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(54) **METHODS AND APPARATUSES FOR LAUNCHING UNMANNED AIRCRAFT, INCLUDING RELEASABLY GRIPPING AIRCRAFT DURING LAUNCH AND BREAKING SUBSEQUENT GRIP MOTION**

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(51) **Int. Cl.**
B64F 1/06 (2006.01)

(52) **U.S. Cl.** .... **244/63**; 244/114 R

(58) **Field of Classification Search** .... 244/63, 244/114 R; 446/63, 64; 89/1.8–1.82
See application file for complete search history.

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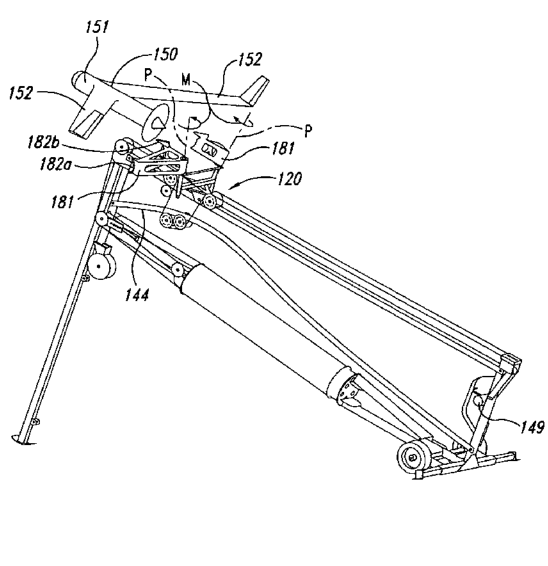
(57) **ABSTRACT**

Methods and apparatuses for launching unmanned aircraft and other flight devices or projectiles are described. In one embodiment, the aircraft can be launched from an apparatus that includes a launch carriage that moves along a launch guide. The carriage can accelerate when portions of the carriage and/or the launch guide move relative to each other. A gripper carried by the launch carriage can have at least one grip portion in contact with the aircraft while the launch carriage accelerates along the launch axis. The at least one grip portion can move out of contact with the aircraft as the launch carriage decelerates, releasing the aircraft for takeoff. A brake can arrest the motion of the gripper after launch.

12 Claims, 9 Drawing Sheets



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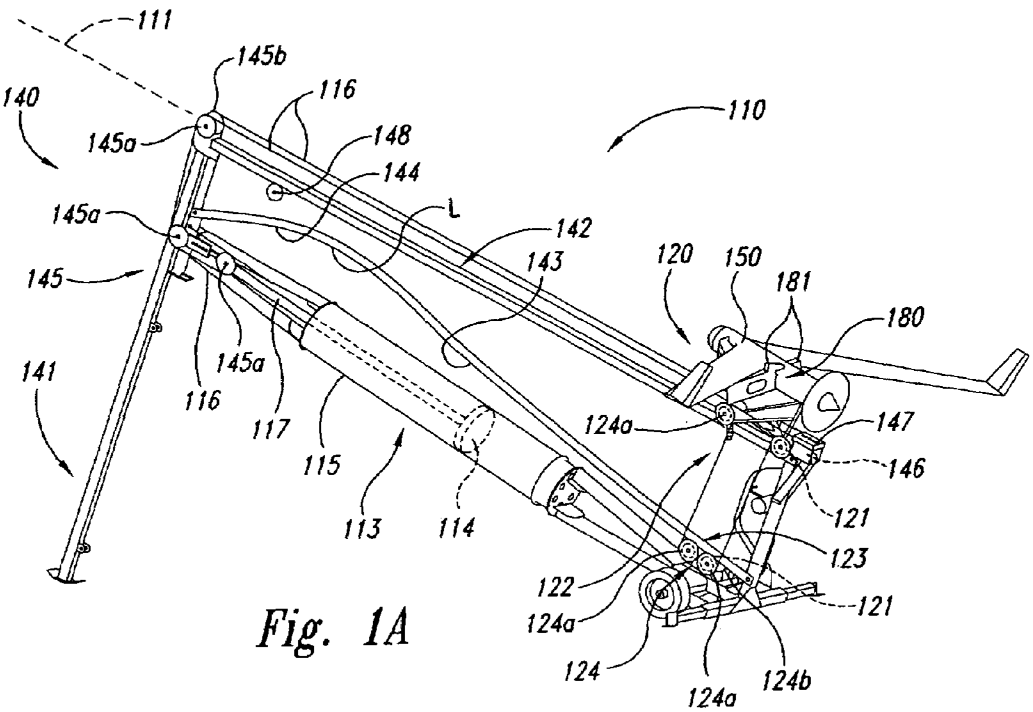
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145b
140
116
148
144
110
145a
145a
L
142
145
143
120
150
181
180
141
145a
116
117
115
124a
147
146
113
114
121
123
122
121
124a
124
124a
124b

Fig. 1A

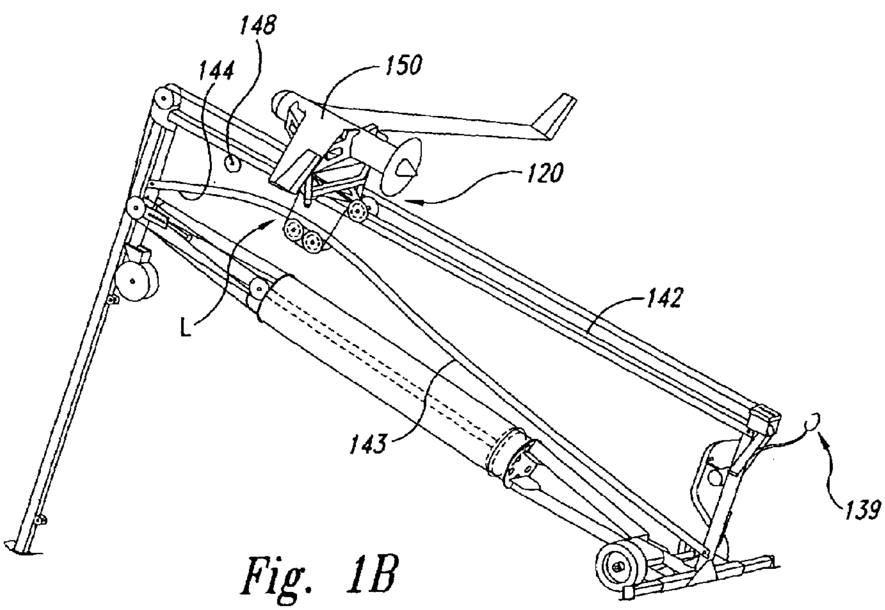
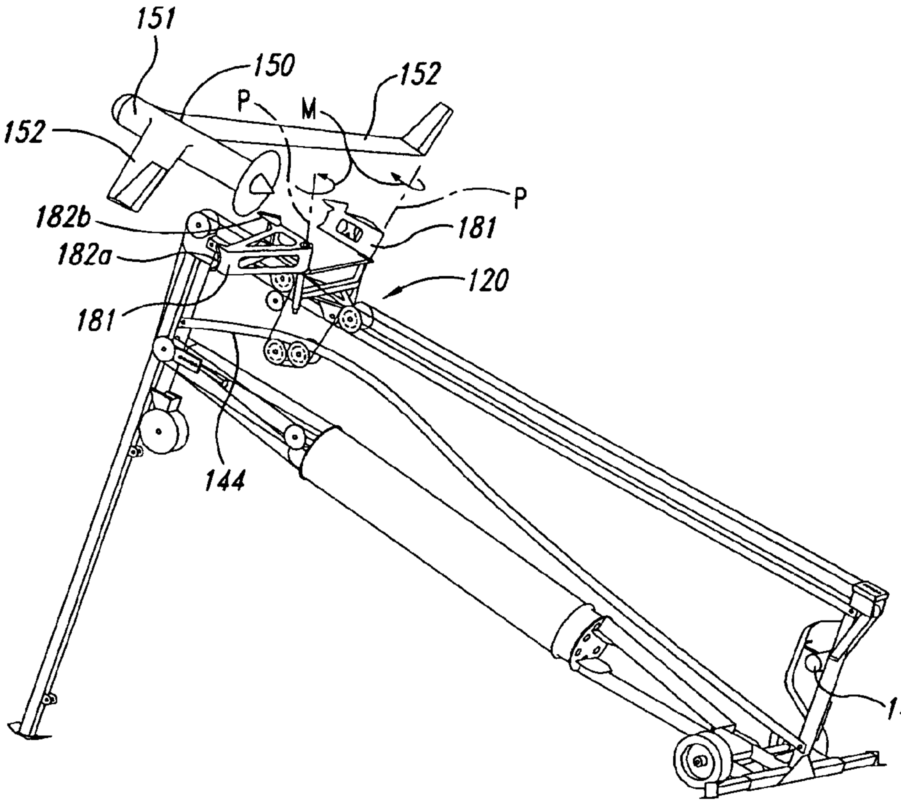

148
150
144
120
L
142
143
139

Fig. 1B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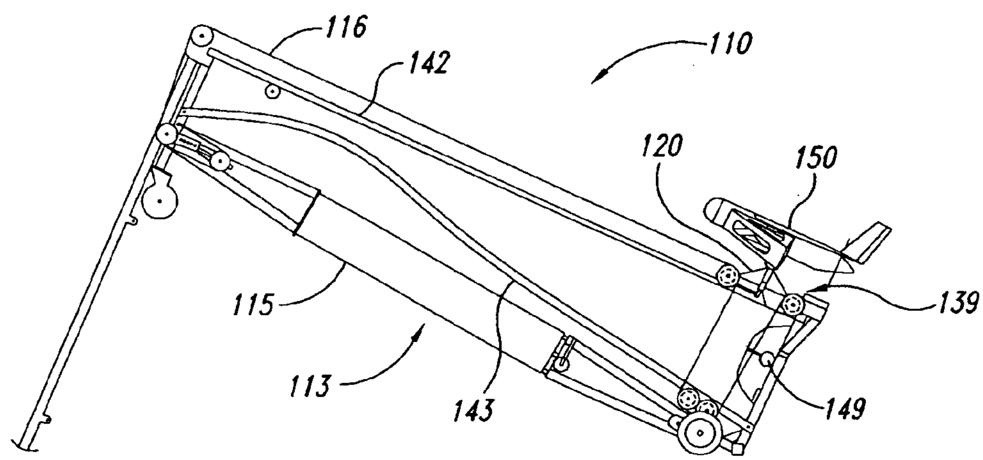
150
152
P
M
152
P
182b
181
182a
120
181
144
149

Fig. 1C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110
142
120
150
139
115
113
143
149

Fig. 2

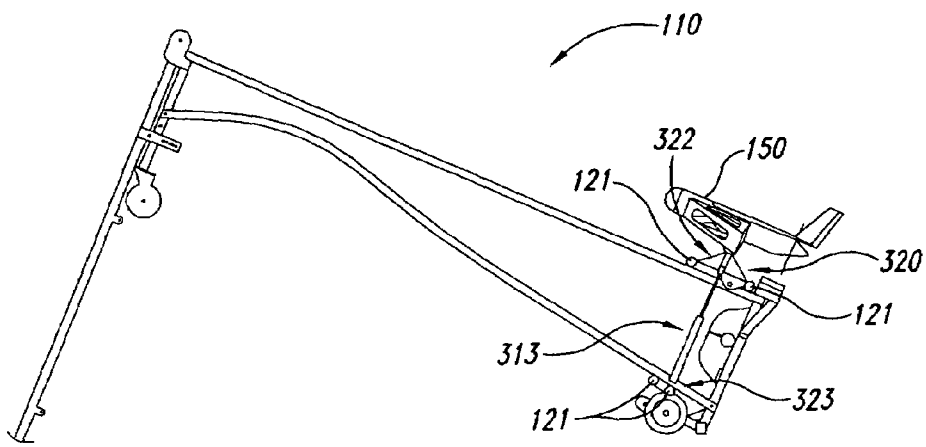


Fig. 3

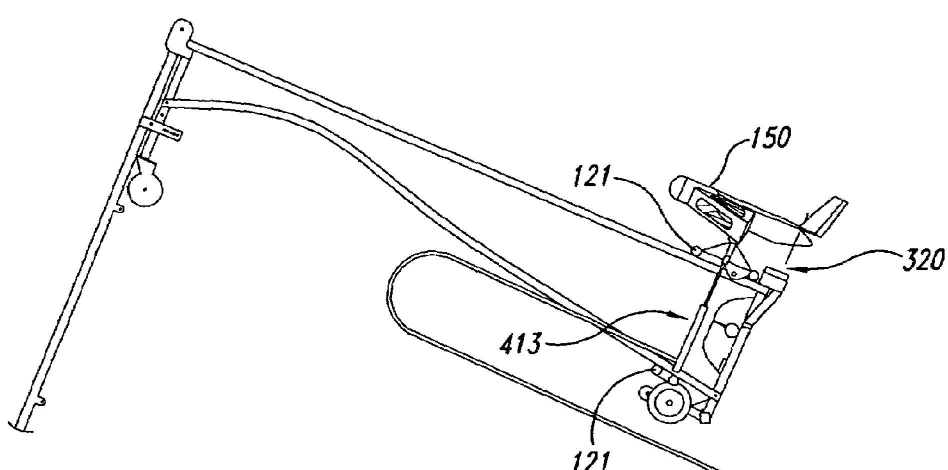


Fig. 4

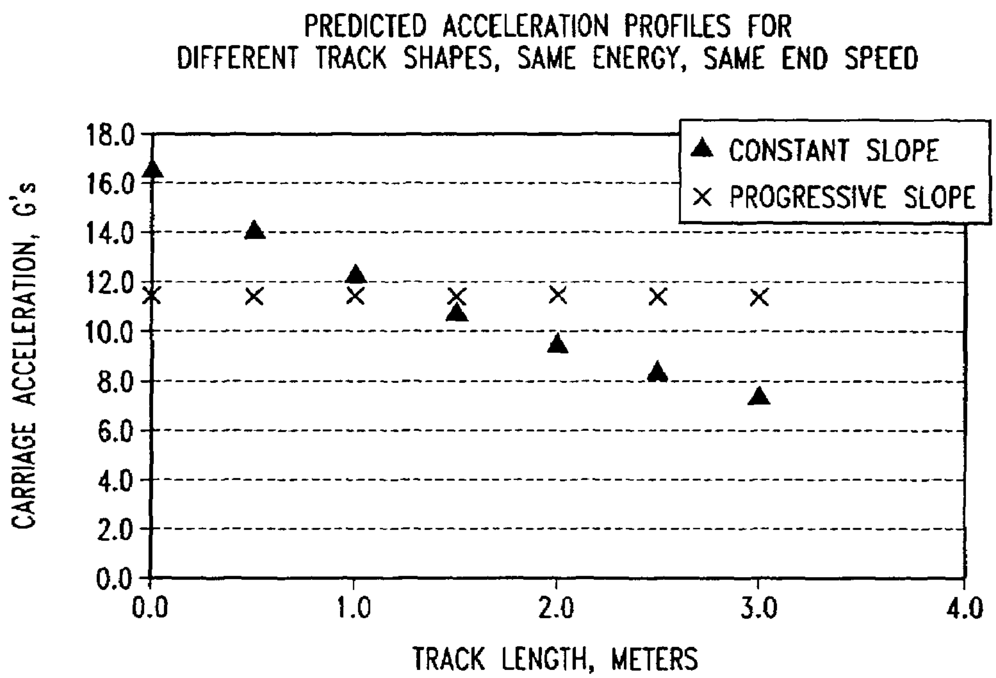

PREDICTED ACCELERATION PROFILES FOR
DIFFERENT TRACK SHAPES, SAME ENERGY, SAME END SPEED
CARRIAGE ACCELERATION, G's
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
1.0
2.0
3.0
4.0
TRACK LENGTH, METERS
CONSTANT SLOPE
PROGRESSIVE SLOPE

Fig. 5

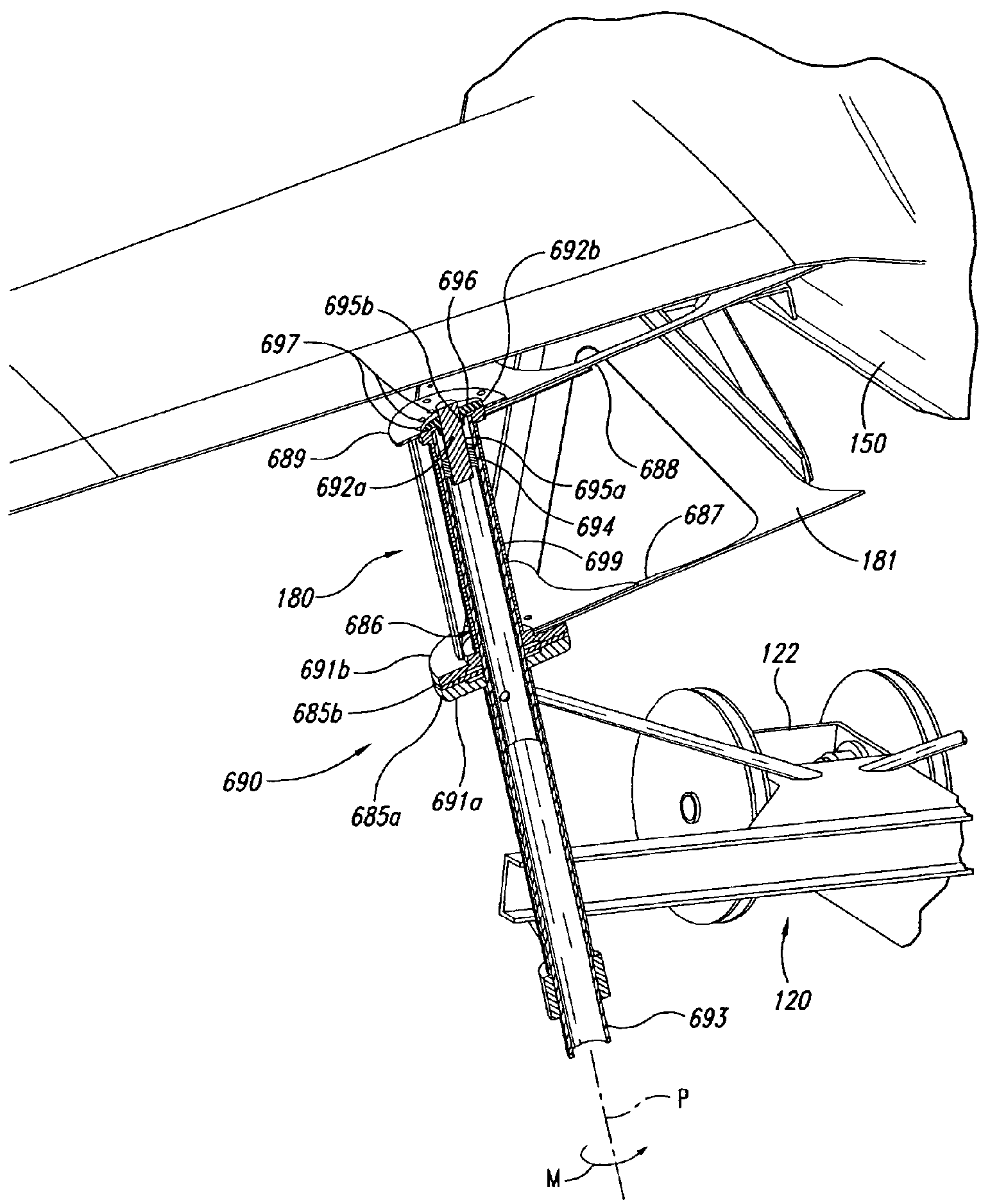

692b
696
695b
697
689
692a
688
695a
694
687
699
181
150
180
686
691b
685b
690
685a
691a
122
120
693
P
M

Fig. 6

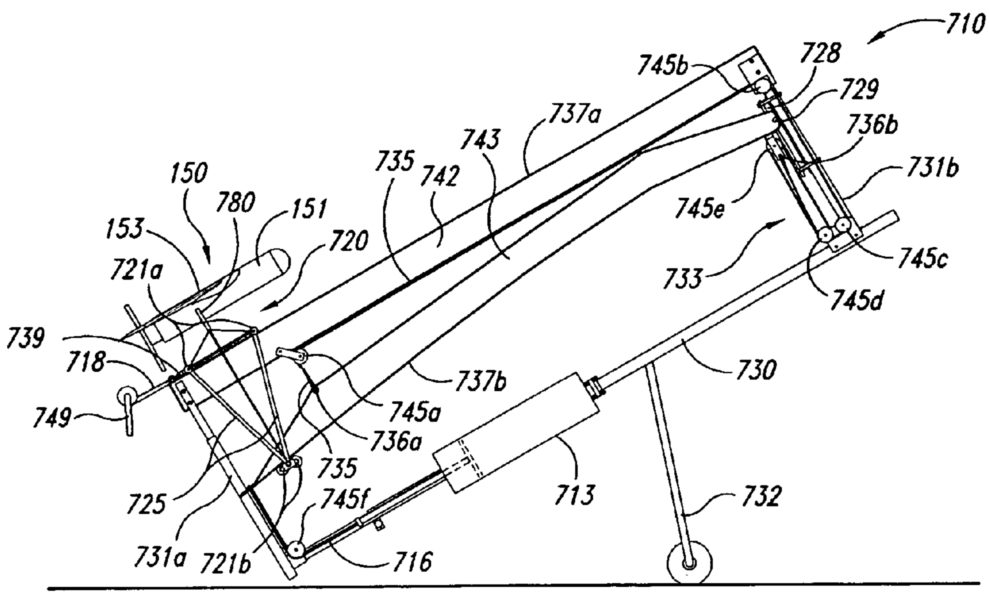

710
745b
728
729
737a
736b
743
731b
735
742
150
780
151
745e
153
720
721a
733
745c
745d
739
718
730
737b
749
745a
736a
735
725
713
745f
732
731a
721b
716

Fig. 7A

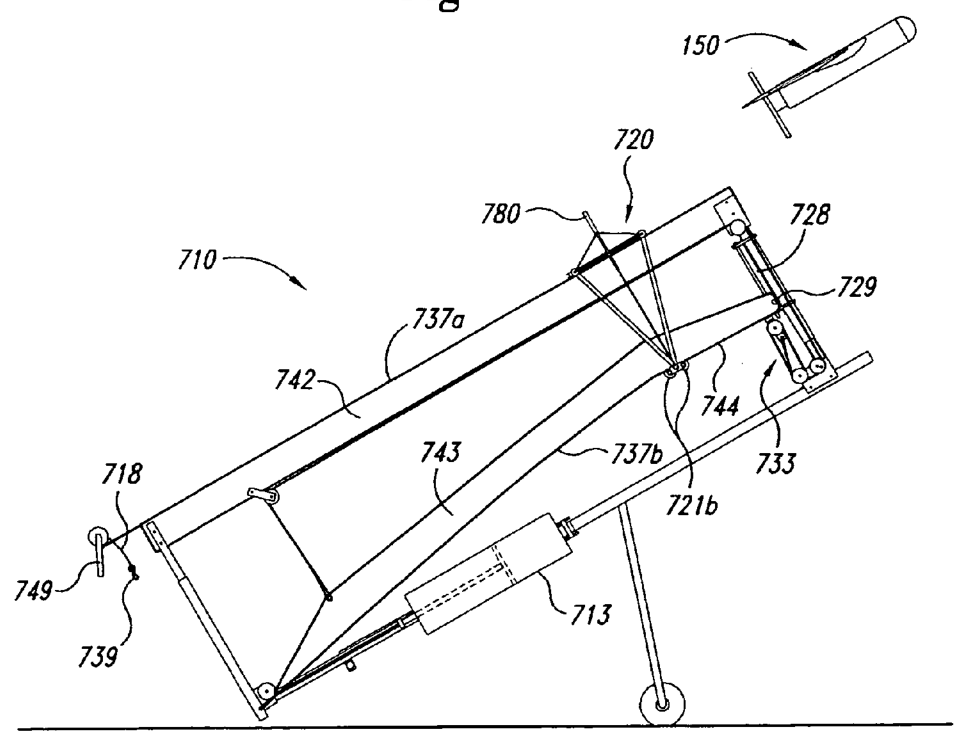

150
720
780
728
710
729
737a
742
744
743
737b
733
718
721b
713
749
739

Fig. 7B

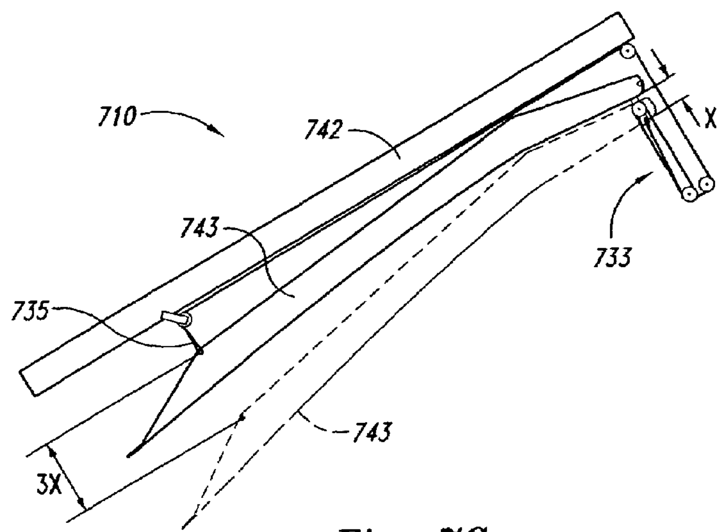

710
742
743
735
733
X
3X
743

Fig. 7C

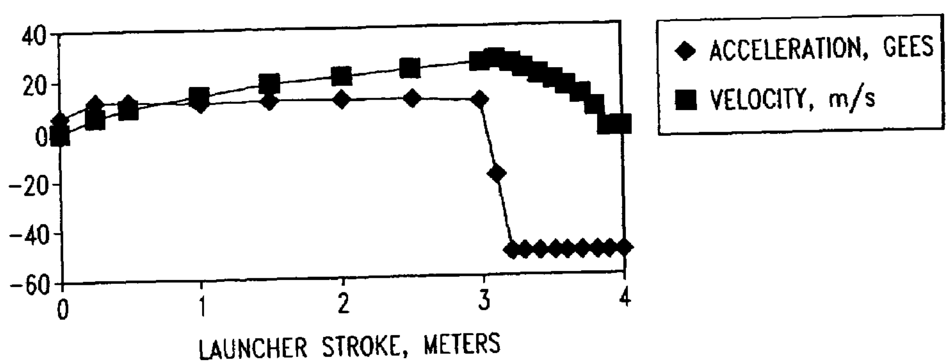
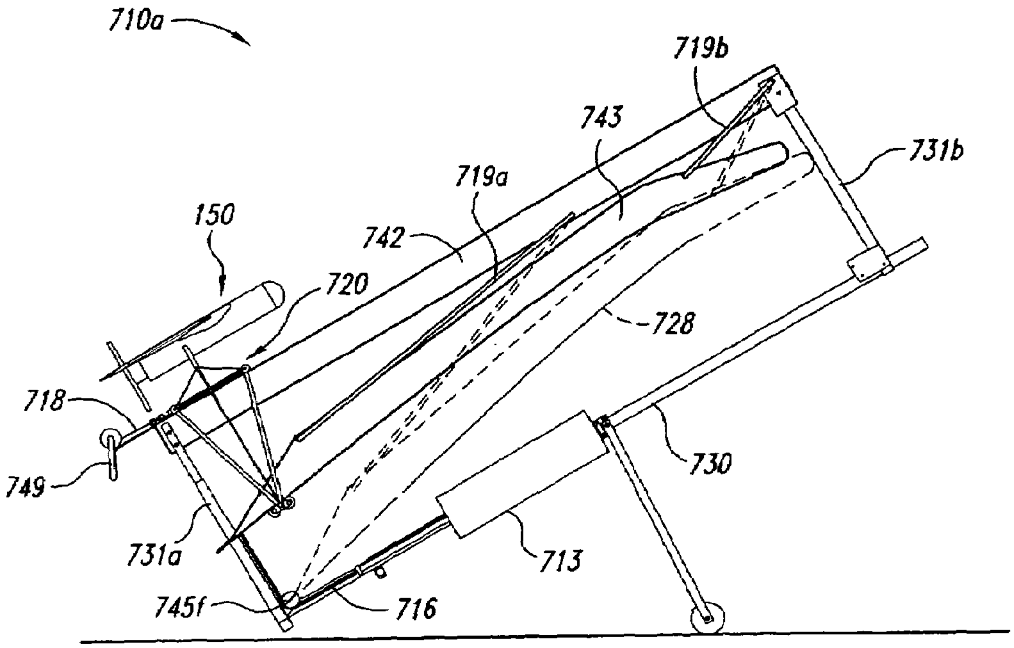

40
20
0
-20
-40
-60
0
1
2
3
4
LAUNCHER STROKE, METERS
ACCELERATION, GEES
VELOCITY, m/s

Fig. 7D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719b
743
731b
719a
742
150
720
728
718
749
730
731a
713
745f
716

Fig. 7E

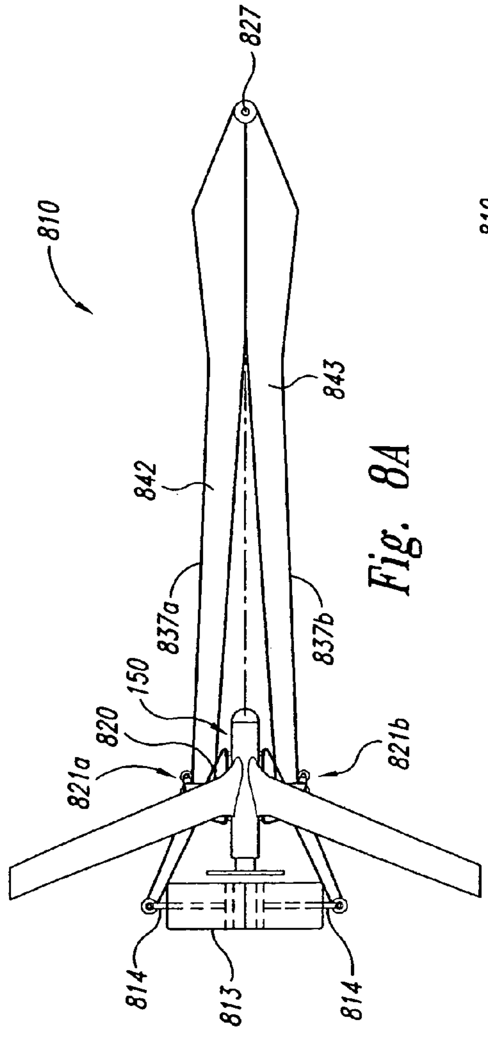
827
810
843
842
837a
837b
150
820
821a
821b
814
813
814

Fig. 8A

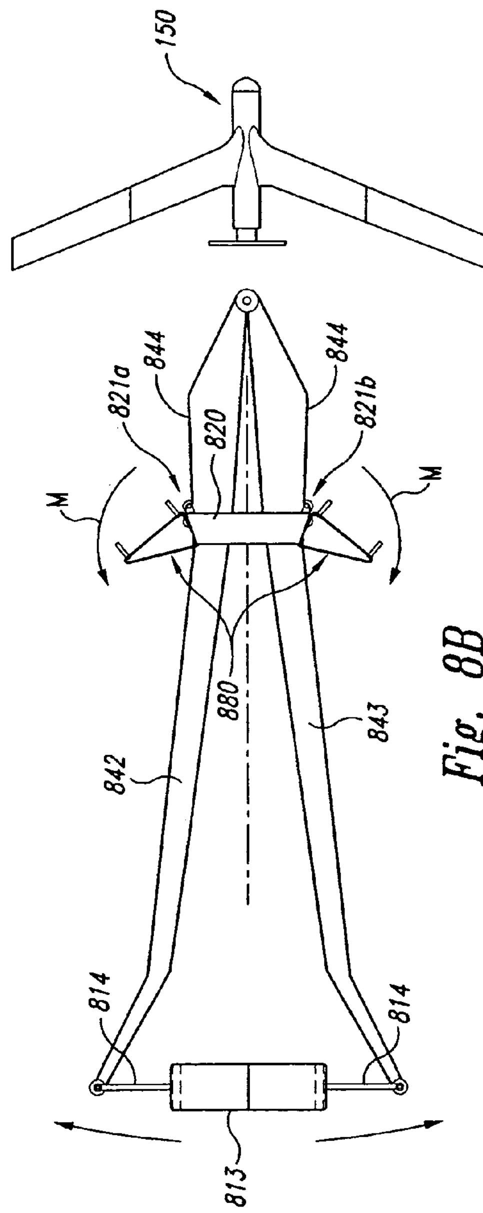
150
810
844
844
821a
820
821b
M
M
880
842
843
814
814
813

Fig. 8B

METHODS AND APPARATUSES FOR LAUNCHING UNMANNED AIRCRAFT, INCLUDING RELEASABLY GRIPPING AIRCRAFT DURING LAUNCH AND BREAKING SUBSEQUENT GRIP MOTION

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a divisional of U.S. patent application Ser. No. 10/808,725, filed Mar. 24, 2004 now U.S. Pat. No. 7,165,745, which claims priority to U.S. Provisional Application No. 60/554,824, filed Mar. 19, 2004, and is a continuation-in-part of U.S. patent application Ser. No. 10/758,955, filed Jan. 16, 2004 now U.S. Pat. No. 7,140,575, which claims priority to U.S. Provisional Patent Application No. 60/440,727 filed Jan. 17, 2003. The disclosures of these applications are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present disclosure describes methods and apparatuses for launching unmanned aircraft, including methods and apparatuses for releasably gripping aircraft during launch and braking subsequent grip motion.

BACKGROUND

Unmanned aircraft or air vehicles (UAVs) provide enhanced and economical access to areas where manned flight operations are unacceptably costly and/or dangerous. For example, unmanned aircraft outfitted with remotely controlled cameras can perform a wide variety of surveillance missions, including spotting schools of fish for the fisheries industry, monitoring weather conditions, providing border patrols for national governments, and providing military surveillance before, during and/or after military operations.

Existing unmanned aircraft systems suffer from a variety of drawbacks. For example, existing unmanned aircraft systems (which can include the aircraft itself along with launch devices, recovery devices, and storage devices) typically require substantial space. Accordingly, these systems can be difficult to install and operate in cramped quarters, such as the deck of a small fishing boat, land vehicle, or other craft. Another drawback with some existing unmanned aircraft is that, due to small size and low weight, they can be subjected to higher acceleration and deceleration forces than are larger, manned air vehicles, and can accordingly be prone to damage. Still another drawback with existing launch devices is that they may not absorb the energy associated with a launch in a manner that effectively prevents or limits loads placed on the launch device and/or the aircraft, exposing the launch device and the aircraft to damage.

SUMMARY

The present invention is directed generally toward methods and apparatuses for launching unmanned aircraft. An apparatus in accordance with one aspect of the invention includes a support, a launch carriage movably carried by the support, and a gripper movably coupled to the launch carriage. The gripper can include at least one grip portion positioned to releasably engage an unmanned aircraft. The gripper can be movable relative to the launch carriage

between a first position with the at least one grip portion positioned to contact the aircraft, and a second position with the at least one grip portion positioned to be out of contact with the aircraft. A brake can be positioned at least proximate to the gripper and can be changeable from a first configuration in which the brake inhibits motion of the gripper by a first amount, and a second configuration in which the brake does not inhibit motion of the gripper, or inhibits motion of the gripper by a second amount less than the first amount. Accordingly, the brake can control the motion of the gripper after the aircraft has been released.

An apparatus in accordance with another aspect of the invention includes a first launch member, a second launch member positioned at least proximate to the first launch member, and a launch carriage having support positioned to releasably carry an unmanned aircraft during a takeoff operation. The launch carriage can include a first portion in contact with the first launch member and a second portion in contact with the second launch member. The launch carriage can be movable relative to the launch members between a first launch carriage location and a second launch carriage location as at least one of the first and second launch members moves relative to the other, or at least one of the carriage portions moves relative to the other, or both.

A method in accordance with a further aspect of the invention includes releasably supporting an unmanned aircraft with a launch carriage, releasably engaging the aircraft with a gripper carried by the launch carriage and accelerating the launch carriage along a launch axis. The method can further include disengaging the gripper from the aircraft by moving the gripper relative to the launch carriage from a first position to a second position, releasing the aircraft from the launch carriage for flight, and at least restricting motion of the gripper relative to the launch carriage after disengaging the gripper.

A method in accordance with another aspect of the invention includes releasably supporting an unmanned aircraft with a launch carriage that is movably carried by and in contact with a first launch member and a second launch member. The launch carriage can be accelerated from a first launch carriage location to a second launch carriage location by moving at least one of the first and second launch members relative to the other while the launch members contact the launch carriage, or by moving at least one portion of the launch carriage relative to the other while the launch members contact the launch carriage, or both. The method can further include releasing the unmanned aircraft from the launch carriage for flight.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**C illustrate an arrangement for launching an unmanned aircraft in accordance with an embodiment of the invention.

FIG. **2** illustrates an embodiment of the arrangement shown in FIGS. **1**A-**1**C after having been reset for a subsequent launch.

FIGS. **3** and **4** illustrate systems for launching an aircraft with a carriage that carries both the aircraft and an actuator.

FIG. **5** illustrates a predicted carriage acceleration associated with an embodiment of the invention.

FIG. **6** is a partially cut-away illustration of a gripper and gripper brake for releasably supporting an aircraft during launch.

FIGS. **7**A-**7**E are partially schematic illustrations of an apparatus having at least one movable launch member for launching an unmanned aircraft in accordance with another embodiment of the invention.

FIGS. **8**A-**8**B are partially schematic illustrations of an apparatus having a movable launch member for launching an unmanned aircraft in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

The following disclosure describes systems and methods for launching aircraft, for example, unmanned aerial vehicles (UAVs). Certain specific details are set forth in the following description and in FIGS. **1**A-**8**B to provide a thorough understanding of various embodiments of the invention. Well-known structures, systems and methods often associated with aircraft launch systems have not been shown or described in detail below to avoid unnecessarily obscuring the description of the various embodiments of the invention. In addition, those of ordinary skill in the relevant art will understand that additional embodiments of the present invention may be practiced without several of the details described below.

FIG. **1**A illustrates a launch system **110** having a launch guide **140** and a carriage **120** that together accelerate and guide an aircraft **150** along an initial flight path **111** at the outset of a flight. The launch guide **140** can include a support structure **141** carrying a first or upper launch member **142** (e.g., a track) and a second or lower launch member **143**, both of which are generally aligned with the initial flight path **111**. The support structure **141** can be mounted to a vehicle (e.g., a trailer or a boat) or to a fixed platform (e.g., a building). Portions of the first launch member **142** and the second launch member **143** can be non-parallel to each other (e.g., they can converge in a direction aligned with the initial flight path **111**) to accelerate the carriage **120**, as described below.

The carriage **120** can include a gripper **180** having a pair of gripper arms **181** that releasably carry the aircraft **150**. The carriage **120** can also include a first or upper portion **122** and a second or lower portion **123**, each of which has rollers **121** (shown in hidden lines in FIG. **1**A). The rollers **121** can guide the carriage **120** along the launch members **142**, **143** while the carriage portions **122**, **123** are driven toward each other. Accordingly, normal forces applied to the rollers **121** can drive the rollers **121** against the launch members **142**, **143**, drive the carriage portions **122**, **123** together, and drive the carriage **120** forward, thereby accelerating the aircraft **150** to flight speed.

An actuator **113** can be linked to the carriage **120** to provide the squeezing force that drives the carriage portions **122**, **123** toward each other and drives the carriage **120** along the launch guide **140**. Many actuators **113** that are configured to release energy fast enough to launch the aircraft **150** also have a spring-like behavior. Accordingly, the actuators **113** tend to exert large forces at the beginning of a power stroke and smaller forces as the power stroke progresses and the carriage **120** moves along the launch guide **140**. An embodiment of the system **110** shown in FIG. **1**A can compensate for this spring-like behavior by having a relative angle between the first launch member **142** and the second launch member **143** that becomes progressively steeper in the launch direction. In one example, the force provided by the actuator **113** can decrease from 6000 lbs to 3000 lbs as the carriage **120** accelerates. Over the same distance, the relative slope between the first launch member **142** and the second launch member **143** can change from 6:1 to 3:1. Accordingly, the resulting thrust imparted to the carriage **120** and the aircraft **150** can remain at least approximately constant.

At or near a launch point L, the carriage **120** reaches the launch speed of the aircraft **150**. The first launch member **142** and the second launch member **143** can diverge (instead of converge) forward of the launch point L to form a braking ramp **144**. At the braking ramp **144**, the carriage **120** rapidly decelerates to release the aircraft **150**. The carriage **120** then stops and returns to a rest position at least proximate to or coincident with the launch position L.

In one embodiment, the actuator **113** includes a piston **114** that moves within a cylinder **115**. The piston **114** is attached to a flexible, elongated transmission element **116** (e.g., a rope or cable) via a piston rod **117**. The transmission element **116** can pass through a series of guide pulleys **145** (carried by the launch guide **140**) and carriage pulleys **124** (carried by the carriage **120**). The guide pulleys **145** can include first guide pulleys **145***a* on a first side of the support structure **141**, and corresponding second guide pulleys **145***b* on a second (opposite) side of the support structure **141**. The carriage pulleys **124** can also include first carriage pulleys **124***a* on a first side of the carriage **120** and second pulleys **124***b* on a second (opposite) side of the carriage **120**. One or more equalizing pulleys **146**, located in a housing **147** can be positioned between (a) the first guide pulleys **145***a* and the first carriage pulleys **124***a* on the first side of the support structure **141**, and (b) the second guide pulleys **145***b* and the second carriage pulleys **124***b* on the second side of the support structure **141**.

In operation, one end of the transmission element **116** can be attached to the first side of the support structure **141**, laced through the first pulleys **145***a*, **124***a*, around the equalizing pulley(s) **146**, and then through the second pulleys **145***b*, **124***b*. The opposite end of the transmission element **116** can be attached to the second side of the support structure **141**. The equalizing pulley(s) **146** can (a) guide the transmission element **116** from the first side of the support structure **141** to the second side of the support structure **141**, and (b) equalize the tension in the transmission element **116** on the first side of the support structure **141** with that on the second side of the support structure **141**.

When the transmission element **116** is tensioned, it squeezes the carriage portions **122**, **123** together, forcing the carriage **120** along the converging launch members **142**, **143**. The carriage pulleys **124** and the rollers **121** (which can be coaxial with the carriage pulleys **124**) are secured to the carriage **120** so that the carriage **120** rides freely along the initial flight path **111** of the aircraft **150** as the carriage portions **122**, **123** move together.

FIG. **1**B illustrates the launch of the carriage **120** in accordance with an embodiment of the invention. The carriage **120** is held in place prior to launch by a trigger device **139**, e.g., a restraining shackle. When the trigger device **139** is released, the carriage **120** accelerates along the launch members **142**, **143**, moving from a first launch carriage location to a second launch carriage location (e.g., to the launch point L). At the launch point L, the carriage **120** achieves its maximum velocity and begins to decelerate by rolling along the braking ramp **144**. In this embodiment, one or more arresting pulleys **148** can be positioned along the braking ramp **144** to intercept the transmission element **116** and further decelerate the carriage **120**.

As shown in FIG. **1**C, once the carriage **120** begins to decelerate along the braking ramp **144**, the aircraft **150** is released by the gripper arms **181**. Each gripper arm **181** can include a forward contact portion **182***a* and an aft contact portion **182***b* configured to releasably engage a fuselage **151** of the aircraft **150**. Accordingly, each contact portion **182** can have a curved shape so as to conform to the curved shape of the fuselage **151**. In other embodiments, the gripper arms **181** can engage different portions of the aircraft **150** (e.g., the wings **152**). Each gripper arm **181** can be pivotably coupled to the carriage **120** to rotate about a pivot axis P. The gripper arms **181** can pivot about the pivot axes P to slightly over-center positions when engaged with the aircraft **150**. Accordingly, the gripper arms **181** can securely grip the fuselage **151** and resist ambient windloads, gravity, propeller thrust (e.g., the maximum thrust provided to the aircraft **150**), and other external transitory loads as the carriage **120** accelerates. In one aspect of this embodiment, each pivot axis P is canted outwardly away from the vertical. As described in greater detail below, this arrangement can prevent interference between the gripper arms **181** and the aircraft **150** as the aircraft **150** is launched.

At least a portion of the mass of the gripper arms **181** can be eccentric relative to the first axis P. As a result, when the carriage **120** decelerates, the forward momentum of the gripper arms **181** causes them to fling open by pivoting about the pivot axis P, as indicated by arrows M. The forward momentum of the gripper arms **181** can accordingly overcome the over-center action described above. As the gripper arms **181** begin to open, the contact portions **182***a*, **182***b* begin to disengage from the aircraft **150**. In a particular aspect of this embodiment, the gripper arms **181** pivot downwardly and away from the aircraft **150**.

An advantage of a gripper arrangement described above with reference to FIG. **1**C is that the gripping action provided by the gripper arms **181** can be distributed fore and aft over the fuselage **151**, thus distributing the gripping load. A further advantage of embodiments of the foregoing arrangement is that the gripper arms **181** can be configured to quickly and completely rotate out of the way of the aircraft **150** as the aircraft **150** takes flight. Still a further advantage of the foregoing arrangement is that no additional hardware (with associated weight and drag), need be provided to the aircraft **150** to allow it to be releasably carried by the carriage **120**. In still further embodiments, the motion of the gripper arms **181** after the aircraft **150** has been released can be controlled, as described in greater detail below with reference to FIG. **6**.

After the aircraft **150** is launched, a pull-back winch **149** can be used to cock the launch system **110** (e.g., return the carriage **120** to its launch position) in preparation for the next launch. FIG. **2** illustrates the system **110** in the cocked position. A rope or strap extends from the pull-back winch **149** to the trigger device **139** which engages with the carriage **120**. The actuator **113** can then be energized (e.g., by pressurizing the cylinder **115**), prior to the next launch.

FIG. **3** illustrates a launch system **110** configured in accordance with another embodiment of the invention. In one aspect of this embodiment, the system **110** includes a carriage **320** having carriage portions **322**, **323** coupled to each other with an actuator **313** that is carried by the carriage **320**. As the actuator **313** contracts, it draws the two carriage portions **322**, **323** toward each other which, because the launch members **142**, **143** converge, causes the carriage **320** to roll forward on the rollers **121**.

In one aspect of this embodiment, the actuator **313** includes a spring that links the carriage portions **322**, **323**. The mass of the carriage **320** accordingly includes that of the actuator **313**, and the energy requirements are correspondingly larger than that of the carriage **120** described above with reference to FIGS. **1**C. On the other hand, the carriage **320** shown in FIG. **3** requires no transmission element **116** or pulleys **145**, **124** (FIG. **1**A).

In yet another embodiment, (shown in FIG. **4**) the carriage **320** carries an actuator **413**, but at least a portion of the energy required by the actuator **413** is provided to the actuator **413** from a ground-based link **418** (e.g., a hose or wire). Accordingly, in one aspect of this embodiment, the actuator **413** can include a pneumatic or hydraulic actuator. In other embodiments, the actuator **413** can include an electric linear actuator or a lead screw actuator.

Embodiments of the present invention can include a relatively small spring (or other actuator) and no rotating cam system to achieve a constant force launch acceleration. Embodiments of the present invention can also employ a movable carriage (or shuttle), and an actuator that strokes through only a fraction of the carriage stroke. The "gain" or amplification of this motion amplifier can correspond to the slope of one launch member relative to one or more opposing launch members. For example, in one embodiment, the piston **114** described above with reference to FIG. **1**A can stroke through a distance of two feet, while accelerating the carriage **120** with a constant force over a distance of ten feet.

FIG. **5** illustrates a graph of predicted carriage acceleration as a function of launch member length for an existing system having a single track and a spring or spring-like actuator, along with a system having two non-parallel launch members (e.g., as shown in FIG. **1**A), also with a spring-like actuator. As shown in FIG. **5**, by tailoring the relative angle between the non-parallel launch members to compensate for the reduced force provided by the actuator over the length of the launch guide, the force applied to the carriage (and therefore the acceleration of the carriage) can be maintained at a constant or nearly constant level until the carriage is deliberately decelerated to launch the aircraft. An advantage of this arrangement is that it can significantly reduce the peak force applied to the aircraft without significantly increasing the energy required by the launch mechanism, or the distance required to accelerate the aircraft to launch velocity.

FIG. **6** is a partially cut-away illustration of an embodiment of the carriage **120** as the gripper **180** supports the aircraft **150** prior to release. For purposes of illustration, only one of the gripper arms **181** is shown in FIG. **6**. The carriage upper portion **122** can include a pivot post **693** extending along the pivot axis P. The gripper arm **181** can include an upper portion **688** and a lower portion **687**. A gripper sleeve **699** can be attached to the upper portion **688** and disposed coaxially about the pivot post **693**. One or more bearings **686** can support the gripper sleeve **699** relative to the pivot post **693**. Accordingly, the gripper arm **181** can rotate smoothly about the pivot axis P as indicated by arrow M.

As discussed above, the gripper arm **181** can pivot both downwardly and outwardly away from the aircraft **150** during release so as to reduce the likelihood that the gripper arm **181** will strike the aircraft **150** as the aircraft **150** takes off. To further reduce the likelihood that the gripper arm **181** will strike either the aircraft **150** or the opposing gripper arm, the system **110** can include a gripper brake **690** that arrests the rotational motion of the gripper arm **181** once the aircraft **150** has been released.

The gripper brake **690** can include a first brake member **691***a* that is fixed relative to the pivot post **693**, and a second brake member **691***b* that is fixed to the gripper sleeve **698** to rotate with the gripper arm **181**. The second brake member **691***b* can also move axially toward the first brake member **691***a* along the pivot axis P during braking. The first brake member **691***a* can include a first brake surface **685***a*, and the second brake member **691***b* can include a second brake surface **685***b*. As the second brake member **691***b* moves toward and rotates relative to the first brake member **691***a*, the brake surfaces **685***a*, **685***b* contact each other and halt the rotation of the gripper arm **181**. Accordingly, the brake **690** can be changeable between a first configuration in which it inhibits motion of the gripper **181** by a first amount (e.g., after launch) and a second configuration in which it does not inhibit motion of the gripper arm **181**, or inhibits motion of the gripper arm **181** by a second, lesser amount (e.g., prior to launch).

To control the motion of the second brake member **691***b* relative to the first brake member **691***a*, the gripper brake **690** can further include a first threaded member **692***a* that can be generally fixed relative to the pivot post **693** and can be supported with a first threaded member support **694**. The first threaded member **692***a* can include external threads **695***a* that engage internal threads **695***b* of a second threaded member **692***b*, carried by the gripper sleeve **699**. As the gripper arm **181** rotates about the pivot axis P, it rotates the second threaded member **692***b* relative to the first threaded member **692***a*. The first threaded member **692***a* and the second threaded member **692***b* can have left-hand threads, so that the second threaded member **692***b* moves axially downwardly as it rotates. This axial motion drives the second brake member **691***b* into engagement with the first brake member **691***a*. As the second threaded member **692***b* continues to rotate, it drives the second brake surface **685***b* against the first brake surface **685***a* with increasing pressure. This action stops the gripper arm **181** from rotating. A corresponding pair of threaded members on the opposite gripper arm can have right-hand threads to provide a generally similar brake action to that gripper arm.

In a particular embodiment, the position of the second brake member **691***b* relative to the first brake member **691***a* when the gripper arm **181** is in the gripping position (as shown in FIG. **6**) can be adjusted so that there is at least a slight gap (or, in one embodiment, no gap, but little or no pressure) between the second brake surface **685***b* and the first brake surface **685***a*. Accordingly, the gripper sleeve **699** can include an adjustment flange **689** having multiple adjustment holes **697**. The second threaded member **692***b* can include an alignment hole **696** that can be selectively aligned with any of the adjustment holes **697** as the second threaded member **692***b* is rotated independently of the gripper arm **181**. Accordingly, a user can rotate the second threaded member **692***b* about the first threaded member **692***a* until a small gap exists between the second brake surface **685***b* and the first brake surface **685***a*. The user can then lock the second threaded member **692***b* relative to the gripper arm **181** by inserting a pin or other fastener through the alignment hole **696** and into a corresponding adjustment hole **697** of the adjustment flange **689**. If, over the course of time, the first and second brake surfaces **685***a*, **685***b* move apart from reach other (e.g., as a result of wear), the initial gap between the brake surfaces **685***a*, **685***b* can be readjusted by simply repositioning the second threaded member **692***b* relative to the adjustment flange **689**.

The materials of at least some of the system components described above can be selected to reduce and/or eliminate interference caused by differential thermal expansion of one component relative to another. For example, the first threaded member support **694**, the pivot post **693**, and/or the first threaded member **692***a* can be formed from the same material as the gripper arm **181**. Accordingly, the position of the second brake member **691***b* relative to the first brake member **691***a* can be less likely to change as the ambient temperature changes. In other embodiments, the materials selected for these or other components can be selected to increase the life expectancy of the components. For example, the first threaded member **692***a* can be selected to include steel and the second threaded member **692***b* can be selected to include brass. In other embodiments, these components can have other material properties and/or arrangements. For example, the gripper brake **690** can brake the gripper arms **181** via an action different than the axial and rotational action described above.

A feature of an embodiment of the system described above with reference to FIG. **6** is that the gripper brake **690** can rapidly, predictably, and repeatably stop the motion of the gripper arm **181** as it pivots away from the aircraft **150** during release. An advantage of this arrangement is that the gripper arm **181** can be less likely to strike either the aircraft **150** or the opposing gripper arm (not shown in FIG. **6**).

In the embodiments of the launch system **110** described above, the portions of the carriage **120** move relative to each other while the launch members **142**, **143** remain fixed. In other embodiments, the launch members can move, in lieu of, or in addition to the movement of the carriage portions. FIGS. **7A**-**8B** illustrate launch systems having moving launch members in accordance with further embodiments of the invention. Beginning with FIG. **7A**, a launch system **710** in accordance with one embodiment of the invention can include a base **730** carrying two or more supports **731** (shown in FIG. **7A** as a first support **731***a* and a second support **731***b*). The base **730** can be configured to incline relative to the ground (for example, with a jack **732**) to orient the aircraft **150** for launch.

The launch system **710** can further include a first launch member **742** (e.g., a first track) and a second launch member **743** (e.g., a second track), both of which support a carriage **720**, which in turn carries the aircraft **150** via a releasable gripper **780**. At least one of the first launch member **742** and the second launch member **743** is movable relative to the other. For example, in one embodiment, the first launch member **742** can be fixed relative to the base **730**, and the second launch member **743** can be movable relative to the base **730**. In other embodiments, the first and second launch members **742**, **743** can have different arrangements. In any of these embodiments, the movement of at least one of the first and second launch members **742**, **743** can accelerate the carriage **720** to launch the aircraft **150**, as described in greater detail below.

In one embodiment, the second launch member **743** can translate and/or rotate relative to the first launch member **742**. In a particular aspect of this embodiment, the motion of the second launch member **743** relative to the first launch member **742** can be controlled by a pin **729**, which depends from the second launch member **743** and which is received in an elongated guide slot **728** of the second support **731***b*. The motion of the second launch member **743** can be further controlled by a block and tackle **733**. In one embodiment, the block and tackle **733** can include a coupling line **735** attached to the second launch member **743** at a first line attachment point **736***a*. The coupling line **735** passes through a series of pulleys **745***a*-**745***e* to a second attachment point **736***b*, also on the second launch member **743**. In other embodiments, the second launch member **743** can be supported relative to the first launch member **742** in other arrangements.

The carriage **720** can engage both the first launch member **742** and the second launch member **743**. For example, in one embodiment, the first launch member **742** can include a first roller surface **737***a* (which engages first rollers or wheels **721***a* of the carriage **720**), and the second launch member **743** can include a second roller surface **737***b* (which engages second rollers or wheels **721***b* of the carriage **720**). Carriage arms or links **725** can support the second wheels **721***b* relative to the first wheels **721***a*.

The second roller surface **737***b* can have a curved profile (or other shape) to control the acceleration of the carriage **720**. Accordingly, the carriage **720** can travel (from left to right as shown in FIG. **7**A) along the first roller surface **737***a* while engaging the second surface roller surface **737***b*. In a particular aspect of this embodiment, the second roller surface **737***b* an be inclined relative to the first roller surface **737***a* and can move in a wedge fashion, so as to force the carriage **720** from left to right to launch the aircraft **150**.

The force required to move the second launch member **743** relative to the first launch member **742** can be provided by an actuator **713**. The actuator **713** can be coupled with an actuator line **716** to the second launch member **743**, after passing around an actuator pulley **745***f*. In one aspect of this embodiment, the actuator **713** can include a compressed gas cylinder, having a piston that retracts the actuator line **716** to draw the second launch member **743** downwardly away from the first launch member **742**, as described in greater detail below with reference to FIG. **7**B. In other embodiments, the actuator **713** can have other arrangements, including a hydraulic cylinder, a bungee, or a spring. In any of these embodiments, the actuator **713** can move the second launch member **743** relative to the first launch member **742**, forcing movement of the carriage **720** from left to right.

The launch system **710** can include a carriage return crank or winch **749** having a carriage return line **718** with a releasable trigger **739** connected to the carriage **720**. The launch carriage **720** is held back in a pre-launch position by the carriage return line **718** while a launch force is applied to the launch carriage **720**. The releasable trigger **739** is then disengaged, allowing the launch carriage **720** to accelerate. After launch, the carriage return line **718** can be used to reset the carriage **720**.

FIG. **7**B illustrates the launch system **710** after the carriage **720** has been accelerated to launch the aircraft **150**. In one aspect of this embodiment, the actuator **713** has rapidly drawn the second launch member **743** downwardly in a manner controlled by the block and tackle **733** and the pin **729** positioned in the slot **728**. As the second launch member **743** moves downwardly relative to the first launch member **742**, the carriage **720** is forced from left to right at a high rate of speed, until the second wheels **721***b* engage a braking portion **744** of the second roller surface **737***b*. Accordingly, the angle between the second roller surface **737***b* and the first roller surface **737***a* changes at the braking portion **744**. At this point, the carriage **720** rapidly decelerates, while the gripper **780** releases, allowing the aircraft **150** to continue forward as it is launched into flight.

Once the actuator **713** has moved the second launch member **743**, it can be effectively decoupled while an operator couples the carriage return line **718** to the launch carriage **720** and activates the carriage return crank **749** to return the carriage **720** to the position shown in FIG. **7**A. For example, when the actuator **713** includes a gas powered piston, the volume of the cylinder in which the piston moves can be opened to atmospheric pressure so that the operator does not need to compress the air within the cylinder when returning the carriage **720** to the launch position. Once the carriage **720** has been returned to the position shown in FIG. **7**A, the actuator **713** can be readied for the next launch, for example, by charging the cylinder in which the piston operates with a compressed gas. In other embodiments, the energy of deceleration can be used to reversibly regain energy to be used during the next launch. In still further embodiments, the actuator **713** can be recharged by the carriage return crank **749**. As the carriage return crank **749** is actuated, it can force the second launch member **743** to its original position as the carriage **720** returns. This movement can also force the piston of the actuator **713** to its starting position and restore gas pressure in the actuator **713**.

FIG. **7**C is a partially schematic illustration of a portion of the launch system **710** illustrating the first launch member **742**, along with the second launch member **743** (shown in its pre-launch configuration in solid lines and in its post-launch configuration in dashed lines). As shown in FIG. **7**C, the portion of the second launch member **743** to which the coupling line **735** is attached can move by distance 3X, which is three times the distance X moved by the right-most portion of the second launch member **743**. The wedge angle between the first launch member **742** and the second launch member **743** increases by translating and pivoting the second launch member **743** relative to the first launch member **742**. By increasing the wedge angle during the launch process, the carriage **720** is accelerated at a constant or nearly constant rate, even as the force from the actuator **713** decreases near the end of the actuator's power stroke.

FIG. **7**D is a graph illustrating predicted acceleration and velocity values for a carriage **720** propelled by a launch system **710** in accordance with an embodiment of the invention. In one aspect of this embodiment, the launch system **710** can provide a generally constant acceleration to the carriage **720**, which instantaneously reverses (when the carriage **720** reaches the braking portion **744** described above). This acceleration profile can provide a generally uniform increase in velocity, as is also shown in FIG. **7**D, up to at least the take-off velocity of the aircraft **150**. In other embodiments, the carriage **720** can be propelled in manners that result in different acceleration and velocity profiles.

FIG. **7**E is a partially schematic illustration of a launch system **710***a* configured in accordance with another embodiment of the invention and having many characteristics in common with the launch system **710** described above with reference to FIGS. **7**A-**7**C. In one aspect of this embodiment, the launch system **710***a* includes a first link **719***a* and a second link **719***b* coupled between the first launch member **742** and the second launch member **743**, in lieu of the block and tackle **733** and pin **729** described above. The motion of the second launch member **743** relative to the first launch member **742** can be generally similar to that described above with reference to FIGS. **7**A and **7**B, to provide acceleration and velocity profiles generally similar to those described above with reference to FIG. **7**D.

FIGS. **8**A-**8**B illustrate a launch system **810** configured in accordance with still another embodiment of the invention. In one aspect of this embodiment, the launch system **810** can include a first launch member **842** coupled to a second launch member **843** at a pivot point **827**. An actuator **813** can be coupled to the first launch member **742** and the second launch member **743** with actuator rods **814** to force the first and second launch members **842**, **843** apart from each other in a transverse plane. A carriage **820** can carry the aircraft **150** and can engage a first roller surface **837***a* of the first launch member **842** with first wheels **821***a*. The carriage **820** can also engage a second roller surface **837***b* of the second launch member **843** with second wheels **821***b*.

Referring now to FIG. **8**B, the actuator **813** can be activated to spread the first launch member **842** and the second launch member **843** apart from each other, forcing the carriage **820** from left to right. When the carriage **820** reaches braking portions **844** of the first and second launch members **842**, **843**, it rapidly decelerates, causing a gripper **880** to open (as indicated by arrows M) while the aircraft **150** continues forward and is launched into flight. In other embodiments, the launch system **810** can have other arrangements.

One feature of embodiments of the launch systems described above with reference to FIG. **1**A-**8**B is that the "wedge action" of the first and second members relative to each other can rapidly accelerate the carriage (and therefore the aircraft **150**) in a relatively short distance. An advantage of this arrangement is that the launch systems can be used in cramped quarters, including the deck of a fishing vessel or a towed trailer.

Another feature of embodiments of the launch systems described above is that the wedge angle between the first and second members can increase as a function of distance (e.g., as shown in FIGS. **1**A-**5**) and/or time (e.g., as shown in FIGS. **7**A-**8**B). This arrangement can provide a constant or nearly constant acceleration to the carriage (and the aircraft **150**), even if the force provided by the actuator decreases near the end of the actuator's power stroke. An advantage of this arrangement is that the aircraft **150** is less likely to be subject to sudden changes in acceleration, which can damage the aircraft **150**.

Yet another feature of the launch systems described above with reference to FIGS. **7**A-**8**B is that they can include a braking portion that rapidly and safely decelerates the carriage carried by the launch system. An advantage of this feature is that the system length required for deceleration can be short relative to that required for acceleration, and the overall length of the system can be correspondingly limited.

Another feature of embodiments of the launch systems described above is that the number of components that move at high speed during the launch process is relatively small. For example, in a particular embodiment (e.g., as shown in FIGS. **7**A-**8**B), the only rolling elements that are traveling at high speed are the carriage wheels, and no high speed pulleys are included. Accordingly, the potential losses associated with components moving at high speed, including losses caused by ropes attached to the carriage suddenly accelerating and decelerating (e.g., "rope slurping") can be reduced and/or eliminated.

From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the invention. For example, the systems described above can be used to launch aircraft having arrangements different than those described above. In other embodiments, these systems can handle projectiles or other airborne devices. Aspects of the systems described in the context of particular embodiments can be combined or eliminated in other embodiments. For example, the system described above with reference to FIG. **1**A can be arranged transversely, as described above with reference to FIGS. **8**A-**8**B. The gripper brake can also have arrangements different than those described above. Further details of related systems and methods are described in the following co-pending U.S. application Ser. No. 10/760,150 entitled "Methods and Apparatuses for Launching Unmanned Aircraft, Including Methods and Apparatuses for Launching Aircraft with a Wedge Action," filed Jan. 16, 2004 and incorporated herein in its entirety by reference. Accordingly, the invention is not limited except as by the appended claims.

We claim:

1. An apparatus for carrying an unmanned aircraft, comprising:

carriage means for carrying an unmanned aircraft during launch;

support means for supporting and guiding the carriage means along a launch axis during takeoff;

gripper means for releasably carrying an unmanned aircraft, the gripper means being movable relative to the carriage means between a first position with the gripper means positioned to contact the aircraft and a second position with the gripper means positioned to be out of contact with the aircraft; and

brake means for at least impeding motion of the gripper means relative to the carriage means.

2. The apparatus of claim **1** wherein the brake means includes a first brake portion and a second brake portion, the second brake portion be rotatable about an axis relative to the first brake portion and movable along the axis toward and away from the first brake portion as it rotates.

3. The apparatus of claim **1** wherein the gripper means includes a gripper having at least one gripper arm pivotally coupled to the launch carriage, the at least one gripper arm carrying the at least one grip portion positioned to releasably engage the fuselage of the aircraft.

4. The apparatus of claim **1** wherein the gripper means is pivotable relative to the carriage means about a pivot axis offset from the launch axis to pivot downwardly and outwardly away from the launch axis as the gripper means moves from the first position to the second position, and wherein at least a portion of the mass of the gripper means is eccentrically offset from the pivot axis to swing the gripper means from the first position to the second position as the carriage means decelerates.

5. A method for launching an unmanned aircraft, comprising:

releasably supporting an unmanned aircraft with a launch carriage;

releasably engaging the aircraft with a gripper carried by the launch carriage;

accelerating the launch carriage along a launch axis;

disengaging the gripper from the aircraft by moving the gripper relative to the launch carriage from a first position to a second position;

releasing the aircraft from the launch carriage for flight; and

at least restricting motion of the gripper relative to the launch carriage after disengaging the gripper.

6. The method of claim **5** wherein at least restricting motion of the gripper relative to the launch carriage includes engaging two brake portions with each other, with one brake portion being movable with the gripper.

7. The method of claim **5** wherein at least restricting motion of the gripper relative to the launch carriage includes rotating one brake portion about an axis and moving the one brake portion along the axis into contact with another brake portion.

8. The method of claim **5** wherein the launch carriage includes a first brake portion and the gripper includes a second brake portion and wherein at least restricting motion of the gripper relative to the launch carriage after disengaging the gripper includes rotating the second brake portion about an axis and moving the second brake portion along the axis to contact the first brake portion as the gripper rotates relative to the launch carriage.

9. The method of claim **5** wherein the launch carriage includes a first brake portion coupled to a first threaded member and the gripper includes a second brake portion coupled to a second threaded member and threadably engaged with the first threaded member, and wherein at least restricting motion of the gripper relative to the launch carriage after disengaging the gripper includes rotating the second brake portion about an axis and moving the second brake portion along the axis to contact the first brake portion as the gripper rotates relative to the launch carriage, and wherein the method further comprises:

- decoupling the second threaded member from the gripper portion; and
- rotating the second threaded member relative to the gripper portion to adjust a clearance between the first brake portion and the second brake portion.

10. The method of claim **5**, further comprising decelerating the launch carriage to move the gripper from the first position to the second position.

11. The method of claim **5** wherein releasably engaging the aircraft with the gripper includes releasably engaging a fuselage of the aircraft with the gripper.

12. The method of claim **5** wherein the gripper includes at least one gripper arm pivotally coupled to the launch carriage, and wherein moving the gripper from a first position to a second position includes rotating the at least one gripper arm downwardly and outwardly away from a longitudinal axis of the aircraft.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,360,741 B2
APPLICATION NO. : 11/603815
DATED : April 22, 2008
INVENTOR(S) : McGeer et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On page 2, in field (56), under "Other Publications", in column 2, line 3, delete "U.s." and insert -- U.S. --, therefor.

Signed and Sealed this

Twenty-third Day of September, 2008

JON W. DUDAS
Director of the United States Patent and Trademark Office