

CATIA V5-Based Parametric Aircraft Geometry Modeler

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ABSTRACT

Current transport aircraft are mature systems, thus require increased fidelity at the beginning of the design process to allow further optimization. Furthermore, a desire exists to explore unconventional aircraft configurations at the conceptual level. This has motivated the development of a tool which effectively manages the trade-off between high-fidelity levels, flexibility and short turn-around times. This paper presents a CATIA V5-based parametric aircraft geometry modeler developed by Bombardier Aerospace. The aim of the tool is to provide consistent high-fidelity geometric data early in the conceptual aircraft design process.

The intended near-term use of the modeler is two-fold: during the early design phase, the modeler computes geometric data such as areas, volumes, ESDU aircraft parameters, etc. In the competitive analysis domain, the tool provides a high-quality three-dimensional model with manageable effort. In both cases, the engineer is presented with a fully parametric three-dimensional CATIA V5 aircraft model. In the medium-term, use by expert departments is envisioned.

Moreover, the geometrical data extracted from CATALIST can be saved into a standard database and fed to various analysis codes to compute aircraft performance characteristics. As aircraft models are in native CATIA V5 format, this fits seamlessly into the established design process at Bombardier Aerospace. Additionally, this approach allows critical analyses to be performed earlier in the conceptual design phase.

Aircraft exterior and interior modules are in use today along with systems modules and a basic structural representation. An overview of the key features of the tool is presented along with sample applications. Tool usability and modeling quality have been extensively validated with selected regional aircraft and business jets from Bombardier.

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INTRODUCTION

The competitive nature of a globalized aerospace industry requires aircraft manufacturers to remain current and push the boundaries of aircraft design in all development phases. Continuous progress in affordable computing power is enabling the use of more precise aircraft analysis codes in the conceptual design phase. Consequently, within a specified timeframe, more analysis loops with higher fidelity can be accomplished, which allows for more optimized designs of an already mature product.

In order to better understand the market positioning of one's products, it is essential to perform thorough analyses of competing products. Provided that a suitable toolset is available, users can also investigate unconventional aircraft

concepts for their improvement potential relative to current aircraft.

Based on these needs, the Advanced Design Department of Bombardier Aerospace decided to pursue the development of a fully parametric three-dimensional aircraft geometry model early in the last decade. At the time, the idea was to replace the two-dimensional drawings typically used to gather geometric data. It was deemed important to enable continuity beyond the conceptual design process. Hence, the model was built on the CATIA V5 platform, which is widely used in the aviation industry. The model rudimentarily implemented the concept of parametric design. Apart from providing consistency, the tool offered higher precision, quicker turn-around time, and a steeper learning curve than the conventional approach. The tool was dubbed CATALIST

(CATIA Advanced Design Linking and Iterations Software and Tool).



Figure 1. CATALIST model of the Bombardier CRJ200

In 2008 additional capabilities and features were implemented into the existing version. The present paper focuses on this work which was performed in the context of a research project. The original CATALIST was redesigned to achieve higher fidelity, at equal or better turn-around times, and most significantly, allow the investigation of unconventional morphologies. It was found that scripts composed in Visual Basic (VB) posed challenges during CATIA software updates. Hence, a basic premise of the research work was to utilize inherent CATIA features from accessible workbenches during the construction of the modeler. As the tool requires the basic service package of the CATIA V5 software only, software updates and license availability have minimal impact on the use of the tool. Owing to the new design philosophy all existing VB codes have been replaced with internal functions and rules included in the CATIA Knowledge Advisor 2 (KWA) workbench.

It should be noted that CATALIST supports a CAD-centric aircraft design approach. This is based on a conscious decision to produce a tool which would provide a significant benefit for designer-in-the-loop design processes. Other parametric geometry modelers based on the computer-aided design (CAD) software are Boeing's General Geometry Generator, NASA's Rapid Aircraft Modeler and Avid's Parametric Aircraft Geometry Engine [1,2,3,4].

TOOL DESCRIPTION

The geometry modeler was developed in CATIA V5 to help ensure the consistency and robustness of the modeler in the design process. The tool is oriented to the designer equipped with basic knowledge of CATIA software. It is of importance to allow the designer to create and modify a design with a minimal amount of effort and achieve the desired model quality. The following section describes the design approach implemented in the development of the CATALIST tool from the developers' perspective, the

modular structure of the tool with a detailed break-down, and the reasoning for the usage of standard part libraries.

Design Approach

CATALIST implements the top-down design approach to establish a sound architecture for handling a complex aircraft system [5]. Specifically, the design of a fully parametric model begins with an aircraft product at the highest level of the hierarchical architecture [5]. Then it progresses downward to the design of aircraft sub-assemblies until finally reaching the part-level details such as individual aircraft components [5].

At the aircraft product level, the general configuration of an aircraft model is defined by the designer via global parameters manipulating the status of product/component activation. Unloading unused products/components from a CATIA session can dramatically reduce the size and the updating time of the model, which is, in particular, beneficial for complex models.

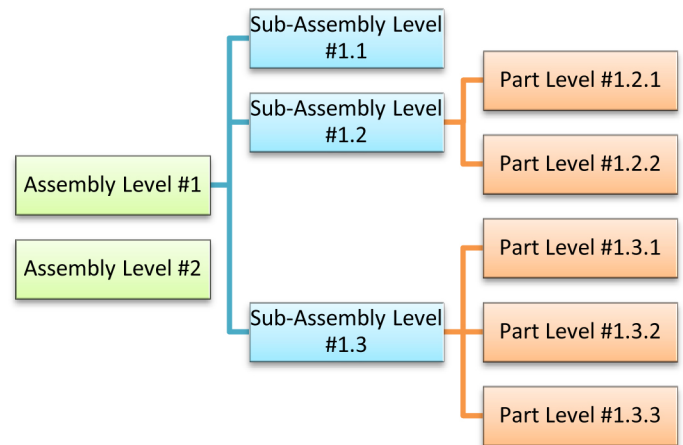


Figure 2. CATALIST architecture

At the sub-assembly level, the model is divided into functional groups that gather all components with similar functionality. Grouping not only helps designers to organize the model structure, but also serves as containment for errors should they occur at the part level.

At the part level, each part is designed in detail on a graphically interactive platform which can reflect design changes without updating other products or parts. Most user-defined parameters are stored at this level along with associated wireframe geometries, where designers can access both simultaneously. The designers can also assign values to these parameters through design tables under the aircraft product which contains all accessible parameters for each product and part. In addition, skeletons and sub-surfaces of an aircraft model are constructed at this level mainly from selected features published from planar sketches. A sub-surface refers to a segment of a part surface, for example, the cockpit of a fuselage surface. Publication serves as a portal that exposes an element or parameter to the user community.

Communication among all levels is established via contextual links in CATIA V5 which are known as parent-and-child relationships between a reference and an instance in the context of a top-level CATProduct [6]. Contextual links are dependency relations for transmitting geometric, parametric, and positioning information between CATProducts or CATParts. The links are unidirectional and always point from the child to the parent. In other words, children have no impact on the definition of the parent. This architecture allows for the re-use of parents in multiple contexts.

In addition to having sound architecture, the aircraft model's quality relies on the techniques and constraints implemented during the construction of surfaces. A majority of sub-surfaces are lofted surfaces based on both profile and guide curves outputted from sketches. However, the cockpit and tail cone of the fuselage are exceptional, which are filled surfaces with wireframe boundaries. Surface continuity contributes the most to the resulting surface quality. Thus, as a minimum requirement, tangency continuity is imposed between all adjacent sub-surfaces such that aerodynamic and stress analyses could be directly performed on the surface model without additional post-processing. It is obvious that the reference curves at the part level have direct impact on the surface quality. Thus, tangency continuity is also imposed between planar and space curves. The sub-surfaces are selectively joined to discrete surfaces at the part level and trimmed with others at the aircraft product level to provide the basis for a water-tight solid model.

This modeling method is consciously chosen over alternative techniques such as a parameterized model with a fixed topology which may increase precision at the expense of flexibility and modeling speed. Figure 3 shows the CATALIST cockpit surface compared to the production loft, and the loss of detail, which is deemed to be acceptable in conceptual design.

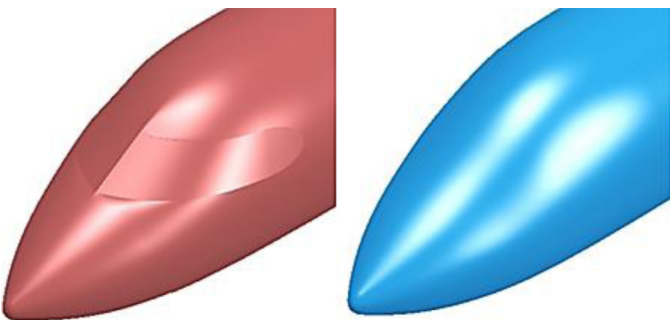


Figure 3. Cockpit surface of Global express production loft model (left) and CATALIST model (right)

To facilitate the design process, design tables have been introduced into the tool to store the user-defined parameters extracted from the latest design. In general, each module owns an individual design table with a choice of activation or deactivation. The use of design tables minimizes the required effort to design a component which can be revised from an

existing one. Moreover, CATALIST is capable of reading a set of associated parameters stored in the design tables and recreating a specific aircraft. All modifications performed in the design tables are recognized by the tool, and reflected on the final aircraft model when it is updated. Upon the completion of modeling, CATALIST outputs derived geometric information of interest via a final design table. A comprehensive set of derived relevant values can be extracted from the geometry, such as ESDU areas, surface areas, CGs of the aircraft components, reference wing parameters, internal volumes, etc.

Modular Architecture

Figure 4 illustrates a top-level break-down of the CATALIST model, which consists of Exterior, Interior, Structures and Systems. Modularity was introduced to represent the main functional groups of a typical transport aircraft. Each module contains a predefined template designers can start with. More details of each module are presented in the following sections.

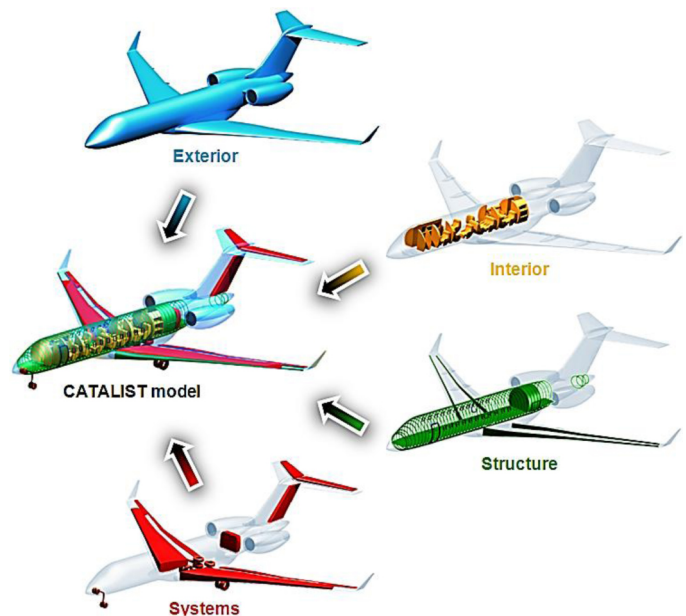


Figure 4. CATALIST tool overview

Exterior

The Exterior module is designed for building the exterior of an aircraft consisting of a vast variety of components for conventional and unconventional aircraft configurations. Contained in this module are the fuselage, wing, vertical/horizontal stabilizers and the power plant. Several of the major components have two instances embedded (primary and secondary). This option was introduced to enhance design flexibility in order to create unconventional designs. Figure 5 illustrates a CATALIST model of the Scaled Composites White Knight Two and Space Ship Two demonstrating the tool's versatility.



Figure 5. CATALIST model of Scaled Composites White Knight Two and Space Ship Two [10]

The wing model includes both an un-deformed shape (jig shape) and an elastic equilibrium shape (flight shape) which are defined by two sets of parameters under the parameter set of the wing. These two representations of the wing are used in two sequential phases of design. In the beginning, the flight shape is of most interest and as the design matures, the jig shape gains in importance while the flight shape is still required to assess performance.

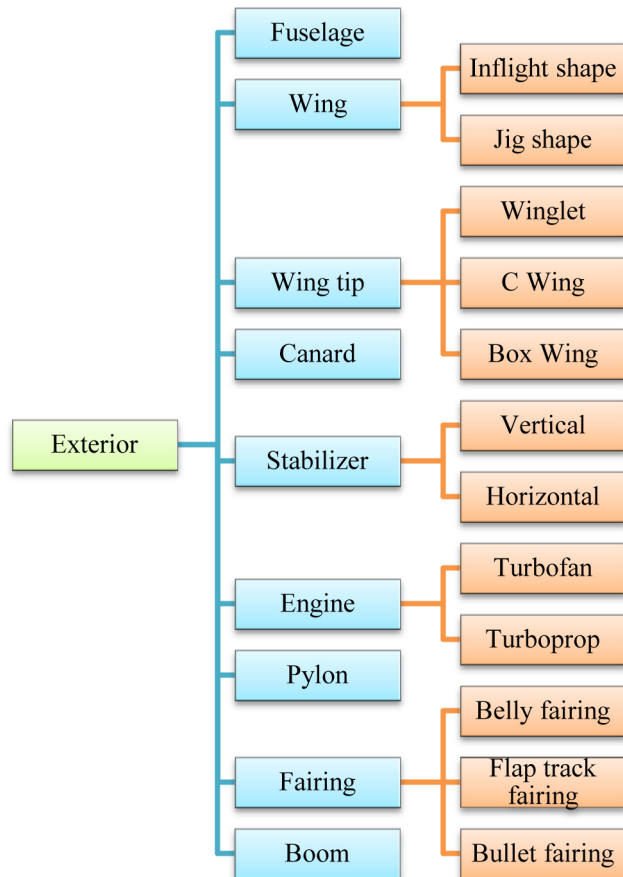


Figure 6. Assembly structure of CATALIST Exterior module

CATALIST allows the representation of conventional turbofans, turboprops and open rotors. The model accounts for the nacelle and locations of the first and last rotor disk as well as the CG of the complete propulsion system. Fan or

propeller diameter can be represented accurately. The rotor failure debris cones are also available where various opening angles represent small, medium and large fragment sizes. Pylons for each engine variation are available and they can be mounted based on the aircraft configuration. A stream tube is defined to obtain the correct system volume, and then subtracted from the total volume. [Figure 6](#) shows the break-down of the exterior module.

All similarly designed components are interchangeable, again increasing flexibility (for example, the stabilizers can be used for pylons or vice versa). Other key features are asymmetric configuration capability, various empennage configurations (V-Tail, H-Tail, Y-Tail) and automated generation of 3-views. Also, CATALIST generates a surface model along with a watertight solid model of the aircraft, which can be further analyzed using CFD or used for other purposes.

Interior

The Interior module is used to build the interior of the aircraft. Once the exterior of an aircraft is defined, this module will help to design and size the cabin. It also aids in defining the cabin layout, seating arrangements, monument and lavatory sizing etc. Interior components are created to have an option to use this tool for business and commercial aircraft interior designs. All interior modules can be resized and rearranged based on the interior layout and component design. A detailed break-down of the interior module can be found in [figure 7](#).

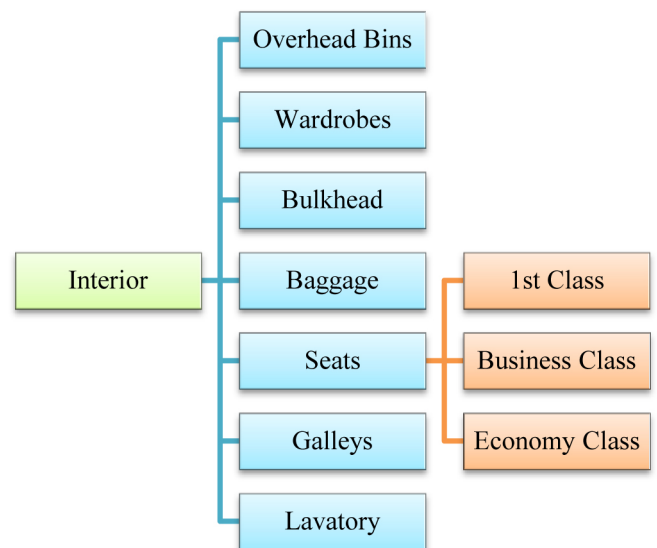


Figure 7. Assembly structure of CATALIST Interior module

Similar to the exterior module, all component parameters are linked to a design table and numerous components are stored in the library, enabling designers to make use of existing libraries as the starting point for a new design.