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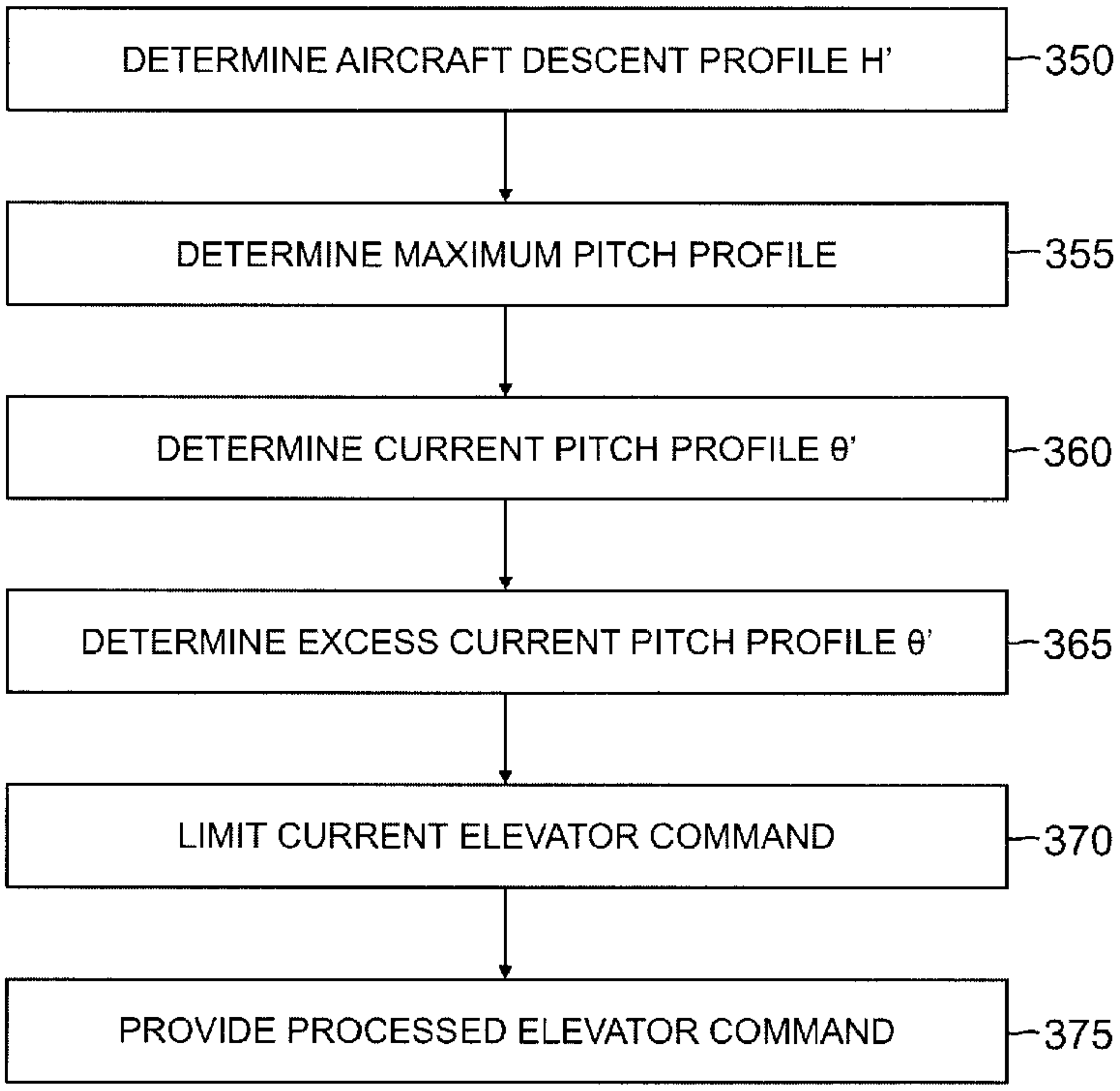

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Systems and methods according to one or more embodiments are provided for limiting elevator deflection commands to avoid the aft body of an aircraft from contacting the ground during a landing maneuver. In one example, a system includes a memory

(57) Abrégé(suite)/Abstract(continued):
configured to store a plurality of executable instructions and a processor. The processor is configured to determine a descent profile and a current pitch profile. A pre-determined maximum pitch profile associated with the descent profile is used to compare to the current pitch profile. The comparison is used to compute an elevator deflection value that limits an elevator command signal in order to avoid a tail strike. Additional systems and methods are also provided.

ABSTRACT

Systems and methods according to one or more embodiments are provided for limiting elevator deflection commands to avoid the aft body of an aircraft from contacting the ground during a landing maneuver. In one example, a system includes a memory configured to store a plurality of executable instructions and a processor. The processor is configured to determine a descent profile and a current pitch profile. A pre-determined maximum pitch profile associated with the descent profile is used to compare to the current pitch profile. The comparison is used to compute an elevator deflection value that limits an elevator command signal in order to avoid a tail strike. Additional systems and methods are also provided.

SYSTEMS AND METHODS TO PREVENT AN AIRCRAFT FROM TAIL CONTACT WITH THE GROUND

TECHNICAL FIELD

The present disclosure relates generally to aircraft flight control, and more particularly, for example, to avoiding aircraft tail contact with the ground.

BACKGROUND

In the field of aircraft control, there is an ongoing effort to improve methods for tail strike avoidance. A tail strike is an event where the aft body of an airplane contacts the runway during takeoff, landing, or go-around. Tail strikes levy an economic cost on airlines because when they occur, aircraft must be pulled from service to be inspected and if necessary repaired. Tail strikes are rare and can typically be avoided through proper operation of the aircraft. When proper operation is not maintained, is not possible, or environmental factors dictate, a control law can provide protection for the aft body.

SUMMARY

Systems and methods are disclosed herein in accordance with one or more embodiments that provide an improved approach to avoiding aircraft tail strikes during landing maneuvers. In some embodiments, a maximum pitch profile may be determined to limit an elevator deflection command to avoid a tail strike. In one example, an aircraft geometry is used to determine a predefined maximum pitch profile. The maximum pitch profile is compared to a current pitch profile to determine an excess current pitch profile. The excess current pitch profile is converted to an incremental elevator deflection value by multiplication with a proportional gain term. A lagged current elevator deflection value is summed with the incremental elevator deflection value to produce a nose-up elevator deflection limit.

In one embodiment, a method includes determining an aircraft descent profile based on a current altitude and a current vertical speed of an aircraft; determining a maximum pitch profile associated with the descent profile; determining a current pitch profile based on a current pitch attitude and a current pitch rate of the aircraft; comparing the current pitch profile with the maximum pitch profile to determine an excess current pitch profile; and limiting an elevator command signal based on the comparison to reduce a probability of an aircraft tail strike.

In another embodiment, a system includes a memory comprising a plurality of executable instructions; and a processor adapted to execute the instructions to: determine a descent profile based on a current altitude and a current vertical speed of an aircraft; determine a maximum pitch profile associated with the descent profile; determine a current pitch profile based on a current pitch attitude and a current pitch rate of the aircraft; compare the current pitch profile with the maximum pitch profile to determine an excess current pitch profile; and limit an elevator command signal based on the comparison.

In one embodiment, there is provided a method comprising determining a descent profile based on a current altitude and a current vertical speed of an aircraft; determining a maximum pitch profile associated with the descent profile; determining a current pitch profile based on a current pitch attitude and a current pitch rate of the aircraft; comparing the current pitch profile with the maximum pitch profile to determine an excess current pitch profile; and limiting an elevator command signal based on the comparison to reduce a probability of an aircraft tail strike.

The current altitude may be based on a distance from an aircraft landing gear to a runway surface as determined, at least in part, by a sensor measurement signal.

Determining the maximum pitch profile may include accessing a table of maximum pitch profiles, wherein each maximum pitch profile is based on a corresponding one of the descent profile, and the maximum pitch profile may be determined, at least in part, on the descent profile and an aircraft geometry.

The method may further involve reducing the maximum pitch profile when a speed brake is extended.

The current vertical speed may be determined by a vertical speed sensor measurement signal; the current pitch rate may be determined by a pitch rate sensor measurement signal; and the current pitch attitude may be determined by a pitch attitude sensor measurement signal.

Comparing may involve converting the excess current pitch profile to an elevator deflection limit command.

The method may further involve applying a lag filter to an output elevator deflection signal to provide a reference elevator deflection command signal.

The method may further involve combining an elevator deflection limit command value and the reference elevator deflection command signal to produce an elevator deflection limiter value; and limiting the elevator command signal to generate an elevator deflection value of no less than the elevator deflection limiter value.

Limiting may involve responding to the elevator command signal to generate an output elevator deflection signal when the elevator deflection limiter value is not exceeded.

Determining may involve periodically updating the descent profile and the current pitch profile to use in limiting the elevator command signal.

In another embodiment, there is provided a system comprising a memory comprising a plurality of executable instructions; and a processor adapted to execute the instructions to determine a descent profile based on a current altitude and a current vertical speed of an aircraft; determine a maximum pitch profile associated with the descent profile; determine a current pitch profile based on a current pitch attitude and a current pitch rate of the aircraft; compare the current pitch profile with the maximum pitch profile to determine an excess current pitch profile; and limit an elevator command signal based on the comparison.

The current altitude may be based on a distance from an aircraft landing gear to a runway surface as determined, at least in part, by a sensor measurement signal.

The maximum pitch profile may be determined, at least in part, on the descent profile and an aircraft geometry.

The system may further include an aircraft speed brake, wherein the maximum pitch profile is adjusted when the speed brake is extended.

The processor may be configured to periodically update the current pitch profile and the descent profile; and the periodic updates may be used to limit the elevator command signal.

The processor may be configured to convert the excess current pitch profile to degrees of elevator deflection value.

The system may further include a lag filter that provides a reference elevator deflection command signal.

The processor may be configured to combine an elevator deflection limit command value and a reference elevator deflection command signal to produce an elevator deflection limiter value; and limit the elevator command signal to generate an elevator deflection value of no less than the elevator deflection limiter value.

The processor may be configured to respond to the elevator command signal to generate an elevator deflection value when the elevator deflection limiter value is not exceeded.

The system may be an aircraft further comprising a pitch attitude sensor configured to provide a pitch attitude measurement signal to the processor; a pitch rate sensor configured to provide a pitch rate measurement signal to the processor; a vertical speed sensor configured to provide a vertical speed measurement signal to the processor; and/or a radio altimeter configured to provide an altitude measurement signal to the processor.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. **1** illustrates a diagram of an aircraft in a landing maneuver in accordance with an embodiment of the disclosure.

Fig. **2** illustrates a block diagram of an aircraft flight control system in accordance with an embodiment of the disclosure.

Figs. **3**A and **3**B illustrate processes to selectively limit elevator deflection to avoid tail strikes by an aircraft in accordance with embodiments of the disclosure.

Fig. **4** illustrates a boundary graph of maximum pitch profiles in accordance with an embodiment of the disclosure.

Figs. **5**A through **5**C illustrate time sequence plots of an aircraft landing maneuver in accordance with embodiments of the disclosure.

Embodiments and their advantages may be best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

Techniques are provided to avoid a tail strike during an aircraft landing maneuver by determining a maximum allowable degrees of elevator deflection to prevent the aft body of the aircraft from contacting the ground. The elevator is a primary control surface of an aircraft, providing longitudinal control. The elevator is flap-like and is deflected up and down. The main objective of elevator deflection is to increase or decrease tailplane lift and tailplane pitching moment. A negative elevator deflection generates a positive pitching motion causing the aircraft tail to rotate downward. A positive elevator deflection generates a negative pitching motion causing the aircraft tail to rotate upward.

In various embodiments, a tail strike avoidance system determines a maximum allowable degrees of elevator deflection based on a descent profile and a current pitch profile. The descent profile may be calculated, for example, based on a current altitude and a current vertical speed. The current altitude (e.g., a current altitude from an aircraft landing gear to a runway surface) may be determined, at least in part, from a radio altimeter measurement signal and/or various other sensors capable of providing altitude measurement signals. The current vertical speed may be determined from a vertical speed sensor measurement signal. The current pitch profile may be calculated based on a pitch attitude and a pitch rate. Pitch attitude may be determined from a pitch attitude sensor measurement signal and pitch rate may be determined from a pitch rate sensor measurement signal.

Furthermore, the descent profile and the current pitch profile may be used to determine a maximum pitch profile and an excess pitch profile value. A predefined maximum pitch profile may be determined, for example, based on the descent profile. The maximum pitch profile may be compared to the current pitch profile to determine an excess pitch profile value. The excess pitch profile value is converted to a maximum allowable degrees of elevator deflection. The maximum allowable degrees of elevator deflection is used to limit an elevator command signal to prevent the aft body of the aircraft from contacting the ground.

In various embodiments, the processing techniques described herein may be used to allow an aircraft, such as a long bodied commercial aircraft, to use a lower landing approach speed than would otherwise be necessary to avoid tail strikes. A pilot may rely on increased landing speed to avoid a tail strike in conventional systems. Lower approach speeds can have a positive effect on a number of aircraft systems and performance metrics including landing field length, high lift, and noise.

Fig. **1** illustrates a diagram of an aircraft **100** in a landing maneuver in accordance with an embodiment of the disclosure. In some embodiments, aircraft **100** of Fig. **1** may be long bodied commercial aircraft. In other embodiments, aircraft **100** may be any aircraft, for example, using a runway surface **102** for a landing maneuver. As shown in Fig. **1**, aircraft **100** may be oriented above runway surface **102** in a flared position. In this regard, fuselage **104** may be oriented with a positive (e.g., +) pitch attitude **106** relative to a horizon **108**. Positive pitch attitude **106** may correspond to aircraft **100** nose-up, and aft body **142** in a downward rotation toward runway surface **102**. Furthermore, aircraft **100** may be rotating around a center of gravity **110** in a longitudinal pitching moment **112** at a pitch rate **114**. Pitch rate **114** is, at least in part, dependent on the magnitude of change of negative elevator deflection **120** and/or positive elevator deflection **122**.

In some embodiments, an aircraft pilot and/or co-pilot may exert a control column force to generate an elevator deflection command signal (e.g., such as elevator command signal **320** of Fig. **3**) to adjust an elevator **116**. In other embodiments, an autopilot may generate an elevator deflection command signal to adjust an elevator **116**. The elevator command signal may command elevator **116** to respond with a negative elevator deflection **120** generating a positive (e.g., nose up) pitching moment **112**. A negative elevator deflection **120** may cause aircraft **100** aft body **142** to rotate in a downward direction toward runway surface **102** and reduce tail height **143** clearance to runway surface **102**. Elevator command signal may command elevator **116** to respond with a positive elevator deflection **122** generating a negative (e.g., nose down) pitching moment **112**. A positive elevator deflection **122** may cause aircraft **100** aft body **142** to rotate in an upward direction away from runway surface **102** and increase tail height **143** clearance to runway surface **102**. Elevator **116** may be mechanically coupled to a horizontal stabilizer **118**. Horizontal stabilizer may be mechanically coupled to fuselage **104** at the aircraft **100** aft body **142**.

As shown in Fig. **1**, aircraft **100** may be descending toward runway **102** with nose landing gear **126** and main landing gear **128** fully extended. Radio altimeter **160** measurement signal provides a distance from a lower surface **105** in the forward part of aircraft **100** to runway surface **102**. Radio altimeter measurement signal may be used, in part, to compute a distance from main landing gear **128** to runway surface **102**. Distance from main landing gear **128** to runway surface **102** (e.g., gear height) may be determined, in part, using measurement signals from radio altimeter **160**. A conversion from radio altimeter **160** to landing gear **128** may be calculated to provide a gear height measurement (e.g., current altitude). A conversion from radio altimeter **160** measurement signal to main landing gear **128** may include, for example, a length determined by a distance from a lower surface **133** of extended main landing gear **128** to lower surface **105** of fuselage **104**. Furthermore, inertial motion data (e.g., a vertical speed **124**, and a pitch attitude **106**) may be combined with the length to determine a current altitude **129**. Vertical speed **124** may provide a rate of closure (e.g., a sink rate) to runway surface **102** during descent of aircraft **100**.

As shown in Fig. **1**, a negative flight path angle **134** may be determined as the angle of an airplane airspeed **136** from horizon **108** as aircraft **100** is descending. In some embodiments, airspeed **136** may be the indicated airspeed of aircraft **100** during descent toward runway **102**. Aileron **138** may be mechanically coupled to wing **132** to provide a change to roll of aircraft **100**. Vertical stabilizer **140** may be mechanically coupled to fuselage **104** to provide a yaw control of aircraft **100**.

Fig. **2** illustrates a block diagram of an aircraft flight control system **200** of aircraft **100** in accordance with an embodiment of the disclosure. Flight control system **200** may be used to receive sensor measurement signals from various sensors within flight control system **200** to determine aircraft pitch attitude **106**, pitch rate **114**, vertical speed **124**, and current altitude **129**, among other aircraft parameters. Flight control system **200** may be used to compute one or more descent and/or pitch profile values and determine a limit for an elevator deflection based on pitch and descent profiles in accordance with various techniques described herein. In one embodiment, various components of flight control system **200** may be distributed within aircraft **100**. In one embodiment, flight control system **200** includes a processor **210**, a pilot controls **220**, a memory **230**, a display **240**, a pitch attitude sensor **250**, a pitch rate sensor **255**, a radio altimeter **160**, a vertical speed sensor **270**, a vertical acceleration sensor **280**, and other components **290**.

Processor **210** may include, for example, a microprocessor, a single-core processor, a multi-core processor, a microcontroller, a logic device (e.g., a programmable logic device configured to perform processing operations), a digital signal processing (DSP) device, one or more memories for storing executable instructions (e.g., software, firmware, or other instructions), and/or any other appropriate combinations of processing device and/or memory to execute instructions to perform any of the various operations described herein. Processor **210** is adapted to interface and communicate with components **160**, **220**, **230**, **240**, **250**, **255**, **270**, and **280** to perform method and processing steps as described herein.

In various embodiments, it should be appreciated that processing operations and/or instructions may be integrated in software and/or hardware as part of processor **210**, or code (e.g., software or configuration data) which may be stored in memory **230**. Embodiments of processing operations and/or instructions disclosed herein may be stored by a machine readable medium **213** in a non-transitory manner (e.g., a memory, a hard drive, a compact disk, a digital video disk, or a flash memory) to be executed by a computer (e.g., logic or processor-based system) to perform various methods disclosed herein.

In various embodiments, the machine readable medium **213** may be included as part of flight control system **200** and/or separate from flight control system **200**, with stored instructions provided to flight control system **200** by coupling the machine readable medium **213** to flight control system **200** and/or by flight control system **200** downloading (e.g., via a wired or wireless link) the instructions from the machine readable medium (e.g., containing the non-transitory information).

Memory **230** includes, in one embodiment, one or more memory devices (e.g., one or more memories) to store data and information. The one or more memory devices may include various types of memory including volatile and non-volatile memory devices, such as RAM (Random Access Memory), ROM (Read-Only Memory), EEPROM (Electrically-Erasable Read-Only Memory), flash memory, or other types of memory. In one embodiment, processor **210** is adapted to execute software stored in memory **230** and/or machine-readable medium **213** to perform various methods, processes, and operations in a manner as described herein.

Flight control system **200** includes, in one embodiment, one or more sensors for providing flight control data signals to processor **210**. In one embodiment, sensors include a pitch attitude sensor **250**, a pitch rate sensor **255**, a vertical speed sensor **270**, a vertical acceleration sensor **280**, and a radio altimeter **160**. Sensors of flight control system **200** provide for sensing inertial motion (e.g., inertial motion measurement signals from sensors **250**, **255**, **270**, and/or **280**) and altitude (e.g., altitude measurement signals from radio altimeter **160**) of aircraft **100**. In some embodiments, sensors **250**, **255**, **270**, **280**, and/or **160** may be implemented as discrete hardware devices. Sensors may provide sensor measurement signals (e.g., sensor data) for computing descent and pitch profile values, for example, current altitude **129**, vertical speed **124**, current pitch attitude **106**, and current pitch rate **114**.

Processor **210** may be adapted to receive sensor data from sensors, process sensor data, store sensor data in memory **230**, and/or retrieve stored sensor data from memory **230**. In various aspects, sensors may be remotely positioned and processor **210** may be adapted to remotely receive sensor measurement signals from sensors via wired or wireless communication buses within aircraft **100**. Processor **210** may be adapted to process sensor data stored in memory **230** to provide sensor data to display **240** for viewing by a user.

Display **240** includes, in one embodiment, a display device (e.g., a liquid crystal display (LCD)) or various other types of generally known video displays, monitors, and/or gauges for use with aircraft flight control system **200**. Processor **210** may be adapted to display sensor data and information on display **240**. Processor **210** may be adapted to retrieve sensor data and information from memory **230** and display any retrieved sensor data and information on display **240**. Display **240** may include display electronics, which may be utilized by processor **210** to display sensor data and information. Display **240** may receive sensor data and information directly from one or more sensors (e.g., sensors **250**, **255**, **160**, **270**, and/or **280**) via processor **210**, or the sensor data and information may be transferred from memory **230** via processor **210**.

Pilot controls **220** include, in one embodiment, a user input and/or interface device having one or more user actuated components, such as a stick, a yoke, and/or other control devices that are adapted to generate one or more user actuated input control signals. In another embodiment, pilot controls **220** include an autopilot system providing the same or similar control signals. Processor **210** may be adapted to sense control input signals from pilot controls **220** and respond to any sensed control input signals received therefrom. For example, in some embodiments, pilot controls **220** may provide control input signals via a control device to adjust primary flight control surfaces. In various embodiments, it should be appreciated that pilot controls **220** may be adapted to include one or more other user-activated mechanisms to provide various other control operations of flight control system **200**, such as navigation, communication, pitch control, roll control, yaw control, thrust control, and/or various other features and/or parameters.

Other types of pilot controls **220** may be contemplated, such as, a graphical user interface (GUI), which may be integrated as part of display **240** (e.g., a user actuated touch screen), having one or more images of the user-activated mechanisms (e.g., buttons, knobs, sliders, or others), which are adapted to interface with a user and receive user input control signals via the display **240**. As an example for one or more embodiments as discussed further herein, display **240** and pilot controls **220** may represent appropriate portions of a tablet, a laptop computer, a desktop computer, or other type of device. Furthermore, pilot controls **220** may be adapted to be integrated as part of display **240** to operate as both a user input device and a display device, such as, for example, a touch screen device adapted to receive input signals from a user touching different parts of the display screen.

Flight control surface actuators **285** include, in one embodiment, actuators to control aircraft **100** primary flight control surfaces. Primary flight control surfaces may include elevator **116**. In some embodiments, a pilot and/or co-pilot may adjust a longitudinal pitch attitude **106** of aircraft **100** by applying a control column force or position to adjust elevator **116** of horizontal stabilizer **118**. Control column force may generate an elevator command signal (e.g., such as elevator command signal **320** of Fig. **3**) to adjust an elevator deflection (e.g., elevator deflection **120** and/or **122**). In other embodiments, an autopilot system (e.g., provided as part of pilot controls **220**) may generate an elevator command signal to adjust an elevator deflection **120** and/or **122**. Processor **210** may receive elevator command signal **320** and provide a corresponding elevator deflection signal (e.g., such as elevator deflection signal **326** of Fig. **3**B provided to an elevator actuator) to adjust elevator **116** of horizontal stabilizer **118**.

Other primary flight control surfaces may be located on wing **132** and vertical stabilizer **140**. Processor **210** may receive a command from pilot controls **220** to adjust an aileron **138** coupled to wing **132** to provide a change to roll of aircraft **100**. Processor **210** may receive a command from pilot controls **220** to adjust vertical stabilizer **140** (e.g., by adjustment of a movable rudder as part of vertical stabilizer **140**) to provide a yaw control of aircraft **100**.

In another embodiment, flight control system **200** may include other components **290**, including environmental and/or operational sensors, depending on the sensed application or implementation, which provide information to processor **210** (e.g., by receiving sensor measurement signals from each of other components **290**). In one embodiment, other components **290** may include a discrete switch (e.g., such as switch **322** of Fig. **3**B). Discrete switch **322** may be controlled by processor **210** to couple and/or uncouple elevator command signal **320** to limiter **319** to activate tail strike avoidance. In various embodiments, other components **290** may be adapted to provide signal data and information related to operating and/or environmental conditions, such as internal and/or external temperature conditions, lighting conditions (e.g., beacons mounted on wing **132** and/or fuselage **104**) and/or distance (e.g., laser rangefinder). Accordingly, other components **290** may include one or more conventional sensors as would be known by those skilled in the art for monitoring various conditions (e.g., environmental and/or operational conditions) on aircraft **100**.

Figs. **3**A and **3**B illustrate processes to selectively limit elevator deflection to avoid tail strikes by an aircraft **100** in accordance with embodiments of the disclosure. In various embodiments, the processes of Figs. **3**A and **3**B may be performed, for example, by processor **210** of aircraft **100**. In particular, Fig. **3**A illustrates an overall process flow, and Fig. **3**B provides further details of the various operations. Accordingly, Fig. **3**A and Fig. **3**B will be described in relation to each other. During the processes of Figs. **3**A and **3**B, various data values may be determined from one or more sensors and/or calculated as further discussed herein.

In block **350** of Fig. **3**A, a descent profile H’ **302** may be computed to determine the position of landing gear **128** in the immediate future relative to runway **102**. The descent profile H’ **302** may be determined by combining a current altitude of main landing gear **128** and a current vertical speed of landing gear **128**. Current altitude **129** may be calculated by combining radio altimeter **160** measurement signal with inertial motion data (e.g., inertial motion data as provided, for example, by pitch attitude sensor **250**, pitch rate sensor **255**, vertical speed sensor **270** and/or vertical acceleration sensor **280**), as described herein. Current vertical speed **124** may be provided to processor **210** by vertical speed sensor **270** measurement signal. Vertical speed **124** may be multiplied by a gain term in the computation of descent profile H’ **302**.

In block **355**, a predetermined maximum pitch profile **304** may be determined from a θ’ vs H’ look up table **303**, using the determined descent profile H’ **302** of block **350**. θ’ vs H’ look up table **303** provides a relationship between maximum pitch profile **304** and descent profile H’ **302**. In this regard, as landing gear **128** approaches runway surface **102**, as indicated by the decreasing value of the descent profile H’ **302**, maximum pitch profile **304** decreases allowing for less positive pitch profile value θ’ **306** of aircraft **100**. The θ’ vs H’ look up table **303** may include a plurality of calculated maximum pitch profiles **304**, where each maximum pitch profile **304** is based on a corresponding one of a plurality of descent profiles H’ **302**. Furthermore, maximum pitch profile **304** may be dependent on aircraft **100** geometry, as described herein.

Referring to Fig. 3B, in some embodiments, maximum pitch profile **304** may be reduced when a wing mounted speed brake **305** is extended. Wing mounted speed brake **305** may be actuated by a speed brake command from processor **210** to produce a positive (e.g., nose-up) pitching moment **112**. Therefore, a reduction of maximum pitch profile **304** may offset the additional nose-up pitching moment **112** caused by actuation of speed brake **305**.

In block **360**, processor **210** may compute a current pitch profile θ’ **306** to determine a pitch trend of aircraft **100**. Current pitch profile θ’ **306** may be calculated by combining a current pitch attitude **106** and a current pitch rate **114**, where pitch rate **114** may be multiplied by a gain term in the computation of current pitch profile θ’ **306**. In this regard, an indication of aircraft **100** pitch attitude in the immediate future may be provided to aid in determining if a tail strike is possible. Current pitch attitude **106** may be provided to processor **210** by a measurement signal produced by pitch attitude sensor **250**. Current pitch rate **114** may be provided to processor **210** by a measurement signal produced by pitch rate sensor **255**.

In block **365**, processor **210** may compare current pitch profile θ’ **306** to maximum pitch profile **304** to determine an excess current pitch profile θ’ **308**. If there is excess current pitch profile θ’ **308** (e.g., current pitch profile θ’ **306** is greater than maximum pitch profile **304**), elevator deflection may be limited based on maximum pitch profile **304** to avoid a tail strike. Furthermore, excess current pitch profile θ’ **308** may be multiplied by a proportional gain term **310** and the product may be converted to a degrees of elevator deflection **309**.

In some embodiments, excess current pitch profile value θ’ **308** may be integrated and summed with the proportional gain term **310**. In this regard, excess current pitch profile θ’ **308** may be converted into a rate of elevator change by an integral gain. The rate of elevator change is integrated to produce an elevator position output (e.g., degrees of elevator deflection). Elevator position output may be summed with proportional gain term **310** to produce degrees of elevator deflection **309**.

In some embodiments, degrees of elevator deflection **309** may be verified to be within a range of elevator full authority **311** (labeled Limiter -**30** to **25**) for aircraft **100**. Elevator full authority **311** provides the full range of elevator deflection for aircraft **100**. For example, in some embodiments, aircraft **100** elevator full authority **311** may include values of elevator deflection inclusive of negative thirty degrees to positive twenty-five degrees. Elevator full authority **311** may be dependent on aircraft **100** geometry and other aircraft elevator full authority **311** may be identical to, less than, or greater than aircraft **100** elevator full authority. Output of elevator full authority **311** is an elevator deflection limit command **312**.

In some embodiments, elevator deflection limit command **312** may be summed with an output of a lag filter **314** (e.g., a reference elevator command signal **315**) to produce an elevator deflection limiter value **318** which is provided to a limiter block **319** (labeled Limiter). In this regard, elevator deflection limit command **312** may increment and/or decrement reference elevator command signal **315** to produce elevator deflection limiter value **318**. Lag filter **314** may provide a feedback of an output elevator deflection signal **326** to produce reference elevator command signal **315** in degrees of elevator deflection. Lag filter **314** effectively outputs a low frequency elevator deflection signal to control aircraft **100** during a landing maneuver.

Referring to Fig. 3B, current pitch profile θ' **306** is compared to maximum pitch profile **304** to provide an output excess current pitch profile θ' **308**. Excess current pitch profile θ' **308** is multiplied by proportional gain term **310** to provide degrees of elevator deflection **309**. In some embodiments, degrees of elevator deflection **309** may be compared to elevator full authority **311** (labeled Limiter -**30** to **25**) to verify elevator deflection value **309** is within the range of elevator deflection of elevator **116** on aircraft **100**. Output of elevator full authority **311** is elevator deflection limit command **312**. Elevator deflection limit command **312** is summed with lag filter **314** to produce the elevator deflection limiter value **318**. Elevator deflection limiter value **318** may be provided to limiter **319** to limit current elevator command signal **320**.

In block **370**, limiter **319** may limit current elevator command signal **320**. In this regard, limiter **319** may impose a lower limit on the elevator command signal values **320** and elevator command signal values **320** greater than elevator deflection limiter value **318** are provided to the output of the limiter **319**.

In block **375**, processor **210** may provide a limited output elevator deflection signal **326** to elevator **116**. Referring to Fig. 3B, lower elevator deflection limiter value **318** may be electrically coupled to limiter **319** to limit elevator command signal **320** through limiter **319**. A switch **322** may be coupled to limiter **319** at switch input **325**.

Again referring to Fig. 3B, switch **322** may be used to turn on tail strike avoidance during aircraft **100** landing maneuvers and switch off tail strike avoidance during other flight conditions of aircraft **100** such as normal flight cruising maneuvers. In one embodiment, switch **322** is implemented in software code and data in processor **210** to turn on and turn off tail strike avoidance elevator command limiting. In another embodiment, switch **322** is implemented as a physical discrete switch (e.g., as provided by other components **290**). In this regard, switch **322** may toggle between receiving elevator command signal **320** output directly and elevator command signal **320** limited by elevator deflection limiter value **318** at limiter **319**. Switch **322** may be electrically coupled to elevator command signal **320** at a switch input **323**. Switch **322** may be electrically coupled to the output of the limiter block **319** at a switch input **325**. Furthermore, a switch wiper **327** may be coupled to output elevator deflection signal **326** at a switch wiper **327** first end **327**a. Processor **210** may produce an electrical signal at switch command input **328** to toggle switch wiper **327** between switch input **325** and switch input **323** at a switch wiper **327** second end **327**b.

In some embodiments, processor **210** may be configured to periodically update descent profile H' **302** and current pitch profile θ' **306**. Furthermore, updated profile values H’ **302** and θ’ **306** may be used to calculate an updated elevator deflection limiter value **318**, as described herein.

Thus, in accordance with various embodiments, elevator command signals **320** may be selectively limited (e.g. by the operation of limiter **319**) based on the output of lag filter **314** and various criteria (e.g., descent profile H’ **302**, current pitch profile θ’ **306**, maximum pitch profile **304**, degrees of elevator deflection **309**, elevator deflection limit command **312** and/or other criteria). In other embodiments, other flight control commands may be selectively limited in the same or similar manner.

Fig. **4** illustrates a boundary graph **400** of maximum pitch profiles **304** in accordance with an embodiment of the disclosure. Boundary graph **400** provides a plot of the relationship between maximum pitch profile **304** and descent profile H’ **302**. Boundary graph **400** may provide a plot of the maximum pitch profile **304** under current profile conditions to avoid a tail strike. In this regard, a sloped line **430** represents the maximum pitch profile **304** based on a determined descent profile H’ **302**. In Fig. **4**, the area above sloped line **430** (e.g., area **440**) are pitch profiles where current pitch profile θ’ **306** exceeds maximum pitch profile **304**. In this regard, current pitch profiles θ’ **306** in the area of **440** may produce elevator deflection limiter values **318** to generate positive elevator deflection **122** to avoid a tail strike. Conversely, the area below sloped line **430** (e.g., area **450**) are pitch profiles **304** where additional current pitch profile θ’ **306** may be allowed up to the maximum pitch profile **304** of sloped line **430** while avoiding a tail strike. As shown in Fig. **4**, as height of landing gear **128** (e.g., height of landing gear **128** as part of descent profile H’ **302**) from runway surface **102** increases, allowable maximum pitch profile (e.g., maximum pitch profile **304** as part of sloped line **403**) increases.

In various embodiments, maximum pitch profiles **304** are dependent on descent profile H’ **302** and aircraft **100** geometry. Aircraft **100** geometry includes a landing gear compression value and is aircraft dependent. In this regard, each type of aircraft may include a unique θ’ vs H’ look up table **303**.

Figs. **5**A through **5**C illustrate time sequence plots of an abusive aircraft **100** landing maneuver in accordance with embodiments of the disclosure. Figs. **5**A through **5**C illustrate plots of parameters associated with tail strike avoidance system **300** during an aircraft **100** landing maneuver. Time sequence plots of Figs. **5**A through **5**C include pitch attitude **106**, current pitch profile θ' **306**, maximum pitch profile **304**, pilot and/or autopilot elevator command signal **320**, and elevator deflection limiter value **318** plotted during sequential periods of the landing maneuver. Time on the x-axis of Figs. **5**A through **5**C is divided into periods **505**, **510**, **515**, **520**, **525**, and **530**. **5**A illustrates a time sequence plot showing pitch attitude **106**, current pitch profiles θ' **306**, and maximum pitch profiles **304** in degrees. Fig. **5**A illustrates aircraft **100** aft body **142** clearance to runway surface **102** in feet. Fig. **5**B illustrates the time sequence of Fig. **5**A showing a plot of column force **512**, in pounds, when pilot asserts an elevator deflection. Fig. **5**C illustrates the time sequence of Fig. **5**A showing a plot of elevator command signal **320**, elevator deflection limiter value **318**, and output elevator deflection signal **326** in degrees of elevator deflection.

Period **505** may correspond to aircraft **100** approaching runway **102**. As shown in Fig. **5**A, degrees of pitch attitude **106** and current pitch profile θ' **306** may be approximately equal indicating no pitch rate **114**. Column force **512** of Fig. **5**B is also approximately zero, indicating the pilot is not attempting to pitch aircraft **100**. Fig. **5**C shows output elevator deflection signal **326** is equal to elevator command **320** indicating limiter **319** is not limiting elevator command **320**. Elevator deflection limiter value **318** is substantially below zero indicating the current pitch profile θ' **306** is substantially less than the maximum pitch profile **304**.

Period **510** may correspond to aircraft **100** on a descent toward runway **102**. As shown in Fig. **5**A, degrees of current pitch profile θ' **306** and pitch attitude are both increasing indicating a nose-up attitude of aircraft **100**. Furthermore, column force **512** is increasing indicating pilot is pitching aircraft **100**. Aft body **142** is on a steep downward slope toward runway surface **102**. As aft body **142** approaches runway surface **102**, maximum pitch profile **304** is decreasing indicating aft body **142** clearance to runway surface **102** is decreasing. Elevator deflection limiter value **318** of Fig. **5**C is moving in a positive response to aft body **142** reduction in clearance to runway surface **102**. At a point **535** in period **510** of Fig. **5**C, elevator deflection limiter value **318**, elevator command signal **320**, and elevator deflection signal **326** intersect. Time **535** corresponds to an aft body **142** height near runway surface **102**. Thereafter, elevator deflection signal **326** is limited by limiter **319** as shown in Fig. **5**C. Pilot may be commanding additional negative elevator deflection **120** as shown in Fig. **5**C. In response to column force **512**, elevator command signal **320** may be commanding additional degrees negative elevator deflection as indicated by Fig. **5**C. However, limiter **319** is limiting elevator command signal **320** to a negative elevator deflection value **326** greater than elevator command signal **320**.

Period **515** corresponds to aft body **142** continuing to approach runway surface **102**. As shown in Fig. **5**A, aft body **142** approaches to nearly zero feet from runway surface **102** as indicated by time **545**. Maximum pitch profile **304** continues to decrease during a time prior to aft body approaching runway surface **102**. Thereafter, maximum pitch profile **304** remains constant. Current pitch profile θ' **306** and pitch attitude **106** both show an overshoot beyond maximum pitch profile **304**. Column force is decreasing during period **515** as pilot may be provided information on display **240** that aft body **142** is approaching runway surface **102**. However, elevator deflection limiter value **318** is commanding elevator **116** to respond with a nose down pitching moment **112** and elevator deflection signal **326** is responding to limiter **319** with positive elevator deflection.

Period **520** may correspond to aircraft **100** decelerating down runway surface **102**. In this regard, aft body **142** clearance to runway surface **102** is moving away from runway surface **102**. Pitch attitude **106** is approximately equal to maximum pitch profile **304** during this period indicating pitch attitude **106** is limited by maximum pitch profile **304** when conditions have stabilized. Elevator deflection limiter value **318** value of nose down command is decreasing during the period and elevator deflection signal **326** is responding to limiter **319**. Elevator command signal **320** is being limited during this period. In this regard, time **555** indicates a strong column force corresponding to pilot commanding a significant change in elevator deflection. Elevator command signal **320** responds with a significant nose-up position. However, as indicated by Fig. **5**C, elevator command signal **320** at time **555** is being limited by limiter **319** as elevator deflection signal **326** does not respond to the pilot input and continues to track to elevator deflection limiter value **318**. Furthermore, time **565** indicates elevator deflection signal **326** may respond to elevator command signal **320** as degrees of elevator command signal **320** is greater than elevator deflection limiter value **318**.

Period **525** may correspond to aircraft **100** de-rotating to runway surface **102**. In this regard, aft body **142** is rotating up from runway surface **102** to the aft body **142** normal height. Pitch attitude **106** and current pitch profile θ' **306** are decreasing indicating a negative pitch rate (e.g, a nose down). Fig. **5**C indicates once again that the current pitch profile θ' **306** is less than the maximum pitch profile **304** as elevator deflection signal **326** is responding to elevator command signal **320** and elevator deflection limiter value **318** is decreasing significantly.

Period **530** may correspond to aircraft **100** taxiing on runway surface **102**. In this regard, aft body clearance to runway surface remains constant. Pitch attitude **106** and current pitch profile θ' **306** remain constant. Furthermore, column force **512** is zero and elevator command signal **320**, elevator deflection signal **326**, and limiter **319** are constant.

In view of the present disclosure, it will be appreciated that by using pitch profile and descent profiles to determine a limiting elevator deflection value implemented in accordance with various embodiments set forth herein may provide for an improved approach to prevent the aft body of the aircraft from contacting the ground during an aircraft landing maneuver. In this regard, limiting an elevator deflection value, while still providing aircraft landing control, allows an aircraft, such as a long bodied commercial aircraft, to use a lower landing approach speed than would otherwise be necessary to avoid tail strikes. A pilot may rely on increased landing speed to avoid a tail strike in conventional systems. Lower approach speeds can have a positive effect on a number of aircraft systems and performance metrics including landing field length, high lift, and noise.

Where applicable, various embodiments provided by the present disclosure can be implemented using hardware, software, or combinations of hardware and software. Also where applicable, the various hardware components and/or software components set forth herein can be combined into composite components comprising software, hardware, and/or both without departing from the spirit of the present disclosure. Where applicable, the various hardware components and/or software components set forth herein can be separated into sub-components comprising software, hardware, or both without departing from the spirit of the present disclosure. In addition, where applicable, it is contemplated that software components can be implemented as hardware components, and vice-versa.

Software in accordance with the present disclosure, such as program code and/or data, can be stored on one or more computer readable mediums. It is also contemplated that software identified herein can be implemented using one or more general purpose or specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various steps described herein can be changed, combined into composite steps, and/or separated into sub-steps to provide features described herein.

While specific embodiments have been described and illustrated, such embodiments should be considered illustrative of the subject matter described herein and not as limiting the claims as construed in accordance with the relevant jurisprudence.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method comprising:

determining a descent profile based on a current altitude and a current vertical speed of an aircraft;

determining a maximum pitch profile associated with the descent profile;

determining a current pitch profile based on a current pitch attitude and a current pitch rate of the aircraft;

comparing the current pitch profile with the maximum pitch profile to determine an excess current pitch profile; and

limiting an elevator command signal based on the comparison to reduce a probability of an aircraft tail strike.

2. The method of claim **1**, wherein the current altitude is based on a distance from an aircraft landing gear to a runway surface as determined, at least in part, by a sensor measurement signal.

3. The method of claim **1**, wherein determining the maximum pitch profile includes accessing a table of maximum pitch profiles, wherein each maximum pitch profile is based on a corresponding one of the descent profile, and wherein the maximum pitch profile is determined, at least in part, on the descent profile and an aircraft geometry.

4. The method of claim **3**, further comprising reducing the maximum pitch profile when a speed brake is extended.

5. The method of claim **1**, wherein:

the current vertical speed is determined by a vertical speed sensor measurement signal;

the current pitch rate is determined by a pitch rate sensor measurement signal; and

the current pitch attitude is determined by a pitch attitude sensor measurement signal.

6. The method of claim **1**, wherein the comparing comprises converting the excess current pitch profile to an elevator deflection limit command.

7. The method of claim **1**, further comprising applying a lag filter to an output elevator deflection signal to provide a reference elevator deflection command signal.

8. The method of claim **7**, further comprising:

combining an elevator deflection limit command value and the reference elevator deflection command signal to produce an elevator deflection limiter value; and

limiting the elevator command signal to generate an elevator deflection value of no less than the elevator deflection limiter value.

9. The method of claim **8**, wherein the limiting comprises responding to the elevator command signal to generate an output elevator deflection signal when the elevator deflection limiter value is not exceeded.

10. The method of claim **1**, wherein the determining comprises periodically updating the descent profile and the current pitch profile to use in limiting the elevator command signal.

11. A system comprising:

a memory comprising a plurality of executable instructions; and

a processor adapted to execute the instructions to:

determine a descent profile based on a current altitude and a current vertical speed of an aircraft;

determine a maximum pitch profile associated with the descent profile;

determine a current pitch profile based on a current pitch attitude and a current pitch rate of the aircraft;

compare the current pitch profile with the maximum pitch profile to determine an excess current pitch profile; and

limit an elevator command signal based on the comparison.

12. The system of claim **11**, wherein the current altitude is based on a distance from an aircraft landing gear to a runway surface as determined, at least in part, by a sensor measurement signal.

13. The system of claim **11**, wherein the maximum pitch profile is determined, at least in part, on the descent profile and an aircraft geometry.

14. The system of claim **13**, further comprising an aircraft speed brake, wherein the maximum pitch profile is adjusted when the speed brake is extended.

15. The system of claim **11**, wherein the processor is configured to periodically update the current pitch profile and the descent profile; and wherein the periodic updates are used to limit the elevator command signal.

16. The system of claim **11**, wherein the processor is configured to convert the excess current pitch profile to degrees of elevator deflection value.

17. The system of claim **11**, further comprising a lag filter that provides a reference elevator deflection command signal.

18. The system of claim **11**, wherein the processor is configured to:

combine an elevator deflection limit command value and a reference elevator deflection command signal to produce an elevator deflection limiter value; and limit the elevator command signal to generate an elevator deflection value of no less than the elevator deflection limiter value.

19. The system of claim **11**, wherein the processor is configured to respond to the elevator command signal to generate an elevator deflection value when the elevator deflection limiter value is not exceeded.

20. The system of claim **11**, wherein the system is an aircraft further comprising:

a pitch attitude sensor configured to provide a pitch attitude measurement signal to the processor;

a pitch rate sensor configured to provide a pitch rate measurement signal to the processor;

a vertical speed sensor configured to provide a vertical speed measurement signal to the processor; and/or

a radio altimeter configured to provide an altitude measurement signal to the processor.

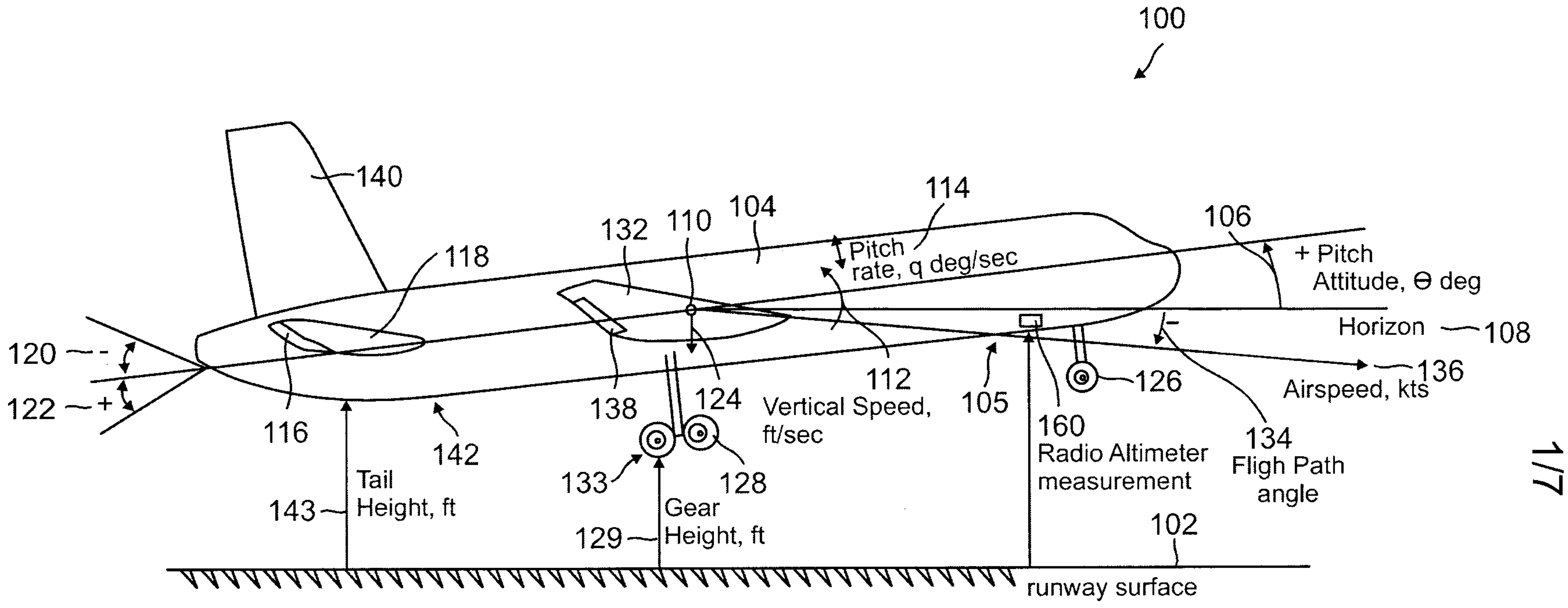

100
140
118
132
110
104
114
106
+ Pitch
Attitude, Θ deg
Pitch
rate, q deg/sec
Horizon
108
120
-
122
+
116
138
124
112
105
126
136
Airspeed, kts
Vertical Speed,
ft/sec
160
Radio Altimeter
measurement
134
Fligh Path
angle
–
142
Tail
Height, ft
143
133
128
Gear
Height, ft
129
102
runway surface

FIG. 1

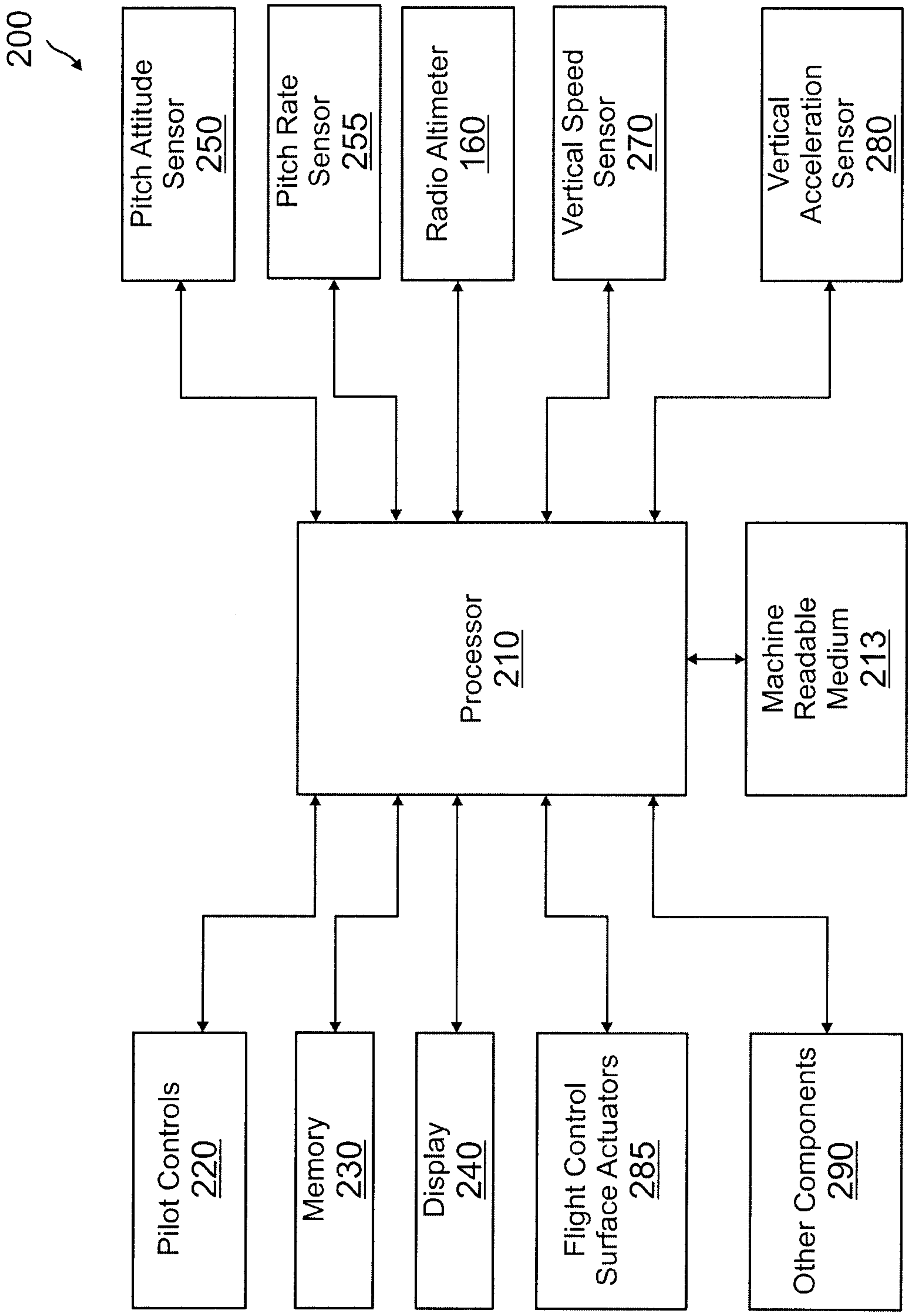

200
Pitch Attitude Sensor 250
Pitch Rate Sensor 255
Radio Altimeter 160
Vertical Speed Sensor 270
Vertical Acceleration Sensor 280
Processor 210
Machine Readable Medium 213
Pilot Controls 220
Memory 230
Display 240
Flight Control Surface Actuators 285
Other Components 290

FIG. 2

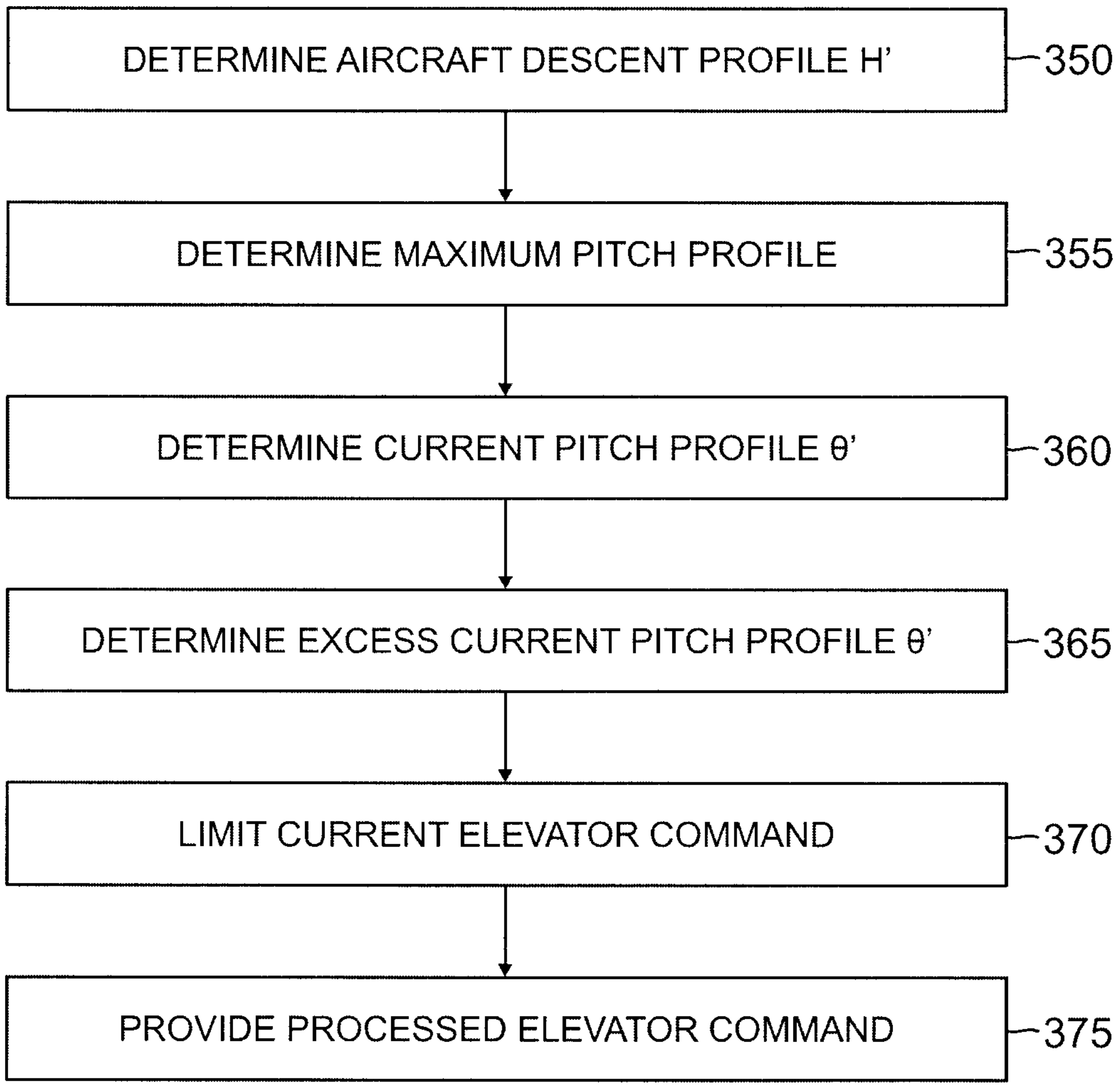

DETERMINE AIRCRAFT DESCENT PROFILE H’
350
DETERMINE MAXIMUM PITCH PROFILE
355
DETERMINE CURRENT PITCH PROFILE θ’
360
DETERMINE EXCESS CURRENT PITCH PROFILE θ’
365
LIMIT CURRENT ELEVATOR COMMAND
370
PROVIDE PROCESSED ELEVATOR COMMAND
375

FIG. 3A

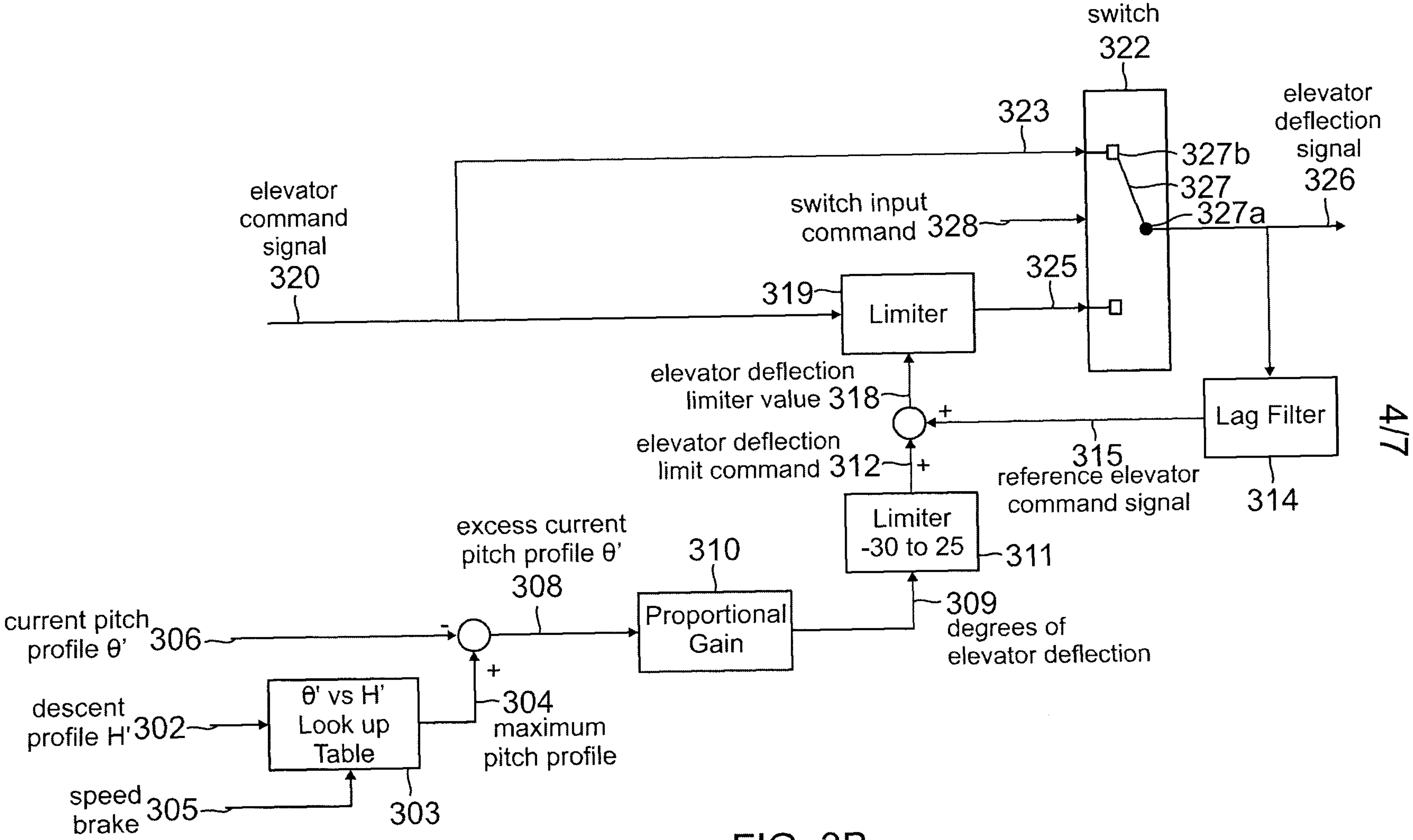

switch
322
323
327b
327
327a
elevator deflection signal 326
elevator command signal 320
switch input command 328
325
319
Limiter
elevator deflection limiter value 318
+
Lag Filter
315
reference elevator command signal
314
elevator deflection limit command 312
+
Limiter -30 to 25
311
excess current pitch profile θ'
308
310
Proportional Gain
309
degrees of elevator deflection
current pitch profile θ'
306
-
+
304
maximum pitch profile
descent profile H'
302
θ' vs H' Look up Table
speed brake
305
303

FIG. 3B

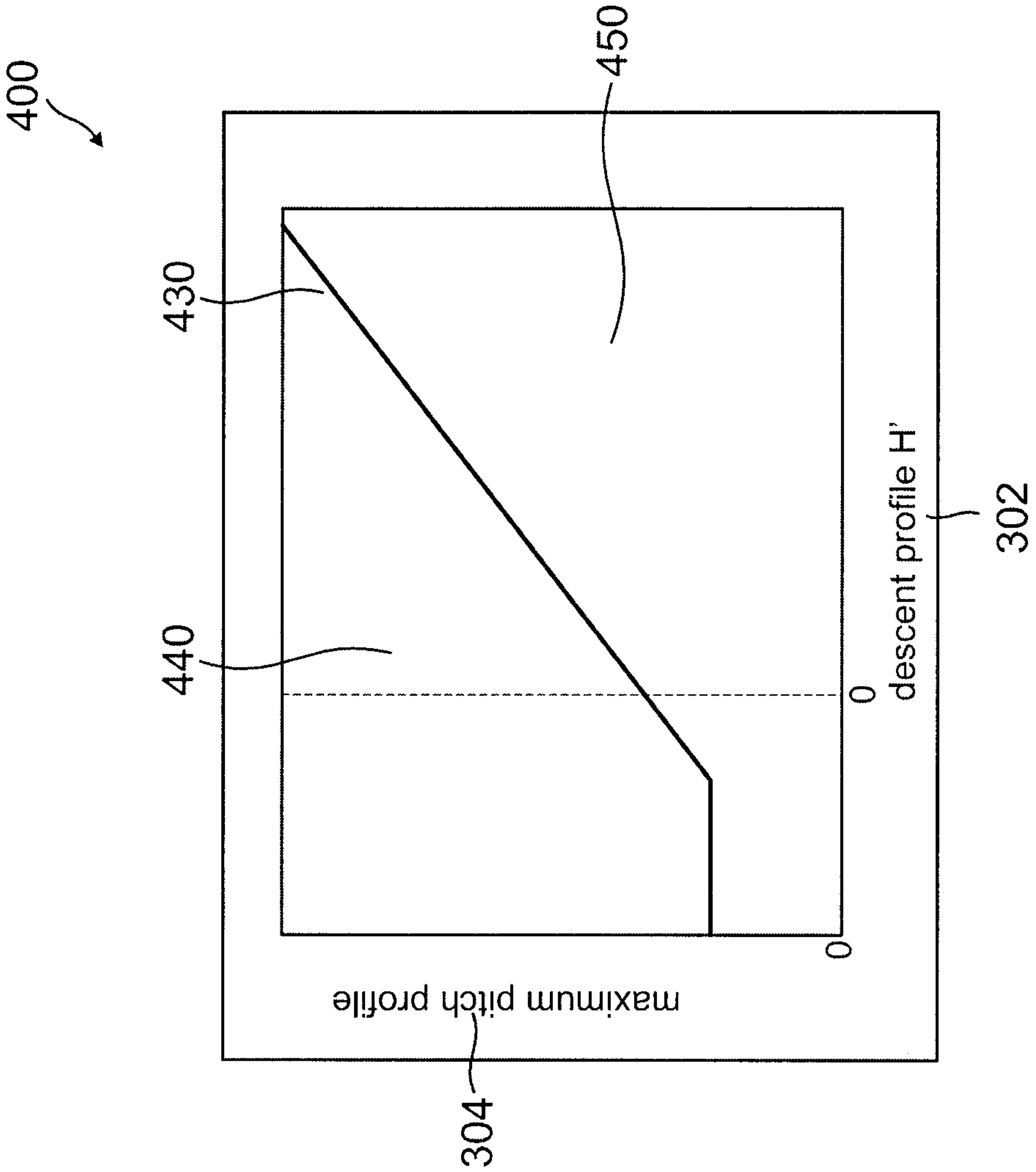

400
450
430
440
descent profile H'
302
0
0
maximum pitch profile
304

FIG. 4

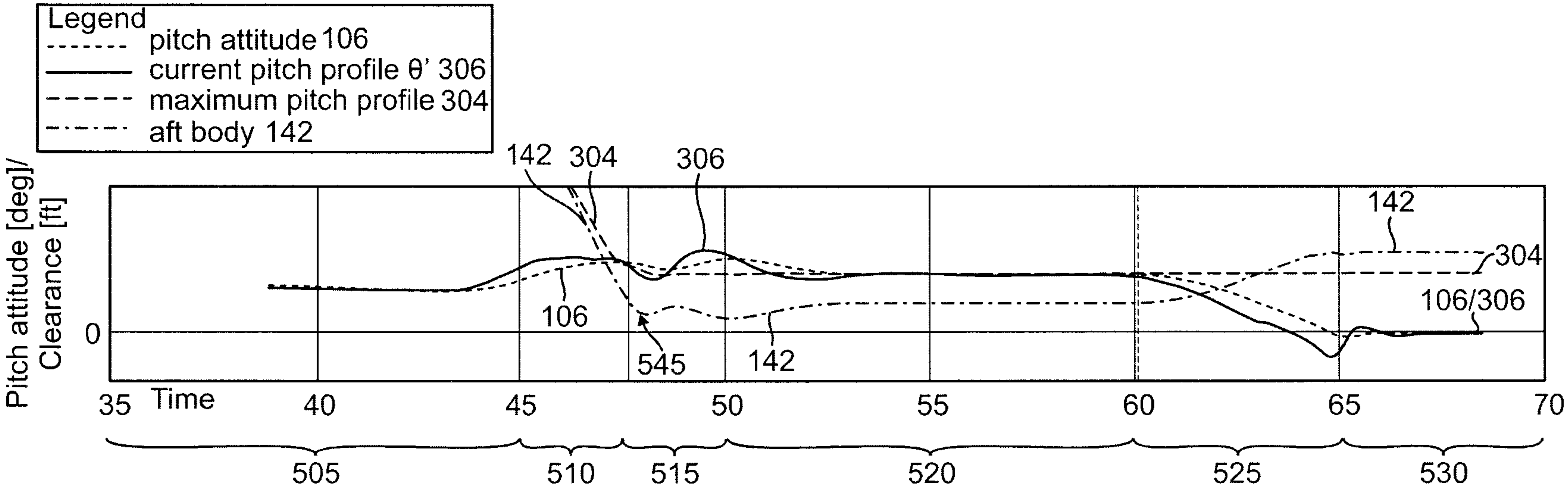

Legend
pitch attitude 106
current pitch profile θ' 306
maximum pitch profile 304
aft body 142
Pitch attitude [deg]/
Clearance [ft]
0
142
304
306
106
545
142
142
304
106/306
35
Time
40
45
50
55
60
65
70
505
510
515
520
525
530

FIG. 5A

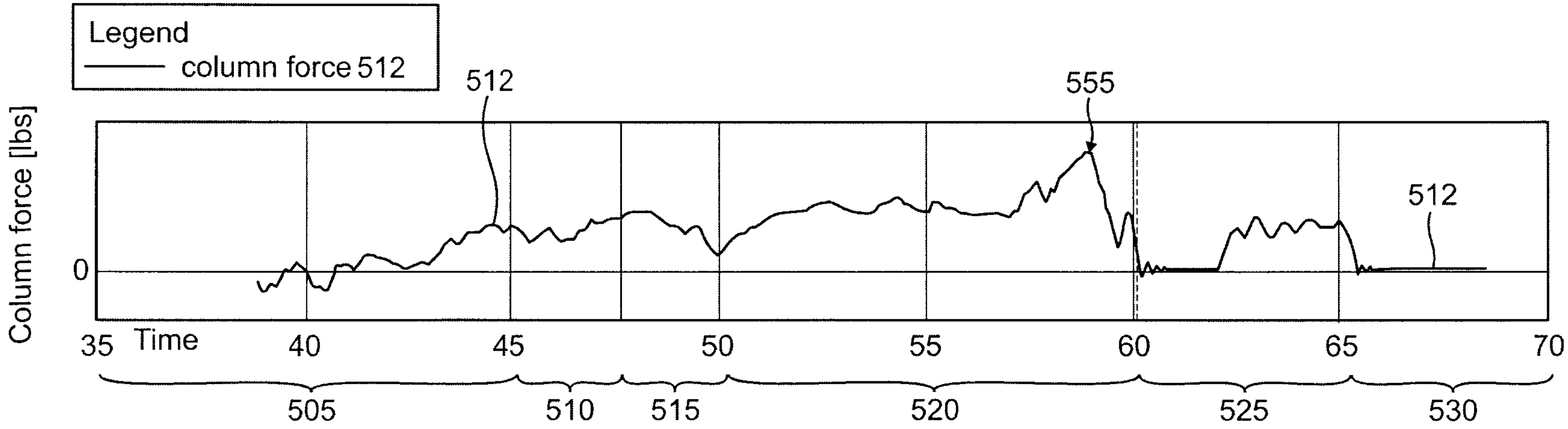

Legend
column force 512
Column force [lbs]
0
512
555
512
35
Time
40
45
50
55
60
65
70
505
510
515
520
525
530

FIG. 5B

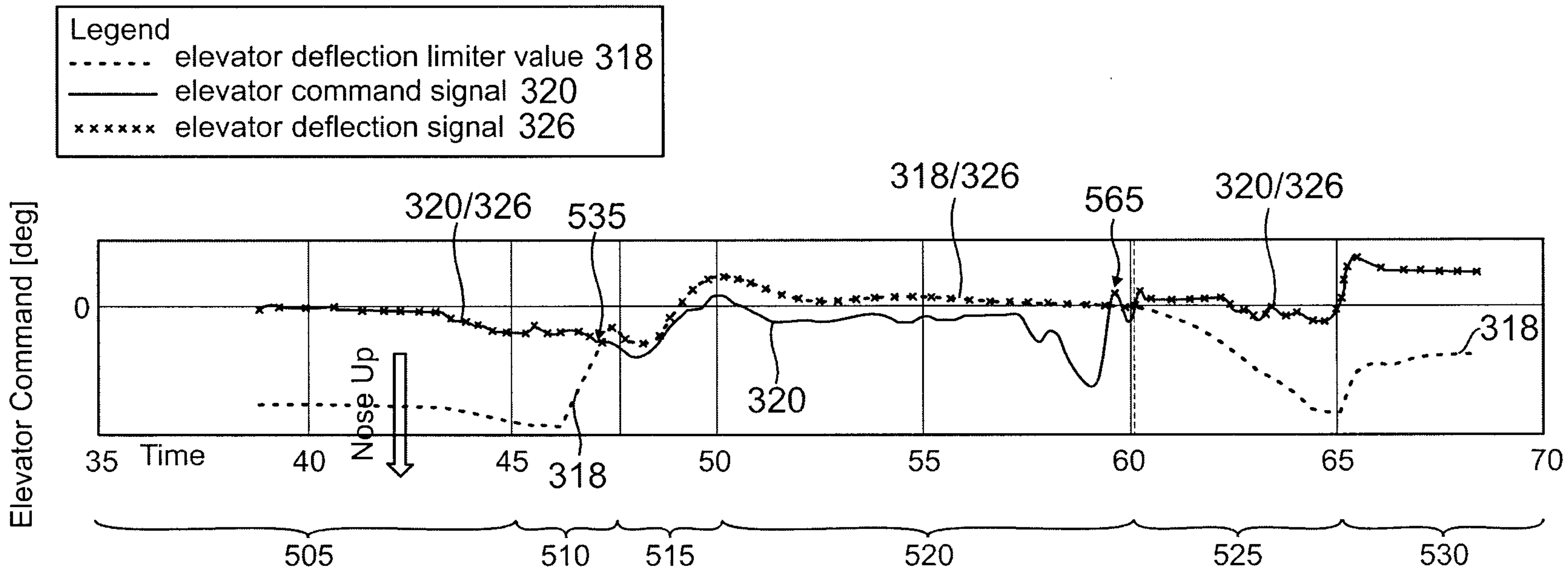
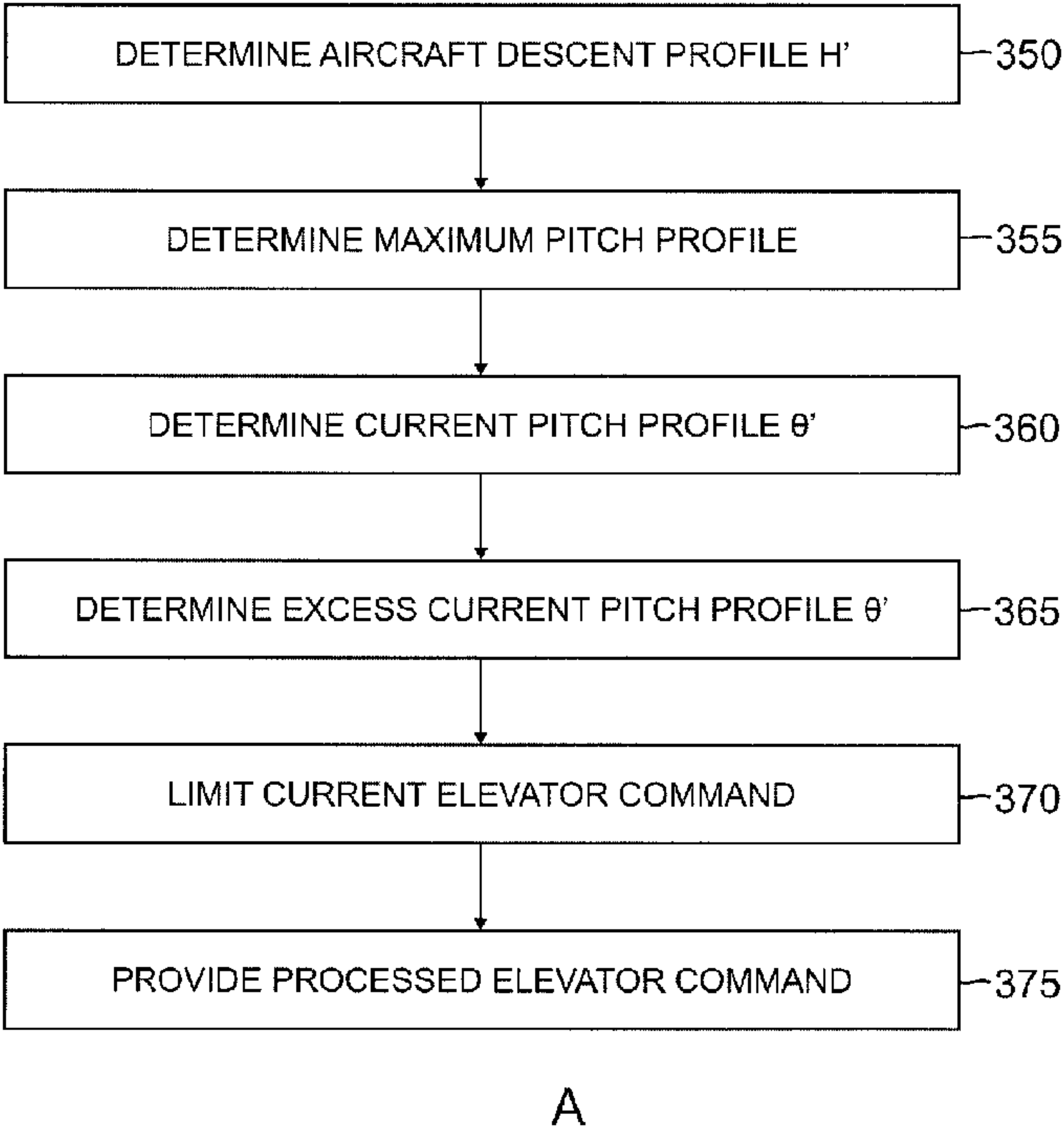

Legend
elevator deflection limiter value 318
elevator command signal 320
elevator deflection signal 326
Elevator Command [deg]
0
Time
35
40
45
50
55
60
65
70
Nose Up
320/326
535
318
318/326
320
565
320/326
318
505
510
515
520
525
530

FIG. 5C


DETERMINE AIRCRAFT DESCENT PROFILE H'
350
DETERMINE MAXIMUM PITCH PROFILE
355
DETERMINE CURRENT PITCH PROFILE θ'
360
DETERMINE EXCESS CURRENT PITCH PROFILE θ'
365
LIMIT CURRENT ELEVATOR COMMAND
370
PROVIDE PROCESSED ELEVATOR COMMAND
375
A