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(54) SYSTEMS AND METHODS FOR CRITERIA ANALYSIS PROTOTYPING

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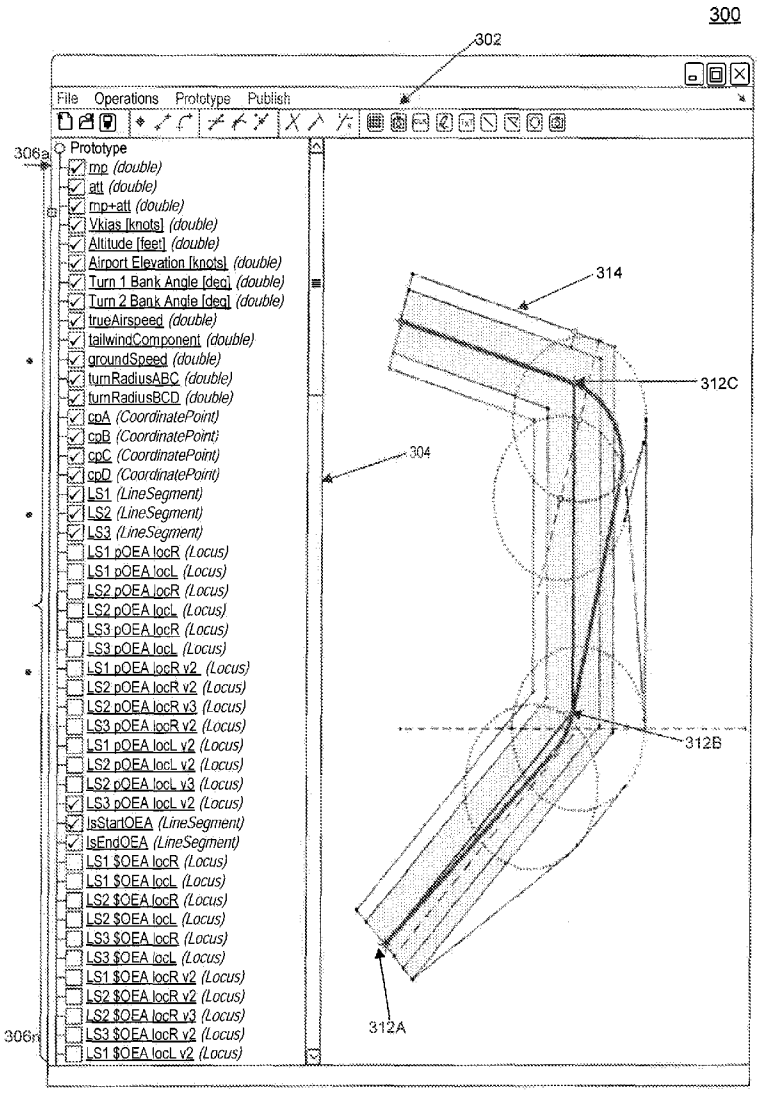
(57) **ABSTRACT**

A flight procedure criteria prototyping system and method is described herein. According to embodiments, the system is configured to generate a prototype, generate a dependency tree based on the prototype, wherein the dependency tree is comprised of one or more dependency tree nodes, translate the dependency tree into one or more construction steps, wherein there is a mapping between the one or more dependency tree nodes and the one or more construction steps, maintain an ordered list of the one or more construction steps, and generate one or more software specifications based on the one or more construction steps.



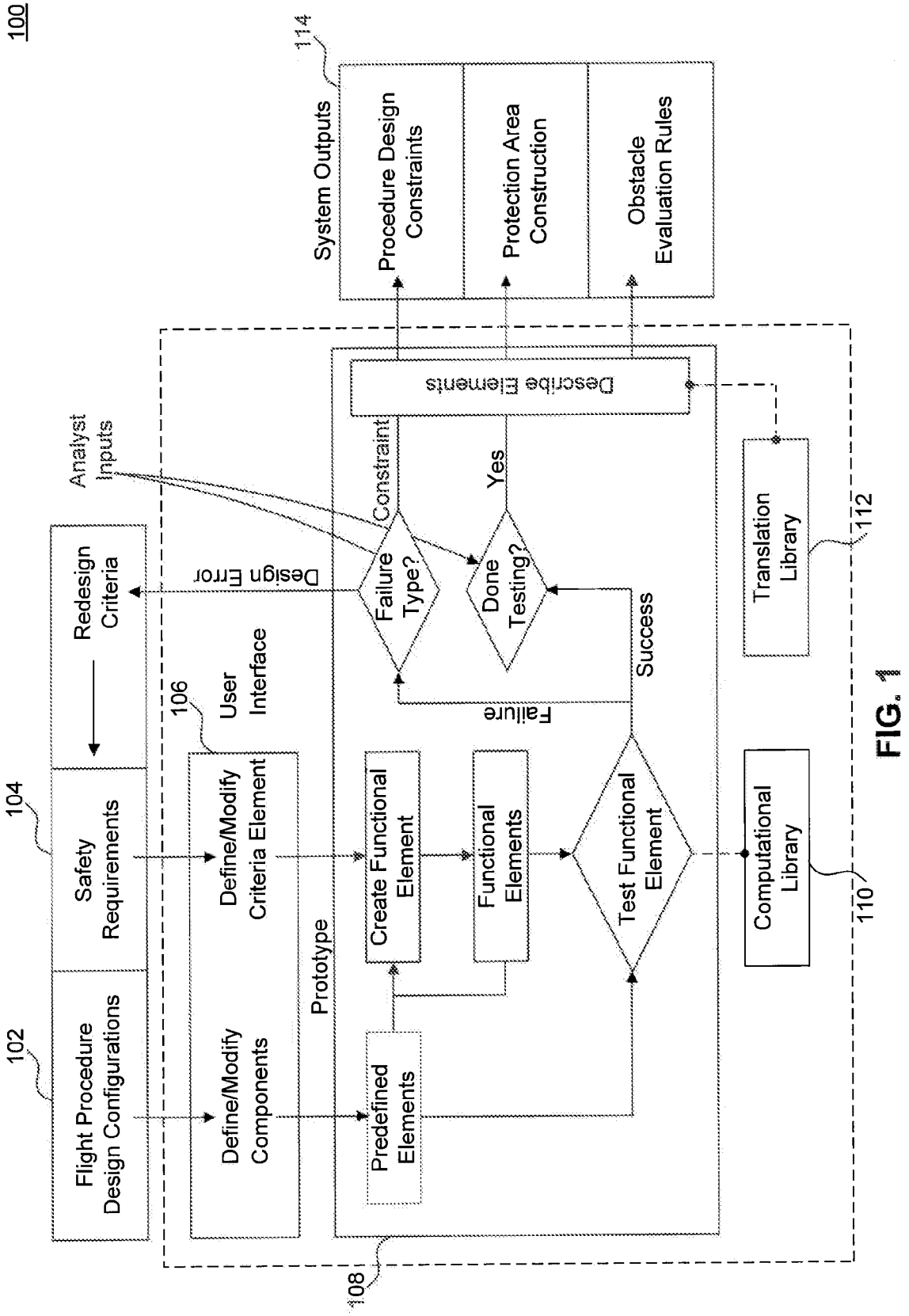

100
114
System Outputs
Procedure Design Constraints
Protection Area Construction
Obstacle Evaluation Rules
Describe Elements
Analyst Inputs
Constraint
Yes
Failure Type?
Done Testing?
Design Error
Success
Failure
Translation Library
112
Redesign Criteria
User Interface
106
Define/Modify Criteria Element
Create Functional Element
Functional Elements
Test Functional Element
Computational Library
110
104
Safety Requirements
Prototype
102
Flight Procedure Design Configurations
Define/Modify Components
Predefined Elements
108

FIG. 1

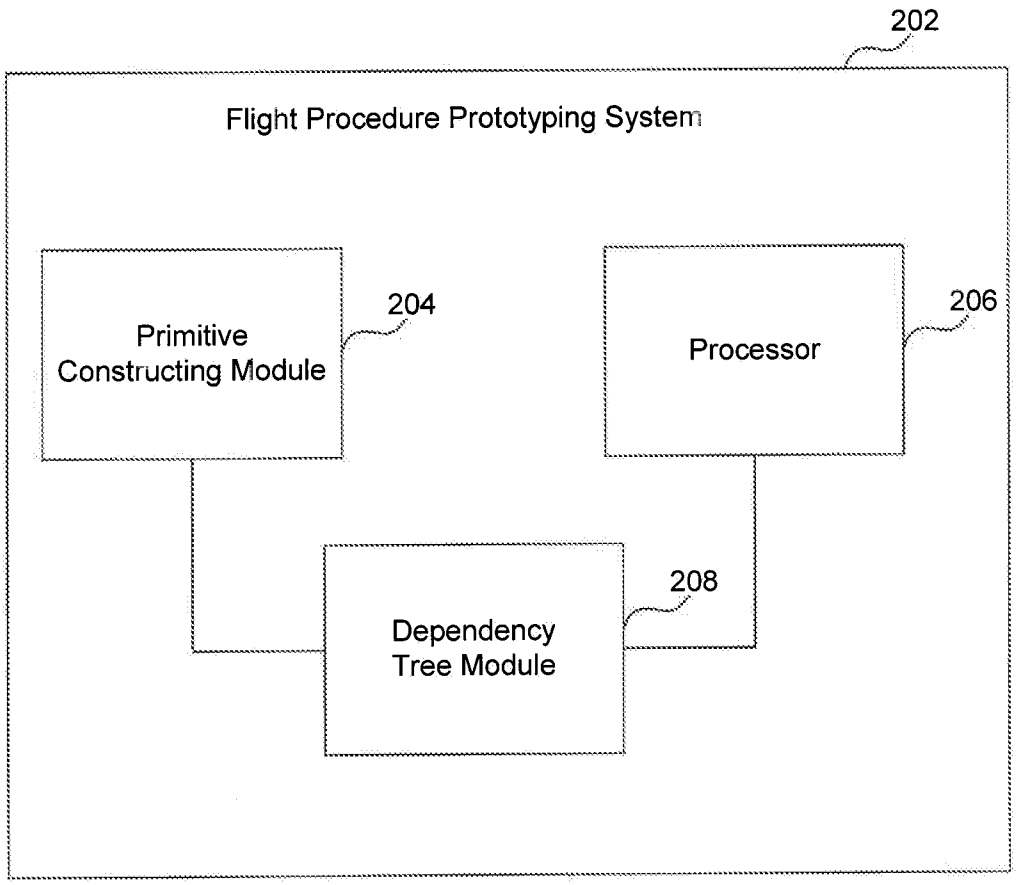

200
202
Flight Procedure Prototyping System
Primitive Constructing Module
204
Processor
206
Dependency Tree Module
208

FIG. 2

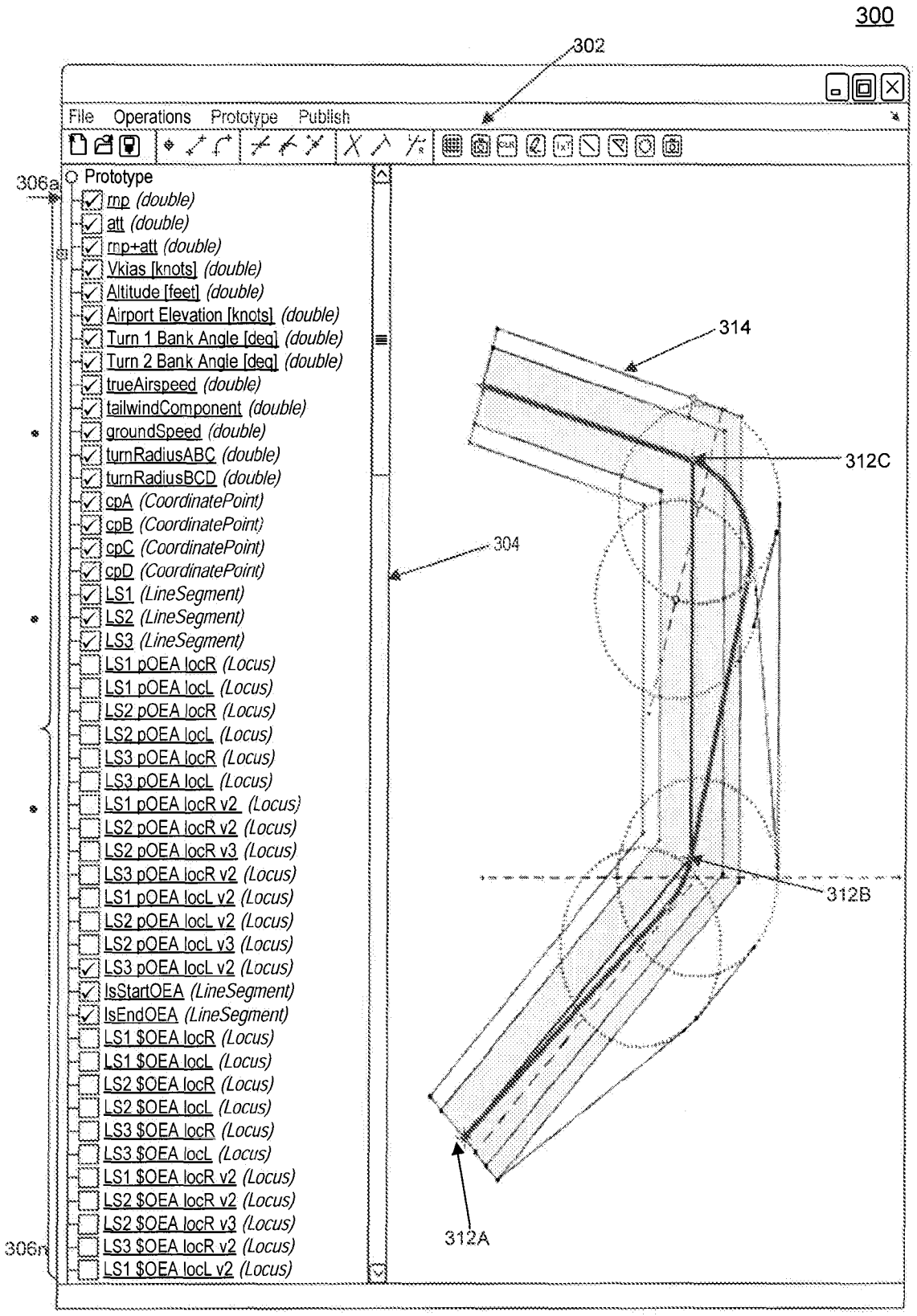

300
302
File Operations Prototype Publish
306a
Prototype
rnp (double)
att (double)
rnp+att (double)
Vkias [knots] (double)
Altitude [feet] (double)
Airport Elevation [knots] (double)
Turn 1 Bank Angle [deg] (double)
Turn 2 Bank Angle [deg] (double)
trueAirspeed (double)
tailwindComponent (double)
groundSpeed (double)
turnRadiusABC (double)
turnRadiusBCD (double)
cpA (CoordinatePoint)
cpB (CoordinatePoint)
cpC (CoordinatePoint)
cpD (CoordinatePoint)
LS1 (LineSegment)
LS2 (LineSegment)
LS3 (LineSegment)
LS1 pOEA locR (Locus)
LS1 pOEA locL (Locus)
LS2 pOEA locR (Locus)
LS2 pOEA locL (Locus)
LS3 pOEA locR (Locus)
LS3 pOEA locL (Locus)
LS1 pOEA locR v2 (Locus)
LS2 pOEA locR v2 (Locus)
LS2 pOEA locR v3 (Locus)
LS3 pOEA locR v2 (Locus)
LS1 pOEA locL v2 (Locus)
LS2 pOEA locL v2 (Locus)
LS2 pOEA locL v3 (Locus)
LS3 pOEA locL v2 (Locus)
lsStartOEA (LineSegment)
lsEndOEA (LineSegment)
LS1 $OEA locR (Locus)
LS1 $OEA locL (Locus)
LS2 $OEA locR (Locus)
LS2 $OEA locL (Locus)
LS3 $OEA locR (Locus)
LS3 $OEA locL (Locus)
LS1 $OEA locR v2 (Locus)
LS2 $OEA locR v2 (Locus)
LS2 $OEA locR v3 (Locus)
LS3 $OEA locR v2 (Locus)
LS1 $OEA locL v2 (Locus)
306n
314
312C
304
312B
312A

FIG. 3

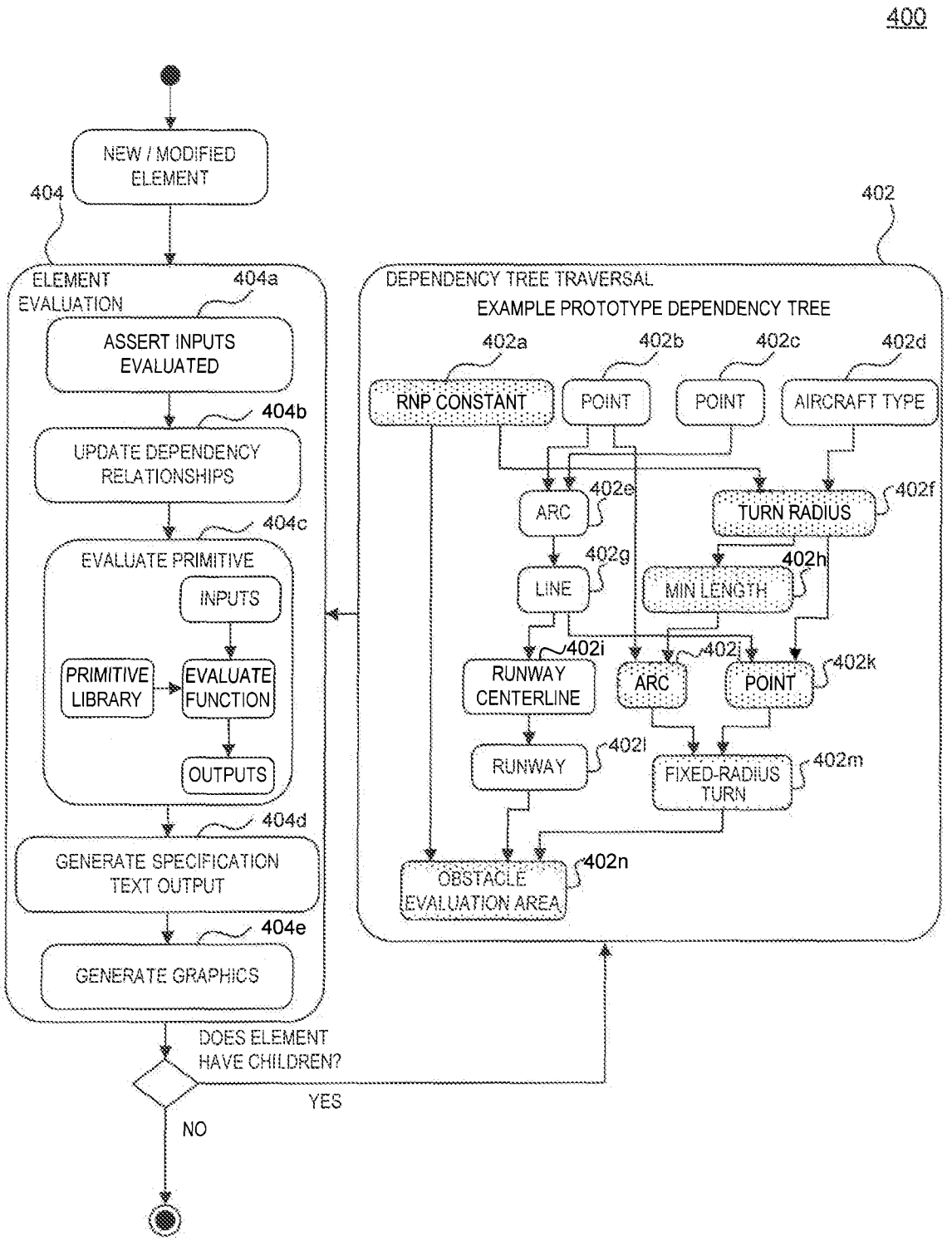

400
NEW / MODIFIED ELEMENT
404
402
ELEMENT EVALUATION
404a
ASSERT INPUTS EVALUATED
404b
UPDATE DEPENDENCY RELATIONSHIPS
404c
EVALUATE PRIMITIVE
INPUTS
PRIMITIVE LIBRARY
EVALUATE FUNCTION
OUTPUTS
404d
GENERATE SPECIFICATION TEXT OUTPUT
404e
GENERATE GRAPHICS
DOES ELEMENT HAVE CHILDREN?
YES
NO
DEPENDENCY TREE TRAVERSAL
EXAMPLE PROTOTYPE DEPENDENCY TREE
402a
RNP CONSTANT
402b
POINT
402c
POINT
402d
AIRCRAFT TYPE
402e
ARC
402f
TURN RADIUS
402g
LINE
402h
MIN LENGTH
402i
RUNWAY CENTERLINE
402j
ARC
402k
POINT
402l
RUNWAY
402m
FIXED-RADIUS TURN
402n
OBSTACLE EVALUATION AREA

FIG. 4

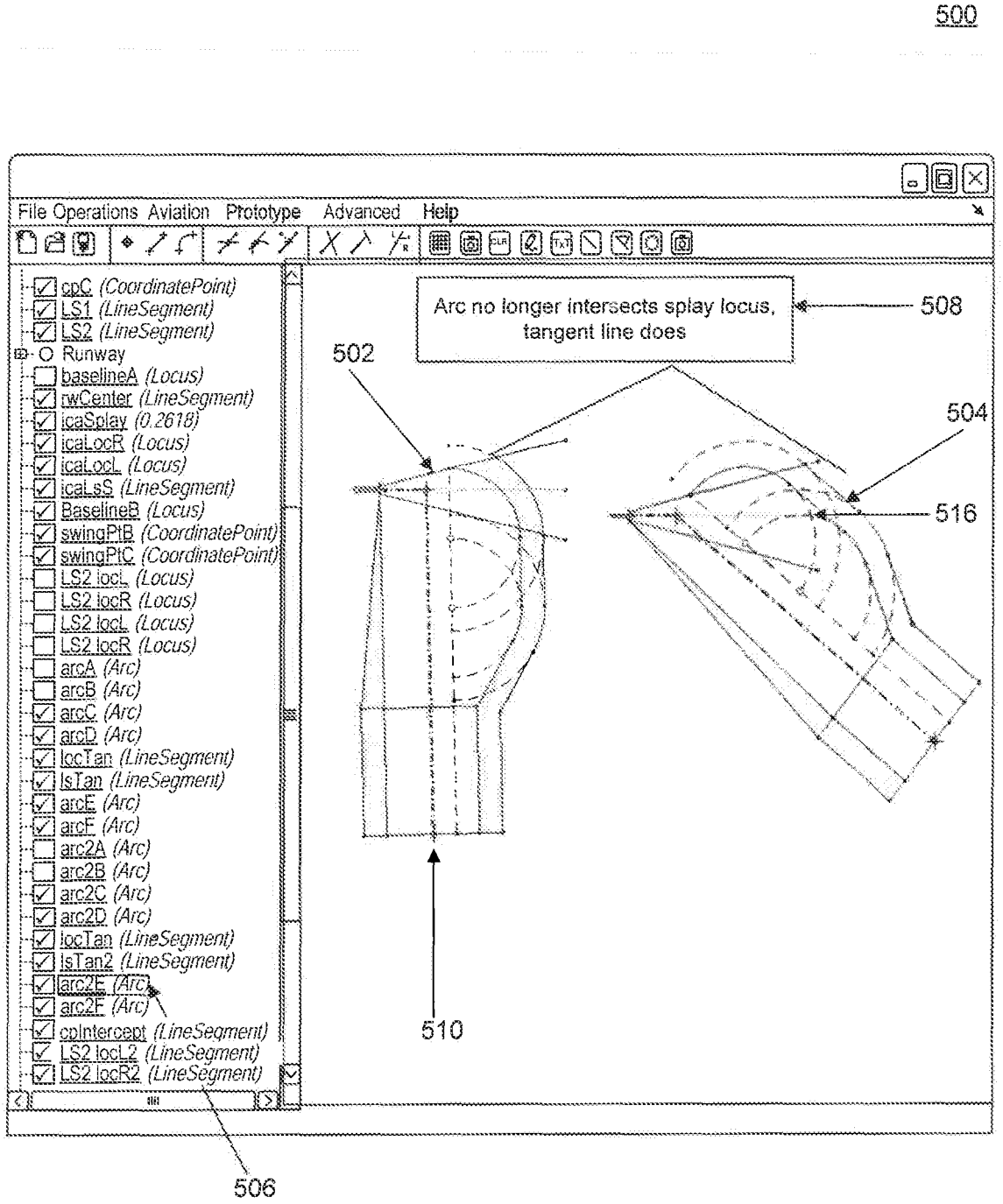

500
File Operations Aviation Prototype Advanced Help
cpC (CoordinatePoint)
LS1 (LineSegment)
LS2 (LineSegment)
Runway
baselineA (Locus)
rwCenter (LineSegment)
icaSplay (0.2618)
icaLocR (Locus)
icaLocL (Locus)
icaLsS (LineSegment)
BaselineB (Locus)
swingPtB (CoordinatePoint)
swingPtC (CoordinatePoint)
LS2 locL (Locus)
LS2 locR (Locus)
LS2 locL (Locus)
LS2 locR (Locus)
arcA (Arc)
arcB (Arc)
arcC (Arc)
arcD (Arc)
locTan (LineSegment)
lsTan (LineSegment)
arcE (Arc)
arcF (Arc)
arc2A (Arc)
arc2B (Arc)
arc2C (Arc)
arc2D (Arc)
locTan (LineSegment)
lsTan2 (LineSegment)
arc2E (Arc)
arc2F (Arc)
cpIntercept (LineSegment)
LS2 locL2 (LineSegment)
LS2 locR2 (LineSegment)
Arc no longer intersects splay locus, tangent line does
508
502
504
516
510
506

FIG. 5

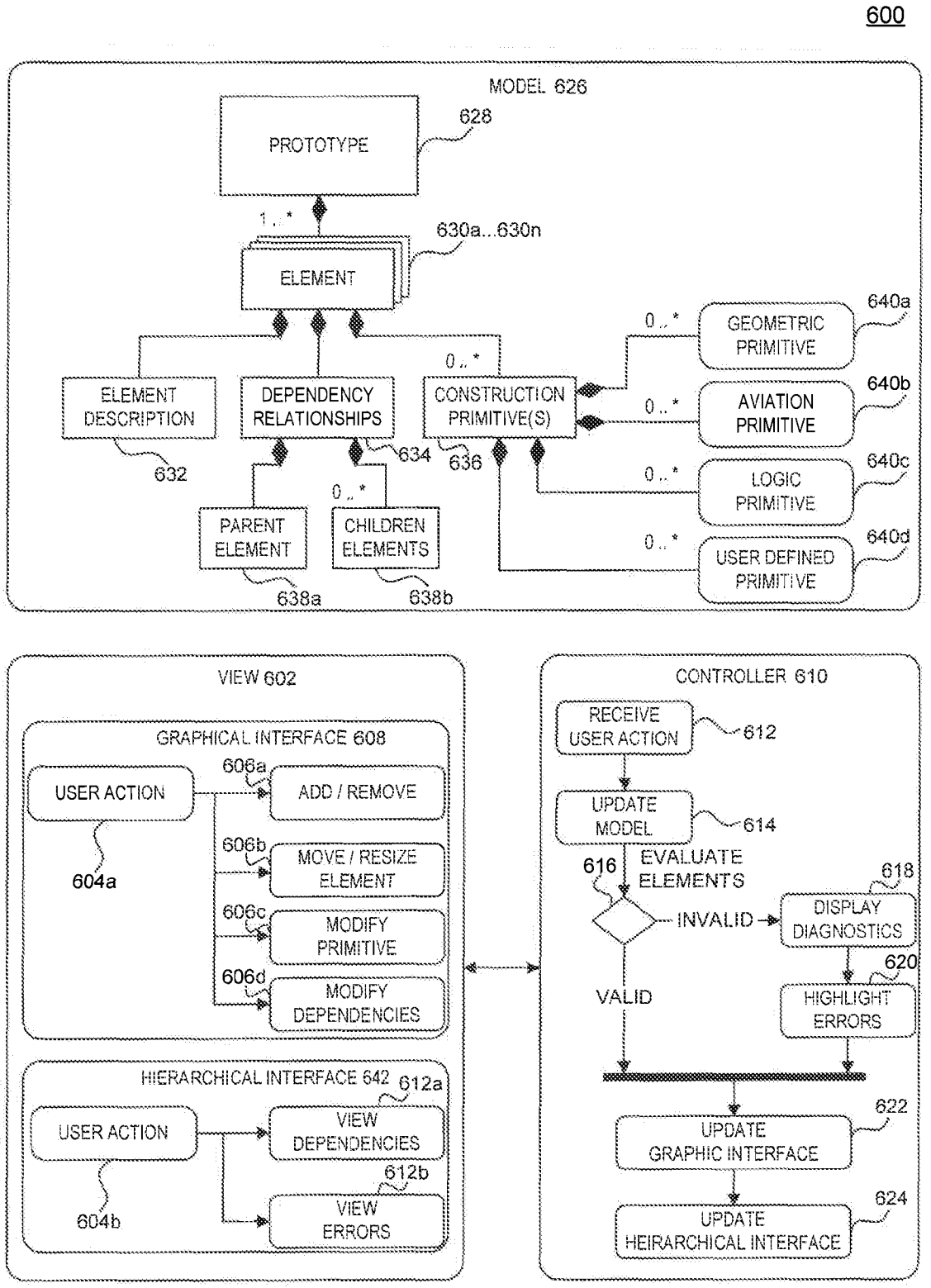

600
MODEL 626
PROTOTYPE
628
1 .. *
630a...630n
ELEMENT
ELEMENT DESCRIPTION
632
DEPENDENCY RELATIONSHIPS
634
0 .. *
CONSTRUCTION PRIMITIVE(S)
636
0 .. *
PARENT ELEMENT
638a
CHILDREN ELEMENTS
638b
0 .. *
GEOMETRIC PRIMITIVE
640a
AVIATION PRIMITIVE
640b
LOGIC PRIMITIVE
640c
USER DEFINED PRIMITIVE
640d
VIEW 602
GRAPHICAL INTERFACE 608
USER ACTION
604a
606a
ADD / REMOVE
606b
MOVE / RESIZE ELEMENT
606c
MODIFY PRIMITIVE
606d
MODIFY DEPENDENCIES
HIERARCHICAL INTERFACE 642
612a
USER ACTION
604b
VIEW DEPENDENCIES
612b
VIEW ERRORS
CONTROLLER 610
RECEIVE USER ACTION
612
UPDATE MODEL
614
616
EVALUATE ELEMENTS
INVALID
618
DISPLAY DIAGNOSTICS
620
HIGHLIGHT ERRORS
VALID
622
UPDATE GRAPHIC INTERFACE
624
UPDATE HEIRARCHICAL INTERFACE

FIG. 6

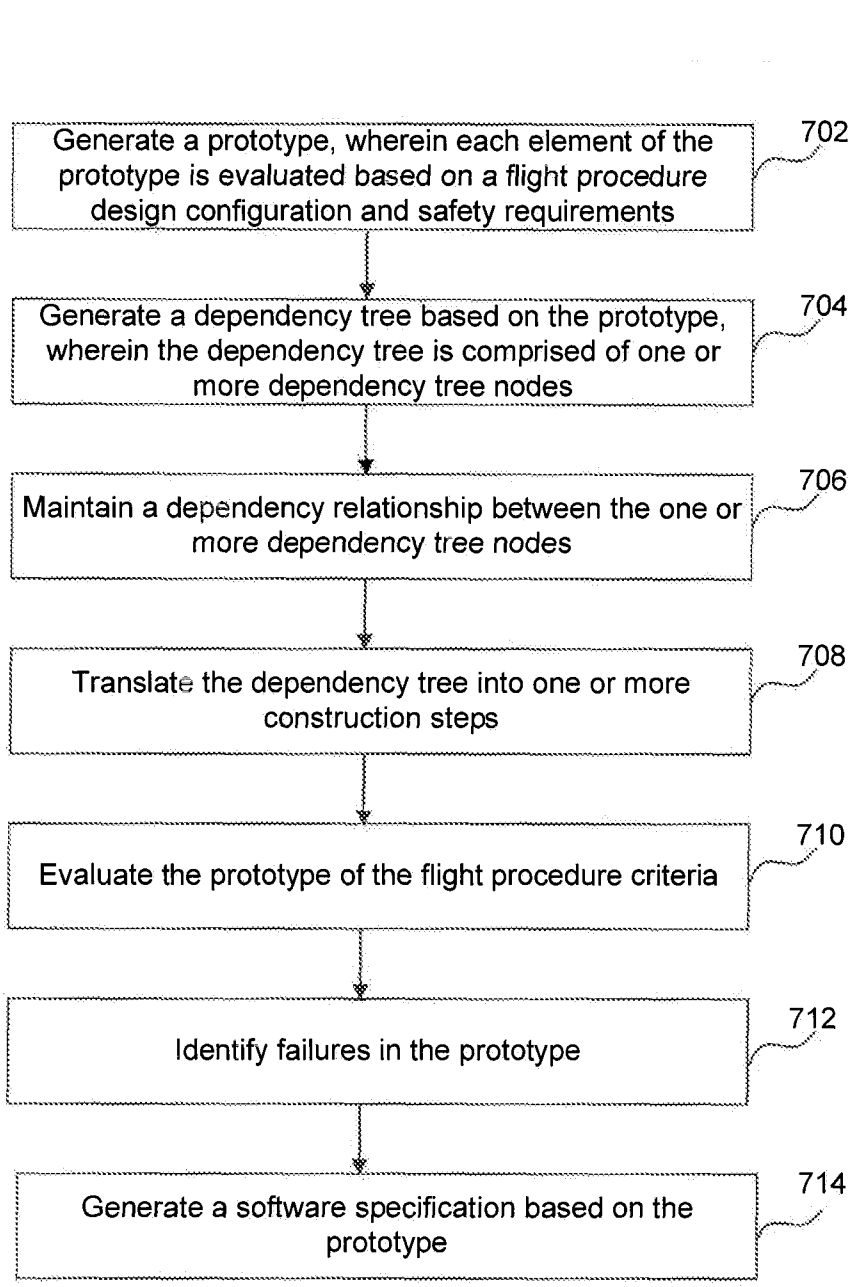

700
Generate a prototype, wherein each element of the prototype is evaluated based on a flight procedure design configuration and safety requirements
702
Generate a dependency tree based on the prototype, wherein the dependency tree is comprised of one or more dependency tree nodes
704
Maintain a dependency relationship between the one or more dependency tree nodes
706
Translate the dependency tree into one or more construction steps
708
Evaluate the prototype of the flight procedure criteria
710
Identify failures in the prototype
712
Generate a software specification based on the prototype
714

FIG. 7

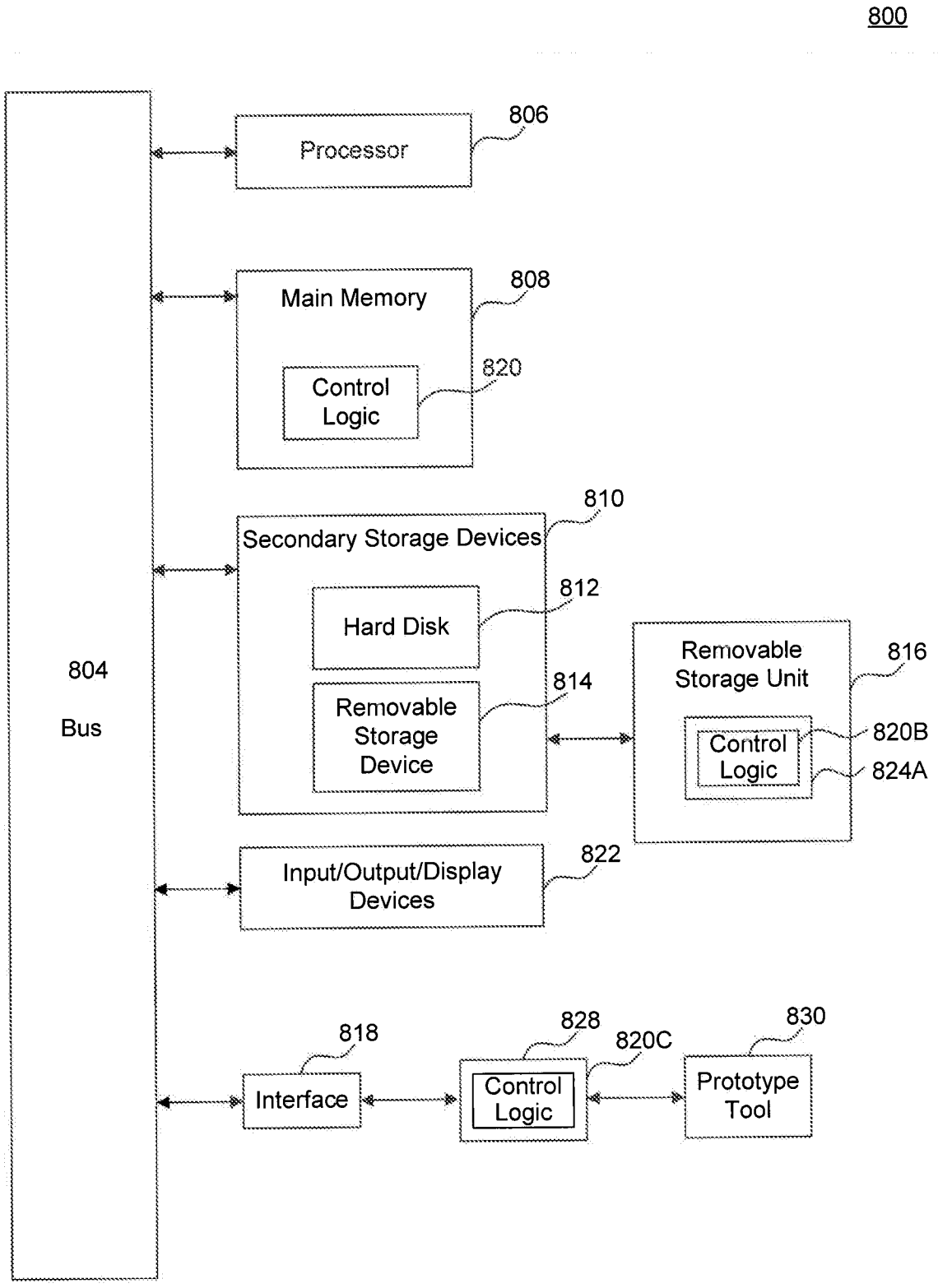

800
804
Bus
Processor
806
Main Memory
808
Control Logic
820
Secondary Storage Devices
810
Hard Disk
812
Removable Storage Device
814
Removable Storage Unit
816
Control Logic
820B
824A
Input/Output/Display Devices
822
Interface
818
Control Logic
828
820C
Prototype Tool
830

FIG. 8

SYSTEMS AND METHODS FOR CRITERIA ANALYSIS PROTOTYPING

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to designing and testing new instrument flight procedure criteria.

[0003] 2. Background Art

[0004] The Federal Aviation Administration (FAA) develops and publishes criteria for Terminal Instrument Procedures (TERPS). These criteria provide guidance for instrument procedure design, setting requirements for parameters such as minimum leg length, required turn radius, and allowable leg combinations. Criteria also include high precision methods for evaluating obstacle clearances in regions surrounding the flight path. These rules ensure that new flight procedures are safe, flyable, and efficient.

[0005] Modern aircraft are now capable of high precision navigation. These improved capabilities have motivated the design of new and more comprehensive criteria. Criteria prototyping provides a valuable means of testing and evaluating the impact of new criteria changes, before they are published. Additionally, it ensures the criteria developed can be implemented in automated design software without altering its original intent. This improves the quality of new criteria and reduces costly future redesign. Accordingly, there is a need for a method, system, and computer program product that facilitates criteria development while reducing the complexity of the FAA's workload and allowing for a rapid and more intuitive design phase.

BRIEF SUMMARY OF THE INVENTION

[0006] Embodiments include a flight procedure criteria prototyping system, method and computer program product. The system can be used for rapid criteria prototyping, which allows for the automation of testing and analysis of flight procedure criteria. According to an embodiment, the system is configured to generate a prototype, generate a dependency tree based on the prototype, wherein the dependency tree is comprised of one or more dependency tree nodes, maintain a dependency relationship between the dependency tree nodes, translate the dependency tree into one or more construction steps, wherein there is a mapping between the dependency tree nodes and the construction steps, and generate one or more software specifications based on the construction steps.

[0007] In an embodiment, a method for constructing flight procedure criteria includes generating a prototype, generating a dependency tree based on the prototype, wherein the dependency tree is comprised of one or more dependency tree nodes, maintaining a dependency relationship between the dependency tree nodes, translating the dependency tree into one or more construction steps, wherein there is a mapping between the dependency tree nodes and the construction steps, and generating one or more software specifications based on the construction steps.

[0008] In an embodiment, a method of using a computer-aided design tool to create and validate instrument flight procedure criteria includes generating a prototype of the flight procedure criteria, evaluating the prototype of the flight procedure criteria based on a user action, identifying failures in the prototype, and generating a specification based on the prototype.

[0009] Further embodiments, features, and advantages of the present invention, as well as the structure and operation of the various embodiments of the present invention, are described in detail below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0010] The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate embodiments of the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention.

[0011] FIG. **1** is a block diagram of an example system for constructing flight procedure criteria, according to an embodiment of the present invention.

[0012] FIG. **2** illustrates an example system for constructing flight procedure criteria, according to an embodiment.

[0013] FIG. **3** illustrates an example screen shot of the flight procedure criteria tool, according to an embodiment.

[0014] FIG. **4** illustrates an example dependency tree and element evaluation for constructing flight procedure criteria, according to an embodiment.

[0015] FIG. **5** illustrates another example screen shot of the flight procedure criteria tool, according to an embodiment.

[0016] FIG. **6** is a system structure diagram for constructing flight procedure criteria, according to an embodiment.

[0017] FIG. **7** is a process flowchart of a method for constructing flight procedure criteria, according to an embodiment.

[0018] FIG. **8** is an example computer system capable of implementing embodiments of the present invention.

[0019] The present invention will be described with reference to the accompanying drawings. The drawing in which an element first appears is typically indicated by the leftmost digit(s) in the corresponding reference number.

DETAILED DESCRIPTION OF THE INVENTION

Overview

[0020] An instrument approach procedure (IAP) is a series of predetermined maneuvers for the orderly transfer of an aircraft under instrument flight conditions (IFC) from the beginning of the initial approach to a landing, or to a point from which a landing may be made visually. Flight procedure criteria are a set of guidelines for developing new instrument procedures. The FAA develops and publishes criteria to ensure that new instrument procedures are safe, able to be flown, and meet operational requirements.

[0021] Developing new criteria is a challenging process. Separate criteria guidelines are required for each phase of flight, including arrivals, departures, and missed approach sequences. Additionally, criteria are dependent on aircraft class and navigation precision. Criteria design considerations include safety, operational impact, algorithmic complexity, flyability, and impact on existing procedures. Automation requirements place additional constraints on the design of new criteria. The objective is to provide software that can check whether new procedures meet criteria guidelines. Criteria must be designed such that the rules can reasonably be expressed in software.

[0022] The invention provides a visual means of prototyping new criteria guidelines. This approach enables a rapid-iteration design process, in which new criteria can be quickly implemented and evaluated against criteria design considerations. The resulting prototype automatically generates a set of explicit instructions and corresponding diagrams for implementing the criteria guideline in software. The invention streamlines the criteria development process, ensuring that criteria meet the intent of the authors and improving the ability of the designer to visualize all the scenarios to which the criteria could be applied.

Example System Embodiments

[0023] FIG. **1** is a block diagram **100** of an example system for constructing flight procedure criteria according to an embodiment of the present invention. Example system **100** can be implemented in software, hardware, or a combination of software and hardware. Example system **100** may implement a variety of methods, computational algorithms, and heuristics, further described below, according to embodiments of the present invention.

[0024] As shown in FIG. **1**, example system **100** includes a user interface **106** configured to receive flight procedure design configurations **102** and safety requirements **104**. Example system **100** generates system outputs **114** which include procedure design constraints, protection area construction, and obstacle evaluation rules.

[0025] According to embodiments, flight procedure design configurations **102** facilitate the identification of a plurality of predefined elements. Upon the receipt of flight procedure design configurations **102** by a user interface, one or more predefined elements may be identified and made available for user interaction based on flight procedure design configurations **102**. The predefined elements represent the root variables of flight procedure design configurations **102**, such as fixes and turn angles. Each predefined element is independent of any other element within the one or more predefined elements identified by flight procedure design configurations **102**. In an embodiment, the one or more predefined elements identified by flight procedure design configurations **102** may be dynamically modified via user interface **106**. One or more flight procedure design configurations **102** may be stored in a database, according to an embodiment.

[0026] According to embodiments, the one or more predefined elements identified by flight procedure design configurations **102** provide a user with the capability to define and modify elements of a prototype **108** for flight procedure criteria. The predefined elements identified by flight procedure design configurations **102** may include numerical constants, geodetic points, geodesics, arcs, loci of points, spirals, and boundary objects. For example, geodetic points may represent a midpoint of an element, center of an arc, intersection of two elements, projection to an element or boundary, or the point closest to another point or element. Geodesics may represent, for example, the path between two points, the tangent to an arc at a point, the tangent to two arcs, the tangent to an arc and intersecting line segment at a known angle, a line segment bisected by another line segment with known half-length, or a line segment bisecting an angle formed by two other line segments with a shared point. In addition, arcs, loci of points, spirals, and boundary objects may represent their standard geometric definitions.

[0027] According to embodiments, the one or more predefined elements of flight procedure design configurations **102** interact through construction operators of user interface **106**. Construction operators include operations such as modifications (i.e. extend line segment/locus, truncate element, move start/end point of element, etc.), course calculations (i.e. course from one point to another, at point on an element, course change from inbound line segment to outbound line segment, etc.), distance calculations (i.e. distance, between two points, of an element, width of locus, etc.), and conditional determinations (i.e. points are equal, point is left/right of line, point is inside arc, element contains point, element intersects, etc.).

[0028] According to embodiments, safety requirements **104** provide the framework for designing flight procedure criteria. Safety requirements **104** provide the requirements that must be satisfied in order to have valid flight procedure criteria. All requirements of safety requirements **104** must be satisfied in order to generate valid flight procedure criteria. Upon the receipt of safety requirements **104** by user interface **106**, a user may define one or more criteria elements. The one or more criteria elements are defined by the user to help construct safety protection areas and evaluation of the flight procedure criteria. According to embodiments, criteria elements allow for operations such as "If this is a left turn, draw this line, else for a right turn, draw that line." Criteria elements interact with the predefined elements of flight procedure design configurations **102** and the construction operators to generate functional elements.

[0029] According to an embodiment, the one or more criteria elements interact with the predefined elements identified by flight procedure configurations **102** during the generation of a prototype **108** for flight procedure criteria. According to an embodiment, the one or more criteria elements are functionally defined so that they are dependent upon other elements. In an embodiment, the functional elements may be represented by a dependency tree having one or more dependency tree nodes. Further discussion of the dependency tree takes place below. According to an embodiment, each functional element has a functional definition based on a geodetic computational library **110**. Geodetic computational library **110** includes a set of mathematical algorithms used in the analysis of flight procedure criteria. Additionally, geodetic computational library **110** may include functions that support conversion between geodetic and mapping coordinates.

[0030] Each functional element maintains a functional relationship between all of its dependent elements. Upon the addition or modification of a predefined element or the addition of a new functional element, all of the successive functional relationships are tested, validated and updated as required by safety requirements **104** and the functional relationships. According to an embodiment, in the event of an algorithmic failure of a flight procedure criteria, the user will be notified and decide if any of the elements require redesign or if the failure represents a procedure design constraint. For example, during the generation of a criteria prototype, a user may attempt to apply a functional element, such as "Find Tangent Point". In the scenario in which a tangent point does not exist as part of the prototype, the user will be notified of the error. According to another embodiment, if all elements are successfully updated, the user will continue adding elements until all safety requirements have been met and all possible procedure configurations have been tested.

[0031] According to an embodiment, the functional elements may be translated into literal construction steps upon passing a functional element test. The functional element test

validates each element within the prototype of the flight procedure criteria to determine that all design and safety requirements have been satisfied. The literal construction steps provide the description of the functional element in words. According to an embodiment, the literal construction steps may be used to generate specifications for flight procedure criteria, which may be used in the design and development of flight procedures. The functional elements may be translated into literal construction steps via a translation library **112**, according to an embodiment.

[0032] System outputs **114** include the criteria necessary to design and implement flight procedure rules. For example, system outputs **114** provide recommendations for instrument procedure design, setting guidelines for parameters such as minimum leg length, required turn radius, allowable leg combinations, along with protection area construction, obstacle evaluation, and obstacle clearance surface heights rules. Criteria also include precision methods for evaluating clearance heights along the flight path. These rules ensure that new flight procedures are safe, flyable, and efficient.

[0033] FIG. **2** illustrates an example system **202** for constructing flight procedure criteria according to an embodiment of the present invention. Example system **202** can be implemented in software, hardware, or a combination of software and hardware. Example system **202** may implement a variety of methods, computational algorithms, and heuristics, further described below according to embodiments of the present invention.

[0034] As shown in FIG. **2**, flight procedure prototyping system **202** includes a primitive constructing module **204**, a processor **206**, and a dependency tree module **208**. Flight procedure prototyping system **202** is configured to construct flight procedure criteria. For illustrative purposes, flight procedure prototyping system **202** will be described with reference to FIG. **3** and FIG. **4** to describe certain embodiments. FIG. **3** illustrates an example screen shot of the flight procedure criteria tool, according to an embodiment. FIG. **4** illustrates an example dependency tree and element evaluation for constructing flight procedure criteria, according to an embodiment.

[0035] FIG. **3** illustrates an example screen shot of the flight procedure criteria tool, according to an embodiment. According to embodiments, flight procedure design configurations **102** and safety requirements **104** along with user actions via user interface **106** may be combined to generate a prototype **300**, as shown in FIG. **3**. Prototype **300** is a visual representation of flight procedure criteria. For example, flight procedure design configurations **102** and safety requirements **104** along with user actions via user interface **106** may be combined to construct criteria for the design of leg length limitations, the nominal flight-path construction for a turn at a fix (fly-over or fly-by), or the obstacle evaluation region for a specific leg of a procedure. As illustrated in FIG. **3**, prototype **300** is an example of a procedure with obstacle evaluation area **314**. Such a procedure may include a number of waypoints or fixes **312**A-**312**C, which may be given by their geographical coordinates.

[0036] According to an embodiment, upon generation of prototype **300**, a construction hierarchical tree **306***a*-**306***n* based on prototype **300** may be generated, wherein the construction hierarchical tree **306***a*-**306***n* is comprised of one or more construction step nodes. The construction hierarchical tree **306***a*-**306***n* provides a visual representation of each of the construction steps used to generate prototype **300**. For example, as illustrated in FIG. **3**, a scaled representation of the flight procedure showing the flight legs may be generated in a step by step process. In each step new elements of the prototype may be added or modified, which is represented by construction step nodes **306***a*-**306***n*.

[0037] According to embodiments, primitive constructing module **204** is configured to generate a prototype **300**, as shown in FIG. **3**. In an embodiment, generating a prototype **300** includes generating a visual representation of the prototype based on one or more flight procedure design configurations, one or more safety requirements and a plurality of user actions and updating the visual representation dynamically based on these inputs. In an embodiment, the system may provide a point and click user interface for constructing flight procedure criteria prototypes. One or more primitive inputs may be combined to create a prototype. The primitive inputs may include geometric primitives, aviation primitives, logic primitives or user defined primitives. For example, the system may generate prototype **300** for a helicopter procedure. As discussed previously, a scaled representation of the flight procedure showing the flight legs may be generated in a step by step process. Each leg may be associated with a path terminator code, such as, but not limited to ARINC 424. Each leg may be terminated at a waypoint which may for example be fly-over, fly-by, or fixed-radius. The prototype may show the expected route of the helicopter along with the obstacle evaluation areas. The obstacle evaluation areas may include the obstacle clearance areas and surface heights that are used to identify the controlling obstacles, which in turn fix the minimum procedure altitudes, glide path angles and climb gradients.

[0038] As stated previously, FIG. **4** illustrates an example dependency tree and element evaluation for constructing flight procedure criteria, according to an embodiment. Dependency tree module **208** is configured to generate a dependency tree based on the prototype wherein the dependency tree is comprised of one or more dependency tree nodes. For example, dependency tree **402** of FIG. **4** may be generated based on a prototype. Dependency tree **402** may capture all of the elements of a prototype and the relationships between the elements. In an embodiment dependency tree **402** has one or more dependency tree nodes **402***a*-**402***n* which may correspond to one or more construction steps of a generated prototype. For example each dependency tree node **402***a*-**402***n* maintains a dependency relationship between other nodes within dependency tree **402**. Each node may have a parent node and/or one or more descendant nodes according to an embodiment. For instance, FIG. **4** illustrates dependency tree **402** including parent node **402***a*. Parent node **402***a* has a plurality of dependent descendant nodes **402***f*, **402***h*, **402***j*, **402***k*, **402***m*, and **402***n*. According to an embodiment, upon a modification of parent node **402***a*, each of the dependent descendant nodes will be evaluated and updated accordingly. During an update, the dependency tree **402** may be traversed using a breadth-first traversal pattern, according to an embodiment. Element evaluation utilizing a breadth-first traversal pattern will successively evaluate each of the dependent descendant nodes **402***f*, **402***h*, **402***j*, **402***k*, **402***m*, and **402***n*. In an embodiment, dependency tree **402** has no cycles. Such a feature ensures that all inputs for an element are defined prior to evaluation of that element and minimizes re-evaluation of any elements.

[0039] According to an embodiment, each element and its dependencies of dependency tree **402** may be evaluated upon

execution of a user action. For example, upon the addition, modification or movement of an element within prototype **300**, the corresponding element and its dependencies may be evaluated and updated using element evaluation process **404**. Evaluation process begins at step **404***a*, where one or more inputs for an element are evaluated. At step **404***a*, it is determined whether all of the inputs for the element are defined prior to evaluating the element. Upon verification of all the inputs for the element, element evaluation process **404** moves to step **404***b*. At step **404***b*, the dependency relationships of the element and existing dependent elements are updated. In an embodiment, dependency relationships of an element are updated when a user adds a new element to a prototype or modifies an existing element of a prototype. Evaluation process **404** proceeds to stop **404***c*, where the primitive is evaluated. At step **404***c*, a primitive element such as element **402***a* is evaluated based on the user action and the change to prototype **300**. The evaluation of a primitive includes evaluating the primitive based on the inputs, and using a function library to produce an output. The output of each element will be the input to its dependent descendant nodes, according to an embodiment.

[0040] Evaluation process **404** proceeds to steps **404***d* and **404***e*, where the specification text is generated or updated and graphics are generated or updated respectively. After an element is evaluated, the specification text associated with that element may be generated or modified based on the evaluation. Furthermore, the graphical representation of the element is updated accordingly. Upon conclusion of the evaluation of an element, evaluation process **404** determines if the element has any dependent descendant nodes. If dependent descendant nodes exist, evaluation process **404** is repeated for each element, until the entire dependency tree **402** has been evaluated and updated. Once there are no more elements to be evaluated, evaluation process **404** is complete.

[0041] Returning to FIG. **2**, according to embodiments, processor **206** is configured to translate a dependency tree into one or more construction steps. A construction step provides a breakdown of the flight procedure criteria and will provide a flight procedure designer or developer detailed instructions of the criteria that must be met during the design and implementation of flight procedures. According to an embodiment, each dependency tree node of dependency tree **402** will maintain a record of the input, output, and resultant action of each construction step. The dependency tree **402** may be traversed, while the record for each dependency tree node **402***a*-**402***n* is translated into one or more instruction steps which describe the flight procedure criteria. In an embodiment, based on the construction steps, one or more software specifications may be generated. The one or more software specifications will provide a comprehensive description of the intended purpose and environment for development of the flight procedure criteria. In an embodiment, the generated software specifications may be exported from flight procedure prototyping system **202** to another system, such as a text editor application for viewing or modifying. In another embodiment, one or more figures for each of the instruction steps may be generated, wherein the one or more figures show one or more inputs and the one or more outputs for each of the instructions steps. For example, each instruction step of the flight procedure criteria will be represented by a generation of its visual counterpart, which will show a scaled version of the flight procedure criteria.

[0042] FIG. **6** illustrates a model-view-controller pattern **600** of an example system for constructing flight procedure criteria according to an embodiment of the present invention. Model-view-controller pattern **600** includes model **626**, view **602**, and controller **610**.

[0043] According to an embodiment, view **602** includes graphical interface **608** and hierarchical interface **642**. View **602** enables a user to generate and modify a prototype according to an embodiment.

[0044] Graphical interface **608** provides a plurality of user actions **604***a*, which enable a user to generate and modify construction steps of a prototype. According to an embodiment, user actions **604***a* may include add/remove element functionality **606***a*, move/resize element functionality **606***b*, modify primitive functionality **606***c* and modify dependencies functionality **606***d*. Add/remove element functionality **606***a* provides a user the ability to add or remove an element for a prototype. For example, a user may add or remove elements identified by flight procedure design configurations **104** such as coordinate points, line segments, arcs, locus of points, and boundary objects. Move/size element functionality **606***b* provides a user the ability to move or resize any of the elements identified by flight procedure design configurations **102**. For example, a user may choose to move an element such as an arc to a different part of the generated prototype. Modify primitive functionality **606***c* provides a user the ability to modify a predefined element of flight procedure design configurations **102**. Modify dependencies functionality **606***d* provides a user the ability to modify an element with a dependency resulting in an update of all dependencies of said element, as discussed previously.

[0045] According to an embodiment, view **602** includes hierarchical interface **642** which provides a visual representation to the user of element dependencies and any errors generated during the design of flight procedure criteria. Hierarchical interface **642** includes additional user actions **604***b*. User actions **604***b* include view dependencies functionality **612***a* which provides a user the ability to view construction step dependencies of a generated prototype. For example, hierarchical interface **642** may be a representation of the generated prototype as a tree with one or more construction step nodes. If a user highlights a node of the tree, all construction steps that may be impacted by the highlighted node may also be highlighted. According to an embodiment, user actions **604***b* include view error functionality **612***b*. View error functionality **612***b* provides a user the ability to view errors that may be introduced during the construction of a criteria prototype. Upon the modification of a prototype, an error may be discovered due to the dependencies between the functional elements. According to embodiments, view error functionality **612***b* may provide traceability of the error, highlighting the root cause of the error. This provides the user the ability to easily identify errors and debug the construction.

[0046] FIG. **5** illustrates an example of the view error functionality. FIG. **5** represents an example of an error identification embodiment. In such a scenario, the user is evaluating two possible orientations for a particular Obstacle Evaluation Area construction, orientation **502** and orientation **504**. The bottom most fix **510** of orientation **502** has been dragged such that the turn angle has been reduced and the tangent line connecting the outermost arcs now intersects the left splay locus **516**. Thus, the truncated arc that was needed to complete the construction in the left scenario **502** can no longer be formed. The construction step corresponding to this arc may

be highlighted to indicate where the error occurred, as shown with hierarchy tree node **506** in FIG. **5**. All subsequent steps that would be impacted are disabled so the tool can continue to operate. The user should now be aware that this specific case was not accounted for and may require additional clarification in the criteria as shown by alert **508**.

[0047] Returning to FIG. **6**, according to embodiments, user actions **604***a* and **604***b* may generate events that are sent to controller **610** via view **602**. Controller **610** handles the events from view **602** and converts the events into appropriate user actions that may be interpreted by model **626** and displayed in view **602**. Controller **610** receives events based on user input and initiates a response by evaluating the impacted elements of model **626**. For example, controller **610** accepts input from the user and instructs model **626** and view **602** to perform actions based on that input. Controller **610** is represented as a flow diagram to illustrate the steps taken upon receipt of any event.

[0048] At step **612**, one or more user action events are received by controller **610**. For example, the one or more user action events may be generated by user actions **604***a* and **604***b* of view **602**. At step **614**, model **626** is updated. For example, upon receipt of the one or more events from view **602**, controller **610** may send instructions to model **626**. The instructions may cause various elements of model **626** to update based on the kind of user action. An update of model **626** includes step **616**. At step **616**, the elements of the criteria prototype are evaluated based on the kind of user action received to determine if the design criteria are valid or invalid given the dependencies between the elements. If the design criteria are invalid, controller **610** is configured to display diagnostics of the evaluation at step **618** and highlight any errors found at step **620**. Steps **618** and **620** generate events that are sent to view **602**, to notify the user of the evaluation results. If the design criteria are valid, controller **610** is configured to generate events that will be sent to view **602** to update graphical interface **608** and hierarchical interface **642**.

[0049] According to an embodiment, model **626** manages the data of model-view-controller pattern **600**. Model **626** is configured to respond to requests for information about its state and responds to instructions to change state. According to an embodiment, model **626** may be a persistent storage mechanism such as a database, which stores both the data and the logic needed to manipulate the data in model-view-controller pattern **600**. Prototype **628** includes one or more elements **630***a* . . . **630***n*. Each of the elements **630***a* . . . **630***n* includes logic and data to handle the element description **632**, according to an embodiment. In another embodiment, each element **630***a* . . . **630***n* handles the dependency relationships **634** between a parent element **638***a* and its descendant elements **638***b*. The visual representation of the model is handled by updates of construction primitives **636**. Construction primitives may include many kinds of primitives, such as geometric primitives **640***a*, aviation primitives **640***b*, logic primitives **640***c*, and user defined primitives **640***d*. According to an embodiment, construction primitives **636** are linked to a mathematical library providing calculations for the construction primitives during updates.

Example Method Embodiments

[0050] Example methods according to embodiments of the present invention are now provided for the purpose of illustration. These example methods may be performed by the example system embodiments described above, and can be implemented using software, hardware, or a combination of software and hardware.

[0051] FIG. **7** is a process flowchart **700** for constructing flight procedure criteria according to an embodiment of the present invention.

[0052] As shown in FIG. **7**, process **700** begins at step **702**, which includes generating a prototype. In an embodiment, each element of the prototype is evaluated based on one or more flight procedure configurations and one or more safety requirements. For example, step **702** includes accepting one or more primitive inputs, one or more flight procedure configurations, and one or more safety requirements, generating a visual representation of the one or more primitive inputs, and updating the visual representation of the one or more primitive inputs dynamically based on a change to the one or more primitive inputs. Each input may include a functional relationship with another input. Upon the addition or modification of an input, all of the successive functional relationships are tested, validated and updated as required by the safety requirements and the functional relationships. For example, step **702** may be performed by primitive constructing module **204** of flight procedure prototyping system **202**.

[0053] In step **704**, a dependency tree based on the prototype is generated, wherein the dependency tree is comprised of one or more dependency tree nodes. For example, step **704** may be performed by dependency tree module **208** of flight procedure prototyping system **202**.

[0054] In step **706**, a dependency relationship between the one or more dependency tree nodes is maintained. For example, step **706** may be performed by dependency tree module **208** of flight procedure prototyping system **202**.

[0055] In step **708**, the generated dependency tree is translated into one or more construction steps. In an embodiment, step **708** includes maintaining a relationship between the one or more dependency tree nodes and automatically updating the relationship when there is a change to the generated prototype. In another embodiment, step **708** includes identifying errors in the one or more construction methods. For example, step **708** may be performed by processor **206** of flight procedure prototyping system **202**.

[0056] In step **710**, the prototype is evaluated. For example, step **710** may be performed by primitive construction module **204** of flight procedure prototyping system **202**. The evaluation of the prototype may be based on events generated by a user action, according to an embodiment. One or more events based on user input may be received and a response may be initiated by evaluating the impacted elements of the prototype. For example, upon receipt of the one or more events a set of instructions for processing may be generated. The instructions may cause various elements of the prototype to update based on the kind of user action. According to an embodiment, the elements of the criteria prototype are evaluated based on the kind of user action received to determine if the design criteria are valid or invalid given the dependencies between the elements. If the design criteria are invalid, diagnostics of the evaluation may be displayed and errors in the prototype may be highlighted.

[0057] In step **712**, one or more failures in the prototype may be identified. For example, step **712** may be performed by primitive construction module **204** of flight procedure prototyping system **202**. Each element of the prototype may maintain a functional relationship between all of its dependent elements. Upon a user action, such as the addition or

modification of a predefined element or the addition of a new functional element, all of the successive functional relationships are tested, validated and updated as required by safety requirements and the functional relationships. According to an embodiment, in the event of an algorithmic failure of a flight procedure criteria, the user will be notified and decide if any of the elements require redesign or if the failure represents a procedure design constraint. As discussed previously, the user may be notified of such a failure by a highlight of the errors in the graphical representation of the prototype.

[0058] In step **714**, one or more software specifications are generated based on the one or more construction steps. In an embodiment, step **714** includes navigating the dependency tree, generating one or more instruction steps based on the dependency tree, recording the one or more instructions steps and exporting the one or more instruction steps to an application or system. In another embodiment, step **714** includes generating one or more figures for each of the instruction steps, wherein the one or more figures show one or more inputs and one or more outputs for each of the instruction steps. For example, step **714** may be performed by processor **206** of flight procedure prototyping system **202**.

Additional Features

[0059] Embodiments of this invention include interfacing with a geometric coordinate system. For example, flight procedure prototyping system **202** may interface with a geodetic coordinate system. A geodetic coordinate system may be used to translate positions to their real positions on earth. The design of flight procedure criteria involves geodetic calculations. These calculations may include operations on geodesic and non-geodesic curves. A geodesic curve is the shortest path between two points on the surface of the earth. A geodesic curve may be defined by either two geodetic points (start- and end-points) or by a start point, starting azimuth, and distance. A non-geodesic curve is any curve that is not the shortest path between two points. The use of a geodetic coordinate system with flight procedure prototyping system **202** allows for high precision calculations during the generation of prototypes.

[0060] In an embodiment, user interface **106** of flight procedure prototyping system **100** may be an interactive sketchpad. The interactive sketchpad allows for visual algorithm development and intuitive testing. Construction primitive inputs may be dragged and dropped onto the interactive sketchpad to generate a prototype. As elements of the generated prototype are selected, the corresponding hierarchical tree node may be highlighted. Upon modification, error traceability is allowed by indicating the root cause of any construction errors. For example, a hierarchical tree node may be highlighted indicating that the node is responsible for the construction error. This enables the simplification of debugging complicated flight procedure criteria constructions. In another embodiment, existing flight procedures may be imported into the system to analyze the impact of any criteria changes.

Example Computer System Implementation

[0061] Various aspects of embodiments of the present invention can be implemented using software, firmware, hardware, or a combination thereof. FIG. **8** illustrates an example computer system **800** in which embodiments of the present invention, or portions thereof, can be implemented as computer-readable code. For example, the method illustrated by process **700** can be implemented in system **800**. However, after reading this description, it will become apparent to a person skilled in the relevant art how to implement embodiments using other computer systems and/or computer architectures.

[0062] Computer system **800** includes one or more processors, such as processor **806**. Processor **806** can be a special purpose or a general purpose processor. Processor **806** is connected to a communication infrastructure **804** (for example, a bus or network).

[0063] Computer system **800** also includes a main memory **808** (e.g., random access memory (RAM)) and secondary storage devices **810**. Secondary storage devices **810** may include, for example, a hard disk drive **812**, a removable storage drive **814**, and/or a memory stick. Removable storage device **814** may comprise a floppy disk drive, a magnetic tape drive, an optical disk drive, a flash memory, or the like. Removable storage drive **814** reads from and/or writes to a removable storage unit **816** in a well-known manner. Removable storage unit **816** may comprise a floppy disk, magnetic tape, optical disk, etc. which is read by and written to by removable storage device **814**. As will be appreciated by persons skilled in the relevant art(s), removable storage unit **816** includes a computer usable storage medium **824**A having stored therein computer software and/or logic **820**B.

[0064] Computer system **800** may also include a communications interface **818**. Communications interface **818** allows software and data to be transferred between computer system **800** and external devices. Communications interface **818** may include a modem, a network interface (such as an Ethernet card), a communications port, a PCMCIA slot and card, or the like. Software and data transferred via communications interface **818** are in the form of signals which may be electronic, electromagnetic, optical, or other signals capable of being received by communications interface **818**. These signals are provided to communications interface **818** via a communications path **828**. Communications path **828** carries signals and may be implemented using wire or cable, fiber optics, a phone line, a cellular phone link, an RF link or other communications channels.

[0065] In this document, the terms "computer usable medium" and "computer readable medium" are used to generally refer to media such as removable storage unit and a hard disk installed in hard disk drive **812**. Computer usable medium can also refer to memories, such as main memory **808** and secondary storage devices **810**, which can be memory semiconductors (e.g. DRAMs, etc.).

[0066] Computer programs (also called computer control logic) are stored in main memory **808** and/or secondary storage devices **810**. Computer programs may also be received via communications interface **818**. Such computer programs, when executed, enable computer system **800** to implement embodiments of the present invention as discussed herein. In particular, the computer programs, when executed, enable processor **806** and Prototyping Application **830** to implement the processes of the present invention. Where embodiments are implemented using software, the software may be stored in a computer program product and loaded into computer system **800** using removable storage drive **814**, interface **818**, or hard drive **812**.

CONCLUSION

[0067] While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

1. A method for constructing flight procedure criteria, comprising:
- generating a prototype;
- generating a dependency tree based on the prototype, wherein the dependency tree is comprised of one or more dependency tree nodes;
- maintaining dependency relationships between the one or more dependency tree nodes;
- translating the dependency tree into one or more construction steps, wherein there is a mapping between the one or more dependency tree nodes and the one or more construction steps; and
- generating one or more software specifications based on the one or more construction steps.

2. The method of claim **1**, wherein generating a prototype further comprises:
- accepting one or more predefined elements, wherein the predefined elements represent flight construction primitives; and
- evaluating each of the one of more predefined elements based on one or more flight procedure configurations and one or more safety requirements.

3. The method of claim **1**, wherein generating a prototype further comprises:
- defining one or more criteria elements, wherein the criteria elements are functionally defined and are dependent on other elements.

4. The method of claim **1**, wherein generating a prototype farther comprises:
- generating a visual representation for the prototype; and
- updating the visual representation of the prototype dynamically based on a change to the prototype.

5. The method of claim **1**, wherein generating a prototype further comprises:
- interfacing with a computational library, wherein the computational library defines operations between elements of the prototype.

6. The method of claim **1**, wherein translating the dependency tree into one or more construction steps further comprises:
- identifying failures in the one or more construction steps; and
- providing one or more functions for resolving the identified failures.

7. The method of claim **1**, wherein generating one or more software specifications based on the one or more construction steps further comprises:
- traversing the dependency tree;
- generating one or more instruction steps based on the dependency tree;
- recording the one or more instruction steps;
- translating the one or more instruction steps; and
- exporting the one or more instruction steps to a program.

8. A computer program product comprising a tangible computer useable hardware medium including control logic stored therein, the control logic when executed by one or more processors causing the processor to perform operations to construct flight procedure criteria, the operations comprising:
- generating a prototype;
- generating a dependency tree based on the prototype, wherein the dependency tree is comprised of one or more dependency tree nodes;
- maintaining a dependency relationship between the one or more dependency tree nodes;
- translating the dependency tree into one or more construction steps, wherein there is a mapping between the one or more dependency tree nodes and the one or more construction steps; and
- generating one or more software specifications based on the one or more construction steps.

9. The computer program product of claim **8**, wherein generating a prototype further comprises:
- accepting one or more predefined elements, wherein the predefined elements represent flight construction primitives; and
- evaluating each of the one of more predefined elements based on one or more flight procedure configurations and one or more safety requirements.

10. The computer program product of claim **8**, wherein generating a prototype further comprises:
- defining one or more criteria elements, wherein the criteria elements are functionally defined and are dependent on other elements.

11. The computer program product of claim **8**, wherein generating a prototype further comprises:
- generating a visual representation for the prototype; and
- updating the visual representation of the prototype dynamically based on a change to the prototype.

12. The computer program product of claim **8**, wherein generating a prototype further comprises:
- interfacing with a computational library, wherein the computational library defines operations between the one or more construction primitive inputs.

13. The computer program product of claim **8**, wherein translating the dependency tree into one or more construction steps further comprises:
- identifying failures in the one or more construction methods; and
- providing one or more functions for resolving the identified failures.

14. The computer program product of claim **8**, wherein generating one or more software specifications based on the one or more construction steps further comprises:
- traversing the dependency tree;
- generating one or more instruction steps based on the dependency tree;
- recording the one or more instruction steps;
- translating the one or more instruction steps; and
- exporting the one or more instruction steps to another program.

15. A flight procedure criteria construction tool, comprising:
- a primitive constructing module configured to generate a prototype;
- a dependency tree module configured to generate a dependency tree based on the prototype, wherein the depen-

dency tree is comprised of one or more dependency tree nodes, and maintain dependency relationships between the one or more dependency tree nodes; and

a processor configured to translate the dependency tree into one or more construction steps, wherein there is a mapping between the one or more dependency tree nodes and the one or more construction steps, and generate one or more software specifications based on the one or more construction steps.

16. The flight procedure criteria construction tool of claim **15**, wherein the primitive constructing module is further configured to accept one or more predefined elements, wherein the predefined elements represent flight construction primitives, and evaluate each of the one of more predefined elements based on one or more flight procedure configurations and one or more safety requirements.

17. The flight procedure criteria construction tool of claim **15**, wherein the primitive constructing module is further configured to define one or more criteria elements, wherein the criteria elements are functionally defined and are dependent on other elements.

18. The flight procedure criteria construction tool of claim **15** further comprising:

a user interface configured to generate a visual representation of the prototype, and update the visual representation of the prototype dynamically based on a change to the prototype.

19. The flight procedure criteria construction tool of claim **15**, wherein the processor is further configured to identify failures in the one or more construction methods, and

provide one or more functions for resolving the identified failures.

20. The flight procedure criteria construction tool of claim **15**, wherein the processor is further configured to traverse through the dependency tree, generate one or more instruction steps based on the dependency tree, record the one or more instruction steps,

translate the one or more instruction steps, and export the one or more instruction steps to a program.

21. A method of using a computer-aided design tool to create and validate instrument flight procedure criteria, comprising:

generating a prototype of the flight procedure criteria;

evaluating the prototype of the flight procedure criteria based on a user action;

identifying failures in the prototype; and

generating a specification based on the prototype.

22. The method of claim **21**, wherein identifying failures in the prototype comprises:

providing a traceability of errors for the flight procedure criteria;

identifying one or more failure cases for the flight procedure criteria; and

identifying one or more design limitations for the flight procedure criteria.

23. The method of claim **21**, wherein the evaluating the prototype of the flight procedure criteria comprises:

identifying one or more inputs from a user;

determining if the one or more inputs are defined; and

updating a dependency relationship for each of the one or more inputs;

24. The method of claim **21** farther comprising:

interfacing with a geodetic computational library, wherein the geodetic computational library provides a set of calculations for the prototype of the flight procedure criteria.

25. The method of claim **21**, further comprising:

designing a set of rules for an obstacles evaluation area; and

designing a set of rules for an obstacle clearance surface height.

26. The method of claim **21**, wherein the generating a specification based on the prototype comprises:

converting the prototype into a textual and graphical representation; and

exporting the textual and graphical representation to a program, wherein the program formats the textual and graphical representation of the prototype into a software specification document, the software specification document providing a description of the intended purpose and environment for development of the flight procedure criteria.

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