TOWBARLESS AIRPLANE TUG

FIELD OF THE INVENTION

The present invention relates generally to systems for airplane ground movement, and more particularly to control methods of ground vehicles of such systems.

BACKGROUND OF THE INVENTION

Airplane tugs are often provided for towing airplanes between ground locations at an airport, thus obviating the need for the airplane to move itself under its own power, saving jet fuel. The tugs may be provided with a towbar, which connects a landing gear with the tug, or towbarless, in which a towbar is not provided, in which, typically, the landing gear sits directly on the chassis of the tug.

SUMMARY OF THE INVENTION

Disclosed herein is~~According to one aspect of the present invention, there is provided~~ a towbarless airplane tug configured for receiving a landing gear of an airplane and towing it thereby, the tug comprising:

- a chassis configured for receiving thereon at least a portion of the landing gear;
- a propulsion arrangement configured to move the tug in a direction along a trajectory and comprising a variable angle swash plate hydraulic pump coupled to a variable angle swash plate hydraulic motor and to a controllable bypass path valve, configured such that a hydraulic fluid circulates between the pump and the motor so as to activate the propulsion arrangement to increase at least one of the speed and the traction force of the tug when the bypass path is in a closed state, and at least most of the hydraulic fluid circulates across the motor via the bypass path valve so as to reduce at least one of a rotational speed and traction force of the tug when the bypass path is in a opened state;
- at least one force sensor configured to measure, directly or indirectly, a force exerted by the chassis on the landing gear in at least the direction due to a speed differential between the tug and the airplane; and
- a controller in communication with the force sensor and being configured to alter one or more parameters of movement of the tug such that the force exerted by the chassis on the

The towbarless airplane tug may further comprise energy absorbers arranged to absorb energy between the landing gear and the chassis.

The altering of the one or more parameters of movement may have an effect so as to and/or be directed to cause the tug to reduce its speed and/or traction force.

The chassis may comprise a support assembly configured for the receiving of the portion of the landing gear and being mounted on the chassis such that it is moveable thereon at least in the direction. In such a case, the force sensor may be configured to measure the force exerted by the support assembly on the chassis in at least the direction.

The parameters of movement may be selected from a group comprising speed, direction, acceleration, and deceleration.

The controller may be configured to calculate a (predicted) resultant force exerted by the chassis on the landing gear at least based on one or more external factors. The external factors may be selected from a group comprising:

- data relating to slopes at various locations along an airplane travel surface to be traversed by the tug;
- data relating to wind forces affecting the airplane and tug;
- data relating to rolling friction forces of the airplane and or tug at various locations along the airplane travel surface; and
- data relating to obstacles.

The data relating to slopes may be provided by an inclination sensing functionality.

The data relating to slopes may be predetermined and stored as slope date in a database, the controller being further configured to determine the position of the tug on the airplane travel surface and to relate the slope data to the position.

The data relating to rolling friction forces may be predetermined and stored as friction date in a database, the controller being further configured to determine the position of the tug on the airplane travel surface and to relate the friction data to the position.

The tug may be configured to detect obstacles along the airplane path.

The controller may be configured to communicate wirelessly with a remote command center, for example via an electronic flight bag.

The towbarless airplane tug may further comprise an electronic flight bag configured to communicate wirelessly with a similar device within the airplane.

Disclosed herein is~~According to another aspect of the present invention, there is provided~~ a method for towing an airplane, the method comprising providing a towbarless airplane tug comprising:

- a chassis configured for receiving thereon at least a portion of a landing gear of the airplane; and

- a propulsion arrangement configured to move the tug in a direction along a trajectory and comprising a variable angle swash plate hydraulic pump coupled to a variable angle swash plate hydraulic motor and to a controllable bypass path valve, configured such that a hydraulic fluid circulates between the pump and the motor so as to activate the propulsion arrangement to increase at least one of the speed and the traction force of the tug when the bypass path is in a closed state, and at least most of the hydraulic fluid circulates across the motor via the bypass path valve so as to reduce at least one of a rotational speed and traction force of the tug when the bypass path is in a opened state;

the method further comprising causing the tug to tow the airplane while altering one or more parameters of movement of the tug such that a force exerted by the chassis on the landing gear is maintained below a predetermined value by regulating at least the power available to the propulsion arrangement, the pump and motor swash-plates, and the state of the bypass path valve.

The tug may be provided as described above.

~~According to a further aspect of the present invention, there is provided a towbarless airplane tug configured for receiving a landing gear of an airplane and towing it thereby, the tug comprising:~~

- ~~a chassis configured for receiving thereon at least a portion of the landing gear;~~
- ~~a propulsion arrangement configured to move the tug in a direction along a trajectory; and~~
- ~~a controller configured to compare between an actual speed of a towbarless airplane tug and a predetermined desired speed thereof, and to direct the propulsion arrangement to maintain the actual speed of the towbarless airplane tug if:~~
  - ~~the actual speed is lower than the desired speed; and~~
  - ~~the actual speed was maintained within a predefined speed range during a predefined period that preceded the comparing.~~

According to an aspect of the present invention, there is provided a towbarless airplane tug configured for receiving a landing gear of an airplane and towing the airplane thereby at an actual speed, said towbarless airplane tug comprising:

a chassis configured for receiving thereon at least a portion of said landing gear;

a propulsion arrangement configured to move the towbarless airplane tug in a direction along a trajectory; and

a controller configured to compare between the actual speed of the towbarless airplane tug, when towing the airplane, and a predetermined desired speed thereof, and to direct said propulsion arrangement to maintain the actual speed of the towbarless airplane tug if:

the actual speed is lower than the desired speed; and

the actual speed was maintained within a predefined speed range during a predefined period that preceded the comparing.

The controller may be further configured to detect airplane pilot-controlled braking and deceleration of the airplane, and is further configured to direct the propulsion arrangement to maintain the actual speed if:

- the actual speed is higher than the desired speed; and
- at least one of an airplane pilot-controlled braking and deceleration of the airplane is detected.

The controller may be further configured to direct the propulsion arrangement to change the actual speed of the towbarless airplane tug to match the desired speed if an airplane pilot-controlled braking is detected.

The towbarless airplane tug may be further configured to apply a positive traction force at all times during a towing of the airplane.

The towbarless airplane tug may be further configured to protect in real time the landing gear from exceeding its maximum allowed fatigue load.

The controller may be further configured to calculate the desired speed.

The controller may be further configured to calculate a desired traction force corresponding to the desired speed.

The controller may be further configured to calculate the desired speed at least based upon a location of the tug.

The controller may be further configured to calculate the desired speed at least based upon a location of the tug and a location of at least one other tug.

The controller may be further configured to calculate the desired speed at least based upon a location of the tug and a location and a speed of at least one other tug that shares at least one path therewith.

The controller may be further configured to calculate the desired speed at least based upon a location of the tug and a desired time of arrival thereof at an end of towing location.

The controller may be further configured to calculate the desired speed at least based upon a location of the tug, an estimated time of arrival of another tug at an end of towing point, and a desired time of arrival of the tug at the end of towing location.

The towbarless airplane tug may further comprise a transmitter configured to transmit information relating to speed and location of the tug. This information may be transmitted, e.g., to an airplane cockpit, to at least one other tug, or a remote command center.

The towbarless airplane tug may further comprise a receiver configured to receive information relating to speed and location of at least one other tug from a remote command center.

The towbarless airplane tug may further comprise a detector configured to detect a speed and a location of at least one other tug by utilizing a sensor; the controller being configured to calculate the desired speed at least based upon the speed and location of the other tug.

The controller may be further configured to calculate the desired speed based upon a desired time of arrival at an end of towing location and an estimated time of arrival of the other tug at an end of towing point.

Disclosed herein is~~According to a still further aspect of the present invention, there is provided~~ a method for controlling a towbarless airplane tug, the method comprising:

- obtaining information relating to speed and location of at least one other tug that is expected to share at least a portion of a towing path with the tug; and

- calculating the desired speed of the tug at least based upon the speed and location thereof and the information.

The method may further comprise calculating the desired speed based upon desired time of arrival of the tug at an end of towing location.

The method may further comprise calculating the desired speed of the towbarless airplane tug based upon an estimated time of arrival of the one other tug at an end of towing point.

The method may further comprise transmitting information relating to speed and location of the tug to the other tug.

The method may further comprise transmitting information relating to speed and location of the tug to a remote command center and receiving there from information relating to speed and location information of the other tug.

The tug may obtain the information relating to speed and location of at least one other tug utilizing a sensor.

Disclosed herein is~~According to a still further aspect of the present invention, there is provided~~ a towbarless airplane tug configured for receiving a landing gear of an airplane and towing it thereby, the tug comprising:

- a chassis configured for receiving thereon at least a portion of the landing gear;
- a propulsion arrangement configured to move the tug in a direction along a trajectory; and
- a controller configured to operate as per the above.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1A is a pictorial illustration of a towbarless airplane tug;

Fig. 1B is a cross-sectional view of the towbarless airplane tug illustrated in Fig. 1A, taken along the lines 1B-1B;

Fig. 1C is a top view of the towbarless airplane tug illustrated in Fig. 1A;

Figs. 2A through **2J** are perspective views of various stages of pre-pushback and pushback operations of the towbarless airplane tug illustrated in Fig. 1A;

Figs. 3A through **3E** illustrate various stages of pilot controlled taxiing operation of the towbarless airplane tug illustrated in Fig. 1A;

Figs. 4A through **4E** illustrate various stages of autonomous taxiing operation of the towbarless airplane tug illustrated in Fig. 1A;

CLAIMS

1. A towbarless airplane tug configured for receiving a landing gear of an airplane and towing it thereby, said tug comprising:

- a chassis configured for receiving thereon at least a portion of said handing gear;
- a propulsion arrangement configured to move the tug in a direction along a trajectory; and
- a controller configured to compare between an actual speed of a Towbarless airplane tug and a predetermined desired speed thereof, and to direct said propulsion arrangement to maintain the actual speed of the towbarless airplane tug if:
    - the actual speed is lower than the desired speed; and
    - the actual speed was maintained within a predefined speed range during a predefined period that preceded the comparing.

2. The towbarless airplane tug according to claim 1 wherein the controller is further configured to detect airplane pilotcontrolled braking and deceleration of the airplane, and is further configured to direct said propulsion arrangement to maintain the actual speed if:

- the actual speed is higher than the desired speed; and
- at least one of an airplane pilot-controlled braking and deceleration of said airplane is detected.

3. The towbarless airplane tug according to claim 2, wherein the controller is further configured to direct said propulsion arrangement to change the actual speed of the towbarless airplane tug to match the desired speed if an airplane pilot-controlled braking is detected.

4. The towbarless airplane tug according to any one of the preceding claims, being further configured to apply a positive traction force at all times during a towing of the airplane.

5. The towbarless airplane tug according to any one of the preceding claims, being further configured to protect in real time the landing gear from exceeding its maximum allowed fatigue load.

6. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate the desired speed.

7. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate a desired traction force corresponding to the desired speed.

8. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug.

9. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug and a location of at least one other tug.

10. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug and a location and a speed of at least one other tug that shares at least one path therewith.

11. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug and a desired time of arrival thereof at an end of towing location.

12. The towbarless airplane tug according to any one of the preceding claims, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug, an estimated time of arrival of another tug at an end of towing point, and a desired time of arrival of the tug at the end of towing location.

13. The towbarless airplane tug according to any one of the preceding claims, further comprising a transmitter configured to transmit information relating to speed and location of the tug.

14. The towbarless airplane tug according to claim 13, further comprising a receiver configured to receive information relating to speed and location of at least one other tug from a remote command center.

15. The towbarless airplane tug according to any one of the preceding claims, further comprising a detector configured to detect a speed and a location of at least one other tug by utilizing a sensor; said controller being configured to calculate the desired speed at least based upon the speed and location of said other tug.

CLAIMS

1. A towbarless airplane tug configured for receiving a landing gear of an airplane and towing the airplane thereby at an actual speed, said towbarless airplane tug comprising:

a chassis configured for receiving thereon at least a portion of said landing gear;

a propulsion arrangement configured to move the towbarless airplane tug in a direction along a trajectory; and

a controller configured to compare between the actual speed of the towbarless airplane tug, when towing the airplane, and a predetermined desired speed thereof, and to direct said propulsion arrangement to maintain the actual speed of the towbarless airplane tug if:

the actual speed is lower than the desired speed; and

the actual speed was maintained within a predefined speed range during a predefined period that preceded the comparing.

2. The towbarless airplane tug according to claim 1 wherein the controller is further configured to detect airplane pilot-controlled braking and deceleration of the airplane, and is further configured to direct said propulsion arrangement to maintain the actual speed if:

the actual speed is higher than the desired speed; and

at least one of an airplane pilot-controlled braking and deceleration of said airplane is detected.

3. The towbarless airplane tug according to claim 2, wherein the controller is further configured to direct said propulsion arrangement to change the actual speed of the towbarless airplane tug to match the desired speed if an airplane pilot-controlled braking is detected.

4. The towbarless airplane tug according to claim 1, being further configured to apply a positive traction force at all times during a towing of the airplane.

5. The towbarless airplane tug according to claim 1, being further configured to protect in real time the landing gear from exceeding its maximum allowed fatigue load.

6. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate the desired speed.

7. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate a desired traction force corresponding to the desired speed.

8. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug.

9. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug and a location of at least one other tug.

10. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug and a location and a speed of at least one other tug that shares at least one path therewith.

11. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug and a desired time of arrival thereof at an end of towing location.

12. The towbarless airplane tug according to claim 1, wherein the controller is further configured to calculate the desired speed at least based upon a location of the tug, an estimated time of arrival of another tug at an end of towing point, and a desired time of arrival of the tug at the end of towing location.

13. The towbarless airplane tug according to claim 1, further comprising a detector configured to detect a speed and a location of at least one other tug by utilizing a sensor; said controller being configured to calculate the desired speed at least based upon the speed and location of said other tug.

14. The towbarless airplane tug according to claim 1, wherein said tug obtains said information relating to speed and location of at least one other tug utilizing a sensor.