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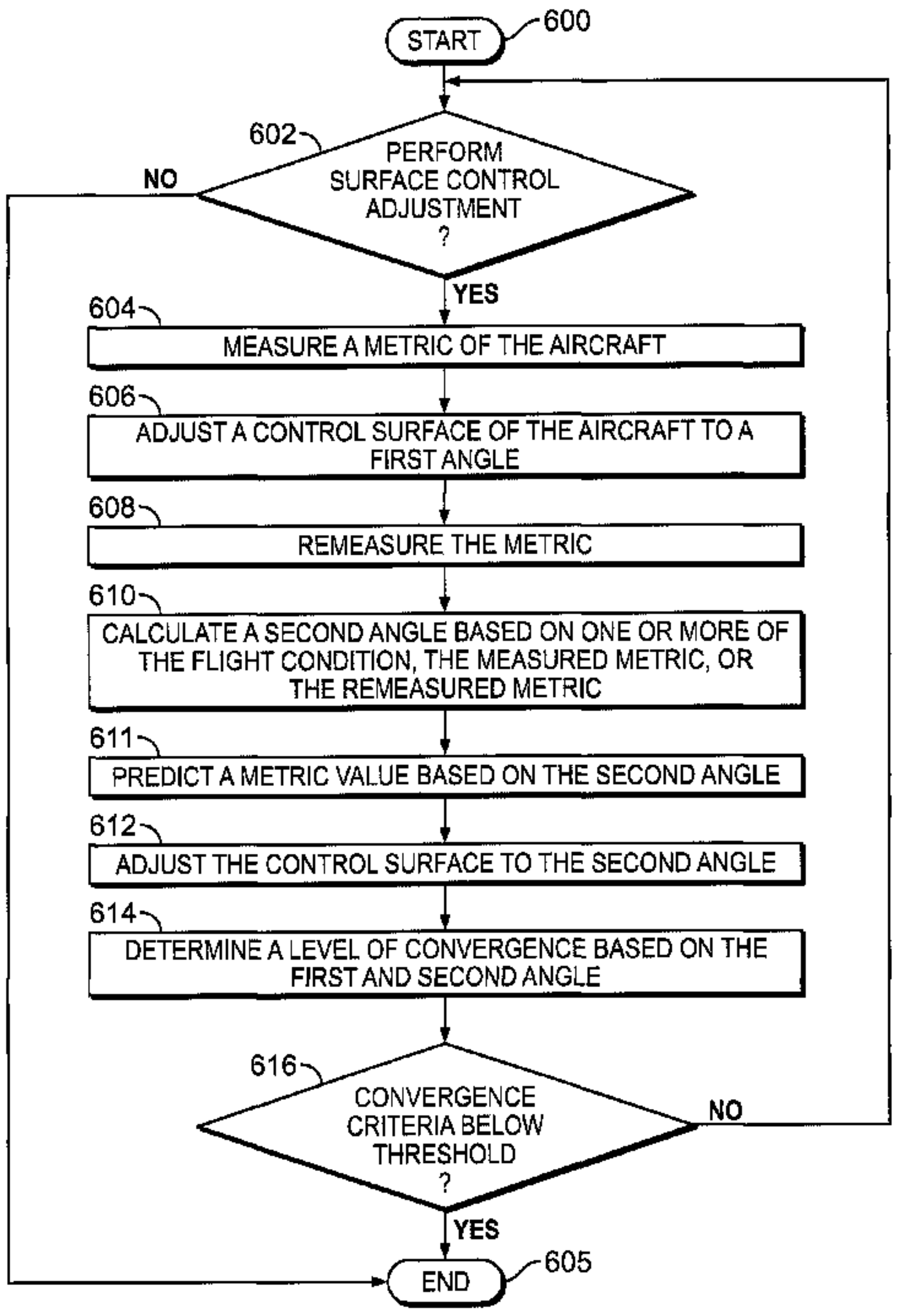

(57) Abrégé/Abstract:
Closed loop control of control surfaces is described herein. One disclosed example method includes measuring a flight metric of an aircraft during flight and calculating, using a processor, a deflection of a control surface of the aircraft based on the flight metric. The disclosed example method also includes adjusting the deflection to an effective deflection level based on the calculated deflection to reduce a drag coefficient of the aircraft.

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ABSTRACT

Closed loop control of control surfaces is described herein. One disclosed example method includes measuring a flight metric of an aircraft during flight and calculating, using a processor, a deflection of a control surface of the aircraft based on the flight metric. The disclosed example method also includes adjusting the deflection to an effective deflection level based on the calculated deflection to reduce a drag coefficient of the aircraft.

CLOSED LOOP CONTROL OF AIRCRAFT CONTROL SURFACES

FIELD OF THE DISCLOSURE

This patent relates generally to aircraft and, more particularly, to closed loop control of aircraft control surfaces.

BACKGROUND

Some aircraft employ a variable camber approach to tailor the shape of an airfoil such as, for example, a trailing edge or other control surface of an aircraft wing. Tailoring the shape of the airfoil allows adjustment of lift characteristics during takeoff. Additionally, the position (e.g., deflection, angle, etc.) of the airfoil may affect drag during cruising speeds. Systems that adjust the airfoil during cruise to lower drag usually rely on a table (e.g., a table look-up) of tabulated reference aircraft data to adjust the airfoil during flight. However, such tables do not usually take into account factors that influence the instantaneous performance of the aircraft such as aircraft-to-aircraft variability, systematic variations, random disturbances, etc.

SUMMARY

An example method includes measuring a flight metric of an aircraft during flight and calculating, using a processor, a deflection of a control surface of the aircraft based on the flight metric. The example method also includes adjusting the deflection based on the calculated deflection to reduce a drag coefficient of the aircraft.

Another example method includes measuring a flight metric of an aircraft, adjusting a control surface of the aircraft to a first angle, remeasuring the metric and calculating, using a processor, a second angle of the control surface based on one or more of a flight condition, the measured flight metric, or the re-measured flight metric to reduce drag of the aircraft. The example method also includes adjusting the control surface to the second angle.

Another example method includes adjusting an aircraft control surface to a first angle, measuring a flight metric after the aircraft reaches steady state, calculating, using a processor, a second angle of the aircraft control surface based on the measured flight metric to reduce a drag coefficient of the aircraft and adjusting the aircraft control surface to the second angle.

One embodiment can involve a method which may include measuring a flight metric of an aircraft during flight; calculating, using a processor, a deflection of a control surface of the aircraft based on the flight metric; and adjusting the deflection based on the calculated deflection to reduce a drag coefficient of the aircraft. Calculating the deflection may include adding a perturbation deflection to a deflection estimate that reduces drag. The method may also include actuating the control surface prior to measuring the flight metric based on an initial deflection. The deflection may involve wing camber. The flight metric may include a drag coefficient or an amount of thrust. Calculating the deflection may include using a Kalman-filter based method to estimate a sensitivity of the flight metric. Calculating the deflection may involve using a drag value, a trim thrust value, or a percent throttle value.

Another embodiment can involve a method that may include measuring a flight metric of an aircraft; adjusting a control surface of the aircraft to a first angle; re-measuring the metric; calculating, using a processor, a second angle of the control surface based on one or more of a flight condition, the measured flight metric, or the re-measured flight metric to reduce drag of the aircraft; and adjusting the control surface to the second angle. The flight metric may include a drag coefficient or an amount of thrust. The first and second angles may involve wing camber. The calculating the second angle may include using a Kalman-filter based method to estimate a sensitivity of the flight metric. Calculating the second angle comprises estimating drag in response to a deflection of the control surface. One or more of calculating the second angle may involve using a drag value, a trim thrust value, table lookup data or a percent throttle value. Calculating the second angle may be further based on table lookup data.

A further embodiment can involve a method that may include adjusting an aircraft control surface to a first angle; measuring a flight metric after the aircraft reaches steady state; calculating, using a processor, a second angle of the aircraft control surface based on the measured flight metric to reduce a drag coefficient of the aircraft; and adjusting the aircraft control surface to the second angle. The method may also include calculating a level of convergence between the first angle and the second angle to determine whether to readjust the aircraft control surface. The first angle may be determined from table lookup data. Calculating the second angle may include adding a perturbation deflection to a deflection estimate that reduces drag. Calculating the second angle may include using a quadratic estimate. Calculating the second angle may be further based on table lookup data.

In one embodiment, there is provided a method involving: measuring a flight metric of an aircraft during flight of the aircraft; calculating, using a processor, a first deflection based on the measured flight metric; inducing a perturbation deflection of a control surface based on the calculated first deflection; re-measuring the flight metric of the aircraft in response to the induced perturbation deflection to gather data about a drag coefficient pertaining to the aircraft; calculating, using the processor, a second deflection of the control surface of the aircraft based on the re-measured flight metric by adding a perturbation estimate increment to a deflection estimate that reduces the drag coefficient of the aircraft; and adjusting the control surface to the second deflection to reduce the drag coefficient of the aircraft.

In another embodiment, there is provided a method involving: measuring a flight metric of an aircraft; inducing a perturbation deflection of a control surface of the aircraft to a first angle based on the measured flight metric; re-measuring the flight metric in response to the induced perturbation deflection to gather data about a drag coefficient pertaining to the aircraft; and calculating, using a processor, a second angle of the control surface based on the re-measured flight metric and one or more of a flight condition, or the measured flight metric. The second angle includes an adjustment angle to reduce the drag coefficient of the aircraft. The method further involves adjusting the control surface to the second angle.

In another embodiment, there is provided a method involving: adjusting an aircraft control surface of an aircraft to a first angle; measuring a flight metric after the aircraft reaches steady state; calculating, using a processor, a deflection of the aircraft control surface based on the measured flight metric; inducing a perturbation deflection of the aircraft control surface based on the calculated deflection; re-measuring the flight metric in response to the induced perturbation deflection to gather data about a drag coefficient pertaining to the aircraft; and calculating, using the processor, a second angle of the aircraft control surface based on the re-measured flight metric to reduce a drag coefficient of the aircraft. The second angle includes an adjustment angle. The method further involves adjusting the aircraft control surface to the second angle.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an example aircraft that may be used to implement example methods and apparatus disclosed herein.

FIG. **2**A illustrates an example wing structure in which the examples disclosed herein can be implemented.

FIGS. **2**B-**2**D illustrate load distributions that are achievable through movement of the control surfaces.

FIG. **3** is a **3**-D contour graph depicting drag coefficient relating to positions of flaps.

FIG. **4** is a schematic representation of a control system of an aircraft that may be used to implement the examples disclosed herein.

FIG. **5** is a flowchart representative of an example method that may be used to implement the control system of FIG. **4**.

FIG. **6** is a flowchart representative of another example method that may be used to implement the control system of FIG. **4**.

FIG. **7** is a block diagram of an example processor platform capable of executing machine readable instructions to implement the example methods of FIGS. **5** and **6**.

FIG. **8** represents example time-history plots of flap positions and drag coefficient of an aircraft with respect to time using the examples disclosed herein.

Wherever possible, the same reference numbers will be used throughout the drawing(s) and accompanying written description to refer to the same or like parts. As used in this disclosure, stating that any part is in any way positioned on (e.g., positioned on, located on, disposed on, or formed on, etc.) another part, means that the referenced part is either in contact with the other part, or that the referenced part is above the other part with one or more intermediate part(s) located therebetween. Stating that any part is in contact with another part means that there is no intermediate part between the two parts.

DETAILED DESCRIPTION

Closed loop control of control surfaces (e.g., flaps, rudders, ailerons, etc.) of an aircraft are disclosed herein. During takeoff, the control surfaces may work to provide the appropriate flight dynamics to allow or facilitate the aircraft taking off from a runway or landing. During cruise and/or takeoff of the aircraft, the positions, angles, or deflections of one or more control surfaces may impact the overall drag coefficient of the aircraft. Multiple control surfaces pose a multi-dimensional problem to be solved via which the drag coefficient may be reduced (e.g., minimized and/or optimized). Drag coefficient reduction can improve fuel economy of the aircraft and, therefore, reduce fuel costs and carbon-dioxide (CO_2) emissions. The examples disclosed herein allow continuous optimization of the positions of the control surfaces and/or allow optimization of the positions of the control surfaces based on unique and/or up-to-date or current conditions of the aircraft (e.g., weight reduction due to fuel consumption, etc.).

The examples disclosed herein may be used to reduce drag coefficient of an aircraft during flight through adjustment of one or more control surfaces of the aircraft. The examples disclosed herein provide current metric data to an estimation and optimization algorithm having an extended Kalman filter to adjust the positions of one or more control surfaces to reduce (e.g., minimize) the overall drag of the aircraft. The estimation and optimization algorithm of the disclosed examples may be used in conjunction with a search pattern lookup and provide uncertainty scaling to determine a perturbation deflection (e.g., perturbation, incremental deflection, etc.) to be combined with an estimated calculated delta resulting in a resultant deflection. In some examples, the estimated calculated delta is a change in control surface deflection calculated to provide the lowest overall drag of the aircraft. This calculated control surface delta may be provided to the control system to cause the control surface to displace (e.g., deflect) by the defined control surface delta. In some examples, the control surfaces are incrementally deflected (e.g., perturbed) to provide the resultant deflection described above. In other words, the control surfaces and/or the calculated delta are perturbed to gather data that may be used to characterize the drag coefficient of the aircraft as a function of control surface position(s).

In some examples, table lookup data, which may be generated through tabulated reference data gathered through numerous aircraft and/or calculations, is used by the estimation and optimization algorithm to continuously estimate the calculated delta for the aircraft control surface. In some examples, the table lookup data is modified based on the estimation and optimization algorithm. In particular, estimates provided by the table are updated by measurements taken during flight of the aircraft. In some examples, the degree to which the table lookup data is applied varies. In some examples, the metric is drag coefficient or thrust. In some examples, the control surfaces are only adjusted for a specified time after cruise speed has been reached. In some examples, the degree to which the control surface is deflected may vary based on behavior of the metric. In some examples, multiple control surfaces are independently adjusted.

As used in the examples disclosed herein, metric data (e.g., flight metric data, flight metric(s), etc.) describes data (e.g., values, table value, etc.) that may be measured and/or calculated from measured data at one or more sensors, for example. Metric data may be measured and calculated at numerous sensors and/or processor(s) and may include, but is not limited to, drag coefficient, thrust, fuel consumption, cruise performance and/or cruise range, etc.

FIG. **1** illustrates an example aircraft **100** having stabilizers **102** and wings **104** attached to a fuselage **106** in which the examples disclosed herein may be implemented. The wings **104** of the illustrated example have control surfaces (e.g., flaps, ailerons, tabs, etc.) **108**, which are located at a trailing edge of the wings **104** and may be displaced or adjusted (e.g., angled, etc.) to provide lift during takeoff, for example. In some examples, the control surfaces **108** are operated (i.e., displaced) independently of one another. The examples described herein may be applied to control surfaces associated with any of the stabilizers **102**, the wings **104** and/or any other exterior or outboard structure (e.g., a horizontal stabilizer, a wing strut, an engine strut, a canard stabilizer, etc.) of the fuselage **106**. In particular, the wings **104** and/or the stabilizers **102** may have control surfaces **110** that can be adjusted to reduce (e.g., minimize) the value of a metric such as drag coefficient, c_d, during cruise, for example. Additionally or alternatively, in some examples, the fuselage **106** has control surfaces, which may be deflected, to alter the flight characteristics during cruise and/or takeoff of the aircraft **100**.

FIG. **2**A illustrates an example wing structure **200** of an aircraft (e.g., the aircraft **100** of FIG. **1**) in which the examples disclosed herein can be implemented. The example wing structure **200** has control surfaces (e.g., trailing edge surfaces defining a wing camber) **202** including an inboard flap **204**, a flaperon **206**, an outboard flap **208** and an inboard aileron **210**. Additionally or alternatively, in some examples, the control surfaces **202** include leading edge surfaces such as spoilers **212** and/or slats **214**. The inboard flap **204** and the outboard flap **208** of the illustrated example alter the lift and drag of the aircraft. The flaperon **206** and the inboard aileron **210** of the illustrated example alter the roll of the aircraft. The spoilers **212** of the illustrated example alter the lift, drag and roll of the aircraft. In this example, the slats **214** alter the lift of the aircraft. The control surfaces **202** of the illustrated example also play a role in determining the overall drag coefficient of the aircraft during cruise. Also, the deflection position of the control surfaces **202** that reduces (e.g., minimizes) drag may vary during flight as conditions (e.g., external conditions) of the aircraft change. Thus, the positions and/or deflection levels of the control surfaces **202** relative to one another may be varied during cruise to maintain an overall drag coefficient of the aircraft. In particular, deflecting the inboard flap **204** and the outboard flap **208** independently of one another may greatly vary the drag coefficient of the aircraft, for example. Additionally, the effect(s) of moving the inboard flap **204** and the outboard flap **208** relative to one another may also greatly vary with operating conditions of the aircraft such as, for example, weight of the aircraft, wing configuration, control surface geometry, etc. In some known examples, flaps, ailerons, and flaperons are positioned at pre-defined angles during cruise based on table lookup data, which does not take into account the current (e.g., instantaneous) operating conditions of the aircraft. Therefore, in some embodiments, it may be advantageous to position (e.g., deflect, angle, displace, etc.) the control surfaces **202** to reduce (e.g., minimize) drag during flight based on one or more of the numerous instantaneous operating conditions.

The control surfaces **202** of the illustrated example may be independently moved (e.g., deflected) to control the load distribution in different directions over the wing structure **200**. Load distribution and/or flight characteristics may be adjusted in a chordwise direction generally indicated by arrows **216**. Likewise, load distribution and/or flight characteristics may be adjusted in a spanwise direction generally indicated by arrows **218**.

Load distributions over the spanwise direction of the wing structure **200** are illustrated in FIGS. **2**B-**2**D. Turning to FIG. **2**B, a load distribution **224** represents a rectangular load. Likewise, a load distribution **226** of FIG. **2**C represents a triangular load along the span of the wing structure **200**. A load distribution **228** of FIG. **2**D represents an elliptical load over the span of the wing structure **200**. The load distributions **224**, **226**, **228** illustrate that control surfaces may significantly alter the load applied across wings via control surfaces. The different load distributions **224**, **226**, **228** may alter the drag coefficient of the aircraft significantly. Thus, independent control of the control surfaces about both spanwise and chordwise directions of the aircraft to reduce (e.g., minimize) drag coefficient is a multidimensional problem.

FIG. **3** is a **3**-D contour graph **300** depicting drag coefficient relating to positions of inboard and outboard flaps of an aircraft such as, for example, the inboard flap **204** and the outboard flap **208** described above in connection with FIG. **2**A. A first axis **302** of the illustrated example represents various positions of an outboard flap. In this example, the positions are represented by positive and negative angles in units of degrees, which represent positions that may be opposite one another (e.g., angled downward versus angled upward), and zero (e.g., a neutral or horizontal position). Likewise, a second axis **304** of the illustrated example represents the inboard flap positions, which are also represented by positive and negative angles, and zero. In this example, a third axis **306** represents drag coefficient, c_d , of the aircraft during cruise at steady-state conditions. A surface contour **308** of the illustrated example represents the variation of drag coefficient for numerous positions of the inboard and outboard flaps. The contour **308** has a lower drag coefficient region depicted by a lower region (e.g., minimum point) **310**. Reducing (e.g., minimizing) the drag coefficient is a multidimensional problem because multiple control surfaces being controlled (e.g., deflected) to affect the overall drag coefficient of the aircraft. Therefore, to reduce the overall drag coefficient, numerous possible positions of the multiple control surfaces are considered. In some examples, spanwise and chordwise control of the multiple control surfaces is taken into account as described in connection with FIG. **2**. In some examples, one or more of the flaps may be incrementally displaced (e.g., perturbed) from their calculated deflections (e.g., calculated deflections to minimize drag coefficient) and/or steady-state deflections to collect data (e.g., metric data) to calculate predicted deflections and/or deflection deltas that defined the predicted change in displacement to reduce (e.g., minimize) drag coefficient, for example. The estimation and optimization algorithm **404** described below in connection with FIG. **4** seeks to characterize (e.g., define) the resultant drag coefficient (e.g., the shape of a contour such as the contour **308**).

FIG. **4** is a schematic representation of a control system **400** of an aircraft (e.g., the aircraft **100** of FIG. **1**) that may be used to implement the examples disclosed herein. In this example, the control system **400** reduces (e.g., minimizes) the drag coefficient of the aircraft by determining (e.g., characterizing) a minimum drag region such as the lower region **310** of the contour **308** described above in connection with FIG. **3** to identify optimal control surface deflections or angles. The control system **400** of the illustrated example incorporates table lookup data **402**, which is provided to an estimation and optimization algorithm **404**. In this example, the table lookup data **402** includes estimated optimal positions or deflections of a control surface(s). In some examples, the table lookup data **402** includes table data (e.g., reference table data) to provide recommended control surface positions or deflections based on inputs such as velocity (e.g., mach number), altitude, coefficient of lift, aircraft design, configuration of flaps, etc. The estimation and optimization algorithm **404** of the illustrated example utilizes an extended Kalman filter framework to generate a calculated deflection change (e.g., delta) **406** of the control surface and provide the calculated deflection change **406** to a plant **408**, which includes the actuators and sensors of the aircraft **401**. In particular, the calculated deflection change **406** defines the amount the control surface should be deflected or actuated by an actuator(s). In this example, the estimation and optimization algorithm **404** of the illustrated example receives metric data **410** measured at the plant **408** and/or the table lookup data **402** to estimate the behavior of the metric (e.g., estimates a predicted value of the metric data **410**), which may be drag coefficient for example, relative to control surface deflections and/or changes in control surface deflections.

To ensure that sufficient information is available to generate such estimates and/or characterize the behavior of the metric data **410** associated with drag coefficient for example, the control surface, in some examples, is incrementally deflected (e.g., perturbed). In this example, a perturbation deflection (e.g., perturbation, incremental deflection, etc.) **412** is added to the calculated deflection change **406** via a data operation **414** yielding a search pattern centered on a current estimate. In some examples, the Kalman filter framework estimates sensitivity of the metric data **410** (e.g., sensitivity of the metric data **410** to changes and/or perturbations of the control surface) to adjust an uncertainty scaling factor **418** and/or the perturbation deflection **412**. In some examples, the estimation and optimization algorithm **404** utilizes a quadratic estimate to calculate deflection change **406** and/or the uncertainty scaling factor **418**.

In this example, the estimation and optimization algorithm **404** provides the calculated deflection change **406** to the data operation **414** and the uncertainty scaling factor **418** to a data operation **420**. A search pattern lookup **422** of the illustrated example provides a multidimensional search pattern (e.g., search pattern matrix) to the data operation **420**, which multiplies the uncertainty scaling factor **418** with the search pattern (e.g., a search pattern matrix) provided from the search pattern lookup **422** resulting in the perturbation deflection **412**. The search pattern of the illustrated example can be scaled or disengaged by the estimation and optimization algorithm **404** via the estimated uncertainty scaling factor **418** to decrease (e.g., minimize) or eliminate incremental deflections or perturbations applied to the control surface. In some examples, the perturbation deflection **412** is based on scaled uncertainty levels computed within the estimation process of the estimation and optimization algorithm **404**. In particular, scaling can lead to large perturbations when there is a relatively large uncertainty regarding the optimal deflection of the control surface. In multi-dimensional examples (e.g., multiple flaps), perturbation of each of the control surfaces may be scaled independently of one another (e.g., independent scaling).

As mentioned above, in this example, the perturbation deflection **412** and the calculated deflection change **406** are added (e.g., an addition operation, summed, etc.) at the data operation **414** to provide a resultant deflection **426** to deflect a control surface(s) via the plant **408**, which may have numerous actuators to deflect the control surface(s). While a resultant deflection **426** is provided to the plant **408** in this example, the calculated surface deflection may, alternatively, be provided directly to the plant **408** from the estimation and optimization algorithm **404**. The plant **408** of the illustrated example, in turn, provides the metric data **410** to the estimation and optimization algorithm **404** via sensors in the plant **408**. In this example, the plant **408** provides the metric data **410** after the aircraft **401** has reached steady-state conditions after deflecting the control surface(s) (e.g., measured after the time necessary for the measured metric to reach a steady-state condition).

The estimation and optimization algorithm **404** of the illustrated example determines and/or reduces a metric value such as, for example, drag coefficient. A minimal value estimation framework of the illustrated example may be demonstrated by the following steps. For example, a calculated u, which may represent a deflection that lowers and/or minimizes drag coefficient (e.g., an optimal deflection), may be computed based on parameter estimates, $\{\hat{Q}_i\}$. A primary assumption is that such a function may be estimated by a quadratic function of a controlled variable such as trailing edge and/or leading-edge surface position(s), for example. A controlled variable, u, may be represented as:

$$f(u) = u^T Q_2 u + Q_1 u + Q_0 \qquad (1),$$

where $u \in \mathbb{R}^m$, $Q_2 \in \mathbb{R}^{m\,x\,m}$, $Q_1 \in \mathbb{R}^{1\,x\,m}$, $Q_0 \in \mathbb{R}$

and it is assumed that $f_m(u) \in \mathbb{R}^m \longrightarrow \mathbb{R}$.

Because Equation **1** is quadratic in u, there is a defined calculated value, u^*, that pertains to a minimum value of the function and/or drag coefficient, for example, and may be calculated by differentiating Equation **1**, which results in Equation **2** below:

$$f_m{}'(u) = \left.\frac{\partial f_m}{\partial u}\right|_u + 2Q_2 u + Q_1^T \qquad \mathbf{(2)}$$

The calculated value of u^* may therefore be represented in Equation **3** as:

$$\hat{u}^* = h_{u^*}(\hat{x}) = -\frac{1}{2}\,\hat{Q}_2^{-1}\,\hat{Q}_1^T \qquad \mathbf{(3)}$$

Equation **4** defines $H_{\hat{u}^*}$ as:

$$H_{\hat{u}^*} = \left.\frac{\partial h_{u^*}(\hat{x})}{\partial x}\right|_{\hat{x}_k} \qquad \mathbf{(4)}$$

Given a state estimate covariance, Σ_x , an approximate estimate of covariance of the minimizing value as shown in Equation **5** :

$$\Sigma_{\hat{u}^*} \approx H_{\hat{u}^*} \Sigma_x H_{\hat{u}^*}^T \qquad (5)$$

The computation of $H_{\hat{u}^*}$ may be complex due to the term, Q_2^{-1}. However, in some examples, the following formula is used to calculate $\frac{\partial Q_2^{-1}}{\partial x}$ to compute a desired Jacobian is shown in Equation **6**:

$$\frac{\partial (X^{-1})_{kl}}{\partial X_{ij}} = (X^{-1})_{ki}(X^{-1})_{jl} \qquad (6)$$

The relationships described above demonstrate an example in which the extended Kalman filter may be implemented. Such examples may use matrices to characterize the behavior of the systems (e.g., characterize metric behavior related to changes in control surface deflection). While an extended Kalman filter is shown, any other mathematical relationship, equations, etc. may be used to estimate control surface deflections based on metric data, for example.

The degree to which the table lookup data **402** is applied to the estimation and optimization algorithm **404** may be varied. In examples where the table lookup data **402** is not applied, the estimation and optimization algorithm **404** relies primarily on the metric data measurement(s) **410** provided from the plant **408**. In other examples, the table lookup data **402** is applied to a large extent to the estimation and optimization algorithm **404** to minimize control surface perturbations. In other examples, the table lookup data **402** is used in a balanced approach for relatively reduced perturbation requirements. In some examples, only the table lookup data **402** is applied using tabulated data to directly update the resultant deflection **426**. In other examples, the degree to which the table lookup data **402** is applied may be changed by synthetic measurement updating, in which the Kalman filter framework allows uncertainty in the table derived values to be incorporated in the update of the estimator state. In particular, the steps of such a process include performing a Kalman update of the states assuming direct measurement of the metric function parameters and sampling the metric at the current location to correct any biasing that developed during the update process. In some examples, incorporating the table lookup data **402** improves tabulated data and/or health monitoring of the control system **400**.

In some examples, the estimation and optimization algorithm **404** may update the table lookup data **402** based on the characterized behavior of the metric. In other words, the estimation and optimization algorithm may introduce incremental changes to the recommended control surface position(s) of the table lookup data **402** based on determined behavior of the metric and/or data measured at the plant **408** during flight. In particular, stored control surface position data of the table lookup data **402** may be updated to reflect updates based on specific metric behavior data of an aircraft that travels a particular trajectory regularly, for example.

In some examples, process noise parameters may be introduced to the estimation and optimization algorithm **404** to model random disturbances applied to the state dynamics. In some examples, the estimation and optimization algorithm **404** detects changes and/or certain behavior (e.g., divergence from predicted behavior, significant change, etc.) of the metric data **410** and re-engages the search pattern lookup **422** to confirm or update the calculated deflection **406** and/or the resultant deflection **426**. In some examples, the estimation and optimization algorithm **404** selects a search pattern based on metric behavior and/or metric behavior changes. In some examples, the estimation and optimization algorithm **404** ignores the metric data **410** if the metric data **410** is considered invalid by, for example, applying a statistical test such as a χ-squared (chi-squared) test.

Flowcharts representative of example methods for implementing the control system **400** of FIG. **4** are shown in FIGS. **5** and **6**. In these examples, the methods may be implemented using machine readable instructions that comprise a program for execution by a processor such as the processor **712** shown in the example processor platform **700** discussed below in connection with FIG. **7**. The program may be embodied in software stored on a tangible computer readable storage medium such as a CD-ROM, a floppy disk, a hard drive, a digital versatile disk (DVD), a Blu-ray disk, or a memory associated with the processor **712**, but the entire program and/or parts thereof could alternatively be executed by a device other than the processor **712** and/or embodied in firmware or dedicated hardware. Further, although the example program is described with reference to the flowchart illustrated in FIG. **4**, many other methods of implementing the example control system **400** may alternatively be used. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, or combined.

As mentioned above, the example methods of FIGS. **5** and **6** may be implemented using coded instructions (e.g., computer and/or machine readable instructions) stored on a tangible computer readable storage medium such as a hard disk drive, a flash memory, a read-only memory (ROM), a compact disk (CD), a digital versatile disk (DVD), a cache, a random-access memory (RAM) and/or any other storage device or storage disk in which information is stored for any duration (e.g., for extended time periods, permanently, for brief instances, for temporarily buffering, and/or for caching of the information). As used herein, the term tangible computer readable storage medium is expressly defined to include any type of computer readable storage device and/or storage disk and to exclude propagating signals and to exclude transmission media. As used herein, "tangible computer readable storage medium" and "tangible machine readable storage medium" are used interchangeably. Additionally or alternatively, the example processes of FIGS. **5** and **6** may be implemented using coded instructions (e.g., computer and/or machine readable instructions) stored on a non-transitory computer and/or machine readable medium such as a hard disk drive, a flash memory, a read-only memory, a compact disk, a digital versatile disk, a cache, a random-access memory and/or any other storage device or storage disk in which information is stored for any duration (e.g., for extended time periods, permanently, for brief instances, for temporarily buffering, and/or for caching of the information). As used herein, the term non-transitory computer readable medium is expressly defined to include any type of computer readable storage device and/or storage disk and to exclude propagating signals and to exclude transmission media. As used herein, when the phrase "at least" is used as the transition term in a preamble of a claim, it is open-ended in the same manner as the term "comprising" is open ended.

FIG. **5** is a flowchart representative of an example method that may be used to implement the control system **400** of FIG. **4**. The example method of FIG. **5** begins at block **500** where an aircraft has taken off and has reached cruising speed (block **500**). An initial deflection of a control surface of the aircraft is determined (block **502**). The initial deflection may be determined by table lookup data such as the table lookup data **402** described above in connection with FIG. **4**. In some examples, the initial deflection is a predefined default position. The aircraft control surface is then actuated (e.g., adjusted, deflected, etc.) to the determined initial deflection (block **504**). Next, a metric such as the metric data **410**, for example, of the aircraft is measured (block **506**). The metric may be a drag coefficient, thrust settings, a trim thrust value, percent throttle value or any other appropriate metric. A deflection of the control surface is then calculated based on the metric data and, in some examples, table lookup data such as the table lookup data **402**, for example. Such a calculation may use Equations **1-6** described above in connection with FIG. **4**. The deflection of the illustrated example is calculated using a search pattern lookup (e.g., the search pattern lookup **422**) along with uncertainty scaling (e.g., the uncertainty scaling factor **418**) to define a perturbation deflection (e.g., incremental deflection) such as the perturbation deflection **412**, for example. This perturbation deflection (e.g., perturbation), in some examples, is then added to the calculated deflection (e.g., the calculated deflection **406**) yielding the resultant deflection (e.g., the resultant deflection **426**) (block **508**). The resultant deflection of the illustrated example is an effective deflection for which the drag coefficient of the aircraft is reduced (e.g., minimized). In some examples, such calculations are accomplished through manipulation of matrices representing multidimensional data (e.g., predictions based on multiple flaps and corresponding multiple flap deflections) and/or search pattern matrices. As mentioned above, the degree to which table lookup data is applied may be varied. Additionally or alternatively, the uncertainty scaling **418** may be varied based on patterns or shifts of the metric data, for example. In some examples, a corresponding metric is predicted based on the calculated surface deflection (block **509**).

Next, the control surface is moved (e.g., deflected, actuated, etc.) to the calculated deflection (e.g., effective deflection, displacement, etc.) (block **510**). In this example, the metric is then re-measured after the control surface has been adjusted (block **512**). In some examples, the metric is not re-measured until the aircraft has reached steady state conditions. After the metric is re-measured, it is determined whether the control surface should be readjusted (block **513**) by the estimation and optimization algorithm **404**, for example. Such a determination may be based on convergence criteria (e.g., a calculated deflection only varies by a small degree to the previously calculated deflection of a previous iteration). In some examples, the control surface may have a time limitation to be adjusted (e.g., the control surface is only adjusted for a time period after the aircraft has reached cruising speed). In some examples, this determination may be accomplished by the calculated narrowing of the determined error band (e.g., a narrowing of an error band surrounding an estimate) in the estimation and optimization algorithm **404**, for example. If it is determined that the control surface is to be readjusted (block **514**), another surface deflection of the control surface is calculated based on the re-measured metric (block **516**), table lookup data, and/or metric data obtained from deflection of the control surfaces, and, thus, a corresponding predicted metric value is predicted (block **509**) and the control surface is adjusted to that calculated surface deflection (block **510**). In contrast, if it is determined that the control surface is not to be adjusted (block **514**), the process ends (block **518**).

FIG. **6** is another flowchart representative of another example method that may be used to implement the control system **400** of FIG. **4**. The example method of FIG. **6** begins at block **600** where an aircraft has taken off and has reached cruising speed (block **600**). Next, it is determined whether a control surface adjustment should be performed (block **602**). Such a determination may occur in response to a threshold time being exceeded after the aircraft has reached cruising speeds, for example. In other examples, this determination results from monitoring flight parameters and/or control systems determining that steady state conditions have been reached. In yet other examples, this determination may occur through convergence of a measured flight metric and/or calculated deflection(s). If it is determined that control surface adjustment is to be performed (block **602**), a metric is measured (block **604**). Conversely, if control surface adjustment is not to be performed (block **602**), the process ends (block **605**). If control surface adjustment is to be performed, a control surface is moved to a first angle (block **606**), which, in some examples, is determined from table lookup data such as the table lookup data

402 described above in connection with FIG. **4**. In some examples, the first angle may be defined by table lookup data, a search pattern lookup and/or metric data.

The metric is then re-measured (block **608**), which may occur after the aircraft has achieved steady state conditions with the control surface being at the first angle. A second angle is then calculated based on one or more of the flight condition, the measured metric, or the re-measured metric (block **610**). Such a calculation may use the estimation and optimization algorithm **404** and/or Equations (**1**)-(**4**) described above in connection with FIG. **4**, for example. In some examples, a metric value based on the second angle is predicted (block **611**). The control surface is then adjusted to the second calculated angle (block **612**). Next, a convergence level such as the degree to which the first and second angles have converged, for example, is determined (block **614**). If the convergence level is above a threshold (block **616**), the process ends (block **605**). If the convergence level is below a threshold (block **616**), the process repeats (block **605**).

FIG. **7** is a block diagram of an example processor platform **700** capable of executing instructions to implement the methods of FIGS. **5** and **6** to implement the example control system **400** of FIG. **4**. The processor platform **700** can be, for example, a server, a personal computer, a mobile device (e.g., a tablet such as an iPad^{TM}), a personal digital assistant (PDA), an Internet appliance, or any other type of computing device.

The processor platform **700** of the illustrated example includes a processor **712**. The processor **712** of the illustrated example is hardware. For example, the processor **712** can be implemented by one or more integrated circuits, logic circuits, microprocessors or controllers from any desired family or manufacturer.

The processor **712** of the illustrated example includes a local memory **713** (e.g., a cache). The processor **712** of the illustrated example is in communication with a main memory including a volatile memory **714** and a non-volatile memory **716** via a bus **718**. The volatile memory **714** may be implemented by Synchronous Dynamic Random Access Memory (SDRAM), Dynamic Random Access Memory (DRAM), RAMBUS Dynamic Random Access Memory (RDRAM) and/or any other type of random access memory device. The non-volatile memory **716** may be implemented by flash memory and/or any other desired type of memory device. Access to the main memory including the volatile memory **714** and the non-volatile memory **716** is controlled by a memory controller.

The processor platform **700** of the illustrated example also includes an interface circuit **720**. The interface circuit **720** may be implemented by any type of interface standard, such as an Ethernet interface, a universal serial bus (USB), and/or a PCI express interface.

In the illustrated example, one or more input devices **722** are connected to the interface circuit **720**. The input device(s) **722** permit(s) a user to enter data and commands into the processor **712**. The input device(s) can be implemented by, for example, an audio sensor, a microphone, a camera (still or video), a keyboard, a button, a mouse, a touchscreen, a track-pad, a trackball, isopoint and/or a voice recognition system.

One or more output devices **724** are also connected to the interface circuit **720** of the illustrated example. The output devices **724** can be implemented, for example, by display devices (e.g., a light emitting diode (LED), an organic light emitting diode (OLED), a liquid crystal display, a cathode ray tube display (CRT), a touchscreen, a tactile output device, a printer and/or speakers). The interface circuit **720** of the illustrated example, thus, typically includes a graphics driver card, a graphics driver chip or a graphics driver processor.

The interface circuit **720** of the illustrated example also includes a communication device such as a transmitter, a receiver, a transceiver, a modem and/or network interface card to facilitate exchange of data with external machines (e.g., computing devices of any kind) via a network **726** (e.g., an Ethernet connection, a coaxial cable, a cellular telephone system, etc.).

The processor platform **700** of the illustrated example also includes one or more mass storage devices **728** for storing software and/or data. Examples of such mass storage devices **728** include floppy disk drives, hard drive disks, compact disk drives, Blu-ray disk drives, RAID systems, and digital versatile disk (DVD) drives.

Coded instructions **732** to implement the methods of FIGS. **5** and **6** may be stored in the mass storage device **728**, in the volatile memory **714**, in the non-volatile memory **716**, and/or on a removable tangible computer readable storage medium such as a CD or DVD.

FIG. **8** represents example time-history plots of a flap position of a flap and drag coefficient of an aircraft with respect to time using the examples disclosed herein. In this example, a first plot **800** represents flap position as a function of time. The first plot **800** of the illustrated example includes a horizontal axis **802**, which represents time as a unitless parameter, and a vertical axis **804**, which represents a flap position measured in degrees. An optimal line **806** of the illustrated example represents a theoretical optimum flap position at steady-state conditions (e.g., a flap position corresponding to the lowest drag coefficient of the aircraft). In this example, an estimation line **808** represents the estimated optimal flap position (e.g., the calculated deflection estimate to minimize the drag coefficient) as calculated by an algorithm such as the estimation and optimization algorithm **404** described above in connection with FIG. **4**, for example. The dotted lines **810** and **812** represent lower and upper error estimates, respectively, of the estimation line **808**. The dotted lines **810** and **812** may be determined by an algorithm such as, for example, the estimation and optimization algorithm **404**. In this example, a positional line **814** represents the actual position of the flap. The positional line **814** of the illustrated example starts at a neutral position at the initial time (i.e., t=**0**). In this example, a command line **816** represents the flap set point (e.g., command set point) determined by the estimation and optimization algorithm **404**, for example. As shown in the first plot **800**, as time progresses, the estimation line **808** converges towards the optimal line **806**. Additionally, the dotted lines **810** and **812** both converge towards the optimal line **806** (e.g., the error band becomes tighter around the estimation line **808**). As time progresses, the shifts of the positional line **814** of the flap decreased about the optimal line **806** as shown by the smaller positional displacements further in time (e.g., the perturbation deflections or perturbations decrease).

A second plot **820** of the illustrated example represents drag coefficient of the aircraft as a function of time. Like the horizontal axis **802** of the first plot **800**, a horizontal axis **822** also represents time as a unitless measurement. A vertical axis **824** of the illustrated example represents drag coefficient. In this example, a predicted line **826** represents the predicted minimal (e.g., optimal) drag coefficient from an algorithm such as the estimation and optimization algorithm **404** described above in connection with FIG. **4**. A truth line **828** of the illustrated example represents a theoretical minimum drag coefficient based on flap position. Scattered points **830** represent actual measured drag coefficient data points. Such scattering may occur from noise in measurements, oscillations, etc. In this example, as time progresses, the predicted line **826** and the truth line **828** converge indicating that the drag coefficient of the algorithm eventually converges to a theoretical prediction. Later scattered points **832** demonstrate that the noise of the drag coefficient measurements continues even though the predicted line **826** and the truth line **828** have converged. The second plot **820** represents how robustly the examples disclosed herein can sort through and/or filter noise in measurements to determine the lowest drag coefficient value and/or region such as the lower region **310** described above in connection with FIG. **3**.

Although certain example methods, apparatus and articles of manufacture have been disclosed herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all methods, apparatus and articles of manufacture fairly falling within the scope of the claims of this patent. While aircraft are described, the example apparatus may be applied to vehicles, aerodynamic structures, etc. While the examples described have been primarily related to an aircraft during cruise, the examples may be applied to takeoff or any other appropriate stage pertaining to the aircraft.

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

1. A method comprising:

measuring a flight metric of an aircraft during flight of the aircraft;

calculating, using a processor, a first deflection based on the measured flight metric;

inducing a perturbation deflection of a control surface based on the calculated first deflection;

re-measuring the flight metric of the aircraft in response to the induced perturbation deflection to gather data about a drag coefficient pertaining to the aircraft;

calculating, using the processor, a second deflection of the control surface of the aircraft based on the re-measured flight metric by adding a perturbation estimate increment to a deflection estimate that reduces the drag coefficient of the aircraft; and

adjusting the control surface to the second deflection to reduce the drag coefficient of the aircraft.

2. The method as defined in claim **1**, wherein adjusting the control surface comprises adjusting a wing camber.

3. The method as defined in claim **1** or **2**, wherein the flight metric comprises an amount of thrust.

4. The method as defined in any one of claims **1** to **3**, wherein calculating at least one of the first and second deflections comprises using a Kalman-filter based method to estimate a sensitivity of the flight metric.

5. The method as defined in claim **4**, wherein the Kalman-filter based method is used to adjust at least one of an uncertainty scaling factor or the perturbation deflection.

6. The method as defined in any one of claims **1** to **4**, wherein the first deflection is calculated further based on an uncertainty scaling factor.

7. The method as defined in any one of claims **1** to **6**, wherein calculating at least one of the first and second deflections comprises using one or more of a drag value, a trim thrust value, or a percent throttle value.

8. The method as defined in any one of **1** to **7**, wherein measuring the flight metric of the aircraft during the flight of the aircraft comprises measuring the flight metric of the aircraft during cruise of the aircraft.

9. The method as defined in any one of claims **1** to **8**, wherein re-measuring the flight metric comprises re-measuring the flight metric to gather the data about the drag coefficient pertaining to the aircraft during cruise.

10. The method as defined in any one of claims **1** to **9**, wherein adjusting the control surface comprises adjusting the control surface to the second deflection to reduce the drag coefficient of the aircraft during cruise.

11. The method as defined in any one of claims **1** to **10**, wherein the flight metric comprises data that is measured from a sensor on the aircraft, or data calculated from the measured data.

12. The method as defined in any one of claims **1** to **11**, further comprising actuating the control surface prior to measuring the flight metric based on an initial deflection.

13. A method comprising:

measuring a flight metric of an aircraft;

inducing a perturbation deflection of a control surface of the aircraft to a first angle based on the measured flight metric;

re-measuring the flight metric in response to the induced perturbation deflection to gather data about a drag coefficient pertaining to the aircraft;

calculating, using a processor, a second angle of the control surface based on the re-measured flight metric and one or more of a flight condition, or the measured flight metric, wherein the second angle includes an adjustment angle to reduce the drag coefficient of the aircraft; and

adjusting the control surface to the second angle.

14. The method as defined in claim **13**, wherein the flight metric comprises an amount of thrust.

15. The method as defined in claim **13** or **14**, wherein at least one of inducing the perturbation deflection or adjusting the second angle comprises adjusting a wing camber.

16. The method as defined in of any one of claims **13** to **15**, wherein calculating the second angle comprises using a Kalman-filter based method to estimate a sensitivity of the flight metric.

17. The method as defined in claim **16**, wherein the Kalman-filter based method is used to adjust at least one of an uncertainty scaling factor or the first angle.

18. The method as defined in any one of claims **13** to **16**, wherein a degree of the induced perturbation deflection of the control surface of the aircraft to the first angle is further calculated based on an uncertainty scaling factor.

19. The method as defined in any one of claims **13** to **18**, wherein the control surface includes a first control surface and the method further comprising:

perturbing a second control surface to a second perturbation deflection based on a scaling factor that relates a first degree of perturbation of the second control surface to a second degree of perturbation of the first control surface.

20. The method as defined in any one of claims **13** to **19**, wherein calculating the second angle comprises estimating drag in response to a deflection of the control surface.

21. The method as defined in any one of claims **13** to **20**, wherein calculating the second angle comprises using one or more of a drag value, a trim thrust value, table lookup data or a percent throttle value.

22. The method as defined in any one of claims **13** to **20**, wherein calculating the second angle is further based on table lookup data.

23. The method as defined in claim **22**, wherein the table lookup data is updated based on at least one of the measured flight metric or the re-measured flight metric.

24. The method as defined in any one of claims **13** to **23**, wherein measuring the flight metric comprises measuring the flight metric of the aircraft during cruise of the aircraft.

25. The method as defined in any one of claims **13** to **24**, wherein re-measuring the flight metric comprises re-measuring the flight metric to gather the data about the drag coefficient pertaining to the aircraft during cruise.

26. The method as defined in any one of **13** to **25**, wherein calculating the second angle comprises calculating the second angle including the adjustment angle to reduce the drag coefficient of the aircraft during cruise.

27. The method as defined in any one of claims **13** to **26**, wherein the flight metric comprises data that is measured from a sensor on the aircraft, or data calculated from the measured data.

28. The method as defined in any one of claims **13** to **27**, further comprising actuating the control surface prior to measuring the flight metric based on an initial deflection.

29. A method comprising:

adjusting an aircraft control surface of an aircraft to a first angle;

measuring a flight metric after the aircraft reaches steady state;

calculating, using a processor, a deflection of the aircraft control surface based on the measured flight metric;

inducing a perturbation deflection of the aircraft control surface based on the calculated deflection;

re-measuring the flight metric in response to the induced perturbation deflection to gather data about a drag coefficient pertaining to the aircraft;

calculating, using the processor, a second angle of the aircraft control surface based on the re-measured flight metric to reduce the drag coefficient of the aircraft, wherein the second angle includes an adjustment angle; and

adjusting the aircraft control surface to the second angle.

30. The method as defined in claim **29**, further comprising calculating a level of convergence between the first angle and the second angle to determine whether to readjust the aircraft control surface.

31. The method as defined in claim **29** or **30**, wherein the first angle is determined from table lookup data.

32. The method as defined in claim **29** or **30**, wherein calculating the second angle is further based on table lookup data.

33. The method as defined in claim **31** or **32**, wherein the table lookup data is updated based on the measured flight metric.

34. The method as defined in any one of claims **31** to **33**, wherein the table lookup data is updated based on the re-measured flight metric.

35. The method as defined in any one of claims **29** to **34**, wherein calculating the second angle comprises adding the perturbation deflection to a deflection estimate that reduces drag.

36. The method as defined in any one of claims **29** to **35**, wherein calculating the second angle comprises using a quadratic estimate.

37. The method as defined in any one of claims **29** to **36**, wherein calculating the second angle includes using a Kalman-filter based method to estimate a sensitivity of the flight metric.

38. The method as defined in claim **37**, wherein the Kalman-filter method is used to adjust at least one of an uncertainty scaling factor or the first angle.

39. The method as defined in any one of claims **29** to **37**, wherein the calculated deflection of the aircraft control surface is further based on an uncertainty scaling factor.

40. The method as defined in any one of claims **29** to **39**, wherein adjusting the aircraft control surface to the first angle comprises adjusting the aircraft control surface to the first angle during cruise of the aircraft.

41. The method as defined in any one of claims **29** to **40**, wherein measuring the flight metric comprises measuring the flight metric of the aircraft during cruise of the aircraft.

42. The method as defined in any one of claims **29** to **41**, wherein re-measuring the flight metric comprises re-measuring the flight metric to gather the data about the drag coefficient pertaining to the aircraft during cruise.

43. The method as defined any one of claims **29** to **42**, wherein calculating the second angle comprises calculating the second angle to reduce the drag coefficient of the aircraft during cruise.

44. The method as defined in any one of claims **29** to **43**, wherein the flight metric comprises data that is measured from a sensor on the aircraft, or data calculated from the measured data.

45. The method as defined in any one of claims **29** to **44**, further comprising actuating the aircraft control surface prior to measuring the flight metric based on an initial deflection.

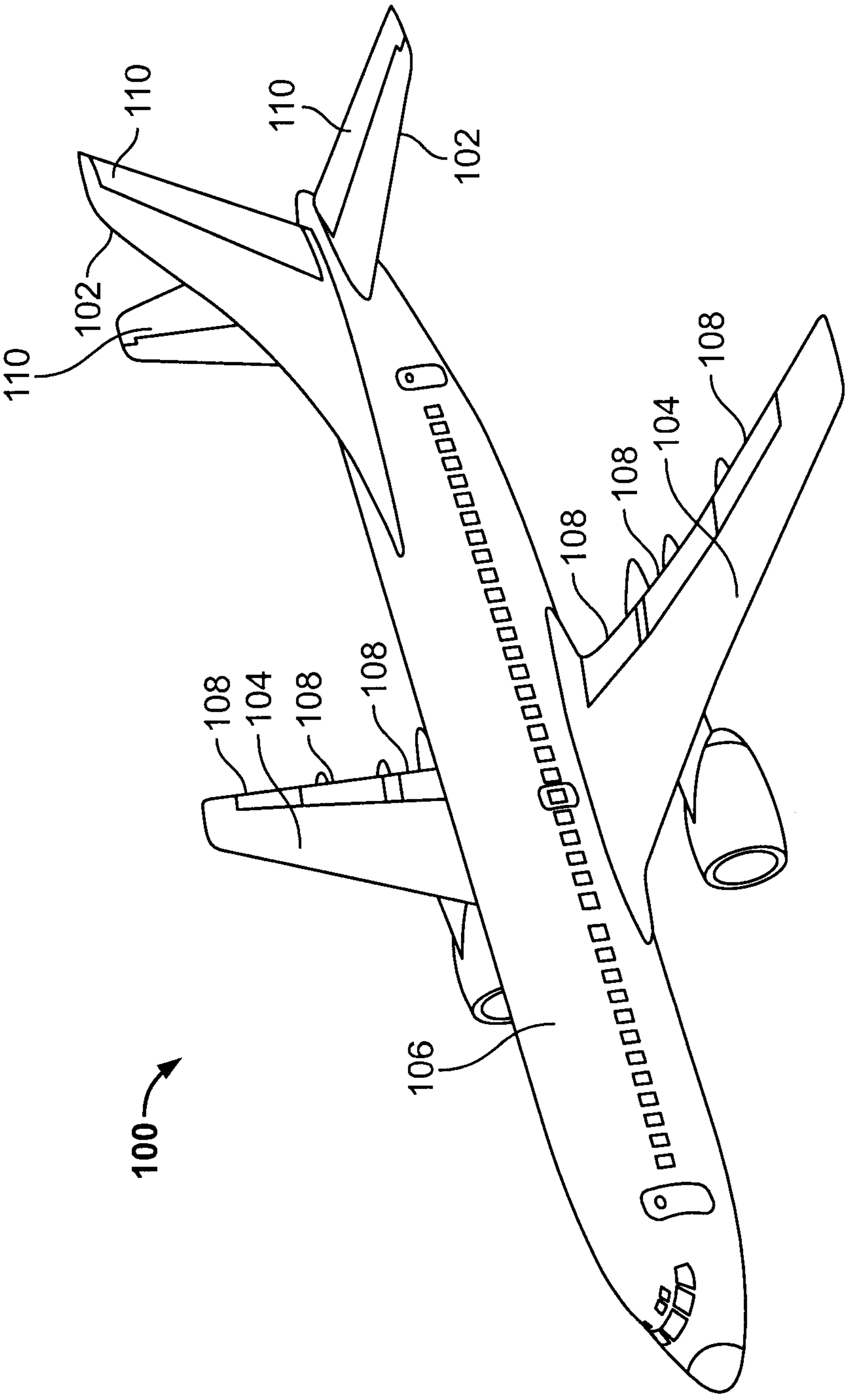


FIG. 1

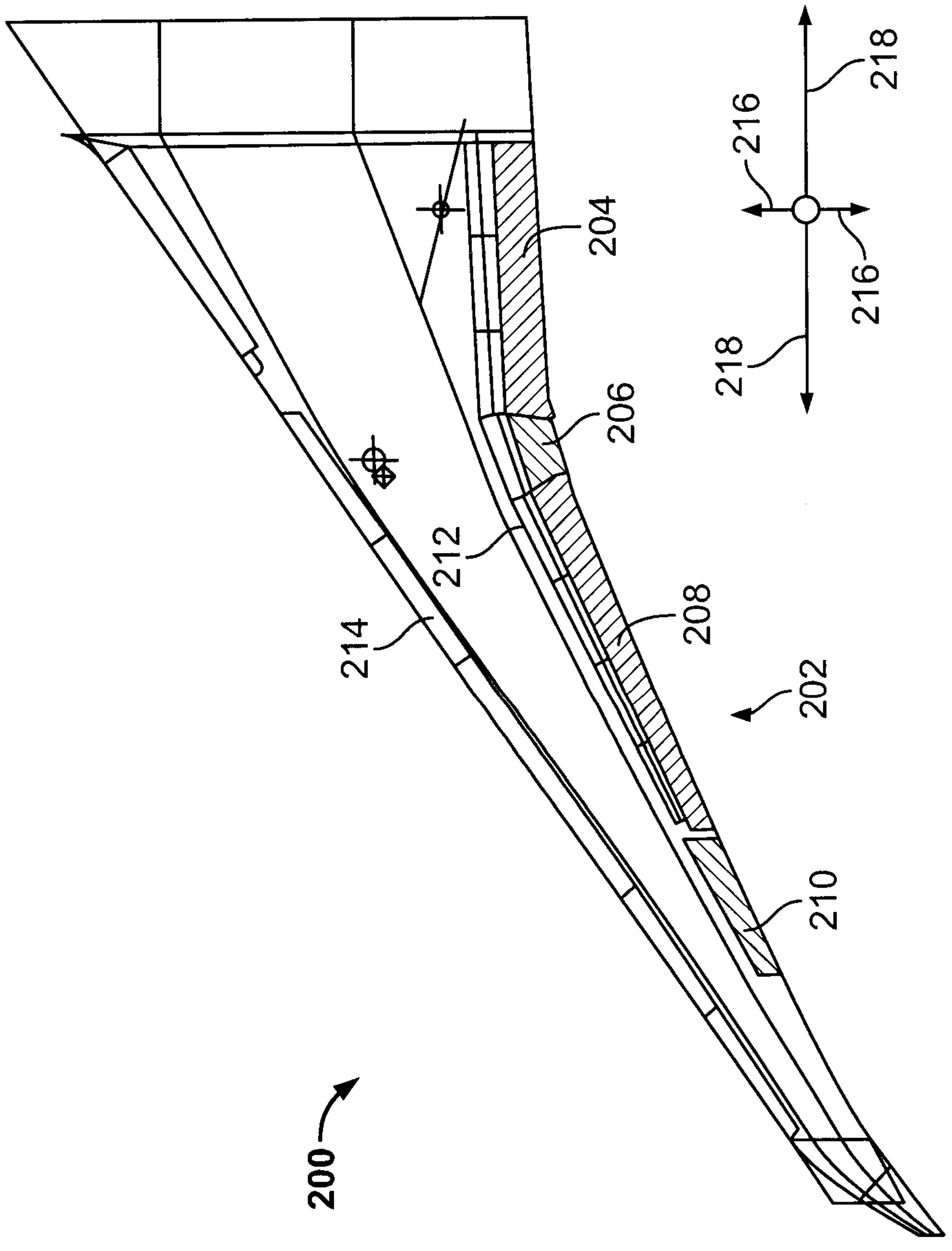


FIG. 2A

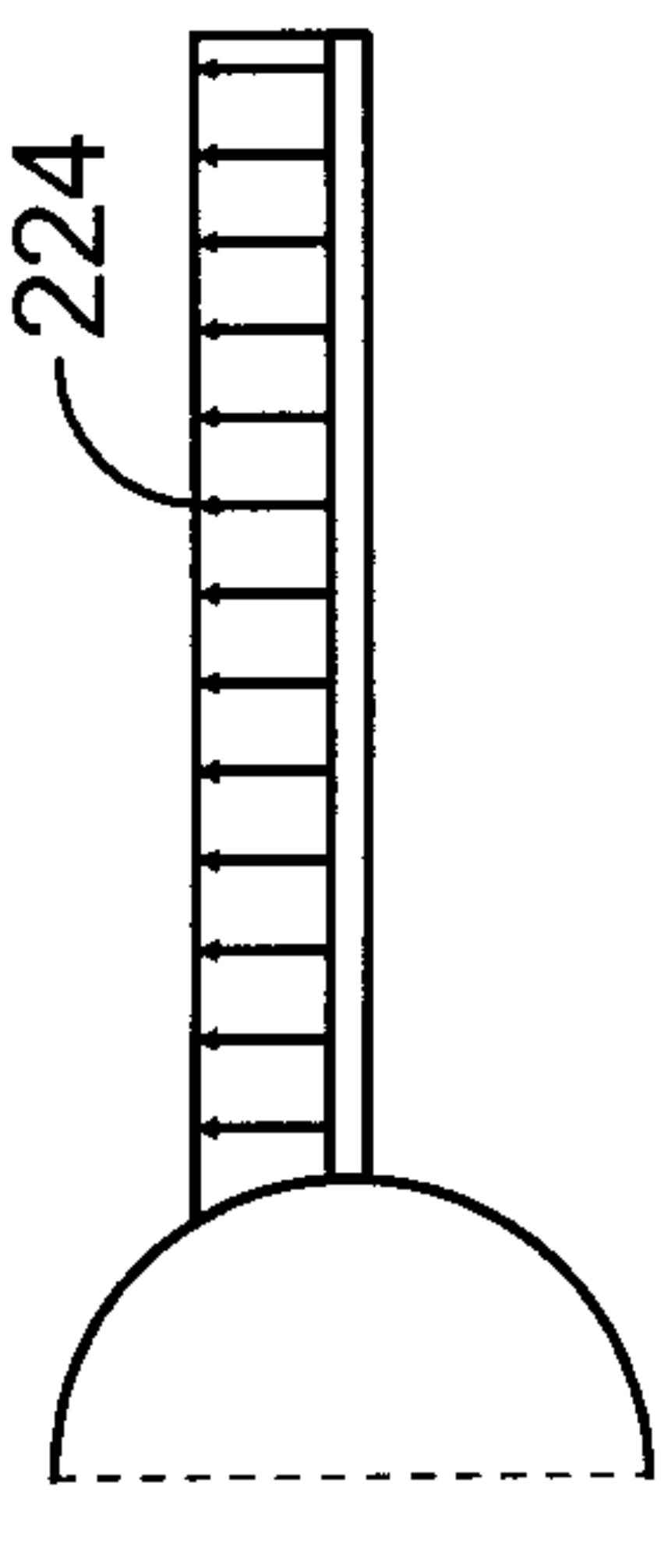


FIG. 2B

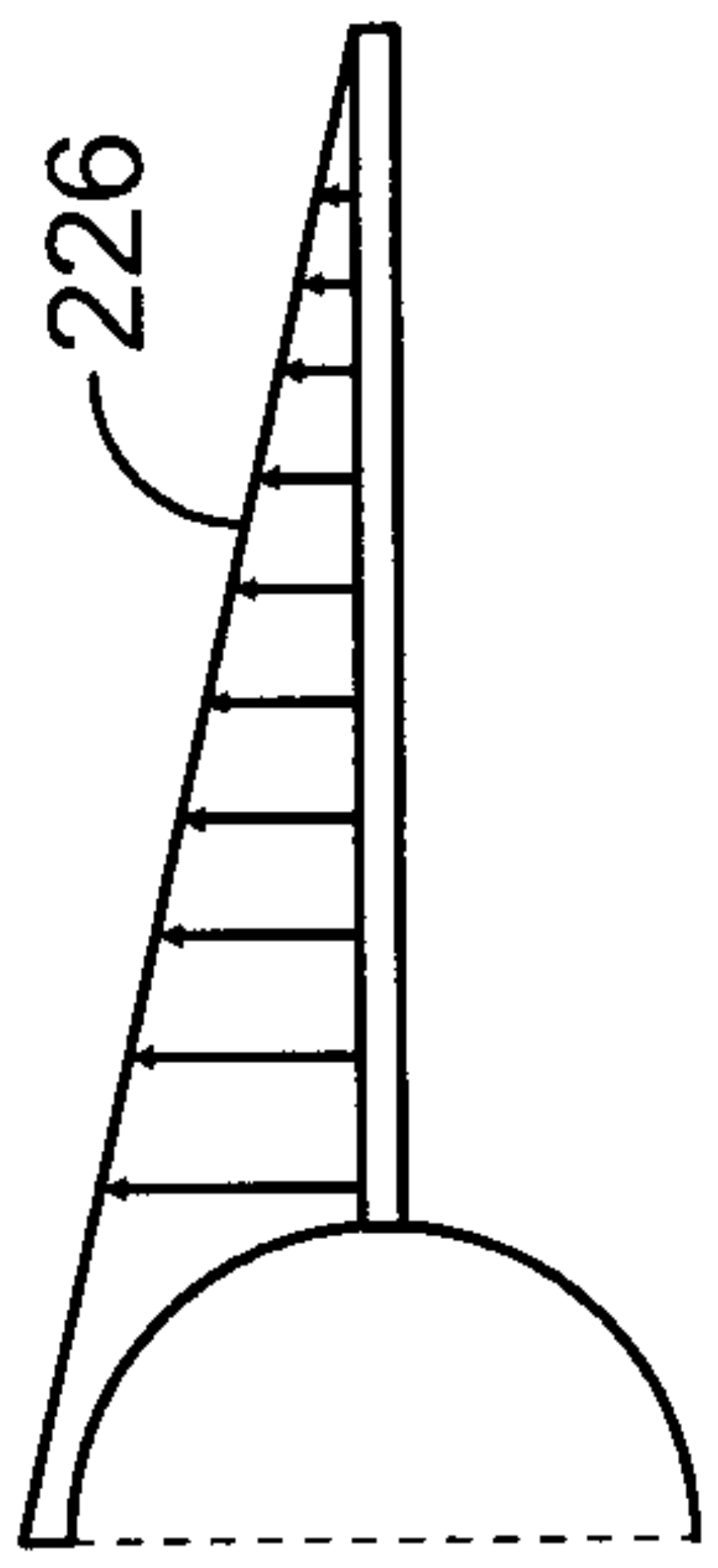


FIG. 2C

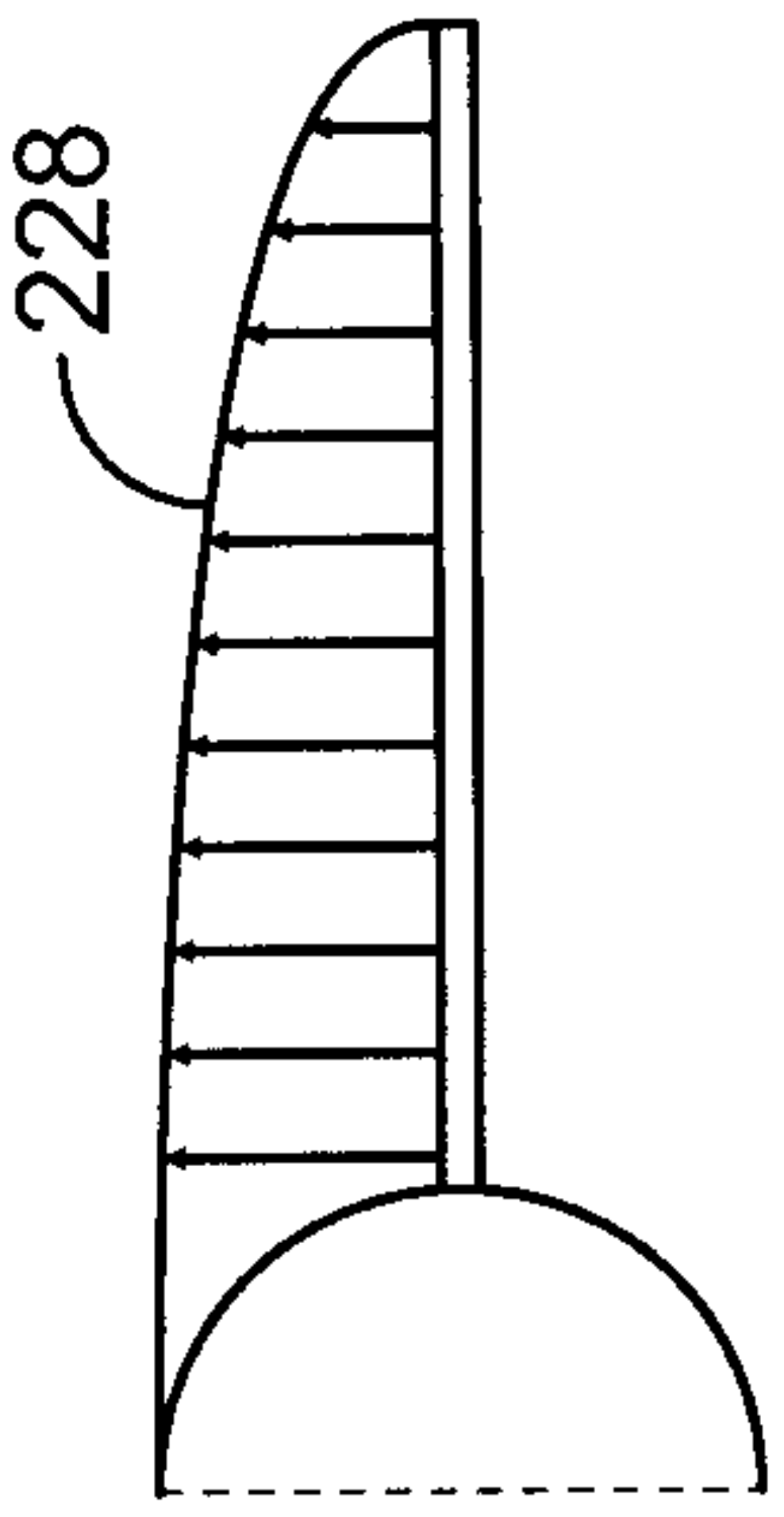


FIG. 2D

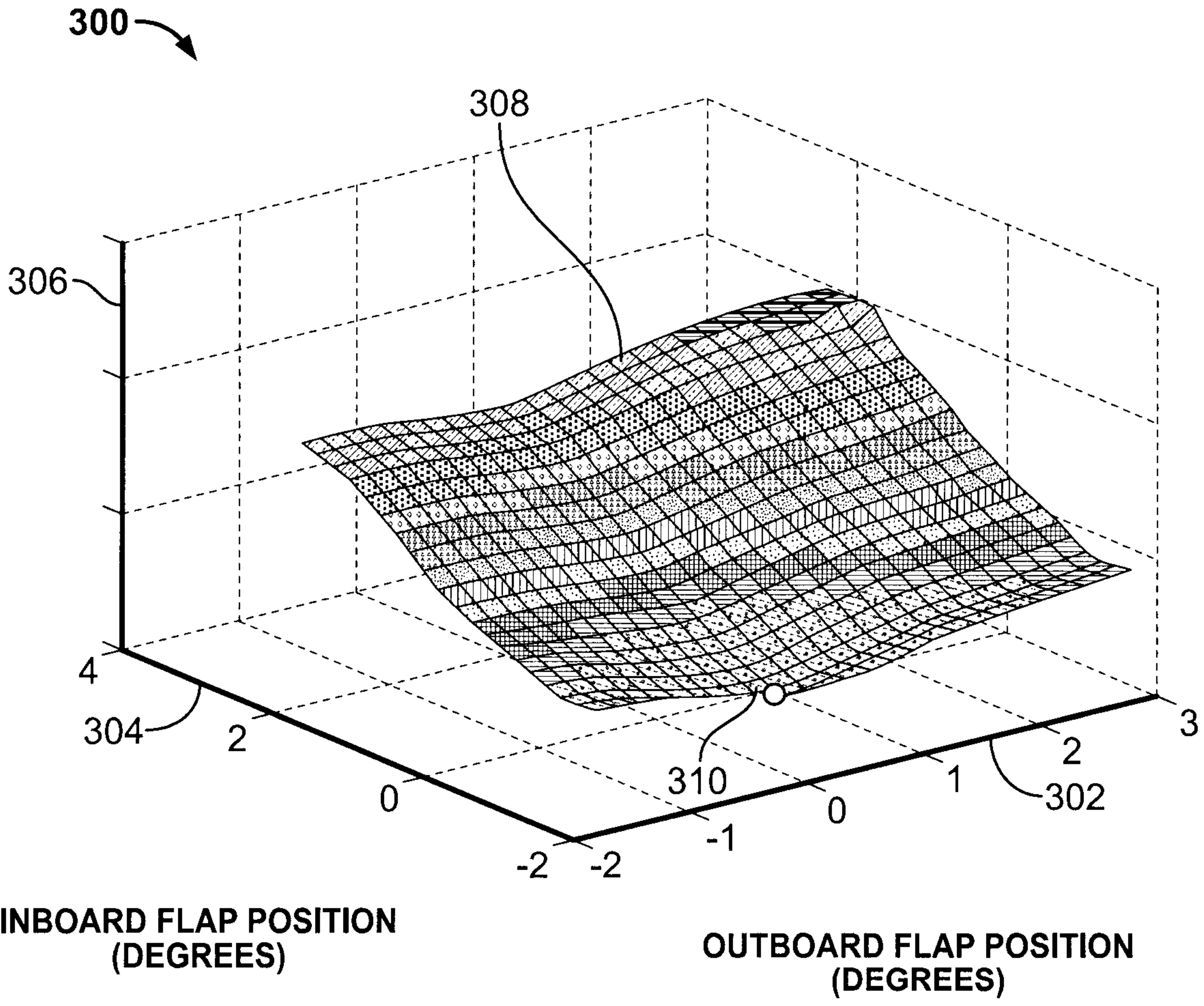

300
308
306
C_d
4
304
2
0
-2
-2
-1
310
0
1
2
302
3
INBOARD FLAP POSITION (DEGREES)
OUTBOARD FLAP POSITION (DEGREES)

FIG. 3

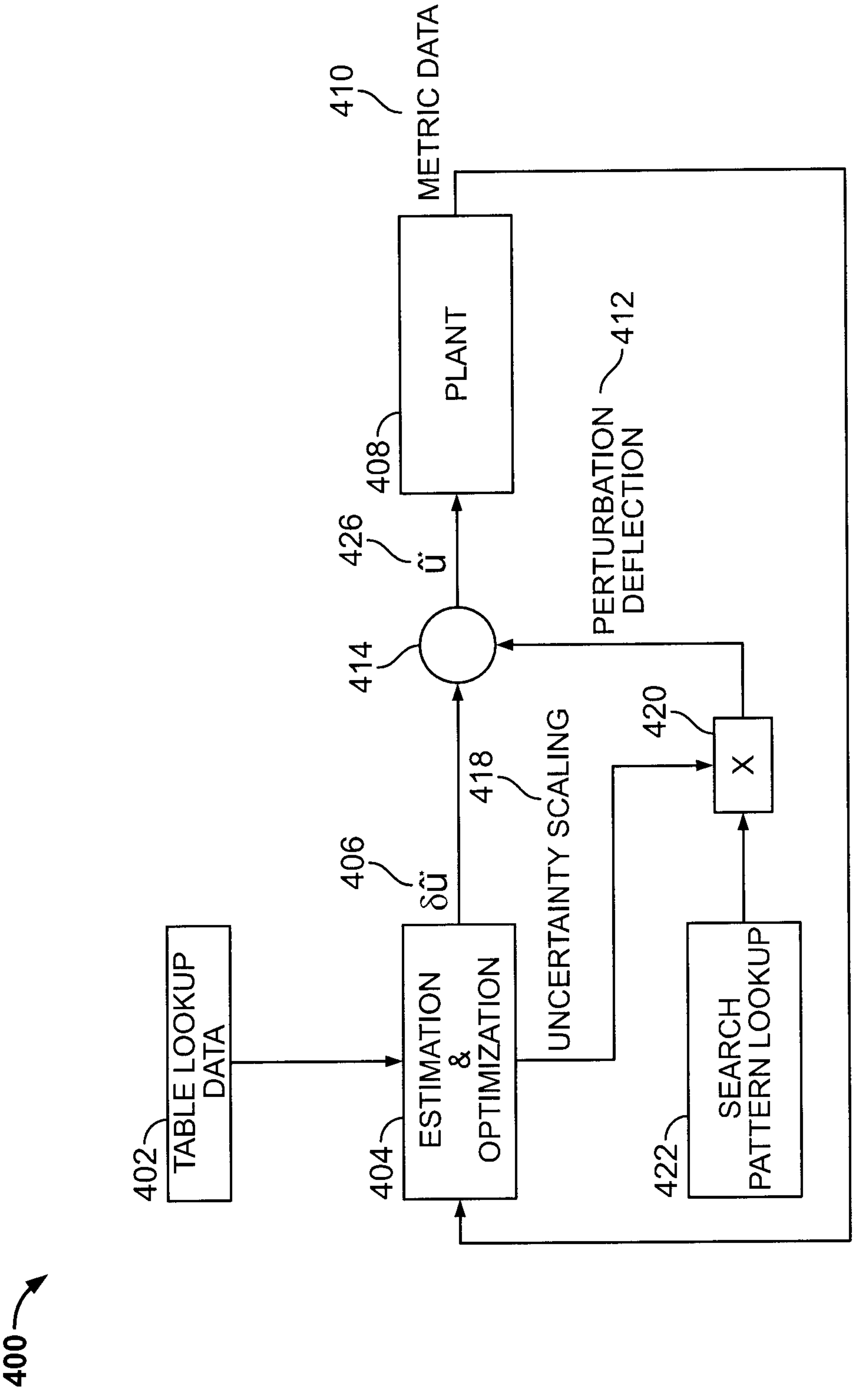

400
402
TABLE LOOKUP DATA
404
ESTIMATION & OPTIMIZATION
406
$\delta\tilde{u}$
418
UNCERTAINTY SCALING
422
SEARCH PATTERN LOOKUP
420
X
414
426
$\tilde{u}$
PERTURBATION DEFLECTION
412
408
PLANT
410
METRIC DATA

FIG. 4

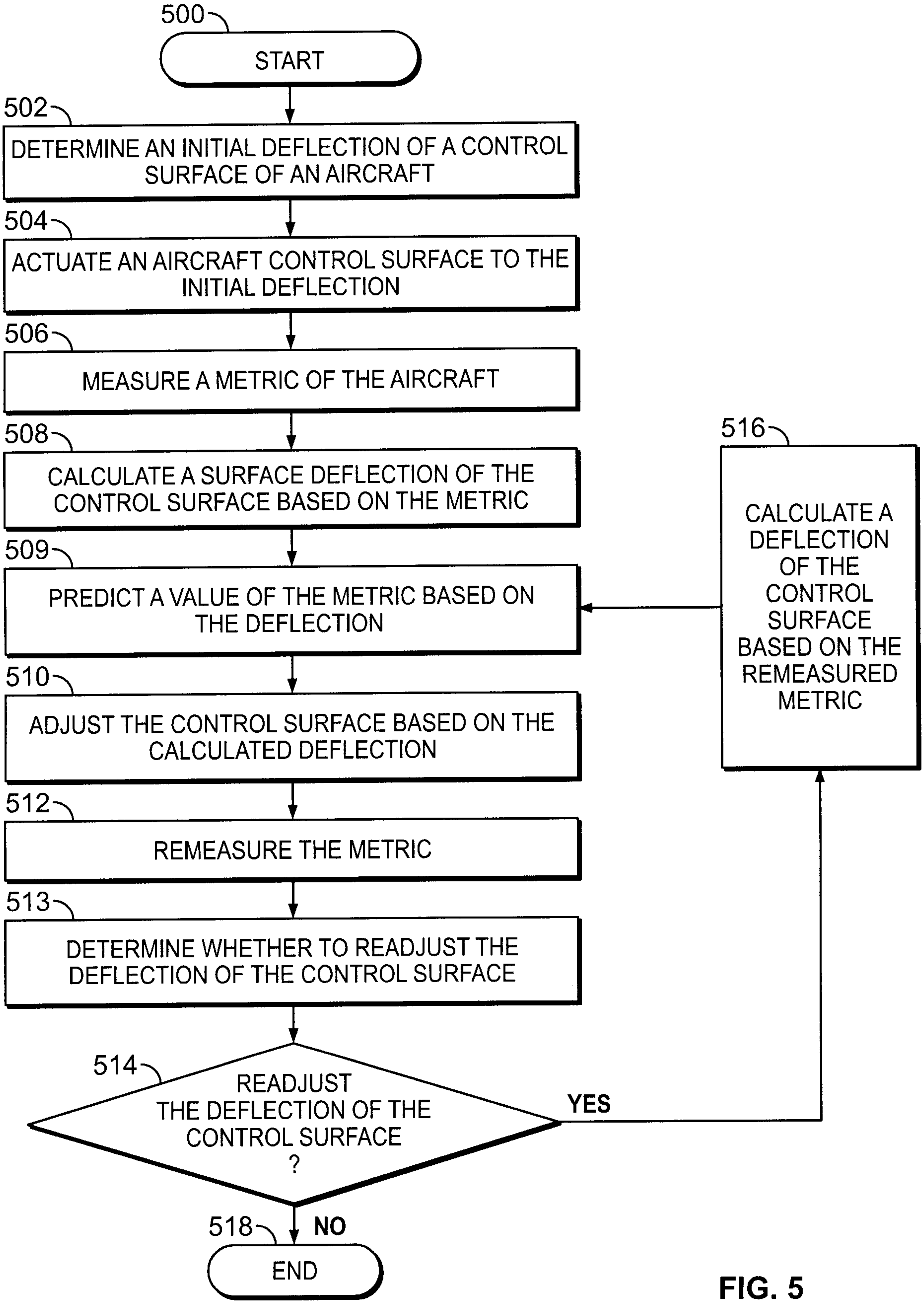

500
START
502
DETERMINE AN INITIAL DEFLECTION OF A CONTROL SURFACE OF AN AIRCRAFT
504
ACTUATE AN AIRCRAFT CONTROL SURFACE TO THE INITIAL DEFLECTION
506
MEASURE A METRIC OF THE AIRCRAFT
508
CALCULATE A SURFACE DEFLECTION OF THE CONTROL SURFACE BASED ON THE METRIC
509
PREDICT A VALUE OF THE METRIC BASED ON THE DEFLECTION
510
ADJUST THE CONTROL SURFACE BASED ON THE CALCULATED DEFLECTION
512
REMEASURE THE METRIC
513
DETERMINE WHETHER TO READJUST THE DEFLECTION OF THE CONTROL SURFACE
514
READJUST THE DEFLECTION OF THE CONTROL SURFACE ?
YES
516
CALCULATE A DEFLECTION OF THE CONTROL SURFACE BASED ON THE REMEASURED METRIC
518
NO
END

FIG. 5

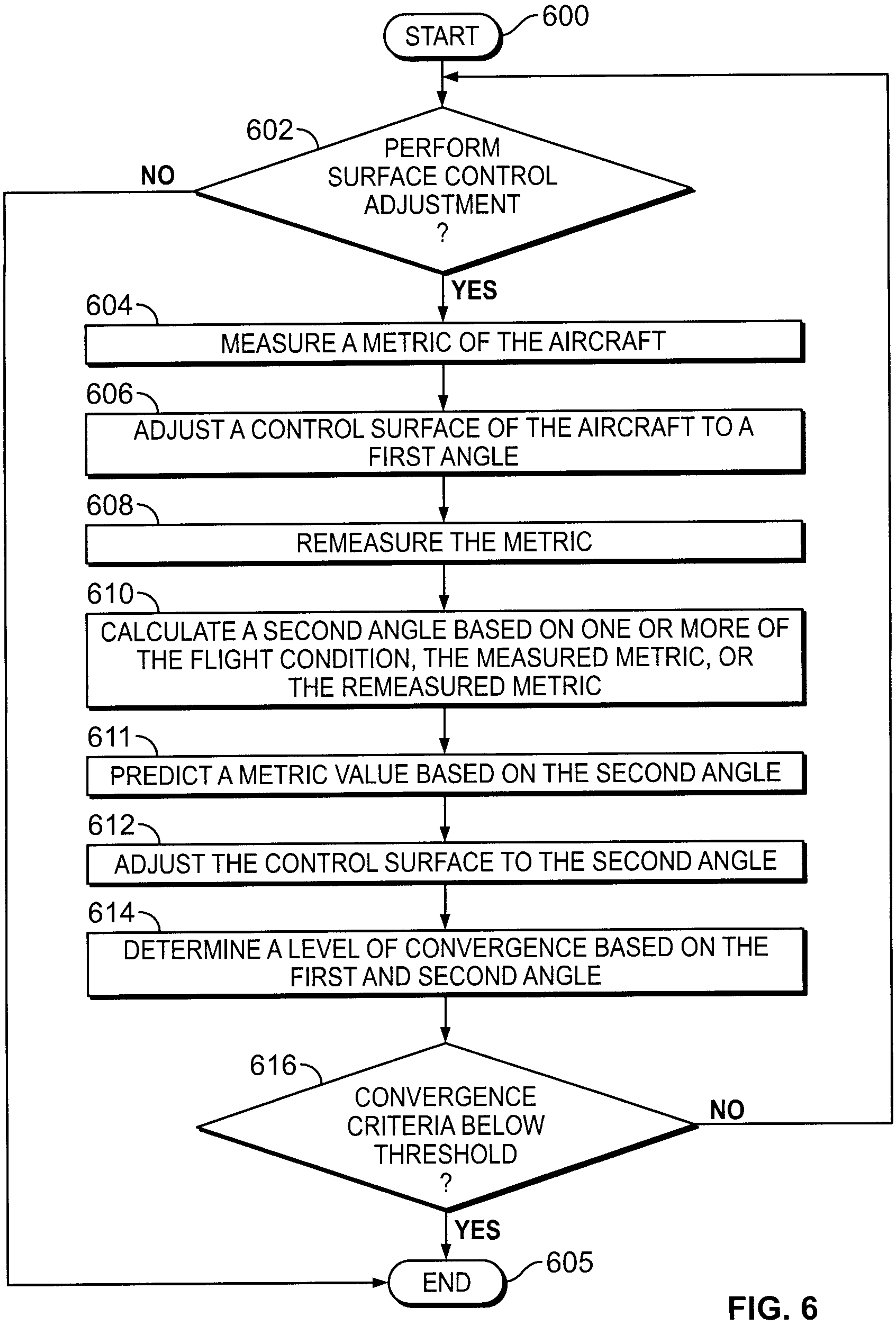

START
600
602
PERFORM SURFACE CONTROL ADJUSTMENT ?
NO
YES
604
MEASURE A METRIC OF THE AIRCRAFT
606
ADJUST A CONTROL SURFACE OF THE AIRCRAFT TO A FIRST ANGLE
608
REMEASURE THE METRIC
610
CALCULATE A SECOND ANGLE BASED ON ONE OR MORE OF THE FLIGHT CONDITION, THE MEASURED METRIC, OR THE REMEASURED METRIC
611
PREDICT A METRIC VALUE BASED ON THE SECOND ANGLE
612
ADJUST THE CONTROL SURFACE TO THE SECOND ANGLE
614
DETERMINE A LEVEL OF CONVERGENCE BASED ON THE FIRST AND SECOND ANGLE
616
CONVERGENCE CRITERIA BELOW THRESHOLD ?
NO
YES
END
605

FIG. 6

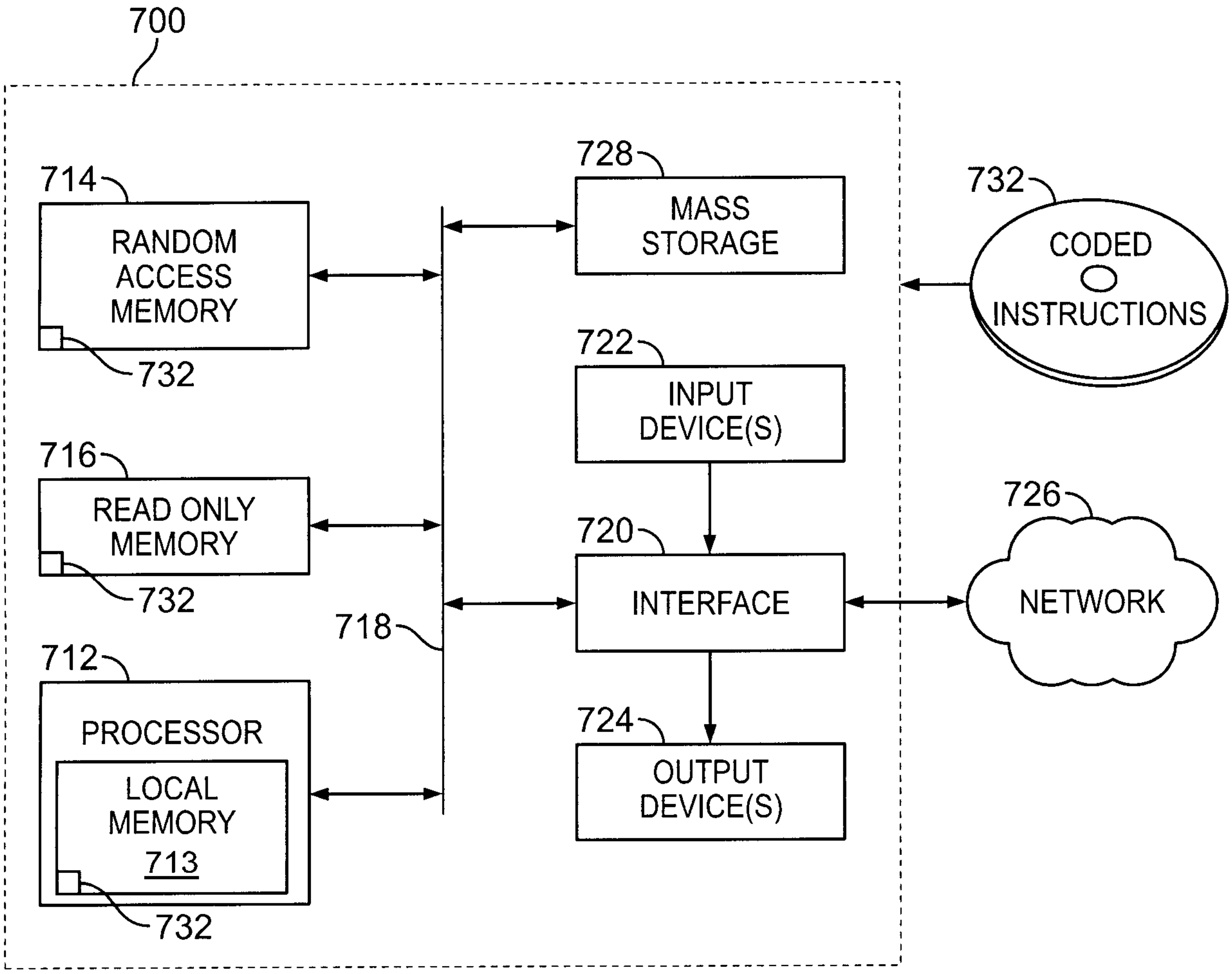

700
714
RANDOM ACCESS MEMORY
732
716
READ ONLY MEMORY
732
712
PROCESSOR
LOCAL MEMORY
713
732
718
728
MASS STORAGE
722
INPUT DEVICE(S)
720
INTERFACE
724
OUTPUT DEVICE(S)
732
CODED INSTRUCTIONS
726
NETWORK

FIG. 7

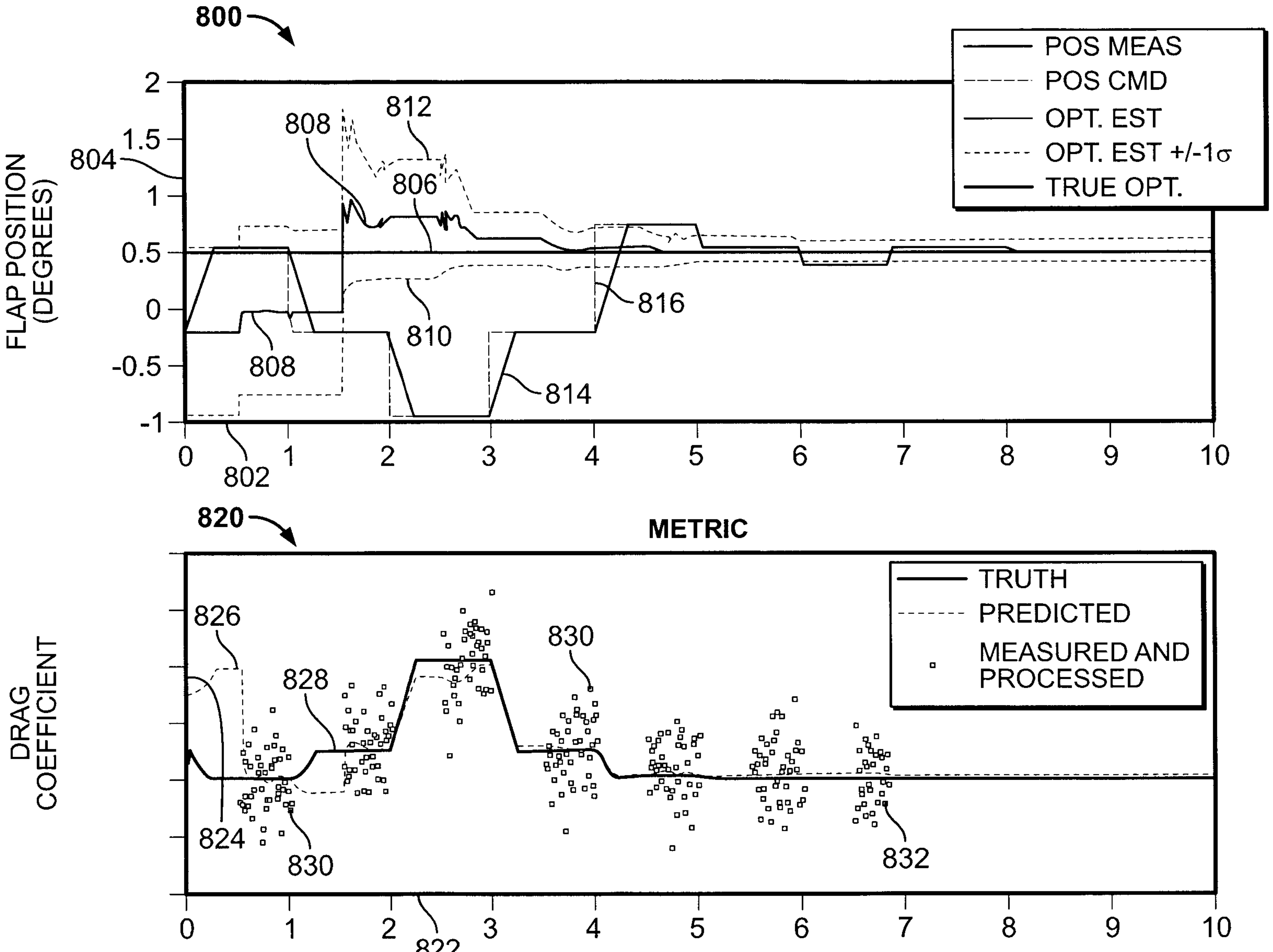
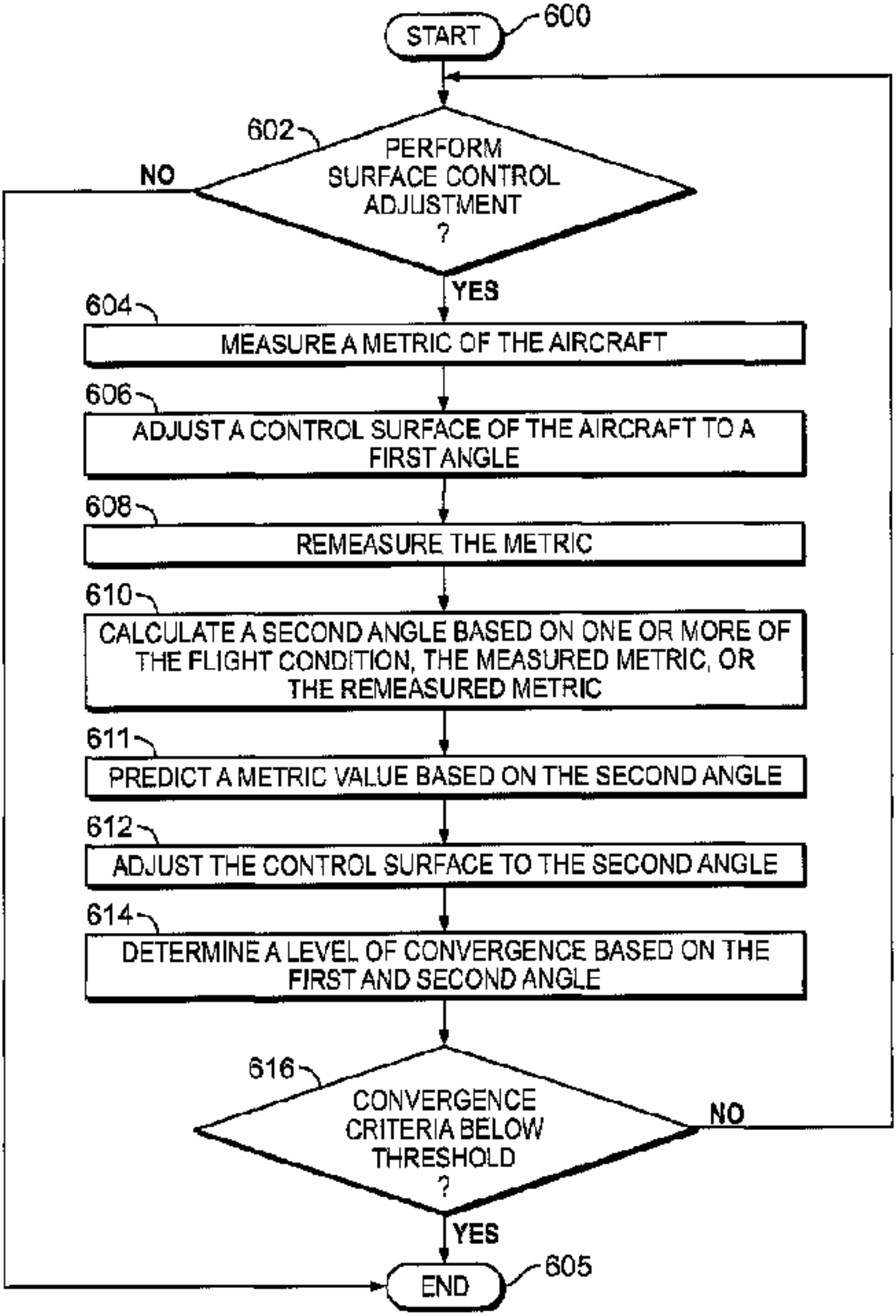

800
POS MEAS
POS CMD
OPT. EST
OPT. EST +/-1σ
TRUE OPT.
FLAP POSITION (DEGREES)
2
1.5
1
0.5
0
-0.5
-1
804
808
812
806
810
808
816
814
802
0
1
2
3
4
5
6
7
8
9
10
820
METRIC
TRUTH
PREDICTED
MEASURED AND PROCESSED
DRAG COEFFICIENT
826
828
830
824
830
832
822
0
1
2
3
4
5
6
7
8
9
10

FIG. 8


START
600
602
PERFORM SURFACE CONTROL ADJUSTMENT ?
NO
YES
604
MEASURE A METRIC OF THE AIRCRAFT
606
ADJUST A CONTROL SURFACE OF THE AIRCRAFT TO A FIRST ANGLE
608
REMEASURE THE METRIC
610
CALCULATE A SECOND ANGLE BASED ON ONE OR MORE OF THE FLIGHT CONDITION, THE MEASURED METRIC, OR THE REMEASURED METRIC
611
PREDICT A METRIC VALUE BASED ON THE SECOND ANGLE
612
ADJUST THE CONTROL SURFACE TO THE SECOND ANGLE
614
DETERMINE A LEVEL OF CONVERGENCE BASED ON THE FIRST AND SECOND ANGLE
616
CONVERGENCE CRITERIA BELOW THRESHOLD ?
NO
YES
END
605