

(12) **United States Patent**  
**Chang et al.**

(10) **Patent No.:** **US 6,921,045 B2**  
(45) **Date of Patent:** **Jul. 26, 2005**

(54) **SUPERSONIC AIRCRAFT WITH CHANNEL RELIEF CONTROL**

(75) Inventors: **Ming Chang**, Valencia, CA (US);  
**Victor Meza**, Saugus, CA (US); **John M. Morgenstern**, Lancaster, CA (US);  
**Alan E. Arslan**, Santa Clarita, CA (US)

(73) Assignee: **Supersonic Aerospace International, LLC**, Las Vegas, NV (US)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

4,913,380 A	4/1990	Vardaman et al.
5,020,740 A	6/1991	Thomas
5,482,228 A	1/1996	Hoshino
5,681,013 A	10/1997	Rudolph
5,692,703 A	12/1997	Murphy et al.
5,927,656 A	7/1999	Hinkleman
5,934,607 A	8/1999	Rising et al.
6,015,117 A	1/2000	Broadbent
6,273,364 B1	8/2001	Tizac et al.
6,279,853 B1	8/2001	Brighton
6,293,497 B1	9/2001	Kelley-Wickemeyer et al.
6,340,134 B1	1/2002	Meschino
6,390,417 B1	5/2002	Yoshino
6,481,668 B2	11/2002	Grossman
6,575,406 B2 *	6/2003	Nelson ..... 244/119

\* cited by examiner

(21) Appl. No.: **10/696,796**

(22) Filed: **Oct. 30, 2003**

(65) **Prior Publication Data**

US 2005/0103929 A1 May 19, 2005

(51) **Int. Cl.**<sup>7</sup> ..... **B64C 5/02**

(52) **U.S. Cl.** ..... **244/15; 244/45 R; 244/87**

(58) **Field of Search** ..... **244/15, 45 R, 244/45 A, 75 R, 1 N, 87**

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

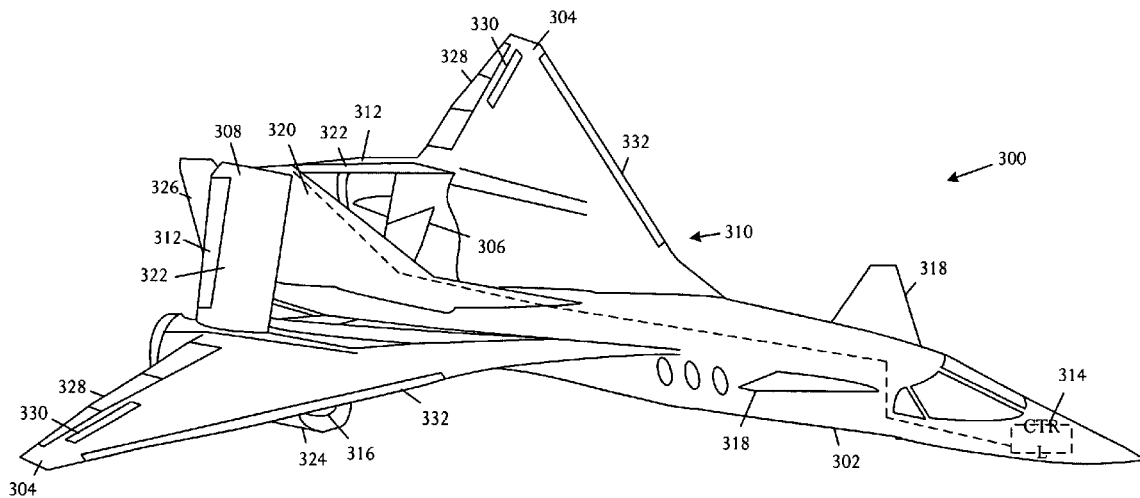
2,472,763 A *	6/1949	Rodeck	244/13
3,018,987 A *	1/1962	Multhopp	244/75 R
3,026,065 A *	3/1962	Holland, Jr.	244/12.4
3,284,028 A *	11/1966	Robertson	244/15
4,161,300 A	7/1979	Schwaerzler et al.	
4,290,612 A *	9/1981	Frosch et al.	277/345
4,351,502 A	9/1982	Statkus	
4,427,168 A	1/1984	McKinney et al.	
4,445,655 A	5/1984	Hueberger	
4,485,992 A	12/1984	Rao	
4,848,700 A	7/1989	Lockheed	

*Primary Examiner*—Galen Barefoot  
(74) *Attorney, Agent, or Firm*—Ken J. Koestner; Koestner Bertani LLP

(57) **ABSTRACT**

A supersonic aircraft comprises a fuselage extending forward and aft along a longitudinal axis, the fuselage having a lower surface and an upper surface, a highly swept low aspect ratio wing coupled to the fuselage and having a forward leading edge and an aft trailing edge, an effector flap coupled to the wing trailing edge, and a tail empennage. The tail empennage is coupled to the fuselage aft of the wing on the fuselage upper surface in a position high relative to the wing. The tail empennage forms a channel region subject to complex shock patterns at transonic conditions. The aircraft further comprises an effector coupled to the tail empennage and a controller coupled to the effector flaps and the effectors. The controller further comprises a control process that reduces drag through channel relief by deflecting both the effector flap down and the effector up.

**7 Claims, 19 Drawing Sheets**



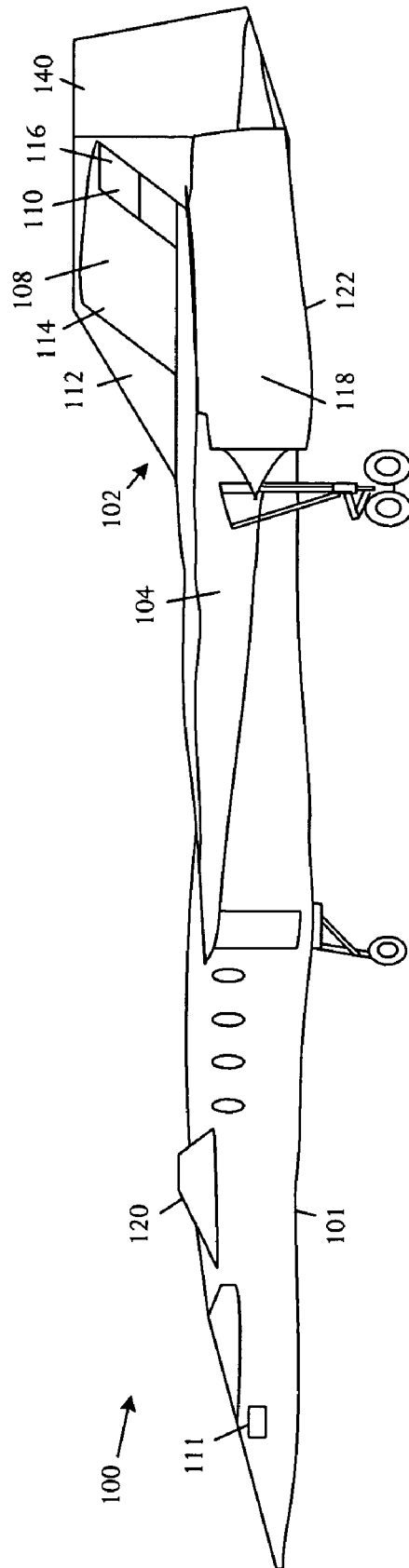


FIG. 1A

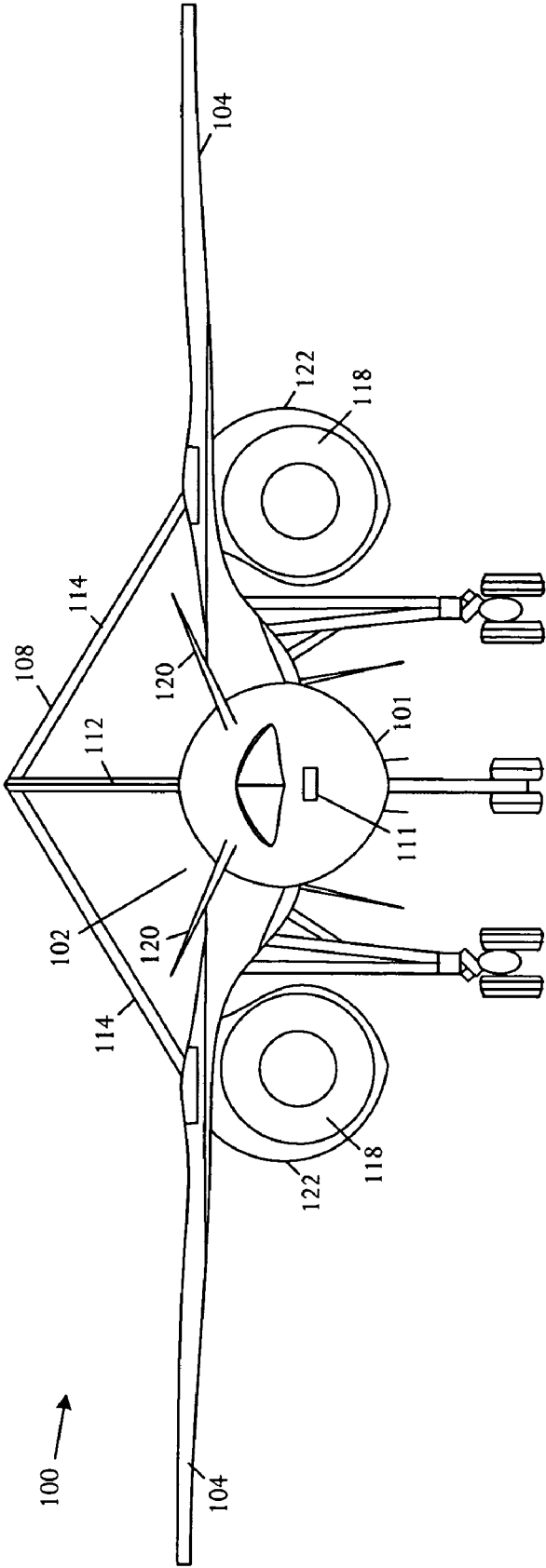


FIG. 1B

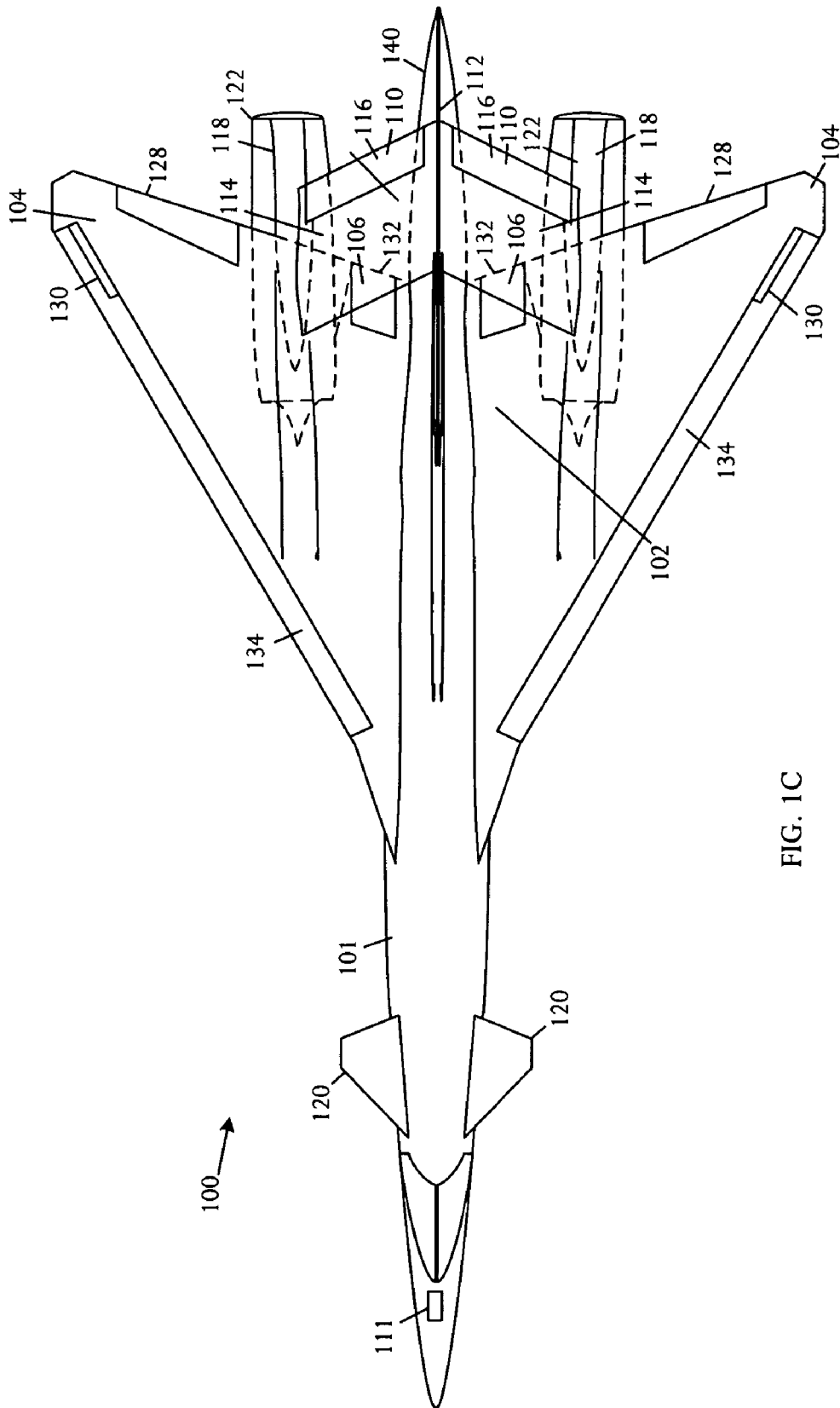


FIG. 1C

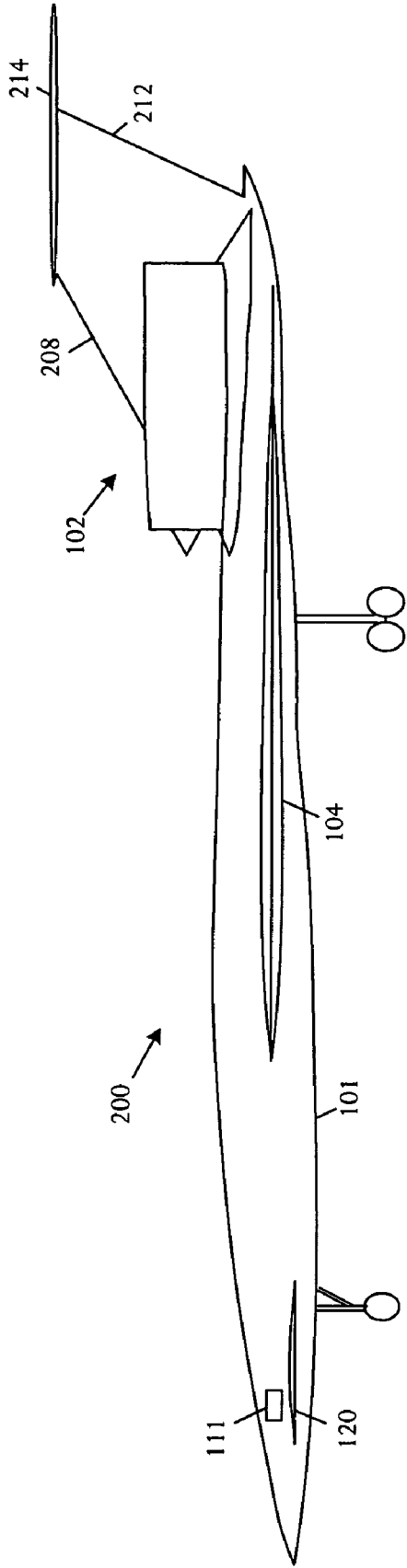


FIG. 2A

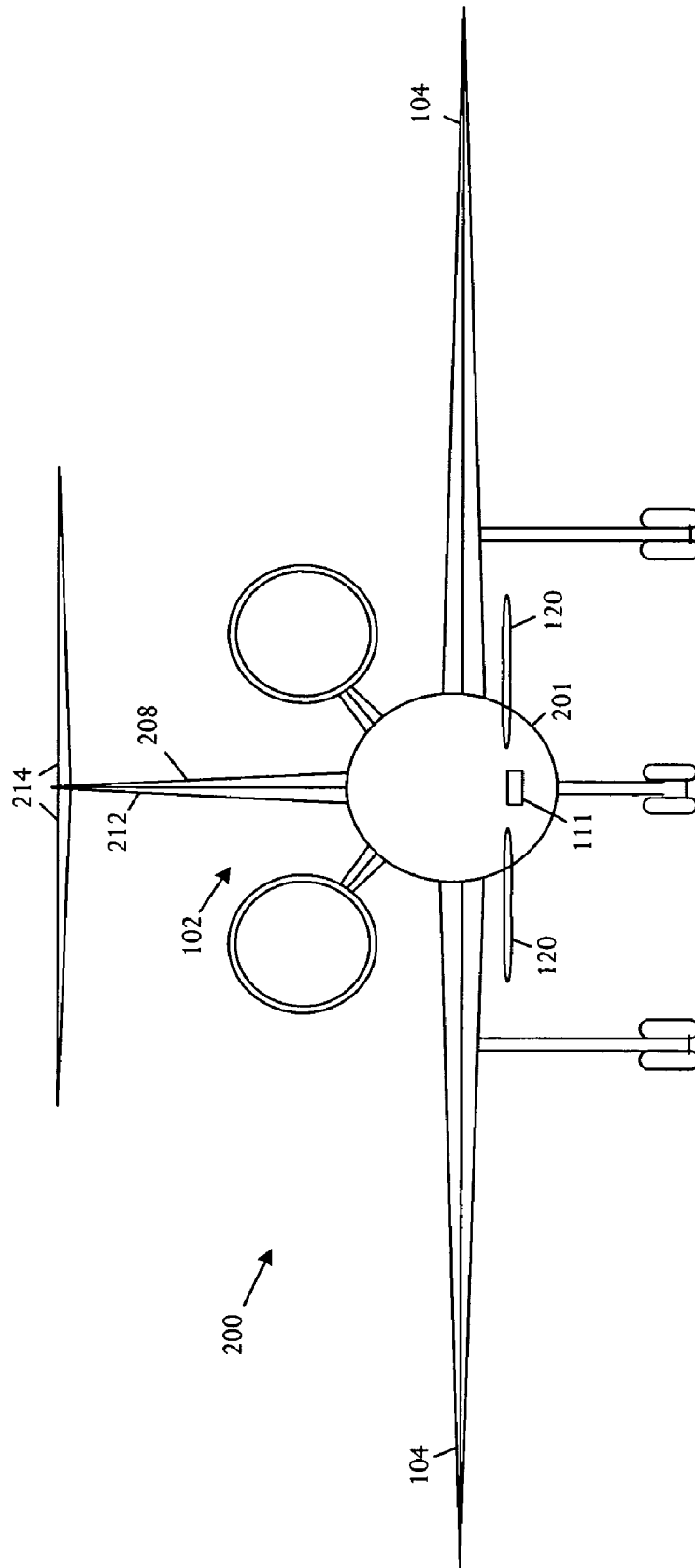


FIG. 2B

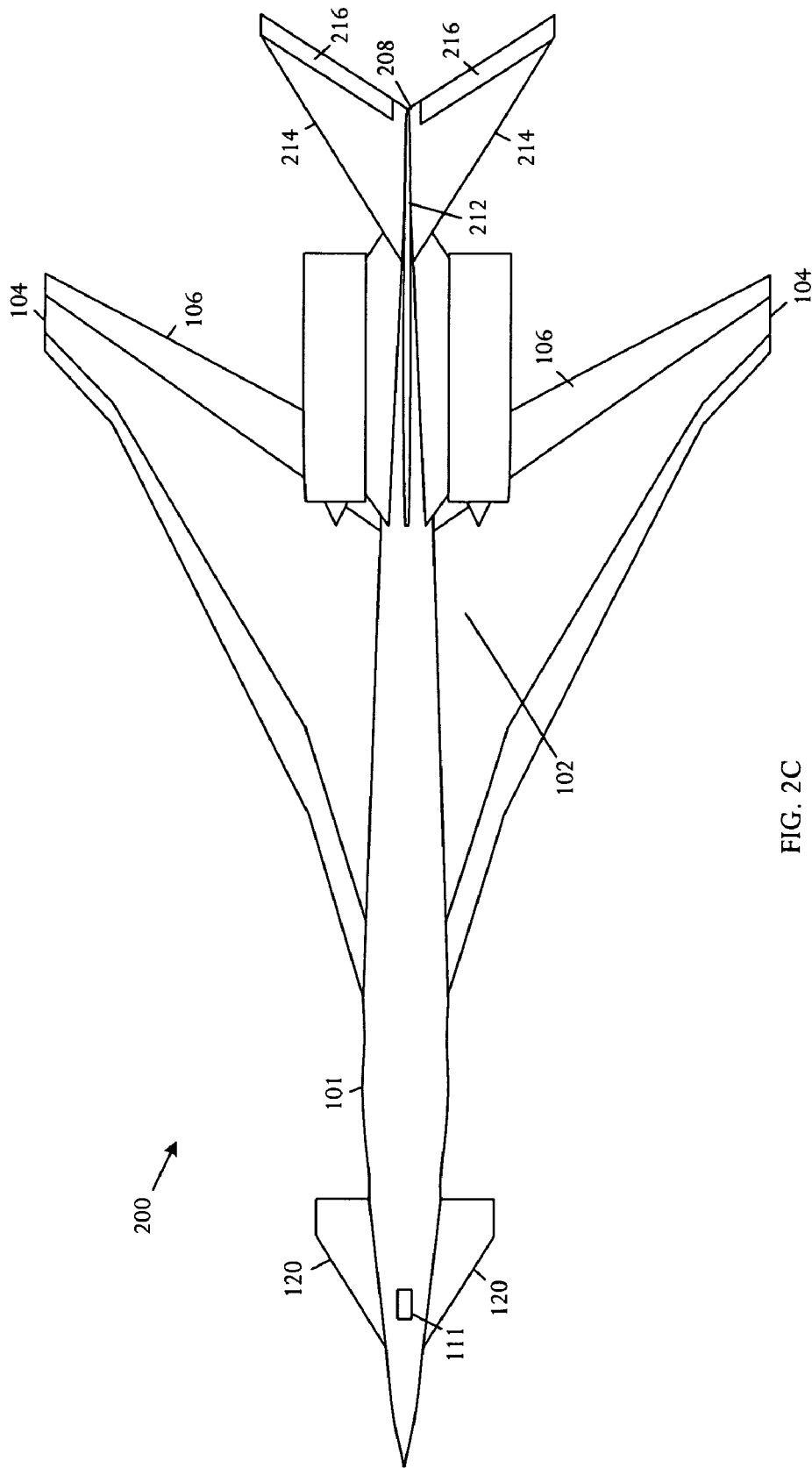


FIG. 2C

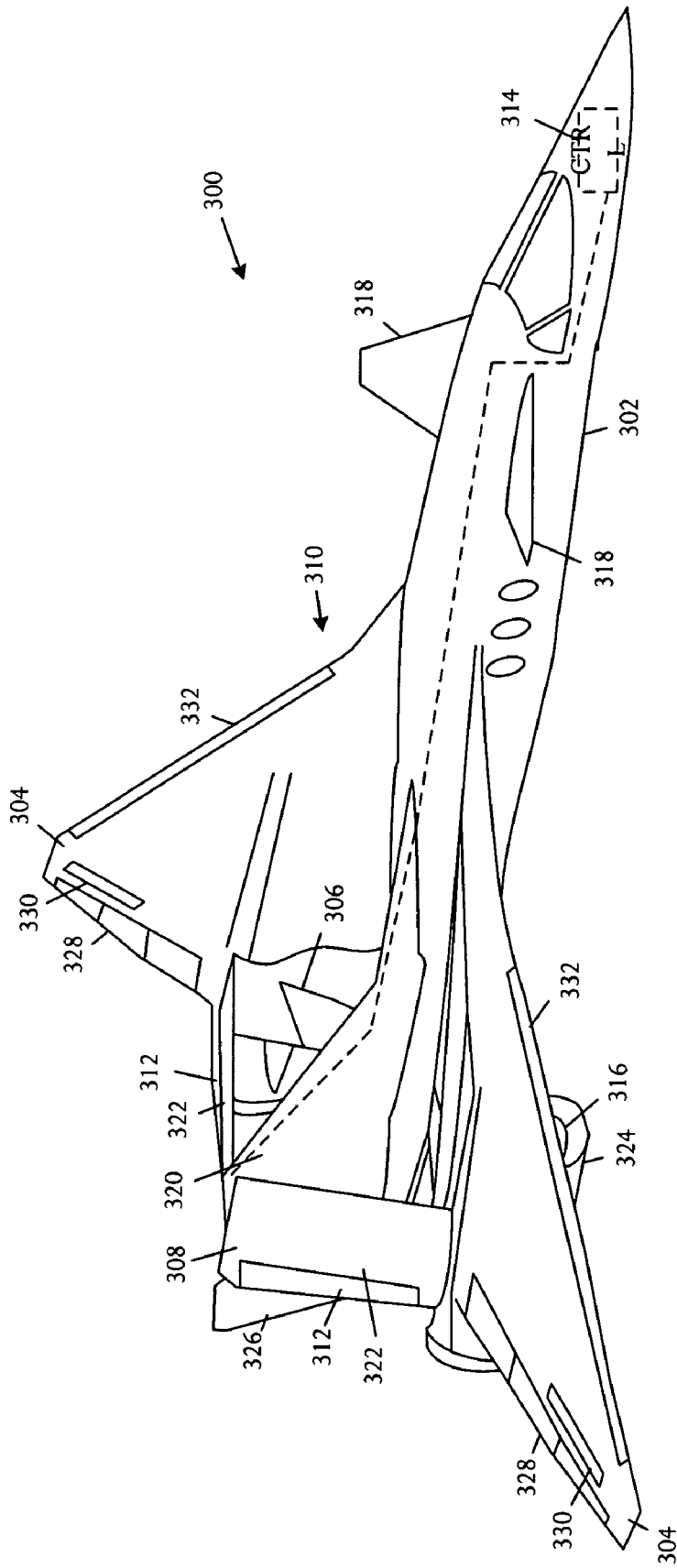


FIG. 3A



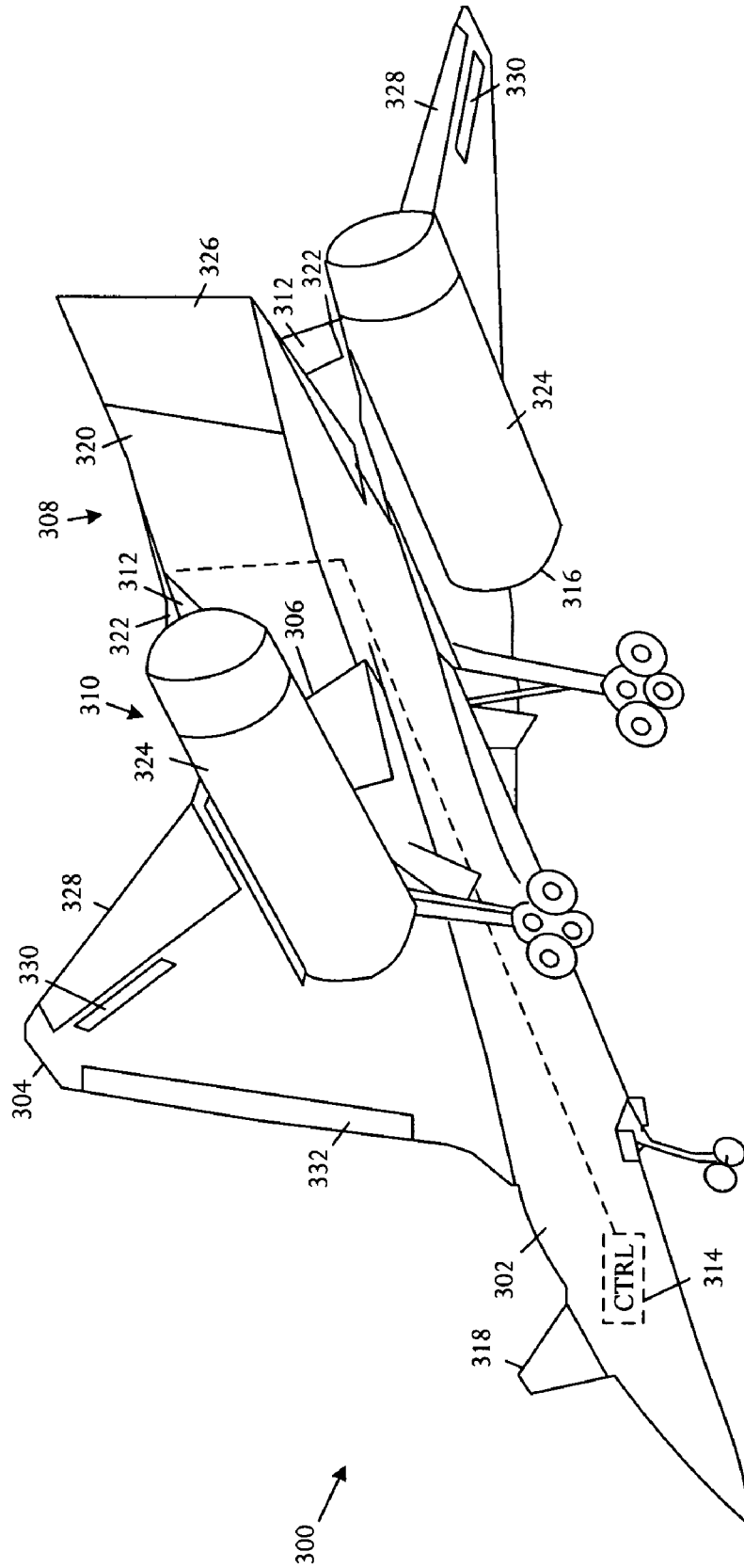


FIG. 3B

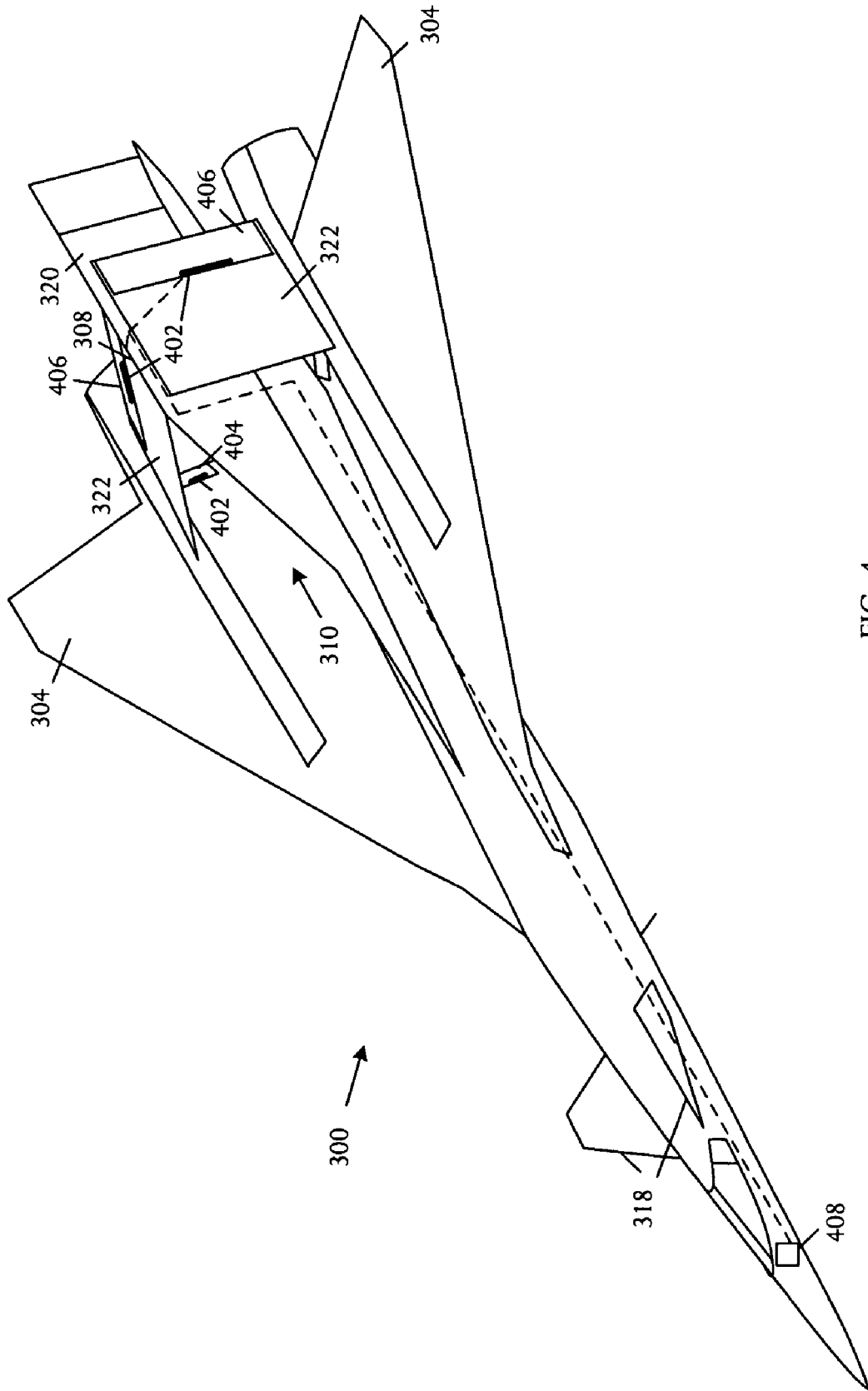


FIG. 4

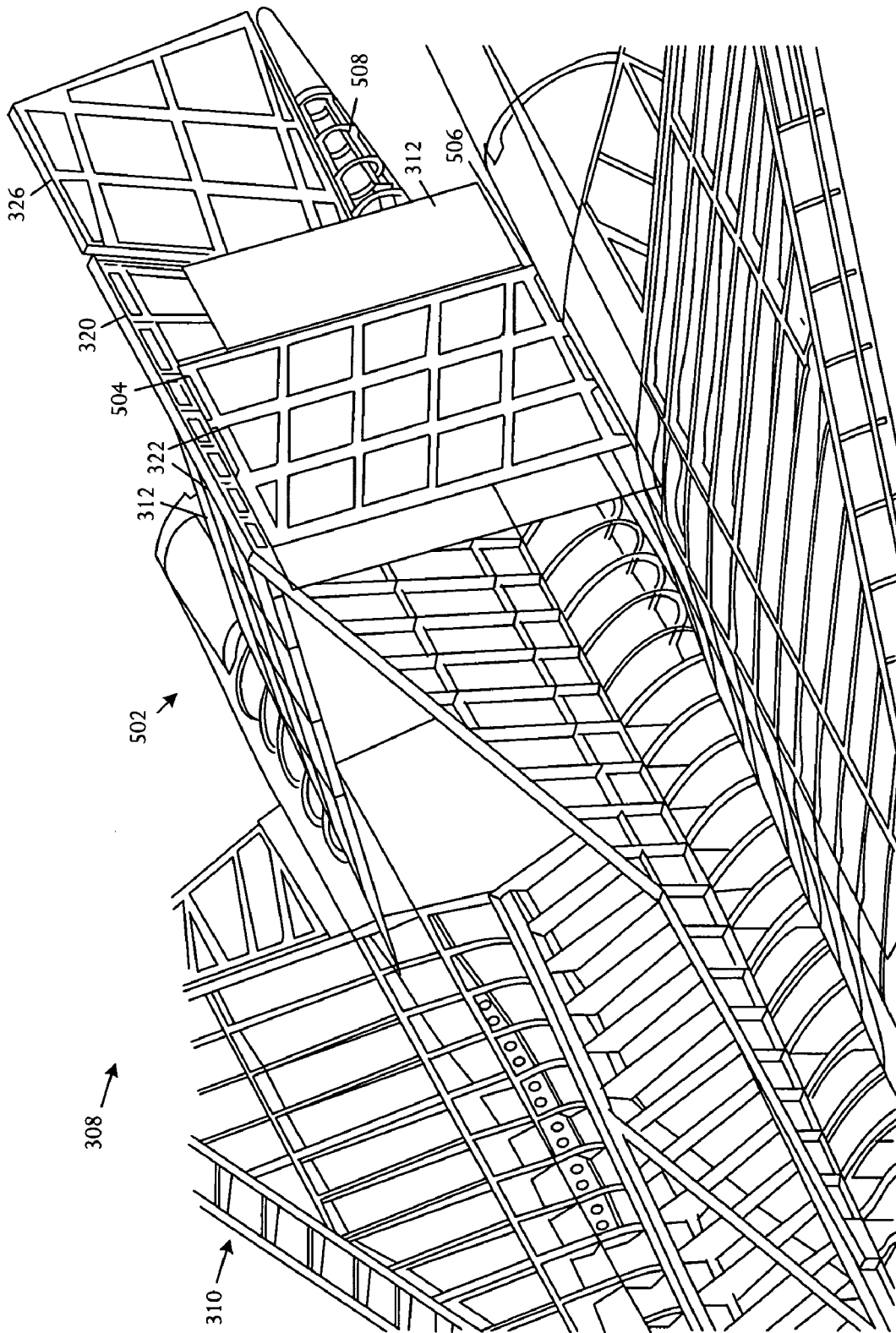


FIG. 5A

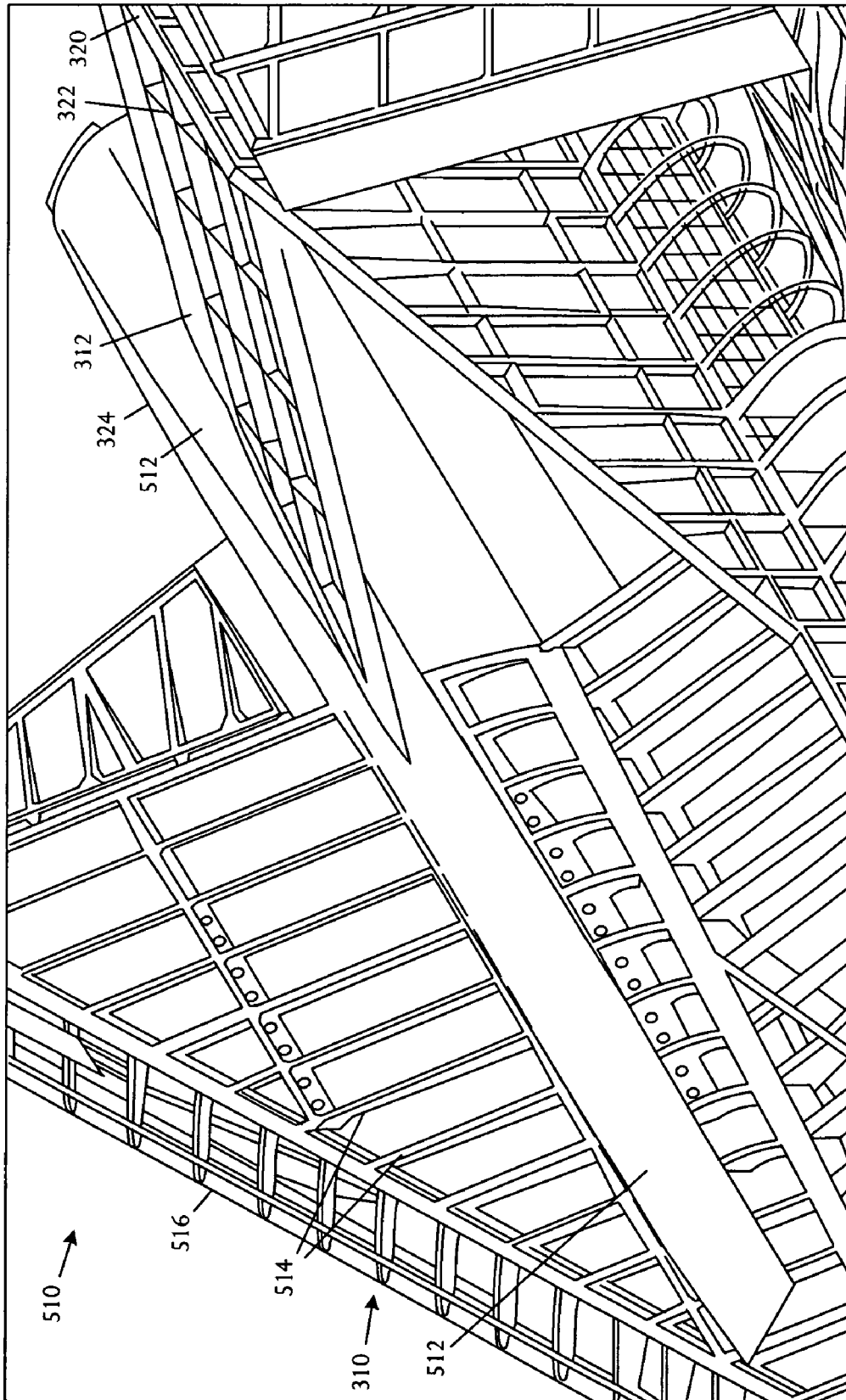


FIG. 5B

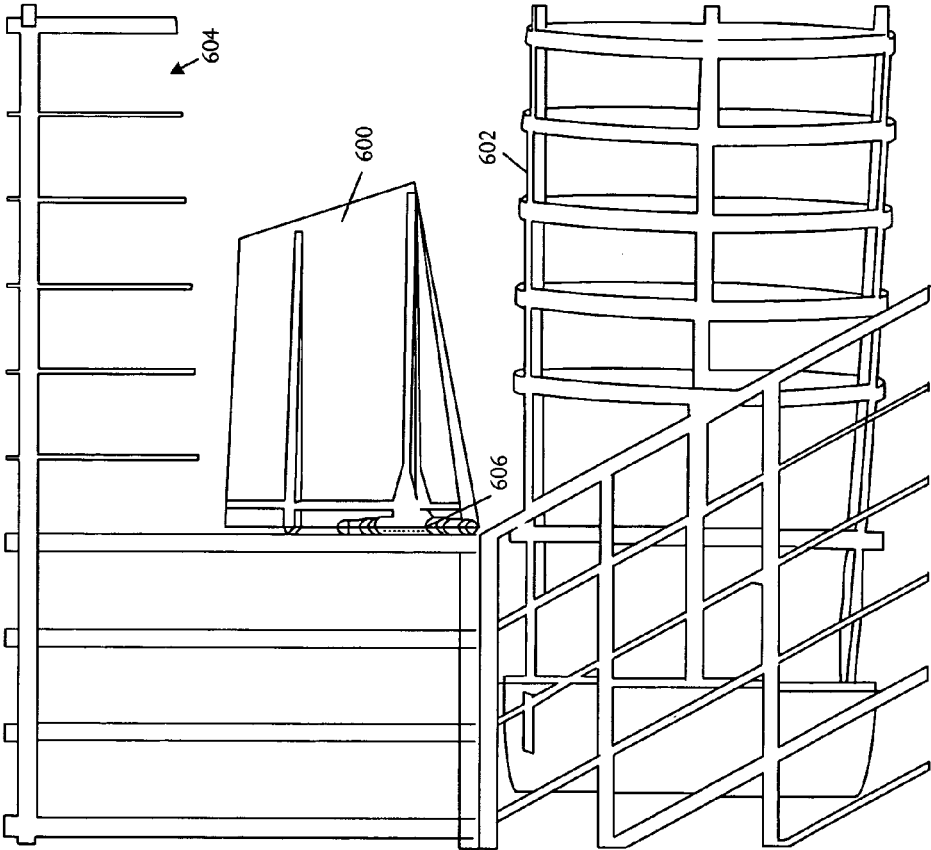


FIG. 6A

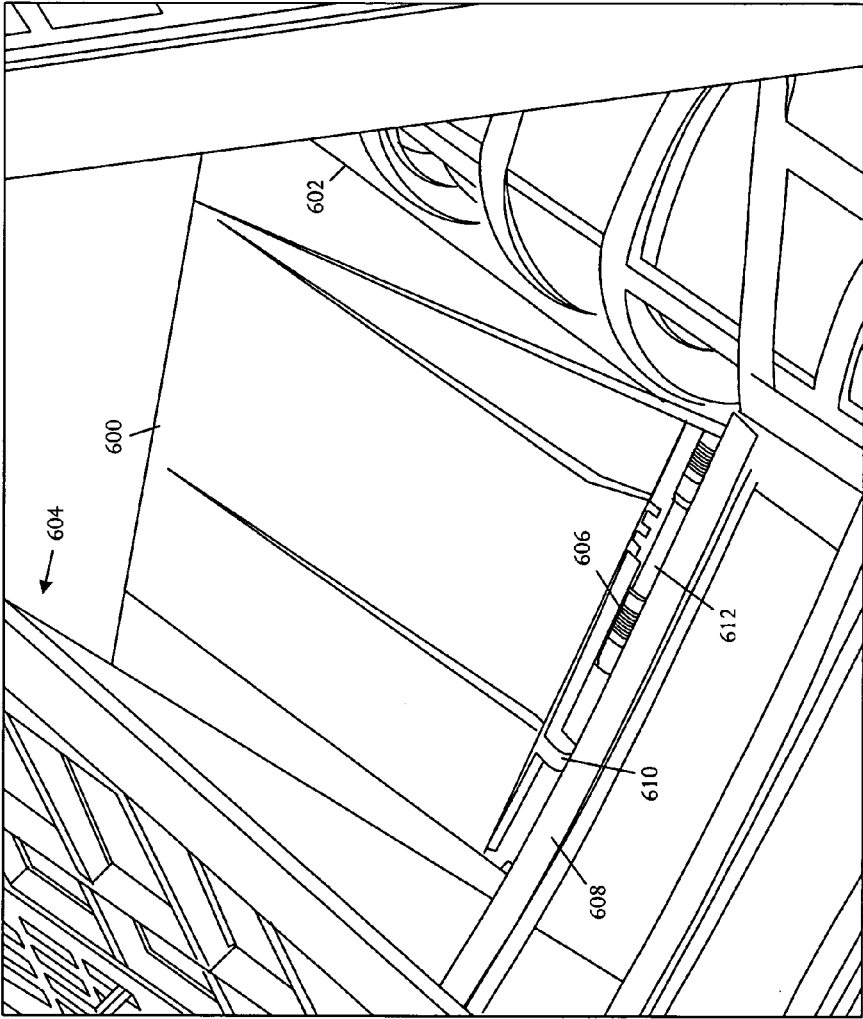


FIG. 6B

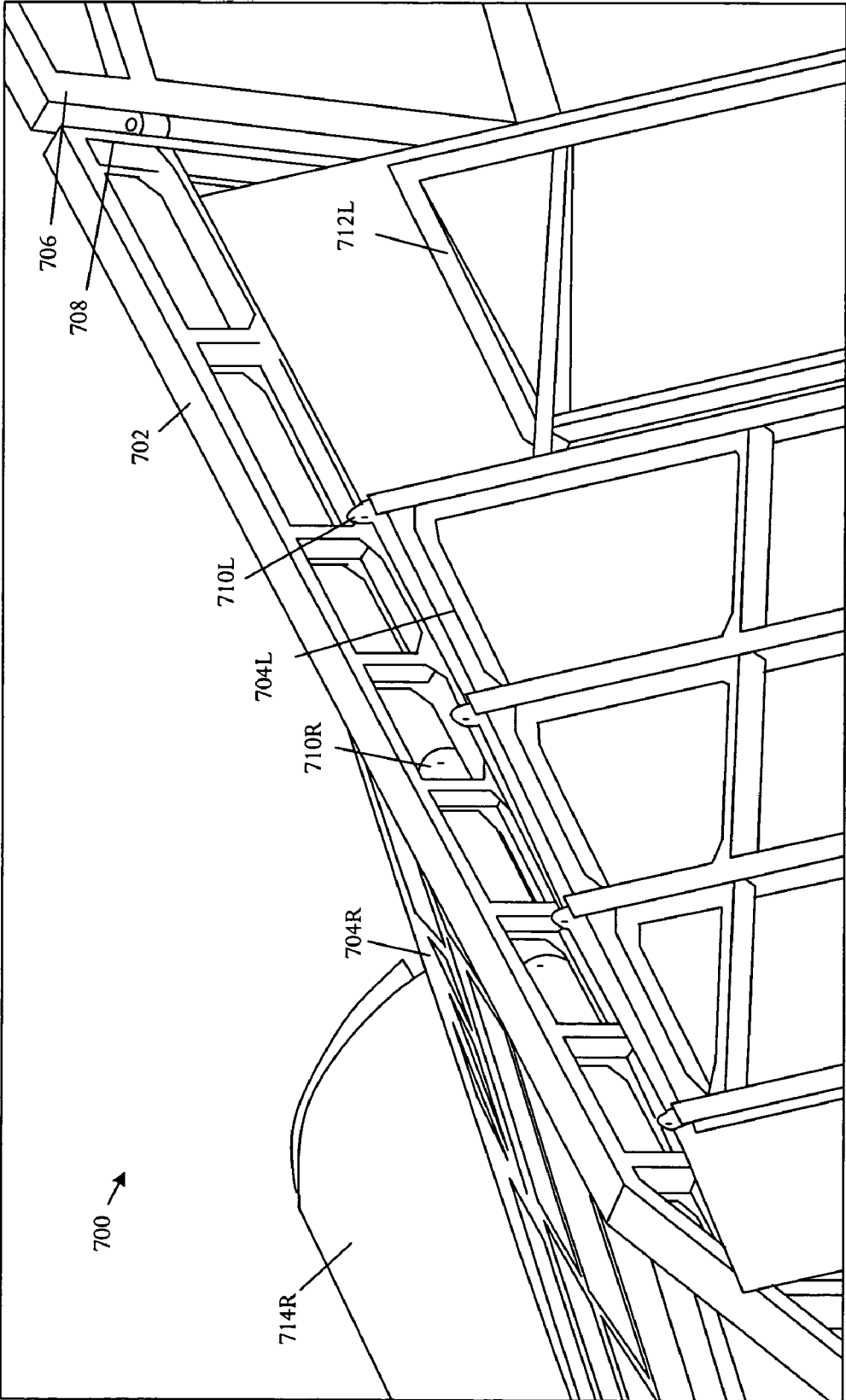


FIG. 7A

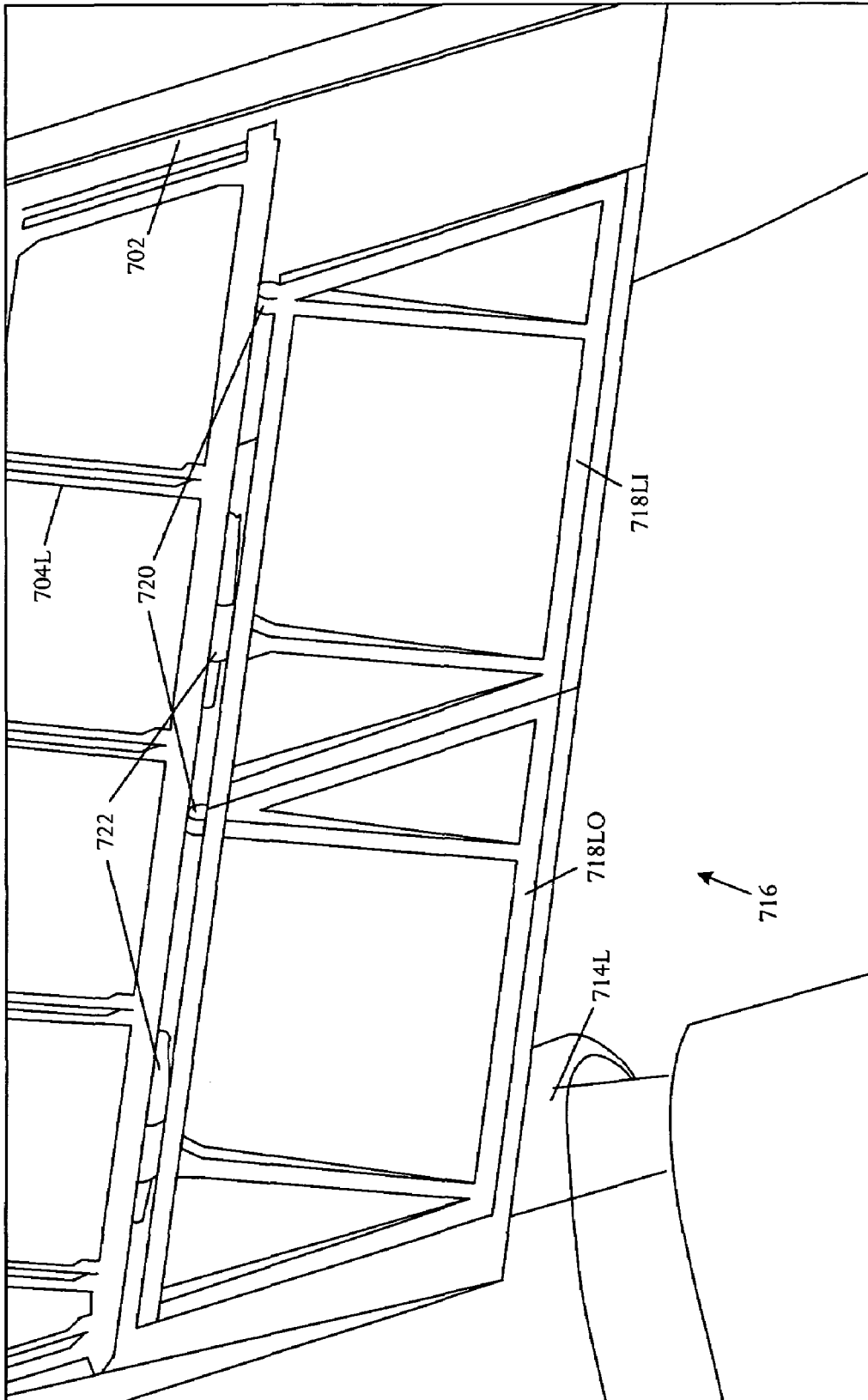


FIG. 7B



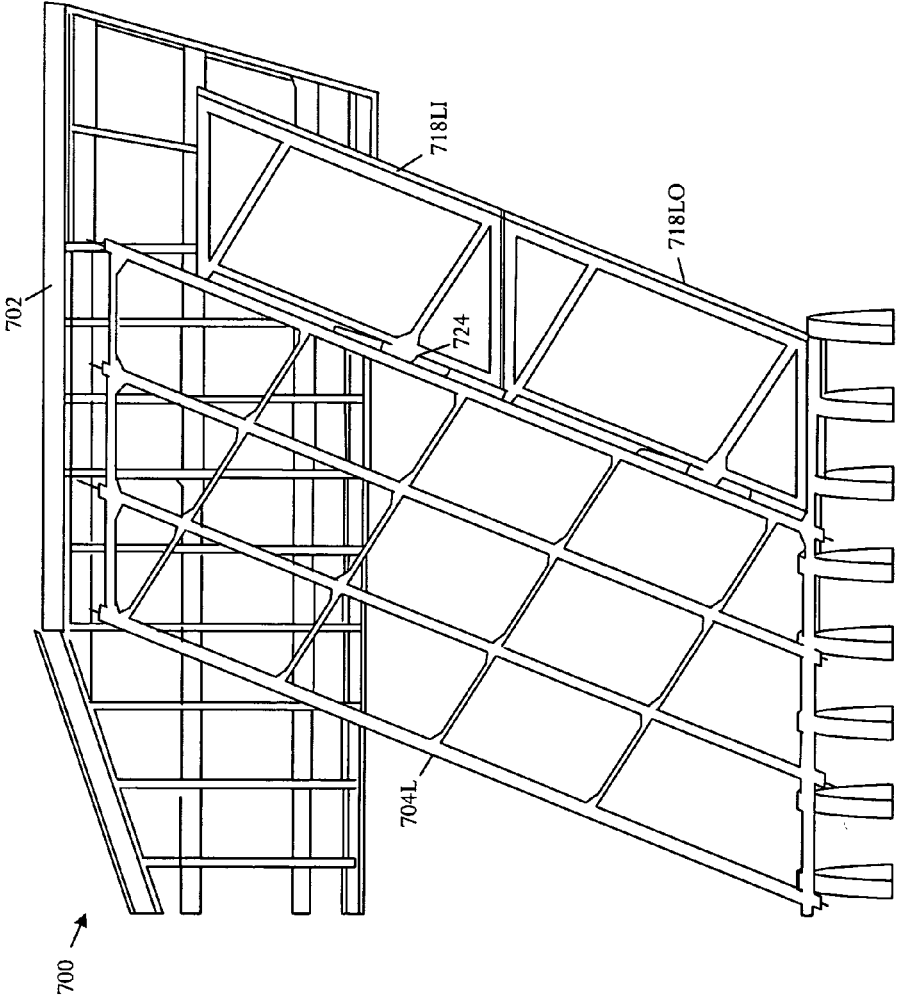
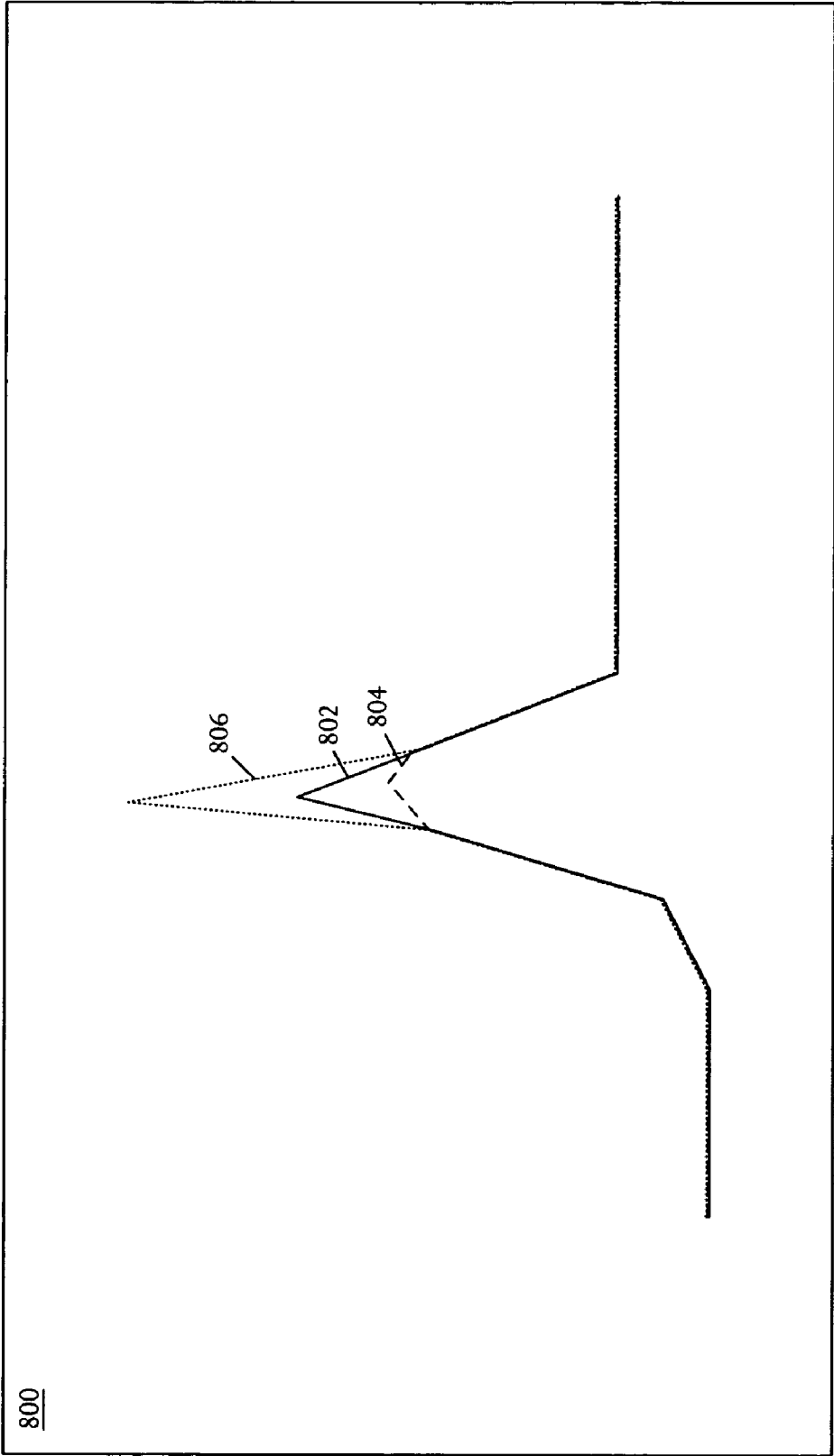


FIG. 7C



MACH

FIG. 8

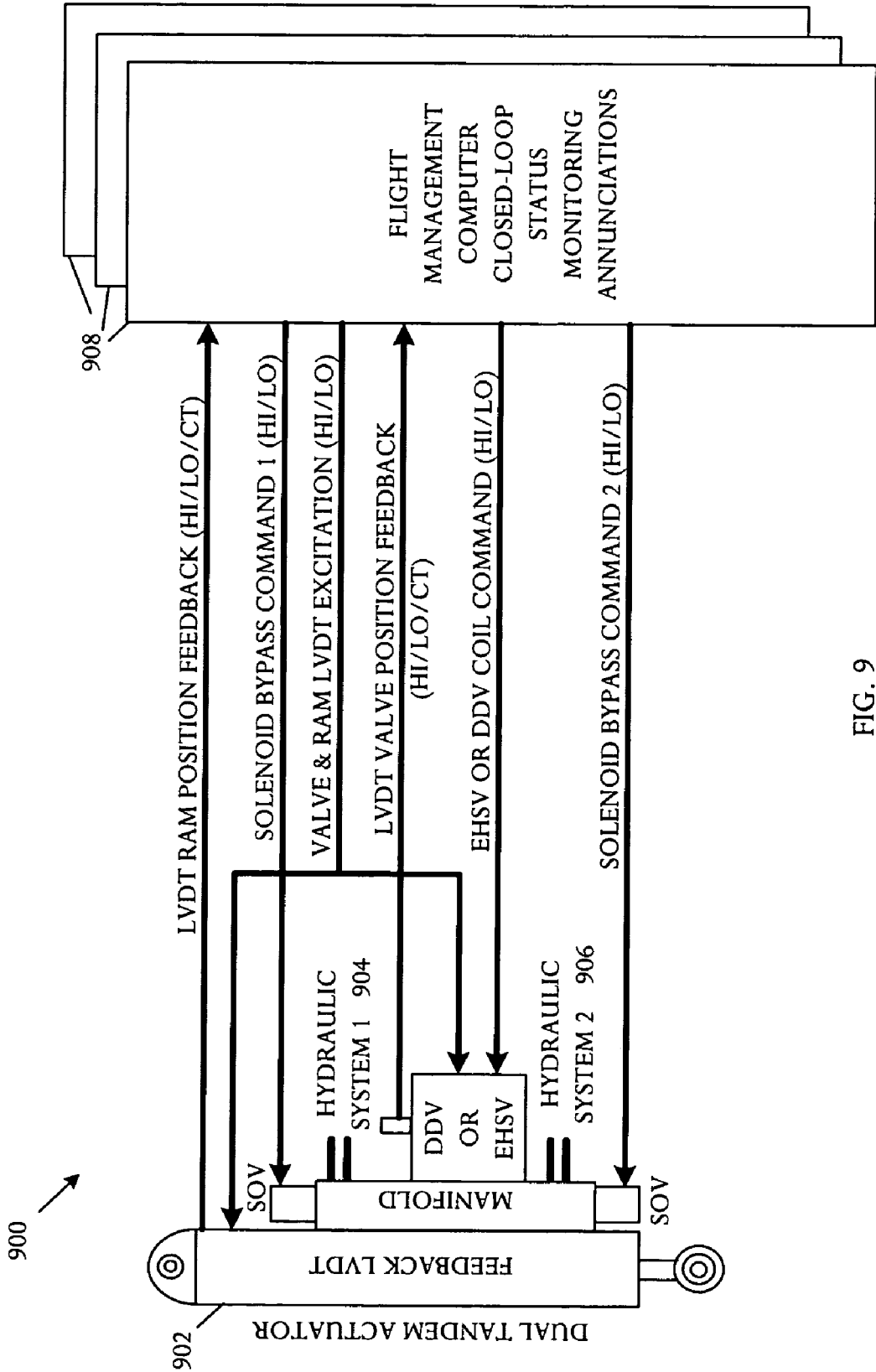


FIG. 9

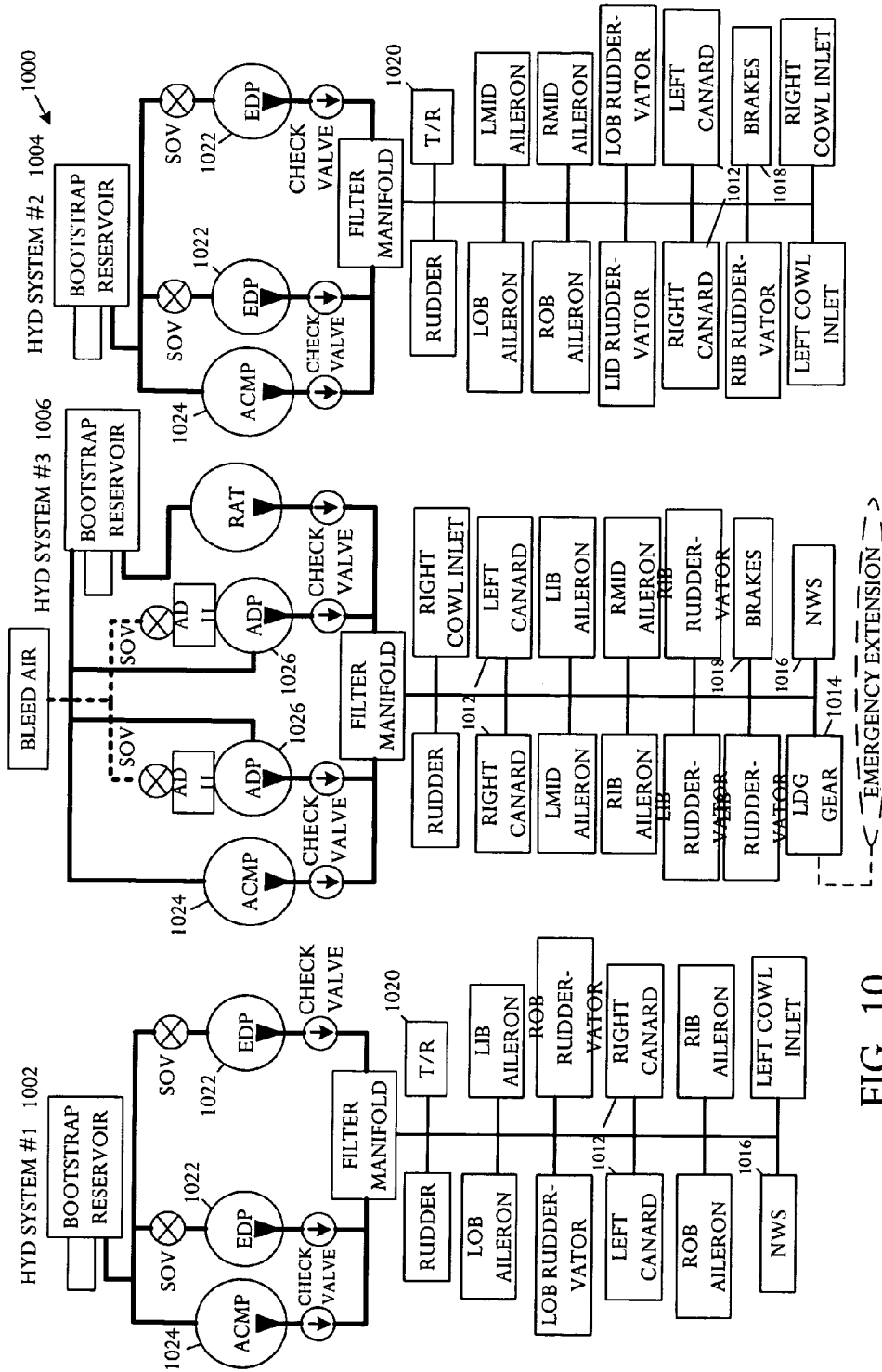


FIG. 10

## SUPERSONIC AIRCRAFT WITH CHANNEL RELIEF CONTROL

### BACKGROUND OF THE INVENTION

The global economy makes long range business travel more essential than ever. However, other than Concorde, with presence declining as transatlantic flights have discontinued, the pace of business travel remains at 1960's-era speeds. Technology advances have produced longer range, safer, and more comfortable aircraft—but not faster flights.

Supersonic overland capability and range are drivers of market potential for aircraft in the commercial and business sector. Buyers of supersonic commercial aircraft are expected to be from entities such as corporations, governments and government agencies, and high net-worth individuals. Most operators are expected to be large organizations, for example corporations and governments, with sophisticated flight departments that can manage multiple aircraft types. Flights are expected to depart and arrive in a wide range of environments, from large international and national airports to small local airfields or suburban airports, with or without substantial service capabilities.

Although a supersonic aircraft for usage in commercial and business environments is to have many characteristics of a high-performance military aircraft, flight characteristics, operations, maintenance, and cost should be compatible to a business or commercial realm. The aircraft should be compatible with the infrastructure, servicing and operations experience base, and air traffic control system of the extant civil business jet.

The user community expects the aircraft to be usable not only in large, urban international hubs but also in suburban airports so that compatibility with shorter runway lengths, narrower taxiways, and lower maximum gross weight surfaces is desirable. Servicing and maintenance compatibility with personnel, equipment, and capabilities found at well-equipped fixed based operators (FBOs) and maintenance facilities is highly useful.

Many of the desirable features of supersonic civilian aircraft, particularly low-boom performance and long range, are very difficult to attain. Bill Sweetman in "Flights of fancy take shape—from Jane's ([www.janes.com](http://www.janes.com))", 21 Jul. 2000, discusses the United States Defense Advanced Research Projects Agency (DARPA) Quiet Supersonic Platform (QSP) program that is aimed at developing an efficient supersonic-cruise aircraft that does not produce a sonic boom. The difficulty of such a result is indicated by the agency's admission that only a revolutionary design will meet the goal, and that incremental application of new technologies, or integration of existing technologies, is expected to be insufficient to attain the reduced boom goal.

Extension of aircraft range involves balancing of fuel capacity, payload volume, fuel consumption at desired speeds, aerodynamic, and other factors. Reduction of aerodynamic drag can assist in extending range, reducing sonic boom, and improving aircraft performance.

For most supersonic and transonic aircraft, wave drag is a major component of total drag so that wave drag reduction is an objective of many design methodologies. Some aircraft have empennages that encompass control surfaces that are sufficiently close to form a channel, forming complex shock patterns which often manifest as extra drag and tend to appear in operation beyond a particular Mach number. The shock patterns can choke the channel at transonic conditions. In an aerodynamic analysis, a drag rise curve becomes more peaked, forming a transonic thrust pinch point, in the

presence of channel choking. In an aerodynamic analysis, the presence of channel choking may cause the transonic drag rise curve to become more peaked, thus forming a transonic pinch point as depicted in FIG. 8.

### SUMMARY OF THE INVENTION

What is desired is a relief mechanism that can clear the transonic pinch point and reduce or eliminate channel choking.

In accordance with some embodiments, a supersonic aircraft comprises a fuselage extending forward and aft along a longitudinal axis, the fuselage having a lower surface and an upper surface, a highly swept low aspect ratio wing coupled to the fuselage and having a forward leading edge and an aft trailing edge, an effector flap coupled to the wing trailing edge, and a tail empennage. The tail empennage is coupled to the fuselage aft of the wing on the fuselage upper surface in a position high relative to the wing. The tail empennage forms a channel region subject to complex shock patterns for transonic flight conditions. The aircraft further comprises an effector coupled to the tail empennage and a controller coupled to the effector flaps and the effectors. The controller further comprises a control process that reduces drag through channel relief by deflecting both the effector flap down and the effector up. In a particular embodiment, the tail can be an inverted V-tail, and the controller deflects a trailing edge flap on the wing down while deflecting a ruddervator on an inverted stabilizer upward.

In accordance with other embodiments, a supersonic aircraft comprises an aircraft body extending forward and aft, a highly swept low aspect ratio wing coupled to the body and having a forward leading edge and an aft trailing edge, an effector flap coupled to the trailing edge of the wing, and an inverted V-tail. The inverted V-tail is coupled at the aft portion of the aircraft body and coupled to the wing in a braced wing configuration. The inverted V-tail forms a channel region that can generate complex shock patterns. The aircraft further comprises ruddervator control surfaces coupled to the inverted V-tail and a controller. The controller is coupled to the effector flap and the ruddervator control surfaces. The controller comprises a control process that reduces drag through channel relief by deflecting both the effector flap down and the ruddervator control surfaces up.

In further embodiments, a channel control system is used in a supersonic aircraft including a fuselage, wings, a tail empennage, and a plurality of control effectors coupled to the wings and the tail empennage. The empennage and wings form a channel region that can form complex shock patterns at transonic speeds. The channel control system comprises a plurality of actuators coupled to the control effectors. The effectors include a flap coupled to the wing and an effector coupled to the tail empennage. The channel control system further comprises at least one vehicle management computer coupled to the plurality of actuators. The vehicle management computers further comprise a process for managing the control effectors in a drag reduction mode through channel relief by deflecting both the flap downward and the tail empennage effector upward.

### BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention relating to both structure and method of operation, may best be understood by referring to the following description and accompanying drawings.

FIGS. 1A, 1B, and 1C are schematic pictorial diagrams respectively showing side, front, and top views of an embodiment of a supersonic aircraft capable of reducing drag through channel relief.

FIGS. 2A, 2B, and 2C are schematic pictorial diagrams respectively showing side, front, and top views of another embodiment of a supersonic aircraft that has a T-tail geometry.

FIGS. 3A and 3B are schematic pictorial diagrams illustrating side and bottom perspective views of another embodiment of a supersonic aircraft in a configuration that enables channel relief.

FIG. 4 is a schematic pictorial diagram illustrating an embodiment of a channel control system that can be used in a supersonic aircraft.

FIGS. 5A and 5B are two schematic pictorial diagrams illustrating the channel region within the wing and empennage in more detail.

FIGS. 6A and 6B are two pictorial diagrams depicting different views of a trailing edge flap that can be used in an embodiment of an aircraft capable of channel relief control.

FIGS. 7A, 7B, and 7C, three schematic perspective pictorial views show detailed diagrams of portions of the tail structure.

FIG. 8 is a graph illustrating a drag rise plot indicative of pressure drag in a supersonic/transonic aircraft.

FIG. 9 is a schematic block diagram showing an example a flight control actuation architecture embodiment that can be used as the controller.

FIG. 10 is a schematic block diagram that depicts an embodiment of a suitable hydraulic power and distribution system architecture for supplying actuating power to the control effectors and systems.

#### DETAILED DESCRIPTION OF THE EMBODIMENTS

Referring to FIGS. 1A, 1B, and 1C, schematic pictorial diagrams respectively showing side, front, and top views of an embodiment of a supersonic aircraft **100**. The supersonic aircraft **100** comprises a fuselage **101** extending forward and aft along a longitudinal axis, a highly swept low aspect ratio wing **104** coupled to the fuselage **101** with an effector flap **106** coupled to the wing trailing edge, and a tail empennage **108**. The tail empennage **108** is coupled to the fuselage **101** aft of the wing **104** on the fuselage upper surface in a high position relative to the wing **104**. The tail empennage **108** and wing **104** form a channel region **102** that is subject to complex shock patterns. The aircraft further comprises an effector **110** coupled to the tail empennage **108** and a controller **111** communicatively coupled to the effector flap **106** and the effector **110**. The controller **111** implements a control process that reduces drag through channel relief by deflecting both the effector flap **106** down and the effector **110** up.

In some configurations, the controller **111** may also deflect other effectors, such as ailerons, while deflecting the effector flap **106** and the effector **110** to counter any resulting pitching moment. In other embodiments, examples of effectors **110** may include leading edge or trailing edge surfaces of the wing **104**. Similarly, examples of effector flaps **106** can include a leading edge device for the horizontal tail or the entire slat of the tail.

In the illustrative aircraft **100** the tail empennage **108** has an inverted V-tail geometry coupled to the wing **104** in a braced wing configuration. The V-tail **108** further connects to a vertical stabilizer **112**, lateral inverted stabilizers **114**,

and inverted V-tail control surface ruddervators **116** capable of adjusting the aircraft longitudinal lift distribution throughout the flight envelope to maintain a low-boom, low-drag trim condition.

In some embodiments, the controller **111** implements a control process that increases drag by choking the channel, deflecting both the effector flap **106** up and the effector **110** down. In the deployment for increased drag, the control effectors can operate as a speedbrake, for example for usage in emergency descents.

The aircraft embodiment **100** further comprises engines **118** coupled to the aft portion of the wing lower surface with the inverted V-tail geometry empennage **108** coupled to the wing in the braced wing configuration carrying lift at the aft portion of the aircraft **100** on a high mounted tail **108**. The length of the aircraft is effectively extended for shock waves below the aircraft **100**, thereby further reducing sonic boom. The inverted V-tail **108** carries tail lift high to maintain a continuous lift distribution and structurally bracing the wing **104** and engines **118**.

Referring to FIG. 1C, control effectors are shown for the supersonic aircraft **100**. Two sets of surfaces are available for pitch control including canards **120** and ruddervators **116**. Roll control uses ailerons **128** and high speed spoilers **130**. Yaw control is supplied by a rudder **140**, ruddervators **116**, and differential canard **120**.

In combination with the canards **120**, the supersonic aircraft **100** has multiple stability and control effectors. The canard **120** and symmetric deflections of the ruddervators **116** control pitch power. A vertical rudder **140** controls yaw. Inboard, midboard and outboard ailerons **128**, and the high speed roll spoilers **130** control roll. The segmented ailerons **128** provide both roll control power and automatic wing camber control to optimize lift and drag throughout the flight envelope. The roll spoilers **130** are configured to control roll at supersonic Mach numbers. High-speed spoilers **130** supplement aileron roll power at transonic and supersonic speeds where Mach number and aeroelastic effects reduce aileron effectiveness.

Some embodiments of an aircraft may include, in combination with the canards **120**, a leading edge device to be used in conjunction with an outboard trailing edge flap deflection, which can be a more effective roll device from both drag and aeroelastic perspectives.

In an illustrative embodiment, trailing edge (TE) flaps **132** are effectors **106** than can be deployed 30° down to generate additional lift during landing. TE flap deployment reduces angle-of-attack specifications by approximately 2° during landing. During second-segment climb, the TE flaps **132** are extended 10° to improve the lift-to-drag ratio for better climb performance.

Leading edge (LE) Krueger flaps **134** are extended 130° for low speed operations including takeoff, approach and landing. The LE Krueger flaps **134** improve lift-to-drag ratio by 1.5, resulting in better climb performance that facilitates second-segment climb in case of engine malfunction.

In some embodiments, the aircraft **100** can be configured with a high lift system that includes simple inboard trailing edge flaps **132** and full-span leading edge Krueger flaps **134**.

The multiple control surfaces of the supersonic aircraft **100**, for example the ruddervators **116** inboard and outboard design, enable continued operation and landing following single actuator failure or a single control surface jamming. Differential canard deflection can generate a yawing moment to counter a jammed rudder. Ailerons **128** and

ruddervators **116** include multiple surfaces, increasing fault tolerant capability and supplying redundant elements for improved reliability.

Referring again to FIGS. 1A, 1B, and 1C, in the illustrative aircraft **100**, shaping of the wing **104**, body **101**, empennage **108**, and the integration of the propulsion system **116** are configured to produce a shaped sonic signature and control supersonic cruise drag. An inverted V-tail geometry **108** facilitates the overall low-boom design and supports nacelles **122** in an appropriate position relative to the wing **104**, as well as enabling for trim to attain a low sonic-boom lift distribution. Inverted V-tail control surfaces, called ruddervators **116**, adjust the aircraft longitudinal lift distribution throughout the flight envelope to maintain a low-boom, low-drag trim condition. The canard **120** supplies additional trim control and augments longitudinal control power.

In various embodiments, the illustrative aircraft **100** may include one or more of several advancements including addition of an all-flying canard **120**, an optimized wing **104**, incorporation of leading edge flaps **134** and spoilers **130**, and a reconfigured body or fuselage **101**. The canard **120** improves takeoff rotation and high-speed control. Wing planform and airfoil shapes are configured to assist high-speed performance, low-speed performance, low sonic boom, stability and control, and structural mass fraction characteristics. Sizes of the inverted V-tail **108** and fins can be configured to improve both structural and aerodynamic integration, benefiting both weight and drag characteristics. Flaps **134** improve takeoff performance. Spoilers **130** assist high-speed roll control.

The illustrative aircraft **100** has a twin-engine, slender-body configuration with a highly swept low aspect ratio wing **104**, a configuration highly appropriate for low-boom performance based on volume-based sonic boom ruling. Equivalent area minimization can be used to reduce sonic boom signature. When equivalent area due to geometric area and lift sum to the minimized distribution, a minimized ground sonic boom occurs. The aft engine location beneath the wing **104**, in combination with a highly integrated wing/inlet geometry, produces both low-boom compatibility and low inlet/nacelle installation drag. The inverted V-tail geometry **108** supplies both a low sonic-boom performance while generating longitudinal trim in cruise, and structural support for the engine/nacelle installation.

Some embodiments of the aircraft **100** implement one or more of several features including a multi-spar wing **104**, a fuselage structure **101** with stringer-stiffened skins supported by frames, canards **120** that are integrated with the pressurized fuselage cabin structure, and aft-located engines **116** supported by a torque-box structure that extends aft of the wing **104** and is attached to the inverted V-tails **108**.

Referring to FIGS. 2A, 2B, and 2C, schematic pictorial diagrams respectively showing side, front, and top views of another embodiment of a supersonic aircraft **200** with a T-tail geometry **208**. The aircraft **200** tail empennage has a supersonic T-tail geometry **208** that includes a vertical stabilizer **212**, a lateral horizontal stabilizer **214**, and a control surface elevator **216** capable of adjusting the aircraft longitudinal lift distribution throughout the flight envelope to maintain a low-boom and/or low-drag trim condition. The horizontal stabilizer **214** is the entire horizontal tail, an all-moving tail.

Referring to FIGS. 3A and 3B, schematic pictorial diagrams show side and bottom perspective views of an embodiment of a supersonic aircraft **300**. The supersonic aircraft **300** comprises an aircraft body **302** extending for-

ward and aft, a highly swept low aspect ratio wing **304** coupled to the body **302** and having a forward leading edge and an aft trailing edge. An effector flap **306** is coupled to the trailing edge of the wing **304**. The aircraft has an inverted V-tail **308**. The inverted V-tail **308** is coupled at the aft portion of the aircraft body **302** and coupled to the wing **304** in a braced wing configuration. The inverted V-tail **308** forms a channel region **310** that can generate complex shock patterns. The aircraft **300** further comprises a ruddervator control surfaces **312** coupled to the inverted V-tail **308** and a controller **314**. The controller **314** is coupled to the effector flap **306** and the ruddervator control surfaces **312**.

The controller **314** implements a control process that reduces drag through channel relief by deflecting both the effector flap **306** down and the ruddervator control surfaces up **312**. In some embodiments, the controller **314** can also implement a control process that increases drag by choking the channel **310**, deflecting both the effector flap **306** up and the effector **312** down. The control process that increases drag can be used, for example, for operation as a speedbrake.

The controller **314** implements a control process that adjusts aircraft longitudinal lift distribution throughout a flight envelope to maintain a low sonic boom, low drag-trim condition.

The illustrative aircraft **300** has two wing-mounted engines **316** positioned beneath the wing **304** at an aft location. The braced wing V-tail **308** supports the engines **316** and enables trim for a low sonic boom lift distribution. In some embodiments, the engines **316** have a highly integrated wing/inlet geometry that enables low-boom compatibility and low inlet/nacelle installation drag. In some embodiments, the body **302** has a slender body configuration that equalizes area forward and aft and facilitates sonic boom reduction. A canard **318** coupled to the body **302** supplies additional trim and augments longitudinal control power.

Other embodiments may utilize a different tail configuration, for example a T-tail or other forms. The illustrative inverted V-tail **308** has a central vertical stabilizer **320**, inverted stabilizers **322** coupled to sides of the central vertical stabilizer **320** and also coupled to the fuselage **302**. The inverted stabilizers **322** and assist the fuselage **302** in supporting engine nacelles **324**. The inverted V-tail **308** also includes ruddervators **312** that are pivotally coupled to the inverted stabilizers **322** and can have operations managed by the controller **314**. Generally, the controller **314** controls the ruddervators **312** to move up and down together for longitudinal control.

The ruddervators **312** can be configured with sufficient torsional stiffness to reduce or minimize flutter resulting from ruddervator rotation coupling with V-tail bending and torsion. Ruddervators **312** have appropriate actuator stiffness and ruddervator torsional stiffness, along with a V-tail mass distribution controlled using ballast weight to manage ruddervator rotation coupling with V-tail bending and torsion. The ruddervators **312** can be symmetrically deflected in combination with the canards to supply pitch control power. The vertical rudder **326** supplies yaw control with roll control supplied by inboard, outboard, and midboard ailerons, and high speed roll spoilers.

The controller **314** also manages other control effectors in combination with the canards **304** and the ruddervators **312**, including leading edge Krueger flaps **332**, trailing edge flaps **306**, ailerons **328**, and spoilers **330**.

Referring to FIG. 4 in combination with FIGS. 3A and 3B, a schematic pictorial diagram illustrates an embodiment of a channel control system **400** is used in the supersonic

aircraft **300** that includes a fuselage **302**, wings **304**, a tail empennage **308**, and a plurality of control effectors coupled to the wings **304** and the tail empennage **308**. The empennage **308** and wings **304** form a channel region **310** that can form complex shock patterns at transonic speeds. The channel control system **400** comprises a plurality of actuators **402** coupled to the control effectors. The effectors include a flap **404** coupled to the wing **304** and an effector **406** coupled to the tail empennage **308**. The channel control system **400** further comprises at least one vehicle management computer **408** coupled to the plurality of actuators. The vehicle management computers implement a process for managing the control effectors in a drag reduction mode through channel relief by deflecting both the flap **404** downward and the tail empennage effector **406** upward. In some embodiments, the vehicle management computers also manage the control effectors in a speedbrake mode that increases drag by choking the channel and deflecting the flap **404** upward and the tail empennage effector **406** downward.

In the illustrative embodiment, the wing **304** is a highly swept low aspect ratio wing with the effector flap **404** mounted on the trailing edge of the wing. The tail empennage **308** is in a configuration of an inverted V-tail coupled at the aft portion of the aircraft body **302** and coupled to the wing **304** in a braced wing configuration. The tail empennage effector **406** is a ruddervator that is coupled to an inverted stabilizer in the inverted V-tail **308**.

The illustrative aircraft **300** further includes a differential canard **318** that is mounted on the body **302**. The canard **318** has an actuator **302** communicatively coupled to a vehicle management computer that can deflect the canard **318** in combination with the control effectors to facilitate drag reduction and drag augmentation for usage as a speed brake.

Referring to FIGS. **5A** and **5B**, two schematic pictorial diagrams illustrate the channel region **310** within the wing **304** and empennage **308** in more detail. The empennage **308** includes a tail structure section **502**, a vertical stabilizer to inverted stabilizer joint section **504**, and an inverted stabilizer to nacelle joint section **506**. The tail structure section **502** includes the vertical stabilizer **320**, and a pair of inverted stabilizers **322**. Control effectors include the rudder **326** pivotally connected to the trailing edge of the vertical stabilizer **320** and ruddervators **312** pivotally connected to the trailing edge of the inverted stabilizers **322**.

The vertical stabilizer **320** is attached to the top of the aircraft center body and aft section **508**. The top of the vertical stabilizer **320** is attached to the tops of the left and right inverted stabilizers **322**.

FIG. **5B** shows a view of a right nacelle structure **510** including the right engine nacelle **324**, a right structural support member **512**, such as a torque box or torsion box, and wing spars **514** within the right wing **516**. The right nacelle structure **418** is attached to the right wing section **516** and the lower right inverted stabilizer **410**.

The wing **516** includes multiple support spars or ribs **514** within an airfoil that supports the airfoil structural support members **512** on the right and left sides of the aircraft. The airfoil structural support members **512** have a configuration that reduces body freedom flutter by increasing chordwise wing bending by engine rib enhancement.

Referring to FIGS. **6A** and **6B**, two pictorial diagrams illustrate different views of a trailing edge flap **600** that can be used in an embodiment of an aircraft capable of channel relief control. The trailing edge flap **600** is located between the engine nacelle **602** and the fuselage **604**. The trailing edge flap surface can rotate in a downward direction in combination with an upward deflection of the ruddervator in

a controlled angle to reduce drag. In an illustrative embodiment, the flap surface can rotate down to a maximum predetermined angle, for example  $20^\circ$ . The engine nacelle **602** has sufficient clearance for the flap **600** to deflect to a maximum deflection angle.

An actuator **606** drives deflection of the trailing edge flap **600**. In an illustrative embodiment, the actuator **606** is an electro-mechanical rotary actuator with integral motors, brakes, and a speed sensor.

FIG. **6B** shows the trailing edge flap **600** attached at the inboard wing rear spar **608**. The trailing edge flap **600** is pivotally connected to the wing rear spar **608** via a flap hinge **610** and an actuator hinge **612**.

Referring to FIGS. **7A**, **7B**, and **7C**, three schematic perspective pictorial views show detailed diagrams of portions of the tail structure **700**. FIG. **7A** depicts a view of the interface between a vertical stabilizer **702** and inverted stabilizers **704L**, **R**. The top of the right **704R** and left **704L** inverted stabilizers are attached to the top of the vertical stabilizer **702**. A rudder **706** is attached to the aft end **708** of the vertical stabilizer **702**. The illustrative inverted stabilizers **704L**, **R** couple to the vertical stabilizer **702** using left **710L** and right **710R** stabilizer upper lugs. Also shown in a left ruddervator surface **712L** pivotally coupled to the left inverted stabilizer **704L**.

The right inverted stabilizer **704R** attaches to the wing adjacent to the right nacelle **714R**.

FIG. **7B** shows a ruddervator section **716** including the left inverted stabilizer **704L** coupling between the vertical stabilizer **702** and the left wing adjacent to the left nacelle **714L**. The illustrative configuration includes two ruddervators on each side, each of which is coupled to the inverted stabilizer. In the depicted view, a left outboard ruddervator **718LO** and a left inboard ruddervator **718LI** are shown coupled to the left inverted stabilizer **704L** using ruddervator hinges **720** and actuator hinges **722** that control movement of the ruddervators.

FIG. **7C** illustrates baseline actuators **724** for the ruddervators **718**. In the illustrative embodiment, the actuators **724** are electro-mechanical rotary-type actuators. When integrated into the inverted V-tail, the rotary actuators **724** do not protrude into the airstream and thereby avoid increases in aerodynamic drag. The illustrative baseline actuators **724** have integral motor drivers, brakes, and a speed sensor. Also in an illustrative embodiment, the ruddervator surface rotates approximately  $\pm 35^\circ$  about the hinge line. An aircraft can include multiple ruddervators **718** on each side, a redundancy that is useful to maintain aircraft control in a jammed-surface condition. The ruddervators **718** in FIG. **7B** include redundant inboard and outboard sections.

Referring to FIG. **8**, a graph illustrates a drag rise plot **800** indicative of pressure drag in a supersonic/transonic aircraft. The plot **800** shows the relationship of pressure drag to Mach number as the aircraft flies at different speeds. A baseline **802** shows drag rise performance for a supersonic aircraft embodiment without effector flap and effector deflection. Below supersonic speeds, pressure drag gradually rises with Mach number. At transonic Mach levels, the baseline drag rise plot **802** peaks, rapidly rising then falling at supersonic speeds. At high Mach numbers, the baseline pressure drag levels. With channel relief **804**, an effector flap is deflected down while the effector is deflected up, relieving the channel and reducing the pressure drag at the transonic levels. During speed brake application **806**, the effector flap and effector are deflected in opposite directions in comparison to channel relief deployment, choking the channel and creating a larger pressure drag peak in the transonic region.



In the subsonic and supersonic regions, the baseline **802**, the channel relief line **804**, and the speed brake line **806** are approximately the same.

Referring to FIG. 9, a schematic block diagram shows an example a flight control actuation architecture embodiment **900** that can be used to control effectors in the empennage to operate in a drag reduction mode and, conversely, to increase drag in operation as a speedbrake. In the illustrative example, primary flight control actuation uses “Fly-by-Wire” dual tandem linear hydraulics with triple electronic redundancy. Dual tandem actuation **902** is powered by two independent hydraulic systems **904** and **906** and sized for full rated performance based on a single system operation. The flight control system is closed-loop and commanded by the Vehicle Management Computers **908**. The flight control system **900** performs control law implementations to produce aircraft handling qualities throughout flight. The system **900** can implement outer loop control modes such as Autopilot, Autoland, and Auto collision avoidance control. The flight control actuation system **900** can also execute system integrity and health management functions. Various types of actuators can be implemented including, for example, Dual Tandem hydraulic actuators, Simplex hydraulic actuators, Rotary vane hydraulic actuators, multiple cylinders hydraulic actuators, integrated rotary electro-mechanical actuators (IREMA), and the like.

The control effector configuration, controlled by the Vehicle Management Computers **908**, uses redundant control surfaces, enabling continued safe flight and landing in event of a single actuator failure or mechanically-jammed control surface. Redundancy is extended to the ailerons and ruddervators, which are also designed into multiple surfaces for increased fault tolerance and improved overall safety.

The Vehicle Management Computers **908** implement processes for controlling the effectors, including the canards to distribute lift to reduce or minimize sonic signature and to drive the aircraft to relaxed stability. In an illustrative embodiment, two electronic flight control systems are used to give superior handling qualities and optimal performance throughout the flight envelope. The first system is a full-authority Fly-By-Wire system designed for stability and handling qualities and determining the basic dynamic response of the aircraft.

The second flight control system is an active center-of-gravity (CG) management system. As fuel is burned throughout the mission, the CG management system redistributes the remaining fuel to maximize range and reduce or minimize sonic boom signature. The CG management system also enables the canard, wing and inverted V-tail to interact in harmony to lift the vehicle efficiently for maximum range while producing a low sonic boom signature.

Referring to FIG. 10, a schematic block diagram shows an embodiment of a suitable hydraulic power and distribution system architecture **1000** for supplying actuating power to the effectors and systems. For high reliability, the system **1000** is highly redundant with a hydraulic system supplying three independent sources **1002**, **1004**, **1006** of hydraulic power to operate primary flight controls, landing gear **1014**, nose wheel steering **1016**, wheel brakes **1018**, and thrust reversers **1020**. The three independent systems **1002**, **1004**, and **1006** give triple redundancy for continued safe flight and landing.

Hydraulic power for the systems is supplied by two engine driven pumps **1022** and an AC motor pump **1024** on system 1 **1002** and system 2 **1004**. The engine driven pumps **1022** can operate continuously while the AC motor pumps **1024** operate on demand basis. Additionally, the AC motor

pumps **1024** are an extra source of hydraulic power that gives redundancy within each system. The AC motor pumps **1024** can be operated on the ground for system checkout without running the engines or using a hydraulic ground carts.

System 3 **1006** has two air driven pumps **1026** and an AC motor pump **1024**. One air driven pump **1026** operates continuously while the other air driven pump **1026** and the AC motor pump **1024** operate on a demand basis. The AC motor pump **1024** in system 3 **1006** can also be operated on the ground for system checkout without running the engines or using a hydraulic ground cart. System 3 **1006** also includes a ram air turbine **1028** for emergency hydraulic and electrical power in the event of dual engine flameout. The ram air turbine **1028** is sized to supply hydraulic and electrical power to essential equipment from the certified altitude to safe landing for level 3 handling quality.

While the present disclosure describes various embodiments, these embodiments are to be understood as illustrative and do not limit the claim scope. Many variations, modifications, additions and improvements of the described embodiments are possible. For example, those having ordinary skill in the art will readily implement the steps necessary to provide the structures and methods disclosed herein, and will understand that the process parameters, materials, and dimensions are given by way of example only. The parameters, materials, and dimensions can be varied to achieve the desired structure as well as modifications, which are within the scope of the claims. Variations and modifications of the embodiments disclosed herein may also be made while remaining within the scope of the following claims. For example, although a particular aircraft geometry and configuration is described, the channel configuration and techniques for controlling the channel can be utilized in aircraft with different geometries. In particular, although the described aircraft has an inverted V-tail configuration, other tail configurations such as T-tail configurations and others may be used. The described propulsion configuration includes two engines mounted at aft positions in a highly swept wing. Other suitable embodiments may have different engine configurations with fewer or more engines, with engines mounted on the fuselage or tail rather than on the wing, or mounted above rather than beneath the wing.

What is claimed is:

1. A supersonic aircraft comprising:

- a fuselage extending forward and aft along a longitudinal axis, the fuselage having a lower surface and an upper surface;
- a highly swept low aspect ratio wing coupled to the fuselage, the wing having a forward leading edge and an aft trailing edge;
- an effector flap coupled to the wing trailing edge;
- a tail empennage coupled to the fuselage aft of the wing on the fuselage upper surface in a position high relative to the wing, the tail empennage forming a channel region subject to complex shock patterns and having an inverted V-tail geometry coupled to the wing in a braced wing configuration further comprising a vertical stabilizer, lateral inverted stabilizers, and inverted V-tail control surface ruddervators; and
- an effector coupled to the tail empennage; and
- a controller coupled to the effector flaps and the effectors, the controller further comprising a control process that reduces drag through channel relief by deflecting both the effector flap down and the effector up, and a control process capable of adjusting the aircraft longitudinal

## 11

lift distribution for a selected supersonic Mach number to maintain a low sonic-boom, low drag-trim condition.

2. A supersonic aircraft comprising:

- a fuselage extending forward and aft along a longitudinal axis, the fuselage having a lower surface and an upper surface;
- a highly swept low aspect ratio wing coupled to the fuselage, the wing having a forward leading edge and an aft trailing edge;
- an effector flap coupled to the wing trailing edge;
- a tail empennage coupled to the fuselage aft of the wing on the fuselage upper surface in a position high relative to the wing, the tail empennage forming a channel region subject to complex shock patterns, and having a supersonic T-tail geometry further comprising a vertical stabilizer, a lateral horizontal stabilizer, and a control surface elevator;
- an effector coupled to the tail empennage; and
- a controller coupled to the effector flaps and the effectors, the controller further comprising a control process that reduces drag through channel relief by deflecting both the effector flap down and the effector up, and a control process capable of adjusting the aircraft longitudinal lift distribution for a selected supersonic Mach number to maintain a low sonic-boom, low drag-trim condition.

3. A supersonic aircraft comprising:

- a fuselage extending forward and aft along a longitudinal axis, the fuselage having a lower surface and an upper surface;
- a highly swept low aspect ratio wing coupled to the fuselage, the wing having a forward leading edge and an aft trailing edge;
- an effector flap coupled to the wing trailing edge;
- engines coupled to the aft portion of the wing lower surface;
- a tail empennage coupled to the fuselage aft of the wing on the fuselage upper surface in a position high relative to the wing, the tail empennage forming a channel region subject to complex shock patterns and an inverted V-tail geometry empennage coupled to the wing in a braced wing configuration and carrying lift at the aft portion of the aircraft on a high mounted tail, the length of the aircraft being effectively lengthened for shock waves below the aircraft, thereby further reducing sonic boom, the inverted V-tail carrying tail lift high to maintain a continuous lift distribution and structurally bracing the wing and engines;
- an effector coupled to the tail empennage; and
- a controller coupled to the effector flaps and the effectors, the controller further comprising a control process that reduces drag through channel relief by deflecting both the effector flap down and the effector up.

4. A supersonic aircraft comprising:

- an aircraft body extending forward and aft;
- a highly swept low aspect ratio wing coupled to the body, the wing having a forward leading edge and an aft trailing edge;
- an effector flap coupled to the trailing edge of the wing;
- an inverted V-tail coupled at the aft portion of the aircraft body and coupled to the wing in a braced wing configuration, the inverted V-tail forming a channel region that can generate complex shock patterns;
- two wing-mounted engines positioned beneath the wing at an aft location, the braced wing V-tail supporting the engines and enabling trim for a low sonic boom lift distribution;

## 12

- ruddervator control surfaces coupled to the inverted V-tail; and
- a controller coupled to the effector flap and the ruddervator control surfaces, the controller comprising a control process that reduces drag through channel relief by deflecting both the effector flap down and the ruddervator control surfaces up.

5. The aircraft according to claim 4 wherein:

- the engines have a highly integrated wing/inlet geometry that enables low-boom compatibility and low inlet/nacelle installation drag.

6. A supersonic aircraft comprising:

- an aircraft body extending forward and aft;
- a highly swept low aspect ratio wing coupled to the body, the wing having a forward leading edge and an aft trailing edge;
- an effector flap coupled to the trailing edge of the wing;
- an inverted V-tail coupled at the aft portion of the aircraft body and coupled to the wing in a braced wing configuration, the inverted V-tail forming a channel region that can generate complex shock patterns;
- ruddervator control surfaces coupled to the inverted V-tail; and
- a controller coupled to the effector flap and the ruddervator control surfaces, the controller comprising a control process that reduces drag through channel relief by deflecting both the effector flap down and the ruddervator control surfaces up, and a control process that adjusts aircraft longitudinal lift distribution for a selected Mach number to maintain a low sonic boom, low drag-trim condition.

7. A channel control system for usage in a supersonic aircraft including a fuselage, wings, a tail empennage, and a plurality of control effectors coupled to the wings and the tail empennage, the empennage and wings forming a channel region that can form complex shock patterns at transonic speeds, the channel control system comprising:

- a plurality of actuators coupled to the control effectors, the effectors including a flap coupled to the wing and an effector coupled to the tail empennage; and
- at least one vehicle management computer coupled to the plurality of actuators, the at least one vehicle management computer further comprising a process for managing the control effectors in a drag reduction mode through channel relief by deflecting both the flap downward and the tail empennage effector upward, wherein;

the wing is a highly swept low aspect ratio wing coupled to the body, the wing having a forward leading edge and an aft trailing edge, and an effector flap coupled to the trailing edge of the wing;

the tail empennage is in a configuration of an inverted V-tail coupled at the aft portion of the aircraft body and coupled to the wing in a braced wing configuration, the tail empennage comprising ruddervator control surfaces coupled to the inverted V-tail; and

the at least one vehicle management computer further comprises a channel relief process that reduces drag through channel relief by deflecting both the effector flap downward and the ruddervator upward.