SOFTWARE TOOL FOR SIMULATION OF AIRCRAFT TRAJECTORIES.

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ABSTRACT: New concepts in air navigation have been introduced recently. Among others, are the concepts of trajectory optimization, 4D trajectories, RBT (Reference Business Trajectory), TBO (trajectory based operations), CDA (Continuous Descent Approach) and ACDA (Advanced CDA), conflict resolution, arrival time (AMAN), introduction of new aircraft (UAVs, UASs) in air space, etc. Although some of these concepts are new, the future Air Traffic Management will maintain the four ATM key performance areas such as Safety, Capacity, Efficiency, and Environmental impact. So much, the performance of the ATM system is directly related to the accuracy with which the future evolution of the traffic can be predicted. In this sense, future air traffic management will require a variety of support tools to provide suitable help to users and engineers involved in the air space management. Most of these tools are based on an appropriate trajectory prediction module as main component. Therefore, the purposes of these tools are related with testing and evaluation of any air navigation concept before they become fully operative.
The aim of this paper is to provide an overview to the design of a software tool useful to estimate aircraft trajectories adapted to air navigation concepts. Other usage of the tool, like controller design, vertical navigation assessment, procedures validation and hardware and software in the loop are available in the software tool. The paper will show the process followed to design the tool, the software modules needed to perform accurately and the process followed to validate the output data.

1. General Aspects of the Tool.

Generally speaking a tool that evaluates the trajectory of any aircraft must have several modules. The most important are the mathematical models for aircraft and any object needed to perform the simulation, the aircraft database and the visualization module.
The first software module for the tool will manage the aircraft performance, the physical environment and the particular inputs to the system as a function of the application. The first one are related with all the parameters related with the aircraft motion, its power plant and the performance of the FCS (Flight Control System), the navigation laws managed by a FMS (Flight Management System) and the equations of motion needed to obtain a desired trajectory. Regarding the physical environment, the weather, earth and geomagnetic models have to be included in the tool. These performances can be considered as perturbations to the system, needed to evaluate real scenarios. Finally the inputs to the system will be adapted to the particular application of the tool.
The aircraft parameters are obtained from specific aircraft database. The function of these databases is to provide available data of aircraft parameters needed to solve the mathematical model of any aircraft. At least, the tool will use aircraft data coming from three databases, BADA, Datcom and one ad-hoc database. Any of them will provide aerodynamic performances, fuel consumption, thrust, drag and weight as main data.
Finally the third component of the tool is the data presentation and visualization to users. This module provides some freedom to the user to select the data needed according to the simulations carried out. The data provided are also used to validate the software tool comparing the information with real data.

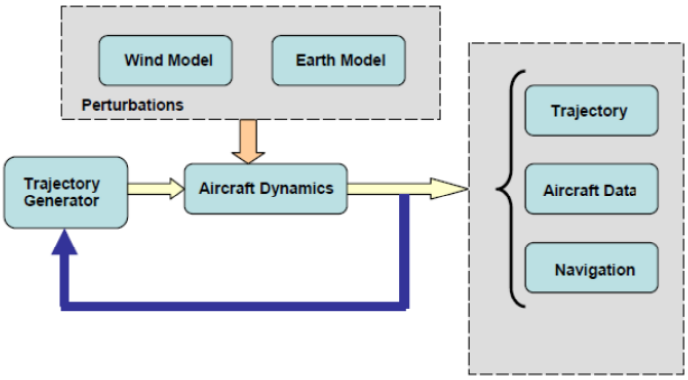
2. Mathematical Models.

The accuracy of the tool depends on the fidelity of the mathematical models selected for the specific application. The tool is going to work with mathematical models for atmospheric, earth and aircraft. The aircraft mathematical models included in the tool are those related with six and three degrees of freedom, although the point mass model will be used mostly for the trajectory prediction. With several mathematical models will be possible to simulate different navigation scenarios and different flight phases.
As an example of the usage of models, let us considerer the aircraft mathematical model as a six degree of freedom non-linear model of any civil transport aircraft included in the BADA database. The non-linear model can be completed with nonlinearities of actuators and a model of wind disturbances. An aircraft can be modelled as a space state using a point mass model, based on Newtonian dynamics. In this case the aircraft dynamics is represented as a state space system, where the state vector is given as: $x = [V \quad \alpha \quad \beta \quad p \quad q \quad r \quad \theta \quad \varphi \quad \psi \quad X \quad Y \quad h]^T$, where V is the aircraft speed,(α, β) are the attack and slip angles respectively, (p, q, r) are the three speed rotation of the aircraft regarding body axes, the symbols (θ,φ,Ψ) are the Euler angles and the position of the aircraft (X,Y,h). Additionally to that, the model includes the needed control inputs, such as engine thrust (T), the bank angle (Φ) and the angle of attack (α) among others.

Another possibility is based on the mathematical model called Total Energy Model (TEM). This model is obtained from the point mass model in which has be taken into account that aircraft operates close trimmed flight conditions (i.e. α = 0). The total energy model considers the variation of available energy between the starting point of the procedure and the final is due to the work of external forces that acting on the aircraft and using different variables that define the state of the aircraft and its evolution (Anderson and Warren 2002, Eurocontrol 2010, Hoffman 1993). The corresponding mathematical equation is: $(\boldsymbol{T}-\boldsymbol{D})\boldsymbol{V}_{TAS} = \boldsymbol{m}g\frac{d\boldsymbol{h}}{dt} + mV_{TAS}\frac{d\boldsymbol{V}_{TAS}}{dt}$, where ***T*** is thrust, drag ***D***, ***m*** the mass of the aircraft, the altitude ***h***, ***g*** the acceleration due to gravity and V_{TAS} the true air speed. The solution of last equation requires express thrust ***T*** and drag ***D*** as function of the kinematic variables ***h*** and V_{TAS}, by using the coefficients collected in the BADA database. With these examples, it is highlighted the freedom of the user to choice the suitable mathematical model for any particular application.

3. Toolbox Structure.

The design of the needed modules of the toolbox will be introduce in progressive way. The first block to be developed will be the aircraft model, in which are included the actuators transfer functions. The trajectory generator will provide the basic data any flight. The aircraft dynamics is a general block that includes besides the aircraft model, the needed controllers for any application, based on different and selectable control laws and the aircraft database. The perturbations block includes the wind and earth models, and finally the outputs block groups several types of data representation and visualization. The following figure depicts a vey simplified toolbox structure.



CONCLUSIONS

The project presented in this abstract is been developed by a group of students conducted by professors of the Technical University of Madrid members of the Research Group for Air Navigation (GINA). The final software tool will allow simulating any aircraft flight phase in order to compute its simulated flight trajectory and to introduce and understand navigation concepts. From the user point of view, we would like to highlight the suitability of this toolbox because of the freedom to select any flight scenario.

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