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(54) EJECTOR AND AIRFOIL CONFIGURATIONS

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(57)   ABSTRACT
A propulsion system coupled to a vehicle. The system
includes an ejector having an outlet structure out of which
propulsive fluid flows at a predetermined adjustable veloc-
ity. A control surface having a leading edge is located
directly downstream of the outlet structure such that pro-
pulsive fluid from the ejector flows over the control surface.

5 Claims, 10 Drawing Sheets
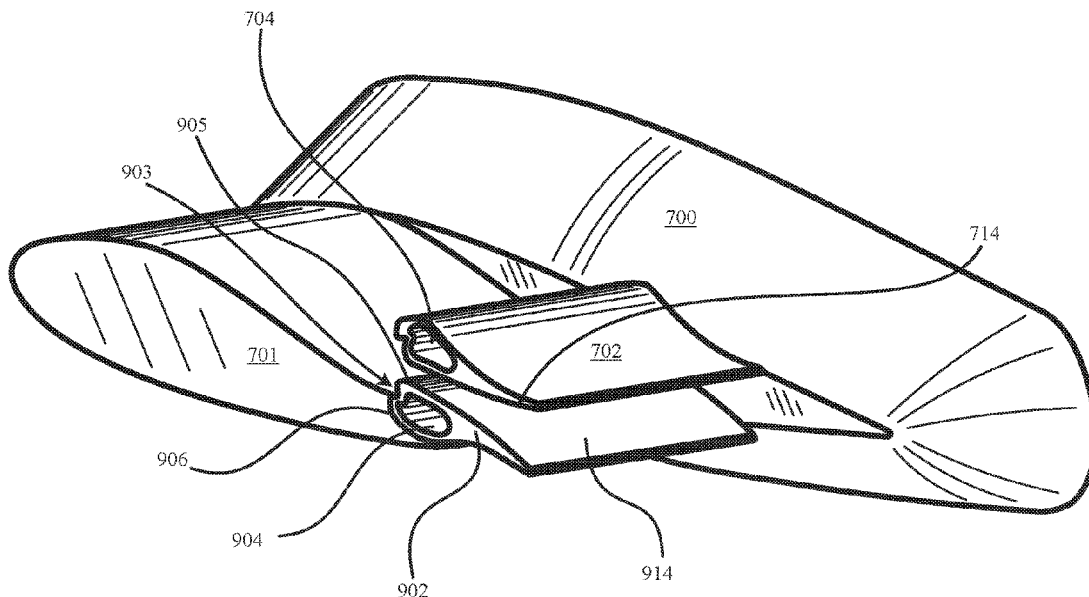
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Fig. 1

200

206

401

210

402

Fig. 2

Fig. 3

Fig. 4

507

507

506

506

502

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Fig. 5

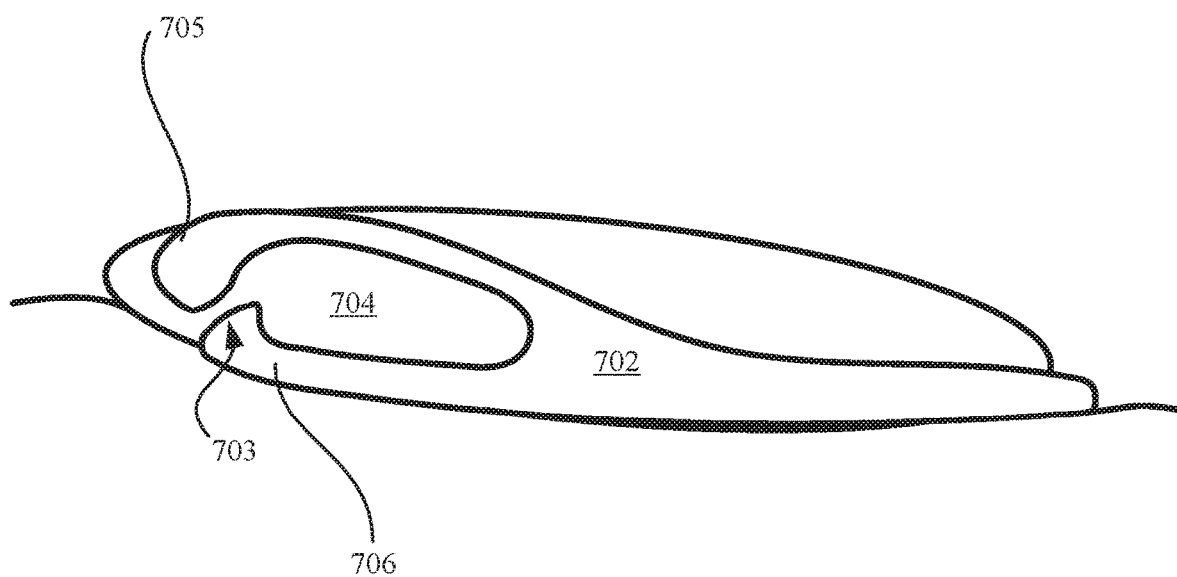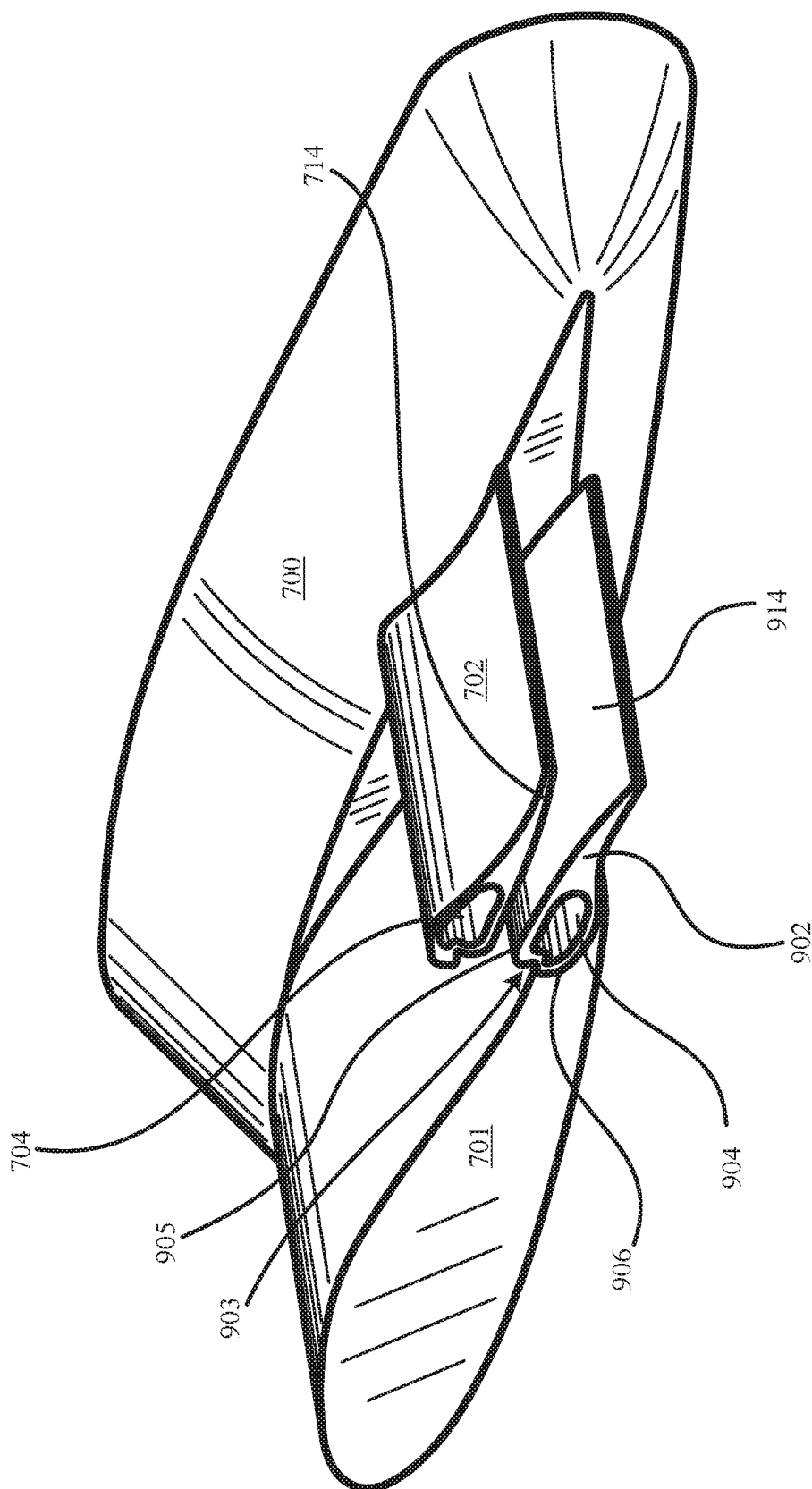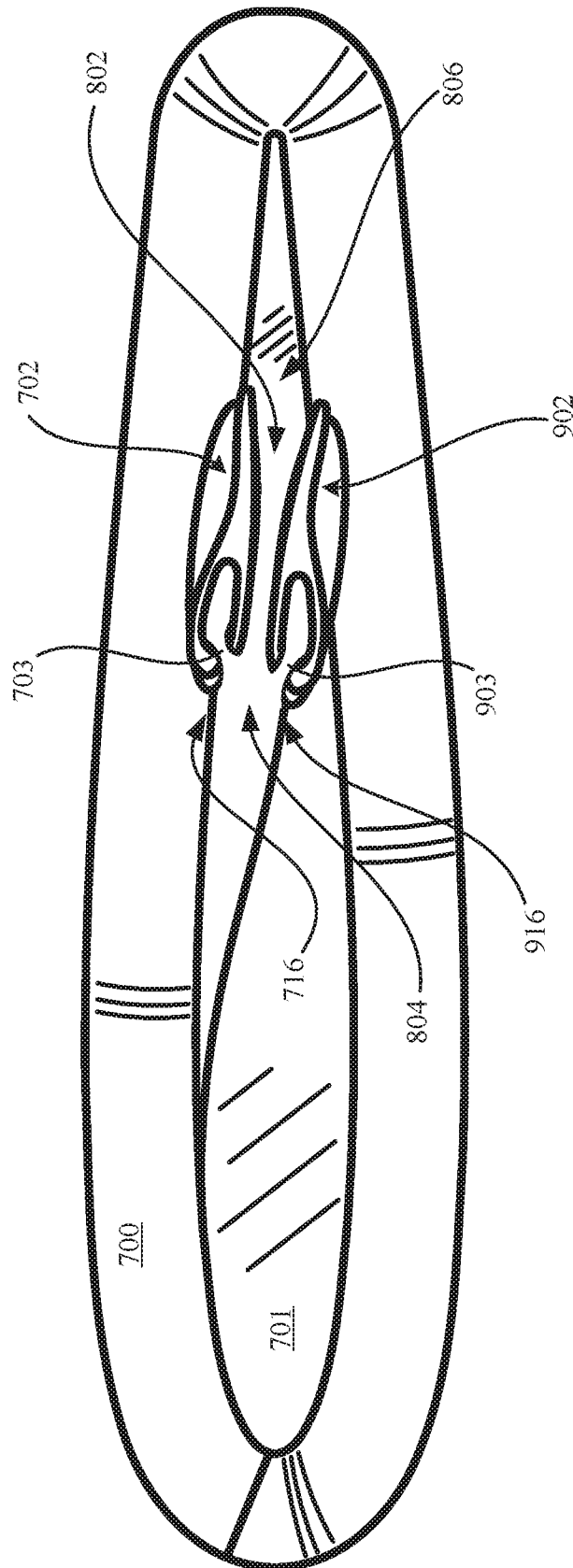*Fig. 6*

705

704

702

703
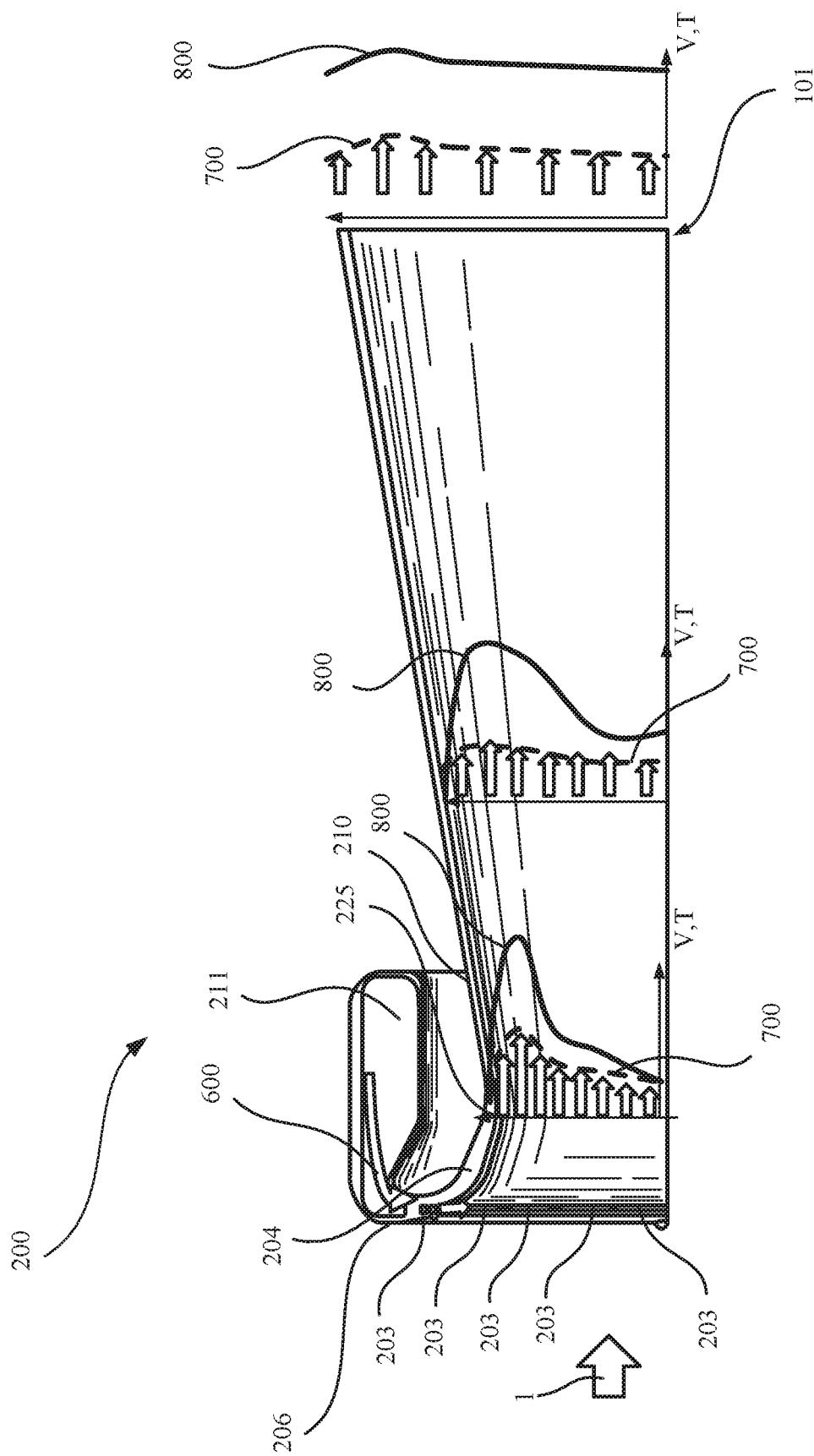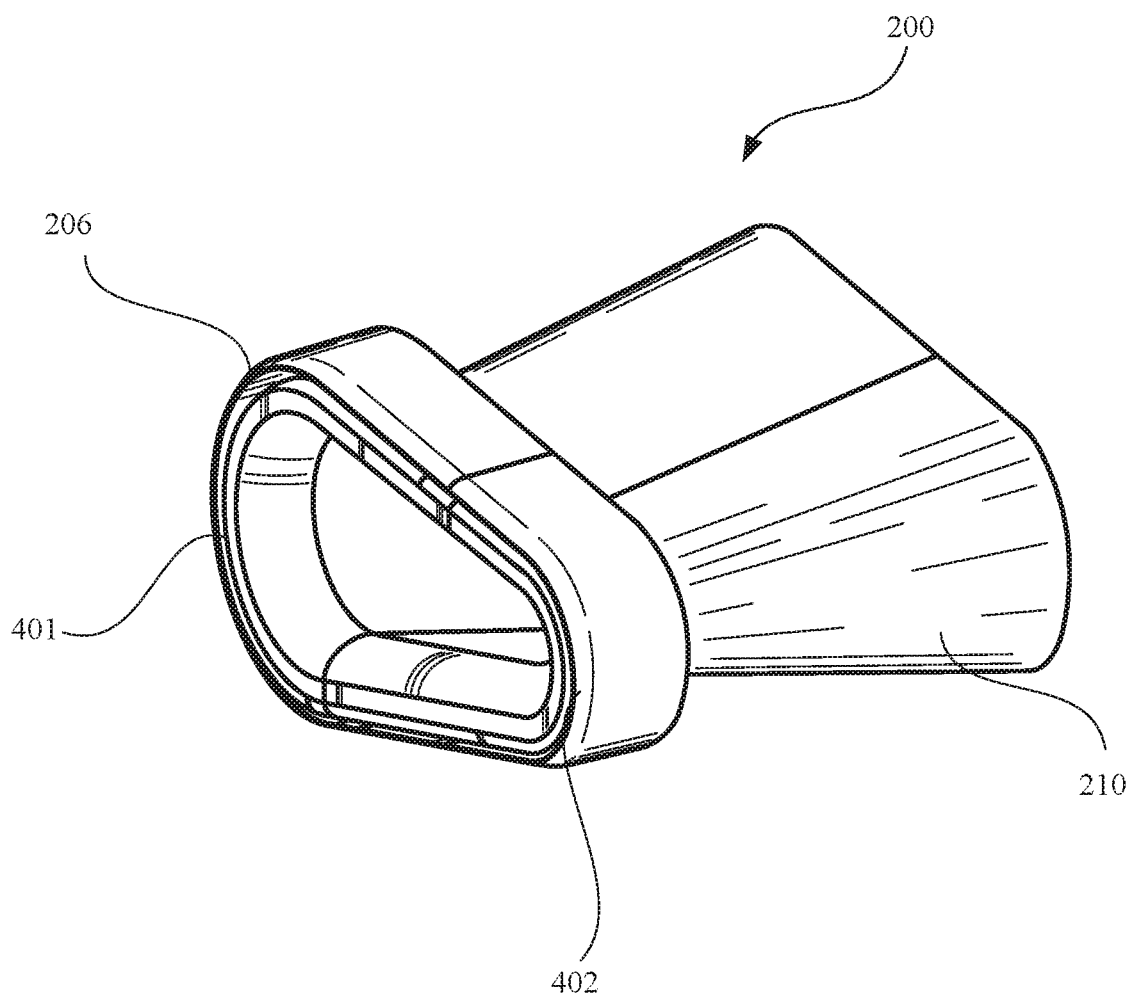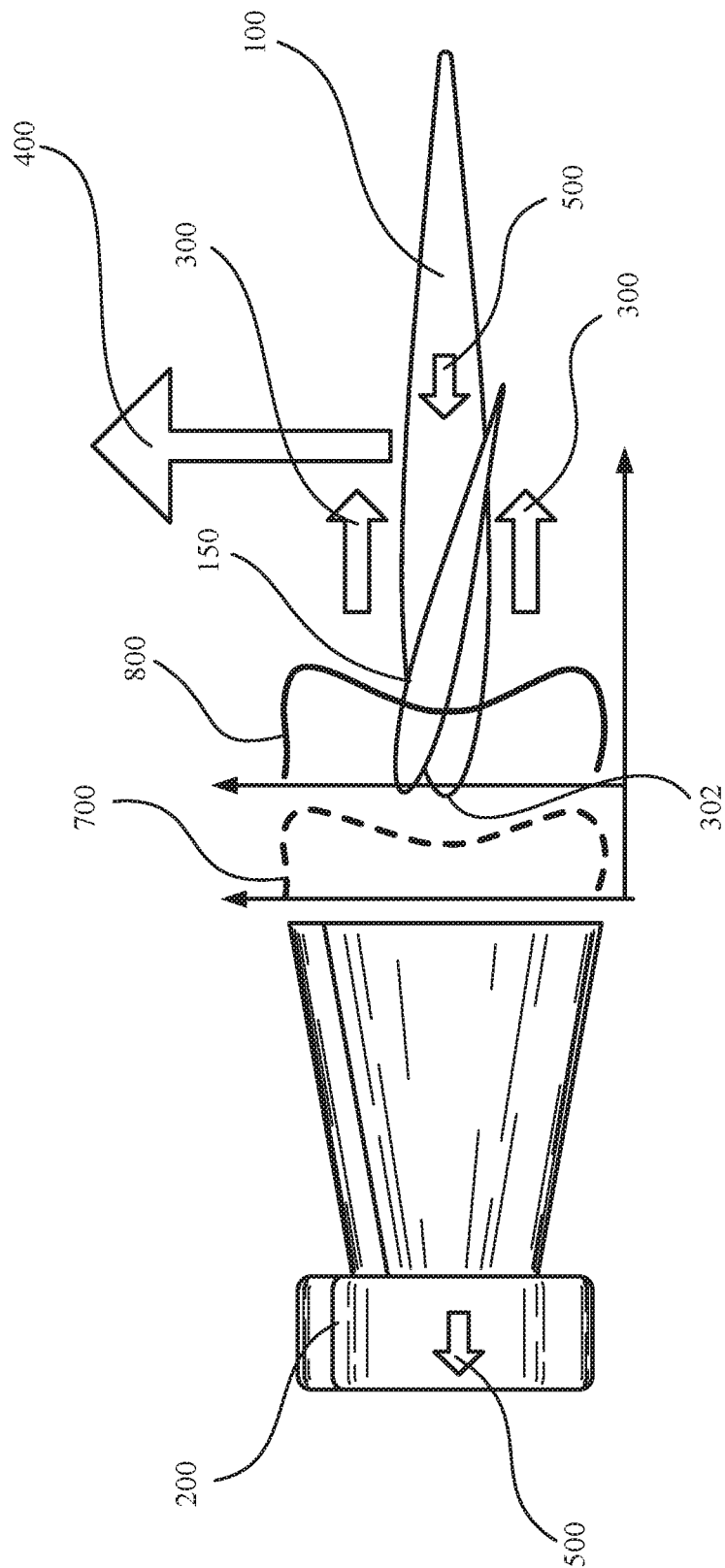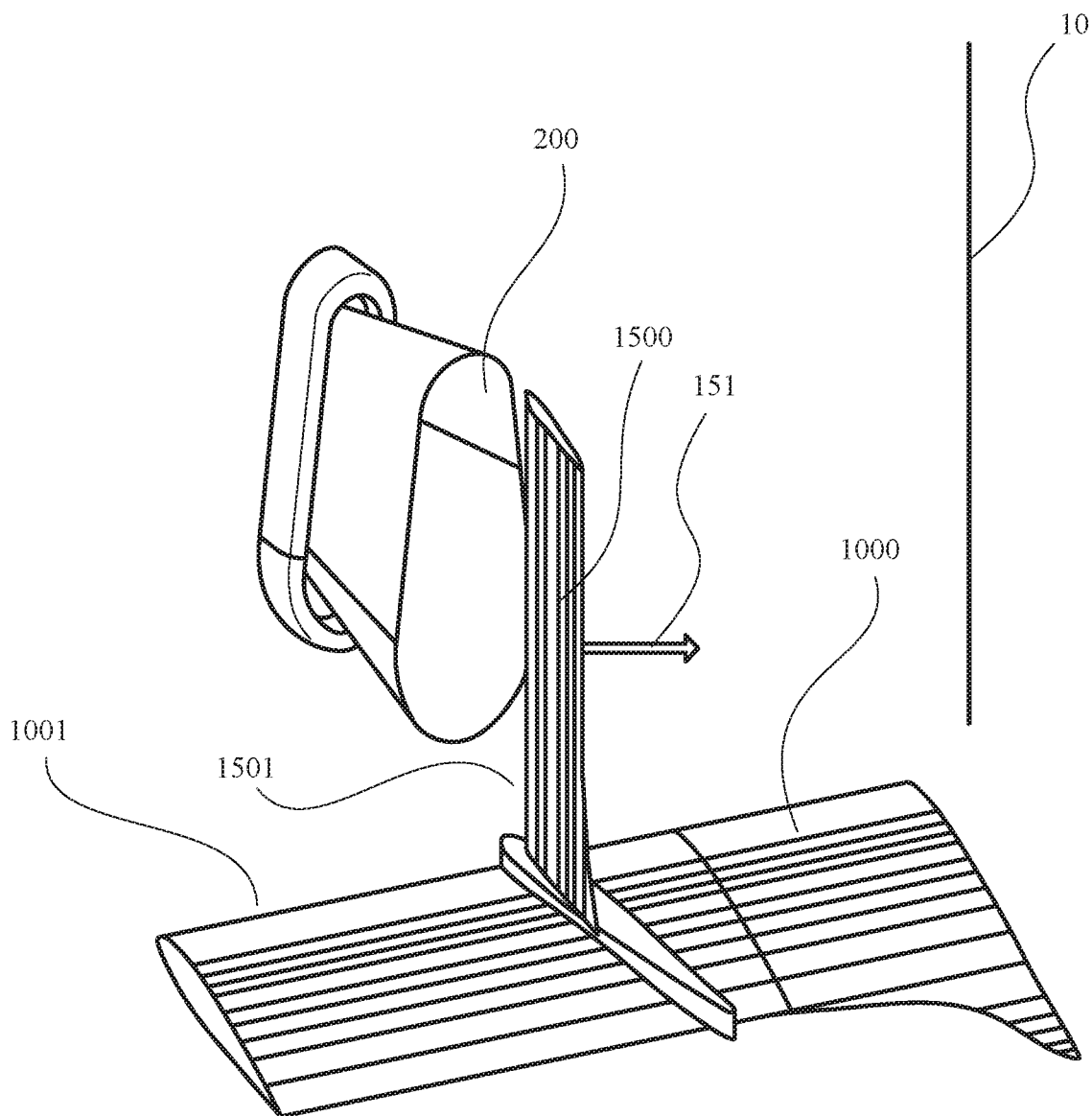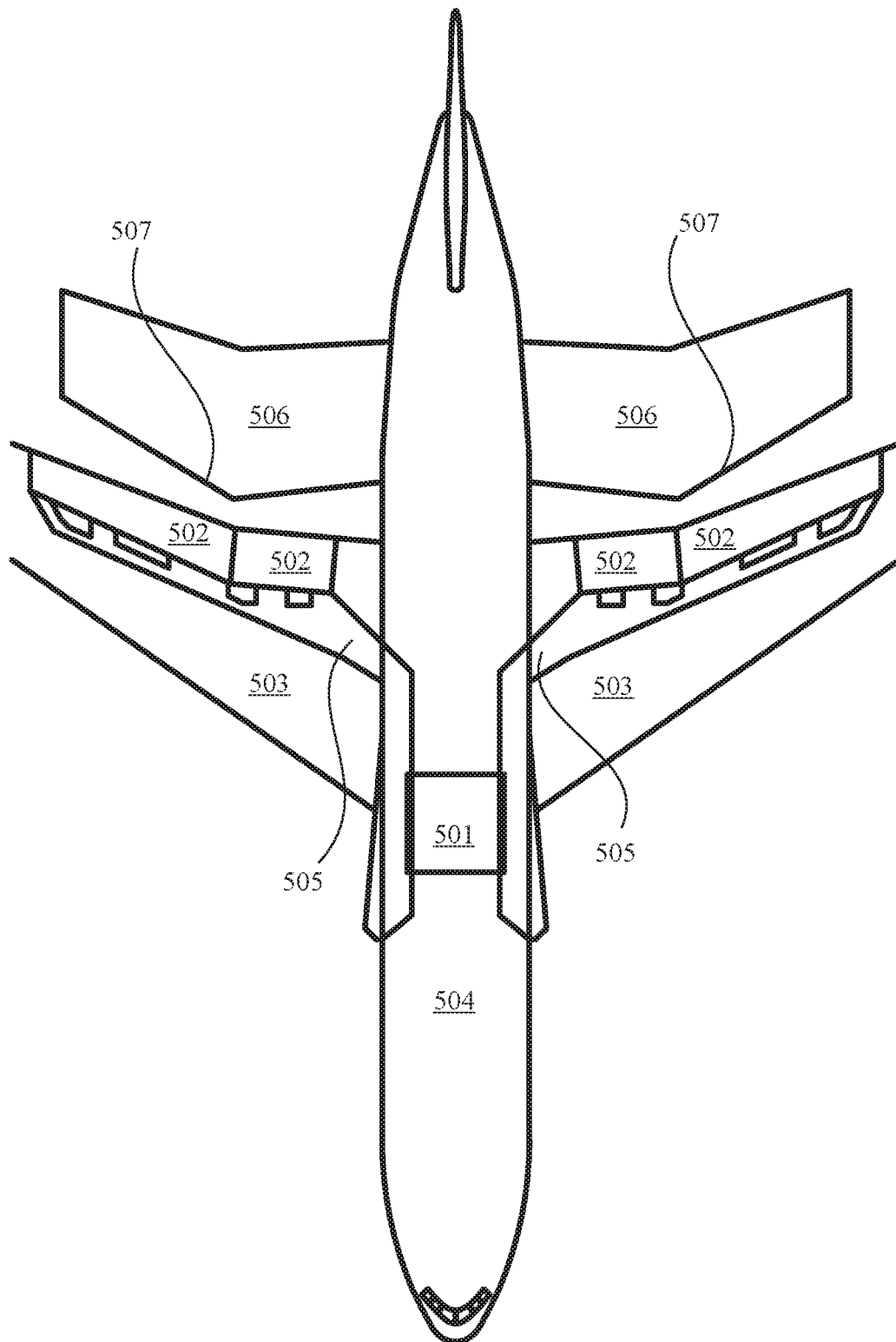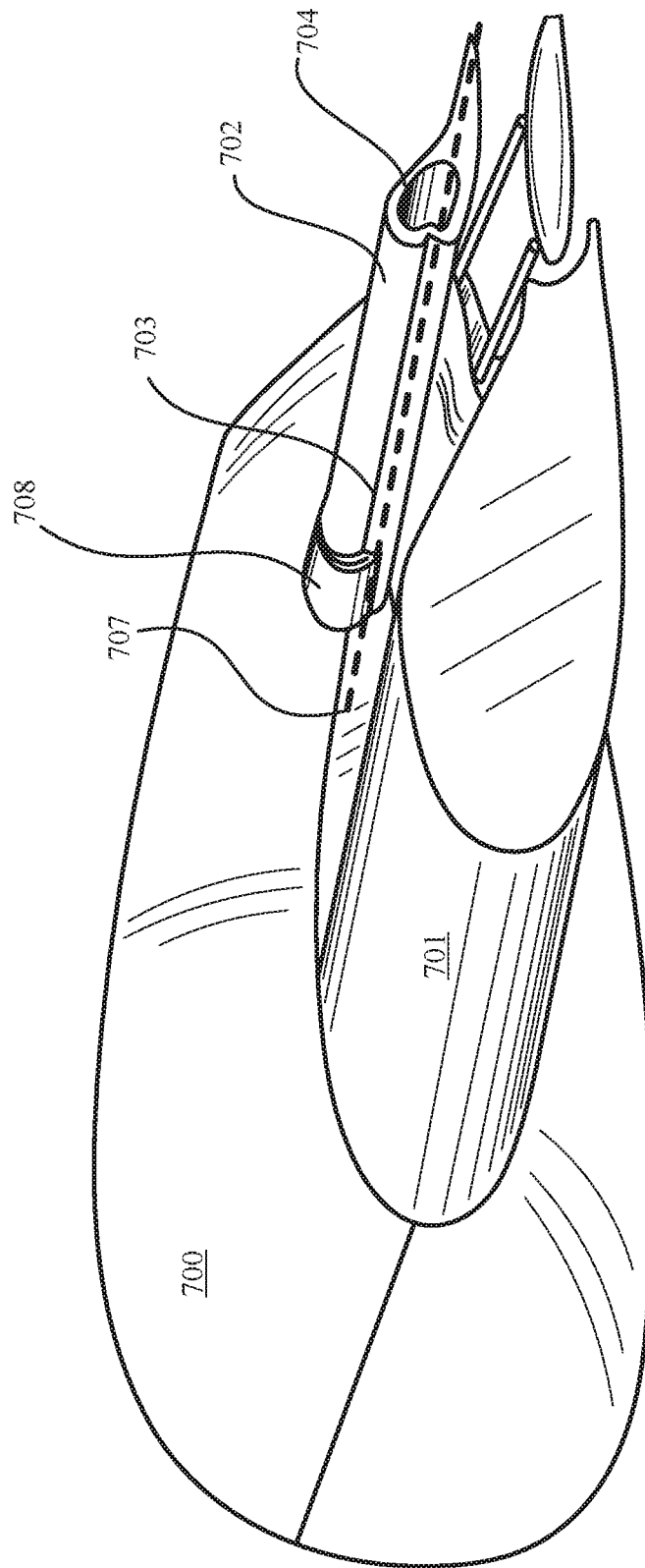
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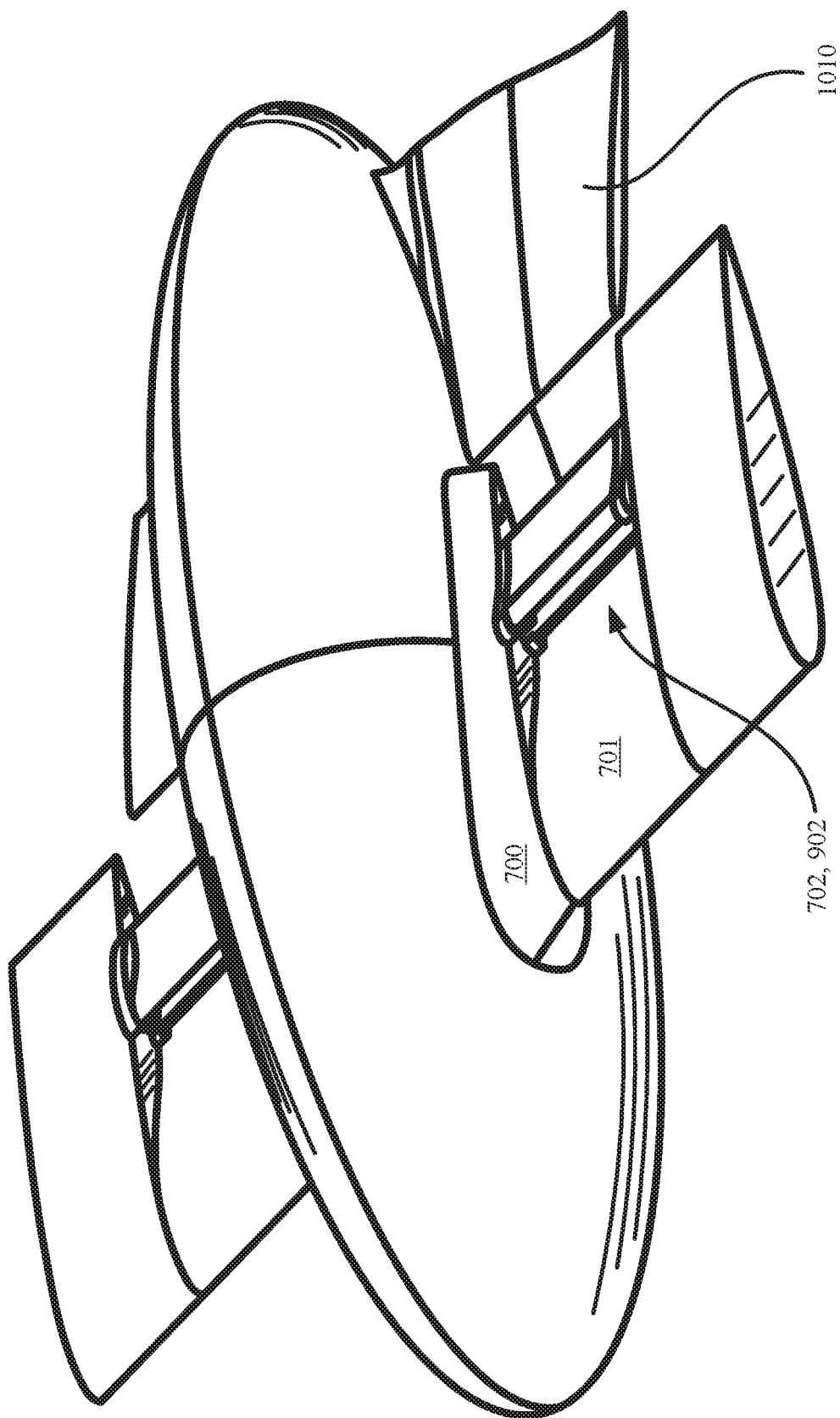
Fig. 7

Fig. 8

Fig. 9

Fig. 10

EJECTOR AND AIRFOIL CONFIGURATIONS

PRIORITY CLAIM

This application claims priority to U.S. Provisional Application No. 62/213,465, filed Sep. 2, 2015, the entire disclosure of which is hereby incorporated by reference as if fully set forth herein.

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BACKGROUND

Aircrafts that can hover, take off and land vertically are commonly referred to as Vertical Take-Off and Landing (VTOL) aircrafts. This classification includes fixed-wing aircrafts as well as helicopters and aircraft with tilt-able powered rotors. Some VTOL aircrafts can operate in other modes as well, such as Short Take-Off and Landing (STOL). VTOL is a subset of V/STOL (Vertical and/or Short Take-off and Landing).

For illustrative purposes, an example of a current aircraft that has VTOL capability is the F-35 Lightning. Conventional methods of vectoring the vertical lift airflow includes the use of nozzles that can be swiveled in a single direction along with the use of two sets of flat flapper vanes arranged 90 degrees to each other and located at the external nozzle. The propulsion system of the F-35 Lightning, similarly, provides vertical lifting force using a combination of vectored thrust from the turbine engine and a vertically oriented lift fan. The lift fan is located behind the cockpit in a bay with upper and lower clamshell doors. The engine exhausts through a three-bearing swivel nozzle that can deflect the thrust from horizontal to just forward of vertical. Roll control ducts extend out in each wing and are supplied with their thrust with air from the engine fan. Pitch control is affected via lift fan/engine thrust split. Yaw control is through yaw motion of the engine swivel nozzle. Roll control is provided by differentially opening and closing the apertures at the ends of the two roll control ducts. The lift fan has a telescoping "D"-shaped nozzle to provide thrust deflection in the forward and aft directions. The D-nozzle has fixed vanes at the exit aperture.

The design of an aircraft or drone more generally consists of its propulsive elements and the airframe into which those elements are integrated. Conventionally, the propulsive device in aircrafts can be a turbojet, turbofan, turboprop or turboshaft, piston engine, or an electric motor equipped with a propeller. The propulsive system (propulsor) in small unmanned aerial vehicles (UAVs) is conventionally a piston engine or an electric motor which provides power via a shaft to one or several propellers. The propulsor for a larger aircraft, whether manned or unmanned, is traditionally a jet engine or a turboprop. The propulsor is generally attached to the fuselage or the body or the wings of the aircraft via pylons or struts capable of transmitting the force to the aircraft and sustaining the loads. The emerging mixed jet (jet

efflux) of air and gases is what propels the aircraft in the opposite direction to the flow of the jet efflux.

Conventionally, the air stream efflux of a large propeller is not used for lift purposes in level flight and a significant amount of kinetic energy is hence not utilized to the benefit of the aircraft, unless it is swiveled as in some of the applications existing today (namely the Bell Boeing V-22 Osprey). Rather, the lift on most existing aircrafts is created by the wings and tail. Moreover, even in those particular VTOL applications (e.g., take-off through the transition to level flight) found in the Osprey, the lift caused by the propeller itself is minimal during level flight, and most of the lift force is nonetheless from the wings.

The current state of art for creating lift on an aircraft is to generate a high-speed airflow over the wing and wing elements, which are generally airfoils. Airfoils are characterized by a chord line extended mainly in the axial direction, from a leading edge to a trailing edge of the airfoil. Based on the angle of attack formed between the incident airflow and the chord line, and according to the principles of airfoil lift generation, lower pressure air is flowing over the suction (upper) side and conversely, by Bernoulli law, moving at higher speeds than the lower side (pressure side). The lower the airspeed of the aircraft, the lower the lift force, and higher surface area of the wing or higher angles of incidence are required, including for take-off.

Large UAVs make no exception to this rule. Lift is generated by designing a wing airfoil with the appropriate angle of attack, chord, wingspan, and camber line. Flaps, slots and many other devices are other conventional tools used to maximize the lift via an increase of lift coefficient and surface area of the wing, but it will be generating the lift corresponding to at the air-speed of the aircraft. (Increasing the area (S) and lift coefficient (C_L) allow a similar amount of lift to be generated at a lower aircraft airspeed (V0) according to the formula $L=\frac{1}{2}\,\rho V^2 S C_L$, but at the cost of higher drag and weight.) These current techniques also perform poorly with a significant drop in efficiency under conditions with high cross winds.

While smaller UAVs arguably use the thrust generated by propellers to lift the vehicle, the current technology strictly relies on control of the electric motor speeds, and the smaller UAV may or may not have the capability to swivel the motors to generate thrust and lift, or transition to a level flight by tilting the propellers. Furthermore, the smaller UAVs using these propulsion elements suffer from inefficiencies related to batteries, power density, and large propellers, which may be efficient in hovering but inefficient in level flight and create difficulties and danger when operating due to the fast moving tip of the blades. Most current quadcopters and other electrically powered aerial vehicles are only capable of very short periods of flight and cannot efficiently lift or carry large payloads, as the weight of the electric motor system and battery may already be well exceeding 70% of the weight of the vehicle at all times of the flight. A similar vehicle using jet fuel or any other hydrocarbon fuel typically used in transportation will carry more usable fuel by at least one order of magnitude. This can be explained by the much higher energy density of the hydrocarbon fuel compared to battery systems (by at least one order of magnitude), as well as the lower weight to total vehicle weight ratio of a hydrocarbon fuel based system.

Accordingly, there is a need for enhanced efficiency, improved capabilities, and other technological advancements in aircrafts, particularly to UAVs and certain manned aerial vehicles.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a cross-section of one embodiment of the present invention depicting the upper half of an ejector and profiles of velocity and temperature within the internal flow;

FIG. 2 illustrates a partial perspective view of an intake structure according to an embodiment;

FIG. 3 illustrates a side plan view of an ejector placed in front of a control surface according to an embodiment;

FIG. 4 is a perspective view of an ejector placed in front of a control surface in combination with another control surface according to an embodiment;

FIG. 5 is a top partial cross-sectional view of an alternative embodiment;

FIG. 6 is a side perspective view of an alternative embodiment;

FIG. 7 is a side view of element of the embodiment illustrated in FIG. 6;

FIGS. 8-9 illustrate another alternative embodiment of the invention; and

FIG. 10 illustrates yet another alternative embodiment of the invention.

DETAILED DESCRIPTION

This application is intended to describe one or more embodiments of the present invention. It is to be understood that the use of absolute terms, such as "must," "will," and the like, as well as specific quantities, is to be construed as being applicable to one or more of such embodiments, but not necessarily to all such embodiments. As such, embodiments of the invention may omit, or include a modification of, one or more features or functionalities described in the context of such absolute terms. In addition, the headings in this application are for reference purposes only and shall not in any way affect the meaning or interpretation of the present invention.

One embodiment of the present invention includes a propulsor that utilizes fluidics for the entrainment and acceleration of ambient air and delivers a high speed jet efflux of a mixture of the high pressure gas (supplied to the propulsor from a gas generator) and entrained ambient air. In essence, this objective is achieved by discharging the gas adjacent to a convex surface. The convex surface is a so-called Coanda surface benefiting from the Coanda effect described in U.S. Pat. No. 2,052,869 issued to Henri Coanda on Sep. 1, 1936. In principle, the Coanda effect is the tendency of a jet-emitted gas or liquid to travel close to a wall contour even if the direction of curvature of the wall is away from the axis of the jet. The convex Coanda surfaces discussed herein with respect to one or more embodiments does not have to consist of any particular material.

FIG. 1 illustrates a cross-section of the upper half of an ejector 200 that may be attached to a vehicle (not shown), such as, for non-limiting example, a UAV or a manned aerial vehicle such as an airplane. A plenum 211 is supplied with hotter-than-ambient air (i.e., a pressurized motive gas stream) from, for example, a combustion-based engine that may be employed by the vehicle. This pressurized motive gas stream, denoted by arrow 600, is introduced via at least one conduit, such as primary nozzles 203, to the interior of the ejector 200. More specifically, the primary nozzles 203 are configured to accelerate the motive fluid stream 600 to a variable predetermined desired velocity directly over a convex Coanda surface 204 as a wall jet. Additionally, primary nozzles 203 provide adjustable volumes of fluid

stream 600. This wall jet, in turn, serves to entrain through an intake structure 206 secondary fluid, such as ambient air denoted by arrow 1, that may be at rest or approaching the ejector 200 at non-zero speed from the direction indicated by arrow 1. In various embodiments, the nozzles 203 may be arranged in an array and in a curved orientation, a spiraled orientation, and/or a zigzagged orientation.

The mix of the stream 600 and the air 1 may be moving purely axially at a throat section 225 of the ejector 200. Through diffusion in a diffusing structure, such as diffuser 210, the mixing and smoothing out process continues so the profiles of temperature (800) and velocity (700) in the axial direction of ejector 200 no longer have the high and low values present at the throat section 225, but become more uniform at the terminal end 101 of diffuser 210. As the mixture of the stream 600 and the air 1 approaches the exit plane of terminal end 101, the temperature and velocity profiles are almost uniform. In particular, the temperature of the mixture is low enough to be directed towards an airfoil such as a wing or control surface.

In an embodiment, intake structure 206 and/or terminal end 101 may be circular in configuration. However, in varying embodiments, and as best shown in FIG. 2, intake structure 206, as well as terminal end 101, can be non-circular and, indeed, asymmetrical (i.e., not identical on both sides of at least one, or alternatively any-given, plane bisecting the intake structure). For example, as shown in FIG. 2, the intake structure 206 can include first and second lateral opposing edges 401, 402, wherein the first lateral opposing edge has a greater radius of curvature than the second lateral opposing edge. Terminal end 101 may be similarly configured.

FIG. 3 illustrates the propulsor/ejector 200, placed in front of a control surface, such as an airfoil 100 having a leading edge 302 and generating a lift force 400. As is illustrated, airfoil 100 is positioned directly behind (i.e., downstream) of outlet structure, such as terminal end 101 of diffuser 210, of ejector such that propulsive fluid from the ejector 200 flows over the airfoil. Indeed, in an embodiment, airfoil 100 may be positioned close enough to terminal end 101 such that only propulsive fluid from the ejector 200, exclusive of other ambient air, flows over airfoil. As used herein, the term "directly behind" may be construed to mean that at least a portion of leading edge 302 is within, or aligned with one of, the planes (a) occupied by surfaces of terminal end 101 that are parallel with the leading edge and (b) extending in the direction axial to ejector 200 (i.e., in the direction of arrows 300 discussed below).

The local flow over airfoil 100 is at higher speed than the speed of the aircraft, due to higher velocity of ejector 200 exit jet efflux, denoted by arrows 300, in comparison with aircraft airspeed denoted by arrow 500. The ejector 200 mixes vigorously the hotter motive stream 600 (FIG. 1) with the incoming cold ambient stream of air at high entrainment rate. Additional control surfaces can be implemented on the airfoil 100, such as elevator surface 150. In an embodiment the entirety of any such control surface is rotatable about an axis oriented parallel to the leading edge 302. By changing the angle of such surfaces 100 and/or 150, the attitude of the aircraft can rapidly be changed with little effort given the higher local velocity of the jet efflux 300. The mixture is homogeneous enough to reduce the hot motive stream 600 of the ejector temperature to a mixture temperature profile 800 that will not negatively impact the airfoils 100 or 150 mechanically or structurally. The velocity profile 700 of the

efflux jet leaving the propulsor is such that it will allow more lift **400** to be generated by airfoil **100** due to higher local speeds.

FIG. **4** illustrates that the propulsor/ejector **200** may also be placed in front of a control surface **1500** in combination with another airfoil **1000** and in a configuration different from that of control surfaces illustrated in FIG. **3**. In the illustrated embodiment, leading edge **1501** of control surface **1500** is disposed at an approximately 90-degree angle with respect to leading edge **1001** of airfoil **1000**. The ejector **200** may be a non-axisymmetric shape, and the control surface may be placed exactly in the wake of said ejector **200**. The ejector **200** mixes vigorously the hotter motive stream **600** (FIG. **1**) with the incoming cold ambient stream of air at high entrainment rate. Similarly, the mixture is homogeneous enough to reduce the hot motive stream **600** of the ejector temperature to a mixture temperature profile that will not negatively impact the control surface **1500** mechanically or structurally. In this embodiment, yaw can be controlled by changing the orientation of control surface **1500**. In similar fashions, and by varying the orientation of a control surface **1500** with respect to a vehicle main body, such as an aircraft fuselage, pitch and roll may likewise be controlled. A function of ejector **200** is to generate thrust, but it can also provide lift or attitude control. In this embodiment, yaw control is in direction **151** creating a rotation around the aircraft axis **10**.

FIG. **5** illustrates an embodiment that provides an alternative to the traditional approach of placing jet engines on the wings of an aircraft to produce thrust. In FIG. **5**, a gas generator **501** produces a stream of motive air for powering a series of ejectors **502** that are embedded in the primary airfoils, such as wings **503**, for forward propulsion by emitting the gas stream directly from the trailing edge of the primary airfoils. In this embodiment, the gas generator **501** is embedded into the main-body fuselage **504** of the aircraft, is fluidly coupled to the ejectors **502** via conduits **505** and is the sole means of propulsion of the aircraft. Ejectors **502** may be circular or non-circular such as is the embodiment illustrated in FIG. **2**, have correspondingly shaped outlet structure similar to terminal end **101** and provide, at a predetermined adjustable velocity, the gas stream from generator **501** and conduits **505**. Additionally, ejectors **502** may be movable in a manner similar to that of flaps or ailerons, rotatable through a 180° angle and can be actuated to control the attitude of the aircraft in addition to providing the required thrust. Secondary airfoils **506** having leading edges **507** are placed in tandem with wings **503** and directly behind ejectors **502** such that the gas stream from the ejectors **502** flows over the secondary airfoils **506**. The secondary airfoils **506** hence receive a much higher velocity than the airspeed of the aircraft, and as such creates a high lift force, as the latter is proportional to the airspeed squared. The entirety of the secondary airfoils **506** may be rotatable about an axis oriented parallel to the leading edges **507**.

In this embodiment of the present invention, the secondary airfoil **506** will see a moderately higher temperature due to mixing of the motive fluid produced by the gas generator **501** (also referred to as the primary fluid) and the secondary fluid, which is ambient air, entrained by the motive fluid at a rate between 5-25 parts of secondary fluid per each primary fluid part. As such, the temperature that the secondary airfoil **506** sees is a little higher than the ambient temperature, but significantly lower than the motive fluid, allowing for the materials of the secondary wing to support and sustain the lift loads, according to the formula: $T_{mix} = (T_{motive} + ER \cdot T_{amb})/(1+ER)$ where T_{max} is the final fluid

mixture temperature of the jet efflux emerging from the ejector **502**, ER is the entrainment rate of parts of ambient air entrained per part of motive air, T_{motive} is the hotter temperature of the motive or primary fluid, and T_{amb} is the approaching ambient air temperature.

FIG. **6** illustrates a propulsion system for a vehicle **700** according to an alternative embodiment. A first augmenting airfoil **702** is coupled to the vehicle **700** and positioned downstream of fluid flowing over a primary airfoil **701** of the vehicle. Airfoil **702** is configured to rotate about axis **707** and controlled by an actuator **708**. As best illustrated in FIG. **7**, the first augmenting airfoil **702** includes a first output structure, such as opposing nozzle surfaces **705**, **706** and at least one conduit, such as plenum **704**, in fluid communication with a terminal end **703** defined by the nozzle surfaces. Nozzle surfaces **705**, **706** may or may not include nozzles similar to nozzles **203** discussed above with reference to FIG. **1**. Additionally, one or more of nozzle surfaces **705**, **706** may include a convex surface that can, consequently, promote the Coanda effect and may have continuously rounded surfaces with no sharp or abrupt corners. Plenum **704** is supplied with hotter-than-ambient air (i.e., a pressurized motive gas stream) from, for example, a combustion-based engine that may be employed by the vehicle **700**. Plenum **704** is configured to introduce this gas stream to the terminal end **703**, which is configured to provide egress for the gas stream toward the primary airfoil **701** and out of the first augmenting airfoil **702**.

Referring to FIGS. **8-9**, an embodiment may include a second augmenting airfoil **902** similar to airfoil **702**, each with a respective trailing edge **714**, **914** diverging from the other trailing edge. More particularly, second augmenting airfoil **902** is coupled to the vehicle **700** and positioned downstream of fluid flowing over the primary airfoil **701** of the vehicle. Airfoil **902** is configured to rotate in a manner similar to that discussed above with reference to airfoil **702**. Airfoil **902** includes a first output structure, such as opposing nozzle surfaces **905**, **906** and at least one conduit, such as plenum **904**, in fluid communication with a terminal end **903** defined by the nozzle surfaces. Nozzle surfaces **905**, **906** may or may not include nozzles similar to nozzles **203** discussed above with reference to FIG. **1**. Additionally, one or more of nozzle surfaces **905**, **906** may include a convex surface that can, consequently, promote the Coanda effect. Plenum **904** is supplied with hotter-than-ambient air (i.e., a pressurized motive gas stream) from, for example, a combustion-based engine that may be employed by the vehicle **700**. Plenum **904** is configured to introduce this gas stream to the terminal end **903**, which is configured to provide egress for the gas stream toward the primary airfoil **701** and out of the second augmenting airfoil **902**.

Each of the first and second augmenting airfoils **702**, **902** has a leading edge **716**, **916** disposed toward the primary airfoil, with the first augmenting airfoil opposing the second augmenting airfoil. In operation, the first and second augmenting airfoils **702**, **902** define a diffusing region **802**, therebetween and along their lengths, similar in function to diffuser **210** discussed above herein. The leading edges **716**, **916** define an intake region **804** configured to receive and introduce to the diffusing region **802** the gas streams from plena **704**, **904** and the fluid flowing over the primary airfoil **701**. The diffusing region **802** includes a primary terminal end **806** configured to provide egress from the diffusing region for the introduced gas streams and fluid flowing over the primary airfoil **701**.

FIG. **10** depicts an alternative embodiment of the present invention featuring tandem wings. In the illustrated embodi-

ment, a secondary airfoil **1010** is placed directly downstream of the augmenting airfoils **702**, **902** such that the fluid flowing over the primary airfoil **701** and the gas stream from the augmenting airfoils flows over the secondary airfoil. The combination of the two relatively shorter wings **701**, **1010** produce more lift than that of a much larger-spanned wing lacking the augmenting airfoils **702**, **902** and that rely on a jet engine attached to a larger wing to produce thrust.

Although the foregoing text sets forth a detailed description of numerous different embodiments, it should be understood that the scope of protection is defined by the words of the claims to follow. The detailed description is to be construed as exemplary only and does not describe every possible embodiment because describing every possible embodiment would be impractical, if not impossible. Numerous alternative embodiments could be implemented, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims.

Thus, many modifications and variations may be made in the techniques and structures described and illustrated herein without departing from the spirit and scope of the present claims. Accordingly, it should be understood that the methods and apparatus described herein are illustrative only and are not limiting upon the scope of the claims.

What is claimed is:

1. A propulsion system for a vehicle, the system comprising:

a primary airfoil coupled to the vehicle;

a first augmenting airfoil coupled to the vehicle and positioned downstream of fluid flowing over the primary airfoil, the first augmenting airfoil comprising a first output structure and at least one first conduit coupled to the first output structure, the at least one first conduit configured to introduce to the first output structure a primary fluid produced by the vehicle, the first output structure comprising a first terminal end

configured to provide egress for the introduced primary fluid toward the primary airfoil and out of the first augmenting airfoil; and

a secondary airfoil located directly downstream of the first augmenting airfoil such that the fluid flowing over the primary airfoil and the primary fluid from the first augmenting airfoil flows over the secondary airfoil.

2. The system of claim **1**, further comprising a second augmenting airfoil coupled to the vehicle and positioned downstream of fluid flowing over the primary airfoil, each of the first and second augmenting airfoils having a leading edge disposed toward the primary airfoil, the first augmenting airfoil opposing the second augmenting airfoil whereby:

the first and second augmenting airfoils define a diffusing region; and

the leading edges define an intake region configured to receive and introduce to the diffusing region the primary fluid and the fluid flowing over the primary airfoil, the diffusing region comprising a primary terminal end configured to mix and provide the introduced primary fluid and fluid flowing over the primary airfoil to the secondary airfoil.

3. The system of claim **2**, wherein the second augmenting airfoil comprises a second output structure and at least one second conduit coupled to the second output structure, the at least one second conduit configured to introduce to the second output structure the primary fluid produced by the vehicle, the second output structure comprising a second terminal end configured to provide egress for the introduced primary fluid toward the primary airfoil and out of the second augmenting airfoil.

4. The system of claim **1**, further comprising a first actuator configured to rotate the first augmenting airfoil relative to the vehicle.

5. The system of claim **2**, further comprising a second actuator configured to rotate the second augmenting airfoil relative to the vehicle.

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