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(54) **LIGHTWEIGHT VERTICAL TAKE-OFF AND LANDING AIRCRAFT AND FLIGHT CONTROL PARADIGM USING THRUST DIFFERENTIALS**

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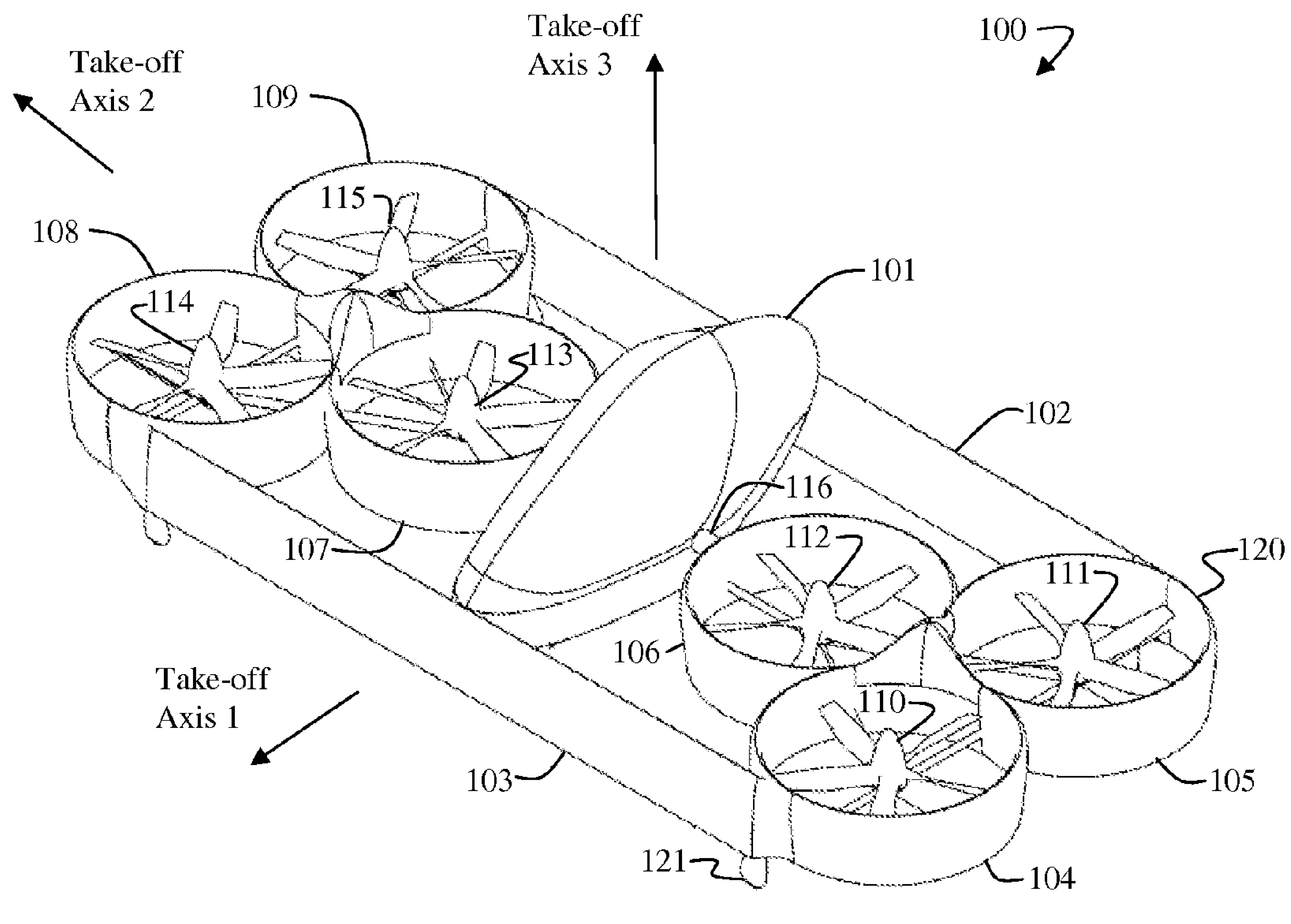
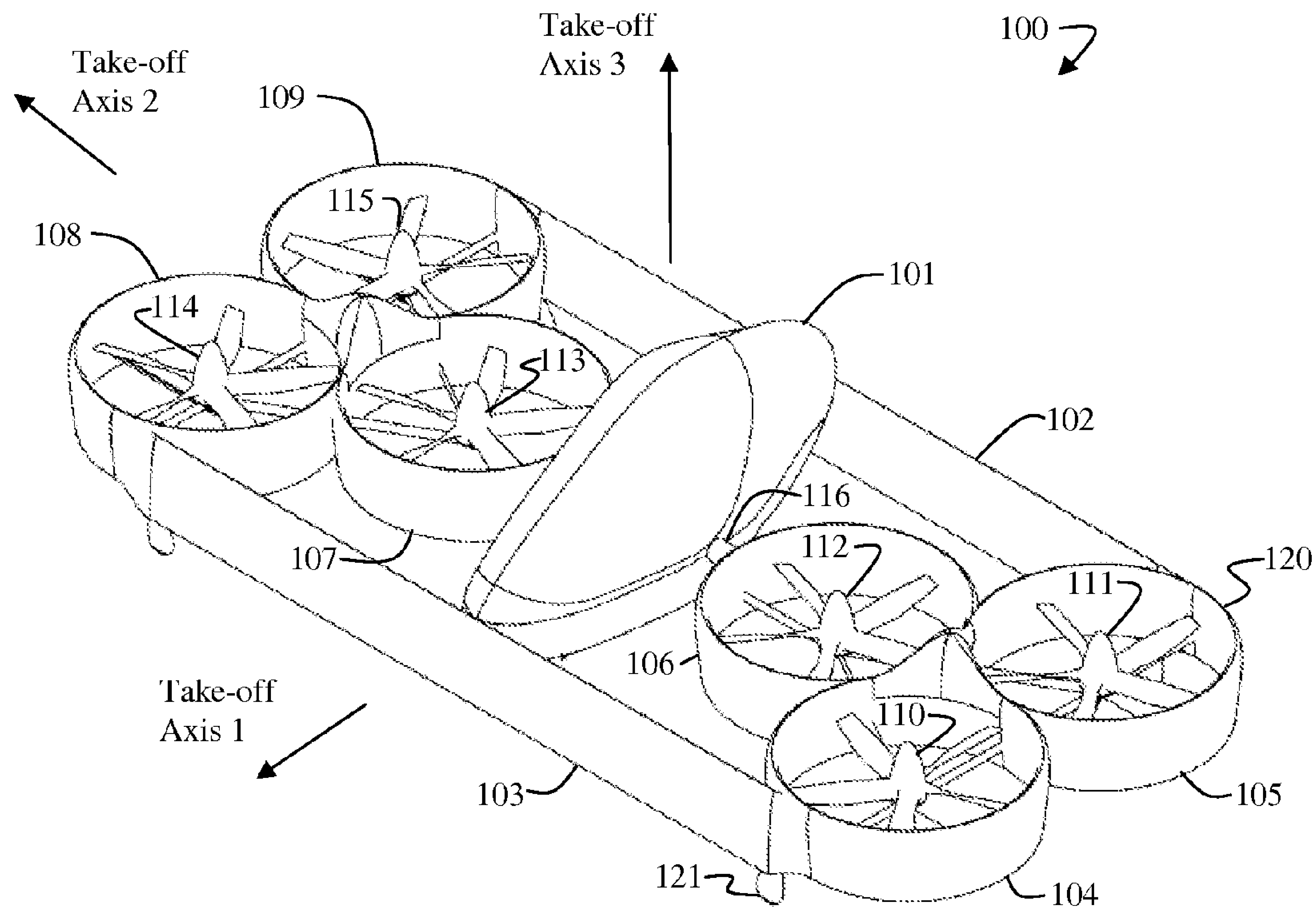
(57) **ABSTRACT**

An aerial vehicle adapted for vertical takeoff and landing using the same set of engines for takeoff and landing as well as for forward flight. An aerial vehicle which uses a rotating platform of engines in fixed relationship to each other and which rotates relative to the main body of the vehicle for takeoff and landing. An aerial vehicle which is adapted to takeoff with the wings in a vertical as opposed to horizontal flight attitude which takes off in this vertical attitude and then transitions to a horizontal flight path. An aerial vehicle which controls the attitude of the vehicle during takeoff and landing by alternating the thrust of engines, which are separated in at least two dimensions relative to the horizontal during takeoff, and which may also control regular flight in some aspects by the use of differential thrust of the engines.





Take-off
Axis 2
109
Take-off
Axis 3
100
108
115
114
113
101
102
116
112
120
107
111
106
Take-off
Axis 1
110
103
105
121
104

FIGURE 1

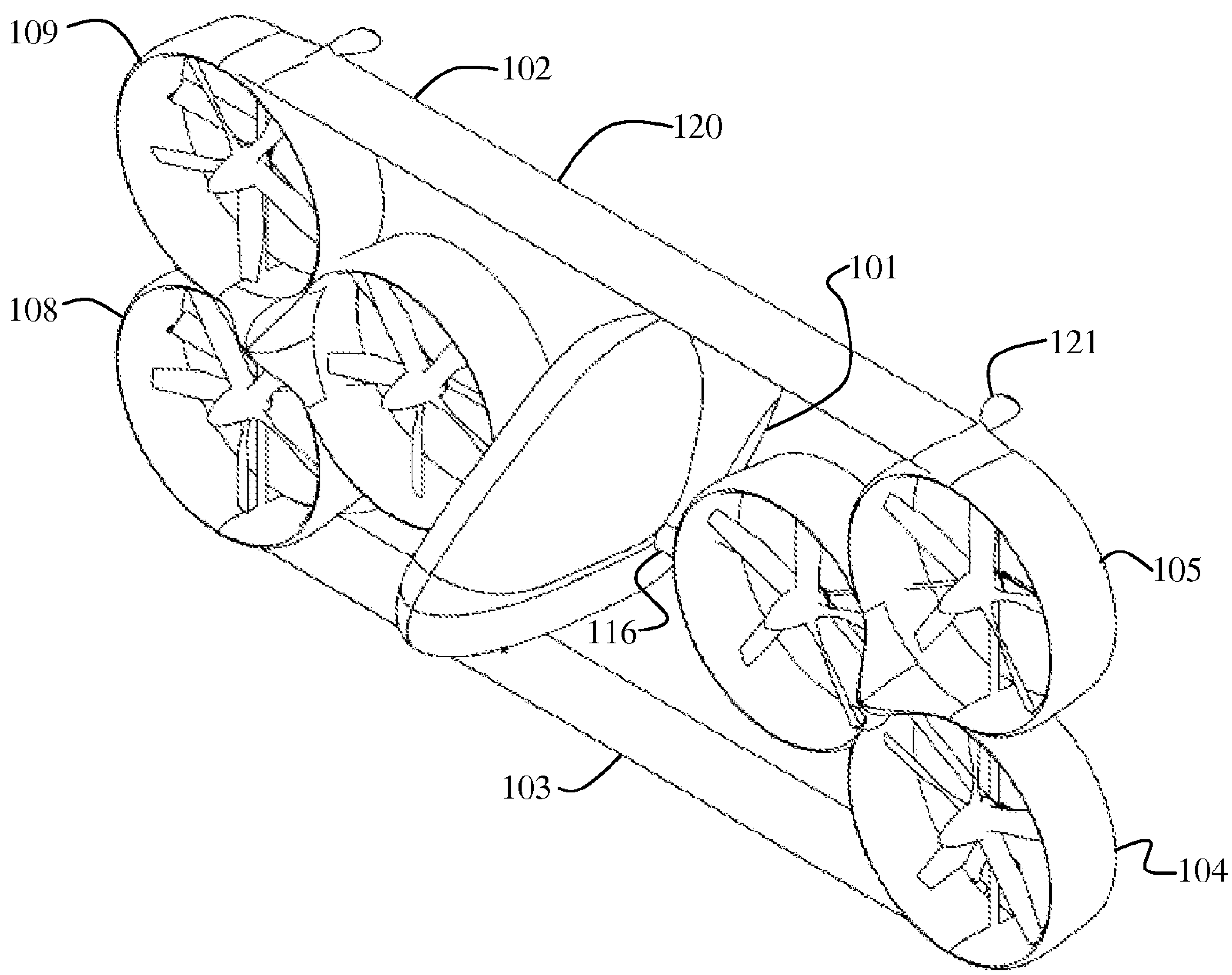


FIGURE 2

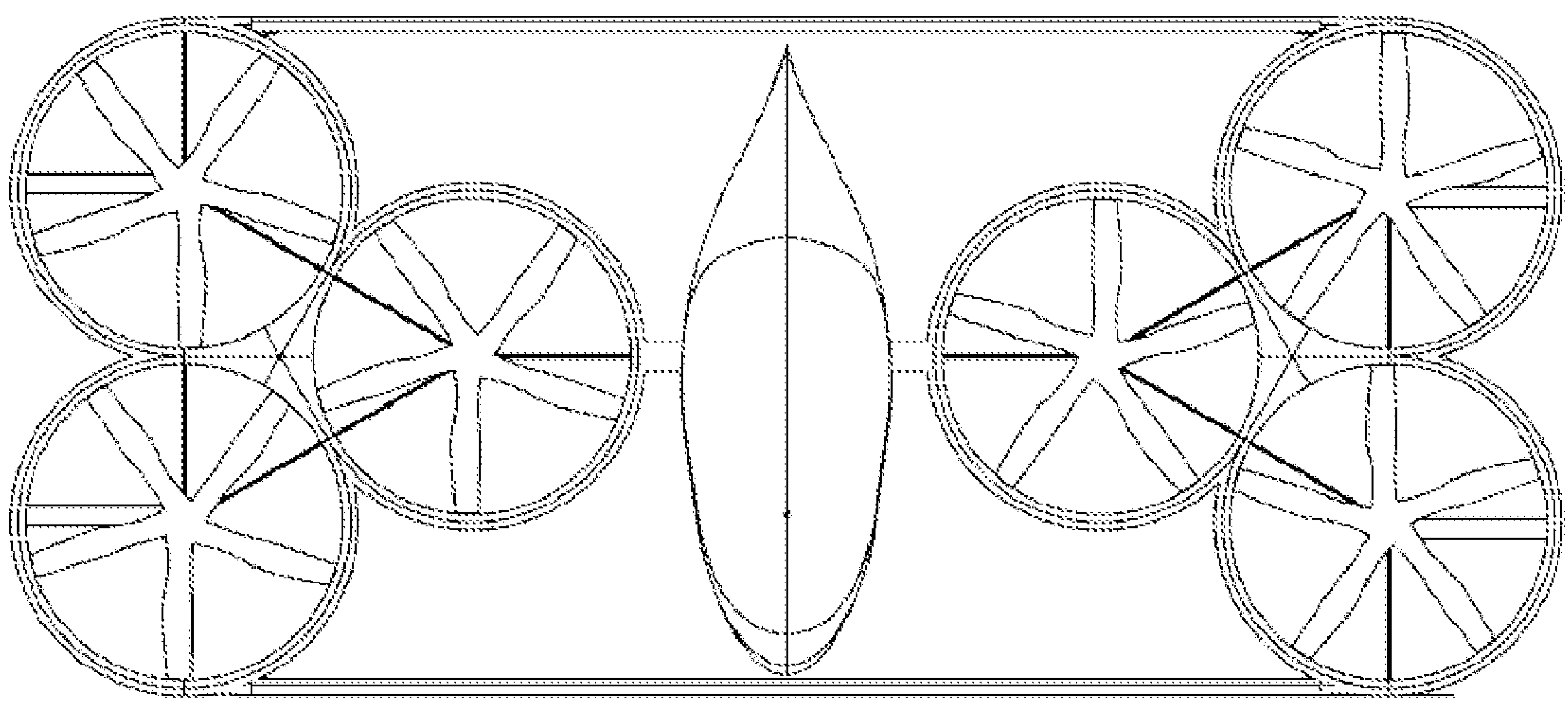


FIGURE 3

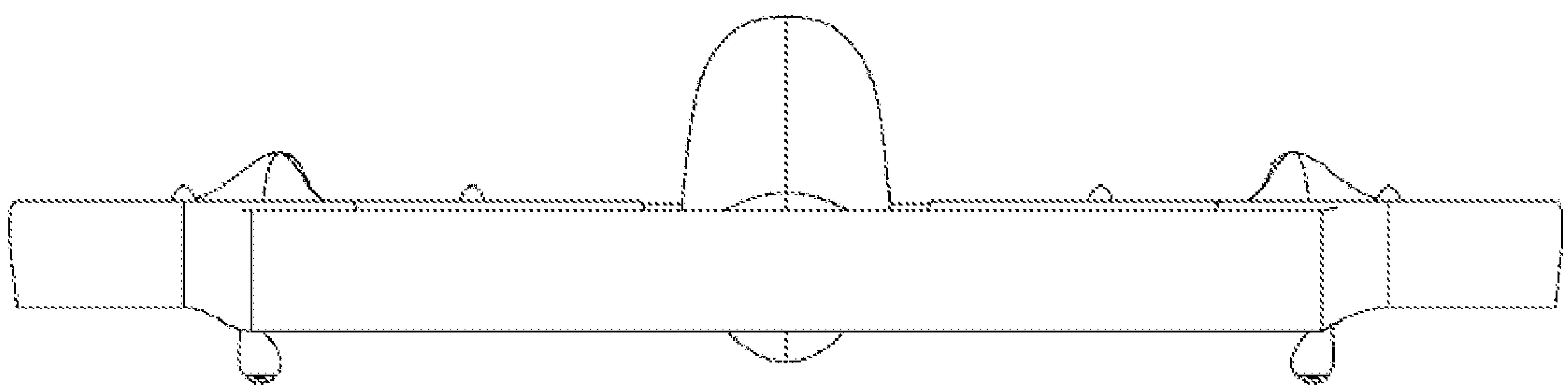


FIGURE 4

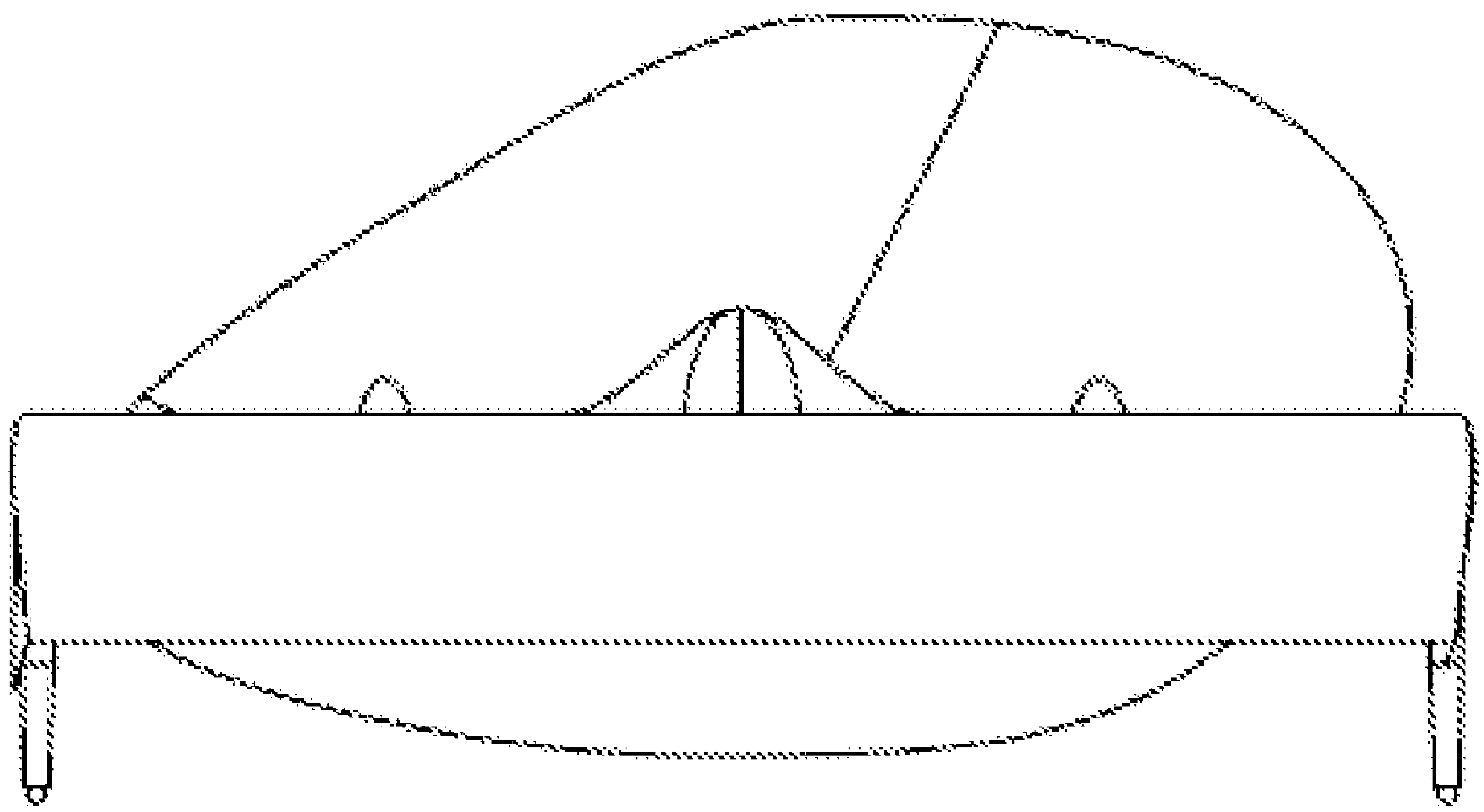


FIGURE 5

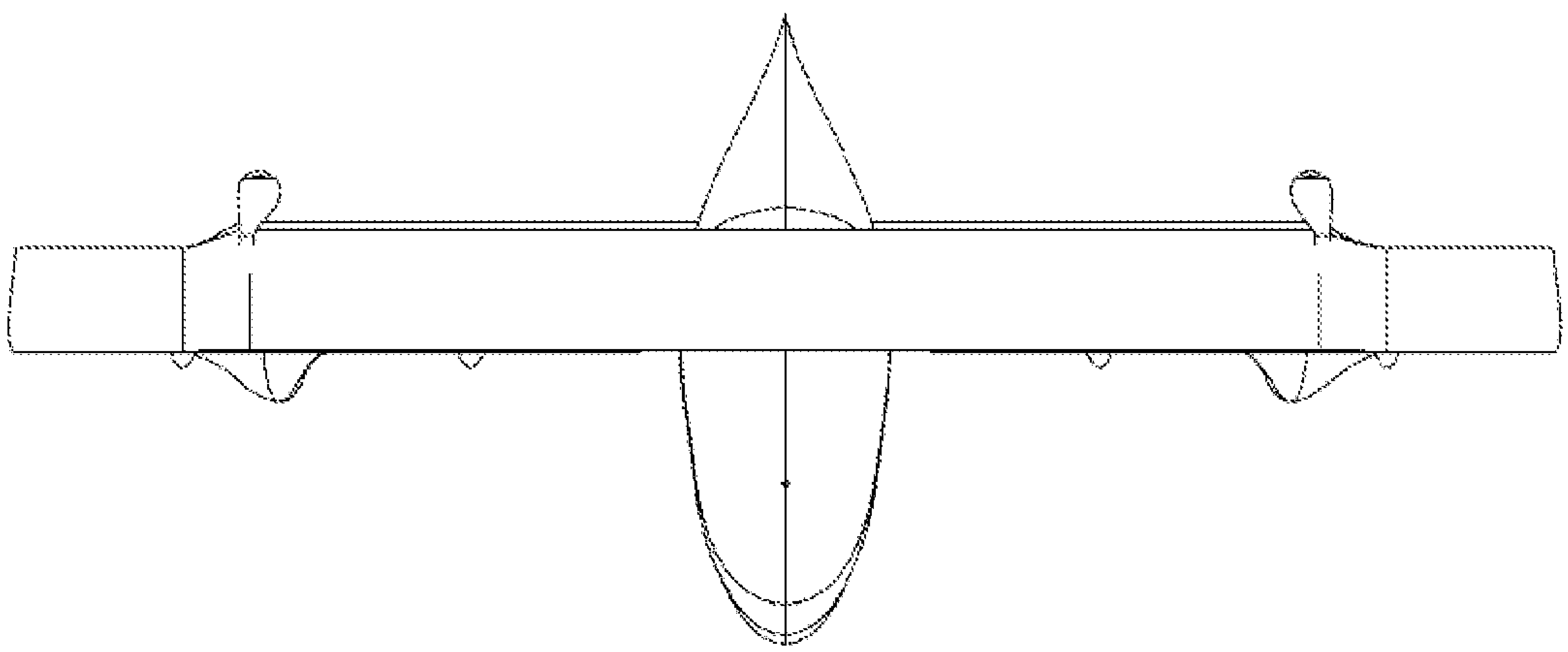


FIGURE 6

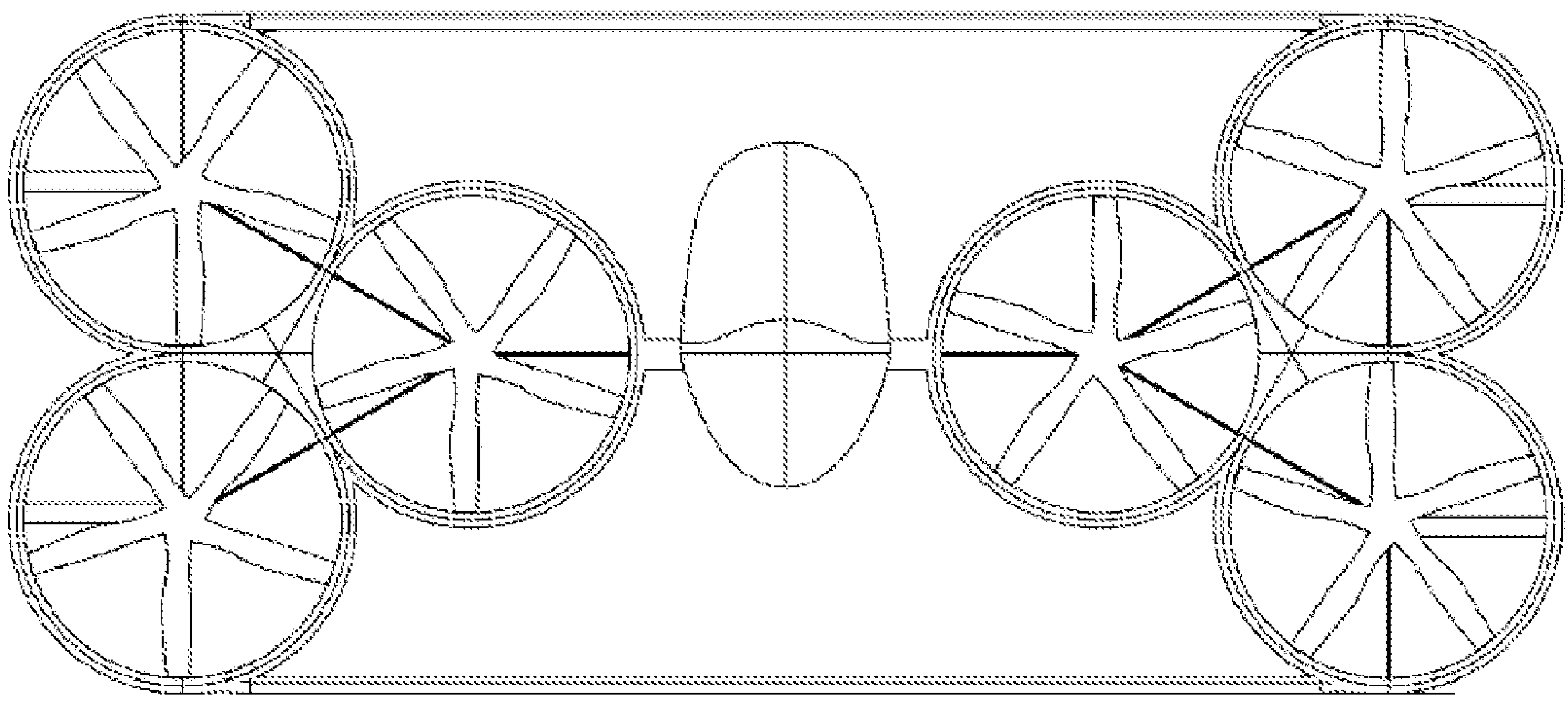


FIGURE 7

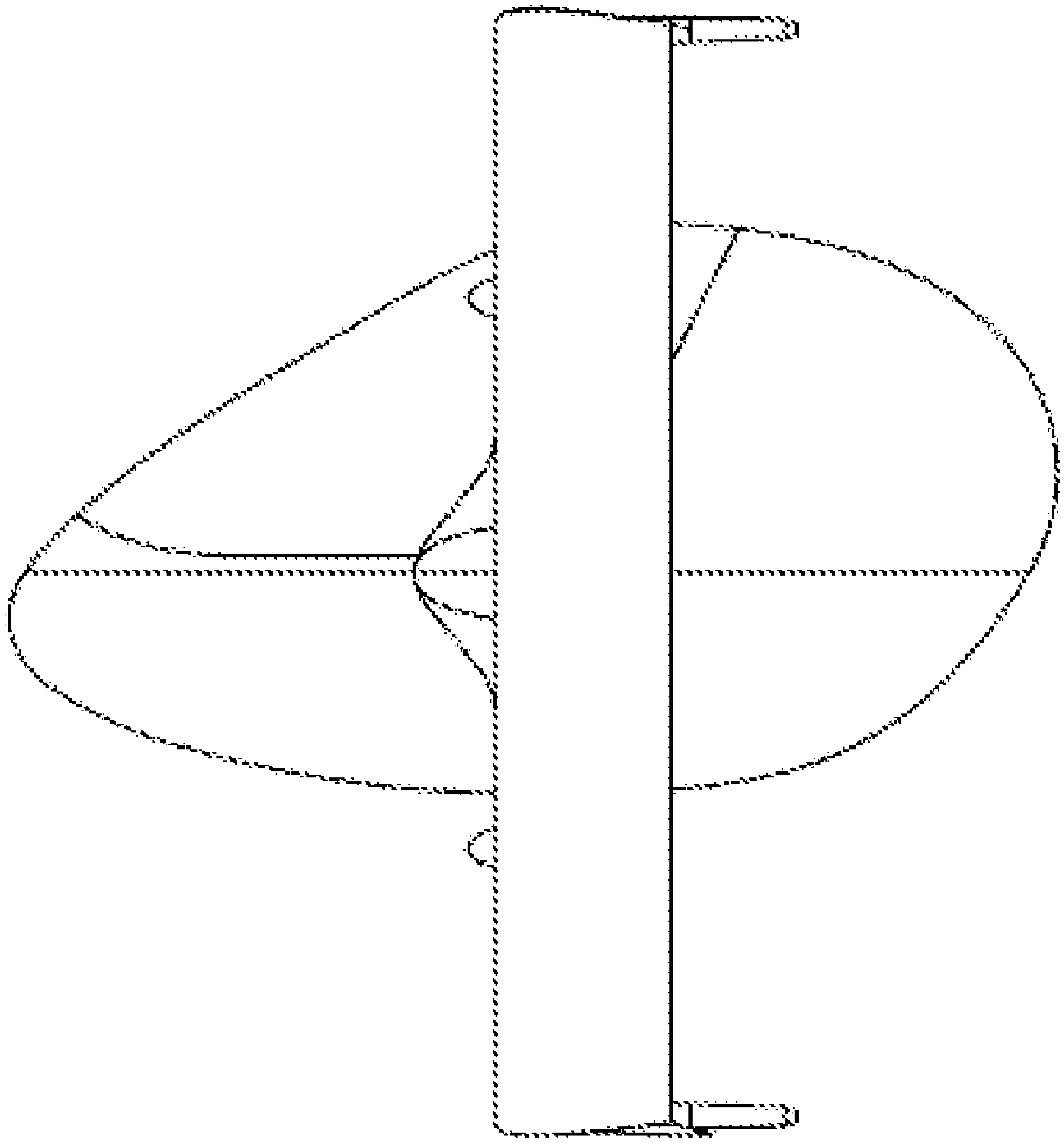


FIGURE 8

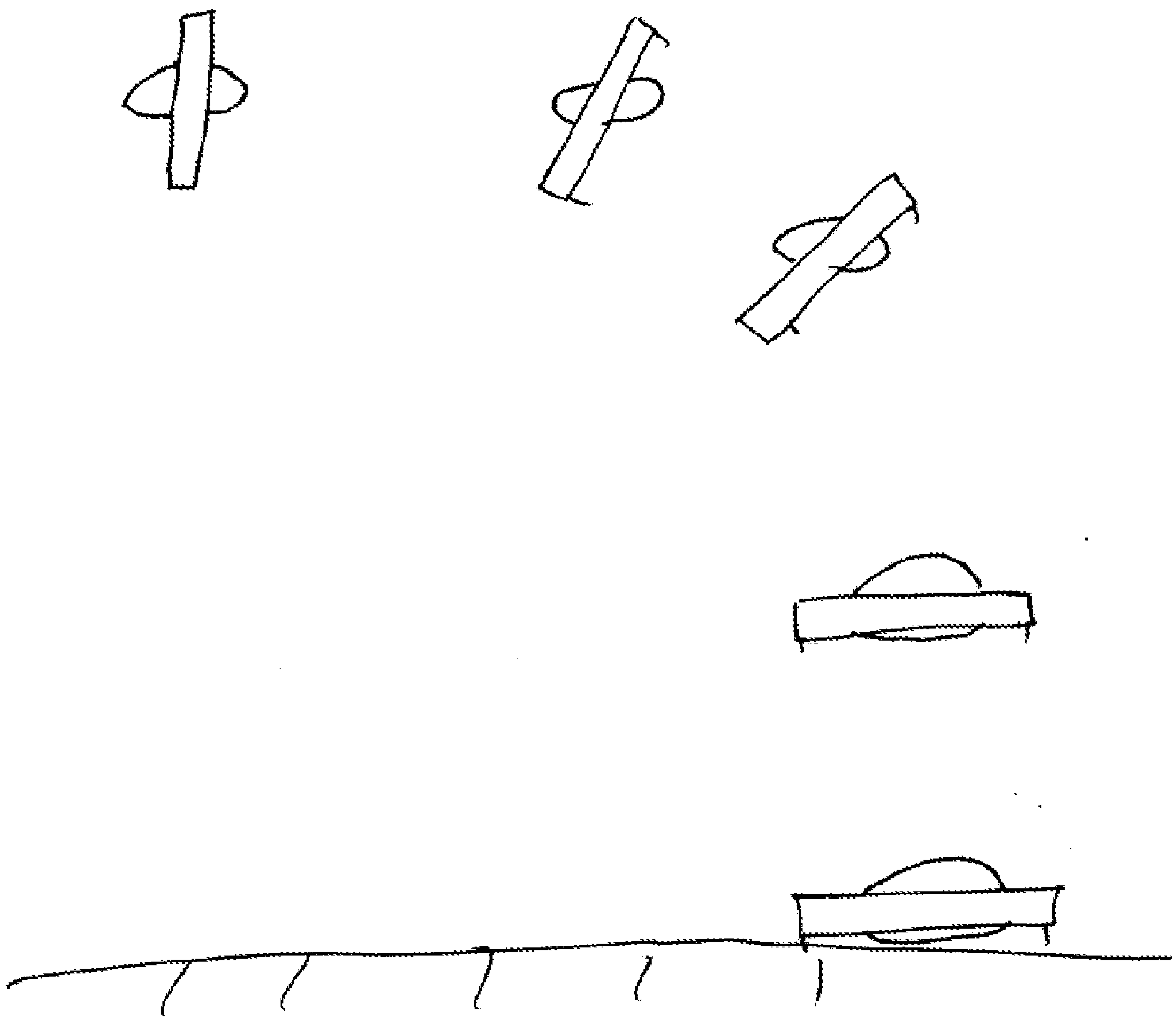


FIGURE 9

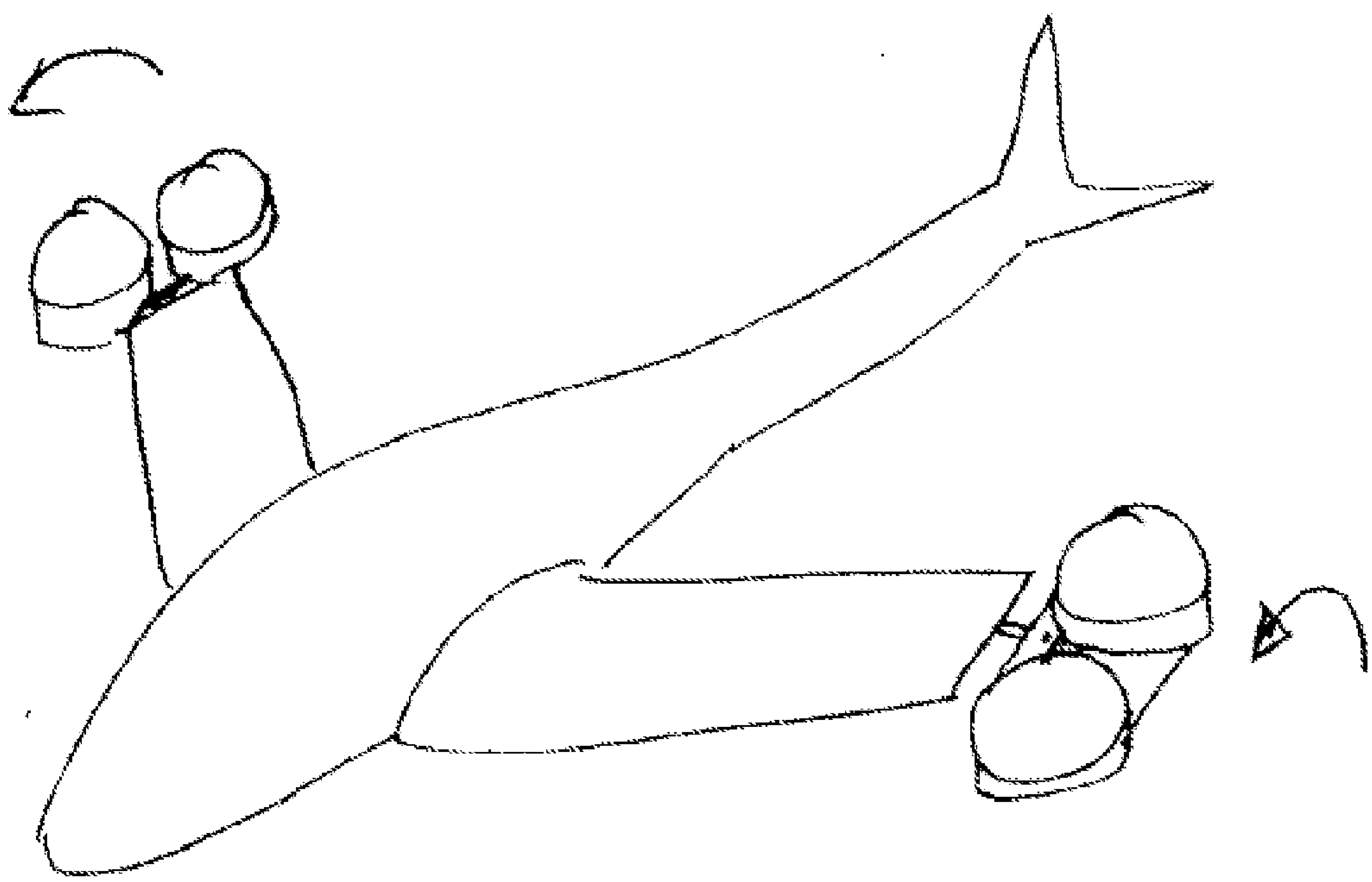


FIGURE 10

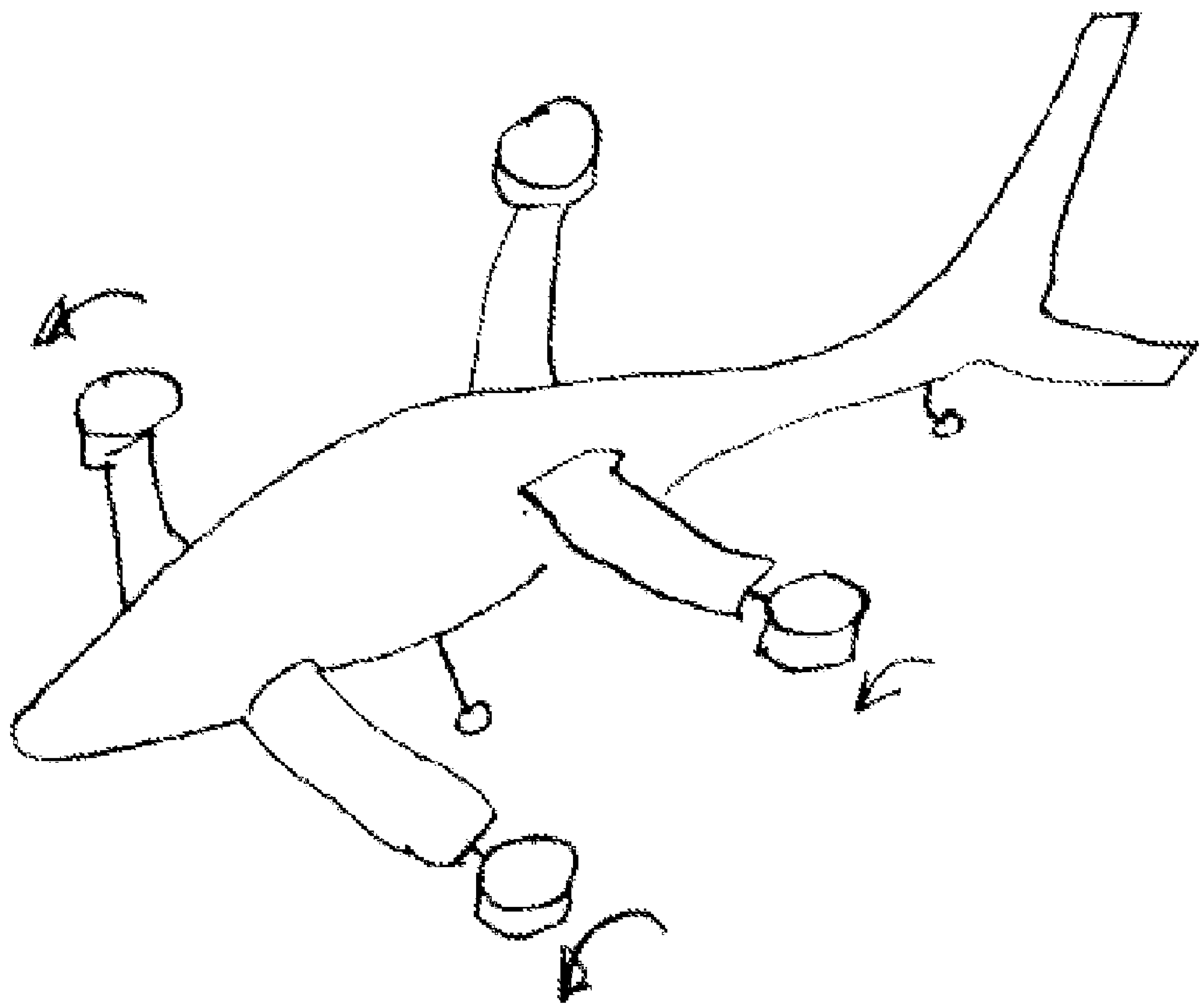


FIGURE 11

LIGHTWEIGHT VERTICAL TAKE-OFF AND LANDING AIRCRAFT AND FLIGHT CONTROL PARADIGM USING THRUST DIFFERENTIALS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/312,188 to Bevirt, filed Mar. 9, 2010, which is hereby incorporated by reference in its entirety. This application claims priority to U.S. Provisional Patent Application No. 61/247,102 to Bevirt, filed Sep. 30, 2009, which is hereby incorporated by reference in its entirety. This application claims priority to U.S. Provisional Patent Application No. 61/236,520 to Bevirt, filed Aug. 24, 2009, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] 1. Field of the Invention

[0003] This invention relates to powered flight, and more specifically to a take-off and flight control aircraft method using thrust differentials.

[0004] 2. Description of Related Art

[0005] There are generally three types of vertical takeoff and landing (VTOL) configurations: wing type configurations having a fuselage with rotatable wings and engines or fixed wings with vectored thrust engines for vertical and horizontal translational flight; helicopter type configuration having a fuselage with a rotor mounted above which provides lift and thrust; and ducted type configurations having a fuselage with a ducted rotor system which provides translational flight as well as vertical takeoff and landing capabilities.

SUMMARY

[0006] An aerial vehicle adapted for vertical takeoff and landing using the same set of thrust producing elements for takeoff and landing as well as for forward flight. An aerial vehicle which is adapted to takeoff with the wings in a vertical as opposed to horizontal flight attitude which takes off in this vertical attitude and then transitions to a horizontal flight path. An aerial vehicle which controls the attitude of the vehicle during takeoff and landing by alternating the thrust of motors, which are separated in at least two dimensions relative to the horizontal during takeoff, and which may also control regular flight in some aspects by the use of differential thrust of the motors. An aerial vehicle which uses a rotating platform of motors in fixed relationship to each other and which rotates relative to the main body of the vehicle for takeoff and landing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a perspective view of an aerial vehicle in takeoff configuration according to some embodiments of the present invention.

[0008] FIG. **2** is a perspective view of an aerial vehicle in a forward flight configuration according to some embodiments of the present invention.

[0009] FIG. **3** is a top view of an aerial vehicle in takeoff configuration according to some embodiments of the present invention.

[0010] FIG. **4** is a front view of an aerial vehicle in takeoff configuration according to some embodiments of the present invention.

[0011] FIG. **5** is a side view of an aerial vehicle in takeoff configuration according to some embodiments of the present invention.

[0012] FIG. **6** is a top view of an aerial vehicle in forward flight configuration according to some embodiments of the present invention.

[0013] FIG. **7** is a front view of an aerial vehicle in forward flight configuration according to some embodiments of the present invention.

[0014] FIG. **8** is a side view of an aerial vehicle in forward flight configuration according to some embodiments of the present invention.

[0015] FIG. **9** is a sketch of the transition from take-off to forward flight mode.

[0016] FIG. **10** is sketch of an aerial vehicle according to some embodiments of the present invention.

[0017] FIG. **11** is a sketch of an aerial vehicle according to some embodiments of the present invention.

DETAILED DESCRIPTION

[0018] In some embodiments of the present invention, as seen in FIG. **1**, an aerial vehicle **100** is seen in take-off configuration. The aircraft body **101** rotationally attached to the left inside duct **106** with a rotational coupling **116**. The aircraft body **101** is also attached to the right inside duct **107** with a rotational coupling. The aircraft body **101** is adapted to rotate relative to the rotating portion **120**.

[0019] In the take-off configuration, the aerial vehicle **100** is adapted to engage in controlled vertical take-off. The rotating portion **120** has landing struts **121** which are adapted to support the aircraft when on the ground. In some embodiments, the aerial vehicle **100** has six thrust producing elements, which may be ducted fans (propellers) driven by electric motors. A left inside duct **106**, which is rotationally coupled to the aircraft body **101**, is attached to an upper left outside duct **105** and a lower left outside duct **104**. The left side ducts house fans **110**, **111**, **112** which may be driven by electric motors. A right inside duct **107**, which is rotationally coupled to the aircraft body **101**, is attached to an upper right outside duct **109** and a lower right outside duct **108**. The right side ducts house fans **113**, **114**, **115** which may be driven by electric motors.

[0020] In a vertical takeoff scenario, the power from the fans **110**, **111**, **112**, **113**, **114**, **115** are varied in power output in order to either change, or maintain, the attitude of the vehicle relative to take-off axis **1** or take-off axis **2**. For example, to effect an attitude change around take-off axis **1**, the relative power output of the left side motors can be varied relative to the power output of the right side motors. To effect an attitude change relative to take-off axis **2**, the relative power output of the upper motors can be varied relative to the power output of the lower motors. In this way, the aerial vehicle can be raised from the ground in a vertical takeoff scenario while maintaining control in these two axes.

[0021] In some embodiments, the aerial vehicle may use a sensor package adapted to provide real time attitude information to a control system which is adapted to perform a vertical takeoff while maintaining the horizontal attitude position of the rotating portion **120** of the aerial vehicle **100**. The control system may be autonomous in keeping the attitude while an operator commands an altitude raise while in takeoff mode.

With the aerial vehicle adapted to take off from a position wherein the leading edges of the wings and the engines face skywards, no relative motion of the engines and the wings is necessary to achieve vertical take off and landing.

[0022] The spacing of the thrust producing elements in two dimensions as viewed from above when the aerial vehicle is on the ground ready for takeoff allows the engine power differentials to control the aircraft in the two aforementioned axes, take-off axis **1** and take-off axis **2**. Although six thrust producing elements are illustrated here, the two dimensional spacing needed to affect two dimensional control could be achieved with as few as three engines.

[0023] Although the control of two axes has been discussed, in some embodiments rotation around take-off axis **3** may also be controlled. In some embodiments, the roll control during takeoff and landing may be controlled using ailerons. In some embodiments, directional vanes are placed behind the ducts, or within the ducts but behind the fans, in order to control take-off axis **3**.

[0024] As seen in FIG. **2**, the aerial vehicle **100** has a forward flight configuration wherein the rotating portion **120** is rotated approximately 90 degrees relative to the aircraft body **101** compared to the take-off configuration. An upper wing **102** is attached to the top of the right upper duct **109** and the left upper duct **105**. A lower wing **103** is attached to the bottom of the right lower duct **108** and the left lower duct **104**. The upper wing **102** and the lower wing **103** are lifting airfoils which are adapted to provide sufficient lift to support the mass of the aerial vehicle **100** during forward flight.

[0025] As seen, the aircraft body may be sized such the rotating portion, including the wings and the ducted fan assemblies, is adapted to rotate from a first take-off position to a second forward flight position without physical interference with the aircraft body in which the pilot may sit. Also seen is that in some embodiments the wings are not attached to the aircraft body, but are attached to the rotating group of fan assemblies.

[0026] FIG. **9** illustrates the transition from vertical takeoff to horizontal flight according to some embodiments of the present invention. As seen, the aerial vehicle first engages in vertical takeoff while maintaining attitude control using an onboard sensor package and by varying the power output of the motors to maintain attitude in a desired range, and may also use ailerons or vanes behind the fans for control in take-off axis **3**. As the aerial vehicle is raised to a desired altitude, the transition to horizontal flight begins. With the use of differential power output control of the motors, the rotating portion, which includes the wings and the motors/fans/ducts, is pitched forward, which alters the wings from their skyward facing position to a more horizontal, normal flying position. This forward pitching of the rotating portion, which then begins to direct thrust rearward, also causes the vehicle to begin to accelerate forward horizontally. With the increase in horizontal velocity coupled with the wing airfoils attitude change to a more horizontal position, lift is generated from the wing airfoils. Thus, as the rotating portion is transitioned to a more horizontal position and their vertical thrust is reduced, lift is begun to be generated from the wing airfoils and the altitude of the aerial vehicle is maintained using the lift of the wings. In this fashion, the aerial vehicle is able to achieve vertical takeoff and transition to horizontal flight without relative motion of the motors to the wings, and using differential control of the power of the motors to achieve some, if not all, of the attitude changes for this maneuver. When landing the craft, these steps as described above are reversed.

[0027] Although not illustrated, in some embodiments the aerial vehicle **100** may have control surfaces such as rudders, elevators, and/or other control surfaces, which may be mounted to the aircraft body. In some embodiments, the aerial vehicle **100** may have ailerons on one or more of its wings which are adapted for roll control.

[0028] The vehicle may be adapted to turn using a simultaneous roll and pitch up, which is affected by the ailerons with regard to roll, and by differentially throttling the motors with regard to pitch. Namely, upper motors may be throttled down relative to the lower motors to achieve an upward change in pitch used in conjunction with the roll of the vehicle to turn the vehicle.

[0029] The control system adapted for attitude control during takeoff using differential control of the thrust elements, which may be electric motors with ducted fans in some embodiments, is also adapted to be used during traditional, more horizontal flight. Although the aerial vehicle may have rudders and elevators in some embodiments, the aerial vehicle and its control system are adapted to use differential control of the thrust elements to vary pitch and yaw during forward flight, and in some embodiments, to control roll as well.

[0030] When the pilot gives a pitch command, the onboard control system then executes a pitch change using a combination of engine thrust differentiation, and also through the use of the ailerons on both sides of the wing in common mode. The pitch change will be executed primarily or fully by differential throttling of the upper and lower motors. A pitch command may be given by the pilot by pulling or pushing a control stick, or by pulling back or pushing on a steering yoke, for example.

[0031] When the pilot gives a roll command, the onboard control system then executes a roll of the aerial vehicle using a combination of aileron control and differential thrusting of counter-rotating motors on the aerial vehicle.

[0032] When the pilot gives a yaw command, the onboard control system then executes a yaw change of the aerial vehicle using engine thrust differentiation. The yaw change will be executed by differential throttling of the right side and left side motors.

[0033] An aerial vehicle **100** according to some embodiments of the present invention thus allows for attitude control of the vehicle during VTOL and regular flight using the same or similar control system parameters, including thrust differentiation of the various thrust producing elements. In some embodiments, the thrust control may involve the reduction or increase of electrical power sent to the motors controlling a propeller or ducted fan assembly. In some embodiments, the thrust control may involve the change of pitch of the propeller/fan blades. In some embodiments, thrust control may use a combination of pitch control and electrical power input control.

[0034] In some embodiments of the present invention, the aerial vehicle may be designed for use as a commuter vehicle. In such a scenario, safety, reliability, compactness, and noise become important design considerations.

[0035] In some embodiments, reliability may be enhanced by the use of two motors on a single shaft driving each of the ducted fan assemblies. The use of two sets of windings wherein one set of windings is used for driving the ducted fan, and the second is a redundant set of windings which may be used in the case of a winding failure, greatly enhances reliability.

[0036] In some embodiments, the electric motors of the aerial vehicle are powered by rechargeable batteries. The use of multiple batteries driving one or more power busses enhances reliability, in the case of a single battery failure. In some embodiments, the batteries may be spread out along the rotating portion, and there may be one battery for each of the motor/ducted fan assemblies. In some embodiments, the battery or batteries may reside in part or fully within the aircraft body, with power routed out to the motors through the rotational couplings.

[0037] In some embodiments, the aerial vehicle is adapted to be able to absorb the failure of one ducted fan assembly and still have sufficient power to engage in both forward flight and also vertical take-off and landing. Given the spacings of the motors, the loss of thrust by one of the thrust producing elements will still allow for attitude control of the vehicle using thrust differentials. The control system of the vehicle may be adapted to sense the failure of one or more thrust producing elements and modify the control paradigms accordingly.

[0038] In some embodiments, the vehicle may have multiple sensor packages adapted to provide attitude, altitude, position, and other information. The sensor packages may be duplicates of each other, allowing for failure of a sensor package in a redundant fashion. In other embodiments, there may be a variety of different types of sensors which are integrated using a common filter, and which also may be able to absorb the loss of one or more of the single sensor types without loss, or without complete loss, of functionality of the vehicle.

[0039] Although ducted fans assemblies are illustrated in the embodiments shown herein, it is understood that other types of thrust producing elements may be used. In some embodiments, ducted fan assemblies may be chosen to enhance safety and to reduce noise of the vehicle.

[0040] In some embodiments, the aerial vehicle may have an emergency safety system such as a ballistic parachute. In the case of absolute failure of the power or control systems, the ballistic parachute may be deployed to allow for an emergency landing.

[0041] In an exemplary embodiment, a vehicle is made primarily from composite materials. The total weight, including the pilot, may be 600 pounds. The weight may be allocated as 200 pounds for the batteries, 150-200 pounds for the pilot, and 200-250 pounds for the remaining aircraft structure less the battery weight. With a six ducted fan/six motor system, the nominal engine load would be 100 pounds per duct. The six ducts may be identical in size, each with an interior diameter of 42 inches. With a 10 horsepower engine per duct, the disc loading is 10 pounds per foot squared. The specific thrust (pounds of thrust/horsepower) is targeted for a range of 8-12.5.

[0042] In this exemplary embodiment, the length of the upper and lower wings is 14 feet, with a chord length of 18 inches. The system may have a stall speed of 70 miles per hour. The system is designed to have a ground parking envelope maximum of 8 feet by 18 feet, which is geared in part to allow it to fit in a parking space.

[0043] The range of the vehicle may be 100 miles, with a flight speed of 100 miles per hour. The range may be achieved using a 15 kWhr battery.

[0044] In some embodiments of the present invention, as seen in FIG. **10**, an aerial vehicle may have two sets of thrust producing elements, one on each side of the aircraft body. The thrust producing elements may be ducted fans driven by electric motors. The thrust assemblies are adapted to rotate from a first position wherein the thrust is primarily downward to a second position adapted for forward flight, with the thrust primarily rearward. With the spacing of the thrust elements as seen, attitude control can be achieved using thrust differentiation both during vertical take-off (the position shown in the figure) as well as during forward flight, as the thrust elements are spaced in two dimensions relative to the direction of motion in both take-off and forward flight modes.

[0045] In some embodiments of the present invention, as seen in FIG. **11**, an aerial vehicle may have four thrust producing elements spread out over two wings. The wings may be set at different heights, thus the thrust elements are spaced in two dimensions in forward flight mode as well as during vertical take-off mode (pictured). The thrust producing elements may be ducted fans driven by electric motors. The thrust assemblies are adapted to rotate from a first position wherein the thrust is primarily downward to a second position adapted for forward flight, with the thrust primarily rearward. With the spacing of the thrust elements as seen, attitude control can be achieved using thrust differentiation both during vertical take-off (the position shown in the figure) as well as during forward flight, as the thrust elements are spaced in two dimensions relative to the direction of motion in both take-off and forward flight modes.

[0046] As evident from the above description, a wide variety of embodiments may be configured from the description given herein and additional advantages and modifications will readily occur to those skilled in the art. The invention in its broader aspects is, therefore, not limited to the specific details and illustrative examples shown and described. Accordingly, departures from such details may be made without departing from the spirit or scope of the applicant's general invention.

What is claimed is:

1. An aerial vehicle adapted for vertical takeoff and horizontal flight, said aerial vehicle comprising:

a main vehicle body; and

a wing and engine array, said wing and engine array comprising:

a first array of engines rotationally coupled to a first side of said main vehicle body;

a second array of engines rotationally coupled to a second side of said main vehicle body; and

one or more wings, each of said wings having a first end and a second end, each of said wings attached to said first array of engines on their first end and attached to said second array of engines on said second end,

wherein said wing and engine array is adapted to rotate relative to said main vehicle body as a single unit.

2. The aerial vehicle of claim **1** wherein said wing and engine array is adapted to rotate from a first position adapted to vertical take-off and landing to a second position adapted for regular flight.

3. The aerial vehicle of claim **2** wherein the thrust of said first array of engines and said second array of engines is pointed downwards while said wing and engine array is in said first position.

4. The aerial vehicle of claim **3** wherein the leading edges of said one or more wings are facing upwards while said wing and engine array is in said first position.

5. The aerial vehicle of claim **4** said wing and engine array comprises two wings.

6. The aerial vehicle of claim **5** wherein said two wings comprise a wing above said main vehicle body and a wing below said vehicle body while said wing and engine array is in said second position.

7. The aerial vehicle of claim **2** wherein said first array of engines and said second array of engines combine to create a two dimensional array of engines in a plane parallel to the ground while said wing and engine array is said first position.

8. The aerial vehicle of claim **4** wherein said first array of engines and said second array of engines combine to create a two dimensional array of engines in a plane parallel to the ground while said wing and engine array is said first position.

9. The aerial vehicle of claim **7** further comprising a control system, said control system adapted to control the attitude of said aerial vehicle during take-off and landing around a first control axis parallel to the ground and a second control axis parallel to the ground, wherein said first control axis and said second control axis are perpendicular to each other.

10. A method for flying an aerial vehicle, said method including the steps of:

rotating a wing and engine assembly relative to an aircraft body into a vertical take-off position, wherein the leading edges of the wings face upward, said wing and engine assembly comprising

a first array of engines rotationally coupled to a first side of said main vehicle body;

a second array of engines rotationally coupled to a second side of said main vehicle body; and

one or more wings, each of said wings having a first end and a second end, each of said wings attached to said first array of engines on their first end and attached to said second array of engines on said second end;

directing thrust from the first array of engines and the second array of engines to effect a take-off from the ground;

controlling the attitude of said aerial vehicle in a first axis and a second axis during take-off by varying the thrust of the engines,

wherein said first axis and said second axis are perpendicular to each other, and wherein said first axis and said second axis are parallel to the ground.

* * * * *