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REFUELING DEVICE

TECHNOLOGICAL FIELD

The presently disclosed subject matter relates to in-flight refueling systems, in particular to boom-type in-flight refueling systems.

BACKGROUND

Airborne refueling (also referred to interchangeably herein as air refueling, in-flight refueling, air to air refueling (AAR), aerial refueling, tanking, and the like) refers to the process of transferring fuel from a tanker aircraft to a receiver aircraft during flight.

Two types of airborne refueling systems are currently in use for refueling airborne military aircraft:

- the so-called “hose and drogue” system, used by the US Navy and many non-US air forces;
- the so-called “boom and receptacle” or “flying boom” system, used by the US Air Force, and also used by Israel, Turkey and the Netherlands.

In the hose and drogue system, the refueling aircraft is provided with one or more non-rigid refueling lines, at the end of each of which there is a drogue which functions as a stabilizer and includes a receptacle, while the receiver aircraft is fitted with a probe that is configured for engaging with the receptacle. In use, the drogue is not actively controlled, but rather aligns itself freely in the airflow aft of the tanker. The pilot of the receiver aircraft controls the flight path thereof to ensure engaging contact between the probe and the receptacle. Thereafter, the receiver aircraft is refueled via the refueling line and probe.

In the boom and receptacle system, the tanker includes a so-called “flying boom”, which is a rigid tube that telescopes outwardly and is gimbaled to the rear of the tanker aircraft, and is otherwise retracted into the tanker fuselage when not in use. The boom carries a fuel line and comprises a fuel transfer nozzle at the end thereof, and the boom is

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equipped with adjustable flight control surfaces. Once the tanker and receiver aircraft are in close proximity and flying in formation, with the receiver aircraft at a position behind the tanker within an air refueling envelope (i.e., safe limits of travel for the boom with respect to the receiver aircraft and within which contact between the receiving aircraft and the boom is safe), a dedicated operator in the tanker controls the position of the boom via the control surfaces, and inserts the end of the boom including the nozzle into a receptacle provided on an upper part of the receiving aircraft, ensuring proper mating between the nozzle and receptacle, after which fuel transfer can begin. During refueling, and while the boom is engaged with the receptacle, the pilot of the receiver aircraft must continue to fly within the air refueling envelope, and if the receiver aircraft approaches these limits the operator in the tanker requires the receiver aircraft pilot to correct the position thereof, and if necessary the boom is disconnected to prevent accidents. All current tankers of this type carry a single boom and can refuel a single receiver aircraft of this type at a time.

In addition, there are some tankers that comprise a flying boom system and at least one hose and drogue system as well, and are commonly known as Multi-Point Refueling Systems (MPRS). In some cases a hose and drogue system is provided at the aircraft tail, and thus only this system or the flying boom system may be used at any one time. In other cases, two under-wing hose and drogue pods, known as Wing Air Refueling Pods (WARPs), can be provided, one under each wing, in addition to the flying boom system.

By way of general background, WO 2013/102903 and WO 2013/102906, assigned to the present Assignee, disclose a variety of refueling devices, systems and methods for use in in-flight refueling. In one example one such device is towed by a tanker aircraft via a fuel hose at least during in-flight refueling, and has a boom member with a boom axis. The boom member enables fuel to be transferred from the fuel hose to a receiver aircraft along the boom axis during in-flight refueling. The device maintains a desired non-zero angular disposition between the boom axis and a forward direction at least when the refueling device is towed by the tanker aircraft in the forward direction via the fuel hose.

Also by way of general background, US 7,562,847 discloses an autonomous in-flight refueling hose end unit including a first end configured to be coupled to a fuel hose of a tanker aircraft. and a second end configured to be coupled to receiver aircraft and

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adjustable control surfaces, and a flight control computer autonomously controls the control surfaces to fly the refueling hose end into contact with the receiver aircraft.

Also by way of general background, in GB 2,237,251 an in flight refueling apparatus mountable on a tanker aircraft has a probe receptor coupled with a fuel line and is arranged to be deployed outboard of the aircraft, and can be provided on a drogue or a boom. In one mode, the apparatus is arranged to provide a parameter which is representative of the deviation of the path of the receptor from a predetermined initial path for actuating control means for changing automatically the position of the receptor relative to the initial path. In another mode, a parameter which is representative of the relative angular position of the receptor with respect to the probe of an approaching refueling aircraft for actuating control means for changing automatically the relative angular position to achieve alignment of receptor and probe.

Also by way of general background, US 2014/346279A discloses a trailing boom system for aerial refueling and a method for aerial refueling of multiple receiver aircraft. The trailing boom system for aerial refueling includes a parent pod capable of being connected to a wing of an aircraft, and a detachable pod releasable from the parent pod, the detachable pod including an extendible boom for refueling aircraft in flight.

Also by way of general background, US 2014/306063 discloses a refueling system that may include a refueling hose and a refueling drone coupled to the hose aft end. The refueling drone may be rearwardly deployable from the tanker aircraft such that the refueling drone is towed by the refueling hose behind the tanker aircraft. The refueling drone may be engaged to a receiver aircraft for transferring fuel from the tanker aircraft to the receiver aircraft.

Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed subject matter.

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GENERAL DESCRIPTION

According to a first aspect of the presently disclosed subject matter there is provided a refueling device for use in in-flight refueling operation, comprising:

- (a) a body configured for being towed by a tanker aircraft in a forward direction via a fuel hose at least during in-flight refueling operation, the body having a body longitudinal axis;
- (b) a boom member carried by the body, the boom member having a fuel delivery nozzle, the fuel delivery nozzle being configured for selectively engaging with a fuel receptacle in a receiver aircraft to enable fuel to be transferred from said fuel hose to the receiver aircraft during said in-flight refueling operation;
- (c) spatial control system configured for selectively providing stability and control to the refueling device;
- (d) a longitudinal displacement control system, comprising:
 - at least one panel element defining a front panel projected area orthogonal to the body longitudinal axis, each said panel element being controllably and reversibly deployable incrementally to each one of a plurality of successive deployed positions between a fully retracted position and a fully deployed position, to provide a respective reversible incrementally increasing aft force to the refueling device at least during the in-flight refueling operation.

For example:

- in the fully retracted position the respective said panel element is retracted within the body and a proportion of said front panel projected area exposed to an airflow over the body, at least during the in-flight refueling operation, is at a minimum, thereby providing a respective minimum said aft force to the refueling device;
- in the fully deployed position the respective said proportion of the front panel projected area of said panel element exposed to the airflow, at least during the in-flight refueling operation, is at a maximum, thereby providing a respective maximum said aft force to the refueling device, and
- in each said successive deployed position a corresponding said proportion of said front panel projected area of the panel element is correspondingly exposed to the airflow, at least during the in-flight refueling operation, thereby providing a corresponding said aft force to the refueling device;

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- a magnitude of said proportion of said front panel projected area is reversibly incrementally increased as the panel element is deployed from the fully retracted position to the deployed position via said successive deployed positions to thereby provide a controllable and reversibly incrementally increasing said aft force having a force magnitude respectively increasing from said respective minimum aft force to said respective maximum aft force.

Additionally or alternatively, for example, at least one said panel element is in the form of a curved plate having a concave cylindrical surface facing the forward direction, and a center of curvature. For example, the concave cylindrical surface comprises arc-shaped cross-sections, each subtending an angle at the center of curvature of between 60 degrees and 90 degrees.

Additionally or alternatively, for example, the at least one said panel element is pivotably mounted to device to allow for pivoting of the at least one said panel element about a pivoting axis co-axial with the center of curvature. For example, said pivoting axis is located longitudinally aft of a center of gravity of the refueling device.

Additionally or alternatively, for example, said pivoting axis is located at a longitudinal position between 60% and 90% of a longitudinal dimension of the body.

Additionally or alternatively, for example, each said pivoting axis is transversely located at a transverse position outside of the body. For example, said pivoting axis is located at a transverse position between 15% and 50% of a transverse dimension of the body.

Additionally or alternatively, for example, each said panel element has a height to width aspect ratio in the range 0.3 to 0.9.

Additionally or alternatively, for example, said pivoting axis is parallel to a pitch axis of the refueling device.

Additionally or alternatively, for example, said body comprises a corresponding slot for each said panel element, into which the respective said panel is retracted into in the respective said fully retracted position.

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Additionally or alternatively, for example, each panel element moves along an arc, corresponding to said curvature, about the respect, pivot axis, between said fully retracted position and said fully deployed position.

Additionally or alternatively, for example, the refueling device comprises an actuator for controllably causing each said panel element to be deployed between the respective said fully retracted position and the respective said deployed position.

Additionally or alternatively, for example, the refueling device comprises two said panel elements, wherein one said panel element is mounted with respect to an upper part of the body, and wherein the other said panel element is mounted with respect to a lower part of the body.

Additionally or alternatively, for example, the refueling device comprises two said panel elements, wherein one said panel element is mounted with respect to a port part of the body, and wherein the other said panel element is mounted with respect to a starboard part of the body.

Additionally or alternatively, for example, the two said panel elements are pivotably mounted to the body at the same longitudinal spacing from a forward end of the body.

Additionally or alternatively, for example, the refueling device is configured for synchronized deployment of the two said panel elements.

Additionally or alternatively, for example, the refueling device further comprises a controller for controlling said magnitude of said aft force by controlling said proportion of said front panel projected area. For example, said controller is configured for controlling said magnitude of said aft force to provide and maintain a tension in said hose within a predetermined tension range. Additionally or alternatively, for example, said controller is configured for controlling said magnitude of said aft force to provide a desired forward to at displacement of the refueling device with respect to the tanker aircraft.

Additionally or alternatively, for example, said boom member has refueling nozzle at a free end thereof, and a boom axis passing through the refueling nozzle,

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wherein at least during in-flight refueling said boom axis is at a non-zero angular deposition with respect to the body axis. For example, the boom member is reversibly pivotable with respect to the body, between a boom stowed position and a boom deployed position, wherein in the boom stowed position the refueling nozzle is closes to the body, and wherein in the boom deployed position engagement with the fuel receptacle of the receiver aircraft is possible. Alternatively, for example, said boom member is in fixed spatial relationship with respect to the body.

Additionally or alternatively, for example, said spatial control system is further configured for selectively providing control moments in at least one of pitch, yaw and roll wherein to enable the refueling device to be flown while towed by the tanker aircraft in said forward direction via said fuel hose.

Additionally or alternatively, for example, said spatial control system comprises selectively controllable aerodynamic control system. For example, said selectively controllable aerodynamic control system comprises a forward set of aerodynamic control surfaces mounted to said body, and an aft set of aerodynamic control surfaces mounted to said body in longitudinally aft spaced relationship with respect to said forward set of aerodynamic control surfaces. For example, said forward set of aerodynamic control surfaces comprises a canard configuration, and said aft set of aerodynamic control surfaces comprises one or more wing elements. Additionally or alternatively, for example, said aft set of aerodynamic control surfaces comprises an H-wing configuration, comprising two vertical wing stabilizers, one each on either side of a respective wing. Additionally or alternatively, for example, said forward set of aerodynamic control surfaces comprises an H-canard configuration, comprising two vertical canard stabilizers, one each on either side of a respective canard.

Additionally or alternatively, for example, said spatial control system is configured for enabling the refueling device to be steered in one, or two, or three degrees of freedom in translation, and in one, or two, or three degrees of freedom in rotation, independently of the tanker aircraft or of the refueling aircraft.

Additionally or alternatively, for example, said longitudinal displacement control system is different from the spatial control system.

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Additionally or alternatively, for example, the refueling device comprises a force generating arrangement configured for selectively generating a force along said aft boom axis in a direction towards said fuel delivery nozzle. For example, said force generating arrangement is configured for selectively generating said force along said aft boom axis in a direction towards said fuel delivery nozzle responsive to said fuel delivery nozzle being in predetermined proximity to the fuel receptacle of the receiver aircraft wherein to force said fuel delivery nozzle into engagement with the fuel receptacle.

Additionally or alternatively, for example, said body comprising a fuel delivery lumen configured for fluid communication with said fuel hose and said boom member at least during the in-flight refueling operation, wherein said body comprises a coupling having a hose interface configured for connecting said lumen to the fuel hose, said coupling configured for allowing relative rotation between the hose and said body in at least one degree of freedom while maintaining said fuel communication.

Additionally or alternatively, for example, the refueling device further comprises a data acquisition system configured for providing spatial data relating to a relative spatial disposition between said fuel delivery nozzle and said fuel receptacle, to enable selectively controlling the refueling device to provide automatic or autonomous or manual engagement of the fuel delivery nozzle to the fuel receptacle of the receiver aircraft.

Additionally or alternatively, for example, the refueling device further comprises a suitable controller for controlling operation thereof.

According to a second aspect of the presently disclosed subject matter there is provided a refueling system comprising a refueling fuel reservoir connected to a refueling device via a hose, the refueling device being as defined herein regarding the aforementioned first aspect of the presently disclosed subject matter.

According to a third aspect of the presently disclosed subject matter there is provided a tanker aircraft comprising at least one refueling system as defined herein regarding the aforementioned second aspect of the presently disclosed subject matter.

According to a fourth aspect of the presently disclosed subject matter there is provided a method for in-flight refueling, comprising:

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- providing a tanker aircraft as defined herein regarding the aforementioned third aspect of the presently disclosed subject matter;
- deploying the refueling device aft of the tanker aircraft when airborne;
- operating the longitudinal displacement control system to provide at least one of:
 - (i) a desired tension in the hose;
 - (ii) a desired fore or aft displacement of the refueling device.

A feature of at least one example of the presently disclosed subject matter is that there is provided a refueling device having longitudinal displacement control system in which the respective one panel element is configured such that the corresponding center-of-pressure (point of application) of the aerodynamic forces acting on the panel element converge toward the corresponding hinge axis of the panel element.

Another feature of at least one example of the presently disclosed subject matter is that, in examples in which at least one respective one panel element is in the form of a plate having an actual or effective center of curvature and a concave surface facing the forward direction, and wherein the panel element is pivotable about a pivoting axis co-axial with the center of curvature, actuation loads for deploying the panel element between the fully retracted position and the fully deployed position can be minimized. In particular, such actuation loads can be significantly less than for corresponding systems in which the corresponding center-of-pressure (point of application) of the aerodynamic forces acting on the panel element do not converge toward the corresponding hinge axis.

Another feature of at least one example of the presently disclosed subject matter is that, in examples in which at least one respective one panel element is in the form of a curved plate, the drag coefficient (normalized by the panel frontal area) of such a panel element can exceed 1.

Another feature of at least one example of the presently disclosed subject matter is that the drag force generated by the longitudinal displacement control system can be controllably changed in an incremental manner by correspondingly incrementally retracting or deploying the respective panel elements, thereby allowing for accurate control of the drag force generated by the longitudinal displacement control system.

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, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1(a) is an aft-top isometric view of a refueling device according to of an example of the presently disclosed subject matter, with the respective longitudinal displacement control system in the fully deployed position; **Fig. 1(b)** is an aft-top isometric view of the refueling device according to the example of Fig. 1(a), with the respective longitudinal displacement control system in the fully retracted position.

Fig. 2(a) is an front-top isometric view of the refueling device according to the example of Fig. 1(a), with the respective longitudinal displacement control system in the fully deployed position; **Fig. 2(b)** is an front-top isometric view of the refueling device according to the example of Fig. 1(a), with the respective longitudinal displacement control system in the fully retracted position.

Fig. 3 is a cross-sectional side view of the aft end of the refueling device according to the example of Fig. 1(a), showing the respective longitudinal displacement control system in the fully deployed position; **Fig. 3(a)** is a front isometric view of a panel element of the example of the longitudinal displacement control system of Fig. 3.

Fig. 4 is a detail cross-sectional side view of part of the aft end of the refueling device according to the example of Fig. 3.

Fig. 5 is a detail cross-sectional side view of part of the aft end of the refueling device according to the example of Fig. 4, showing angular dispositions of the respective panel element of the longitudinal displacement control system at various deployed positions.

Fig. 6 is a cross-sectional side view of the aft end of the refueling device according to the example of Fig. 3, illustrating the forces generated in respective longitudinal displacement control system in the fully deployed position; **Fig. 6(a)** is a vector force diagram of the forces generated in the example of Fig. 6.

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Fig. 7 is a side view of a tanker system according to an example of the presently disclosed subject matter.

DETAILED DESCRIPTION

Referring to Figs. 1(a) to 2(b), a refueling device for use in in-flight refueling operation, according to one example of the presently disclosed subject matter, generally designated **100**, comprises a body **110**, a boom member **130**, a spatial control system **160**, and a longitudinal displacement control system **200**.

As will become clearer herein, and referring also to Fig. 7, the refueling device **100**, and in particular the body **110** is configured for being towed by a tanker aircraft **12** in a forward direction **A** via a fuel hose **52** at least during in-flight refueling operation, the body **110** having a body longitudinal axis **LAB** and a neutral point **NP** (Fig. 3).

Furthermore, the boom member **130** is carried by the body **110**, the boom member **130** having a fuel delivery nozzle **135**, the fuel delivery nozzle **135** being configured for selectively engaging with a fuel receptacle in a receiver aircraft **20** to enable fuel to be transferred from the fuel hose **52** to the receiver aircraft **20** along during the in-flight refueling operation. Furthermore, the spatial control system **160** is configured for selectively providing stability and control to the refueling device **100**.

Referring in particular to Fig. 7, a tanker system **10**, according to one example of the presently disclosed subject matter, comprises the tanker aircraft **12** including one or more in-flight refueling systems **50**. As will become clearer herein, each refueling system **50** comprises a refueling device **100**.

In at least this example, the tanker aircraft **12** has three such in-flight refueling systems **50**, one in-flight refueling system **50** carried by the port wing **14**, another in-flight refueling system **50** carried by the starboard wing **16**, and a third in-flight refueling system **50** located in the rear portion of the fuselage **15**, and the tanker aircraft **12** is configured for in-flight concurrent refueling of up to three receiver aircraft **20**. In alternative variations of this example the tanker aircraft **12** can have at least one, or two, or more than three in-flight refueling systems **50**, arranged in any suitable configuration with respect to the tanker aircraft **12**.

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By way of non-limiting example, such a tanker aircraft **12** can be a suitably equipped Boeing 767, Boeing 747, or Airbus 330, and each receiver aircraft **20** can include any suitable aircraft, for example any one of suitably equipped F-15, or F-16, or F-35, or B1, or B2 stealth bomber, or other suitably equipped fighter, bomber or other aircraft. Alternatively, and also by way of non-limiting example, the tanker aircraft can be an unmanned aerial vehicle (UAV), and/or at least one of the receiver aircraft can be a UAV.

Also by way of non-limiting example, a refueling flight envelope for use with such a tanker system **10** can include a forward speed of between about 220 knots and about 320 knots (typically about 280 knots), and an altitude of between 500ft and between about 30,000ft to about 40,000ft, and in general typically not below about 10,000ft, in which refueling can take place between the tanker aircraft **12** and each receiver aircraft **20**, flying in formation, depending on the operating limits of the tanker aircraft and of the receiver aircraft, as well as other factors.

In at least this example, and referring again to Figs. 1(a) to 2(b), each in-flight refueling system **50** comprises an elongate, non-rigid, fuel delivery hose **52**, reversibly extendible from the tanker aircraft **12**. A first end (not shown) of the hose **52** is connected to a refueling fuel tank (not shown) carried by the tanker aircraft **12**. For example, such a refueling fuel tank can be an internal fuel tank of the tanker aircraft **12**, for example the tanker aircraft's own fuel tanks, or a special fuel reservoir mounted internally in the tanker aircraft **12**, for example in the fuselage, or externally (for example carried in fuel pods).

The hose **52** is flexible and can be retracted into a roll up drum (not shown), suitably provided in the tanker aircraft **12**, and selectively deployed therefrom when required.

The second (aft) end **54** of hose **52** is operatively connected to a respective refueling device **100** that is towed in a forward direction **A** by the tanker aircraft **12** via hose **52** when the hose **52** is extended and the tanker aircraft **12** is in flight.

In at least this example, one in-flight refueling system **50** is centrally-located and mounted with respect to the rear fuselage of the tanker aircraft **12**, and each of the other two in-flight refueling systems **50** is comprised in a respective pod **51** that is attached to the underside of the respective wing.

Thus, and referring again to Figs. 1(a) to 2(b), the refueling device according to a first example of the presently disclosed subject matter, generally designated **100**, is

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configured for use with respect to an in-flight refueling system, for example at least one of the in-flight refueling systems **50** of the example of the tanker system **10** illustrated Fig. 7.

For convenience, and referring again to Figs. 1(a) to 2(b), a roll axis **R**, a pitch axis **P** and a yaw axis **Y** can be conventionally defined with respect to the refueling device **100**. The roll axis **R** is parallel to or co-axial with the longitudinal axis **LAB** of the device **100**; the pitch axis **P** is generally in lateral and orthogonal relationship to the roll axis **R** (i.e., parallel to the horizontal when the body is at a zero roll angle); and yaw axis **Y** is in generally in transverse and orthogonal relationship to the roll axis **R** the pitch axis **P** (i.e., parallel to the vertical when the body is at a zero pitch angle).

Refueling device **100** is affixed to the end **54** of hose **52** and comprises body **110**, which at least in this example is in the form of a generally elongate fuselage, and comprises a longitudinal axis **LAB**. While in at least this example the body **110** comprises a general oval or elliptical cross section, in alternative variations of this example the body **110** can have any other suitable cross-sectional shape, for example circular cross-section, polygonal cross-section, super-elliptical cross-section, and so on.

Referring in particular to Fig. 2(a), the body **110** comprises a fuel delivery lumen **120** and carries boom member **130** (which at least in this example is a substantially rigid boom member) in fluid communication with fuel delivery lumen **120**. The boom member **130** comprises fuel delivery nozzle **135** at a terminus **136** i.e., at the aft end of the boom member **130**. The nozzle **135** is configured for reversibly engaging with the fuel receptacle **22** of a receiver aircraft **20** (see also Fig. 7), and thus can comprise any conventional design of such nozzles, which are well known in the art, or indeed can comprise any other current or future design of such an in-flight refueling nozzle. While in at least this example, the boom member **130** is not extensible, in alternative variations of this example, the boom member **130** can instead be extensible, and comprise for example a plurality of telescopic elements.

The body **110** comprises a coupling **140** at forward end **114** thereof. The coupling **140** comprises a hose interface configured for connecting the lumen **120** to the hose **52**, and thereby to the tanker aircraft **12**. The coupling **140** can be configured for allowing relative rotation between the body **110** and the hose **52** while maintaining fluid communication between the lumen **120** and the hose **52** and thus the refueling tank. In this example, the coupling **140** is in the form of a universal joint or the like (also referred

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to as a universal coupling, a Cardan joint, a Hardy-Spicer joint or a Hooke's joint, and so on), and is thus configured for allowing relative rotation between the body **110** and the hose **52** in three degrees of freedom.

In alternative variations of this example and in other examples, the coupling can instead be configured for allowing relative rotation between the body **110** and the hose **52** in one degree of freedom, or in two degrees of freedom. In particular, the coupling allows the body **110**, and in particular the boom member **130** to freely pivot with respect to the hose **52**, in particular the second end **54**, about at least one axis, so that the spatial orientation of the refueling device **100** can be controllably changed without significant mechanical resistance thereto being generated by the hose **52** such an axis, which is typically parallel the pitch axis **P** of the refueling device **100**, but may be alternatively inclined to the pitch axis **P** and/or to the roll axis **R** and/or to the yaw axis **Y**.

In alternative variations of this example the coupling **140** can be omitted and replaced with a fixed coupling that is configured to maintain a fixed relative spatial disposition between the body **110** and the hose **52** (in particular between the body **110** and the second end **54**) while maintaining fluid communication between the lumen **120** and the hose **52**. For example such a spatial disposition can be an angle μ (see Fig. 7) of about 0° ; or about 30° ; or in a range between about 5° and about 85° ; or in a range between about 10° and about 80° ; or in a range between about 15° and about 70° ; or in a range between about 20° and about 60° ; or in a range between about 25° and about 50° ; or in a range between about 20° and about 40° ; or in a range between about 25° and about 40° ; or in a range between about 28° and about 32° .

The boom member **130** is pivotably mounted to body **110** about axis **C** (generally parallel to the pitch axis **P** of the body **110**) at pivot joint **119**, and is reversibly pivotable between a stowed or boom retracted position **BRP** (shown in the rightmost receiver refueling device in Fig. 7) and a boom deployed position **BDP** (Figs. 1(a) to 2(b)). The boom member **130** is typically in the retracted position **RP** during flight operations excluding actual in-flight operations to reduce drag, while during in-flight refueling operation the boom member **130** is in the boom deployed position **BDP**.

In at least this example, at least during refueling operation the fuel delivery nozzle **135** is longitudinally forward of the neutral point **NP** by a longitudinal spacing. As is well known in the art the neutral point of an air vehicle is the position at which the center

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of gravity needs to be located to provide the aircraft with neutral stability. In practice conventionally, the center of gravity of many conventional air vehicles is often not located at the neutral point, and the distance between the two is referred to as the static margin. The static margin is “positive” if the center of gravity is located forward of the neutral point, providing the aircraft with positive stability, or “negative” if the center of gravity is located aft of the neutral point, providing the aircraft with negative stability. In at least this example, the device **100** is configured with positive stability, and the neutral point **NP** thereof is located aft of the center of gravity **CG**.

It is also to be noted that in practice, the fuel delivery nozzle **135** is spaced below the underside **115** of the body **110** by a transverse spacing to provide sufficient clearance with respect to the receiver aircraft **20**, and thereby minimize risk of collision between the receiver aircraft **20** and the body **110**.

While in at least this example, the boom member **130** is configured as an elbowed boom, in alternative variations of this example the boom member **130** is configured as a rectilinear boom or as a curved boom.

In the stowed or boom retracted position **BRP**, boom member **130** is pivoted about axis **C** into a position where the terminus **136** is closest to the lower side **110B** of body **110**. In the boom deployed position **BDP**, boom member **130** is variably pivoted about pivot axis **C** in a downward direction to provide a desired orientation with respect to the fuel receptacle of the receiver aircraft **20**.

In any case, in general the boom member **130** is in the boom deployed position **BDP** at least during in-flight refueling operation of the device **100**.

A suitable actuation mechanism (not shown) is provided for controllably pivoting the boom member **130** between the stowed or boom retracted position **BRP** and the boom deployed position **BDP**.

The refueling device **100**, in particular the boom member **130**, nozzle **135** and lumen **120** can be sized to allow suitable fuel flow rates for refueling a wide range of receiver aircraft. By way of non-limiting example, relative high fuel flow rates (for example up to 1000 US gallons/6,500 lb per minute) can be provided for refueling operations of large aircraft (for example transport aircraft, bombers, etc.), while for fighter aircraft that cannot accept fuel at the maximum flow rate of the refueling device

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100, the refueling pressure can be correspondingly reduced. Alternatively the refueling device **100**, in particular the boom member **130**, nozzle **135** and lumen **120** can be sized to allow suitable fuel flow rates for refueling a narrow range of receiver aircraft., for example only fighter aircraft or only larger aircraft (for example about 400 US gallons/2,600 lb per minute).

The spatial control system **160** is configured for controlling a spatial disposition of the refueling device **100** when towed aft of the tanker aircraft **12** via the hose **52**, and enables the refueling device **100** to be steered and/or to adopt any desired stable spatial disposition while being towed at the end **54** of hose **52**.

In particular, and referring to Fig. 2(a), spatial control system **160** is configured for selectively and controllably providing a non-zero angular disposition, angle λ , between the aft boom axis **BAA** of the boom member **130** and the forward direction **A**, and enables this angle λ to be selectively maintained between the boom axis **BAA** and the forward direction **A** at least for a part of the time when the refueling device **100** is being towed by the tanker aircraft **12** via hose **52**, in particular during the engagement operation of the fuel device **100** to the receiver aircraft **20** and during refueling thereof.

The spatial control system **160** is also configured for providing stability to the refueling device **100**, while tethered to and towed by the tanker aircraft **12** via the hose **52**, and while the aft boom axis **BAA** is at any desired pitch and/or yaw and/or roll angle to provide the aforesaid angle λ .

In particular, angle λ is such as to provide a design angle that is within a particular angular range which corresponds to the design relative angular position of the boom member **130** (in particular the design relative angular position of the aft boom axis **BAA**) with respect to the receiver aircraft **20**. Thus, at the design angle the aft boom axis **BAA** is in an engagement enabling orientation with respect to the receiver aircraft **20**, and in particular with respect to the fuel receptacle **22**.

In non-limiting examples, angle λ (and in particular the design angle) can be in a range between about 5° and about 85°; or in a range between about 10° and about 80°; or in a range between about 15° and about 70°; or in a range between about 20° and about 60°; or in a range between about 25° and about 50°; or in a range between about 20° and about 40°; or in a range between about 25° and about 40°; or in a range between about

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28° and about 32°. In one non-limiting example, the design angle can be about 30°, and operation of the refueling device **100** to adopt this angle automatically renders it compatible for use with existing receiver aircraft **20**, in which the fuel receptacles **22** are configured for receiving and engaging with a nozzle at the end of a boom where the boom is at about 30° to the longitudinal axis of the receiver aircraft, without the need for modifying the configuration of the fuel receptacle thereof.

Thus, when angle λ is equal to the design angle, the receiver aircraft **20** travelling along direction **A** with zero angle of attack and zero sideslip and zero roll, and aft boom axis **BAA** is at the required spatial orientation to the forward direction **A** of the tanker aircraft and the receiver aircraft such as to ensure engagement between the nozzle **135** in the fuel receptacle **22**, without the need for modifying the configuration of the fuel receptacle thereof.

In this example, the spatial control system **160** comprises a selectively controllable aerodynamic control system **170**, comprising a forward set **172** of aerodynamic control surfaces **173** mounted to body **110** at a forward portion thereof, and an aft set **174** of aerodynamic control surfaces **175** mounted to the body **110** at an aft portion thereof. The aft set **174** is thus in aft spaced relationship with respect to the forward set **172**, and the center of gravity **CG** of the body **110** is disposed longitudinally intermediate the aft set **174** and the forward set **172**, noting that the actual longitudinal position of the center of gravity **CG** can shift between two extreme longitudinal positions according to, *inter alia*, whether the boom member **135** is extended or retracted, and whether fuel is present in the refueling device **100** or absent therefrom.

It is to be noted that at least in this example, the center of gravity **CG** is forward of the neutral point **NP**.

In alternative variations of this example and in other examples, the center of gravity can be forward of both the forward set and the aft set of aerodynamic surfaces, which are configured to provide the required stability to the refueling device **100** with the boom axis **131** at any desired pitch and/or yaw and/or roll angle.

In at least this example, the spatial control system **160** of refueling device **100**, in particular the selectively controllable aerodynamic control system **170**, is configured for enabling the device **100** to be steered in one, or two, or three degrees of freedom in

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translation and in one, or two, or three degrees of freedom in rotation, independently of the tanker aircraft **12** or of the refueling aircraft **20**. Thus, the spatial control system **160**, in particular the selectively controllable aerodynamic control system **170**, is configured providing:

- one or more of: sideslip, up/down translation, forward-aft translation, relative to the tanker aircraft **12** and/or to the refueling aircraft **20**, independently of rotational moments in roll pitch and/or yaw;
- and/or
- rotational moments in one or more of roll pitch and/or yaw, relative to the tanker aircraft **12** and/or to the refueling aircraft **20**, independently of sideslip, up/down translation, forward-aft translation.

The spatial control system **160** is also configured for providing an angle of attack for the body **110** with respect to the forward direction, for example up $\pm 10^\circ$.

In at least this example, the forward set **172** of aerodynamic control surfaces **173** is in the form of a H-canard arrangement at a forward part of the body **110**, comprising swept back canards, mounted to the forward part of body **110**, and comprising vertical fins above and below port and starboard canard wing tips of the canards. While in at least this example, the canards are fixed, and comprise pivotable surfaces to provide control moments to the device **100**, in alternative variations of this example the canards can instead be pivotable. Furthermore, the canard vertical fins, are each pivotable or can instead comprise pivotable surfaces to provide control moments to the refueling device **100**.

The aft set **174** of control surfaces **175** is in the form of a H-tail arrangement, comprising swept back wings, mounted to the aft part of body **110**, and comprising vertical fins above and below port and starboard wing tips of the wings. While in this example the swept back wings are fixed, and comprise pivotable surfaces to provide control moments to the device **100**, in alternative variations of this example the swept back wings can instead be pivotable. The wing vertical fins are each pivotable or can instead comprise pivotable surfaces to provide control moments to the refueling device **100**.

However, other arrangements are also possible for selectively controllable aerodynamic control system **170** and/or for the body **110**.

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For example the forward set **172** of aerodynamic control surfaces **173** and/or the aft set **174** of aerodynamic control surfaces **175** can each be configured to have any one or more of the following features, in any combination:

- monoplane configuration, including any one of: high wing configuration (or shoulder wing configuration), low wing configuration or mid wing configuration
 - mounted on or near an upper part, a lower (bottom) part or in-between the upper and lower part, respectively, of the body **110**; parasol wing configuration - mounted to the body **110** via cabane struts or the like; shoulder wing configuration;
- biplane, triplane, quadruplane, multiplane configurations, having two, three, four, or more than four wing plane elements, respectively, of similar size or dissimilar size with respect to one another, stacked one above the other in unstaggered, or forward staggered, or backwards staggered arrangement;
- combined or closed wing configurations, in which two or more wing elements are joined structurally at or near the respective wing tips in some way; for example a box wing configuration, in which at least one set of overlying (staggered or unstaggered) wing elements is joined together between their tips by vertical fins; tandem box wings; rhomboidal wings in which at least one set of overlying wing elements has a forward swept wing plane and a swept back wing plane, joined between the tips directly or via a vertical fin; annular or ring wing, which can be flat (in the form of the rim of a flat disc) or cylindrical (the wing is shaped as a cylinder), for example;
- at least one wing element is cantilevered (self-supported) and/or externally supported to the body **110** via struts and/or braces;
- wing elements, wherein each can comprise low aspect ratio, moderate aspect ratio or high aspect ratio;
- wing elements, wherein each wing element can be swept forward or swept back or have zero sweep, and/or the sweep angle can be fixed or varied along the span, and/or each wing element can have fixed wing geometry or variable wing geometry, for example variable sweep or oblique wing configurations;
- wing elements, wherein each wing element can have a respective wing chord that can be fixed or varied along the span of the wing element, for example

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including at least one of the following plan shapes: elliptical plan; constant chord plan, tapered plan; trapezoidal plan; reverse tapered plan; compound tapered plan;

- wings elements, wherein each wing element can be based on a delta design, including at least one of the following: regular delta; cropped delta (wing tip is cropped) compound delta; double delta; ogival delta;
- wings elements, wherein each wing element can have dihedral or anhedral angle;
- wings elements, wherein the wing elements can be formed as fins, for example in cruciform “X” or cruciform “+” configuration, or having one, two, three, four, or more than four fins arranged on the body **110** in any geometrical arrangement;
- wings elements, wherein the wing elements can comprise vertical fins or the like, attached on the upper part and/or the lower part at any spanwise position including the tip; and/or the fins can be swept forward or swept back or have zero sweep, and/or sweep angle can be fixed or varied along the span, and/or each vertical fin can have fixed wing geometry or variable wing geometry, for example variable sweep or oblique wing configurations;
- each wing element can be fixed, or can be movably mounted to the body **110** and fully pivotable to operate independently as an integral control surface, or can be fixedly mounted to the body **110** and comprises a pivotal control surface;
- each wing element can be movably mounted to the body **110** to allow for selective relative translational movement therebetween.

For example, the forward set **172** of aerodynamic control surfaces **173** can have any other suitable configuration regarding its geometrical and spatial relationship with respect to the aft set **174** of aerodynamic control surfaces **175**, for example as follows:

- conventional configuration, in which the forward set **172** of aerodynamic control surfaces **173** forms the main lift-generating wing arrangement of the device **100**, while the aft set **174** of aerodynamic control surfaces **175**, forms part of the stabilizer or tail;

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- alternative canard configuration, in which the aft set **174** of aerodynamic control surfaces **175** forms the main lift-generating wing arrangement of the device **100**, while the forward set **172** of aerodynamic control surfaces **173** can be in the form of canards or fins in cruciform configuration as the stabilizer;
- tandem configuration, in which both the aft set **174** of aerodynamic control surfaces **175** and the forward set **172** of aerodynamic control surfaces **173** are configured to provide lift and to provide stability;
- tailless configuration, in which the forward set **172** of aerodynamic control surfaces **173** is omitted, and the aft set **174** of aerodynamic control surfaces **175** is configured to provide lift and to provide stability;
- three-surface or triplet configuration, in which in which the aft set **174** of aerodynamic control surfaces **175** forms the main lift-generating wing arrangement of the device **100**, while the forward set **172** of aerodynamic control surfaces **173** can be in the form of canards or fins forming part of the stabilizer, and further comprising a third set of aerodynamic control surfaces aft of the aft set **174** of aerodynamic control surfaces **175**, forms part of the stabilizer.

For example the forward set **172** of aerodynamic control surfaces **173** and/or the aft set **174** of aerodynamic control surfaces **175** can optionally be blended with the body **100** to provide a blended body configuration.

For example one of the forward set **172** of aerodynamic control surfaces **173** and/or the aft set **174** of aerodynamic control surfaces **175** can be omitted, and the other one of forward set **172** of aerodynamic control surfaces **173** and/or the aft set **174** of aerodynamic control surfaces **175** can be formed as a flying wing configuration, incorporating therein the functions of body **110**, which can then be omitted.

For example the forward set **172** of aerodynamic control surfaces **173** and/or the aft set **174** of aerodynamic control surfaces **175** can both be omitted, and the body **110** can be formed as a lifting body, integrally providing the functions of the aerodynamic control system **170**.

For example, the aerodynamic control system **170** can be replaced with or supplemented by reaction control thrusters.

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According to an aspect of the presently disclosed subject matter, the longitudinal displacement control system **200** is different from the spatial control system **160**.

The longitudinal displacement control system **200** can be operated to selectively provide longitudinal displacements to the refueling device **100**, and/or can be operated as an aerodynamic stabilizer arrangement.

Referring to Figs. 1(a) to 4, and in particular to Fig. 5, the longitudinal displacement control system **200** comprises, in this example, two panel elements **220**; an upper panel element **220A**, and a lower panel element **220B**.

Each panel element **220** is controllably and reversibly deployable incrementally to each one of a plurality of successive deployed positions between a fully retracted position and a fully deployed position. Figs. 1(a) and 2(a) show the panel elements **220** in the fully deployed position, while Figs. 1(b) and 2(b) show the panel elements **220** in the fully retracted position.

In at least this example, the two panel elements **220A**, **220B** are essentially identical; thus when referring herein to a panel element **220**, such reference refers to each one of the two panel elements **220A**, **220B**.

In at least this example, each panel element **220** is in the form of a curved plate **221**, having a concave cylindrical surface **225** facing the forward direction **A** and a center of curvature **231**, and a convex cylindrical surface **226** facing away from the forward direction **A** and spaced from concave cylindrical surface **225** by panel thickness **t**. The concave cylindrical surface **225** comprises arc-shaped cross-sections **225C**, each subtending a non-zero angle ω at the center of curvature **231**, this angle ω being the central angle corresponding to the arc length **225F** of the cross-section **225C**. Each arc-shaped cross-section **225C** is part of an imaginary circle **225B**, having a center **225A** and radius **225R**, and the center of curvature **231** is thus a lateral axis joining the centers **225A** of all the respective circles **225B**.

While in at least this example each panel element **220** is in the form of a curved plate having a circular cross section, in alternative variations of this example each panel element **220** can have any other suitable cross-sectional shape, for example oval or elliptical cross-section, polygonal cross-section, super-elliptical cross-section, flat cross-section, and

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so on. In each case, including at least the illustrated example, the respective panel element is pivotably mounted to the body about a pivot axis that is ahead of the panel element and is spaced from the panel element by the moment arm or radius, in the illustrated example the radius **225R**.

Referring in particular to Fig. 1(a) and Fig. 3(a), the panel element **220**, in particular the curved plate **221**, has a width or lateral dimension **LD**. While the lateral dimension **LD**, in at least this example, is smaller than a width or lateral dimension **W** of the body **110** (at the location of the panel element **220** with respect to the body **110**), the potential effect of the panel element **220** in providing a controllable aft force **AF**, with respect to the lateral dimension **LD** can be maximized by maximizing the lateral dimension **LD** with respect to the body **110**. Accordingly, in at least this example, the lateral dimension **LD** is the largest possible (while still less than lateral dimension **W**) to enable the panel member **220** to also fit laterally within the body **110** in the retracted position.

Referring in particular to Fig. 3, Fig. 3(a) and Fig. 5, the panel element **220**, in particular the curved plate **221**, has rectilinear transverse outer edge **222** and rectilinear transverse inner edge **223**, and curved lateral edges **224** and **225**. Furthermore, the panel element **220**, in particular the curved plate **221**, has a height or transverse dimension **TD**, generally orthogonal to the lateral dimension **LD**. The transverse dimension **TD** is defined as the chord **225D** corresponding to the arc length of the cross-section **225C**. While the longitudinal projection **LTD** of transverse dimension **TD** in the fully retracted position, in at least this example, is smaller than a height or transverse dimension **H** of the body **110** (at the location of the panel element **220** with respect to the body **110**), the potential effect of the panel element **220** in providing a controllable aft force **AF**, with respect to the transverse dimension **TD** can be maximized by maximizing the transverse dimension **TD** with respect to the body **110**, particularly in the fully deployed position. Accordingly, in at least this example, the transverse dimension **TD** is the largest possible (while the longitudinal projection **LTD** of transverse dimension **TD** still less than transverse dimension **H**) to enable the panel member **220** to also fit transversely within the body **110** in the retracted position. Since in at least this example there are two panel members **220** mounted to the body at the same longitudinal position, the transverse dimension **TD** is such that the longitudinal projection **LTD** of transverse dimension **TD**,

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in at least this example, is correlated to (and is less than) half of the transverse dimension **H** of the body **110** (at the location of the panel element **220** with respect to the body **110**).

Furthermore, in at least this example, for a given body height **H**, the transverse dimension **TD** can be increased while maintaining the longitudinal projection **LTD** of transverse dimension **TD** at less than **H/2** by increasing the transverse spacing between the pivot axis **PA** and the respective upper side **110A** or lower side **110B** of the body **10**, or by increasing the transverse spacing between the respective pivot axis **PA** and the longitudinal axis **LA**.

Thus, each panel element has a width or lateral dimension **LD**, and a height or transverse dimension **TD**, and a corresponding height to width aspect ratio **AR**. In at least this example, the aspect ratio **AR** is less than 1, typically in the range about 0.3 to 0.9, and more specifically the aspect ratio **AR** is about 0.8. However, in alternative variations of this example, the aspect ratio **AR** can be 1 or greater than 1.

In at least this example, the each panel member **220** has a uniform thickness **t** and thus the convex cylindrical surface **226** also shares the center of curvature **231**.

In at least this example, angle ω is in the range between 60° and 90° , and more specifically in at least this example angle ω is about 78° .

In at least this example, the curvature ($1/\text{radius } 225R$) of the concave cylindrical surface **225** and the transverse dimension **TD** are related to angle ω via the following geometrical relationship:

$$(\text{transverse dimension } TD)/(2 * \text{radius } 225R) = \sin (\omega/2)$$

Referring in particular to Fig. 2(a) and Fig. 4, each panel element **220** further comprises a structural member in the form of at least one web **230** (also interchangeably referred to herein as web member or web element), interconnecting the plate **221** to the pivot axis **PA**. Each web **230** is generally in the form of a sector of the circle **225B**, having a relatively large aft end **234** joined to the curved plate **221** at the concave cylindrical surface **225**, and a relatively smaller forward end **232**. In at least this example, the web **230** is aligned generally parallel to the yaw-roll plane of the refueling device **100**.

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Each panel element **220** is pivotably mounted to device **100** to allow for pivoting of the panel element **220** about a respective pivoting axis **PA** that is co-axial with the respective center of curvature **231**.

In at least this example, and referring in particular to Fig. 3, the upper panel element **220A** is pivoted (at the respective pivot axis **PA**) with respect to an upper side **110A** of body **110**, while the lower panel element **220B** is pivoted (at the respective pivot axis **PA**) with respect to a lower side **110B** of body **110**. In alternative variations of this example, and in other examples, the device **100** can include two such panel elements **220**, but pivotably mounted instead one panel element **220** to the port side and the other panel element **220** to starboard side of the body **110**. In yet other alternative variations of this example, and in other examples, the device **100** can include three such panel elements **220**, in which one such panel element **220** is pivotably mounted with respect to the upper side **110A** of body **110** or with respect to a lower side **110B** of body **110**, and in which the other two panel elements **220** are pivotably mounted one to the port side and the other one to the starboard side of the body **110**. In yet other alternative variations of this example, and in other examples, the device **100** can include four such panel elements **220**, one such panel element **220** is pivotably mounted with respect to the upper side **110A** of body **110**, another panel element **220** is pivotably mounted with respect to a lower side **110B** of body **110**, and the other two panel elements **220** are pivotably mounted one to the port side and the other one to the starboard side of the body **110**. In yet other alternative variations of this example, and in other examples, the device **100** can include only a single panel element, and this can be pivotably mounted with respect to the upper side **110A** of body **110**, or with respect to a lower side **110B** of body **110**.

In any case, and at least in this example, the upper panel element **220A** is pivoted with respect to an upper side **110A** of body **110** at a first longitudinal position **LC1**, i.e., the respective pivoting axis **PA** is longitudinally at first longitudinal position **LC1**. The lower panel element **220B** is pivoted with respect to a lower side **110B** of body **110** at a second longitudinal position **LC2**, i.e., the respective pivoting axis **PA** is longitudinally at second longitudinal position **LC2**. Furthermore, in at least this example the first longitudinal position **LC1** is identical to the second longitudinal position **LC2**. In at least this example, the first longitudinal position **LC1** and the second longitudinal position

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LC2 are within a range 60% to 90% of a longitudinal dimension **LB** of the body **110**, specifically about 84% of dimension **LB** from the front end of the body **110**.

Furthermore, and referring in particular to Fig. 3, in at least this example each pivoting axis **PA** is located longitudinally aft of a center of gravity **CG** of the refueling device **100**, and also aft of the neural point **NP** of the refueling device **100**.

In at least this example each pivoting axis **PA** is transversely located at a transverse position outside of the body **100**. In at least in this example, the upper panel element **220A** is pivoted with respect to an upper side **110A** of body **110** at a first transverse position **LT1**, i.e., the respective pivoting axis **PA** is transversely located at first transverse position **LT1**, and spaced from the respective upper side **110A**. The first transverse position **LT1** is transversely spaced from the upper side **110A** by a body transverse spacing **LTS1**, and from the longitudinal axis **LA** by a first transverse spacing **TS1**. The lower panel element **220B** is pivoted with respect to a lower side **110B** of body **110** at a second transverse position **LT2**, i.e., the respective pivoting axis **PA** is transversely located at second transverse position **LT2**. The second transverse position **LT2** is transversely spaced from the lower side **110B** by a body transverse spacing **LTS2**, and from the longitudinal axis **LA** by a second transverse spacing **TS2**.

Furthermore, in at least this example the first transverse position **LT1** is transversely disposed with respect to the upper side **110A** in a similar manner (but in an opposed transverse direction) to the disposition of the second transverse position **LT2** with respect to the lower side **110B**. In at least this example, the first longitudinal position **LC1** and the second longitudinal position **LC2** are within a range 15% to 50% of a transverse dimension **H** of the body **110**, for example about 32% of transverse dimension **H**.

Referring in particular to Figs. 2(a), 2(b) and 4, the longitudinal displacement control system **200** further comprises a bracket element **240** for each panel element **220**, each bracket element having a base part **242** and a free end **244**. Each bracket element **240** projects outwardly from the respective upper side **110A** or lower side **110B**, and is fixed to the respective upper side **110A** or lower side **110B** via the respective base part **242**. Each panel element **220** is pivotably mounted to the respective bracket element **240** at the respective free end **244** thereof, via the forward end **232** of the respective web **230**.

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In at least this example, each pivoting axis **PA** is parallel to the pitch axis **P** of the refueling device **100**.

Referring in particular to Figs. 2(a), 2(b) and 4, the body **110** comprises a corresponding slot **260** for each panel element **220**, into which the respective panel element **220** is reversibly retracted into the respective fully retracted position FRP. The slot **260** is generally T-shaped having a longitudinal slot portion **260L** corresponding to the stem of the “T”, and a transverse slot portion **260T** corresponding to the top bar of the “T”. The longitudinal slot portion **260L** is configured for receiving therein the web member **230**, while the transverse slot portion **260T** is configured for receiving therein the panel element **220** itself, i.e., the curved plate **221**.

Referring to Fig. 5, the panel element **220** is selectively pivotable about pivot axis **PA** to any desired angular disposition θ corresponding to the desired deployed position, the desired angular disposition θ being between a first angular disposition $\theta 1$ and a second angular disposition $\theta 2$.

The angular difference between the first angular disposition $\theta 1$ and the second angular disposition $\theta 2$ corresponds to the angle ω of the panel element **220**.

The first angular disposition $\theta 1$ corresponds to the fully retracted position FRP, in which the respective panel element **220** is maximally retracted into the body **110**, and is thus minimally exposed to any airflow over the body **110**, for example as is normally present during in-flight refueling operations. The first angular disposition $\theta 1$ can be defined as the angle between a vertical line **VL** passing through the pivot axis **PA** in Fig. 5, and a first imaginary line **IL1** joining the outer transverse edge **222** (at the fully retracted position **FRP**) with the pivot axis **PA** in the side view shown in Fig. 5.

The second angular disposition $\theta 2$ corresponds to the fully deployed position FDP, in which the respective panel element **220** is maximally deployed from the body **110**, and is thus maximally exposed to any airflow over the body **110**, for example as is normally present during in-flight refueling operations. The second angular disposition $\theta 2$ can be defined as the angle between the vertical line **VL** passing through the pivot axis **PA** in Fig. 5, and a second imaginary line **IL2** joining the outer transverse edge **222** (at

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the fully deployed position **FDP**) with the pivot axis **PA** in the side view shown in Fig. 5.

At any desired angular disposition θ intermediate between the first angular disposition θ_1 and the second angular disposition θ_2 , i.e., at the corresponding desired deployed position **DP**, the respective panel element **220** is partially deployed from the body **110**, and is thus partially exposed to any airflow over the body **110**, for example as is normally present during in-flight refueling operations. Each desired angular disposition θ can be defined as the angle between the vertical line **VL** passing through the pivot axis **PA** in Fig. 5, and a corresponding imaginary line **ILN** joining the outer transverse edge **222** (at the corresponding deployed position **DP**) with the pivot axis **PA** in the side view shown in Fig. 5.

Each panel element **220** defines a front panel projected area **SA** orthogonal to the body longitudinal axis **LA**. As will become clearer herein, each panel element **220** is controllably and reversibly deployable incrementally to each one of a plurality of successive desired deployed positions **DP** between the fully retracted position FRP and the fully deployed position **FDP**, to provide a respective reversible incrementally increasing aft force **AF** to the refueling device **100** at least during the in-flight refueling operation. The projected area **SA** is thus defined on a plane orthogonal to the body longitudinal axis **LA**, and refers to the area projected by the panel element **220** on this plane at the particular deployed positions **DP**. Thus, the projected area **SA** is the product of the exposed height **HD** of the panel element **220** (i.e., the transverse spacing of the outer edge **222** with respect to the respective top side **110A** or bottom side **110B**, at the particular deployed positions **DP**) and the lateral dimension **LD** of the panel element **220**, i.e. :

$$SA = HD * LD.$$

It is to be noted that the particular aft force **AF** generated by the partially exposed panel element **220** in such a deployed position **DP** is proportional to the corresponding projected area **SA**, and in particular:

$$AF \propto 0.5 * \rho * V^2 * SA * C_D$$

Wherein:

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ρ ~ is the density of the air surrounding the panel element **220**;

V ~ is the velocity at which the panel element **220** (i.e., the refueling device **100**) is traveling with respect to the surrounding air;

C_D ~ is the drag coefficient of the panel element **220** at the particular deployed position **DP**.

In the fully retracted position **FRP** the respective panel element **220** is fully retracted within the body **110**, and the proportion of the front panel projected area **SA1** exposed to the airflow over the body (corresponding to the height **TD1** of the outer edge **222** projecting out of the body **110**), at least during the in-flight refueling operation, is at a minimum, thereby providing a respective minimum aft force **AF**, referred to herein as aft force **AF1**, to the refueling device **100**. The front panel projected area **SA1** at the fully retracted position **FRP** is nominally zero, and thus the corresponding minimum aft force **AF1** is also nominally zero.

In the fully deployed position **FDP** the respective panel element **220** is fully deployed from the body **110**, and the proportion of the front panel projected area **SA2** exposed to the airflow over the body (corresponding to the height **TD2** of the outer edge **222** projecting out of the body **110**), at least during the in-flight refueling operation, is at a maximum, thereby providing a respective maximum aft force **AF**, referred to herein as aft force **AF2**, to the refueling device **100**.

The aggregate front panel projected area **SA2** (i.e., of the two panel elements **220A** and **220B** together) at the fully deployed position **FDP** is nominally about 200% of the frontal cross-sectional area of the body **110**, in at least this example. The corresponding aggregate maximum aft force **AF2** (provided by the two panel elements **220A** and **220B**) provides an additional 70% to about 80% (for example nominally about 72%) of the configuration drag in boom deployed configuration **BDC**, which includes the drag generated by body **110** plus boom member **130** in the boom deployed configuration **BDC**. Alternatively, the corresponding aggregate maximum aft force **AF2** (provided by the two panel elements **220A** and **220B**) provides an additional 80% to about 95% (for example nominally about 87%) of the configuration drag in the boom retracted configuration **BRC**, which includes the drag generated by body **110** plus boom member **130** in the boom retracted configuration **BRC**.

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In each successive deployed position **DP** between the retracted position **FRP** and the fully deployed position **FDP**, a corresponding proportion **PP** of maximum front panel projected area **SA2** of the panel element **220** is correspondingly exposed to the airflow, at least during the in-flight refueling operation, thereby providing a corresponding aft force **AF** to the refueling device. The magnitude of this proportion **PP** of the maximum front panel projected area **SA2** is reversibly incrementally increased from 0 to 1 as the panel element **220** is correspondingly deployed from the fully retracted position **FRP** to the fully deployed position **FDP** via the successive deployed positions **DP**, to thereby provide a controllable and reversibly incrementally increasing aft force **AF** having a force magnitude respectively increasing from the aforesaid respective minimum aft force **AF1** to the aforesaid respective maximum aft force **AF2**.

Referring in particular to Fig. 4, the longitudinal displacement control system **200** further comprises an actuator system **290** for controllably causing each panel element **220** to be deployed to any desired deployed position **DDP** intermediate between the respective fully retracted position **FRP** and the respective fully deployed position **FDP**. For example, the actuator system **290** can comprise a hydraulic, pneumatic or solenoidal jack, anchored at one end to the inside of the body **110**, and having a reciprocal piston having a free end thereof hingedly affixed to the web **230**, for example at location **HN**. When the jack is extended, the panel element **220** is pivoted about the pivot axis **PA** towards the fully deployed position **FDP**, and when the piston is retracted the panel element **220** is pivoted about the pivot axis **PA** towards the fully retracted position **FRP**.

Referring in particular to Fig. 6 and Fig. 6(a), at any desired deployed position **DP**, including the fully deployed position **FDP**, an aerodynamic force **TAF** is generated by each panel element **220**. The aerodynamic force **TAF**, which is correlated to the respective projected area **SA**, has a vector having a line of action **LOA** that intersects the respective pivot axis **PA** of the respective panel **220** or passes very close to the pivot axis **PA**.

Without being bound to theory, inventor considers that the overall aerodynamic force **TAF** acting on panel element **220** is the sum of each element of force acting on each infinitely small geometric element composing the panel **200**. Because each of these elements of force is generated by air pressure, each such element of force acts

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perpendicular to the corresponding infinitely small geometric element. By definition, when such a panel element **220** has a circular cross-section, a line perpendicular to each infinitely small geometric element necessarily intersects the center of the respective circle. Thus, the sum of all of these elements of force also converges toward the center of the circle, where the pivot axis **PA** is located.

By “very close” is meant that the line of action **LOA** has a minimum distance to the respective pivot axis **PA**, that is less than 2% of the transverse dimension **TD** of the panel **220**.

Without being bound to theory, inventor considers that the hinge moment coefficient C_h and the drag coefficient C_D acting on the panel **220** are related by the following relation:

$$C_h \sim C_D * x$$

wherein:

C_h is the hinge moment coefficient defined by: $C_h = \text{HM [hinge moment]} / (0.5 * \rho * V^2 * SA * TD)$;

C_D is the drag coefficient defined by: $CD=D \text{ [drag force]} / (0.5 * \rho * V^2 * SA)$;

x is the line of action **LOA** minimum distance to the pivot axis **PA** as a percentage of the transverse dimension **TD** of the panel **220**.

Calculations and wind-tunnel test results relating to an implementation of the example of the longitudinal displacement control system illustrated in the figures, provided the following nominal values for the respective hinge moment coefficient C_h and the respective drag coefficient C_D :

- $C_h \sim 0.02$
- $C_D \sim 1.1$

Using these values for the hinge moment coefficient C_h and the drag coefficient C_D and applying the above relationship ($C_h \sim C_D * x$), the corresponding value for minimum distance $x \sim 0.02$ (i.e., about 2% of the transverse dimension **TD**).

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Without being bound to theory, the inventor considers that drag coefficient greater than 1 is generated due to the concavity of the panel elements of at least this example.

It is to be noted that for panel elements **220** having a pure arc circle cross-section of zero thickness, the corresponding hinge moment coefficient C_h is theoretically zero. Without being bound to theory, inventor considers that in practice, however, the finite thickness **t** of the panel element **220**, as well as the presence of the web element **230**, in particular the aft end **234**, can probably account for the small but finite hinge moment coefficient $C_h (\neq 0)$ that was present as referred to above.

Thus, by arranging in this manner to provide the **LOA** intersecting, at or very close to, the respective pivot axis **PA**, the actual power necessary for the actuator system **290** to operate and pivot the panel elements **220** between their respective fully deployed position **FDP** and fully retracted position **FRP**, and to maintain each panel element at any desired deployed position therebetween, is minimized.

Each panel element **220** has a control arm corresponding to the radius **225R**. Since, as discussed above, in practice the hinge moment coefficient C_h for at least this example is finite and non-zero, the size of the radius **225R** can influence the magnitude of the hinge moment coefficient C_h . As is clear, as each panel element **220** is pivotably deployed to the desired deployed position, the entire concave cylindrical surface **225** moves along the same arc, corresponding to the respective circles **225B**.

The vector of the aerodynamic force **TAF**, and thus of the **LOA**, is at an angle Ω to the body longitudinal axis **LA**, and this angle Ω varies as the respective panel element **220** is pivoted about its pivot axis **PA** between its respective fully deployed position **FDP** and fully retracted position **FRP**. The aerodynamic force **TAF** generated by each panel element **220** can be resolved into a respective aft force **AF**, and a respective transverse force **VAF**. The aft force **AF** of the two panels is in the same direction, aft, and thus the total aft force generated by the longitudinal displacement control system **200** is thus $2*AF$. On the other hand, by having the two panel elements **220** on the upper side and lower side of the body, the respective transverse forces **VAF** are in mutually opposite directions, and thus cancel out.

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It is to be noted that in alternative variations of this example, in which the longitudinal displacement control system **200** comprises, alternatively or additionally, two panel elements **220** located one on the starboard side and the other one on the port side of the body, the respective aerodynamic force **TAF** generated by each such panel element **220** can be resolved into a respective aft force **AF**, and a respective lateral force **VAF**, in which the aft force **AF** of the two panels is in the same direction, aft, and thus the total aft force generated by the longitudinal displacement control system **200** is thus $2*AF$, and in which the lateral force components are in mutually opposed directions and thus cancel each other out.

It is to be noted that in alternative variations of this example, the longitudinal displacement control system **200** comprises one rather than two panel elements transversely located with respect to the body **110**, for example only on the upper side **110A** or only on the lower side **110B** (and optionally also two lateral panel elements **220**). In such cases, the respective transverse force **VAF** can include a nose up or nose down pitching moment to the refueling device **100**, which can be counteracted or balanced using the spatial control system of the refueling system **100**, for example.

Referring again to Fig. 4, the longitudinal displacement control system **200** further comprises a controller **280** for controlling operation of the actuator system **290** to thereby control the magnitude of the aft force **AF** generated by the exposed panel elements **220** at each respective deployed position up to the fully deployed position **FDP**, as will become clearer herein, essentially by controlling the aforesaid proportion **PP** of front panel projected area.

The controller **280** is in particular configured for controlling, via the actuator system **290**, the magnitude of the aft force **AF** to provide and maintain a tension in the hose **50** within a predetermined tension range, and/or for controlling, actuator system **290**, the magnitude of the aft force **AF** to provide a desired forward or aft displacement of the refueling device **100** with respect to the tanker aircraft **12**.

For example, the controller **200** comprises any suitable computer control system, and can be internally or externally mounted in the refueling device **100**. In alternative variations of this example and in other examples, the controller **200** or portions thereof can instead comprise any suitable electronic control unit, or any other suitable control

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unit, and/or the controller **200** or portions thereof can be comprised elsewhere in the in-flight refueling system **50** or in the tanker aircraft **12**.

It is to be noted that at least in this example, operation of the actuator system **290** for selectively deploying and retracting the two panel elements **220** is synchronized, such that each of the two panel elements **220** is deployed or retracted by the same amount (in particular by the same angular displacement θ) and concurrently, responsive to operation of the actuator system **290**.

The refueling device **100** can optionally further comprise a force generating arrangement, configured for selectively generating a force **FB** (see Fig. 2(b)) along the aft boom axis **BAA** in a direction towards nozzle **135** from elbow **131**.

For example, the force generating arrangement comprises: (a) at least some elements of the spatial control system **160**, in particular the selectively controllable aerodynamic control system **170**; and optionally (b) at least some elements of longitudinal displacement control system **200**.

The force generating arrangement can be configured for selectively generating force **FB** in a direction aligned with the aft boom axis **BAA** by generating a negative lift force **LF** (or reducing the lift force by force **LF**) and a drag force **LD**, which together provide force **FB** of the required magnitude and vector. The negative lift force **LF** can be generated by suitably controlling the spatial control system **160**, in particular the selectively controllable aerodynamic control system **170**. For example, appropriately changing an angle of attack, and/or providing a flap angle to the respective control surfaces of the control system **170** can reduce the lift generated by the control system **170**, and thus result in a net downwards force corresponding to negative lift force **LF**. Concurrently, in at least some cases, the drag force **LD** can also be generated by suitably controlling the spatial control system **160**, in particular the selectively controllable aerodynamic control system **170**. For example, appropriately changing an angle of attack, and/or providing a flap angle to the respective control surfaces of the control system **170** can also change the drag generated by the control system **170**, and thus result in an increase in drag corresponding to drag force **LD**. Additional drag force can be generated, where necessary to complement or replace the drag generated by the control system **170** to provide the appropriate drag force **LD**, by controlling the drag generated by the aerodynamic stabilizer arrangement.

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The force generating arrangement is in particular configured for selectively generating a force **FB** having a magnitude sufficient for forcing the nozzle **135** into engagement with the fuel receptacle **22** of the receiver aircraft when the nozzle **135** (and the boom member **130**) and the fuel receptacle **22** are in a predetermined relative spatial disposition, i.e., when the refueling device **100** reaches an engagement enabling position and the aft boom axis **BAA** is in the engagement enabling orientation with respect to the receiver aircraft **20**, and in particular with respect to the fuel receptacle **22**.

The force generating arrangement is further configured for selectively operating in this manner responsive to the nozzle **135** being in a predetermined proximity to the fuel receptacle **22**, i.e. responsive to the nozzle **135** being in a predetermined spacing with respect to the fuel receptacle **22**, typically the engagement enabling spatial position, and can be operated manually or automatically to provide such a force **FB**.

Thus, at the engagement enabling position, when the boom member **130**, in particular the aft boom axis **BBA**, is in a predetermined spatial disposition with respect to the fuel receptacle **22** and the nozzle **135** being in a predetermined spacing with respect to the fuel receptacle **22** (i.e., at the engagement enabling position the aft boom axis **BBA** is at the engagement enabling orientation – corresponding to the design angle), the force generating arrangement can be selectively actuated to compel the boom member **130** to follow a predetermined trajectory (together with the device **100**), for example with the aft boom axis **BBA** aligned in the direction of the receiver aircraft **20**, to ensure alignment and engagement between the nozzle **135** and the fuel receptacle **22**. In this example, the boom member **130** (in particular the aft boom axis **BBA**) is maintained at the engagement enabling orientation – corresponding to the design angle, while the body **110** remains at the same spatial disposition with respect to the receiver aircraft **20**. The body **110** is moved towards the receiver aircraft **20** along a the direction of the aft boom axis **BAA**, maintaining the aft boom axis **BAA** at the engagement enabling orientation – corresponding to the design angle λ_{des} , to effect engagement between the nozzle **135** and the fuel receptacle **22**. In alternative variations of this example, the boom **130** is telescopic, or at least the aft boom portion **138** is telescopic, and is partially or fully telescopically extended towards the receiver aircraft **20** while the device **100** can be moved towards or away from the receiver aircraft **20** to effect engagement between the nozzle **135** and the fuel receptacle **22**.

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Once the nozzle **135** is forced into engagement with the fuel receptacle **22** of the receiver aircraft **20**, the tanker aircraft **12** can begin refueling the receiver aircraft **20**.

In at least this example of the device **100** the controller **280** is also configured for controlling operation of one or more of (a) the force generating arrangement and (b) the spatial control system **160** (in particular the selectively controllable aerodynamic control system **170**), in addition to the longitudinal displacement control system **200**.

Referring again to Fig. 4, in at least this example the refueling device **100** further optionally comprises a suitable spatial data acquisition system **189**, for providing or enabling the calculation of spatial data relating to the relative spatial dispositions between the refueling device **100** and the receiver aircraft **20**, in particular the relative spatial dispositions between the fuel delivery nozzle **135** of the refueling device **100** and the fuel receptacle of the receiver aircraft, to enable selectively controlling the refueling device to provide automatic (optionally including autonomous) and/or manual steering of the refueling device **100** to the engagement enabling position and subsequent selective engagement of the fuel delivery nozzle to the fuel receptacle of the receiver aircraft **20**.

For example, the data acquisition system is in the form of imaging system, in particular configured for providing imaging data of any object coming within a field of regard (FOR) aft of the refueling device **100**. In alternative variations of this example, the imaging system can be replaced with any other suitable data acquisition system for providing the aforesaid spatial data.

In yet other alternative variations of this example and in other examples, the refueling device **100** can omit the spatial data acquisition system **189** and can be actively controlled by an operator, for example, to control the relative spatial position and orientation of the refueling device **100** with respect to the receiver aircraft **20**, in particular the spatial position and orientation of the boom member **130**, in particular the nozzle **135** with respect to the fuel receptacle **22**, so that the nozzle **135** can be selectively and controllably brought into selective engagement with the fuel receptacle **22** in a safe and effective manner, for example via direct visual tracking of the device by one or more operators. For example, such an operator can be in the tanker aircraft **12**, and/or such an operator can be in the refueling aircraft **20**, and/or such an operator can be in another flying platform, for example a chase aircraft independent of the refueling aircraft **20**.

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Alternatively, in yet other alternative variations of this example, the refueling device **100** can be operated as a free flying refueling device towed at the end of hose **52**, and the relative spatial position and orientation of the refueling device **100** with respect to the receiver aircraft **20** (in particular the position and orientation of the boom member **130** and nozzle **135** with respect to the fuel receptacle **22**, so that the nozzle can be controllably brought into selective engagement with the fuel receptacle **22** in a safe and effective manner) is achieved by maneuvering the receiver aircraft **20** only. In such a case, the spatial control system **160** can optionally comprise a non-adjustable aerodynamic stability system that is configured for allowing the refueling device **100** to adopt a particular, pre-set, desired angle λ while maintaining a zero pitching moment (and/or zero yawing moment and/or zero rolling moment), this being the design angle as discussed above for example. Optionally, a suitable air-driven generator can be provided in the refueling device **100** to provide electrical power thereto. Additionally or alternatively, electrical power can be provided to the refueling device **100** by the tanker aircraft **12**. Additionally or alternatively, electrical power can be provided to the refueling device **100** by one or more batteries in the refueling device **100**. Additionally or alternatively, electrical power can be provided to the refueling device **100** by one or more ram air turbines (RAT), affixed internally or externally with respect to the refueling device **100**.

In an alternative variation of the example of Figs. 1 to 7, the boom member, can instead be configured for being fixedly (i.e. non-pivotably) mounted to the body **110** of the device **100**.

In operation of the refueling device **100**, with the tanker aircraft **12** flying in the forward direction **A** and at a velocity suitable for in-flight refueling, the refueling device **100** is deployed from the tanker aircraft **12**, and is displaced aft to a desired distance via the hose **52**. Suitable sensors, typically operatively connected to the drum from which the hose **52** is deployed, determine the tension in the hose **52**. If it is determined that there is insufficient tension, the longitudinal displacement control system **200** is operated to deploy each of the panel elements **220** from the fully retracted position **FRP** to a deployed position **DP** wherein the corresponding aft force **AF** generated thereby is sufficient to increase the tension in the hose **52**. If there is too much tension, the panel elements **220** are retracted partially or fully to the fully retracted position **FRP**. Furthermore, when a receiver aircraft **20** approaches for in-flight refueling, the refueling device **100** maneuvers to an engagement-enabling position,

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using the spatial control system **160** (in particular the selectively controllable aerodynamic control system **170**), and the longitudinal displacement control system **200** is operated to deploy each of the panel elements **220** to variable desired deployed positions DP incrementally, to thereby provide controllable and variable aft forces AF, thereby providing fine forward-aft longitudinal control of the refueling device 100 with respect to the receiver aircraft 20, thereby facilitating attaining and maintain the aforesaid enjoyment enabling opposition. Thereafter, the boom member **130** is engaged with the refueling receptacle **22** and refueling of the receiver aircraft **20** can proceed.

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.

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CLAIMS:

1. A refueling device for use in in-flight refueling operation, comprising:
 - (a) a body configured for being towed by a tanker aircraft in a forward direction via a fuel hose at least during in-flight refueling operation, the body having a body longitudinal axis;
 - (b) a boom member carried by the body, the boom member having a fuel delivery nozzle, the fuel delivery nozzle being configured for selectively engaging with a fuel receptacle in a receiver aircraft to enable fuel to be transferred from said fuel hose to the receiver aircraft during said in-flight refueling operation;
 - (c) spatial control system configured for selectively providing stability and control to the refueling device;
 - (d) a longitudinal displacement control system, comprising:

at least one panel element defining a front panel projected area orthogonal to the body longitudinal axis, each said panel element being controllably and reversibly deployable incrementally to each one of a plurality of successive deployed positions between a fully retracted position and a fully deployed position, to provide a respective reversible incrementally increasing aft force to the refueling device at least during the in-flight refueling operation.
2. The refueling device according to claim 1,

wherein in the fully retracted position the respective said panel element is retracted within the body and a proportion of said front panel projected area exposed to an airflow over the body, at least during the in-flight refueling operation, is at a minimum, thereby providing a respective minimum said aft force to the refueling device;

wherein in the fully deployed position the respective said proportion of the front panel projected area of said panel element exposed to the airflow, at least during the in-flight refueling operation, is at a maximum, thereby providing a respective maximum said aft force to the refueling device, and

wherein in each said successive deployed position a corresponding said proportion of said front panel projected area of the panel element is correspondingly

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exposed to the airflow, at least during the in-flight refueling operation, thereby providing a corresponding said aft force to the refueling device;

wherein a magnitude of said proportion of said front panel projected area is reversibly incrementally increased as the panel element is deployed from the fully retracted position to the deployed position via said successive deployed positions to thereby provide a controllable and reversibly incrementally increasing said aft force having a force magnitude respectively increasing from said respective minimum aft force to said respective maximum aft force.

3. The refueling device according to any one of claims 1 to 2, wherein at least one said panel element is in the form of a curved plate having a concave cylindrical surface facing the forward direction, and a center of curvature.
4. The refueling device according to claim 3, wherein the concave cylindrical surface comprises arc-shaped cross-sections, each subtending an angle at the center of curvature of between 60 degrees and 90 degrees.
5. The refueling device according to claim 3 or claim 4, wherein the at least one said panel element is pivotably mounted to device to allow for pivoting of the at least one said panel element about a pivoting axis co-axial with the center of curvature.
6. The refueling device according to claim 5, wherein said pivoting axis is located longitudinally aft of a center of gravity of the refueling device.
7. The refueling device according to claim 5 or claim 6, wherein said pivoting axis is located at a longitudinal position between 60% and 90% of a longitudinal dimension of the body.
8. The refueling device according to any one of claims 5 to 7, wherein each said pivoting axis is transversely located at a transverse position outside of the body.
9. The refueling device according to claim 7, wherein said pivoting axis is located at a transverse position between 15% and 50% of a transverse dimension of the body.
10. The refueling device according to any one of claims 1 to 9, wherein each said panel element has a height to width aspect ratio in the range 0.3 to 0.9.
11. The refueling device according to any one of claims 5 to 10, wherein said pivoting axis is parallel to a pitch axis of the refueling device.
12. The refueling device according to any one of claims 1 to 11, wherein said body comprises a corresponding slot for each said panel element, into which the respective said panel is retracted into in the respective said fully retracted position.

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13. The refueling device according to any one of claims 4 to 12, wherein each panel element moves along an arc, corresponding to said curvature, about the respect, pivot axis, between said fully retracted position and said fully deployed position.
14. The refueling device according to any one of claims 1 to 13, comprising an actuator for controllably causing each said panel element to be deployed between the respective said fully retracted position and the respective said deployed position.
15. The refueling device according to any one of claims 1 to 14, comprising two said panel elements, wherein one said panel element is mounted with respect to an upper part of the body, and wherein the other said panel element is mounted with respect to a lower part of the body.
16. The refueling device according to any one of claims 1 to 15, comprising two said panel elements, wherein one said panel element is mounted with respect to a port part of the body, and wherein the other said panel element is mounted with respect to a starboard part of the body.
17. The refueling device according to claim 15 or claim 16, wherein the two said panel elements are pivotably mounted to the body at the same longitudinal spacing from a forward end of the body.
18. The refueling device according to any one of claims 15 to 17, configured for synchronized deployment of the two said panel elements.
19. The refueling device according to any one of claims 1 to 18, further comprising a controller for controlling said magnitude of said aft force by controlling said proportion of said front panel projected area.
20. The refueling device according to claim 19, wherein said controller is configured for controlling said magnitude of said aft force to provide and maintain a tension in said hose within a predetermined tension range.
21. The refueling device according to any one of claims 19 to 20, wherein said controller is configured for controlling said magnitude of said aft force to provide a desired forward to at displacement of the refueling device with respect to the tanker aircraft.
22. The refueling device according to any one of claims 1 to 21, wherein said boom member has refueling nozzle at a free end thereof, and a boom axis passing through the refueling nozzle, wherein at least during in-flight refueling said boom axis is at a non-zero angular deposition with respect to the body axis.

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23. The refueling device according to claim 22, wherein the boom member is reversibly pivotable with respect to the body, between a boom stowed position and a boom deployed position, wherein in the boom stowed position the refueling nozzle is closes to the body, and wherein in the boom deployed position engagement with the fuel receptacle of the receiver aircraft is possible.

24. The refueling device according to claim 22, wherein said boom member is in fixed spatial relationship with respect to the body.

25. The refueling device according to any one of claims 1 to 24, wherein said spatial control system is further configured for selectively providing control moments in at least one of pitch, yaw and roll wherein to enable the refueling device to be flown while towed by the tanker aircraft in said forward direction via said fuel hose.

26. The refueling device according to any one of claims 1 to 25, wherein said spatial control system comprises selectively controllable aerodynamic control system.

27. The refueling device according to claim 26, wherein said selectively controllable aerodynamic control system comprises a forward set of aerodynamic control surfaces mounted to said body, and an aft set of aerodynamic control surfaces mounted to said body in longitudinally aft spaced relationship with respect to said forward set of aerodynamic control surfaces.

28. The refueling device according to claim 27, wherein said forward set of aerodynamic control surfaces comprises a canard configuration, and said aft set of aerodynamic control surfaces comprises one or more wing elements

29. The refueling device according to claim 27 or claim 28, wherein said aft set of aerodynamic control surfaces comprises an H-wing configuration, comprising two vertical wing stabilizers, one each on either side of a respective wing.

30. The refueling device according to any one of claims 27 to 29, wherein said forward set of aerodynamic control surfaces comprises an H-canard configuration, comprising two vertical canard stabilizers, one each on either side of a respective canard.

31. The refueling device according to any one of claims 1 to 30, wherein said spatial control system is configured for enabling the refueling device to be steered in one, or two, or three degrees of freedom in translation, and in one, or two, or three degrees of freedom in rotation, independently of the tanker aircraft or of the refueling aircraft.

32. The refueling device according to any one of claims 1 to 31, wherein said longitudinal displacement control system is different from the spatial control system.

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33. The refueling device according to any one of claims 1 to 32, comprising a force generating arrangement configured for selectively generating a force along said aft boom axis in a direction towards said fuel delivery nozzle.

34. The refueling device according to claim 33, wherein said force generating arrangement is configured for selectively generating said force along said aft boom axis in a direction towards said fuel delivery nozzle responsive to said fuel delivery nozzle being in predetermined proximity to the fuel receptacle of the receiver aircraft wherein to force said fuel delivery nozzle into engagement with the fuel receptacle.

35. The refueling device according to any one of claims 1 to 34, said body comprising a fuel delivery lumen configured for fluid communication with said fuel hose and said boom member at least during the in-flight refueling operation, wherein said body comprises a coupling having a hose interface configured for connecting said lumen to the fuel hose, said coupling configured for allowing relative rotation between the hose and said body in at least one degree of freedom while maintaining said fuel communication.

36. The refueling device according to any one of claims 1 to 35, further comprising a data acquisition system configured for providing spatial data relating to a relative spatial disposition between said fuel delivery nozzle and said fuel receptacle, to enable selectively controlling the refueling device to provide automatic or autonomous or manual engagement of the fuel delivery nozzle to the fuel receptacle of the receiver aircraft.

37. The refueling device according to any one of claims 1 to 36, further comprising a suitable controller for controlling operation thereof.

38. A refueling system comprising a refueling fuel reservoir connected to a refueling device via a hose, the refueling device being as defined in any one of claims 1 to 37.

39. A tanker aircraft comprising at least one refueling system as defined in claim 38.

40. A method for in-flight refueling, comprising:

- providing a tanker aircraft as defined in claim 39;
- deploying the refueling device aft of the tanker aircraft when airborne;
- operating the longitudinal displacement control system to provide at least one of:
 - (i) a desired tension in the fuel hose;
 - (ii) a desired fore or aft displacement of the refueling device.