20th ISPE International Conference on Concurrent Engineering
C. Bil et al. (Eds.)

doi:10.3233/978-1-61499-302-5-12

Software Tool Development to Improve the Airplane Preliminary Design Process

W.A.J. Anemaat[a,1], B. Kaushik[a], J. Carroll[a], J. Jeffery[b]
[a] *DARcorporation, 1440 Wakarusa Drive, Suite 500, Lawrence, KS 66049, USA*
[b] *J2 Aircraft Dynamics The Innovation Centre, Sci-Tech Daresbury, Keckwick Lane, Daresbury, Cheshire, WA4 4FS, United Kingdom*

Abstract. Aircraft design is a compromise of many different disciplines. Yet the history books are littered with projects that failed because something was overlooked in the early design stages that have come back to haunt it in the latter stages. This is very evident when it comes to evaluation of flying qualities and aircraft behavior as this is almost left out of the overall picture in the early design phases. It has long been considered that first order approximations are sufficient to indicate any issues in the early stages of design, but these can only show so much and are built on simplifications and approximations of a standard set of modes of motion. As airframes move away from classical designs due to improved materials, advanced manufacturing techniques evolve, or the improved efficiency associated with unconventional designs, so the approximations break down further. At this point it becomes prudent to perform more detailed assessment earlier in the project lifecycle. However, this too can have issues as it may be viewed that there is insufficient data, or the airframe is too complex to build a mathematical model. Then there is the question as to what to test and as such 6-DoF flight modeling is left until later in the process. This can have obvious consequences further down the project as 80% of the project and lifecycle costs are committed in the first 20% of the design. This immediately identifies that more effort should be put in the initial 20% to evaluate the complete design including flight modeling.

All the problems and issues that are presented above are now solvable through modern modeling techniques and software tools. This paper describes the tools developed to integrate flight simulation early on in the design process. Aerodynamics, stability and control estimates from the Advanced Aircraft Analysis software are corrected with the use of wind tunnel data, wind tunnel data is scaled to full size airplane and actual flight conditions. This data is then fed into the J2 Universal Toolkit to actually fly the airplane. Quality 6-DoF models can be built with minimal data and relative ease allowing engineers to start to look at running detailed analyses across multiple ideas and options very quickly and much earlier in the design process combining the more detailed handling qualities assessment with the aerodynamic evaluation, performance, propulsion and weight calculations right from the beginning of the design. Each point in the regulations has a configuration and maneuver associated with proofing compliance, these configurations and maneuvers can be set up in the modeling tool and all ideas and options can be evaluated. This very quickly identifies areas where the aircraft cannot get certified, and these ideas can then either be eliminated or modified. By following an integrated approach and implementing full 6-DoF flight modeling from the early stages of the design using simple methods initially, looking at sensitivity studies and the impact of tolerances throughout the process, and flying the complete certification envelope throughout the design provides a truly concurrent engineering approach to the design as all other disciplines feed into and have an impact on the behavior and flying qualities. This method allows more ideas to be evaluated earlier, enables the impact of changes to be tracked, and ensures that no surprises remain by the time the first flight comes around. This can reduce timescales, reduce the amount and cost of re-work to fix issues following flight test, and result in a better all-round design.

The paper shows the tools developed, the processes followed and an example airplane design using these tools.

Keywords. airplane design, flight dynamics, wind tunnel testing, design tools

---

[1] Corresponding Author.

Introduction

Early in the design stages of an aircraft the primary focus is on the aerodynamics, stability & control and the weight/structural elements of the aircraft. While it is true that the flying qualities are checked, the depth of the analysis into the flying qualities does not reach that of the aerodynamics, stability & control and weight in the conceptual and preliminary design stages. Incorporating a detailed flying qualities analysis in the conceptual and preliminary design phase will decrease the number of configurations tested in the wind tunnel and/or analyzed in CFD and will give the pilots a better idea of the flight characteristics of the aircraft before the aircraft is even built and flight tests are carried out.

Modern modeling tools allow the dynamic simulations of the proposed aircraft configurations to be incorporated sooner in the design and development phases such that there are no surprises in the later design phases and flight testing. The tools used to accomplish this task are the Advanced Aircraft Analysis (AAA) software and the J2 Universal Toolkit. The AAA software is used to generate the aerodynamic, mass and stability & control properties of the conceptual and preliminary design configurations. These aircraft properties are then fed into the J2 Universal Toolkit to perform a dynamic simulation of the aircraft.

1. Tools

The tools used in the analysis are outlined in the subsequent sections.

1.1. Advanced Aircraft Analysis

The Advanced Aircraft Analysis (AAA) software (Reference 1) provides a framework to support the iterative and non-unique process of aircraft conceptual and preliminary design. AAA provides an analysis method based on semi-empirical relationships to take an aircraft from early weight sizing through open loop and closed loop dynamic stability and sensitivity analysis while working within regulatory and cost constraints. The AAA program consists of 10 modules that perform tasks necessary to evaluate the characteristics of a given aircraft at each stage in the conceptual and preliminary design process. The AAA software also has methods for correcting data obtained from wind tunnel tests and scaling them to full scale parameters.

1.2. J2 Universal Toolkit

The j2 Universal Tool-kit (Reference 2) is a complete set of design and analysis tools for Flight Physics. It includes aircraft model building (from any data source from conceptual design to flight test), system integration (external models, FCS, Landing Gear, Weights and balance, aircraft systems, etc.), Flight Mechanics, (Static/Dynamic, Lateral/Longitudinal, Linear/Non-Linear), Performance Analysis, and Flight Test Analysis. The whole system is a data driven solution, effectively divorcing the aircraft model from the analyses. This means the model is self-contained and is responsible for calculating its own states and parameters from the inputs and environmental conditions that are specified. The user interface for the j2 Universal Tool-kit is shown in Figure 1.

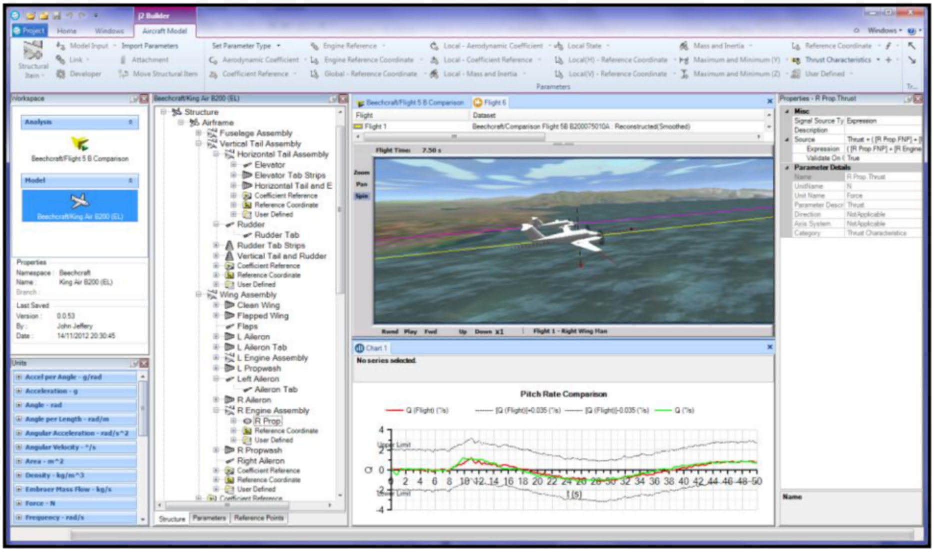

Figure 1: j2 Universal Tool-kit User Interface

Using an integrated environment avoids the continual movement of data around different applications and the possible errors that can result from data transfer steps. Being able to simulate the aircraft through offline tests and a real time environment can help engineers and pilots to understand behavior and rehearse tests, and to compare their experience on the ground to the real aircraft for additional feedback

2. Application

An interface is developed between the J2 Universal Toolkit and the AAA software to facilitate including flight simulation technique at the earliest stages of the design process. This interface will allow quick transfer of information from the AAA software to the J2 Universal Toolkit increasing the configurations considered as well as providing another basis of comparison for many different design configurations to narrow down the design field. This will also detect issues with current design configurations and will allow the designers to fix potential problems before any further testing is done. For these examples, only a cruise condition with landing gear retracted at a single center of gravity location is considered. The method applies for each flight condition and center of gravity location.

2.1. Conceptual Design Phase

During the conceptual design phase, aircraft designers attempt to come up with configurations that satisfy a particular mission. Unfortunately, there are many configurations that will satisfy a particular mission with pros and cons for each configuration. This is where an analysis of the configurations' flying qualities using flight simulation software is utilized. While modern modeling techniques can increase the design field, usually the designer can down select to four to five configurations that warrant further investigation. Including the flight simulation and flying qualities at this stage in the design provides another basis of comparison for the aircraft configurations and may narrow the design configurations further based on the handling qualities of the aircraft configuration.

As an example, the following geometry are determined adequate to perform a given mission. Three-views of the aircraft configurations are shown in Figure 2.

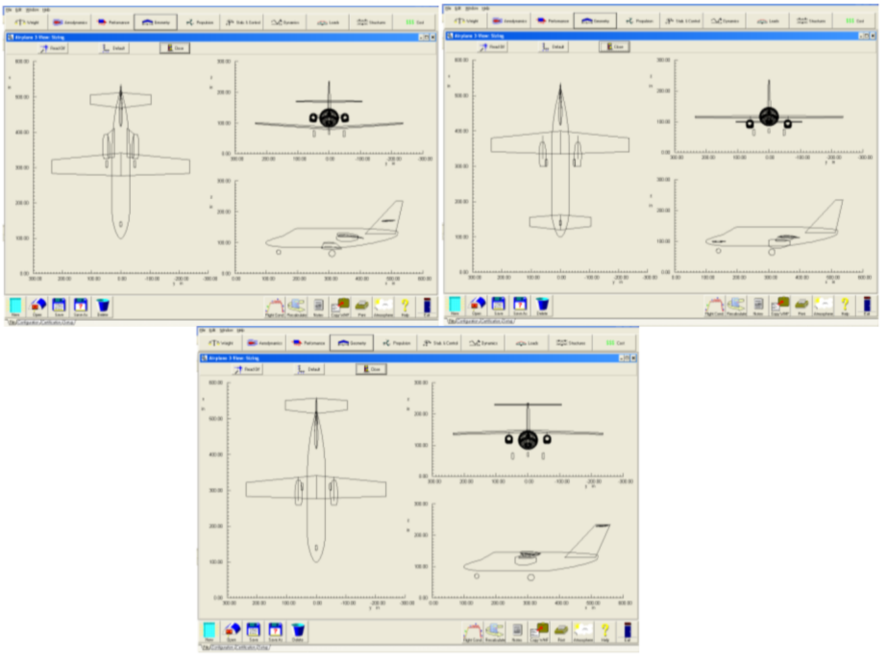

Figure 2: Initial VLJ Configuration

This data is fed into the J2 Universal Toolkit and various maneuvers are performed to determine handling qualities and if the configuration is certifiable. The longitudinal and lateral-directional flight characteristics for the various configurations are given in Table 1 and Table 2, respectively.

Table 1 Longitudinal Flying Qualities

Configuration	Phugoid Stability Level	Short Period Damping Level
Conventional	Level 1	Level 2
Canard	Level 1	Level 1
T-Tail	Level 1	Level 1

Table 2: Lateral-Directional Flying Qualities

Configuration	Spiral Stability Level	Roll Performance Level	Dutch Roll Damping Level
Conventional	Level 1	Level 1	Level 1
Canard	Level 1	Level 1	Level 1
T-Tail	Level 1	Level 1	Level 1

2.2. Preliminary Design Phase

It is assumed that from the conceptual design phase there are wind tunnel tests of the down selected configurations based on the dynamic analysis. The wind tunnel data is then transferred to the AAA wind tunnel module where the aerodynamics and stability & control derivatives are scaled to the full scale aircraft. Select flight response modes are shown in Figure 3 through Figure 5.

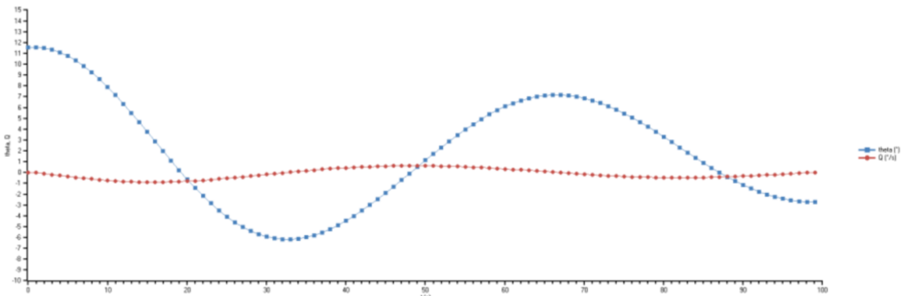

Figure 3: Phugoid Response Mode

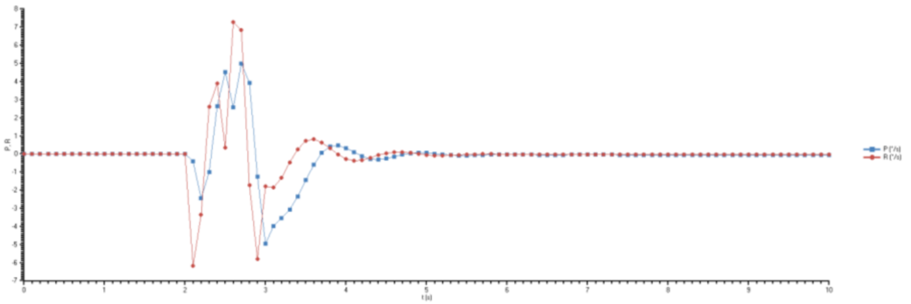

Figure 4: Dutch Roll Response Mode

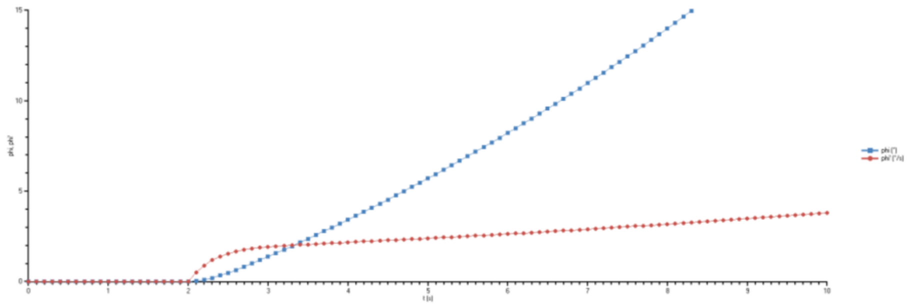

Figure 5: Roll Response Mode

For different configurations, these time responses can then be compared at various flight conditions, aiding in the down selection process for the aircraft.

3. Conclusion

Incorporating flight simulation into the early stages of the design process increases the number of configurations considered, provides an additional basis of comparison for configurations that satisfy the mission requirements, provide insight into design choices that could potentially cause costly design changes in the later on in the life of the design and provide flight test pilots an opportunity to get a feel for how the aircraft will act in the air before the aircraft's first flight. The speed of the modern modeling tools and techniques provide avenues to perform detailed flight handling analyses during the beginning stages of an aircraft design where many configurations are considered and even when a configuration is selected it is under constant development and change. This could potentially lead to fewer flight tests, which translates into lower development costs of the airframe.

References

[1] Anon, Advanced Aircraft Analysis, version 3.5, DARcorporation,2013.
[2] Anon. j2 Universal Toolkit, version 5.1, j2 Aircraft Dynamics 2013.