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(54) **ACTIVE FLOW CONTROL ON A VERTICAL STABILIZER AND RUDDER**

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B64C 9/00	(2006.01)
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B64C 21/00	(2006.01)
B64C 23/00	(2006.01)
B64C 23/06	(2006.01)

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CPC . ***B64C 5/06*** (2013.01); ***B64C 21/00*** (2013.01); ***B64C 23/005*** (2013.01); ***B64C 23/06*** (2013.01); *B64C 2230/04* (2013.01); *B64C 2230/16* (2013.01); *Y02T 50/162* (2013.01); *Y02T 50/166* (2013.01)

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CPC Y02T 50/166; Y02T 50/12; Y02T 50/32; Y02T 50/673; Y02T 50/66; Y02T 50/164; Y02T 50/671; Y02T 50/162; Y02T 50/675; Y02T 50/34; Y02T 50/54; B64C 21/025; B64C 2230/04; B64C 21/08; B64C 21/04; B64C 21/06; B64C 2230/06

USPC .... 244/76 C, 87, 199.1, 199.3, 201, 204, 244/204.1, 205, 208; 137/803, 833, 834

See application file for complete search history.

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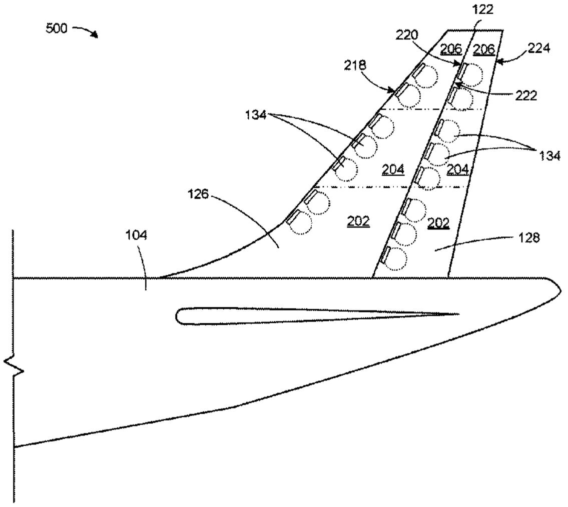
(57) **ABSTRACT**

Systems and methods described herein provide for the control of airflow over a vertical control surface of an aircraft to enhance the forces produced by the surface. According to one aspect of the disclosure provided herein, the vertical control surface of the aircraft is engaged by active flow control actuators that interact with the ambient airflow to alter one or more characteristics of the airflow. An actuator control system detects a flow control event, and in response, activates the active flow control actuators to alter the airflow. According to various aspects, the flow control event is associated with a separation of the airflow, which is corrected through the activation of the appropriate active flow control actuators, increasing the forces produced by the vertical control surface of the aircraft.

17 Claims, 7 Drawing Sheets



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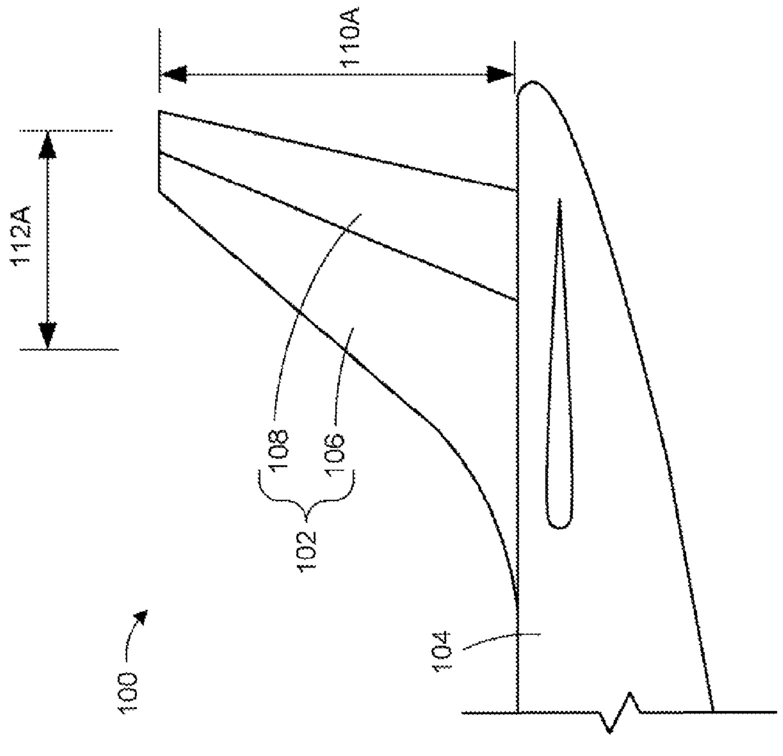


Fig. 1A
(PRIOR ART)

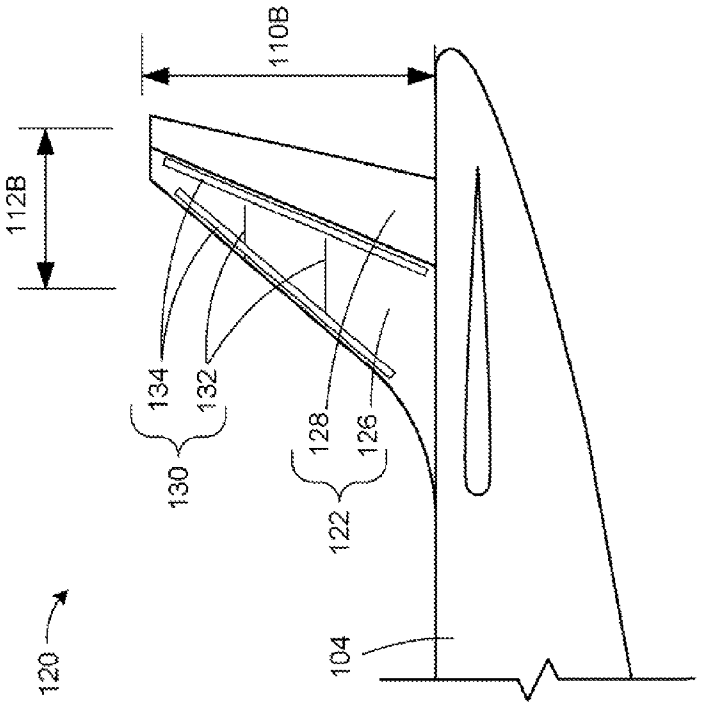
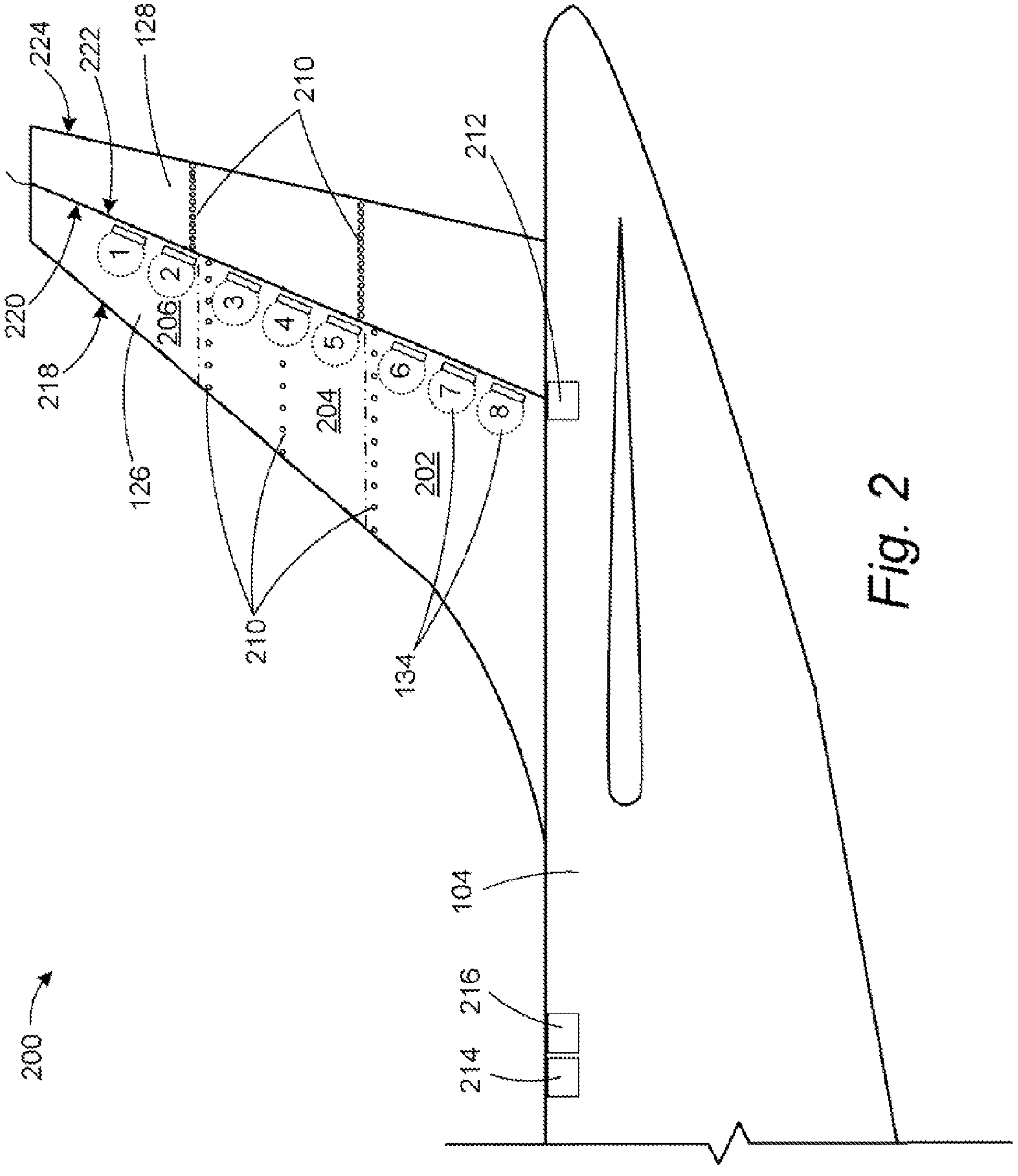


Fig. 1B


200
214
216
104
212
210
210
128
224
222
122
220
218
126
206
204
202
134
1
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3
4
5
6
7
8

Fig. 2

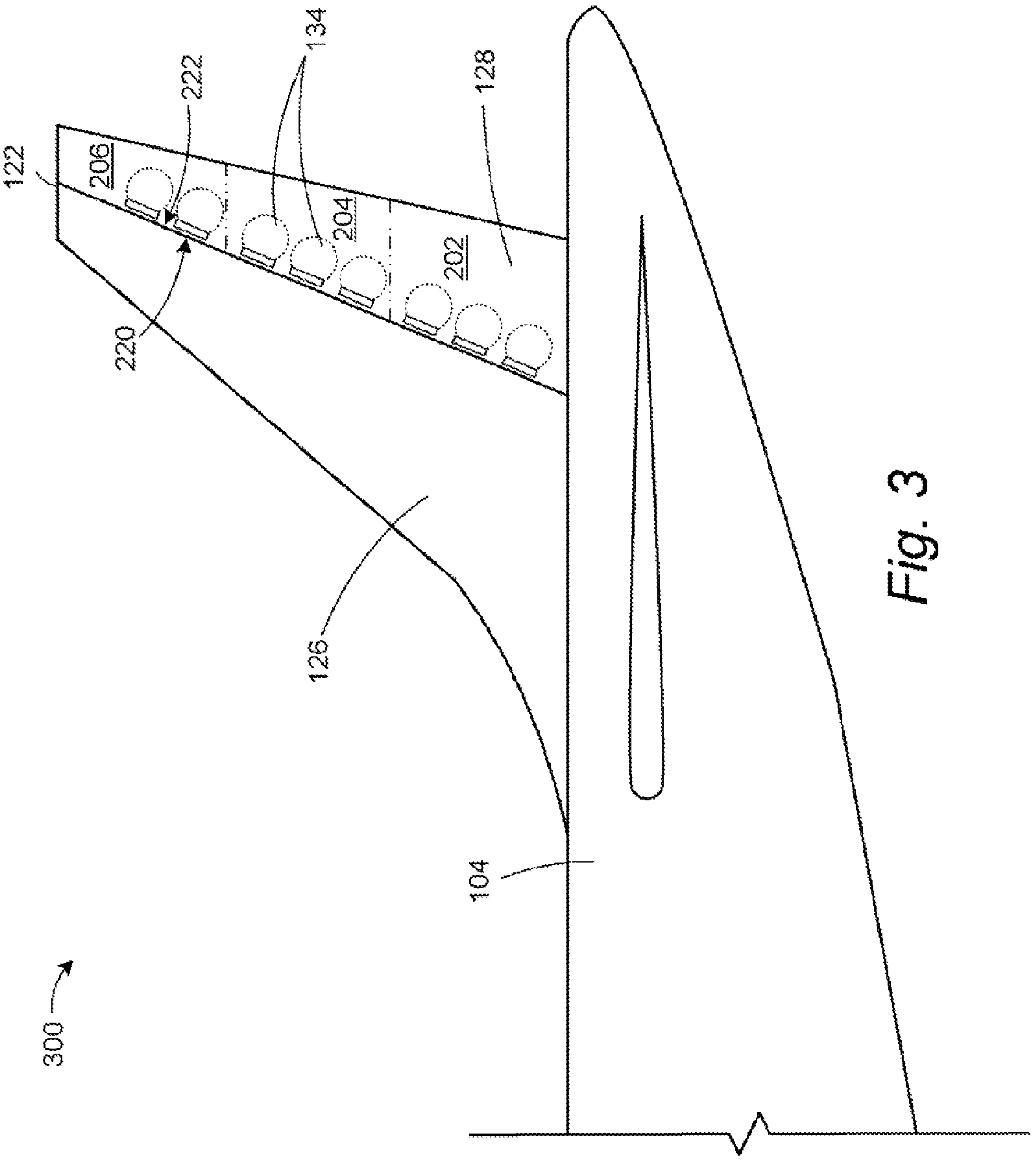

Fig. 3

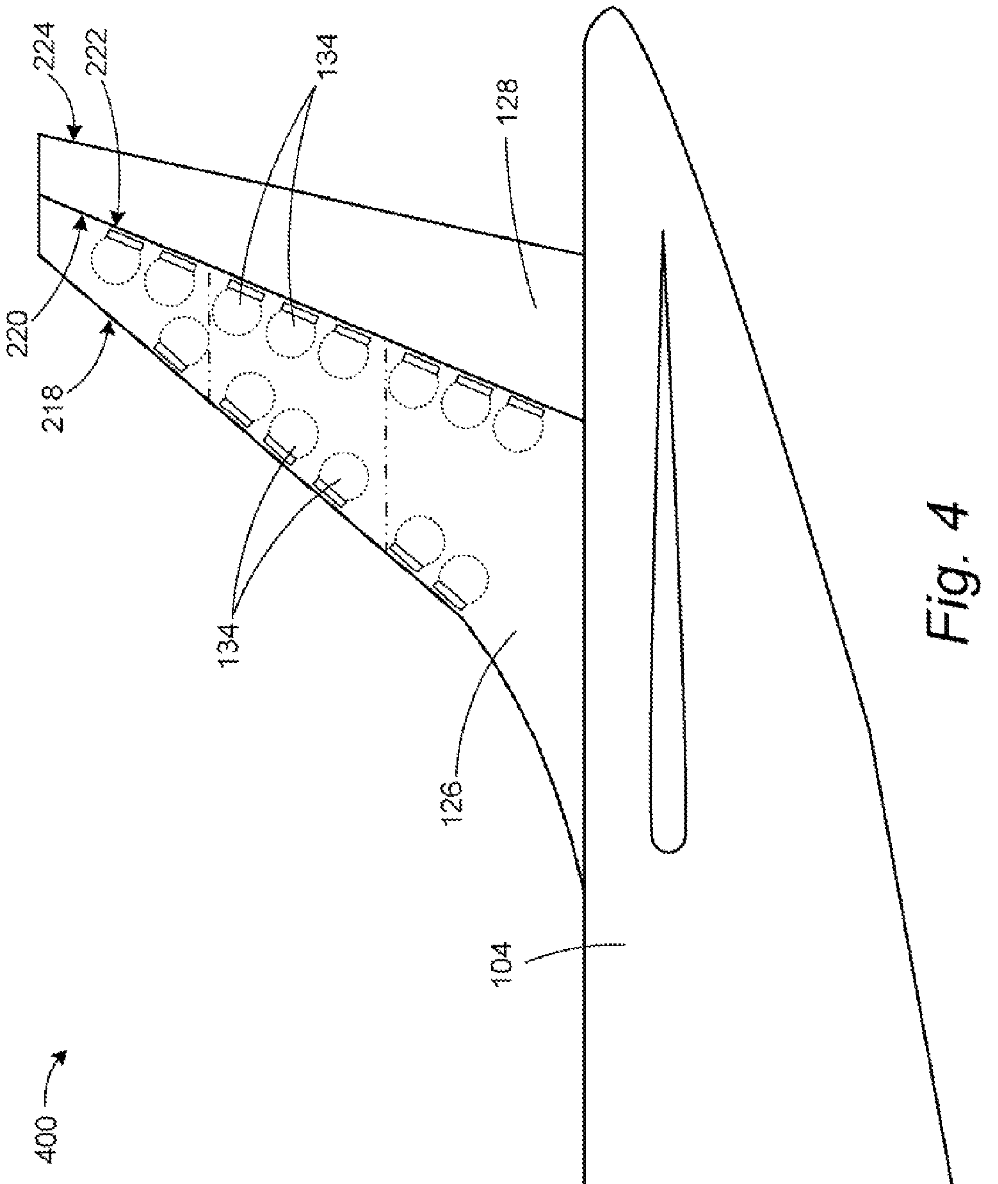

Fig. 4

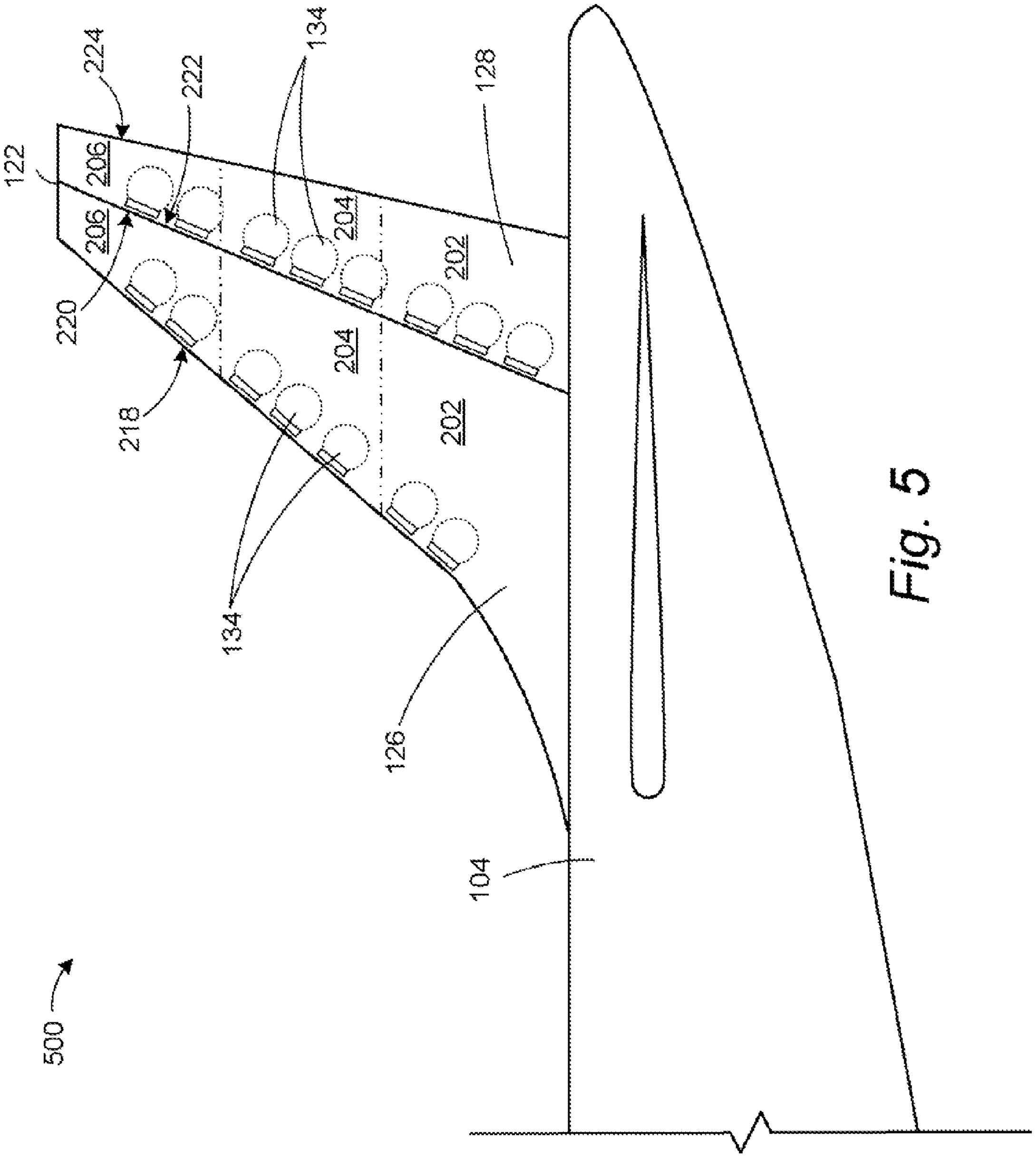
500
224
222
134
128
122
206
206
204
204
202
202
220
218
134
126
104

Fig. 5

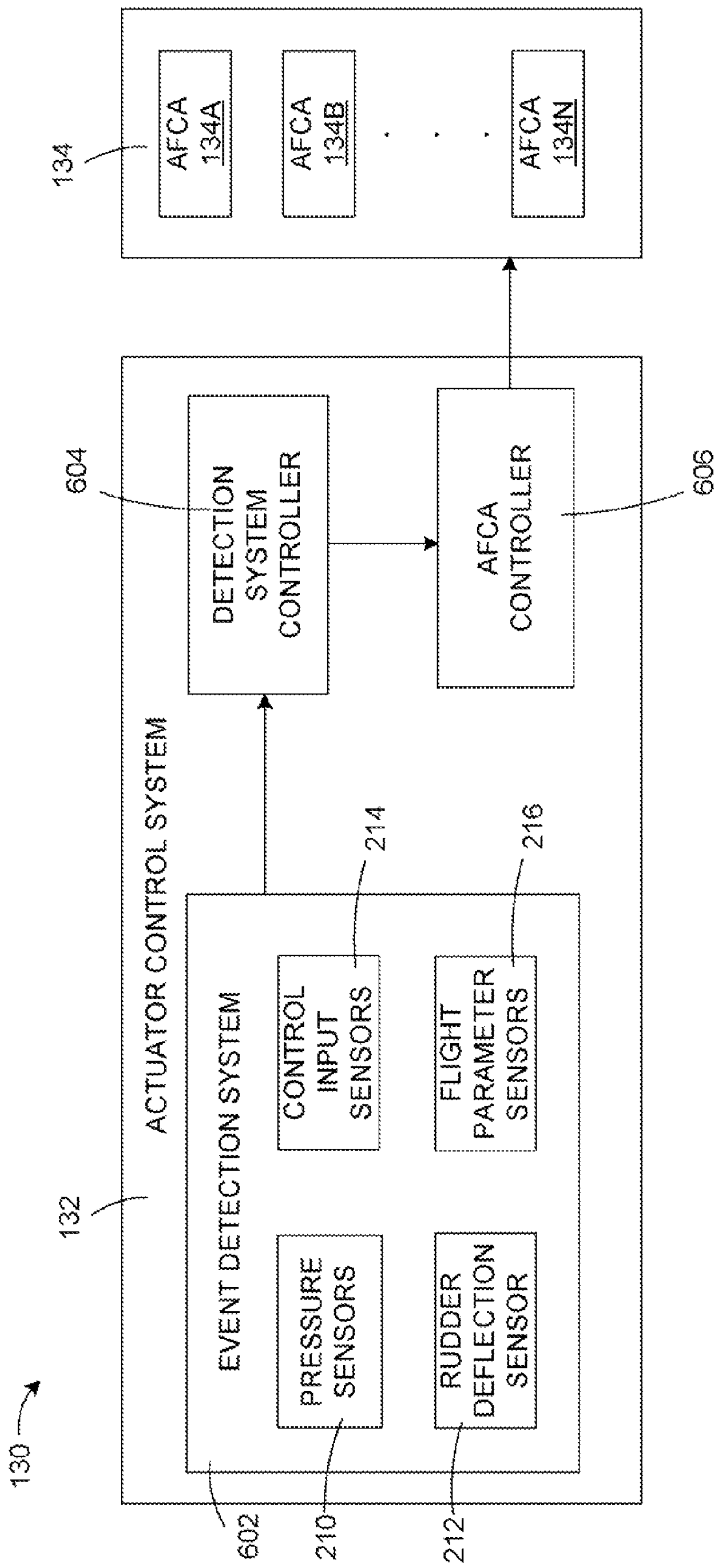
130
132
ACTUATOR CONTROL SYSTEM
602
EVENT DETECTION SYSTEM
210
PRESSURE SENSORS
212
RUDDER DEFLECTION SENSOR
214
CONTROL INPUT SENSORS
216
FLIGHT PARAMETER SENSORS
604
DETECTION SYSTEM CONTROLLER
606
AFCA CONTROLLER
134
AFCA 134A
AFCA 134B
AFCA 134N

Fig. 6

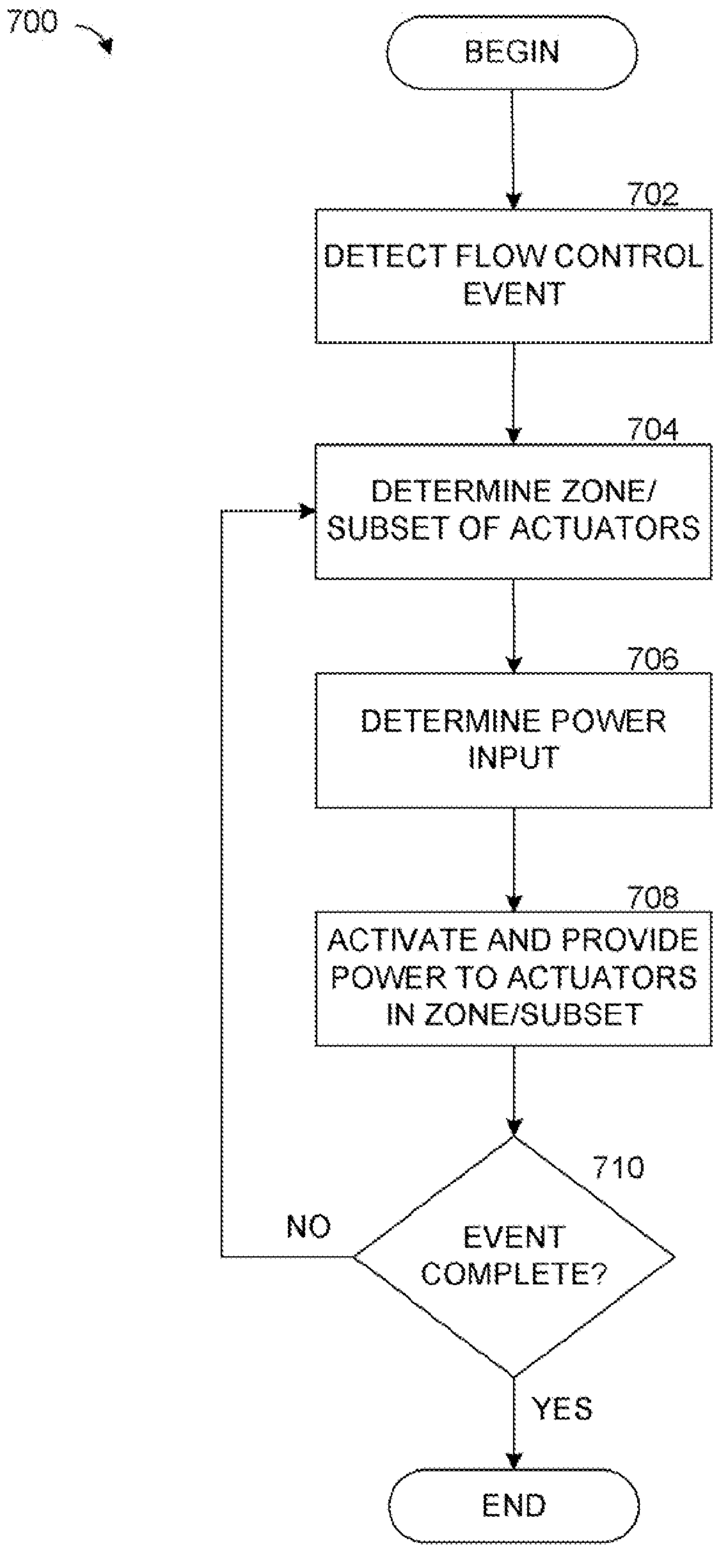
700
BEGIN
702
DETECT FLOW CONTROL EVENT
704
DETERMINE ZONE/ SUBSET OF ACTUATORS
706
DETERMINE POWER INPUT
708
ACTIVATE AND PROVIDE POWER TO ACTUATORS IN ZONE/SUBSET
710
EVENT COMPLETE?
NO
YES
END

Fig. 7

ACTIVE FLOW CONTROL ON A VERTICAL STABILIZER AND RUDDER

BACKGROUND

Conventional commercial aircraft are designed with a vertical tail used to provide stability about the yaw axis. The vertical tail of an aircraft may include a fixed vertical stabilizer and a moveable rudder that is hinged at the trailing edge of the vertical stabilizer. During normal flight operations, the vertical tail provides a force that allows a pilot to properly align and maintain control of the aircraft. By deflecting the rudder, the pilot increases the force created by the vertical tail to provide a desired yawing moment on the aircraft. The size of the vertical tail is determined according to the designed flight envelope in which the aircraft will operate and the necessary forces to sustain controlled flight within the boundaries of that envelope. For example, during emergency situations such as an engine failure or extremely high cross winds, the force required to be produced by the vertical tail to maintain control of the aircraft may be at a maximum. During aircraft design, this force is calculated and the vertical tail is sized accordingly to ensure the capability of producing this force in the event that those emergency situations or flight operations at the boundaries of the desired flight envelope arise.

However, as the size of the vertical tail increases, the corresponding weight of the aircraft increases, as does the amount of drag generated by the vertical tail. As weight and drag increase, the cost of manufacturing and operating the resulting aircraft also increase. Even though the forces required by the vertical tail of an aircraft to maintain stability during normal flight operations would permit a decrease in the size of a conventional vertical tail, reducing the size of the vertical tail is not feasible due to the need to prepare for operations at the edges of the designed flight envelope.

It is with respect to these considerations and others that the disclosure made herein is presented.

SUMMARY

It should be appreciated that this Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to be used to limit the scope of the claimed subject matter.

Systems and methods described herein provide for an active flow control system for controlling an airflow over a vertical control surface of an aircraft. Utilizing the concepts described herein, the forces created by the vertical tail of an aircraft can be selectively enhanced and allow the size and corresponding weight of the vertical tail to be significantly reduced as compared to a conventional aircraft tail while maintaining yaw control for the aircraft throughout the designed flight envelope.

According to one aspect of the disclosure provided herein, an active flow control system includes a vertical control surface, one or more active flow control actuators, and an actuator control system. The active flow control actuators are mounted on or within the vertical control surface and when activated, alter one or more characteristics of the airflow over the surface. The actuator control system detects a flow control event for which airflow actuation is desirable. In response to detecting the event, the actuator control system activates the flow control actuators to control the airflow.

According to another aspect, a method of controlling airflow over a vertical control surface of an aircraft includes detecting a flow control event associated with the surface. In response to detecting the flow control event, one or more active flow control actuators are activated. The active flow control actuators interact with the ambient airflow, altering the airflow as it passes over the vertical control surface.

According to yet another aspect, an active flow control system for controlling an airflow over a vertical control surface of an aircraft includes the vertical control surface, a number of active flow control actuators, and an actuator control system. The active flow control actuators are mounted within the vertical control surface within a number of zones. When activated, the active flow control actuators alter a flow characteristic of the airflow. The actuator control system is linked to the actuators and includes a number of sensors and a controller. The sensors collect data associated with a flow control event. The controller utilizes the collected data to detect the flow control event. After detecting the event, the controller identifies a subset of the total number of actuators for activation. The subset corresponds to a zone in which activation of the member actuators is effective in controlling the airflow in response to the flow control event. The controller activates the actuators within the identified zone or subset of actuators.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B are side views of a conventional aircraft vertical tail and an enhanced flow control tail according to embodiments presented herein, respectively, showing a size comparison between the two vertical control surfaces;

FIG. **2** is a side view of an enhanced flow control tail of an aircraft showing components of an active flow control system with active flow control actuators positioned at a trailing edge of a vertical stabilizer according to one embodiment presented herein;

FIG. **3** is a side view of an enhanced flow control tail of an aircraft showing components of an active flow control system with active flow control actuators positioned at a leading edge of a rudder according to one embodiment presented herein;

FIG. **4** is a side view of an enhanced flow control tail of an aircraft showing components of an active flow control system with active flow control actuators positioned at a leading edge and a trailing edge of a vertical stabilizer according to one embodiment presented herein;

FIG. **5** is a side view of an enhanced flow control tail of an aircraft showing components of an active flow control system with active flow control actuators positioned at a leading edge of a vertical stabilizer and a leading edge of a rudder according to one embodiment presented herein;

FIG. **6** is a block diagram showing components of an active flow control system according to various embodiments presented herein; and

FIG. **7** is a flow diagram illustrating a method for controlling an airflow over a vertical control surface according to various embodiments presented herein.

DETAILED DESCRIPTION

The following detailed description is directed to systems and methods for controlling airflow around a vertical control surface of an aircraft to enhance the forces produced by the surface. As discussed briefly above, typical aircraft vertical tail surfaces are substantially larger than is necessary for normal flight operations. However, due to the need to maintain aircraft stability and control during operations at the outer boundaries of the designed flight envelope, conventional aircraft vertical stabilizers and corresponding rudders are sized accordingly, creating undesirable weight and drag penalties during flight.

However, utilizing the concepts and technologies described herein, active flow control actuation techniques are used to selectively enhance the ambient airflow characteristics over the vertical tail surfaces, and consequently increase the forces produced by the surfaces. In doing so, the relative size of the vertical tail surfaces may be substantially reduced, while maintaining the performance capabilities of a conventionally sized, unactuated aircraft vertical tail.

In the following detailed description, references are made to the accompanying drawings that form a part hereof, and which are shown by way of illustration, specific embodiments, or examples. Referring now to the drawings, in which like numerals represent like elements through the several figures, an active flow control system and method will be described. FIGS. **1**A and **1**B show a comparison between a conventional aircraft vertical tail **100** and an enhanced flow control tail **120** according to embodiments described herein. FIG. **1**A shows an example of the conventional aircraft vertical tail **100**. The conventional aircraft vertical tail **100** includes a vertical control surface **102** mounted to a rear fuselage portion **104**.

According to various embodiments shown and described herein, the vertical control surface **102** includes a vertical stabilizer **106** and a rudder **108** that is attached to the vertical stabilizer **106** via a hinge and rotatable around the hinge to provide the appropriate yawing force according to a corresponding deflection angle. The size of the conventional vertical control surface **102** is illustrated with the dimensional arrows corresponding to a conventional span **110**A and a conventional mean chord length **112**A. It should be appreciated that the figures are not drawn to scale, but are approximated for illustrative purposes. The precise dimensions and configurations of the vertical tail components may vary according to the particular implementation. Moreover, it should be understood that the vertical control surface **102** is not limited to the exact configuration of the vertical stabilizer **106** and rudder **108** shown in the figures. Rather, the vertical control surface **102** may include any control surface configured to control aircraft yaw.

In comparison, FIG. **1**B shows an example of an enhanced flow control tail **120** utilizing the concepts described herein. The enhanced flow control tail **120** includes a vertical control surface **122** mounted to the fuselage portion **104**, which is identical to the fuselage portion **104** shown with the conventional aircraft vertical tail **100** shown in FIG. **1**A. The vertical control surface **122** includes a vertical stabilizer **126** and a rudder **128** that is attached to the vertical stabilizer **126** via a hinge and rotatable around the hinge to provide the appropriate yawing force according to a corresponding deflection angle. A significant observable difference between the enhanced flow control tail **120** utilizing the technology described below and the conventional aircraft vertical tail **100** described above is the size. Although not drawn to scale, it can be seen in FIG. **1**B that the span **110**B of the vertical control surface **122** is shorter than the span **110**A of the conventional vertical control surface **102**. Similarly, the mean chord length **112**B of the vertical control surface **122** is likewise shorter than the mean chord length **112**A of the conventional vertical control surface **102**.

In order to allow for the decreased surface area of the vertical control surface **122**, various embodiments disclosed herein utilize an active flow control system **130**. Among other components that will be described in greater detail below with respect to FIG. **6**, the active flow control system **130** includes an actuator control system **132** and a number of active flow control actuators **134**. Although the actuator control system **132** is depicted as two horizontal lines and the active flow control actuators as two lines positioned parallel to the leading edge and trailing edge of the vertical stabilizer **126**, respectively, it should be understood that the depicted locations of these components on the vertical control surface **122** are shown for illustrative purposes only. It will become clear from FIGS. **2**-**4** and the corresponding descriptions that the locations and the components of the active flow control system **130** may vary according to the particular implementation.

Turning now to FIG. **2**, an enhanced flow control tail **200** will be described according to one embodiment. The enhanced flow control tail **200** includes a vertical stabilizer **126** and an attached rudder **128**. According to this implementation, a number of active flow control actuators **134** are mounted within the vertical stabilizer **126**. While eight active flow control actuators **134** are shown in FIG. **2**, any number of active flow control actuators **134** may be utilized within the scope of this disclosure. The precise number utilized might depend on the type of actuators used, the type of aircraft the actuators are used with, the placement of the actuators, and any other applicable design considerations.

The active flow control actuators **134** of this example are shown to be linearly aligned proximate to and parallel with the trailing edge **220** of the vertical stabilizer **126**. A position that allows for the interaction of actuating air from the active flow control actuators **134** with the ambient airflow over the leading edge of the rudder **128** is an advantageous position for one or more of the active flow control actuators **134** since the deflection of the rudder **128** around the rudder hinge creates a pressure differential that may lead to undesirable flow separation, particularly as the deflection angle of the rudder increases. Control of this separation during the deflection of the rudder **128** increases the aerodynamic forces created by the vertical control surfaces of the aircraft, subsequently allowing for a smaller vertical tail without a detrimental effect on the boundaries of the flight envelope.

The active flow control actuators **134** may be any type of flow control actuators, including but not limited to synthetic jets, sweep jets, flipperons, active vortex generators, and/or any combination thereof. For example, piezoelectric disks may be utilized as active flow control actuators **134** to control the flow over the enhanced flow control tail **200**. It should be clear that the shape and configuration of the active flow control actuators **134** shown in the figures is not intended to be limiting. Examples of active flow control actuators **134** that may be utilized within the various embodiments described herein include those described in co-pending U.S. patent application Ser. No. 12/236,032, entitled "Shaping a Fluid Cavity of a Flow Control Actuator for Creation of Desired Waveform Characteristics" and filed on Sep. 23, 2008, and U.S. patent application Ser. No. 12/696,529, entitled "Multi-Stage Flow Control Actuation" and filed on Jan. 29, 2010, each of which is incorporated by reference herein in its entirety. It should be appreciated that the active flow control actuators **134** may be activated electronically or pneumatically, or according to any desired method depending on the type of actuators used.

According to one embodiment, the active flow control actuators **134** may be configured within zones and utilized according to zone membership. By actuating the flow over the vertical control surface **122** according to zones, power can be managed and allocated to only those actuators necessary to control the airflow at that given moment. Because power management during flight operations is a significant consideration, minimizing the power consumption by the active flow control system **130** is a beneficial attribute of the zone-actuated flow control described herein with respect to various embodiments. Moreover, by minimizing the number of active flow control actuators **134** activated at a given time, wear on actuators and associated components of the active flow control system **130** is also minimized.

The various zones used to group the active flow control actuators **134** may be defined according to a physical location of the actuators along the vertical control surface **122**. In the example shown in FIG. **2**, there are three zones **202**, **204**, **206** sequentially arranged vertically from a root of the vertical control surface **122** abutting the aircraft fuselage **104** to a tip of the vertical control surface **122** opposite the root, the boundaries of which are depicted with broken lines. Tip zone **206** includes actuators **1** and **2**, middle zone **204** includes actuators **3-5**, and root zone **202** includes actuators **6-8**. As an example of zone-actuated flow control, if the active flow control system **130** detected a flow separation condition proximate to the rudder hinge line at the leading edge **222** of the rudder **128** near the tip of the vertical control surface **122**, then the actuators **1** and **2** that are members of the tip zone **206** might be activated while the remaining actuators **3-8** remain deactivated. Depending on the rudder deflection and other flight parameters corresponding the operations of the aircraft and the characteristics of the surrounding environment at the time of actuation, it may be beneficial to activate the active flow control actuators **134** according to differing zone sequences.

According to an alternative embodiment, the zones are not sequentially separated according to root, middle, and tip positioning as described above, but include various predetermined combinations of actuators. For example, a first zone might contain actuators **1**, **3**, and **6**; a second zone including actuators **2**, **4**, and **7**; and a third zone including actuators **4** and **8**. In this scenario, the first zone might be activated first to provide some degree of flow actuation across the entire span of the vertical control surface **122**. As further actuation is required, the second zone would be actuated, followed by the third as necessary.

It should be understood that the zones and corresponding actuator members may be defined in any suitable manner. According to yet another embodiment, the zones are dynamically defined during flight operations according to the particular flight parameters at the particular instance in which flow actuation is desired. For example, the active flow control system **130** may determine that actuators **1** and **2** should be activated to prevent flow separation at an outboard section of the rudder **128**. At the next instant, due to a change in pilot input to the flight control system or to a change in cross-winds or other environmental factor, the system may determine that actuators **1**, **4**, and **6** are to be activated and actuator **2** deactivated. Generally, this embodiment allows for the selective activation of any subset of the total number of active flow control actuators **134** in response to the current conditions of the aircraft and/or the environment.

According to another implementation, in addition to or in combination with the above zone-actuated flow control techniques, the active flow control system **130** may control the output of the activated flow control actuators **134** by controlling the input power distributed to the actuators. For example, should only half of the output capability of a particular actuator be required to prevent or correct a flow separation at a particular location on the vertical control surface **122** given the current flight conditions, then the active flow control system **130** may reduce the input power accordingly to provide the reduced output actuating flow.

The activation of the active flow control actuators **134** occurs when triggered by the actuator control system **132**. The actuator control system **132** includes an event detection system having one or more sensors that are capable of detecting a flow control event. For the purposes of this disclosure, a flow control event includes any condition or parameter with respect to the aircraft and/or the surrounding environment in which it travels, in which active flow control techniques described herein would be desirable.

One example of a flow control event is the detection of a flow separation indicator. A flow separation indicator may include any data that may represent that flow separation on the vertical control surface **122** is occurring, or that conditions are optimal for separation to occur. One example of a flow separation indicator would be the detection of a pressure gradient associated with the airflow indicative of an impending or current flow separation. Another flow separation indicator may include a rudder deflection beyond a threshold deflection angle. Other flow control events might include, but are not limited to, a pilot or flight system control input that is indicative of an increased yaw control demand, an engine out or other emergency state in which increased yaw control is necessary, and one or more flow control flight parameters corresponding to an aircraft operating state and/or an environmental state such as aircraft speed, altitude, sideslip angle, ambient airflow pressure, or any combination thereof.

As stated above, the actuator control system **132** includes an event detection system having one or more sensors that are capable of detecting a flow control event. These sensors may include pressure sensors **210**, a rudder deflection sensor **212**, a control input sensor **214**, a flight parameter sensor **216**, or any combination thereof. For illustration purposes only, FIG. **2** shows multiple rows of pressure sensors **210** configured according to various locations and installation densities. There are three rows of pressure sensors **210** shown on the vertical stabilizer **126**. Some of these are shown to extend from the leading edge **218** of the vertical stabilizer **126** to the trailing edge **220** of the vertical stabilizer **126**. One row of pressure sensors **210** is shown to extend from the leading edge **218** to a location approximately mid-chord of the vertical stabilizer **126**. Other pressure sensors **210** are shown to be more densely placed linearly from the leading edge of the rudder **128** to the trailing edge **224** of the rudder **128**.

It should be understood that in order to increase the accuracy of the representation of the flow field flowing over the vertical control surface **122**, the number of pressure sensors **210** should be increased. FIG. **2** shows several examples of configurations for the pressure sensors **210** to illustrate the concept that the pressure sensors may be linearly aligned at any spanwise location(s) on the vertical stabilizer **126** and/or on the rudder **128** and utilizing any number of sensors. However, in practice, only a minimal number of pressure ports may be utilized to provide an estimation of the flow characteristics while minimizing the cost and maintenance associated with the pressure sensors **210**. According to one embodiment, the rows of pressure sensors **210** may be linearly placed along or near the boundaries of the zones, such as between the root zone **202** and the middle zone **204**, and between the middle zone **204** and the tip zone **206**.

Another sensor that may be used with the event detection system is the rudder deflection sensor **212**. The rudder deflection sensor **212** is linked to the rudder **128** and is capable of sensing the deflection angle corresponding to the deflection of the rudder **128**. As the deflection angle increases, the potential for flow separation over the vertical control surface **122** also increases. Utilizing the active flow control actuators **134** when the rudder **128** is deflected beyond a threshold deflection angle may be beneficial to prevent or delay flow separation. Accordingly, the rudder deflection sensor **212** may be used by the actuator control system **132** to monitor the deflection of the rudder **128** and to activate the appropriate active flow control actuators **134** when appropriate.

A control input sensor **214** may include any number and type of sensors that may be used to detect a control input from a pilot or autopilot to the flight control system of the aircraft. For example, the control input sensor **214** may include a sensor that detects a change in an engine thrust setting and/or a rudder pedal deflection. These control inputs are used by the actuator control system **132** to determine whether actuation of the airflow over the vertical control surface **130** is appropriate given the input itself, as well as in combination with date from one or more pressure sensors **210** and or flight parameter sensor **216**. A flight parameter sensor **216** may be any sensor that provides applicable current environmental and/or flight data to the actuator control system **132**. For example, aircraft speed, altitude, attitude, sideslip data, climb or descent rates, and ambient pressure may all be factors utilized by the actuator control system **132** in determining whether to activate any active flow control actuators **134**.

Turning now to FIG. **3**, an alternative embodiment is shown in which an enhanced flow control tail **300** has the active flow control actuators **134** mounted within the rudder **128** rather than within the vertical stabilizer **126**. In doing so, the actuating flow from the active flow control actuators **134** interacts with the ambient flow on the rudder itself, proximate to the leading edge **222** of the rudder. Because flow separation commonly occurs on the rudder aft of the leading edge **222**, placement of the active flow control actuators **134** within the rudder **128** may be advantageous. However, depending on the particular implementation, structural limitations within the rudder **126** may influence the positioning of the active flow control actuators **134** within the vertical stabilizer **126** so that the actuating flow from the actuators interacts with the ambient flow close to the trailing edge **220** of the stabilizer to maximize the effect on the flow separation over the rudder **128**.

A further embodiment is shown in FIG. **4**, with an enhanced flow control tail **400** that includes two groupings of linearly aligned active flow control actuators **134**. The first is mounted within the vertical stabilizer **126** near the leading edge **218**. The second is mounted within the vertical stabilizer **126** near the trailing edge **220**. Yet another embodiment is shown in FIG. **5**, with an enhanced flow control tail **500** that again includes two groupings of linearly aligned active flow control actuators **134**. However, according to this embodiment, the first grouping of active flow control actuators **134** is mounted within the vertical stabilizer **126** near the leading edge **218**, while the second grouping of active flow control actuators **134** is mounted within the rudder **128** near the leading edge **222**. It should be appreciated that alternative embodiments could include third or fourth groupings of active flow control actuators **134** positioned at the trailing edge **220** of the vertical stabilizer **126** and/or at the trailing edge **224** of the rudder **128**.

By having multiple groupings of active flow control actuators **134**, additional control over the ambient airflow may be maintained. For example, by actuating the airflow near the trailing edge **220** of the vertical stabilizer **126**, the airflow at the leading edge **218** of the vertical stabilizer **126** may be disrupted in a manner that would benefit from flow actuation at the leading edge **218**. From the description of the enhanced flow control tails **200**, **300**, and **400**, it should be clear that the disclosure herein contemplates any number, placement, and zone configurations of active flow control actuators **134**.

Referring now to FIG. **6**, the active flow control system **130** will be described in greater detail. As discussed above, the active flow control system **130** includes an actuator control system **132** and a number of active flow control actuators **134**. The actuator control system **132** includes an event detection system **602** for collection of data corresponding to flow control events, a detection system controller **604** for interpretation of the data from the sensors of the event detection system **602** to determine that a flow control event has occurred, and an active flow control actuator (AFCA) controller **606** for identifying the active flow control actuators **134** for activation in response to the determination that the flow control event occurred, and to activate the appropriate active flow control actuators **134**.

As described above, the event detection system **602** may include any number and type of sensors, including but not limited to the pressure sensors **210**, the rudder deflection sensor **212**, the control input sensors **214**, and the flight parameter sensors **216**. The event detection system **602** transmits the sensor data to the detection system controller **604**, which makes a determination as to whether a flow control event has occurred. This determination and all appropriate data, such as the type of event, the location of the event, and the severity of the event, is forwarded to the AFCA controller **606**. The AFCA controller **606** utilizes this flow control event data to select the appropriate active flow control actuators **134**, either all of the available active flow control actuators **134** or a subset of active flow control actuators **134** with a determined zone, and to activate those actuators. It should be appreciated that the detection system controller **604** and the AFCA controller **606** may be separate controllers or may be a single controller operative to perform the functionality of both controllers. Each controller may be computer hardware and/or software programmed to perform the operations described herein.

Turning to FIG. **7**, an illustrative routine **600** for providing actuating airflow over a vertical control surface **122** will now be described in detail. It should be appreciated that more or fewer operations may be performed than shown in FIG. **7** and described herein. Moreover, these operations may also be performed in a different order than those described herein. The routine **600** begins at operation **702**, where a flow control event is detected. The flow control event may be a flow separation indicator or any other data collected from one or more sensors of the event detection system **602**. This determination that a flow control event has occurred may be made by the detection system controller **604** or the AFCA controller **606**.

From operation **702**, the routine **600** continues to operation **704**, where the AFCA controller **606** determines according to the flow control event data which active flow control actuators **134** or zone of active flow control actuators **134** are to be activated to control the airflow over the vertical control surface **122**. The routine **600** continues to operation **706**, where the AFCA controller **606** determines the power input levels for activating the selected active flow control actuators **134**. As described above, according to various embodiments, the active flow control actuators **134** may be operated at less than full power to conserve aircraft power. This determination may depend on the magnitude of the flow control event, the location of the event, and the number and positioning of the available active flow control actuators **134**.

At operation **708**, the AFCA controller **606** activates the selected active flow control actuators **134** according to the determined zones and power levels. From operation **708**, the routine **600** continues to operation **710**, where a determination is made as to whether the flow control event has completed. If the event is no longer applicable, such as when the conditions causing flow separation have concluded, then the routine **600** ends. However, if at operation **710**, a determination is made that the flow control event has not concluded, then the routine **600** returns to operation **704** and continues as described above.

It should be clear from the disclosure above that the technologies described herein provide for enhanced control of airflow over a vertical control surface **122** of an aircraft. Upon encountering situations in which the forces required to be produced by the aircraft vertical control surface **122** in order to maintain control of the aircraft at the outer boundaries of the designed flight envelope cannot be produced without flow actuation, the appropriate flow actuation techniques described above are employed. In using these techniques, the size of the vertical control surface **122** of an aircraft can be significantly reduced as compared to the vertical control surface **102** of a conventional aircraft.

The subject matter described above is provided by way of illustration only and should not be construed as limiting. Various modifications and changes may be made to the subject matter described herein without following the example embodiments and applications illustrated and described, and without departing from the true spirit and scope of the present invention, which is set forth in the following claims.

What is claimed is:

1. An active flow control system for controlling an airflow over a vertical control surface of an aircraft, comprising:

the vertical control surface comprising a vertical stabilizer, a rudder, and a rudder hinge line between a trailing edge of the vertical stabilizer and a leading edge of the rudder;

a plurality of active flow control actuators positioned within the rudder proximate to and parallel with the rudder hinge line, and within the vertical stabilizer proximate to and parallel with a leading edge of the vertical stabilizer, each active flow control actuator comprising an air cavity fluidly engaging the vertical control surface and operative to provide an actuating airflow from the air cavity out of the vertical control surface into the airflow that alters a flow characteristic of the airflow over the vertical control surface when activated; and

an actuator control system communicatively linked to the plurality of active flow control actuators, the actuator control system operative to detect a flow control event, to dynamically define a subset of active flow control actuators corresponding to the flow control event, and to activate the subset of active flow control actuators to alter the flow characteristic of the airflow.

2. The system of claim **1**, wherein the at least one active flow control actuator comprises a synthetic jet actuator, a sweep jet actuator, a flipperon, or an active vortex generator.

3. The system of claim **1**, wherein the plurality of active flow control actuators are positioned within a plurality of zones of the vertical control surface, and wherein the actuator control system is further operative to define and activate the subset of active flow control actuators according to zone membership.

4. The system of claim **1**, wherein the plurality of active flow control actuators are sequentially vertically arranged from a root of the vertical control surface abutting an aircraft fuselage to a tip of the vertical control surface opposite the root.

5. The system of claim **1**, wherein the flow control event comprises a flow separation indicator.

6. The system of claim **1**, wherein the flow control event comprises a flow separation indicator, and wherein the actuator control system comprises at least one pressure sensor positioned on the vertical stabilizer or the rudder such that the at least one pressure sensor is operative to detect the flow separation indicator corresponding to the vertical stabilizer or rudder.

7. The system of claim **1**, wherein the actuator control system comprises at least one rudder deflection sensor operative to detect a rudder deflection angle, and wherein the flow control event comprises at least a threshold rudder deflection angle.

8. The system of claim **1**, wherein the flow control event comprises one or more control inputs to a flight control system of the aircraft.

9. The system of claim **1**, wherein a second plurality of active flow control actuators are positioned linearly on or within the vertical stabilizer adjacent to the leading edge of the rudder.

10. The system of claim **1**, wherein the plurality of active flow control actuators are positioned linearly on or within the rudder adjacent to the leading edge of the rudder.

11. The system of claim **1**, wherein the plurality of active flow control actuators comprises a first plurality of active flow control actuators and a second plurality of active flow control actuators, and wherein the first plurality of active flow control actuators are positioned linearly on or within the vertical stabilizer adjacent to the leading edge of the vertical stabilizer and the second plurality of active flow control actuators are positioned linearly adjacent to the leading edge of the rudder.

12. A method of controlling an airflow over a vertical control surface of an aircraft, the method comprising:

detecting a flow control event associated with the vertical control surface;

in response to detecting the flow control event, determining a subset of a plurality of active flow control actuators associated with the vertical control surface for activation, the plurality of active flow control actuators positioned within a rudder proximate to and parallel with a rudder hinge line, and within a vertical stabilizer proximate to and parallel with a leading edge of the vertical stabilizer;

determining a reduced power input according to a desired actuating airflow output that is less than a maximum actuating airflow output for one or more active flow control actuators of the subset;

providing the reduced power input to the one or more active flow control actuators; and

expelling an actuating airflow from within the vertical control surface from each active flow control actuator of the subset according to the reduced power input such that actuating airflow alters the airflow over the vertical control surface.

13. The method of claim **12**, wherein expelling the actuating airflow comprises expelling the actuating airflow from the subset of the plurality of active flow control actuators positioned within a plurality of zones of the vertical control surface, the subset of the plurality of active flow control actuators corresponding to a zone associated with the flow control event.

14. The method of claim **12**, wherein detecting the flow control event comprises detecting a rudder deflection angle greater than a predetermined threshold angle, detecting a pressure gradient associated with the airflow indicative of an impending or current flow separation, detecting a control input to a flight control system of the aircraft, or detecting a flow control flight parameter.

15. The method of claim **12**, wherein the vertical control surface comprises the vertical stabilizer and the rudder, wherein detecting the flow control event comprises detecting with a plurality of pressure sensors a pressure gradient associated with the airflow indicative of an impending or current flow separation, and wherein the subset comprises a second plurality of active flow control actuators positioned within the vertical stabilizer proximate to and parallel with a trailing edge of the vertical stabilizer adjacent to a leading edge of the rudder such that the actuating airflow is expelled by the second plurality of active flow control actuators into the airflow over the leading edge of the rudder.

16. An active flow control system for controlling an airflow over a vertical control surface of an aircraft, comprising:

the vertical control surface having a plurality of zones;

a plurality of active flow control actuators mounted within a rudder proximate to and parallel with a rudder hinge line, and within a vertical stabilizer proximate to and parallel with a leading edge of the vertical stabilizer according to the plurality of zones, each active flow control actuator comprising a piezoelectric disk operative to produce an actuating flow that alters a flow characteristic of the airflow over the vertical control surface when the piezoelectric disk is activated and the actuating flow is expelled from the active flow control actuator; and

an actuator control system communicatively linked to the plurality of active flow control actuators, the actuator control system comprising

a plurality of sensors operative to collect data associated with a flow control event, and

a controller operative to utilize the data to detect the flow control event, to identify a subset of the plurality of active flow control actuators corresponding to a zone for controlling the airflow in response to the flow control event, and to activate the subset of the plurality of active flow control actuators.

17. The system of claim **16**, wherein the plurality of sensors comprises a plurality of pressure sensors, wherein the controller being operative to utilize the data to detect the flow control event comprises the controller being operative to utilize pressure sensor data to detect a pressure gradient associated with the airflow indicative of an impending or current flow separation, and wherein the controller is further operative to identify a power input level associated with the subset of the plurality of active flow control actuators such that activating the subset of the plurality of active flow control actuators comprises providing the identified power input level to each of the active flow control actuators of the subset.

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