

## **DEVICE FOR REFUELING AIR VEHICLES**

### **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 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 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.

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.

## **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 and a neutral point;
- (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 (for example along

a boom axis, for example along an aft boom axis) during said in-flight refueling operation;

(c) spatial control system configured for selectively providing stability and control to the refueling device;

(d) wherein at least during refueling operation the fuel delivery nozzle (or the nozzle rotation center of the fuel delivery nozzle) is longitudinally forward of the neutral point.

According to the aforesaid first aspect of the presently disclosed subject matter there is also provided a refueling device for use in in-flight refueling operation between a tanker aircraft and a receiver aircraft, comprising:

- a selectively steerable body configured for being towed by a tanker aircraft via a fuel hose at least during in-flight refueling, and comprising a boom member having an aft boom axis and a fuel delivery nozzle, said boom member configured to enable fuel to be transferred from said fuel hose to a receiver aircraft along said aft boom axis during said in-flight refueling operation;

- wherein at least during said in-flight refueling operation the fuel delivery nozzle (or the nozzle rotation center of the fuel delivery nozzle) is longitudinally forward of a neutral point of the refueling device.

For example, device comprises a spatial control system configured for selectively providing stability and control to the refueling device, thereby enabling selectively steering the body.

According to the aforesaid first aspect of the presently disclosed subject matter there is also provided a boom member for a refueling device for use in in-flight refueling operation, the boom member comprising a forward boom member portion having a forward boom axis, and an aft boom member portion having an aft boom axis, the forward boom member portion being connected to the aft boom member portion via a boom elbow portion wherein the forward boom axis is angularly displaced with respect to the aft boom axis by a non-parallel angular disposition. For example, said angular disposition is between 60° and 120°, for example between 60° and 120°, for example between 70° and

110°, for example between 80° and 100°, for example between 85° and 100°, for example between 90° and 100°, for example between 95° and 105°, for example between 90° and 110°.

Each of the above implementations according to the aforesaid first aspect of the presently disclosed subject matter can include one or more features, for example as follows:

For example, the fuel delivery nozzle is rotatably mounted to a free end of the boom member via a nozzle rotation center of the fuel delivery nozzle, and at least during refueling operation the nozzle rotation center is longitudinally forward of the neutral point.

Additionally or alternatively, for example, the boom member comprising a forward boom member portion having a forward boom axis, and an aft boom member portion having an aft boom axis. For example, the boom member is mounted to the body via the forward boom member portion, and wherein the fuel delivery nozzle is located on said aft boom member.

Additionally or alternatively, for example, in at least one example, the boom member is pivotably mounted to the body via the forward boom member portion. Additionally or alternatively, for example, said boom member is pivotably mounted with respect to the body.

Additionally or alternatively, for example, said boom member is pivotable with respect to the body between a retracted position and a deployed position. For example, in said deployed position the fuel delivery nozzle is configured to enable in-flight refueling. Additionally or alternatively, for example, in said deployed position the fuel delivery nozzle is at a transverse spacing with respect to the body to enable in-flight refueling. Additionally or alternatively, for example, in said retracted position the fuel delivery nozzle is located closer with respect to the body than in the deployed position.

Additionally or alternatively, for example, said forward boom member portion is connected to said aft boom member portion via a boom elbow.

Additionally or alternatively, for example, the forward boom axis and the aft boom axis are in non-parallel spatial relationship.

Additionally or alternatively, for example, the forward boom axis and the aft boom axis are in a fixed non-parallel spatial relationship irrespective of whether the boom member is in the retracted position or the deployed position.

Additionally or alternatively, for example, the forward boom axis is angularly displaced with respect to the aft boom axis by a first angular disposition. For example, said first angular disposition is between  $60^\circ$  and  $120^\circ$ , for example between  $60^\circ$  and  $120^\circ$ , for example between  $70^\circ$  and  $110^\circ$ , for example between  $80^\circ$  and  $100^\circ$ , for example between  $85^\circ$  and  $100^\circ$ , for example between  $90^\circ$  and  $100^\circ$ , for example between  $95^\circ$  and  $105^\circ$ , for example between  $90^\circ$  and  $110^\circ$ .

Additionally or alternatively, for example, said boom member is in said deployed position during said in-flight refueling operation.

Additionally or alternatively, for example, at least during said in-flight refueling operation, said aft boom axis is at a second angular disposition with respect to said body longitudinal axis, said second angular disposition being non-zero.

Additionally or alternatively, for example, said boom member pivots as a rigid body.

Additionally or alternatively, for example, in at least one other example, the boom member is fixedly mounted to the body via the forward boom member portion. For example, the forward boom member portion is in the form of a fin or is accommodated in a fin.

Additionally or alternatively, for example, at least during said in-flight refueling operation, said aft boom axis is at a third angular disposition with respect to a forward direction of said refueling device. For example, said third angular disposition is such as to ensure that the aft boom axis is at a predetermined design angle with respect to the receiver aircraft. For example, said design angle is about  $30^\circ$ . Additionally or alternatively, for example, said refueling device is configured for maintaining said third angular disposition between said aft boom axis and said forward direction at least prior

to engagement of said fuel delivery nozzle with a fuel receptacle of a receiver aircraft that is flying in formation aft of the tanker aircraft.

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, the refueling device further comprises an aerodynamic stabilizer arrangement, different from the spatial control system. For example, said aerodynamic stabilizer arrangement is in the form of a drogue structure having a stowed configuration, in which drogue structure generates a minimum drag, and a deployed configuration in drogue structure generates greater drag than in the inactive configuration.

Additionally or alternatively, for example, the refueling device further 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 comprises 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 with respect to the 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 with respect to the second aspect of the presently disclosed subject matter.

## **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** is a side view of a refueling device according to of an example of the presently disclosed subject matter.

**Fig. 2** is a top view of the example of the refueling device of Fig. 1.

**Fig. 3** is an isometric view of the example of the refueling device of Fig. 1, with the boom member in the deployed position.

**Fig. 4** is an isometric view of the example of the refueling device of Fig. 1, with the boom member in the retracted position.

**Fig. 5** is a side view of a tanker system according to an example of the presently disclosed subject matter.

**Fig. 6** is a detail side view of part of the refueling device of the example of Fig. 1; **Fig. 6(a)** schematically illustrates an example of the spatial relationship between the aft boom axis, body longitudinal axis and forward direction of the example of Fig. 6; **Fig. 6(b)** schematically illustrates an example of the spatial relationship between the aft boom axis, and a selectively generated force on the boom regarding the example of Fig. 6.

**Fig. 7** is a side view of an alternative variation of the example of refueling device of Fig. 1.

## **DETAILED DESCRIPTION**

Referring to Figs. 1 to 4, 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**, and a spatial control system **160**.

As will become clearer herein, and referring also to Fig. 5, 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**.

As is well known in the art the neutral point of an air vehicle is the position at which the center 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. As will become clearer herein, the device **100** is configured with positive stability, and the neutral point **NP** thereof is located aft of the center of gravity **CG**.

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**, in particular prior to engagement of the refueling device **100** with the receiver aircraft **20**. Conventionally, the fuel delivery nozzle **135** is mounted at the free end of the boom member **130** via a ball joint or the like, for example a flexible ball joint, allowing relative rotation between the fuel delivery nozzle **135** and the free end of the boom member **130** in pitch and/or yaw, and in some cases in pitch and/or yaw and/or roll. The center of such rotation is referred to herein as the nozzle rotation center, and generally designated with the reference numeral **139** (Fig. 6).

According to an aspect of the presently disclosed subject matter, and will become clearer herein, at least during refueling operation the fuel delivery nozzle **135**, in particular the nozzle rotation center **139** of the fuel delivery nozzle **135**, is longitudinally forward of the neutral point **NP** by longitudinal spacing **LS**.

Referring in particular to Fig. 5, 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**.

By way of non-limiting example, such a tanker aircraft **12** can be a suitably equipped Boeing 767, Boeing 747, or Airbus A330, 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, 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 and carried in fuel pods, for example.

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 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 to 4, the refueling device according to a first example of the presently disclosed subject matter, generally designated **100**, is 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. 5.

For convenience, and referring again to Figs. 1 to 4, 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 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 Figs. 3 and 4, 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. 5), 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.

In at least this example, the boom member **130** has a fixed axial length **AS** (Fig. 6), at least in the deployed position **DP**, and is thus not extensible, providing for a relatively simple construction.

However, in alternative variations of this example, the boom member **130** can instead comprise a plurality of telescopic elements. For example, boom member **130** or part thereof can be telescopically mounted to body **110**, and is reversibly extendable from a stowed position (in which most of the boom member is accommodated in a sleeve within the body **110**), to a fully extended position for enablement of in-flight refueling, by means of a controllable actuation mechanism. Optionally such a boom member can be telescopically extendable to a controllably variable extended position in a general aft direction up to the aforesaid the fully extended position.

Referring in particular to Fig. 3, the body **110** comprises a coupling **140** at forward end **114** thereof. The coupling **140** comprises a hose interface **142** 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 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** only in one degree of freedom, or only 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 (and typically about two or three (mutually orthogonal) axes), 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**. For example, the second end **54** can comprise a ball joint or the like, for example a flexible ball joint, or a flexible joint, to allow free pivoting between the body **110** and the hose **52** (and in particular between the boom member **130** and the hose **52**), about the aforesaid one, two or three axes.

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  $\mu$  (see Fig. 5) of about  $0^\circ$ ; or about  $30^\circ$ ; or in a range between about  $5^\circ$  and about  $85^\circ$ ; or in a range between about  $10^\circ$  and about  $80^\circ$ ; or in a range between about  $15^\circ$  and about  $70^\circ$ ; or in a range between about  $20^\circ$  and about  $60^\circ$ ; or in a range between about  $25^\circ$  and about  $50^\circ$ ; or in a range between about  $20^\circ$  and about  $40^\circ$ ; or in a range between about  $25^\circ$  and about  $40^\circ$ ; or in a range between about  $28^\circ$  and about  $32^\circ$ . 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 retracted position **RP** (Fig. 4) and a deployed position **DP** (Fig. 3). 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 deployed position **DP**.

According to an aspect of the presently disclosed subject matter, and as mentioned above, at least during refueling operation the fuel delivery nozzle **135**, in particular nozzle rotation center **139**, is longitudinally forward of the neutral point **NP** by longitudinal spacing **LS** (Fig. 1).

Without being bound to theory, the inventor considers that having the fuel delivery nozzle **135**, in particular nozzle rotation center **139**, forward of the neutral point **NP** provides a measure of inherent stability to the refueling device **100**, in particular the body **110**, when the refueling device **100** is coupled to, i.e., engaged with, the receiver aircraft **20** via the boom member **130** and fuel delivery nozzle **135**. The inventor further considers that in such an engaged configuration the spatial control system **160** is not particularly effective in providing stability and control moments to the refueling device **100**, in particular the body **110**, since the boom member **130** is then mechanically constrained at both ends – at the fuel

delivery nozzle **135** (in particular at the nozzle rotation center **139**) by being engaged to the receiver aircraft **20**, and at the opposite end at the body **110**. The inventor further considers that the refueling device **100**, when flying freely and not engaged with the receiver aircraft **20**, can rotate in pitch yaw and roll about a center that is associated with, and located at, the second end **54** of hose **52**. The inventor further considers that the refueling device **100**, when flying in engaged configuration with the receiver aircraft **20**, the center of rotation for the refueling device **100**, in pitch yaw and roll, moves to nozzle rotation center **139**, and thus by having the neutral point **NP** aft of the fuel delivery nozzle **135**, in particular aft of the nozzle rotation center **139**, can provide inherent stability to the refueling device **100**, in particular the body **110**, particular when engaged with the receiver aircraft **20**.

The inventor further considers that in such an engaged configuration such inherent stability is greater as the spacing is increased in the aft direction between the neutral point **NP** and the fuel delivery nozzle **135**, in particular as the spacing is increased in the aft direction between the neutral point **NP** and the nozzle rotation center **139**.

It is also to be noted that in practice, the fuel delivery nozzle **135** (and thus the nozzle rotation center **139**) can be configured such as to be spaced below the underside **115** of the body **110** by a transverse spacing **TS** 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**. The transverse spacing **TS** can also provide sufficient clearance with respect to the receiver aircraft **20**, such as to decouple potential aerodynamic interactions between the spatial control system **160** and the receiver aircraft **20**.

In at least this example, and referring to Fig. 1 and Fig. 6 in particular, the positioning of the fuel delivery nozzle **135** (in particular the position of the nozzle rotation center **139**) longitudinally forward of the neutral point **NP** by longitudinal spacing **LS**, while concurrently maintaining the fuel delivery nozzle **135** in spaced relationship below the underside **115** of the body **110** by a transverse spacing **TS** or greater, is accomplished by configuring the boom member **130** as an elbowed boom as opposed to a rectilinear boom having a single rectilinear boom axis therethrough. Thus, in at least this example, the boom member **130** is configured with a forward boom member portion **132** having a forward boom axis **BAF**, and an aft boom member portion **138** having an aft boom axis **BAA**, joined at a boom elbow **131**, wherein the forward boom axis **BAF** and the aft boom axis **BAA** are a non-parallel angular disposition  $\lambda$  with respect to one another, at least in

the deployed position **DP**. By "non-parallel angular disposition  $\lambda$ " is meant that the forward boom axis **BAF** and the aft boom axis **BAA** can be at any desired angle with respect to one another other than at  $0^\circ$  or at  $180^\circ$  with respect to one another.

While in at least this example, the forward boom member portion **132** and the aft boom member portion **138** are each configured as rectilinear, rigid and generally tubular components, in alternative variations of this example, the forward boom member portion **132** can be configured as a non-rectilinear and/or non-rigid and/or non-tubular component, and/or, the aft boom member portion **138** can be configured as a non-rectilinear component. For example, in such alternative variations of this example, the forward boom member portion **132** can be configured as a flexible hose connected to the aft boom member portion **138** for example via a variable angle coupling, for example similar to coupling **140** as disclosed herein, *mutatis mutandis*.

The boom member **130** is mounted to the body **110** via the forward boom member portion **132**, and the fuel delivery nozzle **135** (including the nozzle rotation center **139**) is located on the aft boom member portion **138**, at terminus **136**.

The boom member **130** is thus configured as a non-rectilinear boom, in particular as a boom member having elbow **131**, joining the forward boom member portion **132** to the aft boom member portion **138** to provide an elbow angle corresponding to the non-parallel angular disposition  $\lambda$  between the forward boom axis **BAF**, and the aft boom axis **BAA** (defined on a plane orthogonal to the pivot axis **B**, typically a plane parallel to the plane including the yaw axis **Y** and the roll axis **R**).

In at least this example, the boom member **130** is configured as a rigid member, wherein the non-parallel angular disposition  $\lambda$  is conserved for all pivot angles about pivot axis **B**, at least between the retracted position **RP** and the deployed position **DP**. In other words, at least between the retracted position **RP** and the deployed position **DP** the boom member **130** behaves as a rigid body.

In at least the deployed position **DP**, the non-parallel angular disposition  $\lambda$  is between  $60^\circ$  and  $120^\circ$ , for example between  $60^\circ$  and  $120^\circ$ , for example between  $70^\circ$  and  $110^\circ$ , for example between  $80^\circ$  and  $100^\circ$ , for example between  $85^\circ$  and  $100^\circ$ , for example between  $90^\circ$  and  $100^\circ$ , for example between  $95^\circ$  and  $105^\circ$ , for example between  $90^\circ$  and  $110^\circ$ .

However, in alternative variations of this example, and in other examples, the boom member **130** is configured as a semi-rigid member, in particular as an articulated member wherein the angular disposition  $\lambda$  is conserved at a non-parallel angular disposition at the deployed position **DP**, but can vary in value at pivot angles about pivot axis **B**, at least between the retracted position **RP** and the deployed position **DP**. For example, in the retracted position **RP** the angular disposition  $\lambda$  can be  $180^\circ$  or close thereto, while in the deployed position **DP** the angular disposition  $\lambda$  can be, for example, between  $60^\circ$  and  $120^\circ$ .

In at least this example, the boom member **130** is pivotably mounted to the body **110** via the forward boom member portion **132**, at hinge axis **C**. Thus, and referring in particular to Fig. 6, the boom member **130** is pivotable between a retracted position **RP** and a deployed position **DP** (shown in phantom lines in Fig. 6), wherein in the retracted position **RP** the fuel delivery nozzle **135** is located closer with respect to the body **110** in the deployed position **DP**.

In at least this example, in the retracted position **RP** the whole of the boom member **130**, in particular the aft boom member portion **138** including the fuel delivery nozzle **135** and nozzle rotation center **139** is located outside of the body **110**. However, in alternative variations of this example, and in other examples, in the retracted position **RP** the whole of the boom member **130**, or part thereof, for example the aft boom member portion **138** and/or the fuel delivery nozzle **135** can be located inside the body **110**, for example in a recess provided therein.

Furthermore, in at least this example, in the deployed position **DP** the aft boom axis **BBA** is at a first angular disposition  $\eta 1$  with respect to the body longitudinal axis **LAB**, while in the retracted position **RP** the aft boom axis **BBA** is at a second angular disposition  $\eta 2$  with respect to the body longitudinal axis **LAB**, wherein the first angular disposition  $\eta 1$  is different from the second angular disposition  $\eta 2$ .

It is further to be noted that at least in this example, in the deployed position **DP** the forward boom axis **BAF** is at a first angular disposition  $g1$  with respect to the body longitudinal axis **LAB**, whereas in the retracted position **RP** the forward boom axis **BAF** is at a second angular disposition  $g2$  with respect to the body longitudinal axis **LAB**, wherein the first angular disposition  $g1$  is greater than the second angular disposition  $g2$ . For example, the first angular disposition  $g1$  can be in the range  $0^\circ$  to about  $90^\circ$ , or in the range  $80^\circ$  to

about 90°, or in the range 70° to about 90°, or in the range 60° to about 90°, or in the range 50° to about 90°, or in the range 45° to about 90°, or in the range 40° to about 90°. On the other hand, for example, the second angular disposition **g2** can be in the range 0° to about 50°, or in the range 0° to about 45°, or in the range 0° to about 40°, or in the range 0° to about 30°, or in the range 0° to about 20°, or in the range 0° to about 10°, or in the range 0° to about 5°.

Thus, in the stowed or retracted position **RP**, boom member **130** is pivoted about axis **C** into a position where the terminus **136** is closest to the underside **115** of body **110**. In this position, the aft boom portion **138** is in proximity to the underside **115** of body **110**. In the deployed position **DP**, boom member **130** is variably pivoted about pivot axis **C** in a downward direction to provide a non-zero angular displacement, i.e., first angular disposition **η1**, between aft boom axis **BAA** and body longitudinal axis **LAB**. In this example, first angular disposition **η1** is an angle in pitch with respect to the refueling device **100**.

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

An actuation mechanism **190** is provided for controllably pivoting the boom member **130** between the stowed or retracted position **RP** and the deployed position **DP**. Actuation mechanism **190** can include, for example, an articulated strut comprising an upper strut connected to a lower strut at a pivoting joint. The upper strut can be pivotably connected to an underside **115** of body **110**, while the lower strut can be pivotably connected to an upper side of boom member **130**. An actuator (not shown) operates to selectively and effectively bring close or distance away the pivoting joint with respect to the body. The actuator or the actuation mechanism **190** can be configured to selectively lock the articulated strut only at each one of the stowed/retracted position **RP** and the deployed position **DP**, to provide a respective fixed angle for the first angular disposition **η1** and/or the second angular disposition **η2**; alternatively, the actuator or the actuation mechanism **190** can be configured to selectively lock the articulated strut at each one of the stowed/retracted position and the deployed position, and at any angular disposition therebetween.

Other alternative configurations for actuation mechanism **190** are of course possible.

Angular components in yaw and/or roll can be provided to the aft boom axis **BAA** with respect to the forward direction **A** for example by suitably orienting the device **100** with respect to the yaw axis **Y** and/or roll axis **R**, respectively.

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 **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 at least while the refueling device **100** is not engaged with the receiver aircraft **20**, 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. 6(a), spatial control system **160** is configured for selectively and controllably providing a non-zero angular disposition, angle  $\theta$ , between the aft boom axis **BAA** and the forward direction **A**, and enables this angle  $\theta$  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**, at least while the refueling device **100** is not engaged with the receiver aircraft **20**, and in particular during the engagement operation of the fuel device **100** to the receiver aircraft **20** and during refueling thereof.

In particular, angle  $\theta$  is in pitch, i.e., about a pitch axis **P** of the refueling device **100** and is defined on a plane including the roll axis **R** and the yaw axis **Y** of the refueling device **100**. Angle  $\theta$  is thus representative of an angle of attack of the aft boom axis **BAA** with respect to forward direction **A** (which is typically, but not exclusively, parallel to the

horizontal direction). Nevertheless, and depending on specific conditions during any particular refueling operation, angle  $\theta$  can include an angular displacement component between the aft boom axis **FAA** and the forward direction **A** in yaw (i.e., about yaw axis **Y**), for example due to sideslip angle, and/or in roll (i.e., about roll axis **R**), instead of or in addition to an angular displacement component in pitch (i.e., about pitch axis **P**).

Thus, 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 at least while the refueling device **100** is not engaged with the receiver aircraft **20**, and while the aft boom axis **BAA** is at any desired pitch and/or yaw and/or roll angle to provide the aforesaid angle  $\theta$ .

In particular, and referring to Fig. 6(a) in particular, angle  $\theta$  is such as to provide a design angle (angle  $\theta_{des}$ ) 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**.

In particular, and referring to Fig. 3, design angle  $\theta_{des}$  is the design relative angular position of the aft boom axis **BAA** with respect to the longitudinal axis of the receiver aircraft **20** (the receiver aircraft **20** being at a predetermined spatial orientation relative to the forward direction **A** (Fig. 5), typically in horizontal forward flight), to enable the boom member **130** to align and engage the nozzle **135** with respect to the fuel receptacle **22** (Fig. 3). Thus, effectively, design angle  $\theta_{des}$  can be considered to be the design relative angular position of the aft boom axis **BAA** with respect to the forward direction **A**.

Thus, angle  $\theta$  (which can have an angular component in yaw and/or in pitch and/or in roll) compensates for any off-nominal pitch of the receiver aircraft **20** (for example if the receiver aircraft **20** is traveling along direction **A** at a non-zero angle of attack) and/or for any off-nominal roll of the receiver aircraft **20** (for example if the receiver aircraft **20** is traveling along direction **A** at a non-zero roll angle) and/or for any off-nominal yaw of the receiver aircraft **20** (for example if the receiver aircraft **20** is traveling along direction **A** at a non-zero sideslip angle) to ensure that the actual angular disposition between the aft boom axis **BAA** and the receiver aircraft longitudinal axis is maintained at design

angle  $\theta_{\text{des}}$  even as the relative spatial orientation between the receiver aircraft **20** and the forward direction changes.

Thus, at the design angle  $\theta_{\text{des}}$  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  $\theta$  (and in particular angle  $\theta_{\text{des}}$ ) can be in a range between about  $5^\circ$  and about  $85^\circ$ ; or in a range between about  $10^\circ$  and about  $80^\circ$ ; or in a range between about  $15^\circ$  and about  $70^\circ$ ; or in a range between about  $20^\circ$  and about  $60^\circ$ ; or in a range between about  $25^\circ$  and about  $50^\circ$ ; or in a range between about  $20^\circ$  and about  $40^\circ$ ; or in a range between about  $25^\circ$  and about  $40^\circ$ ; or in a range between about  $28^\circ$  and about  $32^\circ$ .

In one non-limiting example, angle  $\theta_{\text{des}}$  can be about  $30^\circ$ , 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  $30^\circ$  to the longitudinal axis of the receiver aircraft, without the need for modifying the configuration of the fuel receptacle thereof.

Thus, when angle  $\theta$  is equal to design angle  $\theta_{\text{des}}$ , 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. Referring in particular to Fig. 2, 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 **130** 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**. However, in alternative variations of this example, and in other examples, the center of gravity **CG** can be aft of the neutral point **NP**, or, the center of gravity **CG** can be at 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 at least while the refueling device **100** is not engaged with the receiver aircraft **20**.

The refueling device **100** can optionally further comprises an aerodynamic stabilizer arrangement (not shown), different from the spatial control system **160**. For example, the aerodynamic stabilizer arrangement is in the form of a respective drogue structure fixed to the aft portion of the body **110**, for example similar to that disclosed in WO 2013/102903 and WO 2013/102906 with respect to Figs. 17(a) and 17(b) thereof, *mutatis mutandis*, in which the drogue structure has an inactive (or stowed) configuration, in which drogue structure generates minimum drag, and an active (or deployed) configuration in drogue structure generates more drag than in the inactive configuration, up to a maximum drag. Such a drogue structure can be utilized for generating a drag (when in the active configuration) which in turn induces a tension to the hose **52**, thereby aiding reduction or dampening of vibrations or oscillations in the hose **52** that can otherwise occur.

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 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**, at least while the refueling device **100** is not engaged with the receiver 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, and referring again to Fig. 6(a), at least a part of angle  $\theta$ , in particular a part of the design angle  $\theta_{des}$  is provided first angular disposition  $\eta 1$ , i.e., by pivoting the boom member **130** about axis **C**, depending on the magnitude of the relative angular disposition  $\phi$  between the longitudinal axis **LAB** of the body **110** and the forward direction **A**. This angular disposition  $\phi$  can be positive, representing a positive angle of attack of body **110** with respect to forward direction **A**, or can be negative, or can be zero. In at least this example, the spatial control system **160** is configured for providing a zero or near zero said angular disposition  $\phi$  when the boom member **130** is in its deployed position pivoted such that the aft boom axis **BBA** is at first angular disposition  $\eta 1$ .

Referring again to Figs. 1 to 4, 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 **173C**, mounted to the forward part of body **110**, and comprising vertical fins **173F** above and below port and starboard canard wing tips **173T** of the canards **173C**. While in at least this example, the canards **173C** 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, vertical fins **173F**, 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 **176W**, mounted to the aft part of body **110**, and comprising vertical fins **177F** above and below port and starboard wing tips **178T** of the wings **176W**. while in this example the swept back wings **176W** are fixed, and comprise pivotable surfaces

to provide control moments to the device **100**, in alternative variations of this example the swept back wings **176W** can instead can be pivotable. The vertical fins **177F** 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**.

For example, the forward set **172** of aerodynamic control surfaces **173** and/or the aft set **174** of aerodynamic control surfaces **175** can instead 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;

- wings 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;
- wings 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 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;
- 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 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.

The refueling device **100** can optionally further comprise a force generating arrangement (not shown), configured for selectively generating a force **FB** (see Fig. 6(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 the aerodynamic stabilizer arrangement.

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.

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  $\theta_{des}$ ), 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  $\theta_{des}$ , 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 direction aligned with the aft boom axis **BAA**, maintaining the aft boom axis **BAA** at the engagement enabling orientation – corresponding to the design angle  $\theta_{des}$ , 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**.

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**.

Referring to Fig. 6, in at least this example the device **100** further comprises controller **185** for controlling operation of one or more of: the force generating arrangement, the spatial control system **160** (in particular the selectively controllable aerodynamic control system **170**), the aerodynamic stabilizer arrangement. For example, the controller **185** 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 **185** or portions thereof can instead comprise any suitable electronic control unit, or any other suitable control unit, and/or the controller **185** or portions thereof can be comprised elsewhere in the in-flight refueling system **50** or in the tanker aircraft **12**.

Referring to Fig. 6, in at least this example the refueling device **100** further 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 aft boom portion **138** and/or 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**.

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  $\theta$  while maintaining a zero pitching moment (and/or zero yawing moment and/or zero rolling moment), this being the design angle  $\theta_{des}$  as discussed above for example.

Optionally, a suitable air-driven generator **187** 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 6, and referring to Fig. 7, the boom member, generally designated with reference numeral **230**, is configured for being fixedly (i.e., non-pivotably) mounted to the body **110** of the device **100**.

In the example of Fig. 7, the boom member **230** includes an aft boom portion **238** having an aft boom axis **BAA'**, fuel delivery nozzle **235** and nozzle rotation center **239**, similar to the aft boom portion **138**, aft boom axis **BAA**, fuel delivery nozzle **135** and nozzle rotation center **139**, respectively, as disclosed herein for the example of Figs. 1 to 6, *mutatis mutandis*.

In the example of Fig. 7, the body lumen **120** extends up to and connects to the aft boom portion **238**, for example via a vane member **118** that extends downwardly from the body **110** to thereby provide the required or desired transverse spacing **TS** between the fuel

delivery nozzle **235** and the body **110**. The vane member **118** can thus be considered to be a forward boom member portion of the boom member **230**, that is fixedly connected to the body **110**.

As with the example of Figs. 1 to 6, *mutatis mutandis*, the fuel delivery nozzle **235** of the example of Fig. 7, in particular the nozzle rotation center **239** thereof, is located forward of the neutral point **NP** of the device **100** by a spacing **LS**.

Also as with the example of Figs. 1 to 6, *mutatis mutandis*, the aft boom axis **BAA'** of the example of Fig. 7 is at an angular displacement with respect to the longitudinal axis **LAB** of the body **110** of  $\eta 1$ , which is fixed regardless of whether the device **100** is engaged in in-flight refueling operation or not.

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.

**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 and a neutral point;
  - (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) wherein at least during refueling operation the fuel delivery nozzle is longitudinally forward of the neutral point.
2. The refueling device according to claim 1, the boom member comprising a forward boom member portion having a forward boom axis, and an aft boom member portion having an aft boom axis.
3. The refueling device according to claim 2, wherein the boom member is mounted to the body via the forward boom member portion, and wherein the fuel delivery nozzle is located on said aft boom member.
4. The refueling device according to claim 2 or claim 3, wherein the boom member is pivotably mounted to the body via the forward boom member portion.
5. The refueling device according to any one of claims 2 to 4, wherein said boom member is pivotably mounted with respect to the body.
6. The refueling device according to any one of claims 4 to 5, wherein said boom member is pivotable with respect to the body between a retracted position and a deployed position.
7. The refueling device according to claim 6, wherein in said deployed position the fuel delivery nozzle is configured to enable in-flight refueling.

8. The refueling device according to any one of claims 6 to 7, wherein in said deployed position the fuel delivery nozzle is at a transverse spacing with respect to the body to enable in-flight refueling.
9. The refueling device according to any one of claims 6 to 8, wherein in said retracted position the fuel delivery nozzle is located closer with respect to the body than in the deployed position.
10. The refueling device according to any one of claims 2 to 9, wherein said forward boom member portion is connected to said aft boom member portion via a boom elbow.
11. The refueling device according to any one of claims 2 to 10, wherein the forward boom axis and the aft boom axis are in non-parallel spatial relationship.
12. The refueling device according to any one of claims 2 to 10, wherein the forward boom axis and the aft boom axis are in a fixed non-parallel spatial relationship irrespective of whether the boom member is in the retracted position or the deployed position.
13. The refueling device according to any one of claims 2 to 12, wherein the forward boom axis is angularly displaced with respect to the aft boom axis by a first angular disposition.
14. The refueling device according to claim 13, wherein said first angular disposition is between  $60^{\circ}$  and  $120^{\circ}$ .
15. The refueling device according to any one of claims 5 to 14, wherein said boom member is in said deployed position during said in-flight refueling operation.
16. The refueling device according to any one of claims 2 to 15, wherein at least during said in-flight refueling operation, said aft boom axis is at a second angular disposition with respect to said body longitudinal axis, said second angular disposition being non-zero.
17. The refueling device according to any one of claims 4 to 16, wherein said boom member pivots as a rigid body.

18. The refueling device according to claim 2 or claim 3, wherein the boom member is fixedly mounted to the body via the forward boom member portion.
19. The refueling device according to claim 18, wherein the forward boom member portion is in the form of a fin.
20. The refueling device according to any one of claims 2 to 15, wherein at least during said in-flight refueling operation, said aft boom axis is at a third angular disposition with respect to a forward direction of said refueling device.
21. The refueling device according to claim 20, wherein said third angular disposition is such as to ensure that the aft boom axis is at a predetermined design angle with respect to the receiver aircraft.
22. The refueling device according to claim 21, wherein said design angle is about 30°.
23. The refueling device according to any one of claims 20 to 22, wherein said refueling device is configured for maintaining said third angular disposition between said aft boom axis and said forward direction at least prior to engagement of said fuel delivery nozzle with a fuel receptacle of a receiver aircraft that is flying in formation aft of the tanker aircraft.
24. The refueling device according to any one of claims 1 to 23, 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.
25. The refueling device according to any one of claims 1 to 24, wherein said spatial control system comprises selectively controllable aerodynamic control system.
26. The refueling device according to claim 25, 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.

- 27.** The refueling device according to claim 26, 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
- 28.** The refueling device according to claim 26 or claim 27, 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.
- 29.** The refueling device according to any one of claims 26 to 28, 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.
- 30.** The refueling device according to any one of claims 1 to 29, 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.
- 31.** The refueling device according to any one of claims 1 to 30, further comprising an aerodynamic stabilizer arrangement, different from the spatial control system.
- 32.** The refueling device according to claim 31, wherein said aerodynamic stabilizer arrangement is in the form of a drogue structure having a stowed configuration, in which drogue structure generates a minimum drag, and a deployed configuration in which drogue structure generates greater drag than in the inactive configuration.
- 33.** The refueling device according to any one of claims 1 to 32, further 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.** The refueling device according to any one of claims 1 to 37, wherein the fuel delivery nozzle is rotatably mounted to a free end of the boom member via a nozzle rotation center of the fuel delivery nozzle, and wherein at least during refueling operation the nozzle rotation center is longitudinally forward of the neutral point.

**39.** 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 38.

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

**41.** A refueling device for use in in-flight refueling operation between a tanker aircraft and a receiver aircraft, comprising:

- a selectively steerable body configured for being towed by a tanker aircraft via a fuel hose at least during in-flight refueling, and comprising a boom member having an aft boom axis and a fuel delivery nozzle, said boom member configured to enable

fuel to be transferred from said fuel hose to a receiver aircraft along said aft boom axis during said in-flight refueling operation;

- wherein at least during said in-flight refueling operation the fuel delivery nozzle is longitudinally forward of a neutral point of the refueling device.

**42.** The refueling device according to claim 41, wherein the fuel delivery nozzle is rotatably mounted to a free end of the boom member via a nozzle rotation center of the fuel delivery nozzle, and wherein at least during refueling operation the nozzle rotation center is longitudinally forward of the neutral point.

**43.** A boom member for a refueling device for use in in-flight refueling operation, the boom member comprising:

a forward boom member portion having a forward boom axis, and an aft boom member portion having an aft boom axis,

the forward boom member portion being connected to the aft boom member portion via a boom elbow portion wherein the forward boom axis is angularly displaced with respect to the aft boom axis by a non-parallel angular disposition,

wherein the boom member is pivotably mountable with respect to the refueling device about a pivot axis, to enable, in use, the boom member to be selectively pivotable about the pivot axis with respect to the refueling device between a retracted position and a deployed position; and

wherein the pivot axis is comprised in the forward boom member portion.

**44.** The boom member according to claim 43, wherein said angular disposition is between 60° and 120°.

**45.** The boom member according to any one of claims 43 to 44, wherein said boom member is configured for pivoting about the pivot axis as a rigid body.