement θ_2 can be within any one of the following ranges: 35° to 155° ; 35° to 100° ; 35° to 90° ; 45° to 90° ; 60° to 90° ; 75° to 90° . For example, each one of the non-zero first angular displacement θ_1 and the non-zero second angular displacement θ_2 can be any one of the following angles: 35° , 40° , 45° , 50° , 60° , 75° , 90° , 110° , 120° , 130° , 140° , 155° .

In particular, the wing system **200** in at least this example is configured for synchronizing the pivoting operation, such that the following two pivoting motions of the wings **221**, **222** are synchronized with one another, and thus are synchronized to so that the wings **221**, **222** start pivoting together and finish pivoting together:

- pivoting the first wing **221** about the first pivot axis **PA1** between the stowed configuration **SC** and the deployed configuration **DC**;
- pivoting the second wing **222** about the second pivot axis **PA2** between the stowed configuration **SC** and the deployed configuration **DC**

As will become clearer below, and referring in particular to Figs. 1(a) and 1(b), the wing system **200** in at least this example is configured for providing a levelling operation configured for levelling the first wing **221** and the second wing **222** with respect to one another from the overlying relationship in the stowed configuration **SC**, to a leveled relationship in the deployed configuration **DC**. Thus, prior to the levelling operation (Fig. 1(a)), and in the stowed configuration **SC**, the first wing **221** and the second wing **222** are at different positions along a direction parallel to the yaw axis **Y** of the air vehicle **100**. On the other hand after the levelling operation is completed (Fig. 1(b)), and in the

deployed configuration **DC**, the first wing **221** and the second wing **222** are at the same position along a direction parallel to the yaw axis **Y** of the air vehicle **100**.

In at least this example, and as will become clearer herein, the levelling operation is configured for translating the second wing **222** (in this example in an upwards direction) to the level of the first wing **221**, which remains at the location along a direction parallel to the yaw axis **Y** while pivoting between the stowed configuration **SC** and the deployed configuration **DC**. However in alternative variations of this example, and in other examples, the levelling operation can instead be configured for translating the first wing **221** (for example in a downward direction) to the level of the second wing **222**, which remains at the location along a direction parallel to the yaw axis **Y** while pivoting between the stowed configuration **SC** and the deployed configuration **DC**. In yet other alternative variations of this example, and in other examples, the levelling operation can instead be configured for translating both the first wing **221** and the second wing **222**, to a common location along a direction parallel to the yaw axis **Y** while pivoting between the stowed configuration **SC** and the deployed configuration **DC**, such a location being different from the original corresponding locations of the first wing **221** and the second wing **222** at the stowed configuration **SC**.

In at least this example, and as will become clearer herein, the wing system **200** is configured for providing the aforesaid levelling operation concurrent with the aforesaid transitioning between the stowed configuration **SC** and the deployed configuration **DC**. In particular, the wing system **200** in at least this example is configured for providing the levelling operation concurrent with the pivoting operation. In particular, the wing system **200** in at least this example is configured for synchronizing the levelling operation with the pivoting operation.

Referring in particular to Fig. 3(b). in at least this example, and as will become clearer herein, the wing system **200** is also configured for providing a translation operation configured for selectively translating the first wing **221** and the second wing **222** along a stroke direction **ST** through a stroke length **SL**, between a first axial position **AX1** corresponding to the stowed configuration **SC**, and a second axial position **AX2** corresponding to the deployed configuration **DC**.

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In at least this example, and as will become clearer herein, the stroke direction **ST** is in the aft direction with respect to the air vehicle **100**. Thus, the first axial position **AX1** is forward of the second axial position **AX2**. In alternative variations of this example, the stroke direction can be in the forward direction, for example in examples in which the deployment mechanism is configured for translating the wing system from an aft portion of the air vehicle to a forward portion of the air vehicle.

In at least this example, and as will become clearer herein, the wing system **200** is configured for providing the aforesaid translation operation concurrent with the aforesaid transitioning between **SC** and the deployed configuration **DC**. In particular, the wing system **200** in at least this example is configured for providing the aforesaid translation operation concurrent with the aforesaid pivoting operation. In particular, the wing system **200** in at least this example is configured for synchronizing the aforesaid translation operation with the aforesaid pivoting operation.

It is to be noted that by providing translation operation and the aforesaid pivoting operation, it is possible to maximize the first longitudinal length **LL1** and second longitudinal length **LL2**, respectively of the first wing **221** and the second wing **222** with respect to the fuselage length **FL**, while at the same time ensuring that the neutral point of the air vehicle remains at an axial position with respect to the center of gravity **CG** consistent with the desired static stability of the air vehicle. For example, the transition operation shift the wings aft, and thus the neutral point of the configuration can be close to or aft of the center of gravity to provide required static margin.

As is known in the art, aircraft stability is maintained when the location of the neutral point is aft of the aircraft center of mass, for example by 10%, 15% 20% of mean aerodynamic chord of the wings **220**.

In at least this example, the first longitudinal length **LL1** and second longitudinal length **LL2**, respectively of the first wing **221** and the second wing **222**, are each in the range of 70% to 90% of the fuselage length **FL**.

In alternative variations of this example, the first longitudinal length **LL1** and second longitudinal length **LL2** can each be equal to or greater than the fuselage length **FL**. In examples in which the first longitudinal length **LL1** and second longitudinal length

LL2 are each greater than the fuselage length **FL**, the aircraft packaging volume in the stowed configuration **SC** can be greater than the fuselage volume of the fuselage **110**; nevertheless, it is considered that such a configuration for the air vehicle provides a reduced overall volume as compared with configurations in which the wings cannot be translated along the fuselage axis or as compared with configurations in which the wings must be stowed one besides the other, thereby still providing maximal use of the available volume for enclosing the air vehicle in the stowed configuration – for example inside the aforementioned fairing.

In yet other alternative variations of this example, the first longitudinal length **LL1** and second longitudinal length **LL2** can each be much less than the fuselage length **F**, for example less than 70% of the fuselage length **FL**.

Referring in particular to Fig. 2(a), Fig. 2(b), Fig. 2(c), and Fig. 2(d), the wing system **200** further comprises a deployment system **400** configured for selectively transitioning the wing system **200**, in particular the set of wings **210**, and the first wing **221** and the second wing **222**, between the stowed configuration **SC** and the deployed configuration **DC**, in particular from the stowed configuration **SC** to the deployed configuration **DC**. The deployment system **400** can be operatively connected to the controller to enable the controller to operate the deployment system **400** and in particular thereby cause the deployment system **400** to transition the wing system **200** between the stowed configuration **SC** and the deployed configuration **DC**, in particular from the stowed configuration **SC** to the deployed configuration **DC**, and optionally back from the deployed configuration **DC** to the stowed configuration **SC**.

Referring in particular to Fig. 5, the first wing **221** comprises a first pivot shaft **241** coaxial with the first pivot axis **PA1**, and the second wing comprises a second pivot shaft **242** coaxial with the second pivot axis **PA2**. The first pivot shaft **241** and the second pivot shaft **242** can be considered to be part of the deployment system **400**.

The first wing **221** is fixedly mounted to the first shaft **241**. For example, the first wing **221** comprises a first shaft bracket **231** fixedly connected to the first wing **221**, for example at a location to minimize torsion loads on the first shaft **241**. Such a first shaft bracket **231** can be in the form of a wing root joiner or a wing root fitting.

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For example such a location can be at or near to the main spar of the first wing **221**, for example in examples where the first wing **221** is constructed with such a main spar. In these or other examples, for example, such a location can be at a chordwise position along the chord of the first wing **221** at or near the first wing root **221R**, i.e., of the root chord, from the leading edge thereof. For example such a chordwise position can be about 25% of the root chord and/or about 1% to 2% of the root chord forward of the aerodynamic center of the first wing **221** (for example about 1% to 2% of the root chord forward of the aerodynamic center of the first wing root **221R**). The first shaft bracket **231** has two spaced projections **231A**, **231B** to which the first shaft **241** is affixed.

The second wing **222** is movably mounted to the second shaft **242**. For example, the second wing **222** comprises a second shaft bracket **232** fixedly connected to the second wing **222**, for example at a location to minimize torsion loads on the first shaft **241**. Such a second shaft bracket **241** can be in the form of a wing root joiner or a wing root fitting.

For example such a location can be at or near to the main spar of the second wing **222**, for example in examples where the second wing **222** is constructed with such a main spar. In these or other examples, for example, such a location can be at a chordwise position along the chord of the second wing **222** at or near the second wing root **222R**, i.e., of the root chord, from the leading edge thereof. For example such a chordwise position can be about 25% of the root chord and/or about 1% to 2% of the root chord forward of the aerodynamic center of the second wing **222** (for example about 1% to 2% of the root chord forward of the aerodynamic center of the second wing root **222R**). The second shaft bracket **232** has a projection **232A** to which the second shaft **242** is movably mounted.

In particular, the second wing **222** is movably mounted to the second shaft **242** with respect to one degree of freedom in translation parallel to the second pivot axis **PA2**. In other words, while the second wing **222** is mounted to the second shaft **242**, the second wing **222** can nevertheless move in translation with respect to the second shaft **242** in a direction parallel to the second pivot axis **PA2**, between a first position **P1** corresponding to the stowed configuration **SC**, and a second position **P2** corresponding to the deployed

configuration **DC**, while concurrently transfer torque between the second wing **222** and the second shaft **242**.

The first pivot shaft **241** and the second pivot shaft **242** are configured for supporting loads from the first wing **221** and the second wing **222**, including the bending moment of the respective wing, the twisting (pitching) moment of the respective wing, the shear forces of the respective wing, and the torque required to deploy the respective wing and keep the respective wing in deployed position corresponding to the deployed configuration **DC**.

In at least this example, the deployment mechanism **400** comprises a spline arrangement, and thus the second shaft **242** is in the form of, or comprises, a male spline shaft **242M**. The second wing **222** is movably mounted to the second shaft **242** via a female spline coupling spline coupling **242F** complementary to the male spline shaft **242M**. The engaged splines between the female spline coupling **242F** and the male spline shaft **242M** enable rotational movement of the male spline shaft **242M** to be transmitted to the second wing **222** via the female spline coupling **242F**. At the same time, the engaged splines between the female spline coupling **242F** and the male spline shaft **242M** allow relative translation between the female spline coupling **242F** and the male spline shaft **242M** along a direction parallel to the second pivot axis **PA2**, and thus relative translation between the second wing **222** and the second shaft **242** along a direction parallel to the second pivot axis **PA2**.

In at least some alternative variations of this example, the spline arrangement can be replaced with a machine key arrangement. Such a machine key can also transfer torque in the coupling while still allowing axial movement of the female part of the key with respect to the male part of the key.

Thus, the first pivot shaft **241** is located at or near the first wing root **221R**, and the second pivot shaft **242** is located at or near the second wing root **222R**.

Referring in particular to Fig. 6(a) and Fig. 6(b), the deployment mechanism **400** comprises a load bearing bulkhead **410**. The first wing **221** is pivotably mounted to the load bearing bulkhead **410** via the first pivot shaft **241**, while the second wing **222** is pivotably mounted to the load bearing bulkhead **410** via the second pivot shaft **242**, as

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best seen in Fig. 7(a) and Fig. 7(b). The load bearing bulkhead **410** is a structural member capable of bearing loads from the first wing **221** and the second wing **222** during flight of the air vehicle **100**, and for supporting the wing system **200** in the stowed configuration **SC**, in the deployed configuration **DC**, and throughout the transition between the stowed configuration **SC** and the deployed configuration **DC**. In at least this example, the load bearing bulkhead **410** comprises a load bearing central section **415**. In at least this example, the central section **415** is of general I-beam construction, including an upper and lower flanges **417** spaced by web **416**, and stiffener elements **418**.

Without being bound by theory, inventors consider that load bearing bulkhead **410** supports wing bending moments and wing shear forces, thereby operating as a central load bearing member which, in the deployed configuration **DC**, provides contiguity between the first wing **221** and the second wing **222**, to essentially form a continuous wing spar or the like which spans from the first wing tip **221T** to the second wing **222T**. The inventors further consider that such a configuration can minimize or prevent exposure of the air vehicle fuselage with respect to potentially harmful bending and twisting moments which can be generated by the wings during flight. In other words, if the port and starboard wings, in particular the port and starboard wing spars, are instead connected directly to the fuselage rather than to the load bearing bulkhead, the fuselage would be exposed to very high bending and twisting moments. In the above examples in which the wings are coupled to a load bearing bulkhead which are together translated along the fuselage longitudinal axis, such a configuration can essentially provide weight savings by being able to allow omitting additional load bearing structures in the fuselage to enable the fuselage to support the wings bending and twisting moments along the fuselage area in which the wings are translated. The inventors further consider that such a configuration can generate very low loads in the interface between the fuselage and the wings.

The load bearing bulkhead **410** further comprises a first bearing arrangement **431** fixed to one lateral side of the central section **415** via first bracket projections **431A**, **431B**, in which the bearing arrangement **431** has a plurality of spaced bearings aligned with the first pivot axis **PA1**. The load bearing bulkhead **410** also comprises a second bearing arrangement **432** fixed to the other lateral side of the central section **415** via second bracket projections **432A**, **432B**, in which the bearing arrangement **432** has a plurality of spaced bearings aligned with the second pivot axis **PA2**. The load bearing bulkhead **410**

is dimensioned such as to provide the aforementioned spacing **PS** between the first pivot axis **PA1** and the second pivot axis **PA2**. In some examples such bearings can be ball bearing arrangements or the like, while in other examples, such bearings can be in the form of sleeves or bushes.

The first shaft **241** is rotatably mounted to the load bearing bulkhead **410** via the bearings of the first bearing arrangement **431**, enabling pivoting of the first wing **221** with respect to the load bearing bulkhead **410** about the first pivot axis **PA1**.

The second shaft **242**, in particular the male spline shaft **242M**, is rotatably mounted to the load bearing bulkhead **410** via the bearings of the second bearing arrangement **432**, enabling pivoting of the second wing **222** with respect to the load bearing bulkhead **410** about the second pivot axis **PA2**, via the female spline coupling **242F**.

The deployment mechanism **400** in at least this example is configured for providing, in the aforesaid pivoting operation, a pivoting synchronization operation with respect to the pivoting about the first pivot axis **PA1** and the second pivot axis **PA2**. In such a pivoting synchronization operation, pivoting of the first wing **221** about the first pivot axis **PA1** in a first rotational direction **RD1** is synchronized with pivoting of the second wing **222** about the second pivot axis **PA2** in a second rotational direction **RD2**, opposite to said first rotational direction **RD1**. Accordingly, and referring again to Fig. 7(a) and Fig. 7(b), the deployment mechanism **400** comprises a meshed gear arrangement **450** for providing the aforesaid synchronization operation.

Without being bound by theory, inventors consider that such synchronization ensures or at least enhances stabilization of the air vehicle during transitioning of the wing system **200** between the stowed configuration **SC** and the deployed configuration **DC**. Furthermore, such synchronization complies with at least some regulatory standards.

The meshed gear arrangement **450** comprises a first gear wheel **451** and a second gear wheel **452**.

The first gear wheel **451** is fixedly mounted to the first pivot shaft **231** and co-axial with the first pivot axis **PA1**. While in at least this example, first gear wheel **451** is in the form of a spur gear, with radially projecting straight-cut teeth, in alternative

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variations of this example, the first gear wheel **451** can have any other suitable teeth arrangement, for example helical teeth or herringbone teeth.

The second gear wheel **452** is fixedly mounted to the second pivot shaft **232** and co-axial with the second pivot axis **PA2**. While in at least this example, second gear wheel **452** is in the form of a spur gear, with radially projecting straight-cut teeth, in alternative variations of this example, the second gear wheel **452** can have any other suitable teeth arrangement, for example helical teeth or herringbone teeth.

The first gear wheel **451** is meshed directly with respect to the second gear wheel **452**, and thus have similar types of teeth arrangement. Thus, for example, as the first gear wheel **451** is turned or otherwise pivoted about the first pivot axis **PA1** in one rotational direction, for example rotational direction **RD1**, the second gear wheel **452** is automatically turned or otherwise pivoted about the second pivot axis **PA2** in the other rotational direction, for example rotational direction **RD2**, and vice versa.

The deployment mechanism **400** further comprises a support structure **488**, in at least this example in the form of frame **490**, for supporting and facilitating mounting of the deployment mechanism **400** with respect to load bearing bulkhead **410**.

The deployment mechanism **400** comprises an actuator **495** configured for selectively driving operation of the deployment mechanism **400**. The actuator **495** is configured for selectively providing a torque to at least one of the first gear wheel **451** and the second gear wheel **452** to drive the meshed gear arrangement **450**, to thereby provide the synchronization operation, as well as driving the pivoting operation per se.

In at least this example, the actuator **495** is configured for driving the deployment mechanism **400** to enable the wing system **200** to reversibly transition from the stowed configuration **SC** to the deployed configuration **DC**, and thus to also enable the wing system **200** to transition from the deployed configuration **DC** to the stowed configuration **SC**. Such a transitioning from the deployed configuration **DC** to the stowed configuration **SC** can be useful when for example when it is desired to land the air vehicle **100** in implementation of this and other examples in which the air vehicle lacks a landing gear or in which the landing gear can be malfunctioning or damaged. In such cases, landing the air vehicle with the wing system in the stowed configuration **SC** can potentially minimize impact

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damage to the air vehicle **100** and to the wing system **200** in particular. For example, the air vehicle **100** can be further configured with a deployable parachute and/or air cushion to further potentially minimize impact damage to the air vehicle **100** or to the wing system **200** in particular during landing.

In at least this example, the actuator **495** comprises a motor, for example an electrical motor, operatively coupled to the meshed gear arrangement **450**. However, in alternative variations of this example, the actuator **495** can comprise any other suitable actuator, for example a linear actuator, a rotary actuator, a loaded spring, pyro-technique device, a parachute, or any other type of device or system that is configured for providing the energy needed for the deployment mechanism **400** to enable the wing system **200** to (optionally reversibly) transition from the stowed configuration **SC** to the deployed configuration **DC**. For example, the actuator **495** is operatively coupled to the meshed gear arrangement **450**, via a worm and gear transmission or helical screw transmission.

In at least this example, the actuator **495** is operatively coupled to the controller, so that the controller thereby selectively operates the deployment mechanism **400** to transition between the stowed configuration **SC** and the deployed configuration **DC**.

In at least this example, the actuator **495** is operatively coupled to the meshed gear arrangement **450** to enable selectively driving the deployment mechanism **400**, and further comprises a self-lock device to ensure that the meshed gear arrangement **450**, and thus the deployment mechanism **400**, is locked at any given position, regardless if the motor is energized or not, so long as the actuator **495** is not driving the meshed gear arrangement **450**. In other words, the meshed gear arrangement **450**, and thus the deployment mechanism **400**, is locked at any given position and can only be moved out of the position by the rotation of the motor or actuator **495**.

For example, such shallow-pitch worm-gear transmissions and shallow-pitch screw (linear) transmissions are characterized by the fact that they can only be moved by the input shafts but they cannot be moved by their output shafts. In this example, such an input shaft is connected to the actuator **495** (which is for example in the form of a motor) while such output shaft is essentially connected (for example via the meshed gear arrangement **450**) to the wings **221, 222**. Thus any force generated by or applied to the

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wings **221**, **222** cannot cause rotation about the respective pivot axes because the transmission is locked for any movement originating from the output shaft.

Such “self-lock” characteristics are enhanced when the coupling is via a screw with very shallow pitch (for example via a worm gear with very shallow pitch).

In at least this example, the actuator **495** is operatively coupled to a motor gear wheel **496**, for example directly or via any suitable gear arrangement. The motor gear wheel **496** is meshed with at least one of the first gear wheel **451** and the second gear wheel **452** to drive the meshed gear arrangement **450**, to thereby provide the aforesaid synchronization operation. While in this example the motor gear wheel **496** is meshed with the first gear wheel **451**, in alternative variations of this example the motor gear wheel **496** can instead be meshed with the second gear wheel **452**, *mutatis mutandis*

Thus, as the actuator **495** selectively drives and turns the motor gear wheel **496**, the motor gear wheel **496** turns the first gear wheel **451** which is thus pivoted about the first pivot axis **PA1** in one rotational direction, for example rotational direction **RD1**. Concurrently the first gear wheel **451** turns the second gear wheel **452** which is thus pivoted about the second pivot axis **PA2** in the other rotational direction, for example rotational direction **RD2**, thereby providing the aforesaid pivoting operation and the aforesaid synchronization operation.

It is to be noted that the deployment arrangement **400** is configured for pivoting the first gear wheel **451** (and thus the first shaft **241** and the first wing **221**) about the first pivot axis **PA1** by the non-zero first angular displacement θ_1 , and for pivoting the second gear wheel **452** (and thus the second shaft **242** and the second wing **222**) about the second pivot axis **PA2** by the non-zero second angular displacement θ_2 . In at least this example, the non-zero first angular displacement θ_1 and the non-zero second angular displacement θ_2 are equal in magnitude to one another (although in mutually opposite rotational directions), and thus the first gear wheel **451** and the second gear wheel **452** have the same diameter, in particular at least the same pitch diameter.

It is further to be noted that the deployment arrangement **400** is configured for limiting pivoting the first gear wheel **451** (and thus the first shaft **241** and the first wing **221**) about the first pivot axis **PA1** by the non-zero first angular displacement θ_1 , and for

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limiting pivoting the second gear wheel **452** (and thus the second shaft **242** and the second wing **222**) about the second pivot axis **PA2** by the non-zero second angular displacement θ_2 . For such limiting, the deployment arrangement **400** can comprise suitable mechanism for so doing, for example a mechanical stop can be provided.

In at least this example, the motor gear wheel **496** is in the form of a pinion having a diameter smaller than the diameter of the first gear wheel **451** or of the second gear wheel **452**.

It is further to be noted that at least in this example, the first gear wheel **451** and the second gear wheel **452** are each in the form of a respective sector gear, in which each such respective sector gear is in the form of a portion of a full gear wheel, including the central opening (via which it is connected to the respective first shaft **231** or second shaft **232**) and a sector portion of the gear wheel including the arc portion of the rim with its teeth. Such an arrangement using sector gears can be useful in saving weight and/or providing a more compact arrangement. However, in alternative variations of this example, the first gear wheel **451** and the second gear wheel **452** can each be in the form of a respective full circle gear.

The first gear wheel **241** is meshed with the first gear wheel **241** as well as the motor gear wheel **496**. In at least this example, the center of rotation **497** of the motor gear wheel **496** is provided forward of the first pivot axis **PA1** and of the second pivot axis **PA2**, and thus, the corresponding sector portion of the first gear wheel **241** has a corresponding first sector angle **SA1** (i.e., the angle made by the corresponding arc at the center of rotation, i.e., the first pivot axis **PA1**) nominally equal to the sum of the non-zero first angular displacement θ_1 , plus an additional angular portion θ_w to ensure that the first gear wheel **241** is meshed with the first gear wheel **241** throughout the entirety of the pivoting of the first gear wheel **241** about non-zero first angular displacement θ_1 . For example, the first sector angle **SA1** can be about 5%, 10% or 20% larger than the sum of the non-zero first angular displacement θ_1 and angular portion θ_w . For example, the first sector angle **SA1** can be any one of the following angles: 95°, 100°, 145°, 160°, 180°, 200°, 210°, 220°, 230°, 240°, 250°.

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The second gear wheel **242** is only meshed with the second gear wheel **242**, and thus, the corresponding sector portion of the second gear wheel **242** has a corresponding second sector angle **SA2** (i.e., the angle made by the corresponding arc at the center or rotation, i.e., the second pivot axis **PA2**) nominally equal to the non-zero second angular displacement θ_2 . For example, the second sector angle **SA2** can be about 5%, 10% or 20% larger than the non-zero second angular displacement θ_2 . For example, the second sector angle **SA2** can be any one of the following angles: 40°, 45°, 50°, 60°, 75°, 90°, 95°, 100°, 110°, 120°, 130°, 140°, 150°, 160°, 165°.

The actuator **495** and motor gear wheel **496** are mounted with respect to the load bearing bulkhead **410** via the aforesaid support structure **488**, which in at least this example is in the form of frame **490**.

Referring in particular to Fig. 5, Fig. 6(a), Fig. 8(a), Fig. 8(b) and Fig. 8(c), in at least this example, and according to an aspect of the presently disclosed subject matter, the deployment mechanism **400** comprises a leveling arrangement **470** configured for providing the aforesaid levelling operation, to enable said levelling the first wing **221** and the second wing **222** with respect to one another from the overlying relationship in the stowed configuration **SC**, to a leveled relationship in the deployed configuration **DC**. In at least this example, the leveling arrangement **470** is also configured for synchronizing said levelling operation with said pivoting operation.

It is to be noted that in at least in this example, the second shaft **242** can be considered to be part of the leveling arrangement **470**. In particular, the configuration of the second shaft **242** having a spline arrangement or the like, for example being in the form of, or comprising, a male spline shaft **242M**, and the female spline coupling **242F** can be considered to be part of the leveling arrangement **470**.

Referring the leveling arrangement **470** in at least this example comprises a cam arrangement **475** configured to be operatively coupled to the second wing **222** via the second shaft **242**.

In at least this example, the cam arrangement **475** comprises a cam rail **472**, fixedly mounted with respect to the load bearing bulkhead **410**, for example via the support structure **488**, which in at least this example in the form of frame **490**.

In at least this example, cam rail **472** is helical, having a helical axis **HA** co-axial with the second pivot axis **PA2**.

In alternative variations of this example, the cam rail can have any other suitable shape. For example, the cam rail can be made from a combination of straight sections and helical sections, with varying helix angle. The shape of the cam rail can dictate the leveling motion profile of the wing that is being moved along the respective pivot axis. For example, a straight rail section can be provided for a given angle, in order to allow the wings **221**, **222** to move away from one another, without having any concurrent leveling motion – i.e. only pivoting is occurring while each wing is maintained at its respective level. When wing clearance is achieved, i.e., when the majority of the wings are no longer in overlapping relationship (for example after 20° rotation about each respective pivot axis **PA1**, **PA2**), the cam rail can change shape to helical form and allow the leveling of the wings **221**, **222**.

The leveling motion profile can thus be designed in such manner that wings **221**, **222** will not collide during deployment to the deployed configuration **DC**, and in such manner that lift force generated by the wings **221**, **222** can assist to level the wings **221**, **222**, since in such cases such a lift force can be in the same direction as the direction of the leveling motion.

In at least this example, the helical cam rail **472** has a first end **472A** corresponding to position **P1**, and a second end **472B** corresponding to position **P2**. Furthermore, the first end **472A** is angularly displaced from the second end **472B** with respect to the second pivot axis **PA2** by an angular displacement corresponding to the non-zero second angular displacement θ_2 .

In at least this example, the cam arrangement **475** comprises a cam follower **479** fixedly mounted to the second wing **222**. More specifically, the cam follower **479** is fixedly mounted to projection **232A** to which the second shaft **242** is movably mounted. The projection **232A** projects generally radially and orthogonally with respect to the second pivot axis **PA2**, and the cam follower **479** comprises a roller **478** rotatably mounted at the free end of projection **232A**.

In the deployment arrangement **400**, the cam follower **479** and in particular the roller **478** is constrained to move only along the cam rail **472**, which can only happen as the second shaft **242**, and in particular the second shaft bracket **232** and projection **232A** (and thus the second wing **222**) are pivoted about the second pivot axis.

Thus, the cam arrangement **475** is configured such that movement of the cam follower **479** along the cam rail **472** causes the second shaft **242**, and in particular the second shaft bracket **232** and projection **232A** (and thus the second wing **222**) to translate along the aforesaid degree of freedom parallel to the second pivot axis **PA2** in said levelling operation, responsive to the second shaft **242** being pivoted about the second pivot axis **PA2** non-zero second angular displacement θ_2 .

Thus, as the second shaft **242** is being pivoted about the second pivot axis **PA2** non-zero second angular displacement θ_2 , the second shaft bracket **232** and projection **232A** (and thus the second wing **222**) are concurrently displaced from position **P1** to position **P2**, thereby bringing the second wing **222** to the same level (along the yaw axis **Y**) as the first wing **221**.

Referring in particular to Figs. 4(a) to 4(d), and 10(a) to 10(d), in at least this example, and according to an aspect of the presently disclosed subject matter, the deployment mechanism **400** comprises a translation arrangement **440** configured for providing the aforesaid translation operation, to enable selectively translating the first wing **221** and the second wing **222** along the stroke direction **ST** through the stroke length **SL**, between the first axial position **AX1** corresponding to the stowed configuration **SC**, and the second axial position **AX2** corresponding to the deployed configuration **DC**. In at least this example, the translation arrangement **460** is also configured for synchronizing said translation operation with said pivoting operation.

In at least this example, the translation arrangement **440** comprises a rail system **445** configured to be fixedly mounted with respect to the air vehicle **100**. Furthermore, the load bearing bulkhead **410**, together with all the components of deployment mechanism **400** that are mounted to the load bearing bulkhead **410**, in particular the first wing **221** and the second wing **222**, is moveably mounted to said rail system **445** to enable the load bearing bulkhead **410** to be translated along said stroke direction **ST** through said stroke length **SL**, together with the first wing **221** and the second wing **222**.

In at least this example, the load bearing bulkhead **410** carries with it in such a translation operation, the actuator **495**, the meshed gear arrangement **450**, and leveling arrangement **470**, as well as the first wing **221** and the second wing **222**.

In at least this example, the rail system **445** comprises two rail members **441**, **442**, laterally spaced by spacing **RT**. Furthermore, the rail members **441**, **442** in at least this example are each rectilinear, and are aligned, typically parallel, with the centerline or longitudinal axis **LA** of the air vehicle **100**.

In alternative variations of this example, the rail members **441**, **442** can be concave or convex, for example, generating angular motion of the deployment mechanism when traveling on the rails. If rails are convex or concave, the wing incidence angle (wing chord angle with respect to the fuselage) can change concurrent with the travel of the wings. In such manner, the wing incidence, in the stowed configuration **SC** can be different from the wing incidence in the deployed configuration **DC**.

Furthermore, the translation arrangement **440** comprises a plurality of slider elements **465** configured for engaging with and concurrently moving with respect to the rail members **441**, **442**. For example, such slider elements **465** can include wheels, balls, rollers, or low friction surfaces that are configured to engage and run over the rail members **441**, **442**.

The slider elements **465** are fixedly mounted with respect to the load bearing bulkhead **410**, in at least this example via the support structure **488**, which in at least this example in the form of frame **490**. For example, two slider elements **465** are fixedly mounted on one lateral side of frame **490**, and two other slider elements **465** are fixedly mounted on the other lateral side of frame **490**, as best seen in Figs. 6(a) and 6(b).

In at least this example, the translation arrangement **440** comprises a suitable driving and synchronizing arrangement **460**. The driving and synchronizing arrangement **460** is mounted directly or indirectly to the load bearing bulkhead **410**, and is thus carried by the load bearing bulkhead **410** in the aforesaid translation operation.

The driving and synchronizing arrangement **460** is coupled to the rail system **440** via the sliders **465**, and provides motive power to enable translation of the load bearing bulkhead **410**, together with all the components of deployment mechanism **400** that are

mounted to the load bearing bulkhead **410**, in particular the first wing **221** and the second wing **222**, with respect to the rails **441**, **442**.

Furthermore, the driving and synchronizing arrangement **460** is configured for synchronizing the translation operation with the pivoting operation, such that as the wings **221**, **222** are pivoted about the respective first pivot axis **PA1** and second pivot axis **PA2** through the non-zero first angular displacement θ_1 and the non-zero second angular displacement θ_2 , respectively, the wings **221**, **222** are also translated concurrently from the first axial position **AX1** to the second axial position **AX2**.

In at least this example, the driving and synchronizing arrangement **460** is in the form of, or comprises, a rack and pinion arrangement, including a pinion gear **462** rotatably mounted directly or indirectly to the load bearing bulkhead **410**, and a rack gear **468** mounted in fixed spatial relationship with respect to the rail system **440** or in fixed spatial relationship with respect to the air vehicle **100**. In at least this example, the rack gear **468** is rectilinear, and is aligned, typically parallel, with the centerline or longitudinal axis **LA** of the air vehicle **100**.

The pinion gear **462** is meshed with the rack gear **468** and thus rotation of the pinion gear **462** translates the pinion gear **462** along the length of the rack gear **468**.

The pinion gear **462** is coupled with the meshed gear arrangement **450**, such that actuation of the meshed gear arrangement **450** causes rotation of the pinion gear **462**, and in turn the pinion gear **462** rotates with respect to the rack gear **468** causing translation of the pinion gear **462**, together with the load bearing bulkhead **410** and the wings **221**, **222**, along the stroke direction **ST**.

In at least this example, the pinion gear **462** is coaxial and fixedly mounted to a secondary gear **469** that is directly meshed with the meshed gear arrangement **450**. As best seen in Figs. 7(a) and 7(b), the secondary gear **469** is directly meshed in this example with the first gear **451**. However, in other alternative variations of this example the secondary gear **469** is directly meshed with the second gear **452**, or with both the first gear **451** and the second gear **452**. In at least this example, the diameter of the second gear **452** is smaller than the diameter of each of the first gear **451** and the second gear **452**, and furthermore, the diameter of the pinion gear **462** is larger than the diameter of the pinion

gear **462**. There is thus an amplification effect in that a given angular rotation of the first gear **451** about the first pivot axis **PA1** results in a amplified angular rotation by the pinion gear **462**.

For example, the number of teeth on the pinion gear **462** can define the magnitude of the axial distance the deployment mechanism travels per given angular displacement of the wings **221**, **222**. The number of teeth on the pinion gear **462** can be used to define the ratio between the angular (pivoting) displacement of the wings **221**, **222** about the pivot axis **PA1** and pivot axis **PA2**, respectively, and the axial (linear) displacement of the deployment mechanism **400**.

For a given diameter for each of the first gear **451** and the second gear **452**, and for a given diameter of the pinion gear **462**, the diameter of the secondary gear **469** can be chosen such that the pivoting of first gear **451** about the first pivot axis **PA1** through the non-zero first angular displacement θ_1 results in the pinion gear **462** being translated with respect to the rack gear **468** by the desired stroke length **SL**. Moreover, the rack and pinion arrangement also ensures that the pivoting operation and the translation operation occur at the same time, i.e., start together and terminate together.

In other words, and according to an aspect of the presently disclosed subject matter, it is possible to provide a plurality of such pinion gears, including at least two such pinion gears, each of different diameter one from the other, only one such pinion gear being alternately rotatably mounted to the load bearing bulkhead **410** via the secondary gear **469** to correspondingly provide a correspondingly different magnitude for the stroke length **ST**, while unchanging (or without the need to change) the rest of the deployment mechanism **400** or the magnitude of the non-zero first angular displacement θ_1 or of the non-zero second angular displacement θ_2 .

This feature enables essentially the same deployment mechanism **400** to be easily adapted for installation in a variety of air vehicles, in which the required stroke length can be different in each air vehicle, by essentially changing the pinion gear to suit the required stroke length.

In alternative variations of this example, the driving and synchronizing arrangement **460** can be in the form of, or comprises, a screw and nut mechanism in place

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of the rack and pinion arrangement. In such an example, the screw essentially replaces the rack gear, and the nut replaces the pinion gear, and the screw and nut mechanism is configured such that rotation of the nut causes linear motion along the screw. In such an example, the screw and nut mechanism is coupled with the meshed gear arrangement **450** such that actuation of the meshed gear arrangement **450** causes rotation of the nut, and in turn the nut rotates with respect to the screw causing translation of the nut, together with the load bearing bulkhead **410** and the wings **221, 222**, along the stroke direction **ST**.

In operation, the controller selectively operates the deployment system **400** at the desired time to enable the wing system **200** and thus the air vehicle **100** to transition between the stowed configuration **SC** and the deployed configuration **DC**. For example, the controller is configured for switching on the actuator **495** to thereby initiate the deployment.

Safety protocols can optionally be implemented in the controller to ensure that such transitioning cannot occur other than according to preset conditions – for example that such transitioning cannot occur while the air vehicle is on the ground, or while being transported, or while still accommodated in the fairing. Furthermore, a suitable safety mechanism, for example a mechanical lock, can be configured for mechanically locking the deployment system **400**, and thus the wing system **200**, in the stowed configuration **SC**, at least until the air vehicle is separated from the fairing, or at least until prior to launch of the air vehicle for example while still in the fairing.

In alternative variations of the above examples, and according to another aspect of the presently disclosed subject matter, the translation mechanism can be omitted, *mutatis mutandis* and thus the deployment mechanism can be used in implementation of the presently disclosed subject matter, in which the pivoting mechanism is at a fixed location on the fuselage, resulting the wings leveling by the time they pivot to the deployed configuration.

In alternative variations of the above examples, and according to another aspect of the presently disclosed subject matter, the leveling mechanism can be omitted, *mutatis mutandis* and thus the deployment mechanism can be used in implementation of the presently disclosed subject matter, in which the pivoting mechanism translates along the

fuselage, resulting the wings remaining unlevelled, but displacing through the desired stroke by the time they pivot to the deployed configuration.

In yet other alternative variations of the above examples, and according to another aspect of the presently disclosed subject matter, the levelling mechanism and the translation mechanism can be omitted, *mutatis mutandis*. In such examples, the deployment mechanism can be used in implementation of the presently disclosed subject matter, in which the deployment mechanism is configured for selectively providing a wing pivoting operation, without said displacement operation and without said levelling operation, while each wing is deployed from the stowed configuration to the deployed configuration about its respective pivot axis, where in the two pivot axes are non-coaxial.

In yet other alternative variations of the above examples, and according to another aspect of the presently disclosed subject matter, the levelling mechanism can be omitted, *mutatis mutandis*. In such examples, the deployment mechanism can be used in implementation of the presently disclosed subject matter, in which the deployment mechanism is configured for selectively providing a displacement operation concurrent with the wing pivoting operation, said displacement operation comprising translating the first wing and the second wing through a stroke length concurrent with said pivoting (with or without leveling), between a first axial position corresponding to the stowed configuration, and a second axial position corresponding to the deployed configuration; while the deployment mechanism is configured for enabling changing a magnitude of the stroke length while unaffected the wing pivoting operation. In other words, for a given pivoting angular displacement, the stroke length for the specific deployment mechanism can be changed as desired.

It is to be noted that at least in some implementations of the presently disclosed subject matter, and according to an aspect of the presently disclosed subject matter, there is provided a method of operating an air vehicle, comprising:

- (a) providing an air vehicle as defined herein, the air vehicle in the stowed configuration encapsulated in a fairing, for example as disclosed herein;
- (b) launching the encapsulated air vehicle, for example to a predetermined altitude and a predetermined forward speed;
- (c) separating the air vehicle from the fairing;

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(d) selectively operating the respective wing system to transition the wing system from the stowed configuration to the deployed configuration.

Furthermore, step (b) can include any one of:

- launching the encapsulated air vehicle via a launch barrel;
- launching the encapsulated air vehicle using a booster rocket;
- launching the encapsulated air vehicle from a carrier aircraft.

In the method claims that follow, alphanumeric characters and Roman numerals used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

Finally, it should be noted that the word “comprising” as used throughout the appended claims is to be interpreted to mean “including but not limited to”.

While there has been shown and disclosed examples in accordance with the presently disclosed subject matter, it will be appreciated that many changes may be made therein without departing from the scope of the presently disclosed subject matter as set out in the claims.