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(54) **METHODS AND SYSTEMS FOR GRAPHICAL REPRESENTATION OF REQUIRED TIME OF ARRIVAL (RTA) CONSTRAINT INFORMATION**

(57) Human-machine interface for required time of arrival (RTA) constraint negotiation. Embodiments present critical RTA information and results of associated data calculations to the pilot in a concise and informative manner using a dialogue box with intuitive graphical displays. Embodiments present critical RTA information to assist a pilot in negotiating the RTA constraint with air traffic controllers, accepting the clearance, and having confidence in the system that it will achieve the defined RTA constraint.

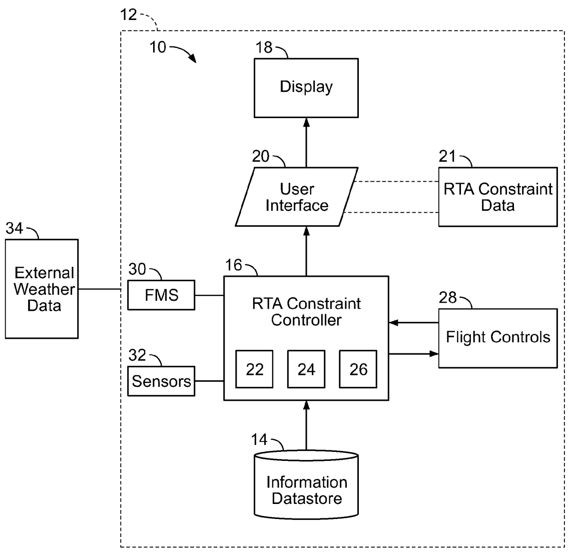

FIG. 1

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Description

TECHNICAL FIELD

[0001] The present disclosure generally relates to methods and systems for presenting flight information on a display, and more particularly relates to methods and systems for graphical representation of required time of arrival (RTA) constraint information on a display of an aircraft.

CROSS-REFERENCE TO RELATED APPLICATION

[0002] This application claims the benefit of IN Provisional Application No. 202011025274, filed June 16, 2020, which is incorporated herein by reference in its entirety.

BACKGROUND

[0003] A function on many available flight management systems (FMS) on an aircraft provides the crew with the ability to enter a Required Time of Arrival (RTA) at a waypoint that is part of a given flight plan. The FMS adjusts the speed profile for the climb flight phase, cruise flight phase, and descent flight phase, as appropriate, in order to arrive at the waypoint within the prescribed RTA, thus improving the predictability of the aircraft. This function is also sometimes called TOAC (Time Of Arrival Control), as part of the arrival management.

[0004] The combination of the RTA and the waypoint may be referred to as an RTA constraint. A technical problem is presented in that many available FMS on an aircraft are insufficient to meet new requirements that the pilot negotiate with Air Traffic Control (ATC) to define an RTA constraint that can be met with a 95% reliable confidence. To meet this confidence level, a pilot may need much more readily and intuitively available information than the available FMS functions can provide.

[0005] Accordingly, improved methods and systems supporting RTA constraints are desirable. Specifically, improved methods and systems for graphical representation of required time of arrival (RTA) constraint information on a display of an aircraft are desirable. Other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

SUMMARY

[0006] This summary is provided to describe select concepts in a simplified form that are further described in the Detailed Description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0007] In accordance with various embodiments, a method for managing required time of arrival (RTA) information for an aircraft and displaying it on a display device configured to generate a display including a trajectory of the aircraft on a flight plan (FP) is provided. The method includes: at a processor, receiving aircraft status data for the aircraft; receiving aircraft performance data from onboard sensors; determining a plurality of phases of flight for the FP; receiving user RTA clearance input including an RTA waypoint on the FP, an associated RTA, and a time tolerance at the RTA; receiving a user input RTA limit speed; computing RTA limits based on the RTA and the time tolerance at the RTA; referencing environmental data; constructing a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed; computing an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data; computing an ETA window based on the RTA limits and the aircraft performance data; adjusting a phase of flight speed to meet the respective speed target for at least one of the plurality of phases of flight, responsive to the ETA; generating a dialogue box in a dedicated area on the display; and presenting, using graphical display techniques, critical data including the RTA, RTA limits, estimated time of arrival (ETA), and the ETA Window, wherein the presenting includes utilizing a visualization technique to depict a performance-tolerance on one or more of the critical data, the performance tolerance being a function of the aircraft performance data.

[0008] Also provided is a system for managing required time of arrival (RTA) information for an aircraft and displaying it on a display device configured to generate a display including a trajectory of the aircraft on a flight plan (FP), comprising: a memory comprising an RTA constraint controller program; and a processor coupled to the memory and configured to: receive aircraft status data for the aircraft; receive aircraft performance data from onboard sensors; determine a plurality of phases of flight for the FP; receive user RTA clearance input including an RTA waypoint on the FP, an associated RTA, and a time tolerance at the RTA; receive a user input RTA limit speed; compute RTA limits based on the RTA and the time tolerance at the RTA; receive environmental data; construct a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed; compute an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data; compute an ETA window based on the RTA limits and the aircraft performance data; adjust a phase of flight speed to meet the respective speed target for at least one of the plurality of phases of flight, responsive to the ETA; generate a dialogue box in a dedicated area on the display; present, using graphical display techniques, critical data including the RTA, RTA limits, estimated time of arrival (ETA), and the ETA Window, wherein the presenting includes utilizing a visualization technique to depict a performance-tolerance on one or more of the critical data, the performance tolerance being a function of the aircraft performance data.

[0009] Also provided is an embodiment of an aircraft. The aircraft including: a display device configured to generate a display including a trajectory of the aircraft on a flight plan (FP); and a system for managing required time of arrival (RTA) information for the aircraft and displaying it on the display device, comprising: a memory comprising an RTA constraint controller program; and a processor coupled to the memory and configured to: receive aircraft status data for the aircraft; receive aircraft performance data from onboard sensors; determine a plurality of phases of flight for the FP; receive user RTA clearance input including an RTA waypoint on the FP, an associated RTA, and a time tolerance at the RTA; receive a user input RTA limit speed; compute RTA limits based on the RTA and the time tolerance at the RTA; receive environmental data; construct a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed; compute an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data; compute an ETA window based on the RTA limits and the aircraft performance data; adjust a phase of flight speed to meet the respective speed target for at least one of the plurality of phases of flight, responsive to the ETA; compute a time error, defined as a difference between the RTA and the ETA; generate a dialogue box in a dedicated area on the display; and present, using graphical display techniques, critical data including the RTA, RTA limits, time error, estimated time of arrival (ETA), and the ETA Window, wherein the presenting includes utilizing a visualization technique to depict a performance-tolerance on one or more of the critical data, the performance tolerance being a function of the aircraft performance data.

[0010] Furthermore, other desirable features and characteristics of the [system/method] will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the preceding background.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will hereinafter be described in conjunction with the following figures, wherein like numerals denote like elements, and wherein:

FIG. 1 is a functional block diagram illustrating a system for graphical representation of required time of arrival (RTA) constraint information for an aircraft in accordance with exemplary embodiments;

FIG. 2 illustrates an arrangement of a cockpit display with a dialog box of the user interface that may be generated by an RTA constraint controller, in accordance with exemplary embodiments;

FIGS. 3-9 illustrate various graphical representations of critical data for an RTA constraint on the dialogue box of the graphical user interface generated by the RTA constraint controller, in accordance with exemplary embodiments

FIG. 10 is a process diagram for a system for graphical representation of required time of arrival (RTA) constraint information for an aircraft, in accordance with exemplary embodiments;

FIG. 11 provides a use case for a system for graphical representation of required time of arrival (RTA) constraint information for an aircraft, in accordance with exemplary embodiments; and

FIG. 12 is a method for graphical representation of required time of arrival (RTA) constraint information for an aircraft, in accordance with exemplary embodiments.

DETAILED DESCRIPTION

[0012] The following detailed description is merely exemplary in nature and is not intended to limit the disclosure or the application and uses of the disclosure. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Thus, any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments. All of the embodiments described herein are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention which is defined by the claims. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary, or the following detailed description.

[0013] The addition of RTA information to a cockpit display, as disclosed in Bretislav et al., U.S. Patent No. 9,047,763 B2 "METHODS AND SYSTEMS FOR REPRESENTING TIME OF ARRIVAL INFORMATION ON A COCKPIT DISPLAY," has increased a pilot's ability to comprehend time of arrival information. The provided embodiments enhance existing RTA functionality by generating and displaying a user interface having at least these additional features:

- User interface enables entry of RTA parameters to define the RTA constraint, such as, but not limited to: a waypoint to apply, the time of the constraint, the type or definition of the bounds of the constraint, the acceptable error to the time, any limits on speeds across the flight phases to be apply to account for passenger comfort, aircraft performance limits, crew preferences, and fuel economy.

- User interface employs intuitive Human Factors to construct a dialogue box and present thereon a graphical display of critical RTA data and information necessary for a pilot to negotiate the RTA constraint with an air traffic controller and to monitor the progress to the RTA constraint throughout the flight. This encompasses information on definition of the RTA constraint, ETA Window of the earliest and latest confident ETA times, predicted ETA of the aircraft. This uses symbology that can be quickly digested by the crew.

- User interface presents a status of the system's ability to meet the constraint including on time, early or late arrivals and the error to the time if the system cannot control to meet the constraint due to unplanned wind condition, an AC limitation, a Flight Planning limitation or a crew defined limitations.
- User interface provides the capability for the crew to Activate/Deactivate the RTA at any point of time, in different phases of flight. Deactivating the RTA implies that the time constraint is deactivated from the flight plan, but it is retained for recovery later.
- User interface provides the capability for the crew could turn on/off RTA for speed control. In addition, Pilots have visibility into the speed targets that will be flown for each region of the flight.
- User interface provides a separate pilot or crew Interface for defining/modifying the RTA Limits for Climb/Cruise/Descent phases of flight and associated limits display.
- User interface provides a graphical display and symbology to represent the state in which the system cannot resolve a reliable solution to meet the constraint.

[0014] Referring now to FIG. 1, exemplary embodiments of the present disclosure are directed to graphical representations of required time of arrival (RTA) constraint information system shown generally at **10** (shortened hereinafter to system **10**) that is associated with an aircraft **12.** The system **10** includes an RTA constraint controller **16** that implements an algorithm and causes the system **10** to perform the functions described herein. As can be appreciated, in various embodiments, the RTA constraint controller **16** can be implemented in any aircraft **12** as an enhanced computing device that is associated with a display device, where the enhanced computing device includes at least a processor **22,** one or more data storage devices **24,** and input/output (IO) circuitry **26** for communication.

[0015] As shown in FIG. 1, the system **10** includes, but is not limited to, an information datastore **14,** the RTA constraint controller **16,** onboard sensors **32,** and a display **18.** The RTA constraint controller **16** transmits commands to and receives data from various flight controls **28.** The RTA constraint controller **16** may be incorporated within or separate from, an existing Flight Management System (FMS **30**). The RTA constraint controller **16** is configured to receive data from external sources, such as weather data source **34**.

[0016] The information datastore **14** stores RTA definition information and pre-calculated time of arrival data which includes, but is not limited to, precalculated estimated time of arrival minimum and maximum predictions for given waypoints of a flight plan, precalculated optimal time of arrival, precalculated fuel predictions, precalculated impact on estimated time en-route (ETE), precalculated estimated time of arrival to destination (ETA), the precalculated estimated distance to go (DTG), and the estimated time of departure (ETD). The values of the precalculated time of arrival data are pre-calculated iteratively with an appropriate confidence envelope and may be stored in the information datastore **14** during an initialization step. As can be appreciated, the information datastore **14** may reside in a data storage device of an enhanced computing device on the aircraft **12,** may reside in a data storage device on an enhanced computing device at a location remote from the aircraft **12** (e.g., on a central server), or may partially reside on the computing device of the aircraft **12** and partially on the computing device at the location remote from the aircraft **12.**

[0017] In various embodiments, the RTA constraint controller **16** includes the processor **22** and one or more instructions implementing an algorithm, for example, as a RTA constraint controller software program stored in memory **24,** that may be executed by the processor **22.** In general, the instructions of the RTA constraint controller **16** coordinate access to and use of the information datastore **14,** construct critical data for an RTA constraint **21** based on the precalculated information in the information datastore **14,** and generate a user interface **20** having graphical representations of the critical data for the RTA constraint **21.** As can be appreciated, depending on the location of the information datastore **14,** the RTA constraint controller **16** may communicate with the information datastore **14** directly, and/or may communicate with the information datastore **14** indirectly through one or more communication circuits and protocols.

[0018] The display **18** is a display device that displays at least a part of the user interface **20.** The display **18** may be located in a cockpit of the aircraft **12** for viewing by, for example, a pilot of the aircraft **12.** In various embodiments, the display **18** can be an interactive display (e.g., a touch screen, or other interactive display) that accepts user input from a user through one or more user input devices (for example, FIG. 10, input device **1004**). For example, a pilot may interact with the user interface **20** using one or more input devices to cause the system to display the estimated time of arrival related information. In another example, the user interface **20** may automatically display the critical data for the RTA constraint **21** based on a flight condition of the aircraft **12** and/or based on information entered by a user.

[0019] In various embodiments, as shown in FIG. 2, the lateral display **206** of a cockpit display generally includes a display box **204** with a lateral display **206** that displays the trajectory of the aircraft **12** along a flight path **208** (e.g., displayed in two or three dimensions), and one or more waypoints. With respect to a waypoint **210** of the RTA constraint operation, the system **10** presents various graphical representations of the critical RTA constraint data **21** in a dialogue box **202** alongside the display box **204,** the specific presentation of the RTA constraint data **21,** as illustrated in FIGS. 3-9, is in accordance with rules and algorithms of the graphical user interface **20.**

[0020] Turning now to FIG. 3, and with continued reference to FIGS. 1-2, the dialogue box **300** displays the waypoint **302** of the RTA constraint operation and the calculated critical data for the RTA constraint **21** to the pilot such that it can be used in the required time of arrival negotiation process between the Air Traffic Controller (ATCo) and the pilot. By means of the user interface **20** and the display methods discussed herein, the pilot can assess different solutions along any point of an already negotiated two or three-dimensional trajectory as requested by the ATCo.

[0021] Dialogue box **300** displays the waypoint **302** name and an RTA progress tab **303** displays the calculated critical data for the RTA constraint **21.** The calculated critical data for the RTA constraint **21** displayed by the user interface **20** may include, but is not limited to, an RTA type **304,** an RTA time **306,** an indication of whether the RTA is active (RTA activation **308**), an area to indicate any RTA error and RTA status **310,** an RTA pointer **312,** a latest ETA **316,** an ETA window band **318,** an allowable band **320** (may be depicted in a first color, such as green), a tolerance band **322** (may be depicted in a second color, such as white), an ETA pointer **324,** an earliest ETA **326,** a current RTA speed target **328,** an indicator for RTA Fix DTG **330,** and an indicator for ETD **332.** Each of these items of data will be described in more detail below.

[0022] With reference to FIG. 4, dialog box **400** shows two additional graphical display features generated by the RTA constraint controller **16** to improve the human-machine interface presentation of critical data for the RTA constraint **21.** An RTA status timeline **402** is added in an area below the RTA activation **308** object; and a Negotiation/Prediction timeline **404** is added to provide detail to the demarcation line connecting the Earliest ETA **326** and Latest ETA **316.**

[0023] FIGS 5-6 illustrate examples of the RTA status timeline **402** feature. In FIG. 5, the RTA type **304** is "at or after," and the text for the RTA status **310** indicates "00:08:30 Early." RTA time text **502** is displayed as 11:45:00+/-10 and an indicator **506** (shown as a first color block) indicates the RTA acceptable range **506** around the RTA time **504.** With respect to the RTA acceptable range **506,** it is bounded by an RTA maximum and an RTA minimum, and based on the current limitations (aircraft performance, environmental, etc), a speed to achieve the RTA maximum and RTA minimum is dynamically calculated. Where either the RTA maximum or RTA minimum are constrained, a constraint boundary symbol is used. IN FIG. 5, a constraint boundary symbol **508** is depicted at the left of the indicator **506;** in this example, the constraint boundary symbol **508** is a triangle oriented to point to the indicator **506.** There is no constraint boundary symbol on the right, at the maximum RTA, in FIG. 5. An indicator for time error line **510** is to the left of the constraint boundary symbol **508,** and this may be scaled to show a time reference and may be rendered in a second color. The time error represents a difference between a pilot input constraint (RTA goal at the waypoint) and the estimated time of arrival at the waypoint. A demarcation line **512** may be placed horizontally below the indicators and symbols **504-510.**

[0024] In FIG. 6, the RTA type **304** is "at," and the text for RTA status **310** indicates "On time." RTA time text **502** is 11:45:00+/-10 and an indicator **506** (shown as a first color block) indicates the RTA acceptable range **506** around the RTA time **504.** Constraint boundary symbol **508** is depicted at the left of the indicator **506;** in this example, the constraint boundary symbol **508** is a triangle oriented to point to the indicator **506.** Constraint boundary symbol **602** is depicted at the right of the indicator **506;** in this example, the constraint boundary symbol **508** is a triangle oriented to point to the indicator **506.**

[0025] FIG. 7 provides detail for graphical information displayed below the demarcation line **512,** on the Negotiation/Prediction timeline **404.** A Control Confidence Band **702** is scaled to a time difference and rendered underneath the demarcation line **512,** bisected by the predicted ETA of the aircraft **710.** An indicator for aircraft physical limits **704** is shown as a hatched area that extends the control confidence band **702** to the left. An indicator for aircraft physical limits **706** is shown as a hatched area that extends the control confidence band **702** to the right. The Earliest confidence time **708** is indicated with a marker on the control confidence band **702.**

[0026] FIGS. 8-9 depict various ways in which the system **10** may use the graphical display to indicate to the pilot that the 95% reliable condition cannot be met for the waypoint. In FIG. 8, dialog box **800** displays "Unreliable RTA" **802** in the area that previously displayed the Negotiation/Prediction Timeline **404.** In FIG. 9, dialog box **900** omits much of the previously described calculated critical data for the RTA constraint **21.**

[0027] Having described the graphical presentation of the critical data for the RTA constraint **21,** via the user interface **20,** we now discuss functionality of the system **10** and the RTA constraint controller **16.** Turning now to FIGS. 10-11, in various embodiments of the system **10,** rules embodied in an algorithm of the RTA constraint controller **16** may direct the receipt of inputs **1002,** such as flight plan data, RTA inputs, and user input, and generation of output commands, data, and controls, such as aircraft control **1008** and speed targets **1006.** The rules embodied in the algorithm of the RTA constraint controller **16** may direct the graphical user interface **20** and presentation of critical RTA constraint data **21** on the display **18.** In various embodiments, the RTA constraint controller **16** may also manage the presentation of the lateral display (FIG. 2, **206**) and a vertical situation display.

[0028] With regard to the inputs **1002,** the user input may be received based on a user interacting with the user interface **20.** The user input may include activating/deactivating the RTA constraint controller **16** functionality, enabling/disabling the RTA, speed limits for a climb, a cruise, and a descent flight phase, the specific waypoint **210,** a target RTA time, and a waypoint distance offset. Other inputs **1002** shown in FIG. 11 may be provided by a Datalink, via ATC transcription, or via a connected technology, these other inputs include a required time of arrival (RTA) definition data waypoint and its position constraint type (at, before, or after) time, an estimated time of departure (ETD), and an RTA tolerance value.

[0029] As mentioned, the RTA constraint controller **16** may receive forecasted external weather reports, and current weather data from onboard sensors **32.** The flight plan (FP) data may be received from a flight plan database or other on-board system or module in control of the flight plan, including the FMS **30.** In various embodiments of the system **10,** the RTA constraint controller **16** may be partitioned into any number of sub-modules, each directed to performing a different process of system **10.** Accordingly, in various embodiments, the RTA constraint controller **16** includes an RTA optimization module **1010,** a real time calculations module **1012,** a trajectory prediction module **1014,** and an earlies/latest ETA module **1016.**

[0030] The RTA optimization module **1010** receives pre-calculated time of arrival data **1018** and the input flight planning data **1002,** as well as estimated RTA waypoint data output from the trajectory prediction module **1014,** and calculates adjustments for flight controls, the adjustments are received by the real time calculations module **1012,** which drives the recommended speed for achieving a target RTA; the output from the real time calculations module **1012** feeds the trajectory prediction module **1014,** the aircraft control **1008,** the speed targets **1006,** and ultimately the flight controls **28.**

[0031] The user interface **20** presents the output **1102** data as described and shown in FIGS. 3-9. For example, the displayed RTA constraint data **1104** may include the current RTA speed **328** to achieve the goal waypoint, the ETA (graphically, an ETA pointer **324,** and an ETA band - the negotiation/prediction timeline **404-** extending from an ETA earliest **326,** and ETA latest **316**). The time error is also included with the RTA status **310** (the time error being a difference between the input RTA provided by the pilot and the ETA that has been calculated by the system **10**), a RTA status timeline **402** (as described in connection with FIGS. 5-6) and alphanumeric RTA status **310,** display of RTA speed limiting reasons, such as thrust or operating performance reasons, and the display of any current limitations, for example, as shown with the AC physical limits bands **704** and **706** on the control confidence band **702.** Unreliable condition **1106** feedback may be presented on the user interface **20** as shown in FIG. 8, **802,** as an alphanumeric message with other viewing areas zeroed out. The system **10** determines that an unreliable condition has occurred when it determines that the aircraft cannot meet, based on aircraft performance data or environmental (weather) data, the 95% confidence interval to meet the RTA. Additional mission feedback **1108** may be presented.

[0032] In various embodiments, the RTA constraint controller **16** retrieves from the information datastore **14** precalculated data, such as a precalculated ETA minimum data, precalculated ETA maximum data, and a precalculated optimal RTA value for a given point on the flight path that is near or associated with the waypoint **210.** The RTA constraint controller **16** data may then interpolate the precalculated data based on the RTA tolerance **1020** and a waypoint distance offset. In some embodiments, the RTA tolerance may be plus or minus ten seconds.

[0033] In various embodiments, simple linear interpolation or any other suitable interpolation procedure may be performed on the precalculated data considering internal segmentation of the flight plan related data in the information datastore **14.** The RTA constraint controller **16** data manager module may therefrom generate the critical data for the RTA constraint based on the results of the interpolation. As can be appreciated, the RTA constraint controller **16** data manager module may similarly access the information datastore **14** for the fuel impact, the ETE values, the flown distance impact, and the other values as described above.

[0034] Turning now to FIG. 12, the system **10** described above may be implemented by a processor-executable method **1200.** For illustrative purposes, the following description of method **1200** may refer to elements mentioned above in connection with FIGS. 1-11. In practice, portions of method **1200** may be performed by different components of the described system. It should be appreciated that method **1200** may include any number of additional or alternative tasks, the tasks shown in FIG. 12 need not be performed in the illustrated order, and method **1200** may be incorporated into a more comprehensive procedure or method having additional functionality not described in detail herein. Moreover, one or more of the tasks shown in FIG. 6 could be omitted from an embodiment of the method **1200** as long as the intended overall functionality remains intact.

[0035] Prior to starting method **1200,** an initialization may be performed, the initialization may include loading instructions and the software program into a processor within the RTA controller **16,** as well as loading predefined values into one or more datastore(s) **14.**

[0036] At **1202,** an RTA constraint is received, it comprises a user selected waypoint (WPT) and a required time of arrival (RTA) at the WPT. At **1204** precalculated times of arrival data are referenced for the WPT. At **1206,** critical data for the RTA constraint is calculated. The critical data calculation step **1206** include steps **1208-1212,** described in connection with respective modules in FIG. 10. At **1208,** the RTA optimization is performed, at **1210** the real time calculations using aircraft specific performance data, environmental data, and the like, are performed. At **1212** the current trajectory is predicted for the aircraft. At **1214** the earliest and latest ETA are generated for the negotiation/prediction timeline **402,** and at **1216,** the speed targets to achieve the goal of the RTA are generated. At **1218,** the suite of RTA constraint data **21** is displayed on the dialogue box **202.**

[0037] Thus, an objectively improved human-machine interface is provided for RTA constraint negotiation. Embodiments present information and results of the data calculations back to the pilot in a concise and informative manner to ease the workload of the crew in negotiating this critical constraint with ATCo, accepting the clearance and having confidence in the system that it will achieve the defined RTA constraint.

[0038] Those of skill in the art will appreciate that the various illustrative logical blocks, modules, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. Some of the embodiments and implementations are described above in terms of functional and/or logical block components (or modules) and various processing steps. However, it should be appreciated that such block components (or modules) may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention. For example, an embodiment of a system or a component may employ various integrated circuit components, e.g., memory elements, digital signal processing elements, logic elements, look-up tables, or the like, which may carry out a variety of functions under the control of one or more microprocessors or other control devices. In addition, those skilled in the art will appreciate that embodiments described herein are merely exemplary implementations.

[0039] The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0040] The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal

[0041] In this document, relational terms such as first and second, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. Numerical ordinals such as "first," "second," "third," etc. simply denote different singles of a plurality and do not imply any order or sequence unless specifically defined by the claim language. The sequence of the text in any of the claims does not imply that process steps must be performed in a temporal or logical order according to such sequence unless it is specifically defined by the language of the claim. The process steps may be interchanged in any order without departing from the scope of the invention as long as such an interchange does not contradict the claim language and is not logically nonsensical.

[0042] While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

Claims

1. A method for managing required time of arrival (RTA) information for an aircraft and displaying it on a display device configured to generate a display including a trajectory of the aircraft on a flight plan (FP), comprising:
at a processor,

    receiving aircraft status data for the aircraft;
    receiving aircraft performance data from onboard sensors;
    determining a plurality of phases of flight for the FP;
    receiving user RTA clearance input including an RTA waypoint on the FP, an associated RTA, and a time tolerance at the RTA;
    receiving a user input RTA limit speed;
    computing RTA limits based on the RTA and the time tolerance at the RTA;
    referencing environmental data;
    constructing a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed;
    computing an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data;
    computing an ETA window based on the RTA limits and the aircraft performance data;
    adjusting a phase of flight speed to meet the respective speed target for at least one of the plurality of phases of flight, responsive to the ETA;
    generating a dialogue box in a dedicated area on the display; and
    presenting, using graphical display techniques, critical data including the RTA, RTA limits, estimated time of arrival (ETA), and the ETA Window, wherein the presenting includes utilizing a visualization technique to depict a performance-tolerance on one or more of the critical data, the performance tolerance being a function of the aircraft performance data.

2. The method of claim 1, further comprising:

    computing a time error, defined as a difference between the RTA and the ETA; and
    wherein the critical data further includes the time error, displaying the time error in the dialogue box.

3. The method of claim 2, further comprising:

    determining a time status based on the time error, the time status being one of early, on time, and late; and
    wherein the critical data further includes the time status, displaying the time status in the dialogue box.

4. The method of claim 1, wherein the user RTA clearance input further includes an RTA type from among at the RTA, at or before the RTA, and at or After the RTA.

5. The method of claim 1, further comprising:

    receiving a user input modification of at least one of the user RTA clearance input and the time tolerance at the RTA; and
    repeating, based on the modification, the steps of:

        computing RTA limits based on the RTA and the time tolerance at the RTA;
        referencing environmental data;
        constructing a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed;
        computing an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data;
        computing an ETA window based on the RTA limits and the aircraft performance data; and
        adjusting a phase of flight speed to meet the respective speed target for at least one of the plurality of phases of flight, responsive to the ETA.

6. The method of claim 1, wherein the environmental data includes weather data from a weather data source, and further comprising:

    subsequent to the step of computing and validating,
    determining that the aircraft cannot achieve the RTA; and
    presenting, in the dialogue box, an unreliable condition message.

7. The method of claim 1, further comprising depicting the time error in the dialogue box as a visually distinguishable band.

8. The method of claim 1, further comprising: transmitting, via a communications circuit onboard the aircraft, the Time Error and aircraft status data to a neighbor aircraft or air traffic control (ATC).

9. The method of claim 1, further comprising: identifying an RTA speed limiting reason, responsive to determining that the aircraft cannot achieve the RTA.

10. A system for managing required time of arrival (RTA) information for an aircraft and displaying it on a display device configured to generate a display including a trajectory of the aircraft on a flight plan (FP), comprising:

a memory comprising an RTA constraint controller program; and
a processor coupled to the memory and configured to:

receive aircraft status data for the aircraft;
receive aircraft performance data from onboard sensors;
determine a plurality of phases of flight for the FP;
receive user RTA clearance input including an RTA waypoint on the FP, an associated RTA, and a time tolerance at the RTA;
receive a user input RTA limit speed;
compute RTA limits based on the RTA and the time tolerance at the RTA;
receive environmental data;
construct a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed;
compute an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data;
compute an ETA window based on the RTA limits and the aircraft performance data;
adjust a phase of flight speed to meet the respective speed target for at least one of the plurality of phases of flight, responsive to the ETA;
generate a dialogue box in a dedicated area on the display; and
present, using graphical display techniques, critical data including the RTA, RTA limits, estimated time of arrival (ETA), and the ETA Window, wherein the presenting includes utilizing a visualization technique to depict a performance-tolerance on one or more of the critical data, the performance tolerance being a function of the aircraft performance data.

11. The system of claim 10, wherein the processor is further configured to:

compute a time error, defined as a difference between the RTA and the ETA; and
wherein the critical data further includes the time error, displaying the time error in the dialogue box.

12. The system of claim 11, wherein the processor is further configured to:

determine a time status based on the time error, the time status being one of early, on time, and late; and
wherein the critical data further includes the time status, displaying the time status in the dialogue box.

13. The system of claim 10, wherein the user RTA clearance input further includes an RTA type from among at the RTA, at or before the RTA, and at or After the RTA.

14. The system of claim 11, wherein the processor is further configured to:

receive a user input modification of at least one of the user RTA clearance input and the time tolerance at the RTA; and
repeat, based on the modification, the steps of:

computing RTA limits based on the RTA and the time tolerance at the RTA;
referencing environmental data;
constructing a plan comprising, for each phase of flight of the plurality of phases of flight for the flight plan, a respective speed target, for the aircraft to arrive at the RTA within the time tolerance and as a function of the environmental data and the RTA limit speed;
computing an estimated time of arrival (ETA) based on a summation of the phase of flight speed targets and the aircraft performance data;
computing an ETA window based on the RTA limits and the aircraft performance data; and
adjusting a phase of flight speed to meet the respective speed target for at least one

of the plurality of phases of flight, responsive to the ETA.

15. The system of claim 10, wherein the environmental data includes weather data from a weather data source, and wherein the processor is further configured to:
subsequent to the step of computing and validating,

determine that the aircraft cannot achieve the RTA; and
present, in the dialogue box, an unreliable condition message.

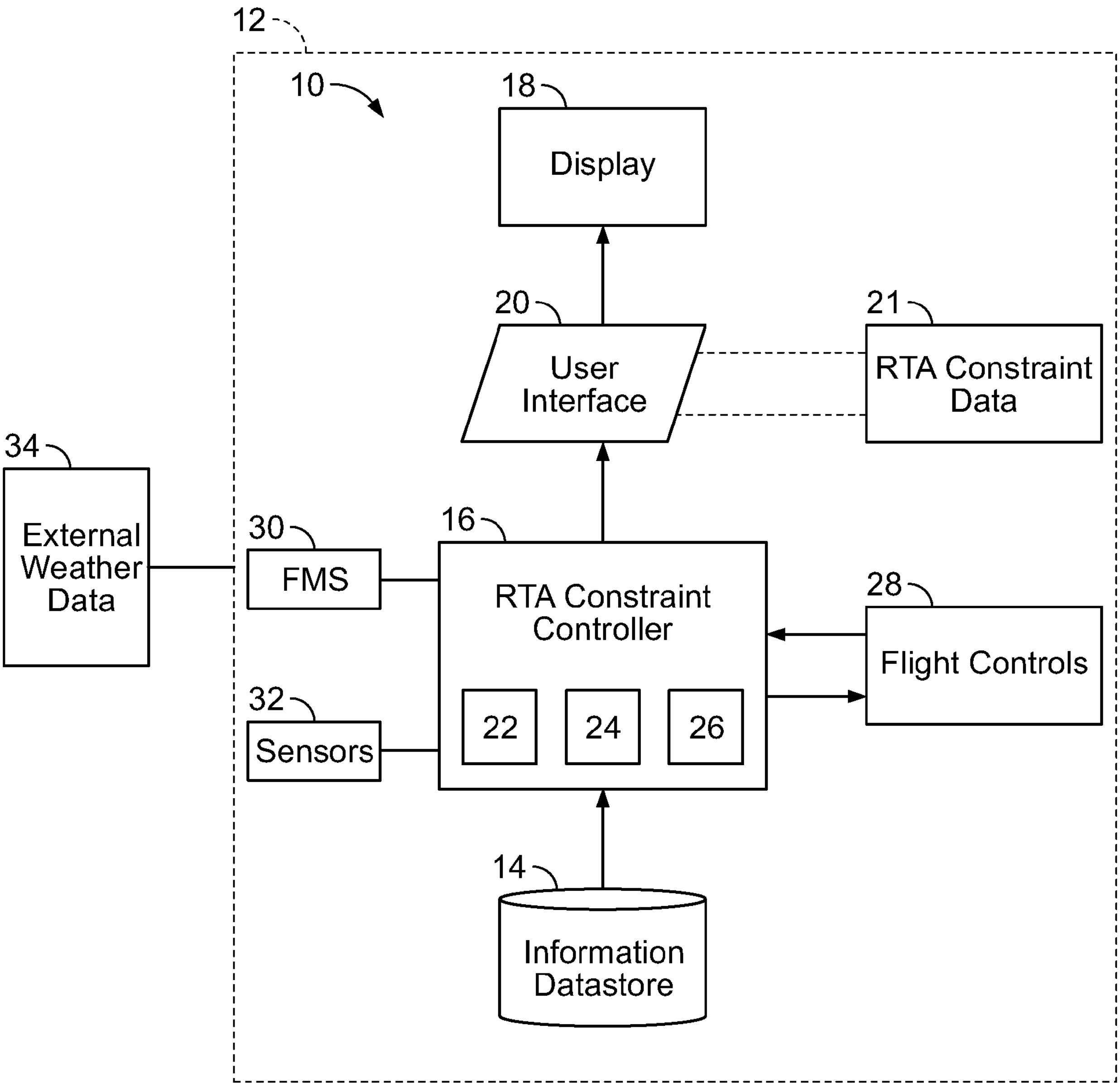

12
10
18
Display
20
User
Interface
21
RTA Constraint
Data
34
External
Weather
Data
30
FMS
16
RTA Constraint
Controller
22
24
26
28
Flight Controls
32
Sensors
14
Information
Datastore

FIG. 1

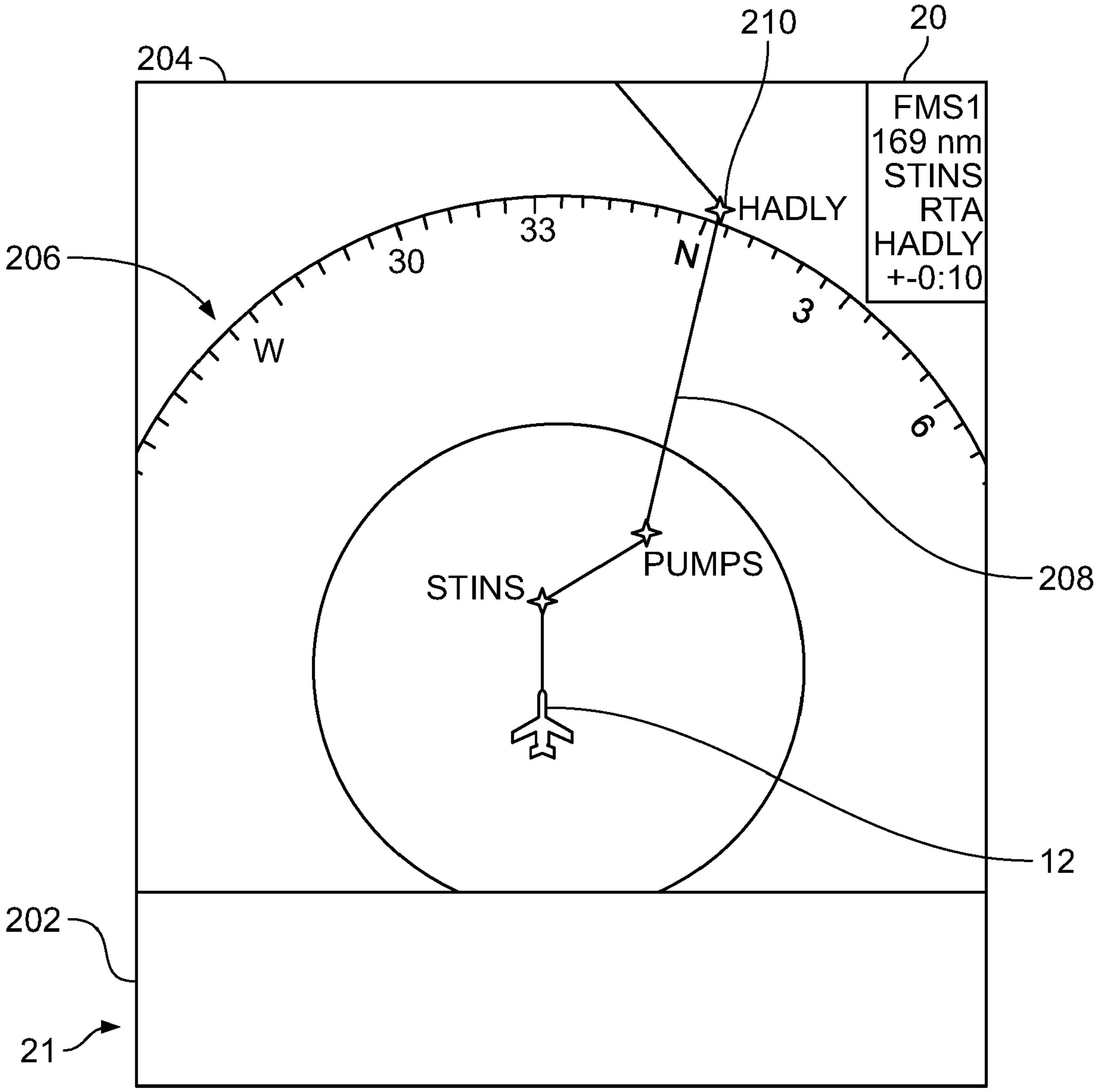

210
20
204
FMS1
169 nm
STINS
RTA
HADLY
+-0:10
HADLY
206
33
30
N
3
W
6
208
PUMPS
STINS
12
202
21

FIG. 2

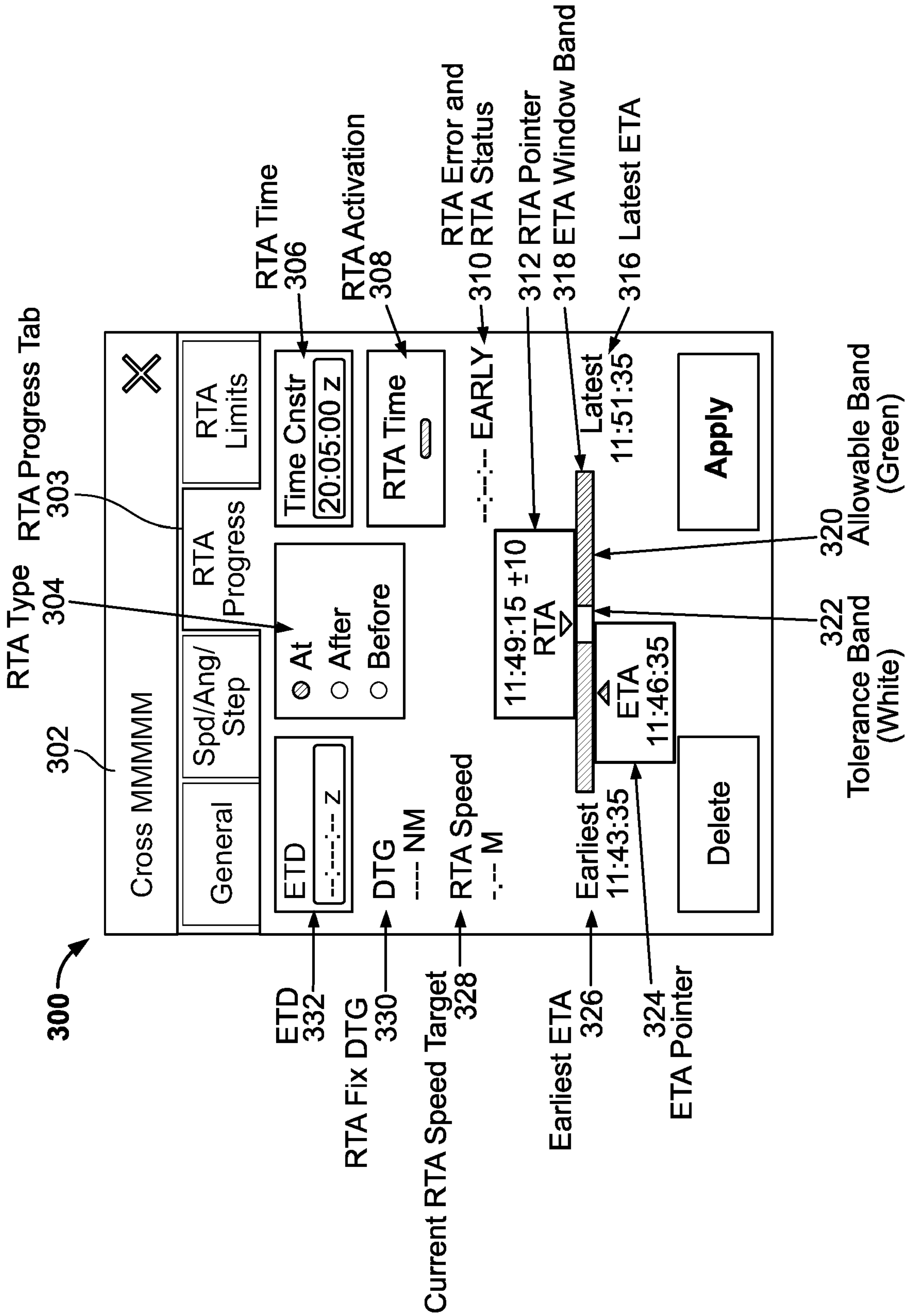

300
302
Cross MMMMM
General
Spd/Ang/ Step
RTA Progress
RTA Limits
RTA Type 304
RTA Progress Tab 303
RTA Time 306
RTA Activation 308
RTA Error and 310 RTA Status
312 RTA Pointer
318 ETA Window Band
316 Latest ETA
ETD
--:--:-- z
At
After
Before
Time Cnstr
20:05:00 z
RTA Time
--:--:-- EARLY
DTG
---- NM
RTA Speed
-.-- M
11:49:15 ±10
RTA
ETA
11:46:35
Earliest
11:43:35
Latest
11:51:35
Delete
Apply
ETD 332
RTA Fix DTG 330
Current RTA Speed Target 328
Earliest ETA 326
324 ETA Pointer
322 Tolerance Band (White)
320 Allowable Band (Green)

FIG. 3

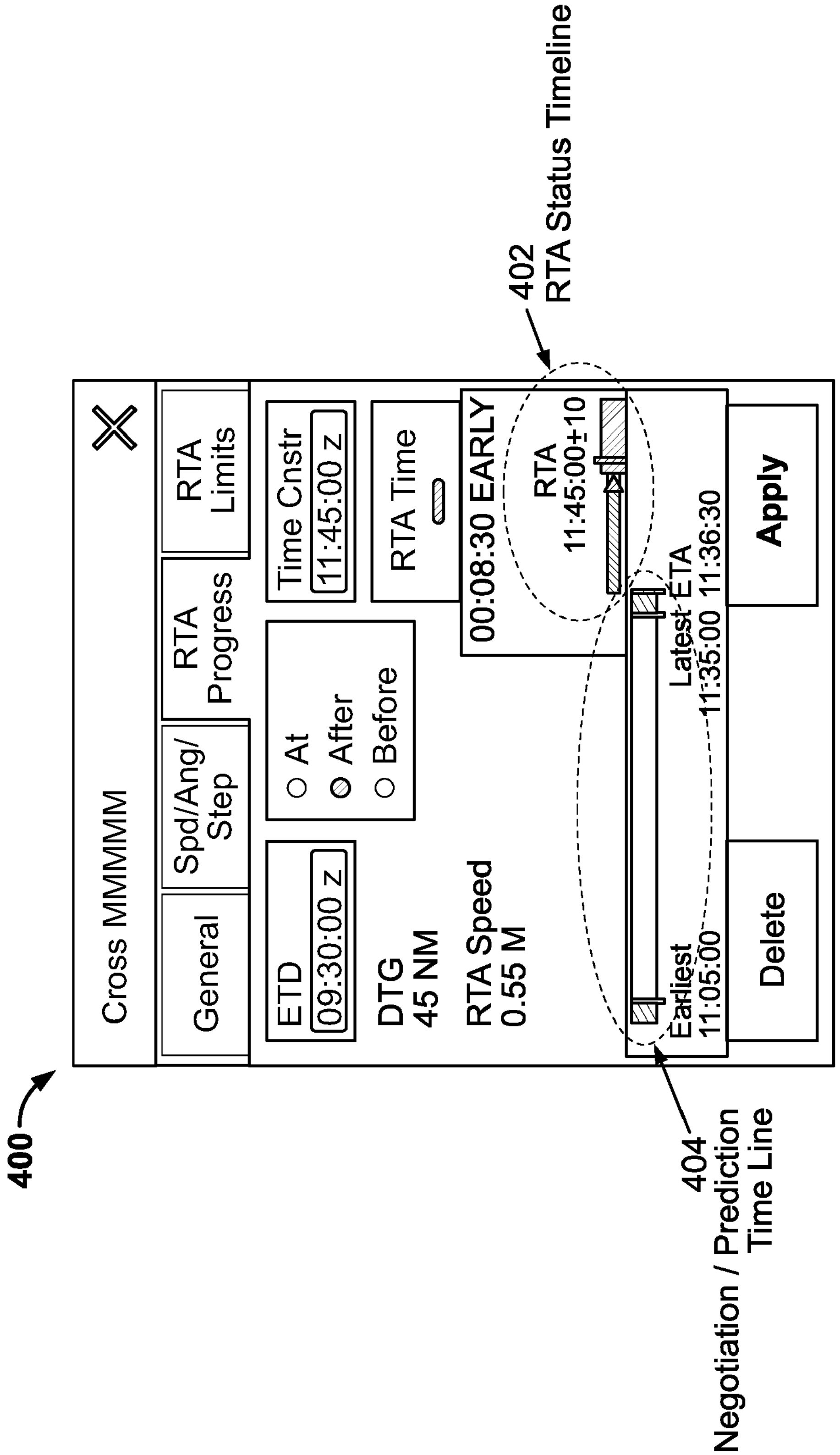

400
Cross MMMMM
General
Spd/Ang/
Step
RTA
Progress
RTA
Limits
ETD
09:30:00 z
DTG
45 NM
RTA Speed
0.55 M
At
After
Before
Time Cnstr
11:45:00 z
RTA Time
00:08:30 EARLY
RTA
11:45:00±10
Earliest
11:05:00
Latest
11:35:00
ETA
11:36:30
Delete
Apply
402
RTA Status Timeline
404
Negotiation / Prediction
Time Line

FIG. 4

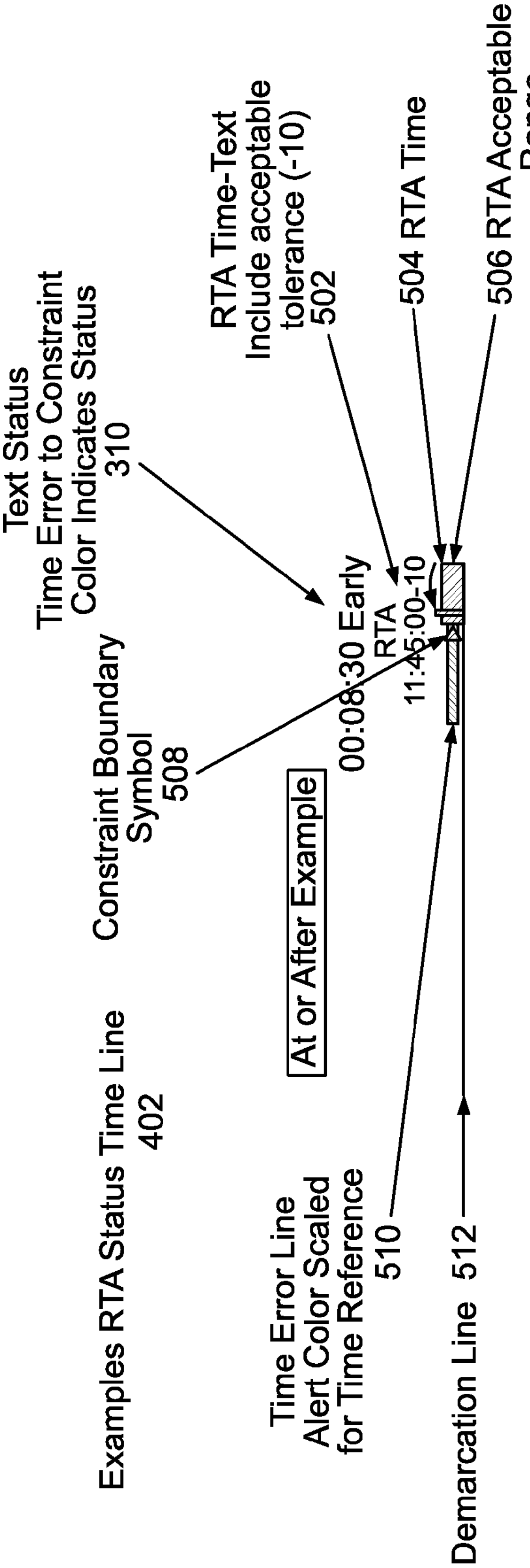

Examples RTA Status Time Line
402
At or After Example
Constraint Boundary
Symbol
508
Text Status
Time Error to Constraint
Color Indicates Status
310
00:08:30 Early
RTA
11:45:00-10
RTA Time-Text
Include acceptable
tolerance (-10)
502
504 RTA Time
506 RTA Acceptable
Range
Time Error Line
Alert Color Scaled
for Time Reference
510
Demarcation Line 512

FIG. 5

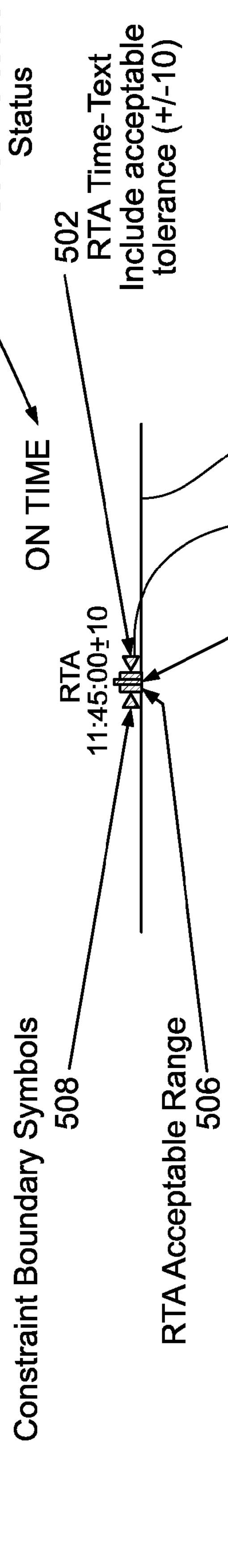
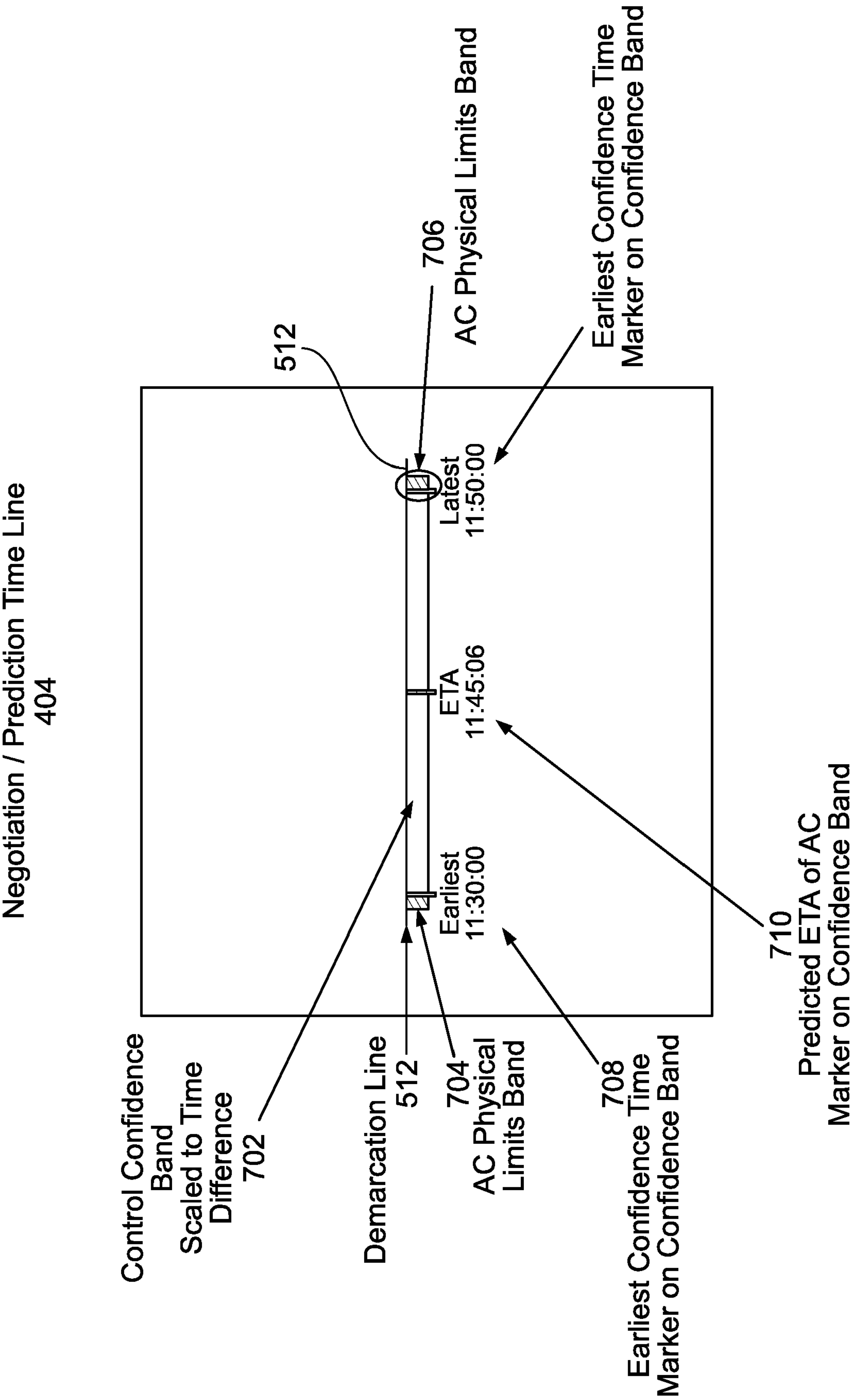

At Example
ON TIME
310
Text Status
Color Indicates
Status
502
RTA Time-Text
Include acceptable
tolerance (+/-10)
RTA
11:45:00±10
512
602
504
Constraint Boundary Symbols
508
RTA Acceptable Range
506

FIG. 6



Negotiation / Prediction Time Line
404
Control Confidence Band Scaled to Time Difference
702
Demarcation Line
512
704
AC Physical Limits Band
708
Earliest Confidence Time Marker on Confidence Band
Earliest
11:30:00
ETA
11:45:06
Latest
11:50:00
512
706
AC Physical Limits Band
Earliest Confidence Time Marker on Confidence Band
710
Predicted ETA of AC Marker on Confidence Band

FIG. 7

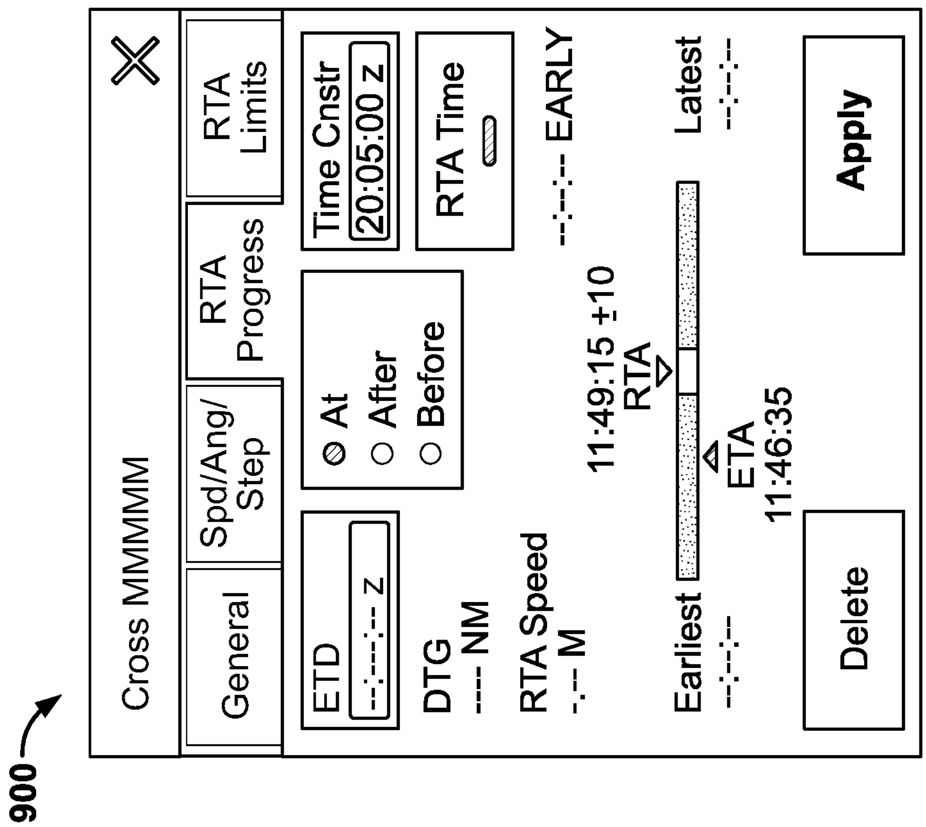

900
Cross MMMMM
General
Spd/Ang/ Step
RTA Progress
RTA Limits
ETD
--:--:-- z
At
After
Before
Time Cnstr
20:05:00 z
RTA Time
DTG
---- NM
RTA Speed
-.-- M
11:49:15 ±10
RTA
--:--:-- EARLY
Earliest
--:--:--
ETA
11:46:35
Latest
--:--:--
Delete
Apply

FIG. 9

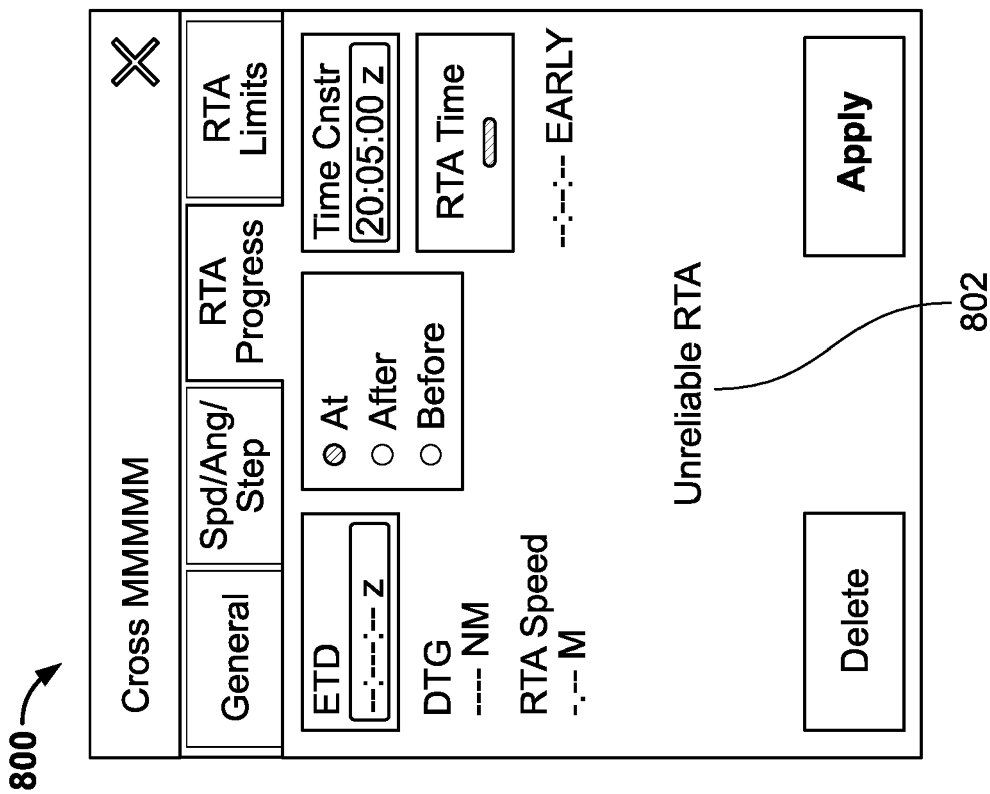

800
Cross MMMMM
General
Spd/Ang/ Step
RTA Progress
RTA Limits
ETD
--:--:-- z
At
After
Before
Time Cnstr
20:05:00 z
RTA Time
DTG
---- NM
RTA Speed
-.-- M
--:--:-- EARLY
Unreliable RTA
802
Delete
Apply

FIG. 8

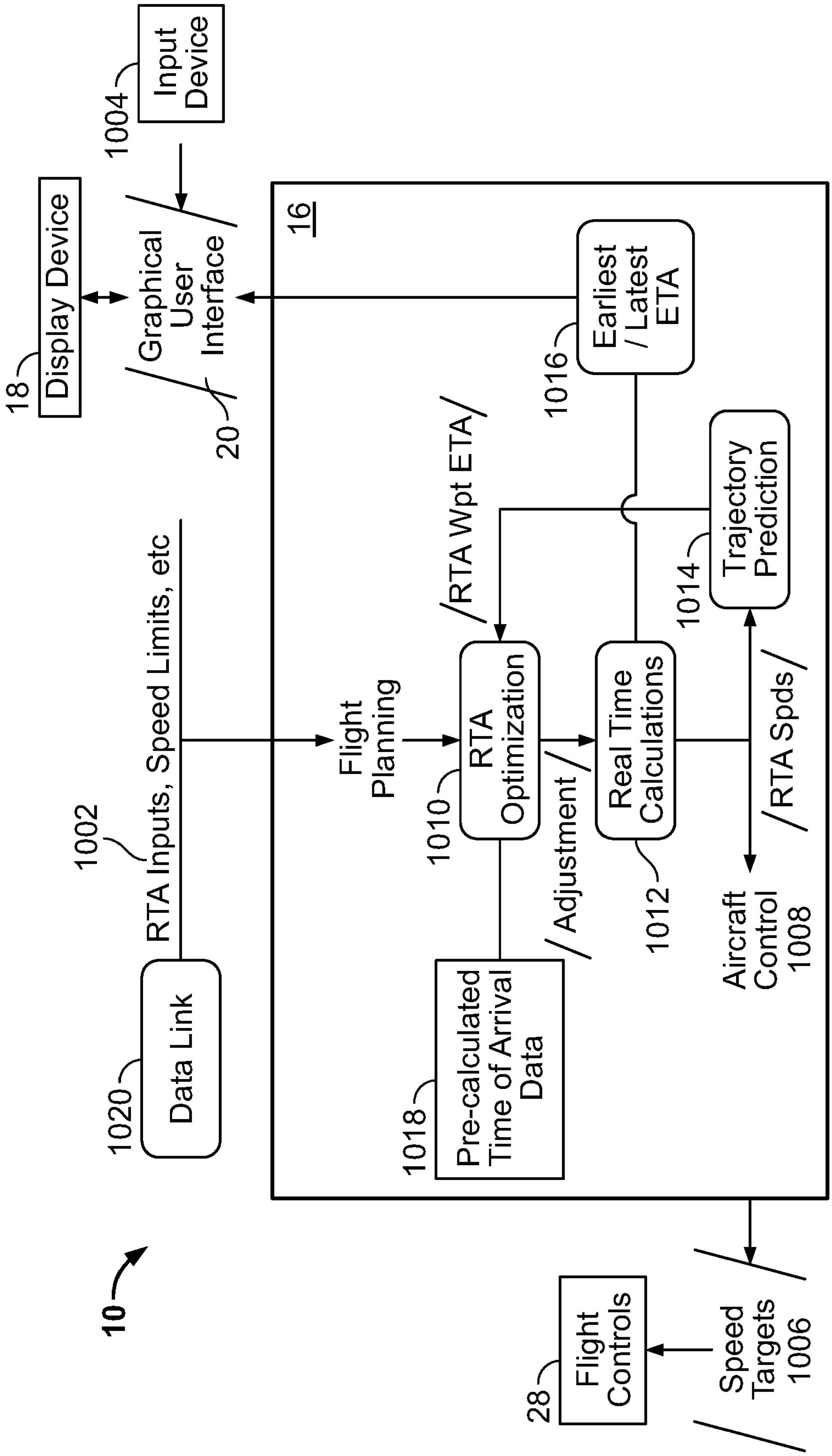

10
Display Device
18
Graphical User Interface
20
Input Device
1004
16
Earliest / Latest ETA
1016
RTA Wpt ETA
Trajectory Prediction
1014
RTA Inputs, Speed Limits, etc
1002
Flight Planning
RTA Optimization
1010
Adjustment
Real Time Calculations
1012
RTA Spds
Aircraft Control 1008
Data Link
1020
Pre-calculated Time of Arrival Data
1018
Flight Controls
28
Speed Targets 1006

FIG. 10

USE CASE: DATA BLOCK DIAGRAM

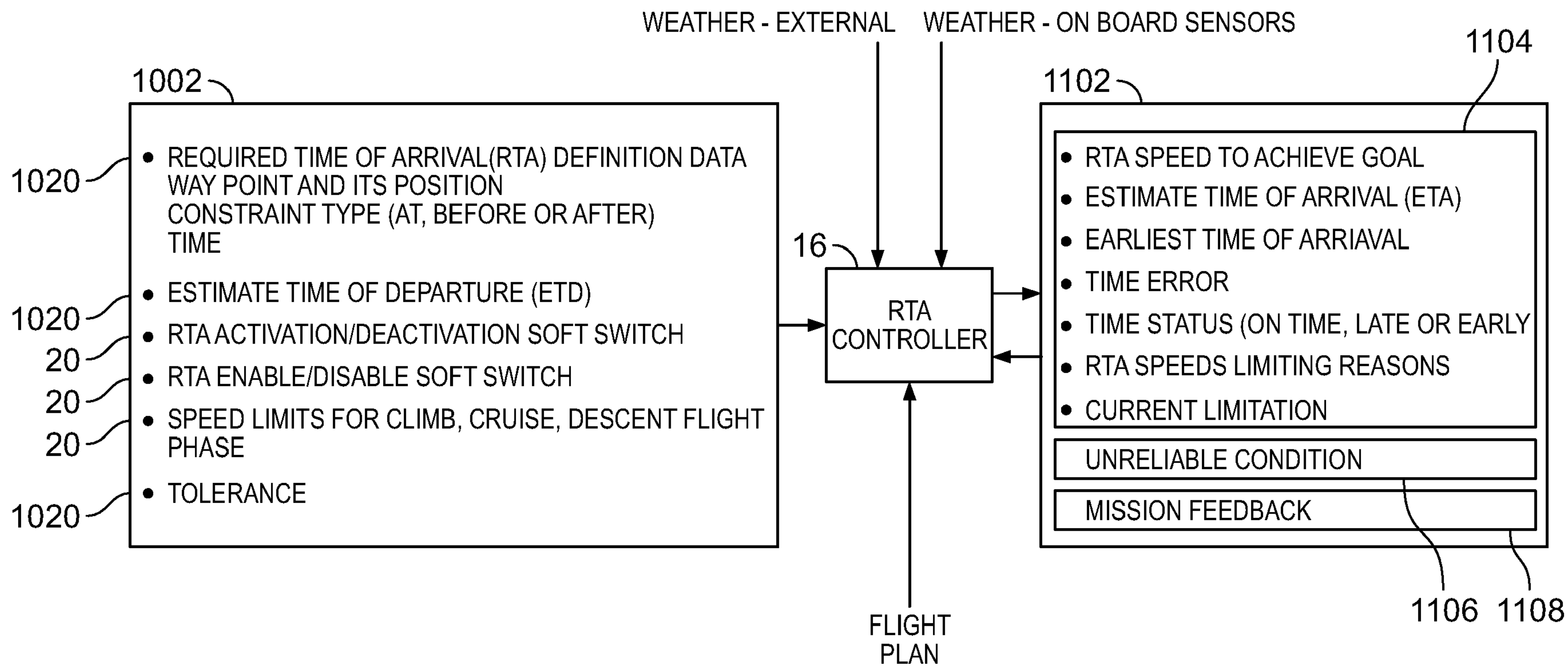


FIG. 11

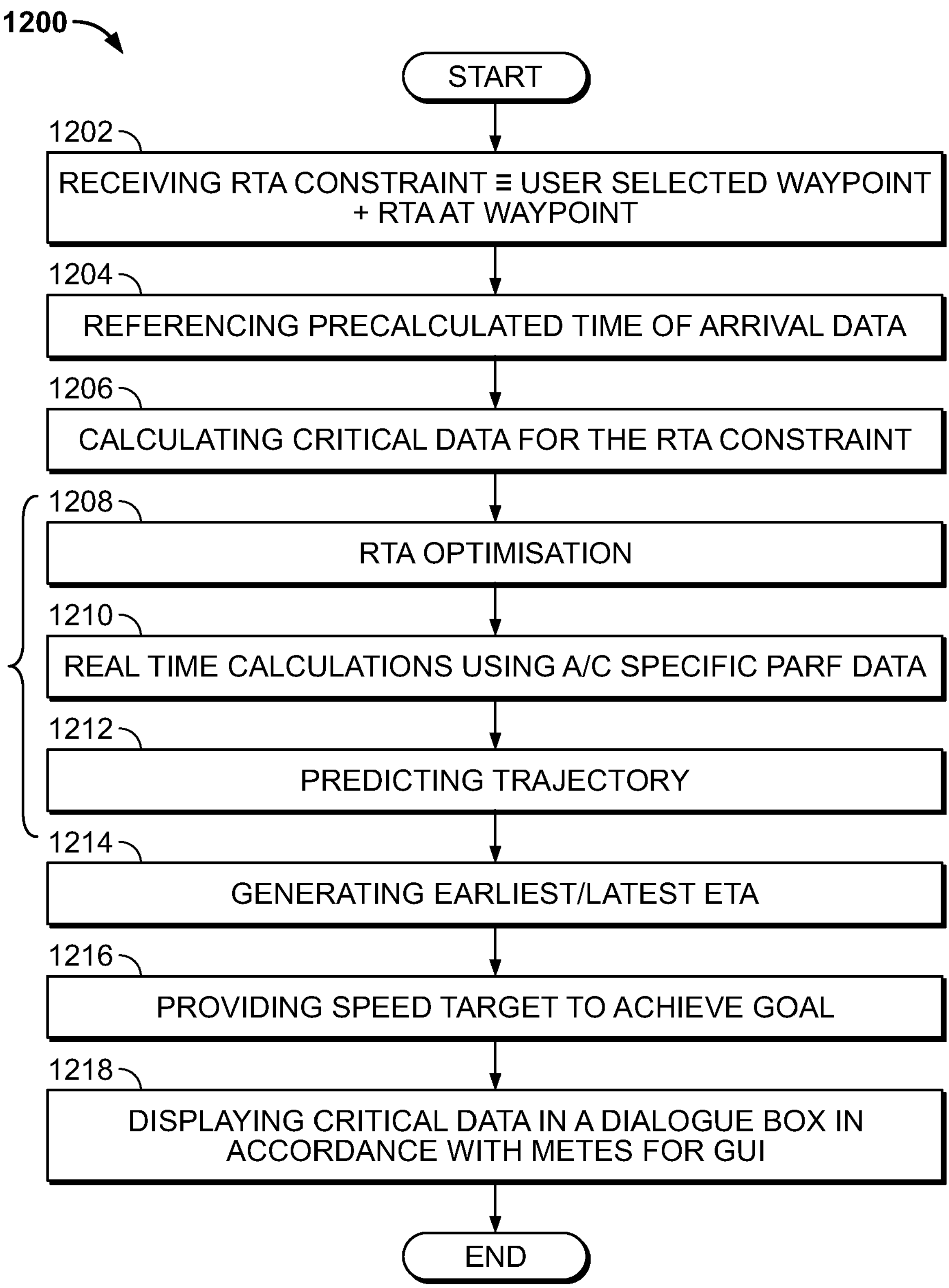

1200
START
1202
RECEIVING RTA CONSTRAINT ≡ USER SELECTED WAYPOINT + RTA AT WAYPOINT
1204
REFERENCING PRECALCULATED TIME OF ARRIVAL DATA
1206
CALCULATING CRITICAL DATA FOR THE RTA CONSTRAINT
1208
RTA OPTIMISATION
1210
REAL TIME CALCULATIONS USING A/C SPECIFIC PARF DATA
1212
PREDICTING TRAJECTORY
1214
GENERATING EARLIEST/LATEST ETA
1216
PROVIDING SPEED TARGET TO ACHIEVE GOAL
1218
DISPLAYING CRITICAL DATA IN A DIALOGUE BOX IN ACCORDANCE WITH METES FOR GUI
END

FIG. 12

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EUROPEAN SEARCH REPORT

Application Number
EP 21 17 7208

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	EP 2 804 066 A1 (BOEING CO [US]) 19 November 2014 (2014-11-19) * paragraphs [0001], [0003] - [0005], [0017] - [0028] * * figures 1, 2 *	1-15	INV. G08G5/00
Y	US 7 765 061 B1 (BARBER SARAH [US] ET AL) 27 July 2010 (2010-07-27) * column 1, lines 13-27, 39-46 * * column 2, line 52 - column 4, line 47 * * figures 2-7, 9, 15, 16 *	1-15	
A	US 9 829 341 B1 (SWIDERSKI FRANK J [US] ET AL) 28 November 2017 (2017-11-28) * the whole document *	1-15	
A	US 2020/168106 A1 (DE PRINS JOHAN L [BE] ET AL) 28 May 2020 (2020-05-28) * paragraphs [0006], [0011], [0014], [0015], [0018] - [0023], [0049], [0051], [0054], [0059], [0061], [0067] - [0071], [0075] * * figures 4A-4C, 6A-6C, 9 *	1-15	TECHNICAL FIELDS SEARCHED (IPC): G08G
A	EP 1 943 571 A1 (HONEYWELL INT INC [US]) 16 July 2008 (2008-07-16) * paragraphs [0001], [0003], [0004], [0012], [0013], [0021] - [0025], [0027] - [0032] * * figures 2, 3A-3D *	1-15	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	10 November 2021	Roxer, Adam

CATEGORY OF CITED DOCUMENTS

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		WO 2007053636 A1	10-05-2007

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