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(72) Inventor; and

(71) Applicant: CAO, Yiding [US/US]; 16302 Sw 68th Ter,
Miami, FL 33193 (US).

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(54) Title: RECIPROCATING LIFT AND THRUST SYSTEMS

(57) Abstract: A reciprocating lift and thrust system includes at least an airfoil and a reciprocating driver configured to produce a reciprocating motion of the airfoil. The system may further include a control unit to change or maintain a suitable angle of attack of the airfoil for lift or thrust as well as to facilitate the cyclic control of the flying vehicle driven by the reciprocating system. The lift and thrust system may be deployed in module that includes at least two airfoils and is configured to substantially cancel out the inertia forces and moments associated with the individual airfoils. The reciprocating driver may be, but not limited to, a mechanical, an electromagnetic, an electrical, or a hydraulic driver. The embodiments of the subject invention provide novel and advantageous reciprocating lift or thrust system for aircraft, flying motor vehicles, or watercraft.



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This application is a continuation in part of a provisional patent application 62/761,109 filed March 12, 2018, a non-provisional patent application 15/998,036 filed June 18, 2018, and a provisional patent application 62/739,317 filed September 30, 2018.

Background of the Invention

The use of airfoils by fixed-wing aircraft has the benefit of attaining an increased lift as compared to the thrust needed to overcome the aerodynamic resistance and sustain the flight of the aircraft. In general, a fixed-wing aircraft with finite-span airfoils may have a lift 10 times greater than the needed thrust that may be provided by a jet engine or propeller, resulting in a great leverage ratio by using fixed wings. In conjunction with other advantages, the fixed-wing aircraft have become a mass transportation means in most countries. However, the generation of a sufficiently high lift requires a substantially high aircraft speed, and subsequently a runway for aircraft takeoff or landing is needed.

Helicopters or rotorcraft have been developed for vertical takeoff and landing as well as easier maneuvering in the air at a low speed. But the use of the helicopter so far is rather limited, far from the goal of a mass transportation means, which may represent a grand challenge. Since the vertical takeoff and landing (VTOL) aircraft may be a potentially more efficient and convenient means of transportation for passengers as compared to fixed-wing aircraft, overcoming this grand challenge may have the potential to revolutionize passenger transportation, improve the quality of people's lifestyle, and better utilize the territory of many countries.

The technical difficulties that hold back the use of helicopters may include, but not limited to, the following: (1) The needs for helicopter main-rotor related anti-torque mechanisms and in-flight control of helicopter vibration and instabilities, among other issues, may have made the helicopter complex and expensive. The helicopter is difficult to operate by non-professional pilots and safety is a major concern for many potential helicopter passengers; (2) The main rotor diameter is normally several times greater than the width of the helicopter body, significantly limiting its use in populated areas; (3) The global lift-to-drag ratio of the main rotor during takeoff or landing as well as cruise are much lower than that of a fixed-wing aircraft, resulting in substantially increased power consumption and reduced flight range; and (4) During takeoff or landing, the helicopter may generate very strong wind and loud noise, both of which are negative factors that may hinder mass adoption of the helicopter. It is understood that in the past, many technological advancements or innovations have been made to improve the performance and safety of the helicopter. However, they may also add additional complexity and costs, which may further hinder the mass adoption of the helicopter.

Summary of the Invention

Embodiments of the subject invention provide novel and advantageous reciprocating lift and thrust systems for vehicles that leverage the high lift-to-drag ratio of airfoils without requiring a runway. In particular, the invention produces reciprocating airfoil systems that enable aircraft takeoff, landing, hovering, or easier maneuvering in the air without relying on a complex rotary wing system associated with rotorcraft. The invented reciprocating airfoil system may match or exceed the performance of a fixed wing, but without incurring many technical difficulties and high costs of a rotorcraft. The invention also creates reciprocating thrust systems to provide thrust for the vehicle to fly. The lift or thrust system includes at least an airfoil and a reciprocating driver that engages said airfoil and generates a reciprocating motion of the airfoil. A control unit may be included to generate suitable airfoil angles of attack in reciprocating cycles for needed lift or thrust. The lift or thrust system may be deployed in module that includes at least two airfoils and is configured to substantially cancel out the inertia forces and moments associated with the individual airfoils.

An application of this invention is to create aircraft within a broad category of vertical takeoff and landing (VTOL) vehicles. In addition to the aircraft for conventional transportation purposes, the reciprocating lift and thrust systems of this invention may be employed for military jets, unmanned aerial vehicles (UAV), personal vehicles, and recreational aircraft. The reciprocating thrust system of this

invention may also replace the propeller or jet engine of fixed-wing aircraft using a runway for takeoff and landing.

Yet another application of the reciprocating lift and thrust systems of this invention is to create flying motor vehicles, such as but not limited to, flying cars, flying busses, flying trucks, flying motorcycles, and flying off-road vehicles, to enable vertical takeoff and landing as well as travelling either in the air or on the ground.

Yet another application of this invention is to provide thrust for ships, submarines, and boats. In addition to the applications mentioned above, the disclosed reciprocating lift and thrust systems may find other industrial applications as well.

Compared to helicopters or rotorcraft, the reciprocating lift or thrust system according to this invention may have the following technological advantages: (1) Unlike the main rotor in a rotorcraft, the motion of the airfoil of this invention is reciprocating and primarily linear during the operation and the primary concern related to potential vibration is the balance of the inertia forces and moments due to the reciprocating motion. The system may be easily balanced by using more than one airfoil units similar to the use of multiple pistons and cylinders in a reciprocating compressor or engine. As a result, many difficult issues related to rotorcraft, such as anti-torque mechanisms and in-flight control of vibration and instabilities, are removed. Thus, an aircraft built upon the system of this invention may have significantly improved safety and reliability; (2) When a crankshaft mechanism is used for the reciprocating driver of this invention, the cost of the driver system of this invention may be potentially lower than the cost of an air compressor of similar size. The lower costs of the aircraft of this invention may enable their penetration into mass markets; (3) Great modularity and controllability are other advantages of the system of this invention. In particular, multiple airfoil assemblies may be flexibly deployed at different locations of a vehicle for the benefits of operation and balancing inertia forces and moments. For example, a plurality of airfoils may be arranged on the top or bottom surface of a vehicle, which may share the same reciprocating driver or be driven by separate drivers. Additionally, more than one airfoil assembly may be deployed in a vertical direction, which may share the same reciprocating driver. For rotorcraft, however, the deployment of multiple rotors is a challenging undertaking. For these reasons, an aircraft of this invention may be able to deploy much larger airfoil area per unit volume of the aircraft main body, resulting in significantly reduced footprint as compared to a helicopter of similar loads. This substantially reduced footprint may permit the aircraft of this invention to enter passenger transportation markets in crowded urban areas; (4) The performance of a reciprocating airfoil may match or exceed the performance of a wing of similar size in a fixed-wing aircraft and can have a lift and lift-to-drag ratio much greater than those of a helicopter main rotor. Consequently, an aircraft equipped with the present lift or thrust system could have a significantly improved flight range due to the greatly increased energy efficiency. The aircraft of this invention can also fly much faster than the helicopter because the reciprocating airfoils of this invention may be shaped like fixed wings and function as fixed wings during the cruise. The aircraft of this invention are thus a natural extension of fixed-wing aircraft with added reciprocating-motion functionality of the airfoils for vertical takeoff and landing; and (5) In a fixed-wing aircraft, the lift-to-drag ratio of a finite-span wing is significantly lower than that of a corresponding infinite-span airfoil due to the trailing-edge vortex that creates a downward velocity component, called downwash. Due to the reciprocating motion of the airfoil of this invention at a sufficiently high frequency, the trailing-edge vortex may be difficult to grow. Considering the motion of an airfoil with a finite span from the right end to the left end in a stroke, the trailing-edge vortex may attempt to develop near the trailing edge at the right end of the airfoil. However, before the trailing-edge vortex may have fully established, the airfoil may have reached the left dead end. The left leading edge moves downward to become a trailing edge and the right trailing edge moves upward to become a leading edge while the airfoil changes direction and moves from the left to the right. These combined actions may quickly destroy the trailing-edge vortex before it is fully established. Consequently, the lift-to-drag ratio of the airfoil of this invention with a finite span may potentially approach that of an airfoil with an infinite span.

Brief Description of the Drawings

FIG. 1 shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing an airfoil assembly being driven by a reciprocating driver and moving from the right to the left with a suitable angle of attack in a stroke,

FIG. 2 shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing the airfoil assembly moving from the left to the right with a suitable angle of attack in the following, reverse stroke,

FIG. 3 shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing an airfoil section on the right being deflected downward by a control mechanism while the airfoil assembly moving from the right to the left in a stroke,

FIG. 4 shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing an airfoil section on the left being deflected downward by a control mechanism while the airfoil assembly moving from the left to the right in the following stroke,

FIG. 4a shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing the implementation of an airfoil leading edge slat,

FIG. 5 shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing the center of rotation of an airfoil being disposed at a location away from the airfoil,

FIG. 5a shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention, showing more than one airfoil being disposed in a substantially vertical direction and both airfoil assemblies sharing a reciprocating driver.

FIG. 6 shows a schematic, sectional view of an embodiment of a reciprocating driver employing a crankshaft mechanism as well as control mechanisms to tilt, raise, or lower the airfoil reciprocating plane,

FIG. 6a shows a schematic, sectional view of an embodiment of the reciprocating driver employing a crankshaft, with at least a spring coil or spring coil assembly being disposed to reduce inertia force related stresses in reciprocating members,

FIG. 7 shows a schematic, sectional view of an embodiment of a reciprocating driver employing a crankshaft that generates a reciprocating motion of a beam structure on which an airfoil assembly being mounted, said airfoil assembly moving along with the beam,

FIG. 8 shows a schematic, sectional view of an embodiment of an electromagnetic reciprocating driver, employing a pair of electromagnets and a pair of permanent magnets to generate a reciprocating motion of an airfoil assembly,

FIG. 9a shows a schematic, sectional view of an embodiment of a hydraulic reciprocating driver, which employs a larger piston and a smaller piston in a liquid loop to attain an increased reciprocating stroke of an airfoil assembly,

FIG. 9b shows a schematic, sectional view of an embodiment of a hydraulic reciprocating driver, which couples the motion of the smaller piston with that of the airfoil assembly through magnetic forces,

FIG. 9c shows a schematic view of an embodiment of a hydraulic reciprocating driver, which uses the smaller-piston related loop section as the track of an airfoil assembly and couples the motion of the smaller piston with that of the airfoil assembly through a truss structure,

FIG. 9d shows a schematic view of an embodiment of a hydraulic reciprocating driver, which couples the motion of the smaller piston with that of the airfoil assembly without a bearing on the outer surface of the smaller-piston related loop section,

FIG. 10 shows a schematic, top view of the crankshaft and airfoil assemblies with a horizontally-opposed arrangement for the cancellation of inertia forces and moments, with two airfoils reciprocating generally in a lateral direction of a vehicle,

FIG. 10a shows a schematic, top view of an arrangement of the crankshaft, airfoil assemblies, and fixed wings, with the crankshaft being disposed in a generally perpendicular direction to a vehicle's main body, and said airfoils reciprocating in a lateral direction of the vehicle and being supported by the fixed wings,

FIG. 11 shows a schematic, top view of an arrangement of crankshaft and airfoil assemblies for cancellation of inertia forces and moments, said airfoils being disposed in a longitudinal direction of a vehicle and reciprocating in a front-back direction of the vehicle,

FIG. 11a shows a schematic, top view of two airfoils in a RA module, which is disposed in a longitudinal direction of a vehicle and reciprocating in a front-back direction of the vehicle, with recesses to accommodate the rotation of the cranks for reduction of the distance between the vehicle main body (or fuselage) and the airfoils/reciprocating driver,

FIG. 11b shows a schematic, top view of two airfoils in a RA module, which is disposed in a longitudinal direction of a vehicle and reciprocating in a front-back direction of the vehicle, with the crankshaft being disposed in a vertical position to reduce the distance between the vehicle main body and the airfoils,

FIG. 11c shows a schematic, top view of two airfoils in a RA module with the incorporation of a slotted bar/slider mechanism to increase the reciprocating stroke of the airfoils for a given crank radius,

FIG. 11d shows a schematic, top view of two airfoils in a RA module with the incorporation of a slotted bar/slider mechanism to increase the reciprocating stroke of the airfoils for a given crank radius in conjunction with fixed tracks,

FIG. 11e shows a schematic, top view of two RA modules that are disposed in a longitudinal direction of the vehicle while reciprocating in a forward-backward direction, driven by a crankshaft mechanism,

FIG. 12 shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention, wherein said reciprocating system producing lift for vertical takeoff and landing, or hovering of the aircraft with the airfoils reciprocating in a longitudinal direction of the aircraft,

FIG. 13 shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention during aircraft vertical takeoff and landing, or hovering, with the airfoils reciprocating in a lateral direction of the aircraft,

FIG. 14a shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention during forward flight, with airfoils being tilted forwardly while reciprocating in a longitudinal direction of the aircraft,

FIG. 14b shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention during forward flight, with airfoils being tilted forwardly while reciprocating in a lateral direction of the aircraft,

FIG. 15 shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention, utilizing a reciprocating thrust system of this invention to provide thrust and another reciprocating lift and thrust system for lift,

FIG. 15a shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention, utilizing a reciprocating thrust system of this invention for thrust, and two airfoils in another reciprocating lift and thrust system for lift by forming combined, fixed wings during cruise,

FIG. 16 shows a schematic, sectional view of a reciprocating thrust system according to this invention,

FIG. 17 shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention for lift, while utilizing a propeller for thrust,

FIG. 18 shows a schematic view of an aircraft employing a reciprocating lift and thrust system of this invention for lift, while utilizing a jet engine for the thrust during cruise,

FIG. 19 shows a schematic view of an aircraft employing reciprocating lift and thrust systems of this invention for lift in conjunction with fixed wings, while employing a propeller for thrust,

FIG. 20 shows a schematic view of an aircraft employing a reciprocating thrust system of this invention for thrust, while utilizing fixed wings for aircraft lift,

FIG. 21 shows a schematic view of a flying car employing reciprocating lift and thrust systems of this invention, utilizing a reciprocating thrust system of this invention to drive the car while travelling on the ground,

FIG. 22 shows a schematic view of a flying car employing a reciprocating lift and thrust system of this invention for both lift and thrust while the car is flying in the air,

FIG. 23 shows a schematic view of a submarine employing a reciprocating thrust system of this invention to provide thrust,

FIG. 24 shows a schematic, sectional view of an embodiment of a mechanical control unit, said unit being actuated near or at a dead end of a stroke of an airfoil assembly,

FIG. 25 shows a schematic, enlarged partial view of the mechanical control unit in FIG. 24, including a stopper and a mechanical moving contact,

FIG. 26 shows a schematic, sectional view of an embodiment of a mechanical control unit, employing a rack-pinion gear unit to rotate an airfoil around a rotating center,

FIG. 27 shows a schematic, sectional view of an embodiment of a mechanical control unit, employing a rack-pinion gear unit to rotate an airfoil around a rotating center near leading edge,

FIG. 28 shows a schematic, sectional view of an embodiment of a mechanical control unit, employing a rack-pinion gear unit to raise or lower an airfoil,

FIG. 29 shows a schematic, sectional view of an embodiment of the electromagnetic or electrical control unit, said unit being actuated near or at a dead end of a stroke of an airfoil assembly,

and FIG. 30 shows a schematic, enlarged partial view of the electromagnetic or electrical control unit in FIG. 29, including a non-reciprocating electrical contact and a reciprocating electrical contact,

Detailed Description of the Invention

FIG. 1 shows a schematic illustration of a sectional view of a reciprocating lift or thrust system according to an embodiment of the subject invention. Referring to FIG. 1, the system **100** comprises an airfoil **102** and a reciprocating driver **106** that may produce a reciprocating motion of the airfoil **102** with a stroke S . Said stroke may be defined based on any section of the airfoil and it may be related to a reference section such as a midsection of the airfoil. In FIG. 1, said airfoil **102** travels from the right dead end **120** of a stroke to the left dead end **122** of the stroke with a positive angle of attack α and produces a lift or thrust. The system further comprises a control unit with an embodiment **108** or **112** shown in the figure. Near or at the left dead end **122**, the activation of the control unit **108** or **112** may generate a counter clockwise rotation of the airfoil around a joint mechanism **116** as the airfoil changes direction and moves from the left end **122** to the right end **120** with an angle of attack α' , as shown in FIG. 2. As the airfoil is near or at the right end **120** of the stroke, the action of the control mechanism may produce a clockwise rotation of the airfoil as the airfoil changes direction and moves from the right end to the left end, returning to the condition shown in FIG. 1 and completing a reciprocating cycle.

It is well known in the airfoil field that trailing-edge high-lift mechanisms comprising a trailing edge flap or leading-edge high-lift mechanisms comprising a leading-edge slat, flap, or droop are commonly employed during the takeoff and landing of fixed-wing aircraft. Similar principles may be adapted for the present reciprocating lift or thrust system. FIG. 3 shows a schematic, sectional view of an embodiment with two airfoil sections, **140** and **142**. Referring to FIG. 3, the airfoil section **140** moves from the right dead end **120** to the left dead end **122** with a positive angle of attack. The airfoil section **142** is deflected downward by the control mechanism **112** while moving along from the right end to the left end. Similar to the trailing edge flap mechanism of a fixed-wing aircraft, this downward defection of the airfoil section **142** may significantly increase the lift or thrust of the system. When the airfoil assembly is near or at the left dead end **122** of the stroke, the control mechanisms **112** is activated to push the airfoil section **142** upward, while the airfoil section **140** is deflected downward by the control mechanism **108**, as the airfoil assembly travels from the left dead end **122** towards the right dead end **120** (see FIG. 4). An embodiment of the control mechanisms may involve a linkage **146** for the airfoil section **140** and a linkage **154** for the airfoil section **142**, which may be disposed along a hinge **150** in a direction generally perpendicular to the paper to enable independent movement of the sections **140** and **142**. Alternatively, the airfoil sections **140** and **142** may be linked together by a single linkage as a single airfoil and may rotate together around the hinge **150** (not shown).

The two airfoil sections in FIG. 3 and FIG. 4 may not be the same or symmetric with respect to the joint mechanism **150**; they may have different shapes or dimensions, depending on performance considerations or deployment of the lift or thrust system on a vehicle in conjunction with the corresponding reciprocating driver **106**. Similarly, the joint mechanism **116**, as well as the related center of rotation shown in FIG. 1 and FIG. 2, is for illustration convenience. The joint mechanism may a hinge or a three-dimensional joint such as a ball joint. The center of rotation may be located at the center of pressure of the airfoil **102** for structural consideration or other locations for performance or deployment consideration. Accordingly, the center of rotation of an airfoil may be located anywhere from the leading edge to the trailing edge of the airfoil. More generally, the airfoil may be rotated near each end of a stroke around a

center of rotation that may be located at any location, on or off the airfoil, for airfoil structural, performance, or deployment consideration.

The concept of high-lift devices employing a leading-edge slat may also be adapted for the system of this invention. Referring to FIG. 4a, a leading-edge portion **158** of the airfoil section **140** is integrated with the rest of the section with a linkage **156** but having a gap **157** between the leading-edge portion **158** and the rest of **140**. Said gap **157** may allow airflow to pass through between the bottom and top of the airfoil. Thus, the leading portion **158** is acting as a slat that could permit a higher airfoil angle of attack for a higher lift. The concept of the leading-edge flap or droop may also be implemented but it is not shown herein.

The configuration as shown in FIG. 3 and FIG. 4 may be similar to the configuration of a single-element trailing-edge flap in a fixed wing aircraft. Multi-element trailing-edge flaps are also within the scope of this invention. As shown in FIG. 4a, because of the gap **159**, the airfoil section **142** is essentially a trailing-edge flap with two elements. More sophisticated multi-element trailing-edge flaps may be adopted although they are not shown herein.

As mentioned before, in the above figures the center of rotation for changing or maintaining the angle of attack is shown at a location of the airfoil. However, the center of rotation may also be disposed at a location away from the airfoil. As shown in FIG. 5, an airfoil **102** integrated with optional supporting structures **110** may be rotated around a center of rotation **150**, which is spaced away from the airfoil **102**, for changing the angle of attack or maintaining a positive angle of attack for both the leftward and rightward strokes. In FIG. 5, the supporting structures **110** are disposed in a direction of the airfoil chord. However, they may also be deployed in a direction of the airfoil span, considering that the span may be longer than the chord. It should be noted that for the airfoil shown in FIG. 5, the two strokes in a cycle may produce different performance. The stroke that produces a better airfoil performance than the other is termed the primary stroke in this disclosure.

It is well understood in the arts that the control unit may have a broad functionality that could maintain a positive or negative angle of attack α as well as constantly change the magnitude of α for desired lift or thrust during operation. Additionally, α' in FIG. 2 may be positive or negative and may have the same value as the α in FIG. 1, but it may also take a value significantly different from the value of α . The embodiments **108** and **122** with push or pull rods (or tubes) are for the convenience of illustration; other control units with only one rod or without a rod may also be employed. The embodiments, **108** and **122**, could be two components of a single unit but a control unit with a single component may also accomplish the same control functionality. Said control unit may be, but not limited to, a mechanical control unit, an electromagnetic control unit, an electrical control unit, or a hydraulic control unit.

In the embodiments of this invention, the x axis, shown in FIG. 1, is generally designated as the direction of the reciprocal motion of an airfoil, z designated as the direction perpendicular to the reciprocating motion, and y designated as the span direction of the airfoil. The geometric shape, construction, and materials of the airfoil may be similar to those of existing airfoils such as those related to aircraft or may be adapted for better performance and reciprocating condition of this invention. For convenience, the combination of the airfoil, the supporting structure, such as **114** shown in the above figures, and the related control mechanism are termed as an airfoil assembly in this disclosure. Because of the reciprocating motion of the airfoil assembly, significant inertia forces and related inertia moments may be generated. It is therefore essential that the mass of the airfoil assembly be minimized while maintaining its integrity and strength. Advanced modern wing construction techniques may be adapted in conjunction with lighter and stronger materials, including carbon fiber and other composite materials, to achieve maximum strength to weight performance of the airfoil assembly of this invention.

More than one airfoil assembly may be disposed in y or x direction of the coordinate system shown in FIG. 1. Additionally, more than one airfoil assembly may be disposed in the direction of z . Each airfoil assembly may engage an independent reciprocating driver, but the disposed airfoil assemblies may also share a common reciprocating driver. FIG. 5a shows a schematic illustration of a sectional view of a reciprocating lift or thrust system with two airfoil assemblies, **102** and **102a**, being disposed in a substantially vertical direction and sharing the same reciprocating driver **106**. The two airfoils may be the

same or different, and they may be rotated respectively around rotation centers **150** and **150a** for setting, changing, or maintaining the angle of attack.

Similar to the reciprocating motion of a piston in a reciprocating compressor or reciprocating internal combustion engine, the speed of the airfoil, V , in a reciprocating lift or thrust system of this invention may vary between the two dead ends in a stroke, reaching a maximum speed between the two ends and a zero speed at each end. A useful velocity is the mean velocity in a stroke, $\bar{V}$. Accordingly, a lift or thrust coefficient, C_L or C_T , may be defined based on this mean velocity:

$$F_L = C_L \frac{1}{2} \rho \bar{V}^2 A_p \quad (1)$$

$$F_T = C_T \frac{1}{2} \rho \bar{V}^2 A_p \quad (2)$$

wherein ρ is the density of a fluid and A_p is the planform area of an airfoil. The mean velocity is linked to reciprocating stroke S and reciprocating frequency f (or reciprocating cycles per second) by the following relation:

$$\bar{V} = 2 \times S \times f \quad (3)$$

For a crankshaft related driver, $S = 2r$, wherein r is the radius of the crank. A sufficiently long stroke or high frequency, or both, may produce a sufficiently high mean speed to provide a needed lift or thrust for a vehicle in conjunction with an acceptably large airfoil planform area A_p .

Any reciprocating driver that may provide a sufficiently long reciprocating stroke or sufficiently high frequency is within the scope of this invention, which may be, but not limited to, a mechanical, electromagnetic, electrical, or hydraulic reciprocating driver.

Said reciprocating mechanical driver may be, but not limited to, a slider-crank mechanism driver, a cam-follower mechanism driver, a scotch yoke mechanism driver, a swash plate mechanism driver, or a wobble (Nutator or Z-crank) driver. FIG. 6 shows schematically an embodiment **200** with an airfoil **208** driven by a slider-crank mechanism driver, employing a crankshaft mechanism **202** driven by a driveshaft **204**, which in turn is driven by a power system (not shown). Through a connecting rod **206** as well as a supporting structure **210** that may include a roller or bearing structure **212**, the rotation of the crankshaft **202** creates a reciprocating motion of the airfoil **208**. Said roller or bearing **212** may be mounted on a track structure **216**, and slide, together with the airfoil **208**, along the track **216**. The track **216** works a guide for the reciprocating motion of the airfoil assembly **208** and may carry the loads of the lift or thrust as well as the weight of the airfoil assembly. The track **216** may be any shape or structure to accommodate the shape or structure of the roller or bearing **212**, or may be simply a beam structure. The roller or bearing **212** may incorporate the rolling slider or rolling bearing mechanism to minimize the friction between the roller and track.

As an option for cyclic control of a vehicle of the present invention, said track **216** may be mounted on a section of a vehicle body **220** through a support **218** having a joint **224** and a control mechanism **226** that may tilt the track **216** in different directions. For example, at least one of the connecting rod joints, **230** or **228**, as well as the joint **224**, may accommodate multi-directional movements. Thereby, through the control mechanism **226**, which may act independently from the pitch control mechanism **108** or **112**, the track **216** as well as the reciprocating plane of the airfoil **208** may be tilted in desired directions for the purposes of cyclic control of vehicle flight. Together with other possible supports, the action of the control mechanism **226** and support **218** may also raise or lower the track structure **216** and the airfoil **208**, relative

to the vehicle body section **220**. Alternatively, for the cyclic control purpose, the entire reciprocating lift or thrust system of this invention including the reciprocating driver may be tilted, raised, or lowered by related control mechanisms (not shown).

A disadvantage of the lift or thrust system of this invention is that the reciprocating driver may be subject to significant inertia forces due to acceleration or deceleration of the airfoil assembly in each stroke, which could generate significant stresses in the structural members of the reciprocating driver, particularly near the dead ends of the stroke. To mitigate this problem, spring coils may be employed to reduce the inertia force related stresses. FIG. 6a shows schematically such an embodiment, which employs two springs coils or spring coil assemblies containing a plurality of spring coils, **234** and **236**. In the crank position measured by the crank angle θ shown in FIG. 6a, approximately within $0 \leq \theta < 90^\circ$, the airfoil assemble may accelerate and move from the right end toward the left end. In this case, the compressed spring coil **234** would expand, releasing the energy stored during the last stroke and pushing the airfoil assembly forward to reduce the stress of the driver members. Approximately within $90^\circ < \theta \leq 180^\circ$ in the same stroke, the airfoil assembly may decelerate. In this case, the airfoil assembly would compress the spring coil **236** while the spring coil **236** receives an amount of energy from the airfoil assembly. Said energy would be used to push the airfoil assembly forward after the airfoil assembly changes the direction and moves from the left end toward the right end in the next stroke (not shown).

In FIG. 6 and FIG. 6a, the airfoil assembly is mounted on a track structure and slides along the track while the track is fixed to the body of a vehicle to reduce inertia force. In some applications where the working environment of an airfoil may need to be isolated from the reciprocating driver or the related power system, the airfoil assembly may be fixed to a beam structure and undergo a reciprocating motion with the beam. FIG. 7 shows schematically such a case employing a crankshaft related mechanical driver **250**. Through a connecting rod **254**, the reciprocating driver created a reciprocating motion of a beam structure **258**. An airfoil assembly **262** is fixed to the beam **258** and reciprocates along with the beam. Said airfoil assembly **262** generates a thrust F_T while the outside environmental fluid surrounding the airfoil assembly is substantially isolated from the driver **250** through a partition **264**. The beam **258** and the airfoil assembly **262** may be supported by a supporting structure **266** that may also work as a bearing track or rolling slider guide and may include seals to minimize the leakage of the fluid from the outside of the partition **264** into the inside space. To reduce the inertia stresses of the reciprocating driver members, spring coils or spring coil assemblies may also be disposed, particularly near the ends of the supporting structure **266** (not shown).

Another embodiment of the reciprocating driver is an electromagnetic driver. FIG. 8 shows schematically an embodiment **300** of the electromagnetic driver, employing a pair of electromagnets **302** and **304** and a pair of permanent magnets **310** and **312**. Said electromagnets may be energized by a power source such as a battery system (not shown) of suitable current and voltage. In the case of FIG. 8, the polarity of the electromagnet is set in such a way that it repels the corresponding permanent magnet when the electromagnet is energized. Through connecting rods **314** and **316**, said permanent magnets **310** and **312** are connected to an airfoil assembly **350** through supporting structures **320**. Said supporting structure **320** includes a bearing or rolling slider **324** that may slide along a track **328**. When the permanent magnet **312** is near the right dead end of a reciprocating stroke, the electromagnet **302** is energized and the generated repulsive electromagnetic force pushes the permanent magnet **312** as well as the airfoil assembly **350** to the left, as shown in FIG. 8. When the permanent magnet **310** is near the left dead end of the stroke, the electromagnet **302** would be de-energized and the electromagnet **304** would be energized while the airfoil assembly is pushed from the left dead end toward the right dead end (not shown). Spring coils or spring coil assemblies **340** and **342** may be employed to reduce energy consumption of the driver. Referring to FIG. 8, when the airfoil assembly **350** moves from the right to the left, the compressed spring coil **340** associated with the permanent magnet **310** expands and pushes the airfoil **350** to the left. Before the permanent magnet **312** reaches its left dead end in the stroke, the spring coil **342** would be compressed and a substantial amount of the kinetic energy associated with the airfoil assembly as well as the permanent

magnets may be stored as the potential energy by the spring coil 342. The stored energy would be released to help push the airfoil assembly to move from the left to the right in the next stroke (not shown).

Yet another embodiment of the reciprocating driver is a hydraulic driver. FIG. 9a shows a schematic illustration of an embodiment 400 of a hydraulic driver, with a purpose of magnifying the reciprocating stroke of an airfoil assembly. Said hydraulic driver includes a loop filled with a fluid such as, but not limited to, oil or water, a larger piston (or partition) and a smaller piston (or partition) disposed within the loop. Because of the piston sealing functionality and the near incompressibility of the liquid, a smaller reciprocating stroke of the larger piston may generate a larger reciprocating stroke of the smaller piston, thereby increasing the reciprocating stroke of the associated airfoil assembly. Referring to FIG. 9a, a larger piston 404 is disposed in a chamber 408 having a cross sectional area of A_1 and a smaller piston 410 is disposed in a loop section 412 having a smaller cross-sectional area A_2 . Said larger piston is driven by a reciprocating driver 414 through a connecting rod 416 and a seal 418. Said reciprocating driver 414 may be, but not limited to, a slider-crank mechanism driver, a cam-follower mechanism driver, a scotch yoke mechanism driver, a swash plate mechanism driver, a wobble (Nutator or Z-crank) driver, an electromagnetic driver, or an electrical driver such as a linear actuator. The smaller piston 410 is connected to an airfoil assembly 420 through a connecting rod 422 and a seal 424. Because of the near incompressibility of the liquid enclosed within the chamber 408 and the other loop sections, the ratio of the stroke of the airfoil assembly 420 (or the stroke of the smaller piston 410), S_2 , to the stroke of the reciprocating driver 414 (or the stroke of the larger piston 404), S_1 , may be approximately proportional to the ratio of A_1 to A_2 :

$$\frac{S_2}{S_1} \propto \frac{A_1}{A_2}$$

For example, if the area ratio above is over 10, the airfoil stroke may be increased by more than 10 times as compared to the stroke of the reciprocating driver 414. To reduce the force load of the driver, the airfoil assembly 420 may be supported by a track 430 as in the case for some other reciprocating drivers disclosed. For a small and light airfoil assembly, the airfoil assembly 420 may be carried by the connecting rod 422 without a track (The same is true for other disclosed reciprocating drivers). When the stroke of the reciprocating drive 414 is small or moderate, the seal 418 may be a bellows that could be leakage free. Additionally, the seal 424 may be replaced by a bellows or a bellows assembly (not shown). To reduce the friction related to the pistons and seals, rolling slider or rolling bearing mechanism may be employed.

Alternatively, the connecting rod 422, the seal 424, and the track 430 in FIG. 9a may be eliminated and the airfoil assembly 420 may be directly disposed on the section 412 of the loop and slide along the section 412 with the smaller piston 410. For example, the smaller piston may be substantially a magnetic material 440 and the airfoil assembly 420 is attached to a magnet 444 of unlike poles, which is mounted outside of the loop section 412 and is attracted to the magnet 440. As the magnet piston 440 moves reciprocally inside the loop, the external magnet 444 as well as the airfoil assembly 420 may move along with the magnet 440, creating a reciprocating motion of the airfoil assembly 420. The magnets 444 and 440 may be permanent magnets or electromagnets depending on specific designs and applications. One of the advantages is the compactness of the system. Adequate lubrication between the external magnet 444 and the outer surface of the loop section 412 may be required for this system.

Similar to other reciprocating drivers disclosed, spring coils or spring coils assemblies may be employed inside of or outside of the liquid loop, as well as for any suitable reciprocating driver 414 to reduce the stresses of reciprocating members or to lower the power consumption of the driver (not shown). In particular, for the case in FIG. 9b, spring coils or spring coil assemblies may be disposed outside of the loop section 412 to reduce the inertia force load and to prevent magnet 444 from sliding away from the location of the magnet 440 (not shown).

Yet another alternative hydraulic driver is to directly mount the airfoil assembly on the smaller piston related loop section that acts as a track for the airfoil assembly. Referring FIG. 9c, through a bearing structure 450, the airfoil assembly 420 is directly mounted on the outside surface of the loop section 412

that is supported by a section of the vehicle (not shown). A truss structure **452** (front or back, or both front and back) with the connecting rod **422** links the smaller piston **410** with the airfoil assembly **420**, thereby a reciprocating motion of the airfoil assembly **420** is generated by the reciprocating motion of the smaller piston **410**. A joint **454** that links the connecting rod **422** and the truss structure **452** may permit independence between the dimensional tolerance of the smaller piston **410** with the inner surface of the loop section **412** and the dimensional tolerance of the bearing structure **450** with the outer surface of the loop section **412**.

Yet another alternative hydraulic driver is to directly couple the motion of the smaller piston with that of the airfoil assembly without a sliding motion of the airfoil assembly on the outer surface of the smaller-piston related loop section. Referring to FIG. 9d, the bearing **450** in FIG. 9c is eliminated. The airfoil assembly is supported by the inner surface of the loop section **412** through truss structures **452** together with the connecting rods **422** and the smaller piston **410**, while undergoing a reciprocating motion with the smaller piston.

Within the loop and outside of the loop of the hydraulic driver, frictional heat may be generated due to the friction between the piston/connecting rod and the inner wall of the loop as well as the friction between bearing and the outer surface of the loop. Fins or heat pipes may be disposed at some locations of the loop and the loop fluid may be cooled through natural convection or forced convection through a fan. Additionally, a liquid compensation mechanism may be installed to accommodate certain thermal expansion or contraction as well as a small amount of fluid leakage through the seals over a time period to ensure the loop integrity and the loop be completely filled with the liquid.

It is understood that the inertia forces and moments generated by the reciprocating airfoil assembly and the reciprocating driver need to be balanced to avoid significant system vibration. It is also well established in the reciprocating engine or compressor industries that the use of an even number of pistons combined with proper piston and crank arrangements may be able to cancel the related inertia forces and moments. The well-known piston-cylinder geometries may include, but not limited to, in-line, horizontally opposed, opposed piston, V-shaped, and radial arrangements. For the reciprocating driver of this invention using a crankshaft, the counterpart of the piston and cylinder combination may be the combination of the airfoil assembly and track as shown in FIGs. 6 and 6a. When the airfoil assembly is fixed to a beam and moves along with the beam, the counterpart of the piston and cylinder combination may be the combination of the beam-airfoil assembly and the supporting bearing structure for the beam, as shown in FIG. 7. Accordingly, the arrangements and balancing methods taught by reciprocating engine or compressor industries are all within the scope of this invention.

FIG. 10 shows a schematic, top view of a crankshaft and airfoil assembly arrangement **500**, with a preferred horizontally-opposed arrangement, to minimize or eliminate the requirement for crankshaft counterweights. Referring to FIG. 10, two airfoil assemblies, **502** and **504**, reciprocate in a lateral direction and are disposed respectively on the two sides of a crankshaft **506**, which is driven by a power system **510** through a driveshaft **514**. Cranks **518**, connecting rods **520**, roller structure **522**, and related track structure **524** for airfoil **502**; and cranks **526**, connecting rods **528**, roller structure **530**, and related track structure **532** for airfoil **504** are also shown in the figure.

In FIG. 10, the airfoil assembly **502** moves from the right to the left of a stroke while the airfoil **504** moves from the left to the right of a stroke, and both airfoil assemblies are moving towards the crankshaft **506** with velocity V of almost identical magnitude but in opposite directions. Since the two airfoil assemblies as well as their associated cranks and connecting rods are substantially identical, inertia forces and moments created by the acceleration or deceleration may be substantially cancelled out in conjunction with this arrangement. One skilled in the art may recognize that only two airfoil assemblies are displayed in FIG. 10, but additional airfoil assemblies and related crank mechanisms may be added to the crankshaft **506** to accommodate lift or thrust needs or for more complete cancellation of the inertia forces and moments. One skilled in the art may also recognize that due to air downdraft, the center of the airfoils may be sufficiently away from the planform **536** of a vehicle's main body to avoid significant blocking of the downdraft by the top surface of the aircraft body. Additionally, the reciprocating airfoil may take any shape, not just the rectangular one for schematic illustration, for performance and structural considerations. It

should be mentioned that the crankshaft related reciprocating driver shown in FIG. 10 may be replaced by a different reciprocating driver, such as, but not limited to, a different kind of mechanical driver, an electromagnetic driver, an electrical driver, or a hydraulic driver. For some applications, a crankshaft and airfoil-assembly arrangement other than the horizontally-opposed arrangement shown may also be employed.

In FIG. 10, the lateral reciprocating of the airfoils may be unable to take the full advantage of the airflow cross the airfoils during cruise for lift generation. The reciprocating lift system of this invention may be deactivated or work at a low reciprocating speed to reduce energy consumption and increase flight range if fixed wings are available to generate lift during cruise. Additionally, in FIG. 10, the crankshaft is deployed generally parallel to the vehicle's main body, which may need to raise the reciprocating driver as well as the airfoil assemblies to a sufficiently high level above the top surface of the vehicle body (or below the bottom surface of the body when the airfoils are deployed below the vehicle's main body) to accommodate the rotation of the cranks. For a relatively large reciprocating stroke that demands a relatively large crank radius, this arrangement may cause aerodynamic losses and structural concerns.

Referring to FIG. 10a, a crankshaft **506** is deployed in a direction generally perpendicular to the vehicle's main body with two cranks **518** and **526** being disposed along the crankshaft **506** in the perpendicular direction, under a horizontally-opposed arrangement. The cranks **518** and **526**, through connecting rods **520** and **528**, respectively, drive airfoil assemblies **502** and **504**. The airfoils assemblies, including rollers **522** and **530**, are respectively guided by tracks **524** and **532** that are integrated and supported, respectively, by fixed wings **502a** and **504a**. Like the case in FIG. 10, both airfoil assemblies **502** and **504** reciprocate in a lateral direction with almost identical velocity magnitude but in opposite directions to significantly cancel out inertia forces and moments. The vehicle flight speed V_o is also shown in FIG. 10a. During takeoff or landing, V_o is almost zero and lift or thrust is generated almost exclusively due to the reciprocating motion of the airfoils. But during the cruise at a relatively high speed, the fixed wings **502a** and **504a** may generate lift through the flight speed of the vehicle, in addition to that generated due to the reciprocating motion of the airfoils **502** and **504**. If the fixed wings **502a** and **504a** can generate sufficiently high lift, the airfoils **502** and **504** may stop reciprocating or reciprocate at a low speed to conservation energy. Alternatively, if no other thrust means is equipped in the vehicle, the reciprocating airfoils **502** and **504** may tilt forward to provide thrust for flight while also producing certain lift. The combination of the reciprocating and fixed wings in FIG. 10a also has certain structural merits as the fixed wings **502a** and **504a** are essentially the tracks for the reciprocating wings **502** and **504**.

The airfoils may also reciprocate in a front-back direction of the vehicle to take the advantage of the airflow cross the airfoils during cruise for lift generation. Referring to FIG. 11, two airfoils, **502** and **504**, are shaped like the wings of a fixed-wing airplane and are deployed substantially in a front-back direction of the vehicle with a horizontally-opposed arrangement, in which both airfoils, as a pair, reciprocate in a longitudinal direction of the vehicle with almost the same velocity magnitude but in opposite directions for the balancing purpose. During takeoff or landing when the vehicle cruise speed is zero, this deployment may benefit from the longer airfoil span perpendicular to the reciprocating motion for a higher lift-to-drag ratio. During the cruise, the vehicle flight speed is superposed with the reciprocating speed, which creates a substantially higher effective velocity across the airfoils. This substantially increased effective velocity would at least benefit the primary strokes of the airfoils for a significantly increased lift. The cranks **518** for the airfoil **502** and the cranks **526** for the airfoil **504** are driven by a crankshaft **506**. The related connecting rods **520** and **528**, rollers (or bearings) **522** and **530**, and tracks **524** and **532** are also shown in the figure. The airfoil deployments as shown in FIG. 10, FIG. 10a, and FIG. 11 all involve at least a pair of airfoils with substantially neutralized inertia forces and moments. This pair of reciprocating airfoils may be referred to as a reciprocating airfoil (RA) module or a RA cell. For the operation of a vehicle, one or more such a RA module may be deployed at any suitable location and reciprocates in any preferred direction, driven by the same mechanism or separate mechanisms. The reciprocating direction or the reciprocating plane of the RA module may be raised, lowered, or tilted in any direction as needed by control mechanisms.

As discussed before, the deployment of the crankshaft generally parallel to the vehicle's main body surface may need to raise the lift system or airfoils to a sufficiently high level above the body surface, which could incur additional aerodynamic losses under high-speed flight. To mitigate this problem, recesses may be created in the vehicle body, which may accommodate the rotation of the cranks without raising the lift system as well as the airfoil assemblies to an undesirable level. Referring to FIG. 11a, a recess **540** is created for the airfoil **502** while a recess **542** is created for the airfoil **504**. Also, in this deployment, a crank and connecting-rod combination located at a midsection of the airfoil is employed to drive each airfoil assembly through a linkage mechanism **544** or **546**. The linkage may engage a spar that runs through the airfoil. One skilled in the art may recognize that it may be difficult to completely cancel out inertia forces or moments under desired component arrangements in a reciprocating system. However, some conventional ways such as adding or removing some masses at different locations may help. For example, a small amount of mass **A** may be added on the left part of the airfoil assembly **502**, while the small amount of mass **B** is added on the right part of the airfoil assembly **504**. Through the adjustment of the amount of the mass as well as the perpendicular distance between these two masses, some unwanted inertial moments may be balanced.

Alternatively, similar to the case in FIG. 10a, the crankshaft may be deployed in a generally perpendicular direction to the main-body surface of a vehicle. Referring to FIG. 11b, a crankshaft **506** is deployed in a direction generally perpendicular to the vehicle body with two cranks **518** and **526** being disposed in the perpendicular direction, but also with a horizontally-opposed arrangement. The cranks **518** and **526**, respectively, drive airfoil assemblies **502** and **504** that are shaped like some wings of fixed-wing airplanes, through connecting rods **520** and **528**, respectively. The deployment as shown in FIG. 11b is especially beneficial for high-speed vehicles. Because the spacing between the two cranks, **518** and **526**, in the vertical direction can be limited, the entire lift system as well as the airfoil assemblies may be disposed sufficiently close to the surface of the vehicle body. With relatively short fairing, the effect of the cranks and connecting rods on the aerodynamic losses may be minimized. Also, the elevation difference between the front and rear airfoils may be flexibly adjusted, which may be beneficial for the formation of a combined, fixed wing during high-speed cruise.

The average reciprocating speed of the present reciprocating system is directly proportional to the reciprocating stroke. A longer stroke may have the potential to reduce the reciprocating frequency for a given average reciprocating speed, which is particularly important for inertia force reduction and structural consideration. However, a longer stroke would demand a longer crank radius, which in turn could cause higher inertia stresses in reciprocating members. Therefore, there is an incentive to increase the airfoil reciprocating stroke without increasing the crank radius. A slotted bar/slider mechanism taught and demonstrated by Thang010146 [1] is adapted for the present application. FIG. 11c shows schematically a crankshaft driven RA module that employs two slotted bars, **550a** and **550b**, to increase the stroke of the airfoils over that without the slotted bars. To illustrate the working mechanism, the functionality of the slotted bar **550a**, which engages a roller **522a** through a joint **552a** to drive the airfoil assembly **502**, is considered. The slotted bar **550a** is in turn driven by the connection rod **520** of the crank **518** through a slider **554a** mounted on the bar. Further to the right, another slider **556a** is disposed on the bar. The slider **556a** has a revolution joint **558a** that pivots the slider **556a** and would allow the slider **556a** to rotate around the joint **558a**. When the airfoil assembly **502** moves toward an end of the track **524a**, as indicated by the velocity V in FIG. 11c, the slotted bar **550a** could accordingly accommodate a longer travelling distance of the airfoil assembly along the track, through a combined motion of sliding through the slider **556a** and rotation around **558a**, so that the stroke of the airfoil is increased. The stroke of the airfoil may also be adjusted by changing the position of the slider **556a** with the revolution joint **558a**. It should be mentioned that although in FIG. 11c the slotted bars drive the airfoil assemblies through the rollers **522a** and **530a**, they may engage any suitable locations of the airfoil assemblies to drive the airfoils.

Another slotted bar/slider mechanism taught and demonstrated by Thang010146 [2] is adapted herein, which is similar to the one used in FIG. 11c, but the slotted bar is driven by the crankshaft along a fixed beam that may be oriented parallel to an airfoil track. FIG. 11d shows schematically a crankshaft driven RA module that employs two slotted bars, **560a** and **560b**, that are driven by connecting rods, **520** and **528**, respectively, along two fixed beams **564a** and **564b**. To illustrate the working mechanism, the

functionality of the slotted bar **560a**, which engages a midsection of an airfoil **502**, is considered. Referring to FIG. 11d, a slider **568a**, which is mounted on the slotted bar **560a**, engages the airfoil **502** at a midsection to drive the airfoil along its tracks **524a** and **524b**. The slider **568a** engages the slotted bar **560a** and would permit the slotted bar to slide through. Further to the right, another slider **562a** with its pivot is disposed on the bar. Through its connecting rod **520**, a crank **518** drives the slotted bar **560a** through a slider **566a** along the fixed beam **564a**, creating a reciprocating motion of the slotted bar along the beam **564a**, although the slotted bar may rotate around a joint with the slider **566a**. Through combined motion of sliding and rotation of the slotted bar, the stroke of the airfoil could be doubled or tripled compared to that without the slotted bar. In addition, adjusting the position of slider **562a** along with its pivot could change the stroke of the airfoil. To reduce the friction related to the slotted bar, rolling mechanisms between sliding interfaces may be employed. Yet another well-known mechanism involving a fixed rack gear and a movable rack gear may be potentially employed to double the stroke of the airfoils for the present application.

FIG. 11e shows two RA modules that are disposed in a longitudinal direction of the vehicle while reciprocating in a forward-backward direction, driven by a crankshaft mechanism. In this case, airfoils **570** and **572** form a first RA module driven by a crankshaft **574**, which is driven by a driveshaft **506** through a transmission means or a gear box **576**. Airfoils **580** and **582** form a second RA module driven by a crankshaft **584**, which is driven by the same driveshaft **506** through a transmission means or a gear box **586**. For simplicity, the related connecting rods, rollers (or bearings), and tracks are lumped into **578** and **588**, respectively, for the two modules. To reduce the distance between the airfoils and the vehicle's top main-body surface, both **578** and **588** could be disposed off the planform area of the vehicle, or crankshafts generally perpendicular to the top surface, like those seen in FIGs. 10a and 11b, can be employed. It is understandable that compared to a fixed airfoil, the size of a reciprocating airfoil may be limited due to the related inertia forces associated with the airfoil. However, with the concept of the RA module, a number of relatively smaller RA modules may be deployed at different locations to drive a relatively large, heavy vehicle or for more completely balancing the inertia forces and moments for the vehicle. It is also understandable that the crankshaft drivers may be replaced by non-crankshaft drivers. In this case, the timings and relative locations of the related reciprocating members of the reciprocating drivers or driver sections, such as the moving permanent magnets in FIG. 8 and the pistons in FIGs. 9a-9d, may be carefully arranged for more complete cancellation of the inertia forces and moments.

A RA module reciprocating in a front-back direction may be able to take the advantage of relatively high vehicle speed for a higher lift. However, aerodynamic interaction of the two airfoils may be a concern. It is well known in the field that trailing vortices are a serious issue to be considered. As discussed earlier in the summary of this disclosure, reciprocating motion of the airfoil could minimize this effect. However, in high speed flight when the reciprocating motion is deactivated and the airfoil would act as a fixed wing, this issue may need to be addressed particularly for the rear airfoil in a RA module. One of the approaches is to maintain a shorter distance between the two airfoils or dispose the rear airfoil at a lower elevation to form a combined wing with the frontal one when the RA module works in a fixed wing mode. Another approach is to make the span of the rear airfoil shorter than that of the frontal one. As seen in FIG. 11e, the span of airfoil **572** is shorter than that of airfoil **570**. The airfoil **572**, however, would still have the same equivalent mass as that of the airfoil **570** for balancing inertia forces and moments. Also, the second module behind involving airfoils **580** and **582** may be disposed at a higher elevation than the first module to reduce the vortex effect of the frontal module. Still, if the approaches above may not work satisfactorily, the airfoils may continue to reciprocate, albeit at a lower speed, to minimize the trailing vortex effect under high-speed cruise. Additionally, for compact vehicles with limited airfoil area, the airfoil may continue its reciprocating mode through entire flight range, but at a lower speed when the flight speed is high, for the RA module involving frontal and rear airfoils.

In general, a RA module may be formed with two airfoils having substantially different shapes or different performance. The strokes as well as related crank radii and connecting rod lengths of the two airfoils may also be different, and the airfoil that produces a higher lift or thrust may be termed as the primary airfoil of the RA module. In a special situation, one of the airfoils in the module may be replaced by a non-airfoil body. In this case, the RA module becomes a single airfoil with counterweights and

sufficiently high lift or thrust may still be produced. Similar to a fixed-wing aircraft with foldable wings, the airfoils in the system of this invention may be folded when the vehicle travels on the ground. In the above embodiments of the RA modules, both airfoils in the RA are seen to be driven by the same reciprocating driver. However, the two airfoils in the module may be disposed at different locations and driven by two different drivers. With the motion of the same magnitude but in opposite directions, the related inertia forces and moments may still be cancelled out. The use of a larger number of smaller sized RA modules may not be always feasible, but the arrangement could minimize potential lift fluctuation at low reciprocating frequency by setting different modules with different reciprocating speeds at a given time.

The airfoils in FIG. 10 through FIG. 11e are driven by a power system, such as **510** shown in the above figures. Said power system may be, but not limited to, an internal combustion engine, a gas turbine engine, an engine driven by a pressurized gas from a storage tank, an electromagnetic force driven engine, a combination of an electric motor and fuel cell stacks, an electric motor, a battery pack, or an electric generator. Having described working principles and certain embodiments of the reciprocating lift and thrust systems of this invention, their applications to several transportation systems are disclosed.

Aircraft

The lift or thrust system of this invention may create a new category of vertical takeoff and landing (VTOL) aircraft. As an embodiment, the lift or thrust system of this invention may replace the rotary wing in a helicopter to create aircraft that can take off and land vertically, hover in the air, and easily maneuver without relying on the complex rotary lift system. Because of the higher lift-to-drag ratio of the reciprocating airfoil, the aircraft thus created may operate with much higher energy efficiency and increased flight range. FIG. 12 shows a schematic view of an aircraft **600** that employs a RA module comprising two airfoil assemblies **604** driven by at least a reciprocating driver system **608**, which in turn is driven by a power system **612**, during takeoff, landing, or hovering in the air. In this case, the reciprocating direction or plane of the airfoil assemblies **604** may be oriented substantially horizontally, while undergoing a reciprocating motion in a longitudinal direction of the aircraft similar to the cases in FIG. 11 - FIG. 11e. Like the case in FIG. 10 and FIG. 10a, the airfoil assemblies may also reciprocate in a direction generally parallel to a lateral direction of the aircraft, as shown in FIG. 13. In accordance with the coordinate designations in FIG. 1 of this disclosure, y generally designates the span direction of the airfoil while x designates its reciprocating direction. The airfoil assemblies **604** work as wings and produce a lift F_L that would counterbalance the weight and payload of the aircraft, G . For simplicity, the airfoil in the figure is a schematic view that signifies its reciprocating direction or plane, without showing detailed configuration, control mechanisms, or the change of angle of attack during the reciprocating motion. One skilled in the field may recognize that although the airfoils reciprocate in a lateral or a longitudinal direction, the airfoils may reciprocate in any suitable directions to generate needed lift. In the aircraft shown in FIG. 12, any suitable airfoil-driver arrangement such as those in FIGs. 11-11e may be employed; and in FIG. 13, any suitable airfoil-driver arrangement such as those in FIGs. 10 and 10a may be deployed. In these two figures as well as the following figures, more than one RA module may also be deployed.

Like the cyclic control of a helicopter, the airfoil assemblies **604** may be tilted in a desired direction through a control mechanism such as those in earlier embodiments to produce a thrust in that direction. As shown in FIG. 14a and FIG. 14b, the aircraft **600** flies forward in a direction designated by V_0 , and the airfoil assemblies **604** tilt in that direction, producing both a lift F_L and a thrust F_T in the forward direction. In the case shown in FIG. 14a, the reciprocating direction or reciprocating plane of the airfoil assemblies are also tilted accordingly. However, in the case shown in FIG. 14b, the reciprocating direction of the airfoils remains the same.

Similar to the forward flight, the aircraft may fly backward, right sideward, or left sideward, by tilting at least an airfoil assembly in the respective direction (not shown). In general, for an airfoil assembly reciprocating in a forward-backward direction (FIG. 14a), the forward and backward flights would involve the tilting of the reciprocating direction in the forward and backward directions, respectively, while for an

airfoil assembly reciprocating in a lateral direction (FIG. 14b), the right sideward and left sideward flights would involve the tilting of the reciprocating direction in the right sideward and left sideward directions, respectively. The tilting of an airfoil assembly may be realized by tilting its reciprocating track as discussed earlier in this disclosure, tilting a planform that includes the airfoil assemblies and the reciprocating drivers, or tilting a planform that includes the airfoil assemblies and the reciprocating drivers as well as the associated power system. However, the airfoil tilting may also be realized without involving the above actions as will be illustrated in later embodiments.

The tilting of an airfoil assembly may also produce an air braking effect to slow down the aircraft (not shown). The heading control may also be realized by tilting at least an airfoil assembly. For example, tilting a rear airfoil in left sideward direction may cause the nose 620 of the aircraft to yaw to the right (not shown). Alternatively, at least an air jet mechanism at the tail 624 or nose 620 may be employed to accomplish the heading control. Furthermore, a thrust module such as a fan may be employed to undertake this heading task (not shown). In addition to the heading control, the air jet mechanism or thrust module such as a fan may also alternatively be employed for some of the cyclic control actions (not shown).

As the operation of the aircraft changes from the takeoff to cruise, a unidirectional flow with a magnitude of the aircraft flight speed is superposed to the motion of the reciprocating airfoil, which may increase the lift of the airfoil above that needed for takeoff, particularly, when the primary stroke of the airfoil is in the same direction of the aircraft flight. In this case, the power consumption of the aircraft during the cruise may be reduced by either reducing the angle of attack of the airfoil or by reducing the average reciprocating speed of the airfoil, which may be accomplished by decreasing the rotating speed of the crankshaft when a crankshaft mechanism is employed. Furthermore, at a sufficiently high aircraft flight speed, the pitch control unit of the airfoil may be deactivated, which may have a benefit of increasing the reliability of the aircraft. Eventually, the airfoils may stop reciprocating and function as fixed wings.

In the flight conditions shown in FIG. 14a and FIG. 14b, both lift and thrust are provided by the reciprocating airfoils with or without the aid of fixed wings. Alternatively, the airfoils may primarily produce lift while a separate thrust system is used to provide the needed thrust. The related operations may include the following three modes: (A) Once the aircraft is in the air and reaches a sufficiently high speed, the airfoil assemblies may switch the operational mode and work as fixed wings to produce lift without a reciprocating motion if a thrust means is incorporated into the aircraft. When a runway for takeoff and landing is available, the aircraft of this invention may also take off and land like a fixed-wing aircraft; (B) The airfoils reciprocates to provide lift while a thrust means provides the thrust; and (C) Similar to the operation of mode A with the airfoils being arranged to produce lift due to the motion of the aircraft, but the airfoil maintains the reciprocating motion, albeit at a slower speed or smaller angle of attack, to provide additional lift, while a thrust means provides the thrust. When a runway for takeoff and landing is available, the aircraft under this mode may operate as a short takeoff and landing (STOL) aircraft, wherein the lift provided by the reciprocating airfoil enables an aircraft to take off and land on a short runway.

FIG. 15 shows schematically an embodiment of mode A when the airfoil assemblies 604 work as fixed wings to produce lift without a reciprocating motion during cruise, while a reciprocating thrust system 640 of this invention is employed to produce thrust F_T to push the aircraft forward. With the thrust from the thrust system 640, the airfoil assemblies 604 may be arranged in such a manner that they form a larger fixed wing assembly with a desired positive angle of attack to produce needed lift for the aircraft, as shown in FIG. 15a. The two airfoil assemblies 604 may also move as closer as possible to each other to reduce the distance between them under the fixed-wing flight mode. Additionally, because of the independent control mechanisms, the rear airfoils may be deflected more downwardly to function as a trailing edge flap (not shown). This trailing edge flap as a high-lift device may be especially important when the aircraft of this invention takes off and lands like a fixed-wing aircraft with the availability of a runway.

A schematic view of the thrust system 640 employing a crankshaft reciprocating driver is shown in FIG. 16. The thrust system 640 may include at least two airfoil assemblies, 642 and 644, that are configured to reciprocate in a direction generally perpendicular to the aircraft flying direction, producing a thrust F_T in that direction. The related members of the crankshaft driver, crankshaft 648, cranks 650 and 656, connecting rods 652 and 658, as well as the airfoil tracks 654 and 660, are also shown in the figure. Additional airfoil

assemblies may be needed to more completely balance the related inertia forces and moments, and a reciprocating driver other than the crankshaft driver can also be employed for the thrust system **640** herein. It is important that the airfoils of the thrust system, such as **642** and **644** in FIG. 16, be substantially exposed to the ambient. Any supporting structures, such as **630** or **632** (such as bars, beams, or trusses) shown in FIG. 15 and FIG. 15a, are primarily for the integrity of the aircraft without significantly hindering the exposure of the airfoils to the ambient. Furthermore, the thrust system **640** may be deployed at a tail section **624** for better exposure to the ambient (not shown). The power system that is needed to drive the thrust system **640** may be a separate power system (not shown). Alternatively, the same power system, such as **612** in FIG. 15, may also be used to drive the thrust system **640**.

The thrust system **640** in FIG. 15 or FIG. 15a is seen as being separated from the lift-producing airfoil assemblies **604** and being deployed between the aircraft main body and the tail section **624**. However, the thrust system **640** may be a member of the airfoil-assembly family **604** having multiple airfoil assemblies, which may also produce lift. But at least one of the airfoils associated with the lift or thrust system **604** may be tilted in a more vertical position to mainly produce thrust as needed (not shown).

FIG. 17 shows schematically an embodiment of mode B when the airfoils reciprocate substantially in a horizontal direction to provide lift, while a different thrust means, such as a propeller **670**, is deployed to provide thrust for the flight. In general, a thrust means, such as but not limited to, a fan, a propeller, a jet, or a jet engine, may be disposed at a suitable section of the aircraft to provide the thrust needed.

FIG. 18 illustrates schematically an embodiment of a jet engine powered aircraft according to the present invention wherein the airfoil assemblies **604a** and **604b** may provide needed lift during vertical takeoff and landing and the jet engine **680** may provide the needed thrust during cruise. The airfoils assemblies **604a** and **604b** may be powered by a separate power source, but they may also be powered by the same jet engine **680**. The jet engine **680** may include an auxiliary turbine **682** such as a radial or axial type, or a transmission mechanism to extract power from an engine turbine shaft, to drive the airfoil assemblies through a driveshaft **684**, a transmission means **686**, and a crankshaft **692**. To allow the airfoils to be disposed close to the aircraft main body, the crankshaft is preferably deployed in a substantially vertical orientation to the aircraft body and two cranks **688a** and **688b** are arranged along the crankshaft to respectively drive airfoils **604a** and **604b**. The jet engine **680** may be equipped with a three-way gas flow control means to control the gas flow to the auxiliary turbine. During takeoff, landing, or hovering, the combustion gas after a power turbine may mostly or completely be routed to the auxiliary turbine to drive the reciprocating airfoils assemblies **604a** and **604b**. Once the aircraft is in the air and reaches a certain speed, as the airfoils begin to function partially as fixed wings with reduced reciprocating speed and power demand, the power to drive the airfoils may be reduced. The percentage of the gas flow to the auxiliary turbine may be reduced, while the gas flow to the jet engine nozzle is increased for thrust. At a sufficiently high aircraft speed, the gas flow to the auxiliary turbine may be completely stopped and the airfoil assemblies would work completely as fixed wings and the aircraft operates as a fixed-wing jet engine aircraft. If the aerodynamic interaction of the airfoils **604a** and **604b** under high-speed flight would affect performance, the airfoil **604b** could have a substantially reduced size, just having enough mass to balance the inertia forces and moments, as shown in FIG. 18. Alternatively, the airfoil **604b** could be completely removed and replaced by counterweights (not shown). Another option is to employ the reciprocating airfoils/fixed wings combination as shown in FIG. 10a in this jet-engine powered aircraft (not shown). Finally, the track **690** may preferably be disposed on the top surface of the aircraft body and fasteners may be used to more securely fixed the airfoils to the aircraft body when the airfoils work as fixed wings.

With respect to the embodiment of mode C when the lift provided by the airfoil assemblies as the fixed wings, such as those shown in FIG. 15 or FIG. 15a, is not enough, some or all the airfoils **604** may also reciprocate to provide additional lift. The reciprocating action, even at a substantially reduced reciprocating speed, may have the benefit of drag reduction due to a significantly decreased trailing-edge vortex level of the airfoils. Again, for all three operational modes, any suitable thrust means may be employed, not limited to the one shown in a respective figure.

Furthermore, permanent fixed wings **680** may be added to further increase lift needed, as shown in FIG. 19, employing a propeller system for thrust. One skilled in the art may recognize that although some

primary objectives of this invention is to generate lift and thrust, the reciprocating system of this invention can be employed to primarily generate thrust. In this regard, as an example, the airfoil assemblies 604 in FIG. 19 as well as the reciprocating driver system 608 may be removed. Thus, as schematically shown in FIG. 20, the fixed wings 680 would provide lift for the aircraft while the reciprocating thrust system 640 would provide thrust for the aircraft, creating a fixed-wing aircraft powered by the reciprocating thrust system of this invention. In comparison with a propeller powered fixed-wing aircraft, reciprocating thrust system of this invention could operate at a much higher flight speed with a significantly increased thrust-to-drag ratio. As a result, a fixed-wing aircraft equipped with the thrust system of this invention could significantly improve the energy efficiency and extend the flight range.

The disclosed reciprocating lift and thrust systems according to this invention are not limited to the aircraft shown in the above embodiments; they may be employed in any aircraft within a broad category of vertical takeoff and landing (VTOL) aircraft that include a variety of types of aircraft, such as fixed-wing aircraft, helicopters and other powered aircraft such as tiltrotors. In addition to the aircraft for conventional transportation purposes, the reciprocating lift and thrust systems may be used for military jets, unmanned aerial vehicles (UAV), recreational aircraft, and personal vehicles. When the system of this invention works as a thrust means, it may replace the propeller or jet engine of fixed-wing aircraft and use a runway for takeoff and landing.

Flying Motor Vehicles

The lift or thrust system in accordance with this invention may be employed to build a flying motor vehicle such as a flying car 700, which is schematically shown in FIG. 21, when the car travels on the ground. In addition to the airfoil assemblies 704 driven by a reciprocating driver system of this invention 708 for the lift, the flying car shown in FIG. 21 may employ a reciprocating thrust system 640 of this invention to provide thrust when the car is in the air. When the car is travelling on the ground, a power system such as a combustion engine or an electric motor/battery system in conjunction with a transmission system may be employed to drive the car (not shown). However, the reciprocating thrust system 640 may also be used to drive wheels, such as 710 or 714, on the ground (FIG. 21). A single power system, such as 720, may provide the needed power when the flying car is both in the air and on the ground. For example, when the car is on the ground, the power system 720 may disengage the reciprocating driver 708 for the airfoils 704 or the thrust system 640 (if such system is deployed) and provide power for the wheels 710 or 714. However, the power system 720 may disengage the reciprocating driver 708 for the airfoils 704 and provide power for the thrust system 640 to drive the wheels 710 or 714. It is also understandable that the thrust system may be powered by a separate power system (not shown).

Once a flying car is in the air, as shown in FIG. 22, many flying modes as well as operational control mechanisms including cyclic control and heading may be similar to those of the embodiments related to aircraft (FIGs. 6-20), and therefore they will be repeated herein. Furthermore, permanent fixed wings may be added to the flying car for further lift. Particularly, the fixed wings may aid in short-distance takeoff or landing, and the wings including the reciprocating airfoils may also be folded whenever necessary, such as the cases when the car is travelling on the ground (not shown).

Although the above embodiments are related to flying cars, flying buses, flying trucks, flying motorcycles, and flying off-road vehicles can be similarly constructed using the reciprocating lift and thrust systems of this invention. Because they may use similar systems of this invention, the related illustrations are not presented herein.

Ships, Submarine, and Boats

So far in this invention, a gaseous fluid such as air is involved for the operation of the airfoil assemblies of this invention. However, the thrust system can also be employed for watercraft or waterborne-vessel propulsion to generate thrust and move a ship, a submarine, or a boat across water. FIG. 23 shows

schematically a submarine **800** that incorporates a reciprocating system of this invention as a thrust system **804** for the submarine propulsion. Similar to the reciprocating systems such as those shown in FIG. 7 and FIG. 16 when a mechanical driver involving a crankshaft is employed, said reciprocating thrust system includes at least two airfoil assemblies **808** and **814** submerged in the water and driven by a reciprocating driver **818**. The airfoils and the reciprocating driver are so configured that a thrust F_T is produced by the reciprocating airfoils, which pushes the submarine forward. The reciprocating driver **818** may also be one of the other reciprocating-driver types disclosed before. Like the reciprocating system in FIG. 7, the reciprocating system in FIG. 23 may be able to substantially isolate the water surrounding the airfoils from the inside space of the submarine **800** or the reciprocating driver **818** inside of the submarine. Additionally, many embodiments of this invention related to the pitch control units as well as the cyclic control mechanisms may be applicable to this marine application. In FIG. 23, two airfoils are being seen, however additional airfoils may be employed for higher thrust and more complete balance of the inertia forces and moments. Although the illustration of the application of this invention in FIG. 23 is for a submarine, similar applications to ships or boats can be undertaken with the airfoil being submerged in the water. One skilled in the art may have noticed that the two airfoils, as schematically shown in FIG. 23, reciprocate vertically. However, this is for the demonstration purpose; the two airfoils may also reciprocate in a horizontally direction (not shown). Because of sufficiently high thrust-to-drag ratio of the reciprocating thrust system, the replacement of a conventional propeller for a watercraft by the system of this invention could significantly reduce the power consumption of the watercraft.

One of the important elements of the reciprocating lift and thrust systems disclosed is the control mechanism. Similar to a helicopter, a present vehicle capable of vertical takeoff and landing (VTOL) may also require cyclic control functionality through adequate control mechanisms. In general, the control mechanisms of this invention may facilitate rotating airfoils, preferably near the end of a reciprocating stroke, as well as raising or lowering the airfoils. In a special case when the rotation center of an airfoil is on an airfoil chord line but off the airfoil, the rotation of the airfoil may also have the outcome of raising or lowering the airfoil. Any control mechanism that would accommodate the needed functionality may be within the scope of this invention, which may be, but not limited to, a mechanical, electromagnetic, electrical, or hydraulic control system. Energy or action may be needed to actuate needed control activities. For example, electrical energy may be needed for triggering a control activity when an electromagnetic or electrical control unit is employed. The needed energy source may be carried with the reciprocating airfoil assembly, which, however, may increase the associated inertia force or may not be physically permissible. One of the advantages of the reciprocating system of this invention, just like many other reciprocating systems, is that the moving speed of an airfoil assembly near each dead end of a stroke is small or nearly zero, which may provide a window of opportunity to provide mechanical action or electric power to facilitate control objectives. During the takeoff or landing, the airfoil loads such as lift or thrust near the dead ends of a stroke may be nearly zero, so that the power consumption of a control mechanism is rather limited.

FIG. 24 shows schematically an airfoil assembly employing a push or pull rod (or tube) related mechanical control mechanism **108**. Two stoppers, **160** and **162**, are respectively disposed near the left and right dead ends of a reciprocating stroke of the airfoil assembly **102**. While both stoppers do not reciprocate with the airfoil assembly, two moving contacts, **164** and **166**, are part of the airfoil assembly, which may experience the same reciprocating motion of the airfoil assembly **102** but may move relative to the rest of the airfoil assembly when being actuated upon by a stopper. Referring to FIG. 24, as an example, when the stoppers may be actuators, the moving contact **164** of the airfoil assembly strikes the stopper arm **160a** when the airfoil is near its left dead end of the stroke while moving from the right to the left end. An enlarged view related to this action is schematically shown in FIG. 25. The stopper **160a** creates a motion of the contact **164**, V_r , relative to the airfoil, from the left to the right, which may trigger an action of the control rod **108b** to push the airfoil **102** up and an action of the rod **108a** to pull the airfoil **102** down, thereby generating a desired angle of attack for the next stroke from the left to the right. When the airfoil **102** is near the right dead end, the moving contact **166** would strike the stopper **162a**, which may trigger an

action of the control rod **108a** to push the airfoil **102** up and an action of the rod **108b** to pull the airfoil **102** down, creating a desired angle of attack for the next stroke from the right to the left (not shown).

FIG. 26 shows a schematic illustration of an embodiment of the control system using a rack-pinion gear unit. Said unit includes a rack gear **170** that includes a tooth section and a contact **164** on the left and a contact **166** on the right, a pinion gear **172** engaging the rack gear **170**, and a control arm **174** that rotates with the gear **172** and engages push/pull rods **108a** and **108b** that in turn engage an airfoil **102**. Through a linear motion of the rack gear **170**, actuated by stoppers as discussed in FIG. 24 (not shown), which causes a rotation of the gear **172** and the action of the push/pull rods, the airfoils **102** may be rotated around a joint **176** clockwise or counter-clock wise to set or change the angle of attack for reciprocating strokes. In FIG. 26, the rack-pinion gear unit is integrated with a roller or bearing unit **178** that integrates with the airfoil through the joint **176** and engages an airfoil track (not shown). For a relatively large pinion gear, the control arm **174** may be eliminated and the push/pull rods **108a** and **108b** may directly engage the gear **172**.

In the embodiment shown in FIG. 26, the rotating center of the airfoil is seen near the pressure center of the airfoil **102** during a primary stroke. However, the airfoil may be rotated around any center of rotation for the performance and structural considerations. FIG. 27 shows a schematic illustration of an embodiment of a control system that rotates the airfoil near the leading edge of the airfoil through a rack-pinion gear unit. Said unit includes a rack gear **170**, a pinion gear **172** engaging the rack gear **170**, and a push/pull rod **108** that engages the gear **172** and the airfoil **102**. Through a linear motion of the rack gear **170**, actuated by stoppers (not shown), the airfoils **102** may be rotated around a joint **176** near the leading edge clockwise or counter-clock wise to set or change the angle of attack of the airfoil. To prevent the rotation of the gear **172** under airfoil loads after the action is nearly complete, a locker mechanism **180** may be disposed. The locker **180** may be part of the rack gear **170** and would move with the rack gear. Once the rack gear reaches a desired position for the rotation of the airfoil, the locker **180** may engage a section of the gear system **172** and locks the gear **172** in place. The section may rotate or not rotate with the gear **172** and the position of the locker on the rack gear may be adjustable. A similar locker may also be disposed on the left side of the rack gear **170** or in the system associated with FIG. 26, although they are not shown. Again, the roller or bearing system **178** may be integrated with the airfoil and the rack-pinion gear unit. For structural concern, the roller system may be so positioned that the resultant load forces may be near a midsection of the roller system.

A similar rack-pinion gear unit may also be employed to raise or lower an airfoil. FIG. 28 shows a schematic illustration of an embodiment of the control system using a rack-pinion gear unit to raise or lower an airfoil **102**. In this case, the airfoil **102** may be supported by a movable beam **182** having a tooth section **186** through a joint **176**. The beam **182** is housed by a holding tube **184** that may be integrated with a roller or bearing (not shown) and has an open section for the teeth **186** of the beam **182**. The teeth **186** engage the pinion gear to raise or lower the airfoil **102** due to the rotation of the pinion gear **172** driven by the motion of the rack gear **170** (In this case behind the holding tube **184**). To limit the displacement of the airfoil, stoppers **188** may be disposed on a top position of the holding tube **184**.

In addition to a common need to rotate an airfoil near the end of a stroke to maintain the angle of attack for the following stroke, the magnitude of the angle of attack may need to be adjusted due to the change in lift demand. This may be achieved through adjusting the rotating angle of the airfoil through adjusting the position of the stopper arm or the stopper. Referring to FIG. 24, starting from a symmetric deployment of the two stopper arms, **160a** and **162a**, with a reference to the midsection of a stroke that is approximately defined based on the midsection of a roller **114** in FIG. 24, an equal amount of symmetric displacement of the two stoppers toward the midsection of the stroke could increase the rotating angle of the airfoil and subsequently its angles of attack for both strokes in a reciprocating cycle. On the other hand, an equal amount of symmetric displacement of the two stoppers away from the midsection of the stroke could decrease the rotating angles of the airfoil and subsequently its angles of attack for both strokes in the reciprocating cycle.

A dissymmetric displacement of the two stoppers would have the effect of tilting the reciprocating direction or plane of an airfoil. Recalling the discussion related to the control unit in FIG. 6, the reciprocating direction of the airfoil may be tilted through tilting the airfoil track or the entire reciprocating

system. However, this option sometimes may be undesirable or impractical. Without tilting the track, the reciprocating direction of an airfoil may be defined as the average angle of attack (AoA) of the two strokes in a reciprocating cycle with reference to the direction of the vehicle flight or track. For example, if the AoA of a primary stroke, moving in the vehicle cruise direction, is based on the conventional definition and the AoA of the reverse stroke is based on the negative of the conventional definition, a positive AoA of 25 degree for the primary stroke and a negative AoA of 5 degree for the reverse stroke would result in tilting the airfoil by 10 degree relative to the flight direction. This may be interpreted as that the airfoil has tilted backward by 10 degree. The effective AoA with reference to the tilted direction would be positive 15 degree for the primary stroke. On the other hand, a positive AoA of 5 degree for the primary stroke and a negative AoA of 25 degree for the reverse stroke would result in tilting the airfoil by -10 degree relative to the flight direction. This may be interpreted as that the airfoil has tilted forward by a 10 degree, and the effective AoA with reference to the tilted direction would be positive 15 degree for the primary stroke. The above results are based on unweighted average AoA of the two strokes; if a weighted average on the basis of performance is used, the outcome could be changed.

The airfoil tilting as defined herein may be realized by a dissymmetric displacement of a stopper. As an example, starting from the symmetric deployment of both stoppers in FIG. 24, a displacement of the stopper **162a** toward the midsection of the stroke without the displacement of the stopper **160a** would increase the angle of attack for the primary stroke for the airfoil **102** in FIG. 26 without a corresponding increase in the angle of attack for the reverse stroke, effectively tilting the reciprocating direction of the airfoil. During the vehicle cruise under certain conditions, the airfoil may be maintained at a desired tilting angle without change even if the airfoil is under a reciprocating motion. This may be achieved by adjusting the position of one stopper to generate the desired angle of attack when this stopper engages the corresponding moving contact. At the same time, the other stopper may retreat away from the midsection of the stroke to a position that is out of the range of possible engagement with the corresponding moving contact. Eventually, the first stopper would also retreat to a position without possible engagement with its corresponding moving contact. The outcome is the deactivation of the pitch control unit and the airfoil is maintained at an angle relative to the flight direction without change.

The cyclic control functionality may also involve tilting the airfoil right sideward or left sideward, which may be achieved by employing the control unit shown in FIG. 28. As an example, consider the cyclic control of airfoil **504** in FIG. 11b. As an option, the roller **530a** may involve the functionality of pitch control including forward and backward tilting, while roller **530b** may install a control unit like that in FIG. 28 and involve right sideward or left sideward tilting of the airfoil. Starting from a neutral position of the airfoil, with the engagement of one stopper with its corresponding moving contact, the beam **182** in FIG. 18 may be raised, which may cause an upward rotation of the airfoil **504** around a joint associated with roller **530a**, resulting in a left sideward tilting of the airfoil. With the retreat and disengagement of the stopper and the engagement of the other stopper with its corresponding moving contact, the beam **182** may be lowered, which may return the airfoil to its initial position or cause a downward rotation of the airfoil **504** around the joint associated with roller **530a**, resulting in a right sideward tilting of the airfoil.

In the illustrations so far, the function of rotating, raising, or lowering an airfoil is achieved by separate control units. However, these control units may be combined into one control system that could undertake both rotating as well as raising or lowering tasks. The change of the position of a stopper may be realized through the change in the length of the arm for an actuator stopper. However, the position of the actuator may also be changed through other means. Stopper contacts such as **160a** and **162a** and moving contacts such as **164** and **166** may be configured structurally or materially to mitigate potential damage or noise during engagements between the stopper and moving contacts (not shown).

In addition to the mechanical control units, other control units may also be used. Referring to FIG. 29, when an electromagnetic or electrical control unit is employed, the stoppers **160** and **162** in FIG. 24 may be respectively replaced by stationary contacts **192a** and **192b**, while the mechanical contacts **164** and **166** in FIG. 24 may be respectively replaced by moving electrical contacts **194a** and **194b**. In the condition shown in FIG. 29, as an example, the airfoil **102** is near the left dead end in a stroke from the right to the left, and the left moving electrical contact **194a** is in contact with the stationary contact **192a**. An enlarged

view related to this action is schematically shown in FIG. 30, wherein the moving contact **194a** pushes the electrical contact of **192a** to the left supported by a spring coil **196**. The circuit formed by electrical wires **198a** and **198b** are thus closed and electricity is supplied to the control unit **108** of the airfoil **102** to rotate the airfoil **102** as it changes its direction and moves from the left to the right. For most figures in the embodiments of this invention, the pitch control units are shown to be push or pull rod related. However, this is for illustration purposes; other types of control units are also within the scope of this invention. For example, the control unit **108** in FIG. 29 may be in terms of a motor that rotates the airfoil **102** through a hinge to produce a positive angle of attack for the second stroke and lock it in place near the dead end of a first stroke in a reciprocating cycle. Alternatively, the rotation center may be located at another location of the airfoil assembly, as discussed before. In addition to changing or maintaining the angle of attack of an airfoil when the airfoil changes the direction of its motion from one stroke to the next, the magnitude of the angle of attack may be changed to adjust the lift or thrust needed during operation. This may be accomplished by adjusting the current flow through the circuit.

Due to the schematic nature of the drawings in the embodiments, the ratio of the stroke to the airfoil chord in the figures may not be to scale. Although a short stroke is within the scope of this invention, a longer stroke may have the benefit to reduce the reciprocating frequency requirement for a given average reciprocating speed, which in turn may be beneficial for the reduction of inertial forces and moments. A longer stroke may have aerodynamic advantages of attaining a higher lift or thrust coefficient as well as lift-to-drag ratio. As discussed before, the trailing-edge vortex, which may have a significant effect on the performance of a fixed wing, may have a reduced effect on a reciprocating wing. However, tip or trailing vortex or may have certain adverse effect on a finite-span reciprocating airfoil, which may be addressed by existing techniques such as winglets, or special devices that are unique to reciprocating wings may be considered for this purpose.

In some applications in which simplicity may be one of the most important factors, an airfoil may be configured to work without a pitch control unit. For example, the airfoil for this purpose may be specially designed so that in the first stroke or primary stroke with a positive angle of attack, significant lift or thrust is generated. However, in the second stroke or reverse stroke with a negative angle of attack (without the rotation near the end of the first stroke), negative lift or thrust is produced. However, the combination of the two strokes in a cycle may still produce a meaningful lift or thrust.

As discussed before, a reciprocating lift or thrust system of this invention may be considered to work in cycle. Accordingly, the working principle described in conjunction with FIGs. 1-4 may be regarded as working in a two-stroke cycle with substantial rectilinear motion between the two ends of a stroke. However, the airfoil may work in a cycle with more than two strokes. The airfoil may also accommodate certain non-linear motion between the two ends of a stroke for desired lift or thrust.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application. All patents, patent applications, provisional applications, and publications referred to or cited herein are incorporated by reference in their entirety, including all figures and tables, to the extent they are not inconsistent with the explicit teachings of this specification.

References cited:

1. Thang010146. "Mechanism for Increasing Stroke Length 3." *YouTube* video, December 3, 2014. <https://www.youtube.com/watch?v=ITYKyGWmD9Q>
2. Thang010146. "Mechanism for Increasing Stroke Length 2." *YouTube* video, December 3, 2014. <https://www.youtube.com/watch?v=4G6mSwPguK4>

CLAIMS

What is claimed is:

1. A reciprocating lift or thrust system, comprising:
at least an airfoil with configured angle of attack; and
a reciprocating driver configured to produce a reciprocating motion of said airfoil for lift or thrust.
2. The reciprocating lift or thrust system according to claim 1, further comprising at least a control unit to facilitate at least one of the following actions: rotating said airfoil by an angle, raising said airfoil, and lowering said airfoil.
3. The reciprocating lift or thrust system according to claim 2, the control unit being at least one of a mechanical control unit, an electromagnetic control unit, an electrical control unit, and a hydraulic control unit.
4. The reciprocating lift or thrust system according to claim 2, said control unit being actuated when the airfoil is near or at a dead end of a reciprocating stroke by an actuating means that does not reciprocate with the airfoil.
5. The reciprocating lift or thrust system according to claim 1, the reciprocating driver being at least one of a mechanical driver, an electromagnetic driver, an electrical driver, and a hydraulic driver.
6. The reciprocating lift or thrust system according to claim 5, the mechanical driver being at least one of a crankshaft related slider-crank mechanism driver, a cam-follower mechanism driver, a scotch yoke mechanism driver, a swash plate mechanism driver, and a wobble (Nutator or Z-crank) driver.
7. The reciprocating lift or thrust system according to claim 5, the reciprocating driver being a hydraulic driver, said hydraulic driver including a loop of liquid body, a larger piston in the loop driven by a reciprocating driver having a smaller reciprocating stroke, and a smaller piston in the loop engaging the airfoil, thereby the smaller stroke of the reciprocating driver being amplified to produce a longer reciprocating stroke of the airfoil.
8. The reciprocating lift or thrust system according to claim 6, said mechanical driver being a crankshaft related driver and the reciprocating stroke of the airfoil being increased without increasing the crank radius by incorporating a slotted bar and slider mechanism; said slotted bar driving the airfoil at one section of the bar and in turn being driven by the crankshaft through a connecting rod and a slider on the bar in a midsection of the bar; and said slotted bar being pivoted through a slider that allows the bar to swing and slide through.
9. The reciprocating lift or thrust system according to claim 6, said mechanical driver being a crankshaft related driver and the reciprocating stroke of the airfoil being increased without increasing the crank radius by incorporating a slotted bar and a fixed track creating a linear motion for a first section of the bar; said slotted bar driving the airfoil at a second section of the bar and in turn being driven by the crankshaft at the first section through a connecting rod and a slider along the fixed track; and said slotted bar being pivoted through a slider that allows the bar to swing and slide through at a third section of the bar.
10. The lift or thrust system according to claim 1, two of said reciprocating airfoils forming a reciprocating airfoil (RA) module, said two airfoils in the module being driven by the same reciprocating driver and moving with almost the same velocity magnitude, but in opposite directions, to cancel out the inertia forces and moments related to the acceleration or deceleration of the airfoils and their supporting structures.
11. The lift or thrust system according to claim 1, at least one reciprocating lift or thrust system being employed in an aircraft to provide lift or thrust for flight operations, said aircraft being at least one of a vertical takeoff and landing (VTOL) aircraft, a short takeoff and landing (STOL) aircraft, an unmanned aerial vehicle (UAV), a recreational aircraft, a personal vehicle, or a fixed-wing aircraft.
12. The aircraft according to claim 11, the airfoil in the reciprocating system providing lift for takeoff, landing, or hovering, and said airfoil tilting in a direction to provide both lift and thrust for the flight of the aircraft.
13. The aircraft according to claim 11, said reciprocating lift and thrust system producing lift for

the aircraft while the thrust being provided by at least one of a fan, a propeller, an air jet, and a jet engine for the flight of the aircraft.

14. The aircraft according to claim 11, at least one reciprocating lift and thrust system providing thrust for the aircraft while the lift being provided by another reciprocating lift and thrust system for the aircraft.

15. The aircraft according to claim 11, said reciprocating lift and thrust system providing thrust for the aircraft while the lift being provided by fixed wings.

16. The aircraft according to claim 11, the reciprocating function of said lift and thrust system being deactivated and the airfoils of the reciprocating lift and thrust system function as fixed wings to provide lift under a sufficiently high aircraft flight speed.

17. The aircraft according to claim 11, the reciprocating driver in the reciprocating lift and thrust system being a crankshaft related driver, said driver being disposed in a generally perpendicular direction to the aircraft's main body to reduce the distance between the airfoils and the top or bottom surface of the aircraft.

18. The aircraft according to claim 11, the airfoils in said reciprocating lift and thrust system being shaped like the wings of a fixed-wing airplane and being disposed with his span generally perpendicular to a front-back direction of the aircraft; said airfoils reciprocating in the front-back direction to generate lift during aircraft takeoff, landing, or hovering; and said airfoils utilizing the aircraft's flight speed to generate needed lift while working under reduced reciprocating speed or non-reciprocating condition for energy conservation.

19. The aircraft according to claim 11, at least two airfoils in said reciprocating lift and thrust system being disposed with their spans generally parallel to a front-back direction of the aircraft; said airfoils reciprocating in a lateral direction generally perpendicular to the front-back direction and being guided and supported, respectively, by two fixed wings; and said reciprocating airfoils tilting forward to provide both lift and thrust, while said fixed wings generating additional lift for the aircraft.

20. The lift or thrust system according to claim 1, at least one reciprocating lift or thrust system being employed in a flying motor vehicle to provide lift or thrust, said flying motor vehicle being at least one of a car, a bus, a truck, a motorcycle, or an off-road vehicle.

21. The flying motor vehicle according to claim 20, the airfoil in the reciprocating system providing lift for takeoff, landing, or hovering, and said airfoil tilting in a direction to provide both lift and thrust for the flight of the flying motor vehicle.

22. The flying motor vehicle according to claim 20, said reciprocating lift and thrust system producing lift for the vehicle while the thrust being provided by at least one of a fan, a propeller, an air jet, and a jet engine for the flight of the vehicle.

23. The flying motor vehicle according to claim 20, at least one reciprocating lift or thrust system providing thrust while the lift being provided by another reciprocating lift or thrust system.

24. The flying motor vehicle according to claim 20, said reciprocating lift and thrust system providing thrust for the flying motor vehicle while lift being provided by fixed wings.

25. The flying motor vehicle according to claim 20, the reciprocating function of said lift and thrust system being deactivated and the airfoils of the reciprocating lift and thrust system function as fixed wings to provide lift under a sufficiently high vehicle flight speed.

26. The flying motor vehicle according to claim 20, the reciprocating driver in the reciprocating lift or thrust system being a crankshaft related driver, said driver being disposed in a generally perpendicular direction to the vehicle's main body to reduce the distance between the airfoils and the top or bottom surface of the vehicle.

27. The flying motor vehicle according to claim 20, the airfoils in said reciprocating lift or thrust system being shaped like the wings of a fixed-wing airplane and being disposed with his span generally perpendicular to a front-back direction of the vehicle; said airfoils reciprocating in the front-back direction to generate lift during vehicle takeoff, landing, or hovering; and said airfoils utilizing the vehicle's flight speed to generate needed lift while working under reduced reciprocating speed or non-reciprocating condition for energy conservation.

28. The flying motor vehicle according to claim 20, at least two airfoils in said reciprocating lift and thrust system being disposed with their spans generally parallel to a front-back direction of the vehicle; said airfoils reciprocating in a lateral direction generally perpendicular to the front-back direction and being guided and supported, respectively, by two fixed wings, and said reciprocating airfoils tilting forward to provide both lift and thrust, while said fixed wings generating additional lift for the vehicle.

29. The flying motor vehicle according to claim 20, said vehicle being driven by a reciprocating thrust system while said vehicle travelling on the ground.

30. The thrust system according to claim 10, said reciprocating thrust system being employed in at least one of a submarine, a ship, and a boat, to provide thrust for watercraft propulsion, while said airfoils of the system being submerged in the water and the water being substantially separated from the inside space of the watercraft by a partition structure.

31. The control unit according to claim 2, said control unit being a rack-pinion gear related unit.

32. The hydraulic driver according to claim 7, at least one loop section being a track for the airfoil.

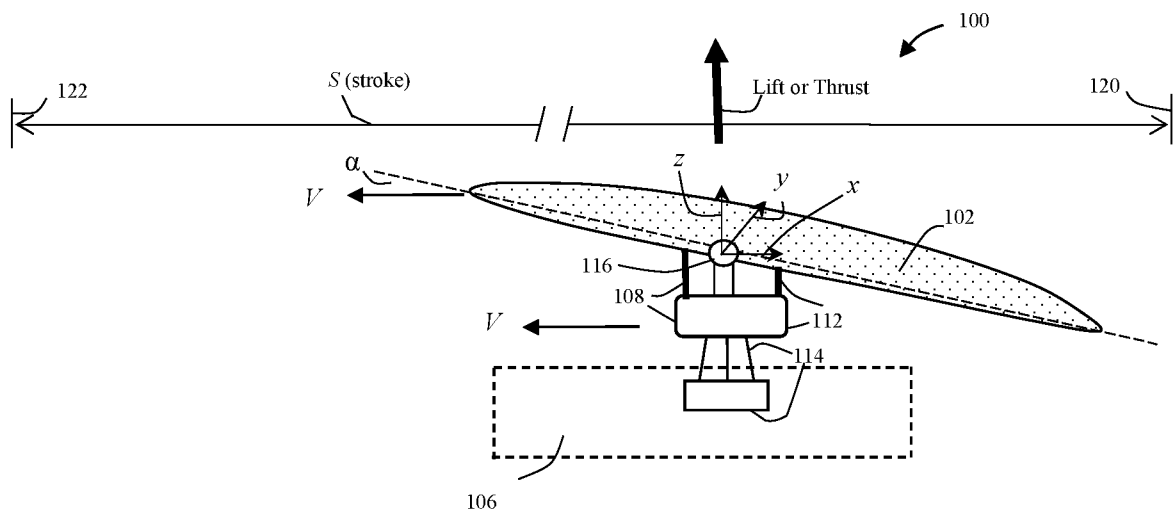


FIG. 1

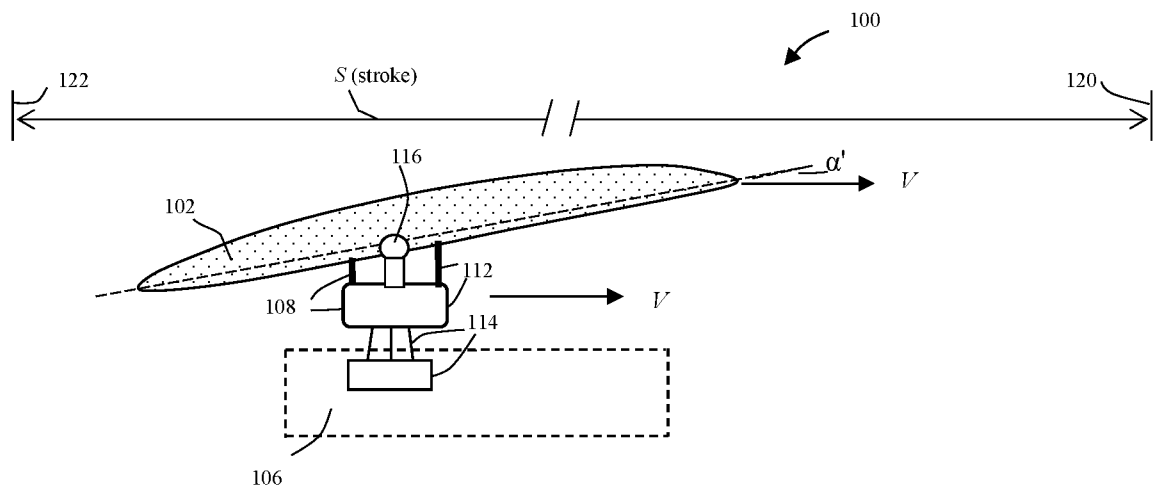


FIG. 2

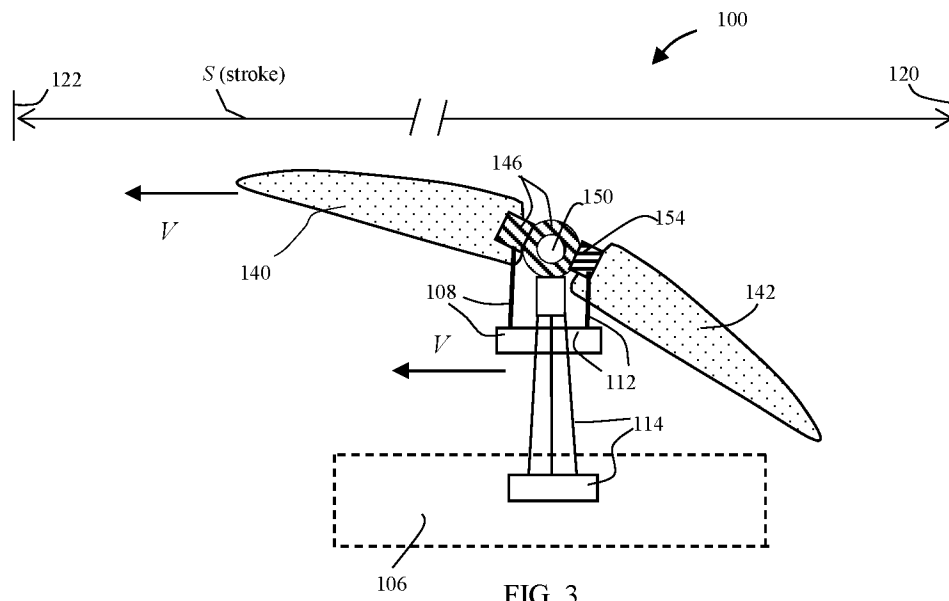


FIG. 3

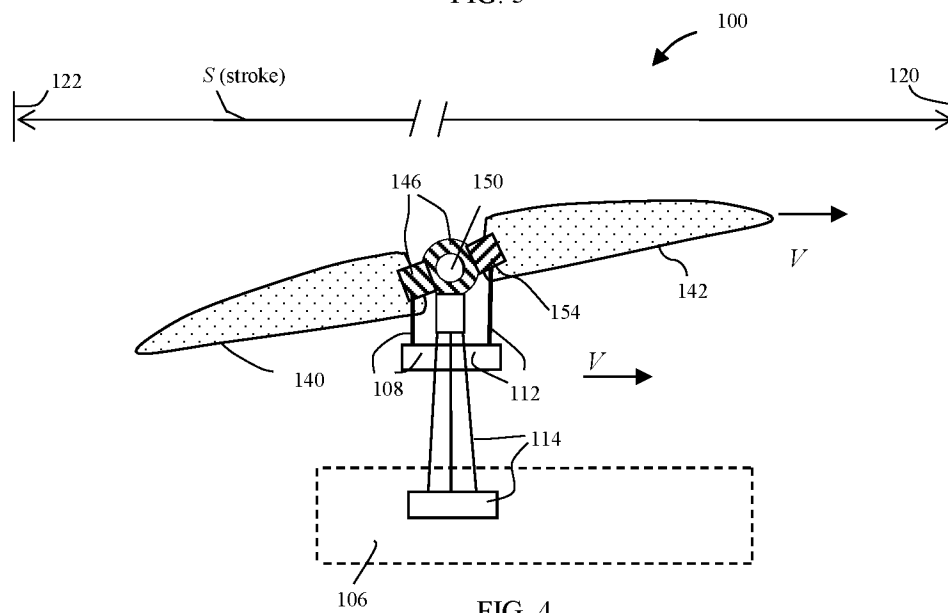


FIG. 4

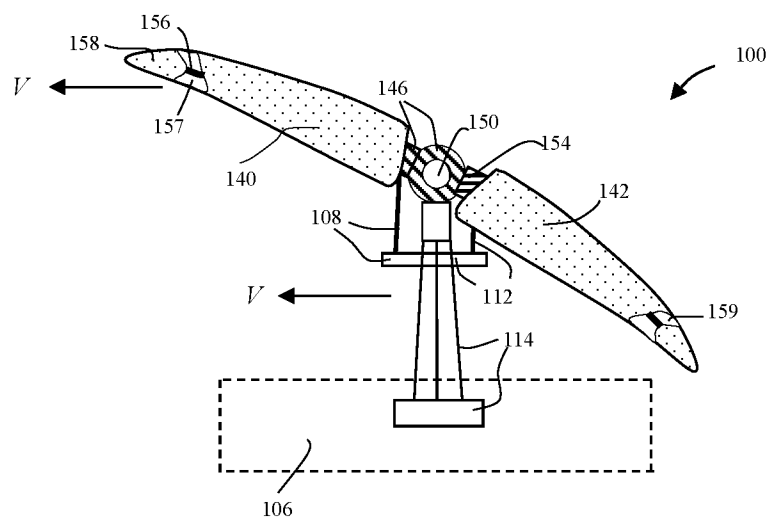


FIG. 4a

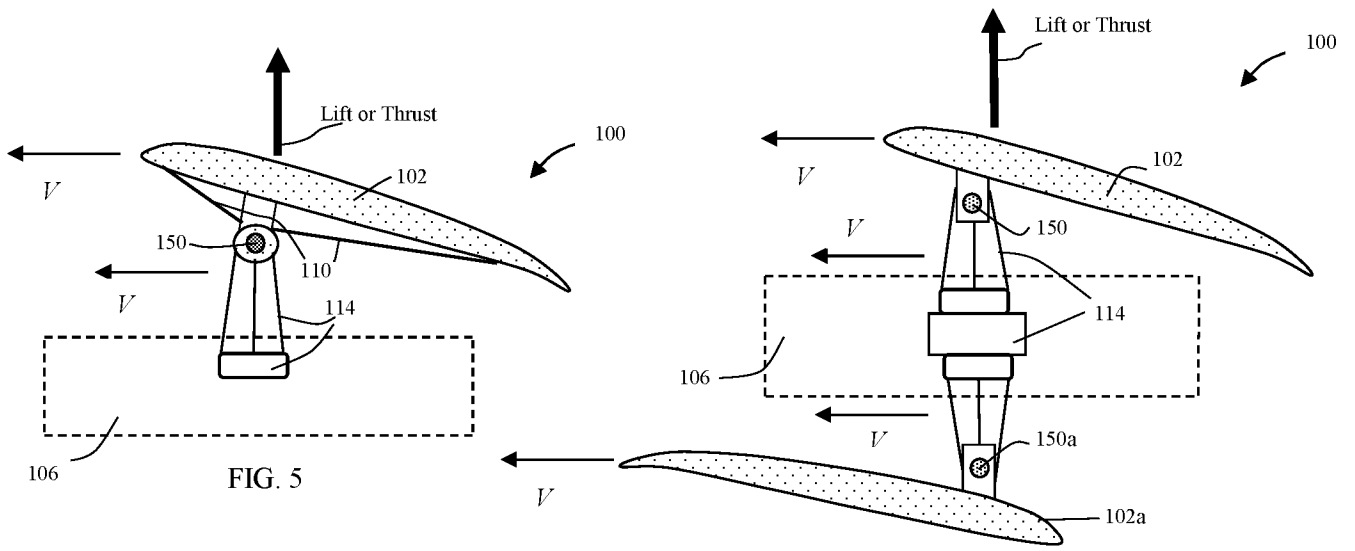


FIG. 5

FIG. 5a

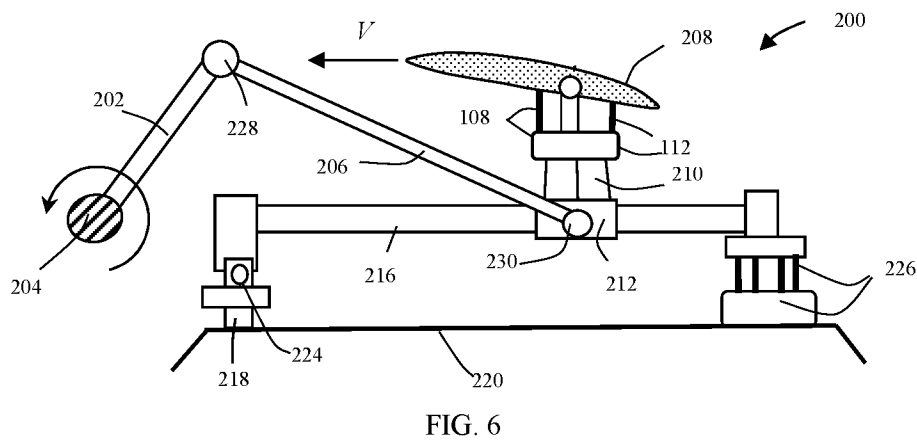


FIG. 6

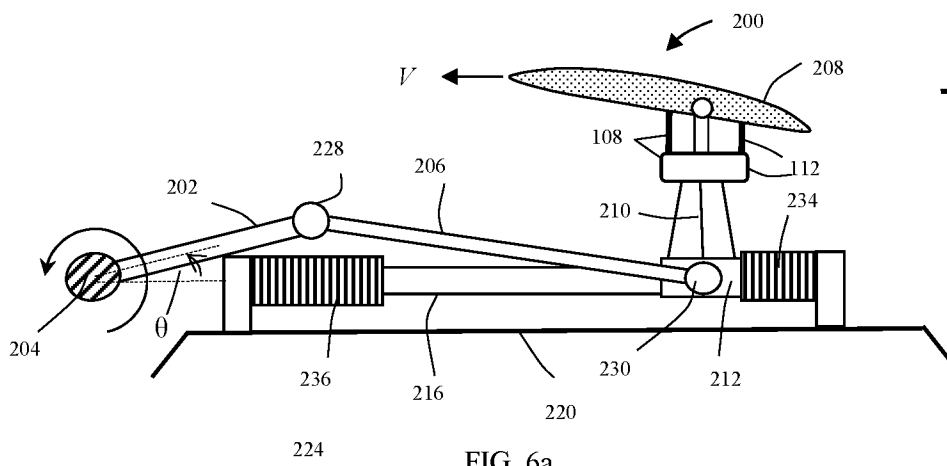


FIG. 6a

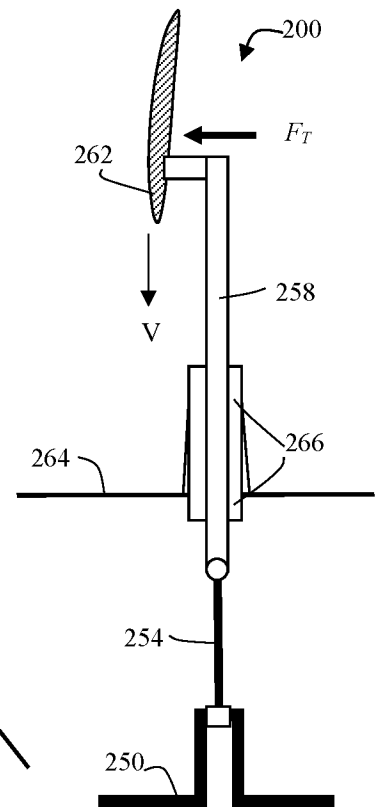


FIG. 7

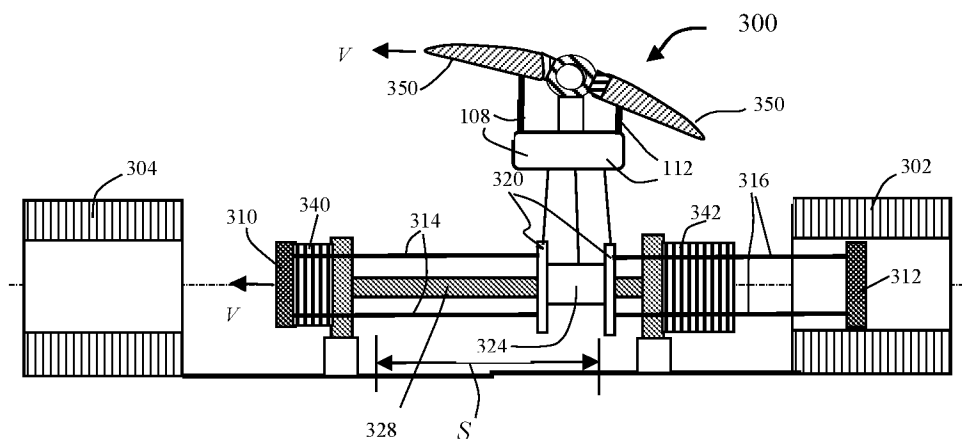


FIG. 8

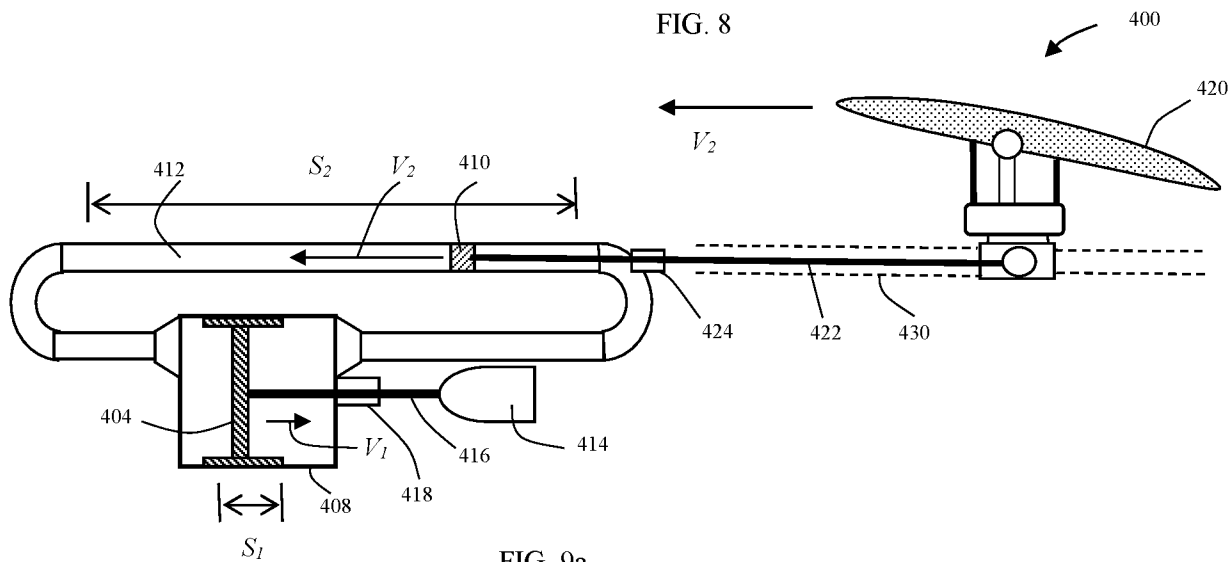


FIG. 9a

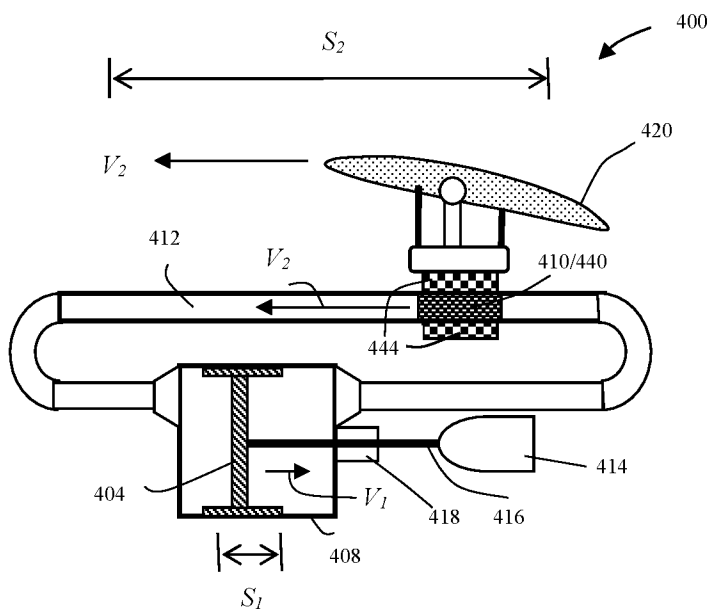


FIG. 9b

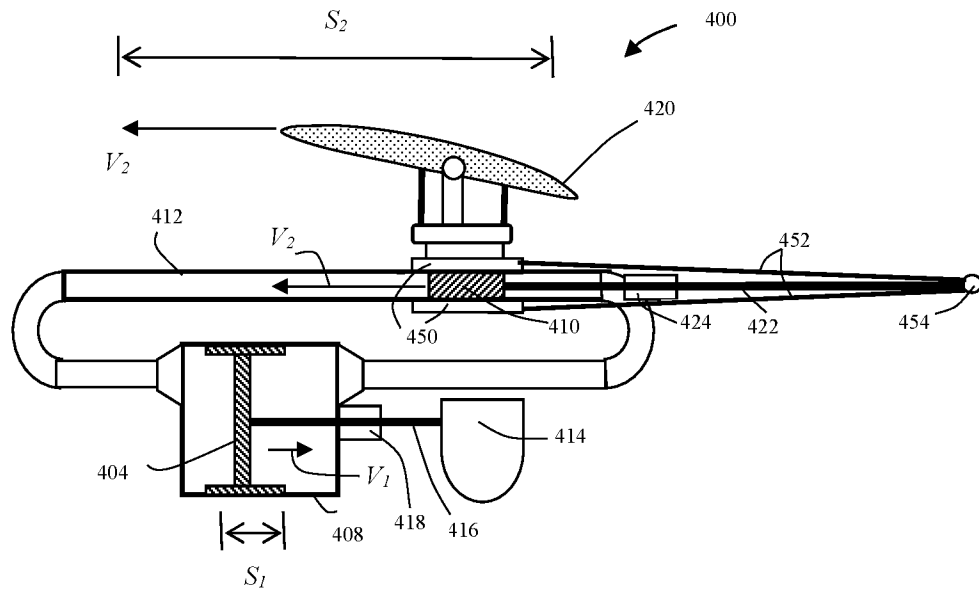


FIG. 9c

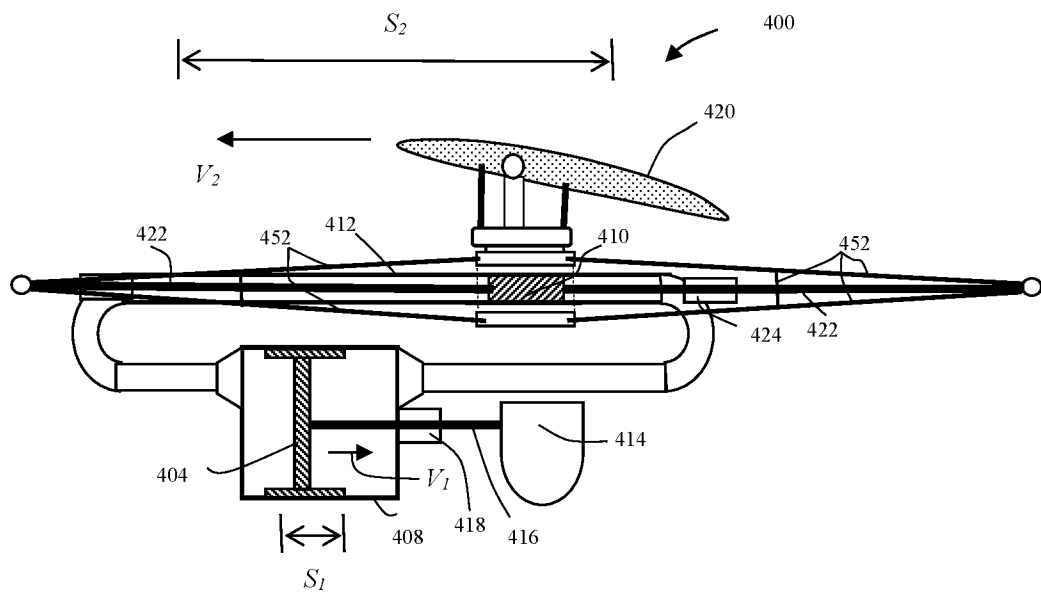


FIG. 9d

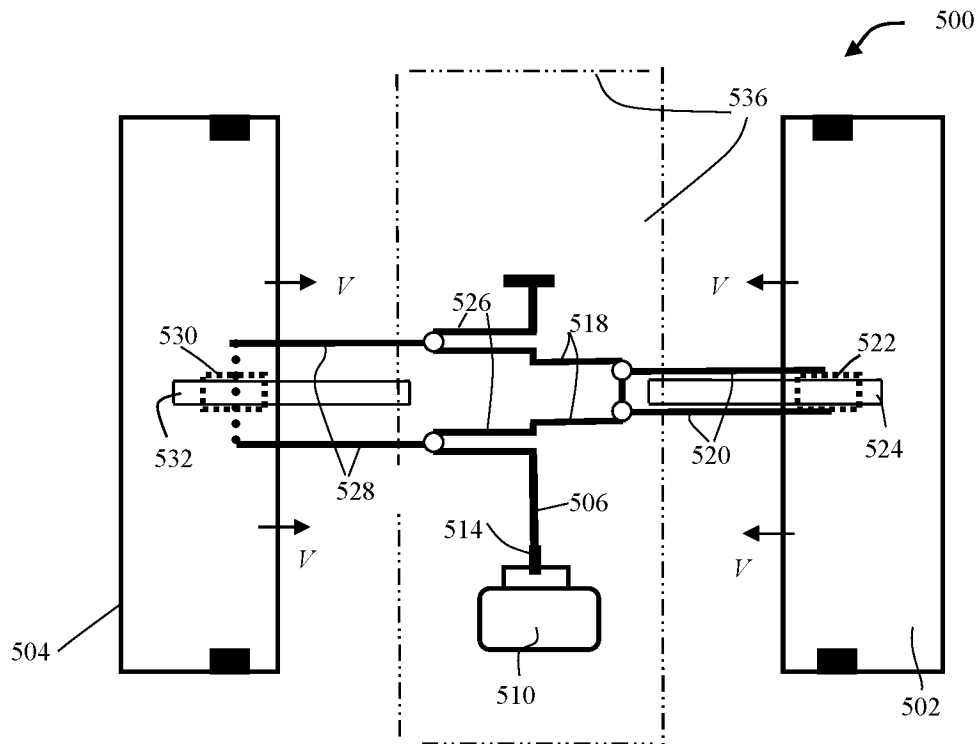
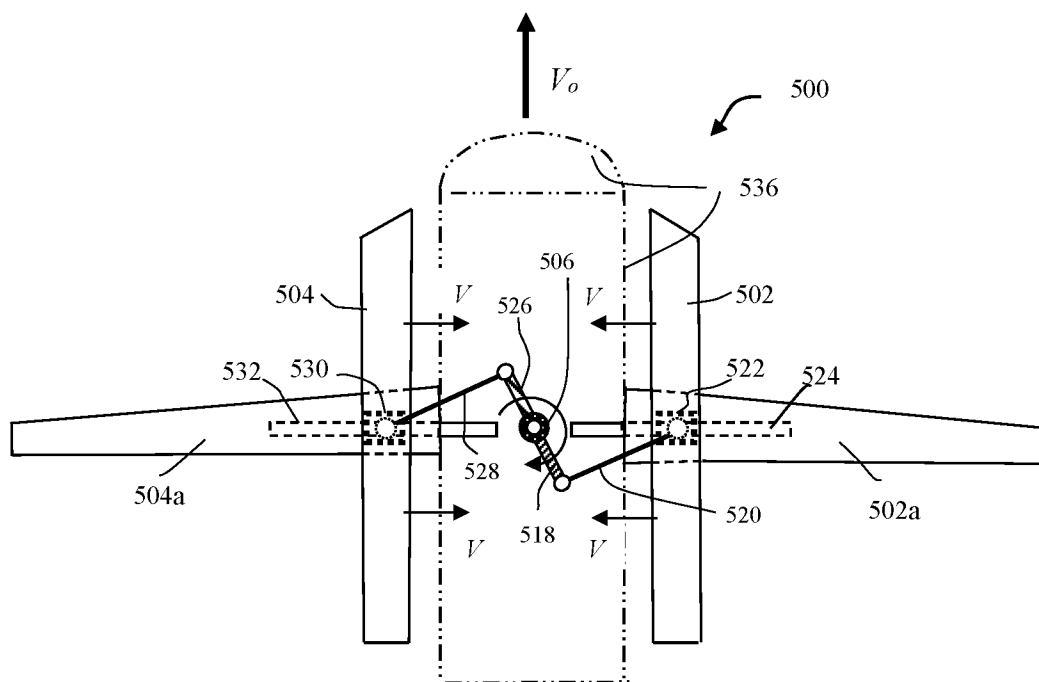
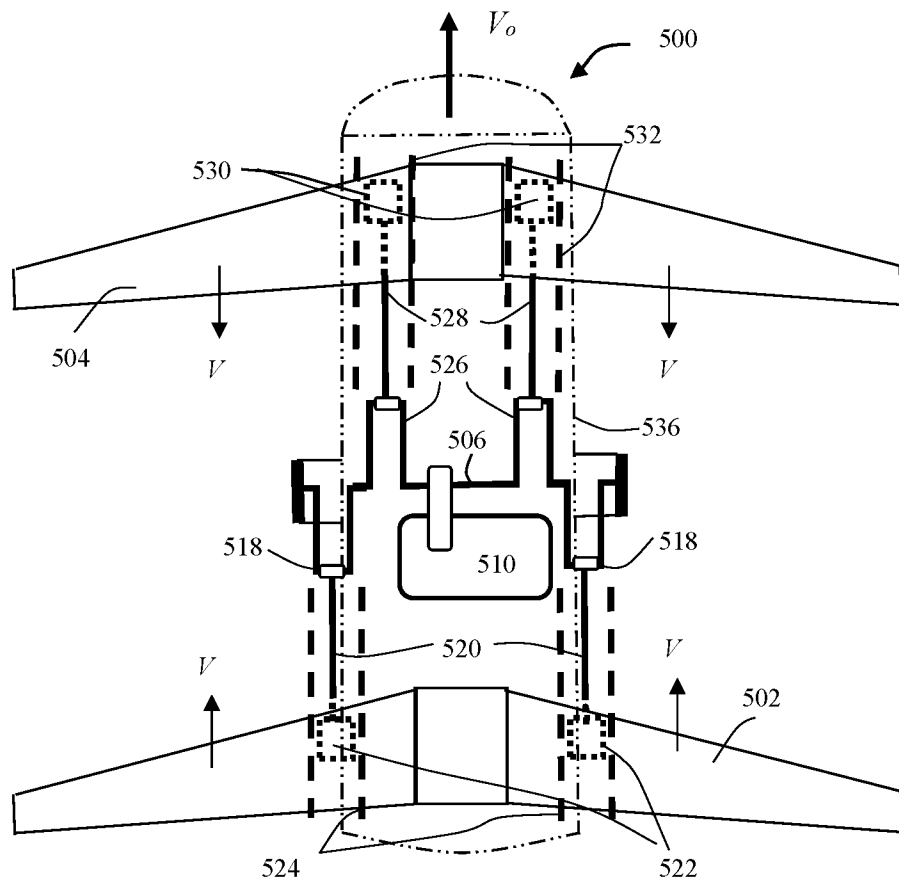


FIG. 10



V : Reciprocating speed relative to vehicle/ V_o : Vehicle flight speed

FIG. 10a



V : Reciprocating speed relative to vehicle/ V_o : Vehicle flight speed

FIG. 11

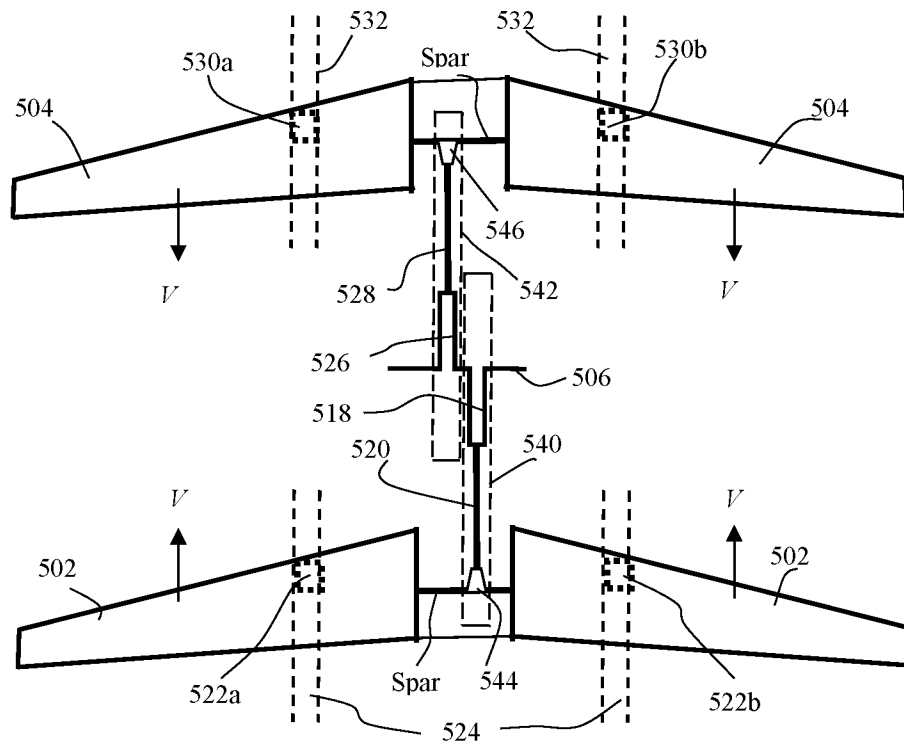


FIG. 11a

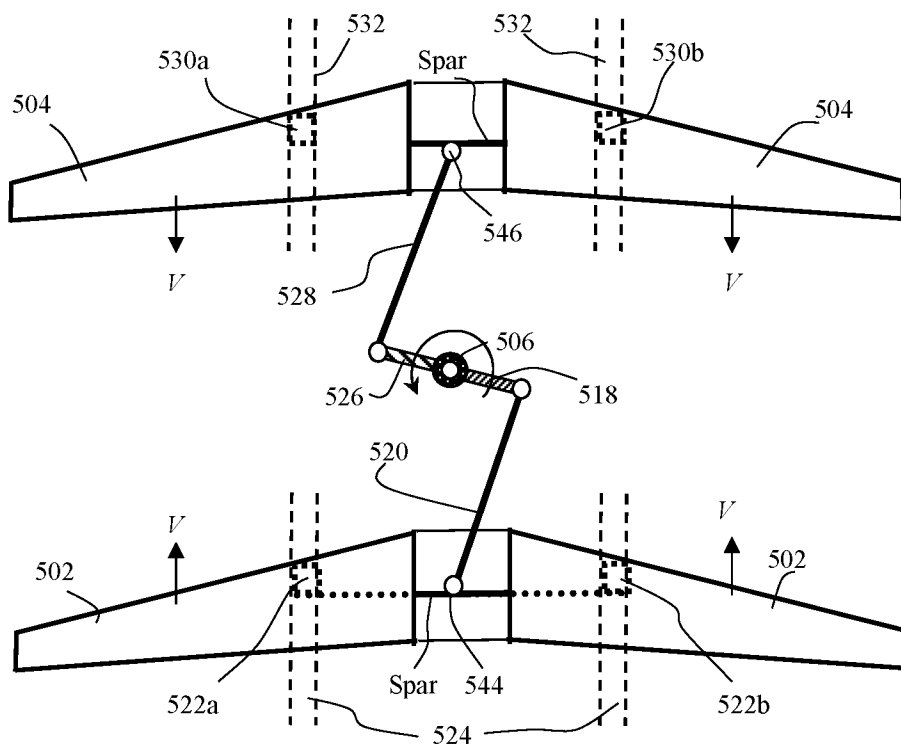
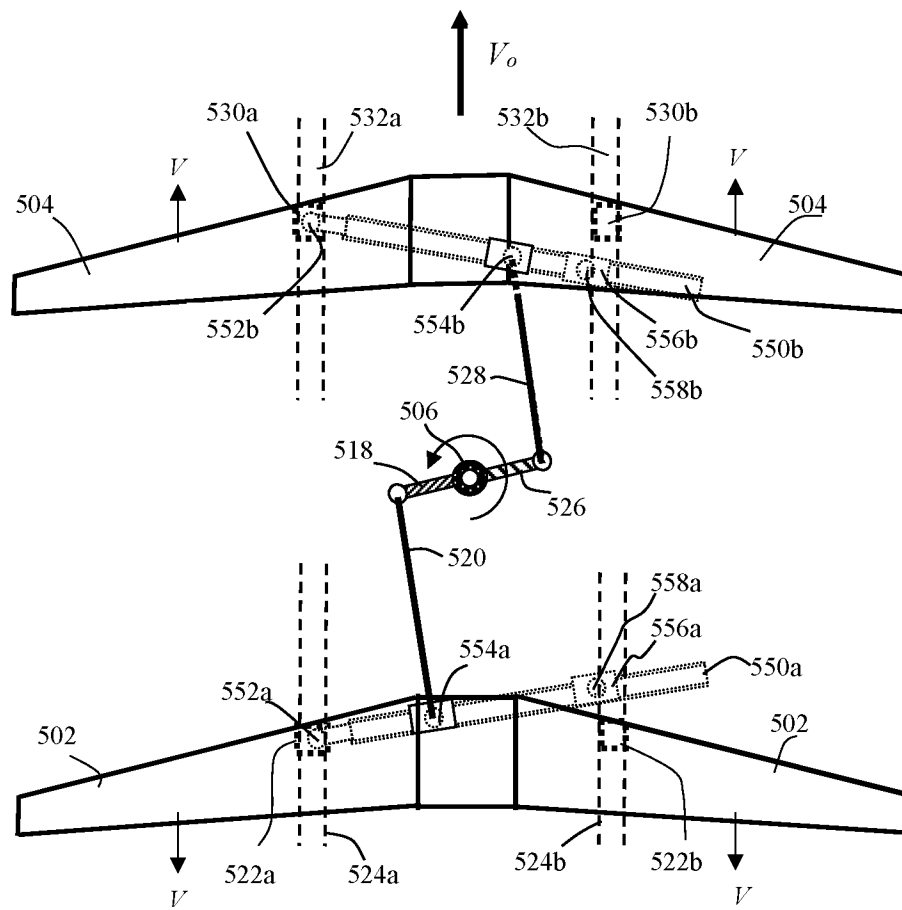
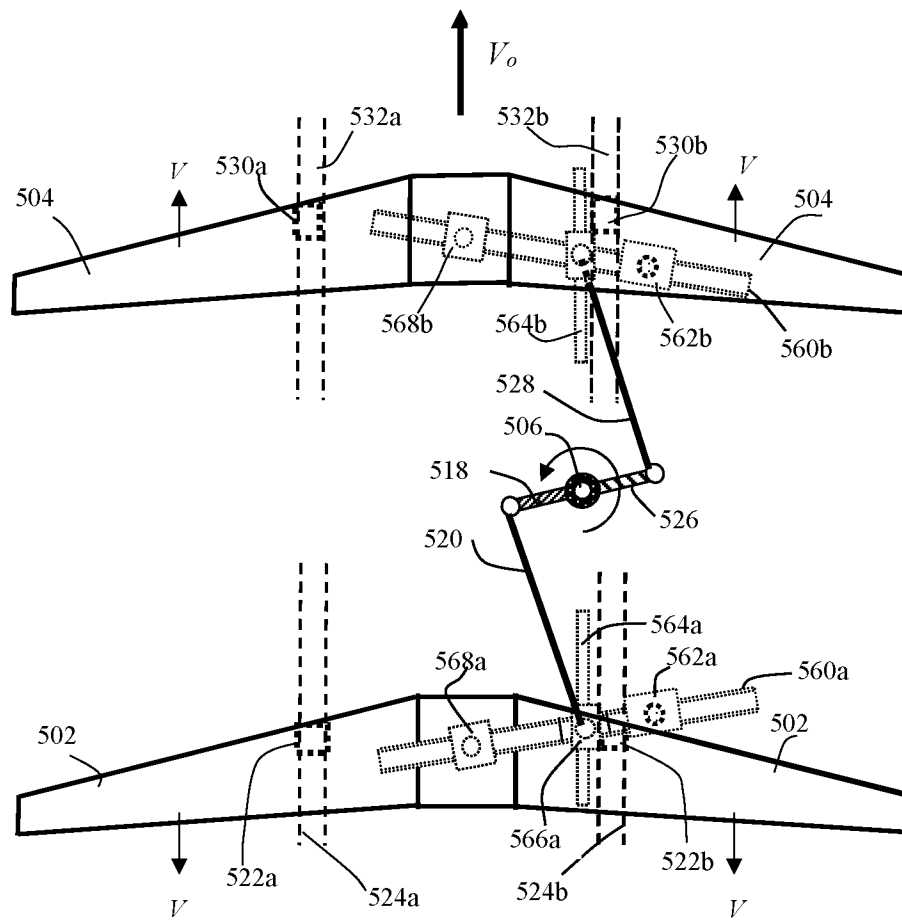


FIG. 11b



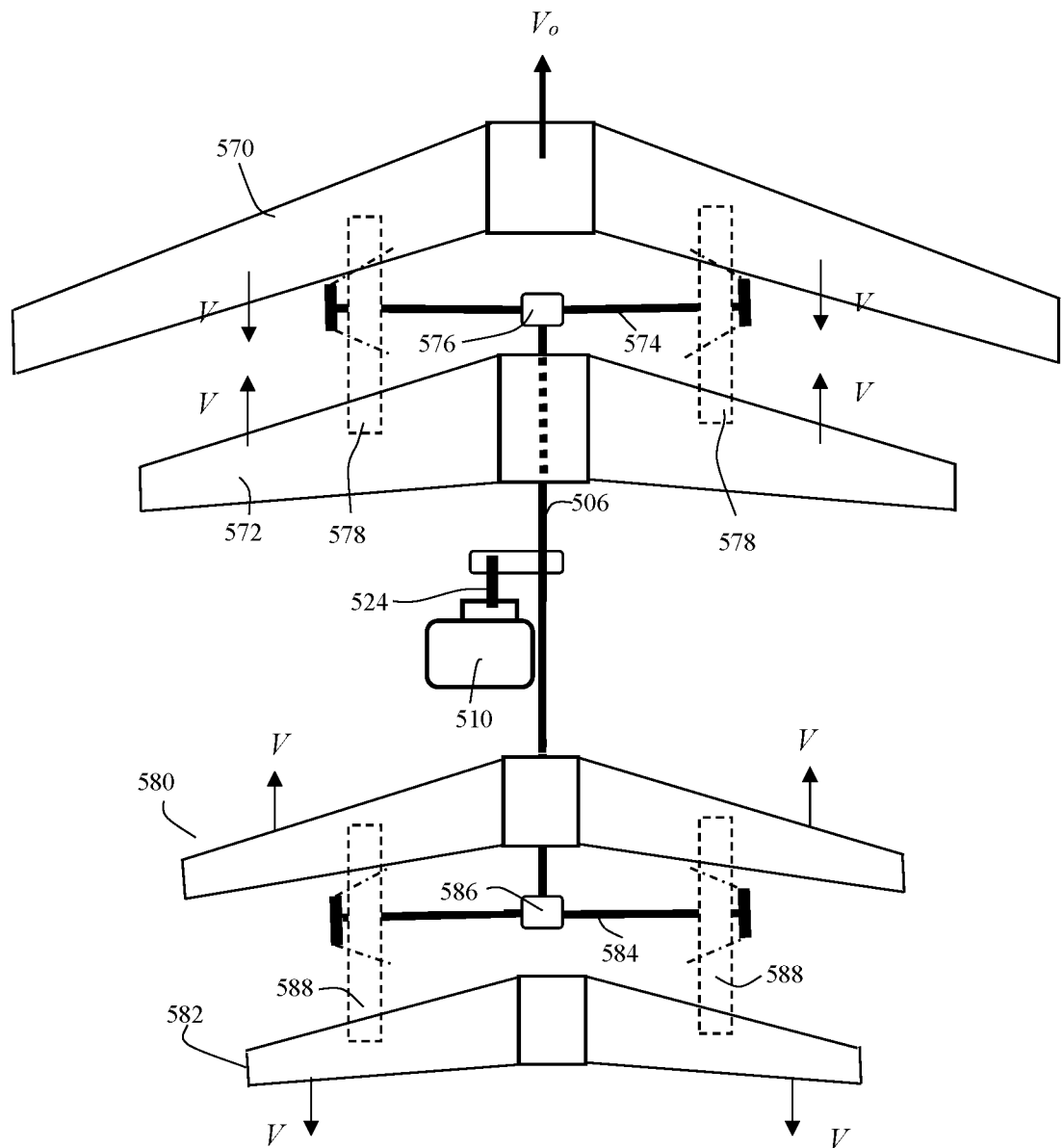
V : Reciprocating speed relative to vehicle/ V_o : Vehicle flight speed

FIG. 11c



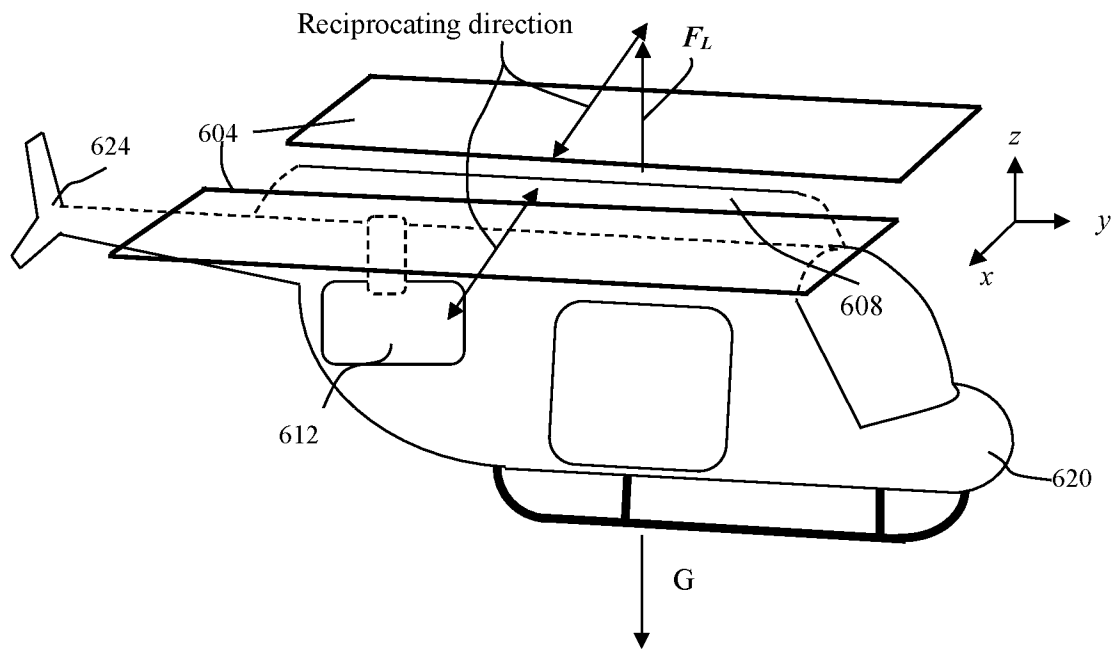
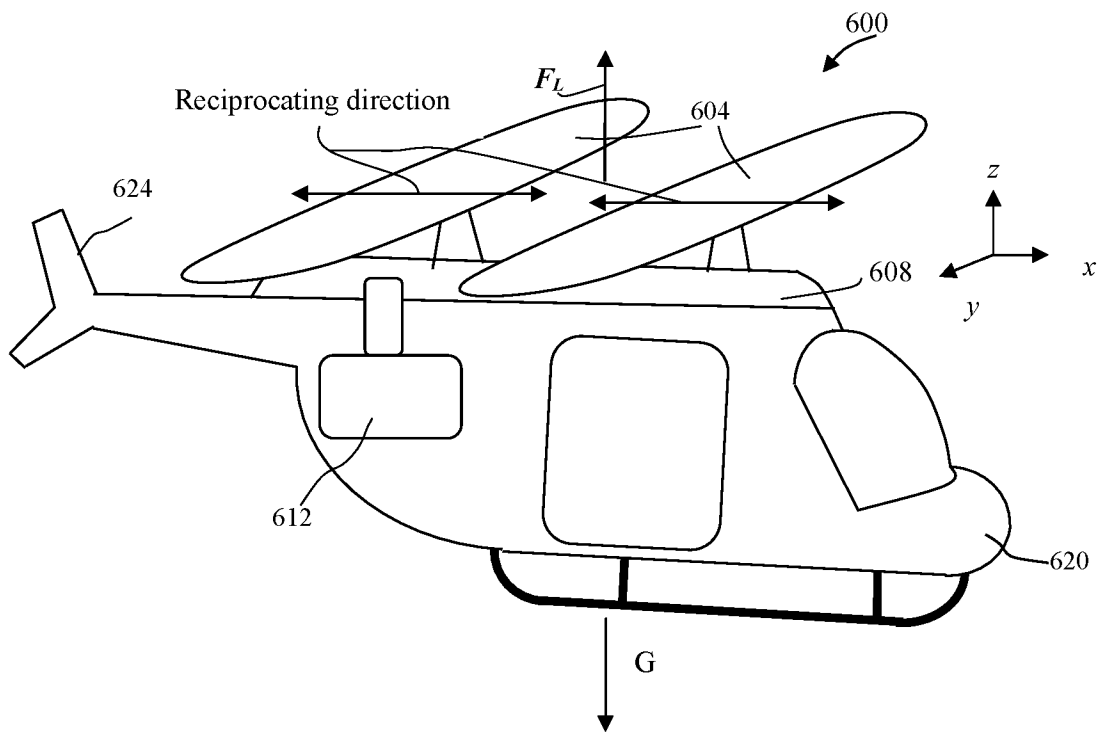
V : Reciprocating speed relative to vehicle/ V_o : Vehicle flight speed

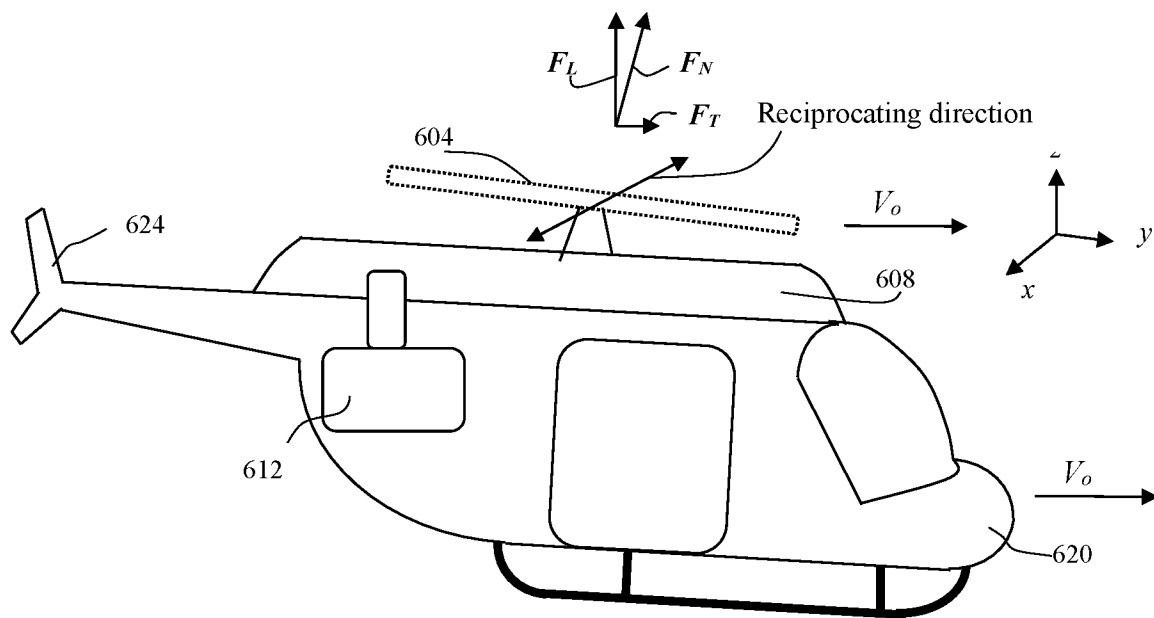
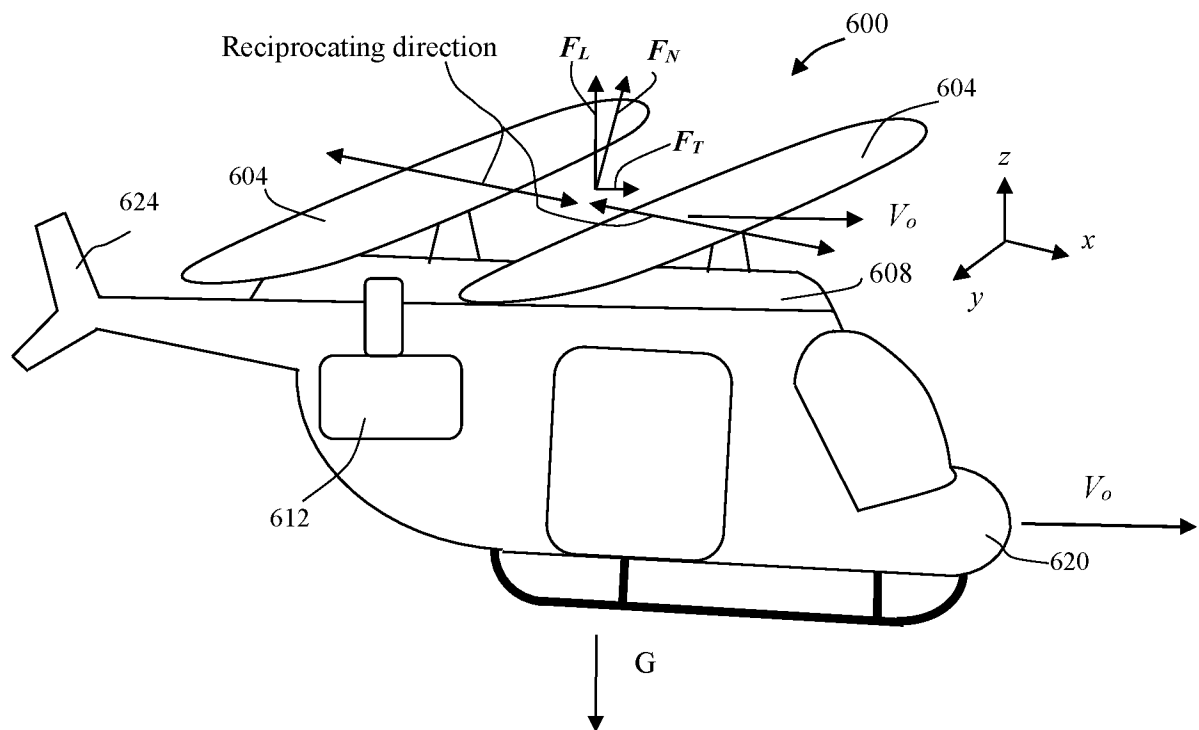
FIG. 11d



V : Reciprocating speed relative to vehicle/ V_o : Vehicle flight speed

FIG. 11e





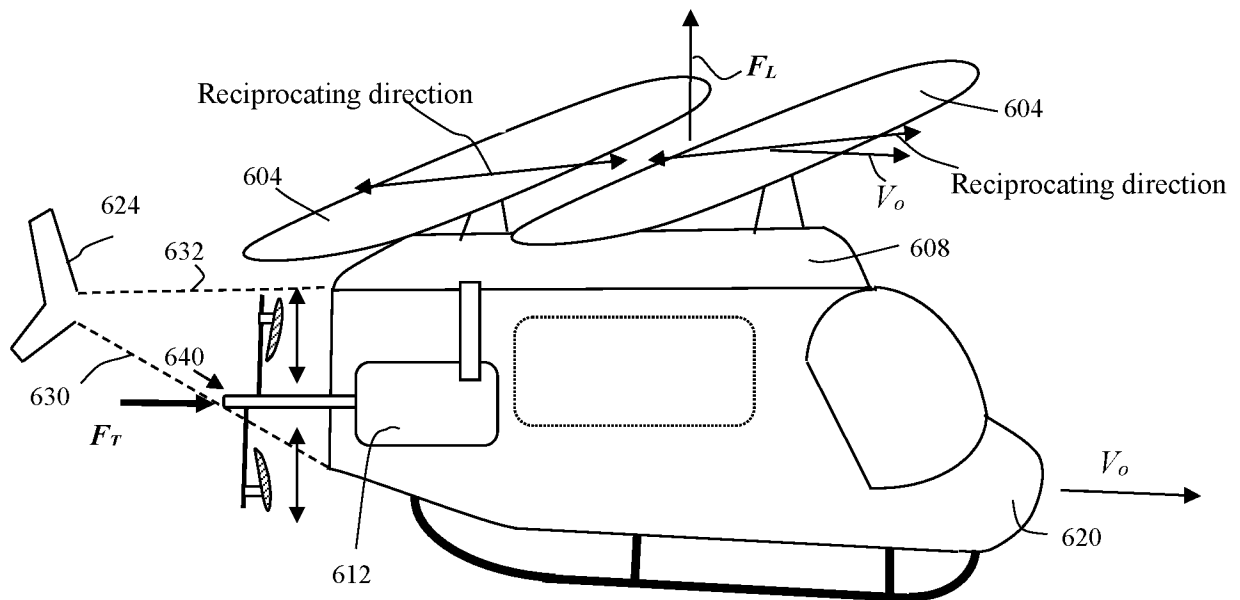


FIG. 15

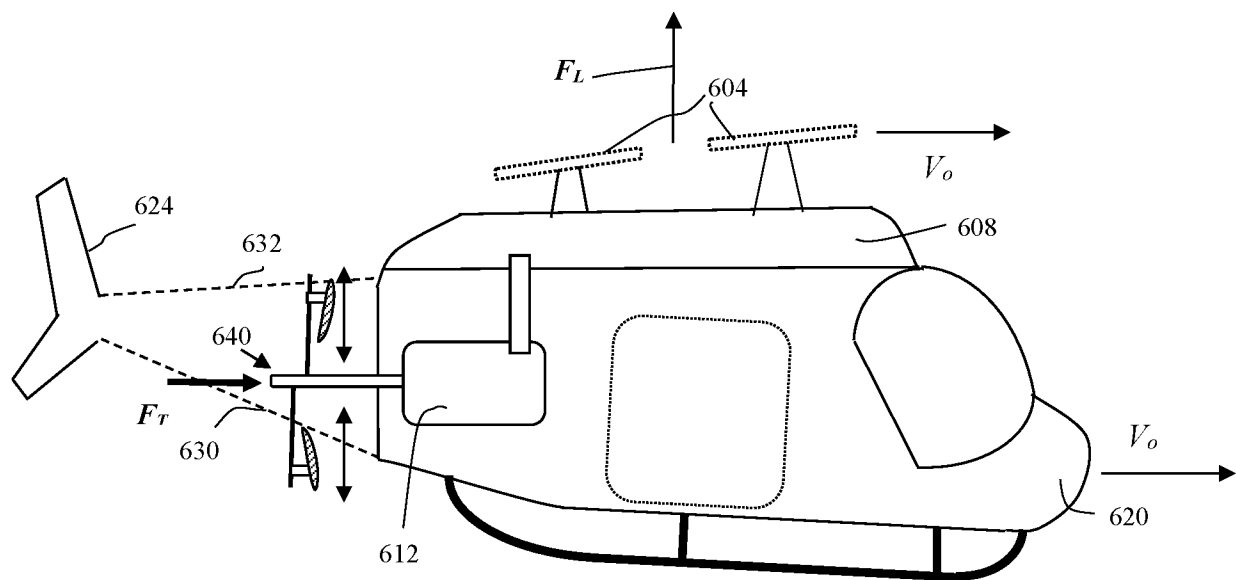


FIG. 15a

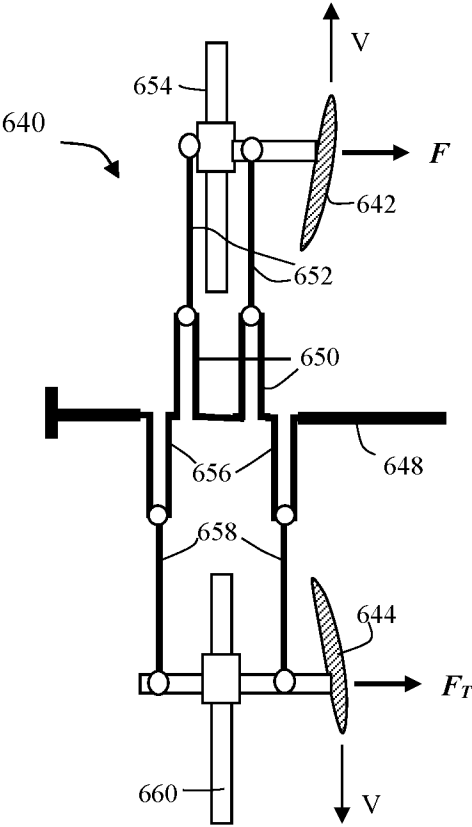


FIG. 16

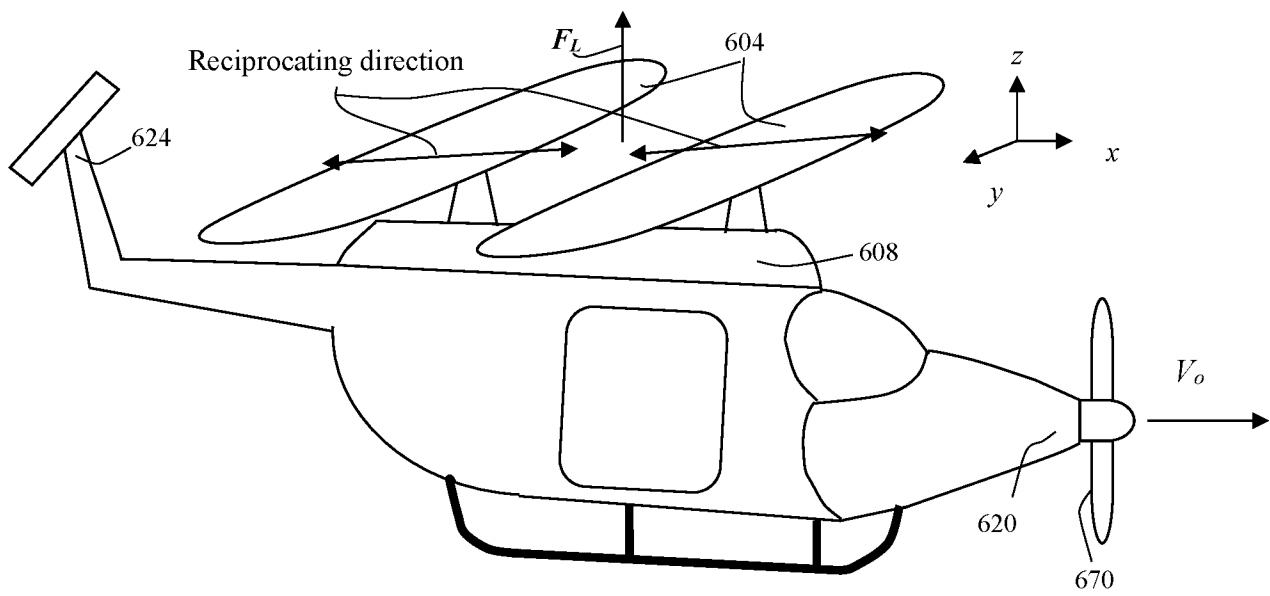


FIG. 17

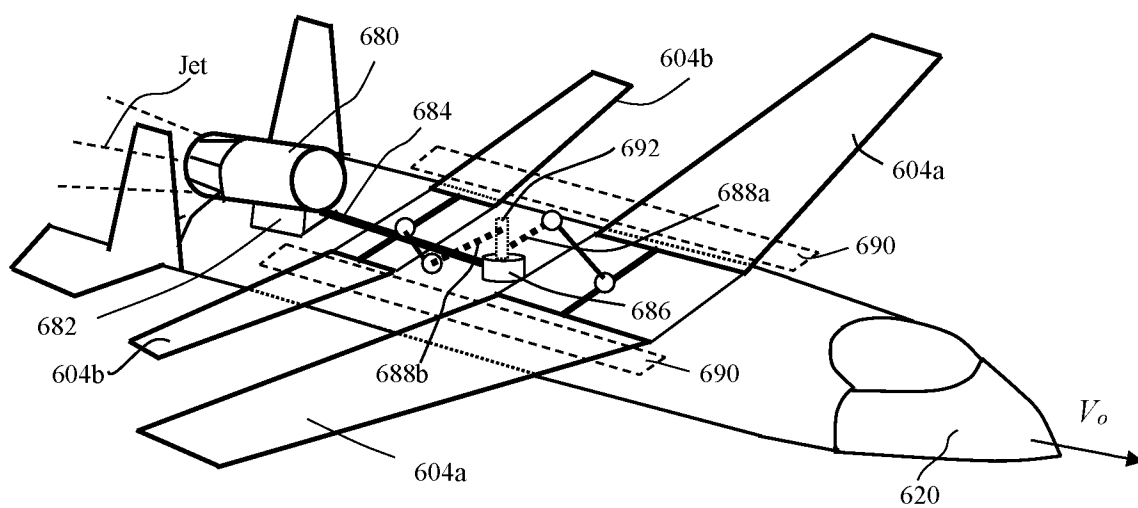


FIG. 18

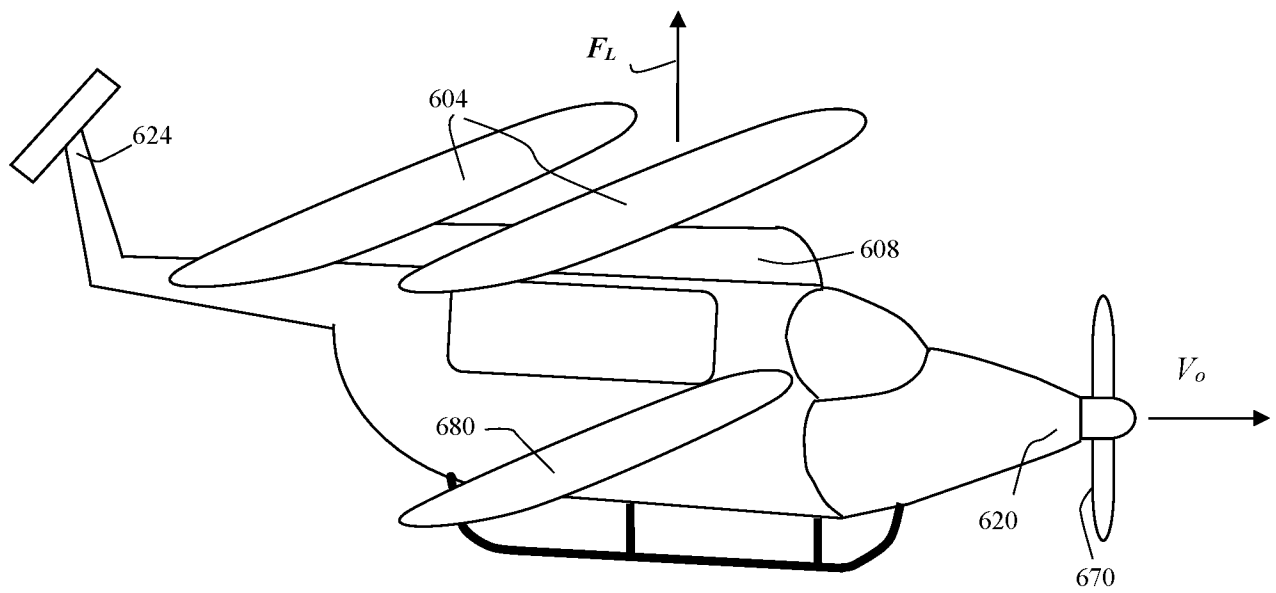


FIG. 19

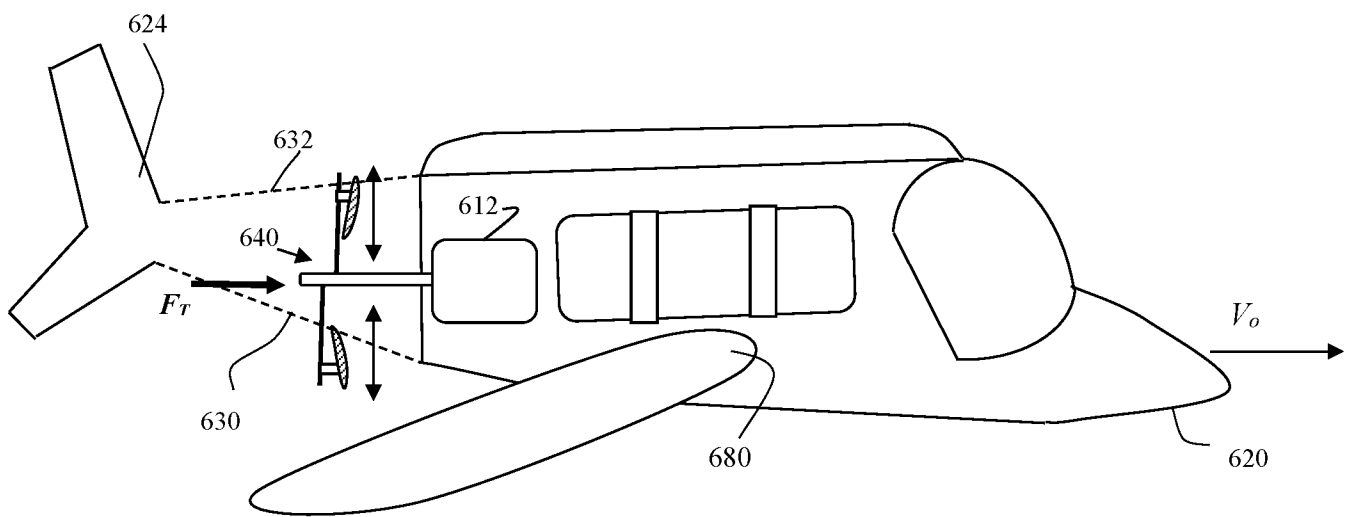


FIG. 20

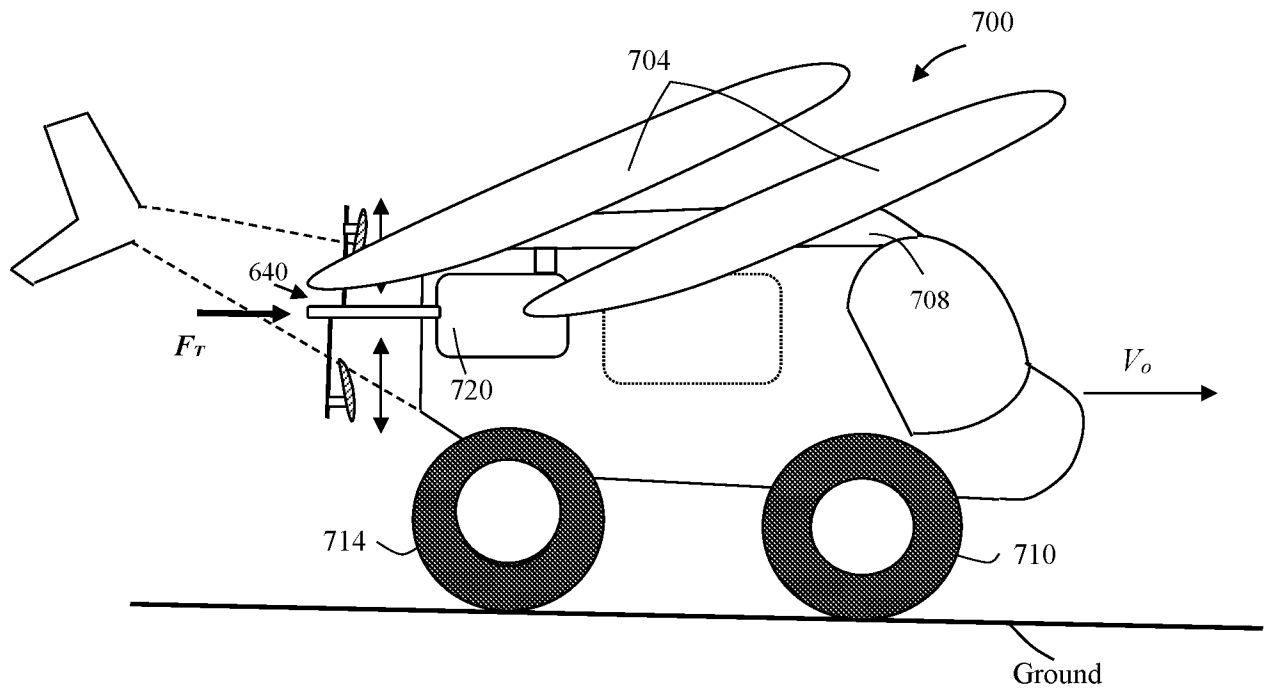


FIG. 21

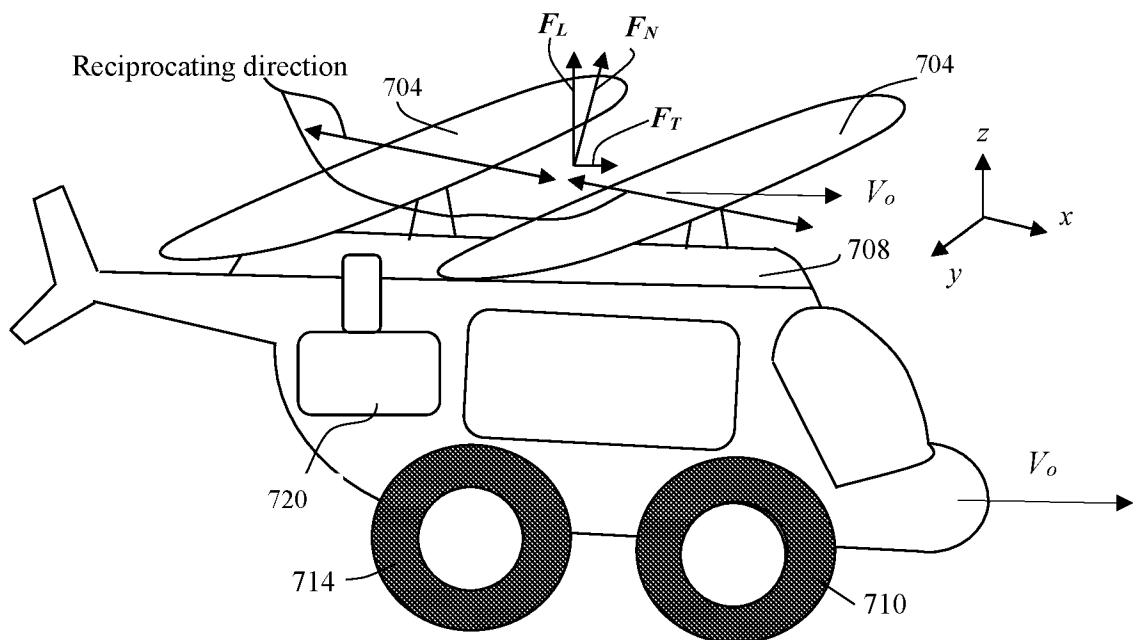


FIG. 22

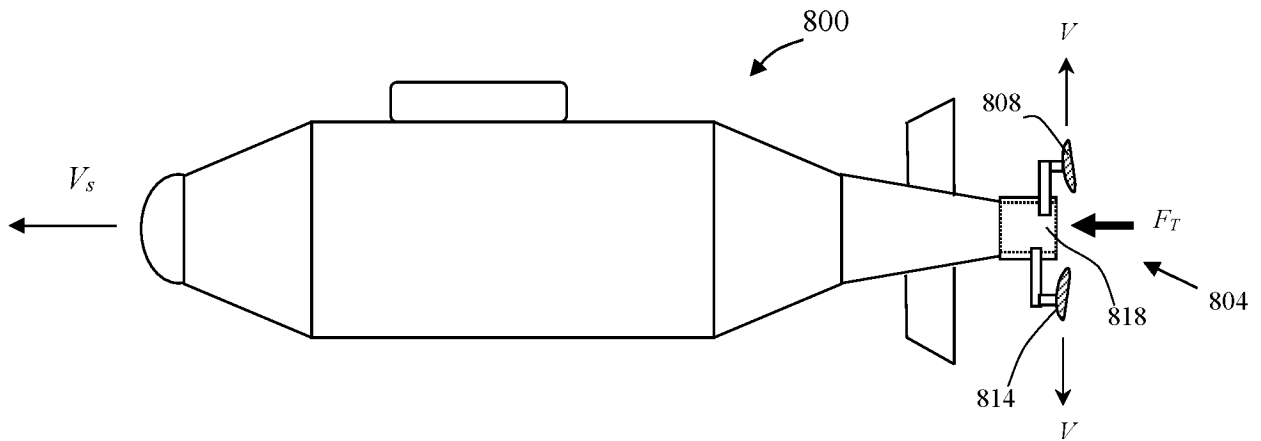


FIG. 23

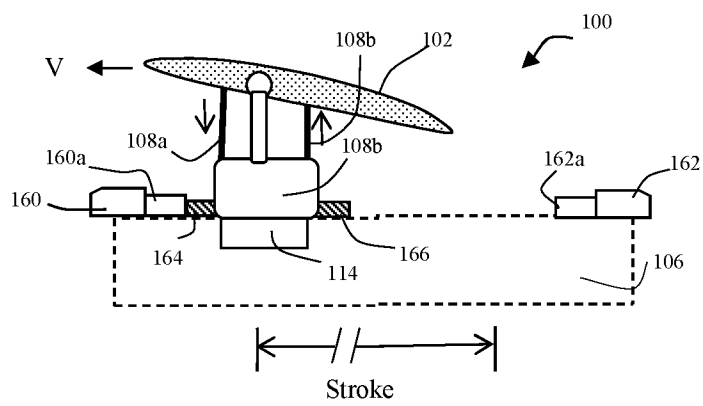


FIG. 24

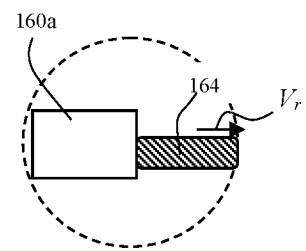


FIG. 25

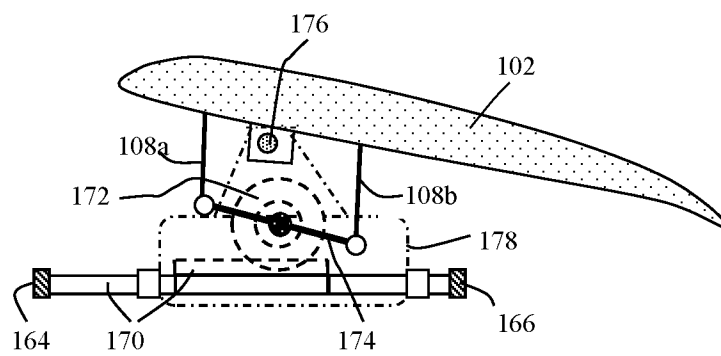


FIG. 26

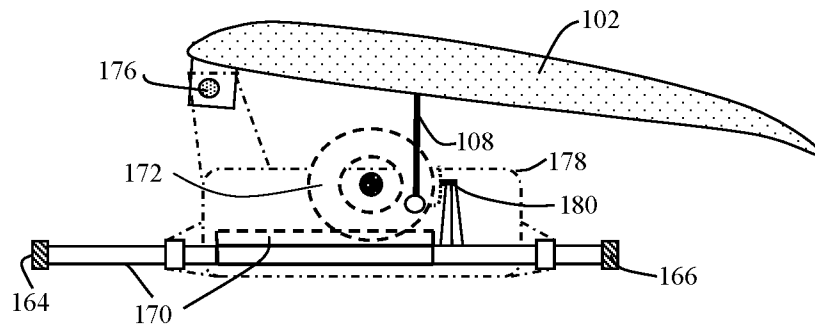


FIG. 27

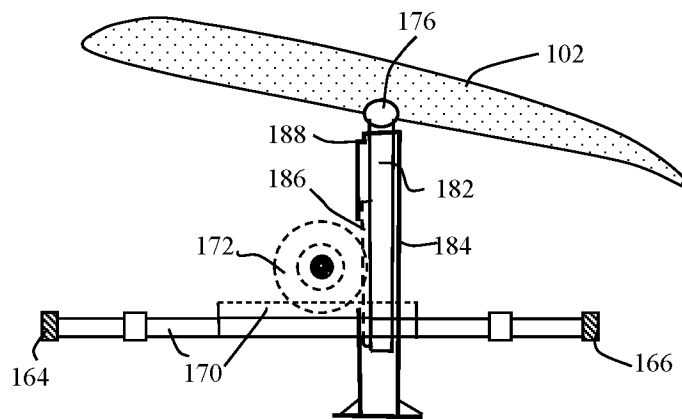


FIG. 28

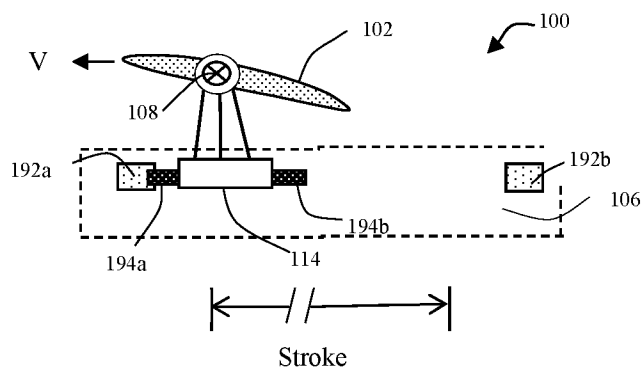


FIG. 29

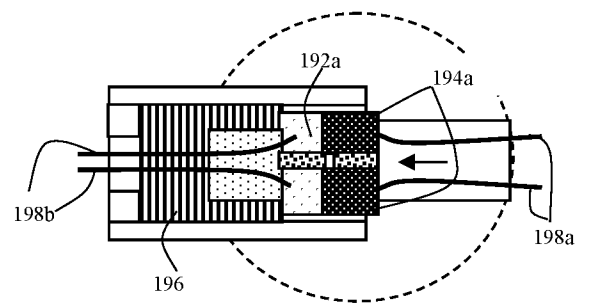


FIG. 30