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(71) Applicant *(for all designated States except US)*: **BOREALIS TECHNICAL LIMITED** [US/GB]; 27 Heathway Court, London, England, NW3 7TS (US).

(72) Inventor; and
(71) Applicant *(for all designated States except US)*: **PERKINS, Scott** [US/US]; 12440 SE 235 Street, Kent, WA 98301 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **EDELSON, Jonathan** [US/US]; 2425 SW Nebraska Street, Portland, OR 97239-1972 (US). **COX, Isaiah, Watas** [US/US]; 3505 Bancroft Road, Baltimore, MD 21215 (US). **GILLERAN, Neal** [US/US]; 520 Lexington Ct., Long Beach, CA 90803 (US).

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(54) **Title**: METHOD OF OPERATING AIRCRAFT DRIVE MOVE AN AIRCRAFT UNDER ADVERSE GROUND CONDITIONS

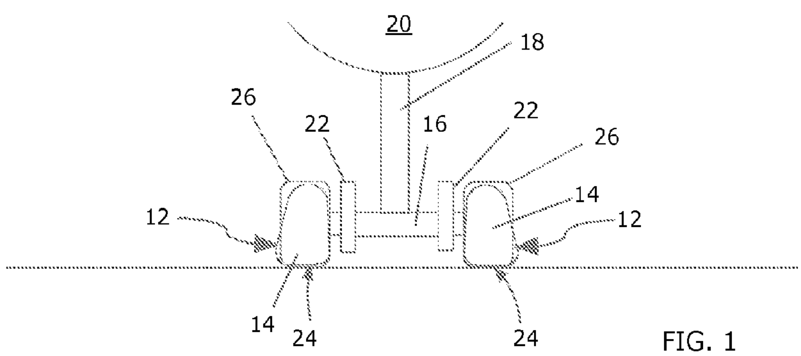

FIG. 1

(57) **Abstract**: A method is provided for restoring mobility to an aircraft equipped with at least one self-propelled drive wheel powered by a driver when the aircraft has been rendered immobile as a result of one or more wheel tires adhering to and becoming stuck to tarmac or another ground surface. The method uses forces generated by the cooperative action of the wheel driver, the aircraft steering, and the aircraft braking system to release adherent tires of each set of main wheels and/or nose gear wheels by applying differential force to one set of wheels at a time to release any adherent tires so that the aircraft is able to move on the ground surface and travel in a desired direction at a desired speed.

WO 2012/106643 A1

NEW PATENT APPLICATION

FOR

METHOD OF OPERATING AIRCRAFT DRIVE TO MOVE AN AIRCRAFT UNDER ADVERSE GROUND CONDITIONS

Priority

U.S. Provisional Patent Application No. 61/439,579, filed February 4, 2011 and Non Provisional Application No. 13/366,006 filed February 3, 2012.

Technical Invention

The present invention relates generally to the operation of aircraft on the ground under adverse ground conditions and specifically to a method of moving, under adverse ground conditions, an aircraft equipped with a powered self-propelled drive wheel from a position where the aircraft is temporarily immobile to full mobility and movement.

Background of the Invention

Arriving and departing aircraft must travel on the ground between landing and subsequent takeoff along runways and taxiways associated with an airport. Over time, the tarmac surface of a runway or taxiway can change as a result of rubber buildup from the application of aircraft brakes, paint used for marking, chemicals, and erosion of the tarmac material. These changes in the runway surface produce changes in the friction between the runway surface and the aircraft's tires. The presence of moisture, whether from rain, slush, snow, or ice, however, is a major factor in the degradation of runway surfaces. At a minimum, braking action is diminished, and a longer landing distance is required.

Aircraft tires may also become stuck to the runway surface under adverse ground conditions. The coefficient of runway friction or slipperiness, μ, is theoretically 1 when the runway friction characteristics are 100%. For a runway with 0% friction characteristics, $\mu = 0$. All other friction characteristics fall between 0% ($\mu = 0$) and 100% ($\mu = 1$). Most new runways have a coefficient of friction of about $\mu = 0.6$ (60% friction characteristics). A coefficient of friction $\mu > 0.4$ (greater than 40% friction characteristics) is generally considered to be good. The factors mentioned above all contribute to runway deterioration and decrease the coefficient of friction, affecting aircraft braking and landing distance. The presence of moisture, particularly in the form of snow or ice, can have a significant effect on the friction characteristics between an aircraft's tires and the runway surface. This can lead to a situation in which the frictional forces between the tire and the runway cannot be overcome by direct aircraft pressure, resulting in a stuck aircraft with one or more tires adhered to the runaway surface.

When an aircraft is completely stopped and at rest on the ground, there are numerous factors in addition to friction characteristics that can make movement of the aircraft from this resting condition difficult, particularly in cold weather. For example, tires that are cold tend to become misshapen, making them harder to turn. When a tire has become flattened where it contacts the tarmac, the force required to move the aircraft includes the force needed to lift the aircraft over the misshapen tire. Aircraft tires can also become stuck to the tarmac when water freezes between the tire and the tarmac or through light adhesion between the tire and tarmac in drier conditions. In winter conditions, snow and slush buildup can exacerbate the situation. In addition, when the aircraft wheel bearings are cold, they are more resistant to movement than when the bearings are warm, adding an additional frictional force to be overcome. Under these conditions, the force required initially to move an aircraft from a resting condition to a moving condition can be much greater than the force required to keep the aircraft moving, once frictional forces and inertia have been overcome and movement has started.

Aircraft are most often in immobile after arrival, when they are parked at a gate or other docking structure. The time an aircraft is required to spend at a gate will depend, in part, on the turnaround schedule. Some aircraft have longer turnaround times than others. In inclement weather, especially when the temperatures are around freezing, the likelihood of ice forming between one of more of the aircraft tires and the tarmac can be quite high, causing the tires and, hence, the wheels to become stuck to the tarmac.

Methods and apparatus for reducing the adhesion between ice on a travel surface and an object traveling on the surface are known. U.S. Patent No. 7,034,257 to Petrenko et al, for example, proposes a method to modify friction between an object and ice or snow that is suggested to be applicable to aircraft landing gear. This method employs a heating element to apply a pulse of thermal energy to melt ice at the interface of an object and the ice or snow. While this method may be effective in other applications, it involves having available additional equipment and additional ground personnel to use the equipment to free a parked aircraft stuck to ice and get the aircraft moving. U.S. Patent No. 7,743,653 to Stommel describes a method of adapting tires of aircraft and other vehicles to travel surface conditions by changing the shape of the tire to increase or decrease contact between the tire and the travel surface, thereby increasing or decreasing friction between the tire and the travel surface, by raising or lowering tire pressure in response to a sensed travel situation. Stommel, however, does not even remotely suggest that this system would be effective or could be used in snow, ice, or other conditions to release an aircraft tire that has become stuck, directly or indirectly, to the travel surface.

An aircraft with one or more tires immobilized by ice presents challenges during push back when a tow vehicle or tug is used. The weight of the tug helps to apply sufficient force to overcome the frictional, inertial, and other forces keeping the aircraft stuck in the ice. Aircraft equipped with self-propelled drive wheels powered by electric drivers, such as the system disclosed in U.S. Patent Application No. 2009/0114765 to Cox et al, work very effectively to move aircraft on the ground without external assistance under almost all environmental conditions. These systems, however, are functionally required to be small and lightweight and cannot apply the same force as a tug to free aircraft wheels stuck in ice. Increasing the size of the driver in a powered self-propelled aircraft wheel to provide more force directly to the wheel to overcome ice adhesion is not a viable solution because these systems must remain as small and lightweight as possible, in part to fit within the space allotted for an aircraft's landing gear.

It would be highly desirable to be able to fully utilize the benefits of a powered self-propelled aircraft drive wheel, particularly at push back, under all types of runway and environmental conditions, especially those which cause adhesion of the aircraft's tires to the tarmac. The prior art has not provided a method for operating a powered self-propelled aircraft drive wheel under adverse runway conditions which have caused one or more of the aircraft's tires to adhere directly or indirectly to the tarmac that employs the powered self-propelled drive wheel to release the aircraft tires and enable the aircraft to move.

Summary of the Invention

It is a primary object of the present invention, therefore, to provide a method for operating a powered self-propelled aircraft drive wheel under adverse runway conditions which have caused one or more of the aircraft's tires to adhere directly or indirectly to the tarmac that employs the powered self-propelled drive wheel to release the aircraft tire and enable the aircraft to move.

It is another object of the present invention to provide a method for using a powered self-propelled aircraft drive wheel to effectively free an aircraft wheel tire that has become stuck directly or indirectly to the tarmac without increasing the size of the wheel driver.

It is a further object of the present invention to provide a method for releasing one or more aircraft tires stuck to the tarmac or to ice on the tarmac that uses the aircraft's steering in conjunction with the aircraft's powered self-propelled wheel driver to release a stuck tire.

It is yet another object of the present invention to provide a method for releasing an aircraft tire stuck directly or indirectly to the tarmac that uses the aircraft powered self-propelled driver wheel driver to apply differential force to the stuck wheel to release it.

It is yet a further object of the present invention to provide a method for utilizing the driver from a powered self-propelled aircraft drive wheel to release stuck aircraft tires that will not otherwise move under direct aircraft pressure.

In accordance with the aforesaid objects, a method is provided for operating a powered self-propelled aircraft drive wheel under adverse runway conditions which have caused one or more of the aircraft's tires from the main wheels or the nose wheels to adhere directly or indirectly to the tarmac that employs the aircraft powered self-propelled drive wheel to release the tire and enable the aircraft to move. The method uses the aircraft steering system to steer the aircraft, preferably by steering the nose wheels, in a first direction and then in a second direction, while powering and activating the wheel driver to move the aircraft in a forward or in a reverse direction during the steering maneuver to apply differential force to the one or more wheels, thereby releasing any tires stuck to the tarmac.

Other objects and advantages will be apparent from the following description, drawings, and claims.

Brief Description of the Drawings

Figure 1 illustrates a diagram of a set of powered aircraft self-propelled nose wheels showing deformation in the tires caused by adherence of the tire to the tarmac; and

Figure 2 illustrates a diagram of a set of powered aircraft self-propelled nose wheels and two sets of main wheels showing the differential forces applied to the wheels to move them from a condition of being stuck to the tarmac to being in motion.

Description of the Invention

A powered self-propelled nose wheel or other powered aircraft drive wheel is uniquely positioned to maneuver an aircraft in a variety of circumstances on the ground without assistance from external vehicles. The driver for the powered drive wheel optimally exerts sufficient power to move the aircraft at runway speeds, and its small size enables the driver to fit within the landing gear space. When weather conditions and, hence, runway conditions are adverse, particularly when the weather is cold, icy, or snowy, it is not unusual for aircraft tires to adhere either directly to the tarmac or to ice formed by water freezing between the tire and tarmac surface. The method of the present invention uses a powered self-propelled nose wheel or other wheel driver in conjunction with the aircraft steering and, when indicated, the aircraft brakes to apply enough force to a stuck tire to release it from its stuck position, thereby enabling the aircraft to move on the ground in a desired direction.

An aircraft with a powered self-propelled nose wheel or other aircraft wheel will have one or more wheel drivers mounted in driving relationship with one or more of the aircraft wheels to move the wheels at a desired speed and torque. Wheel drives useful for this purpose may be selected from those known in the art. One wheel drive preferred for this purpose is a high phase order electric motor of the kind described in, for example, U.S. Patent Nos. 6,657,334; 6,838,791; 7,116,019; and 7,469,858, all of which are owned in common with the present invention. A geared motor, such as that shown and described in U.S. Patent No. 7,469,858, is designed to produce the torque required to move a commercial sized aircraft at an optimum speed for ground movement. The disclosures of the aforementioned patents are incorporated herein by reference. Any form of electric motor capable of driving an aircraft on the ground, including but not limited to electric induction motors, permanent magnet brushless DC motors, switched reluctance motors, hydraulic pump/motor assemblies, and pneumatic motors may also be used to power drive wheels in accordance with the present invention. Other motor designs capable of high torque operation across the speed range that can be integrated into an aircraft drive wheel to function as described herein may also be suitable for use in the aircraft ground movement system of the present invention. In addition, hydraulic or other types of drives known in the art could also be used to power an aircraft wheel that can be released when stuck to the tarmac according to the method of the present invention.

The direction of travel of the aircraft is typically controlled by the pilot steering the aircraft nose gear using an aircraft steering system, usually a hydraulic steering system. A nose wheel or other wheel driver may also be used to steer the aircraft, however, by varying the rotation and/or direction of rotation of each wheel in a pair of wheels to apply differential thrust between the wheels.

Referring to the drawings, Figure 1 diagrammatically illustrates an aircraft nose gear 10 in which the tire shape has been deformed by one or more conditions, such as, for example, loss of tire pressure due to cold temperatures. The nose gear 10 includes a pair of wheels 12 on each of which is mounted a tire 14. The wheels 12 are rotatably mounted on an axle 16 supported by a strut 18 connected to the aircraft body 20. In the nose gear shown in Figure 1, each one of a pair of nose wheel drivers 22 is mounted on the axle 16. Although the drivers 22 are shown mounted interiorly of the wheels 12 toward the strut 18, other mounting positions for the drivers 22 relative to the wheels are contemplated to be within the scope the present invention. Such positions and locations could include, for example without limitation, within a nose wheel or main wheel, within a nose wheel or main wheel landing gear space, or in any other convenient onboard location inside or outside the wheel. Additionally, although a pair of drivers 22 is shown mounted adjacent to each wheel, a single driver may be mounted adjacent to a selected wheel to perform the method of the present invention. While the present invention is shown and described primarily with respect to the wheels of an aircraft nose landing gear, as indicated above, drivers 22 could be mounted to drive any one or more other aircraft wheels, including main landing gear wheels.

It can be seen in Figure 1 that the tarmac contacting surface 24 of each tire 14 is deformed when compared to the optimum tire shape shown in dashed lines at 26. A misshapen tire is harder to turn, and the force required moving the aircraft must include the additional force needed to lift the aircraft over the misshapen tire.

As previously indicated, a tire stuck to the tarmac surface, either directly through light adhesion or indirectly through ice formed when water is present between the tire and the tarmac, is difficult to move and requires the correct application of force to release the tire without damaging the nose gear structures. Even if adhesion exists between only one tire, and/or possibly more tires, and the tarmac, all of the aircraft wheels must be operating to move the aircraft. Moreover, the stuck wheel or wheels could be any of the aircraft wheels, including the aircraft main gear wheels as well as the nose gear wheels. The method of the present invention enables a pilot to use a powered self-propelled wheel drive system, such as the nose wheel drive shown in Figure 1 or a main wheel drive system (not shown), to free the stuck tire or tires and get the aircraft moving in all situations. A powered self-propelled wheel driver, whether mounted on the nose gear or elsewhere is uniquely suited to accomplish this.

When confronted with one or more aircraft wheels adhered to the tarmac, the pilot begins the maneuver to release the stuck wheel or wheels by initially steering the aircraft, preferably, but not necessarily, using the nose wheel steering, in a first direction and then in a second direction different from the first direction. The steering maneuver is accomplished by using either the aircraft hydraulic steering or by activating a wheel driver or drivers to produce differential thrust between the wheels. For example, turning the nose gear wheels in a first direction, as shown in Figure 2, and then a second direction (not shown) will rotate the nose gear wheels away from the area of adhesion to the tarmac and release the adhesion between the tire and the tarmac. The pilot then activates the powered nose wheel driver or drivers 22, or other powered wheel driver, to move the aircraft forward or reverse while the nose wheel is steered to the right or to the left of center. This maneuver effectively applies differential force to one main wheel set 28 as compared to the second main wheel set 30. (Figure 2) The net result is that the nose wheel driver does not have to overcome whatever frictional, inertial, or other forces are keeping all sets of the aircraft wheels in place so the aircraft is not moving. By steering the nose wheels in one direction and applying force with the nose wheel or another wheel driver, the driver can release one set of wheels at a time.

The maneuvers described above can be supplemented by the application of the aircraft brakes to whichever main wheel is not meant to be released, ensuring that full turning power is applied to just one set of main wheels, 28, 30. In an aircraft with a main wheel powered by an onboard driver like the nose wheel driver described above (not shown), the method of the present invention allows all available power to be focused on a single set of aircraft wheels. In an aircraft with the typical tricyclic landing gear configuration shown in Figure 2, the application of the brakes to a wheel in a main wheel set (28, 30) and/or turning the nose gear steering can help concentrate the forces required to release one stuck wheel at a time. Additionally, differential force can be applied to each main wheel set (28, 30) in conjunction with turning the nose gear steering. For example, the right wheel set 28 can be driven forward, while the left set 30 can be driven backward, as indicated by the arrows 32 and 34, respectively. While this approach would turn the aircraft slightly, the maneuver will help rock the aircraft back and forth until the tires are successfully released, and the aircraft is able to move in the desired direction.

Although it should be apparent to the pilot and/or ground crew when one or more aircraft wheels are stuck because one or more tires has adhered to the tarmac, a sensor associated with each aircraft wheel or tire could be employed to relay information to the flight crew or ground crew confirming this. Devices that sense wheel rotation or movement and other wheel properties relating to wheel rotation or movement are known in the art and could be used with the present method.

It is also contemplated that the present method could be utilized in some runway excursion situations in which the aircraft has left the runway and one or more sets of aircraft wheels is stuck in the surface adjacent to the runway. The surface adjacent to the runway may be a variety of different materials, such as gravel, dirt or grass, and may be covered by snow or ice in the winter. Depending on the depth to which the wheel is stuck, the method described herein may effectively be used to free the aircraft wheel and move the aircraft back onto the tarmac. Additional similar uses are contemplated to be within the scope of the present method.

Industrial Applicability

The method of the present invention will find its primary applicability for use with aircraft equipped with one or more powered self-propelled drive wheels, each having a driver that is activated to rotate and drive the powered wheel, to maneuver the aircraft from a resting position in which the aircraft has been rendered immobile by the adhesion of one or more tires to the runway or other surface to a fully mobile position in which the aircraft is capable of moving in a desired direction.

Claims

1. A method for using an onboard powered wheel driver of an aircraft equipped with at least one said onboard powered wheel driver and rendered immobile by tires of one or more aircraft wheels adhered to the aircraft ground travel surface and unmovable under direct aircraft pressure, comprising activating said powered wheel driver to drive said one or more wheels while steering said aircraft to release one or more adherent tires and restore mobility to the aircraft.

2. The method for using an onboard powered wheel driver described in claim 1, wherein substantially all available power from said powered wheel driver is directed to a single adherent wheel tire or set of wheels with at least one adherent tire while brakes are applied to wheels with free, nonadherent tires and the steering is selectively applied to concentrate forces resulting from the activation of the powered wheel driver and the steering on at least one adherent wheel tire, thereby releasing said adherent tire.

3. The method for using an onboard powered wheel driver described in claim 1, wherein in an aircraft with more than one set of main wheels, differential force is applied to each set of main wheels while the aircraft steering is applied to turn the aircraft nose gear.

4. The method for using an onboard powered wheel driver described in claim 3, wherein said differential force is applied by rotating one main wheel set in a forward direction and another main wheel set in a reverse direction.

5. The method for using an onboard powered wheel driver described in claim 1, further comprising simultaneously steering the aircraft and using the powered wheel driver to apply differential force to selected adherent wheel tires to release the selected adherent wheel tires one at a time.

6. The method for using an onboard powered wheel driver described in claim 1, wherein the aircraft is equipped with an onboard powered wheel driver selected from the group comprising high phase order electric motors, electric induction motors, permanent magnet brushless DC motors, switched reluctance motors, hydraulic motors, and pneumatic motors.

7. The method for using an onboard powered wheel driver described in claim 1, wherein said aircraft is steered and direction of travel is controlled by the aircraft steering system.

8. The method for using an onboard powered wheel driver described in claim 1, wherein said aircraft is equipped with a pair of onboard powered wheel drivers, each mounted to drive a pair of nose wheels, and said aircraft is steered and direction of travel is controlled by selectively activating each one of said wheel drivers to vary the rotation or direction of rotation of each wheel to apply differential thrust between the wheels.

9. The method for using an onboard powered wheel driver described in claim 1, wherein at least one of said tires is misshapen as a result of adverse environmental conditions, and force applied to restore mobility to the aircraft includes the force required to lift the aircraft over the misshapen tire.

10. A method comprising moving an aircraft equipped with pilot input steering, a set of nose gear wheels, and at least two sets of main wheels, each of said wheel sets having tires attached thereto, and at least one self-propelled drive wheel powered by a driver capable of moving the aircraft in a desired direction at a desired speed from a first immobile position wherein at least one tire is adhered to a tarmac or other ground surface to a second fully mobile position wherein the tire has been released from adherence to the surface and the aircraft is capable of moving in the desired direction at the desired speed, said method further comprising the steps of:

a. turning the nose gear wheels in a selected direction to the right or to the left of the longitudinal center of the aircraft;

b. activating the drive wheel driver to rotate the driven wheel in a reverse direction or in a forward direction to apply differential force to a selected set of wheels to release a tire or tires attached to the selected set of wheels from adherent contact with the tarmac or ground surface;

c. turning the nose gear wheels in the same or in a different selected direction and activating the drive wheel driver to rotate the driven wheel in a forward or reverse direction to apply differential force to a second selected set of aircraft wheels to release adherent tires on the second set of aircraft wheels; and

d. repeating step c as required to release adherent tires on each set of aircraft wheels until all tires attached to the wheels are no longer stuck to the tarmac or other ground surface and the aircraft is moving in the desired direction at the desired speed.

11. The method described in claim 10, wherein each set of main wheels includes brakes, further comprising the step of applying the brakes to a selected main wheel not intended to be released so that full turning power is applied to an unselected main wheel set to release adherent tires on the unselected main wheel set.

12. The method described in claim 10, further comprising the steps of using the aircraft steering to turn the nose gear wheels in the selected direction while applying a differential force to each one of said two sets of main wheels.

13. The method described in claim 12, wherein said applied differential force causes one set of main wheels to rotate in a forward direction and the other set of main wheels to rotate in a reverse direction.

14. The method described in claim 10, wherein at least one of said tires is misshapen as a result of adverse environmental conditions, and the differential force applied to move the aircraft includes the force required to lift the aircraft over the misshapen tire.

15. The method described in claim 10, wherein the aircraft is equipped with an onboard powered wheel driver selected from the group comprising high phase order electric motors, electric induction motors, permanent magnet brushless DC motors, switched reluctance motors, hydraulic motors, and pneumatic motors.

16. The method described in claim 10, wherein said nose gear wheels are steered and direction of travel is controlled by an aircraft pilot using the aircraft steering system.

17. The method described in claim 10, wherein said aircraft is equipped with a pair of onboard powered wheel drivers, each mounted to drive a pair of nose wheels, and said aircraft is steered and direction of travel is controlled by selectively activating each one of said wheel drivers to vary the rotation or direction of rotation of each wheel to apply differential thrust between the wheels.

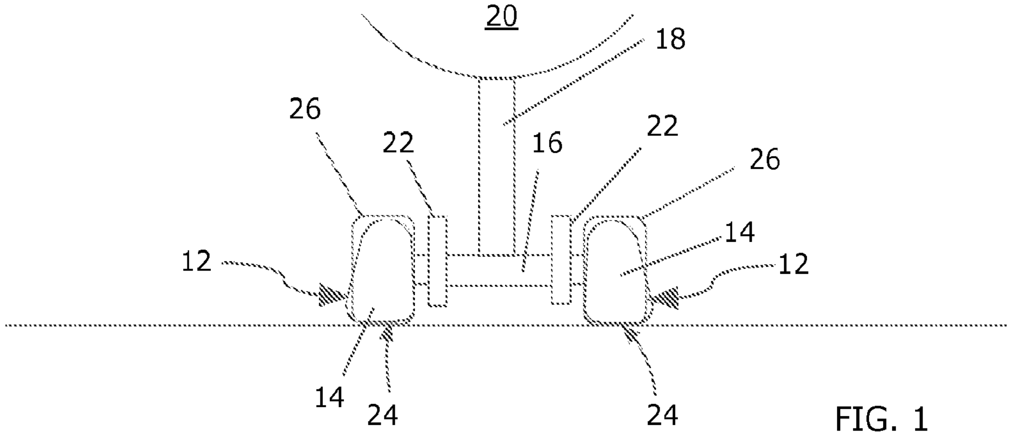

FIG. 1

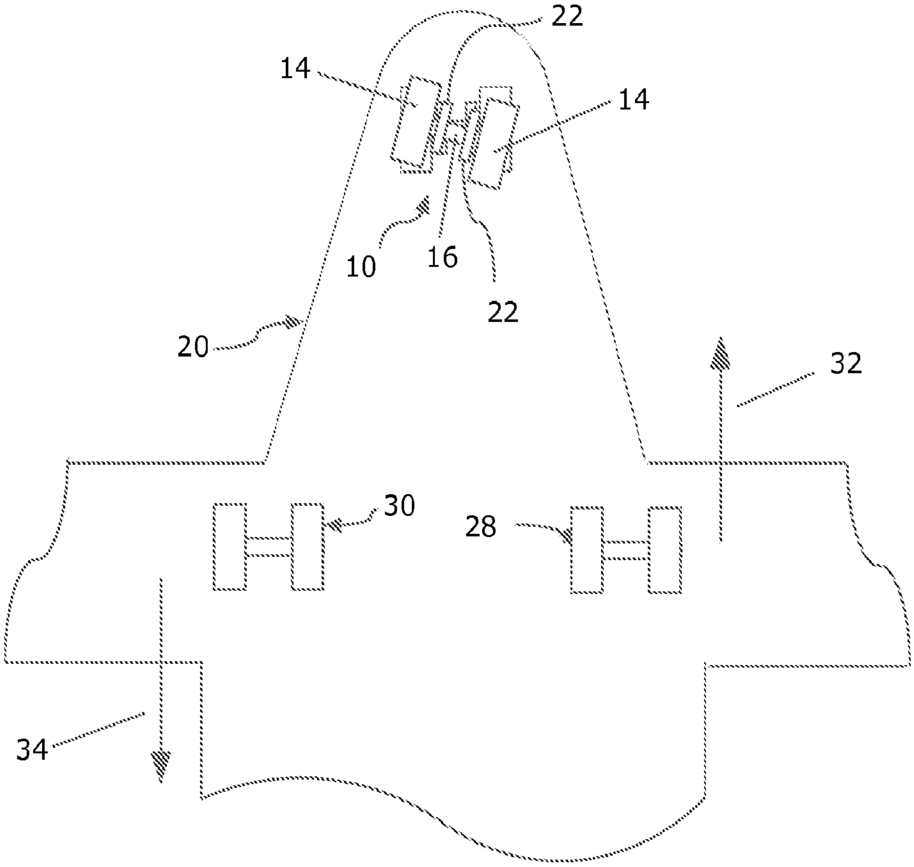

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 12/23840

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B64C 25/34 (2012.01)
USPC - 244/103R
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B64C 25/34 (2012.01)
USPC - 244/103R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 244/50, 100R, 103S (text search - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(USPT,PGPB,EPAB,JPAB); Google Scholar; Google Patents
Search Terms: airplane, aircraft, power, drive, wheel, tire, adhered, stuck, frozen, differential, power, force, brake, pivot, turn, steer, high, phase, electric, permanent, magnet, brushless, switched, reluctance, motor, immobile, ground, tarmac, snow, overcome, restore,... etc.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/0218440 A1 (Dilmaghani et al.) 03 September 2009 (03.09.2009), fig 1, para [0017], [0019]-[0020] and [0022]-[0023]	1-17
Y	US 2007/0282491 A1 (Cox et al.) 06 December 2007 (06.12.2007), para [0043]-[0044] and [0064]	1-17
A	US 2006/0065779 A1 (McCoskey et al.) 30 March 2006 (30.03.2006), fig 2, para [0040] and [0043]	1-17
A	US 2009/0261197 A1 (Cox et al.) 22 October 2009 (22.10.2009), para [0050] and [0075]	1-17

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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Date of the actual completion of the international search	Date of mailing of the international search report
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Facsimile No. 571-273-3201

Authorized officer:
Lee W. Young
PCT Helpdesk: 571-272-4300
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