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A Knowledge Based Aircraft Conceptual Design Tool**

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RAPID – Robust Aircraft Parametric Interactive Design (A Knowledge Based Aircraft Conceptual Design Tool)

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Abstract

Conceptual design is the early stage of the aircraft design process where results are needed faster both analytically and visually so that the design can be modified or changed at the earliest stages. Although there is no necessity for a CAD model from the very beginning of the design process it can be an added advantage to have the model, to get the impression and appearance.

Tango and RAPID are knowledge based aircraft conceptual design applications being developed in Matlab and CATIA respectively. The user can work in parallel with both programs and exchange the data between them via XML. This paper describes the knowledge based design automated methodology of RAPID and its application in the courses “Aircraft conceptual design” and “Aircraft project course” at Linköping University. A multifaceted user interface is developed to assist in the whole design processes.

1 Introduction

Conceptual design tools always need to be refined and improved. There is no end to it and this is how it should be. One such much needed refinement is to be able to communicate between the analytical design tool and the 3D

environment, i.e. CATIA. Data communication between conceptual design programs has always been a major obstacle which now has found a solution through this work, presently being done at Linköping University. A seamless connection appeals to the designer, but it has to work both ways. There are a handful of existing software tools in the industry, at universities and research centers. Some have connections to CAD programs, but the connection is usually not seamless and even more rarely they work both ways [11].

Existing aircraft conceptual design tools:

- RDS [1]
- ADS [8]
- Desktop Aero [10]
- J2 Universal Tool Kit [7]
- Piano [9]
- CEASIOM [3]
- PADLab [4]
- VSP [4]
- Bauhaus Luftfahrt: Conceptual Design Tool (CDT) [6]

2 Knowledge Based Engineering Design

Knowledge Based Engineering can be explained as reusable information that exists in the specific method or form; this knowledge is reused either manually or automatically and the whole process of using existing knowledge such that it adapts to the new environment can be

termed as *Knowledge Based System (KBS)* [12] and [13]. The automation is performed in CATIA [22] using Power Copy and User Defined Feature (UDF) wherever necessary. *Visual Basic (VB)* scripts use the power copies and Knowledge Pattern use UDFs to save the knowledge that is created for automation. Power Copy or UDF is a set of features stacked together that can be reused at a later stage. A Catalog is needed to store the location of the UDF. The Knowledge Pattern Algorithm script is written using the *Engineering Knowledge Language (EKL)* to control the UDF. UDF is used repeatedly to obtain a desired configuration. Further the UDF can be updated depending on the necessity and used accordingly. Creating a KBS is time consuming and the user needs to have some knowledge of the system in case of modifying it; once it is built there are numerous uses of it and could help the user build the necessary system quicker faster and in less time.

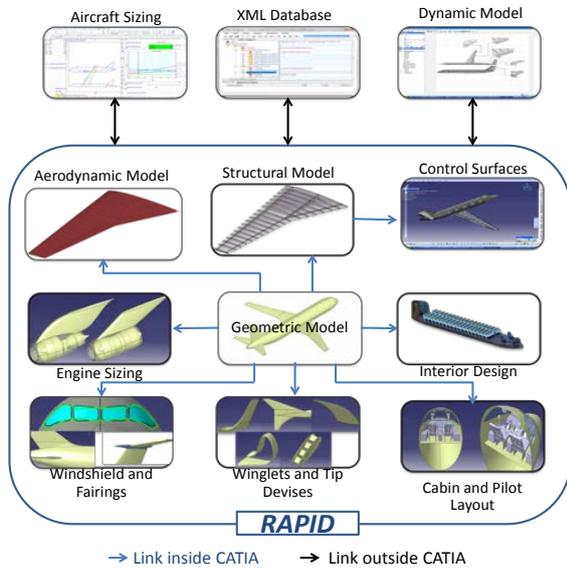


Fig. 1 RAPID Tool

3 Data management

Data created in RAPID is saved as an XML document. XML stands for “eXtensible Markup Language”. XML contains both the information and is self-explanatory format. XSL

Transformation (XSLT) is used to change one XML Document to another XML Document [21]. For more information on XML database and XML data handling in RAPID refer “*Integrated Aircraft Design Network*” [20].

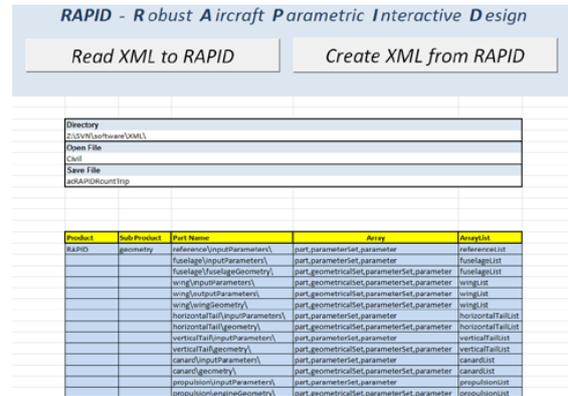


Fig. 2 RAPID-XML Interface

3.1 Create an XML file for CATIA parameter sets

Creating the XML is done in the following way:

- Parameter Sets that need to be represented in XML are written in the excel sheet as rows.
- These Rows from excel are read into VBA and compared with the whole list of parameter sets from CATIA.
- The matched Parameters and Parameter Set are formed into XML strings using DOM Object.
- The Final XML DOM object is written and saved as an XML document.

3.2 Read XML file

- The Required XML Document is loaded into VBA.
- Each XML node in the document is parsed, the Data in the last nodes is extracted and updated into the corresponding CATIA Parameters.
- CATIA is updated using CATIA – VB Scripts for the changes to reflect.

4 RAPID

RAPID is a geometry oriented design tool used in the framework of aircraft conceptual design. The core incentive to use CATIA is to allow the geometry propagation from conceptual design to preliminary design. *Knowledge Pattern* (KP) and *Visual Basic* (VB) embedded in CATIA are used for automation at necessary stages. There are three ways the user can design the aircraft in RAPID.

- By modifying the existing model after loading from XML data library.
- By updating the model from the Sizing Excel.
- By bottom-up design approach.

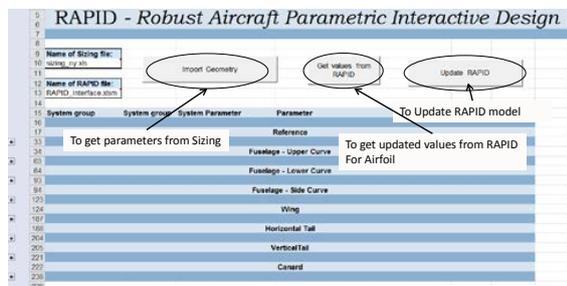


Fig. 3 User interface for Geometry

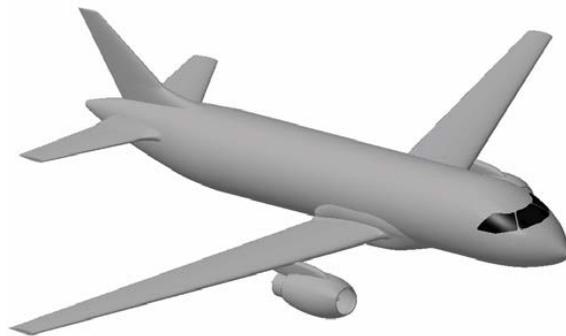


Fig. 4 Example of Civil transport aircraft geometry loaded from database

The bottom-up design approach can be employed in RAPID to design from scratch or the user can load the existing aircraft model from the XML data library. The user begins by modifying the fuselage curves according to design requirements and later adapting the wing. The empennage is automatically sized

depending on the given fuselage parameters and wing parameters. The adaptability of the model helps to obtain different aircraft configurations.

4.1 Geometry Model

After the initial setup of the wireframe model of the aircraft, a more detailed geometry can be developed (Fig. 6). The user chooses the number of frustums needed for the fuselage and the number of partitions needed for wing, empennage and canard depending on the requirement.

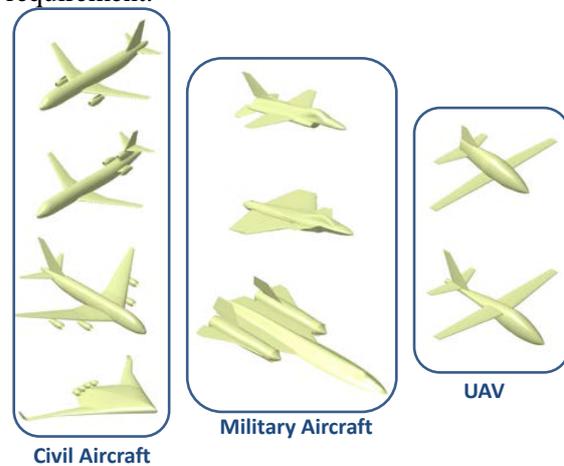


Fig. 5 Different aircraft configurations of geometry model RAPID

4.1.1 Fuselage Geometry Description

Fuselage wireframe is composed of four supporting splines; they are upper curve, bottom curve, side curve and center curve (Fig. 6). The splines are created in desired manner which are then taken as reference for the instantiation of frustums. A frustum is formed by two Bézier curves joined by a surface. Bézier curves are parametric and can be modified to get desired cross-section at each frustum (Fig. 7).

A quarter of the fuselage cross-segment is portrayed by third-order Bézier curve. The angle is measured from the horizontal line for “upper line” and “lower line” and angle is measured from the vertical line for “side upper line” and “side lower line”. The Points 1, 4 and 7 shown in Fig. 7 are the intersection points with the fuselage curves while points 2, 3, 5 and 6 are

positioned along the respective lines as a fraction.

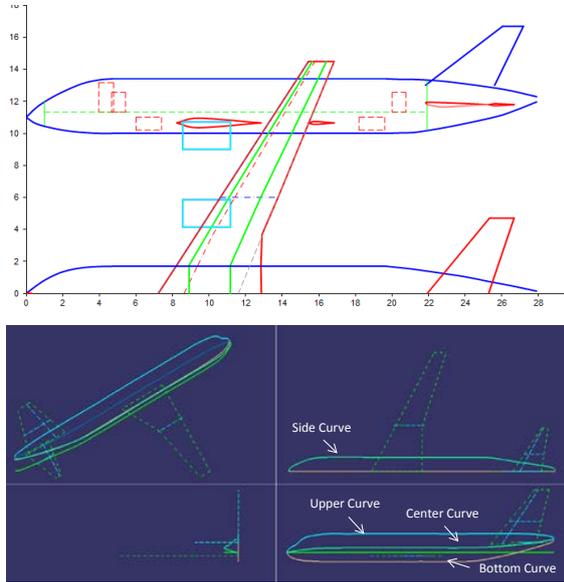


Fig. 6 Fuselage curves in Sizing Excel (Top); Fuselage curves in RAPID (Bottom)

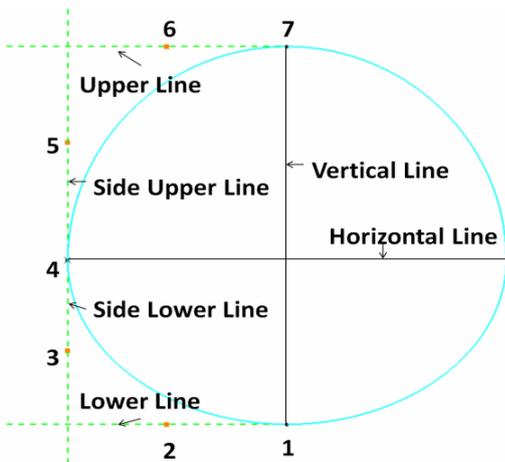


Fig. 7 Description of RAPID fuselage Cross-section [11]

4.1.2 Wing Geometry Definition

Wing wireframe is generated by taking the reference area, taper ratio and aspect ratio as reference. The user has an option to choose the angle either from leading edge or 25% root chord to obtain trapezoidal wing area (shown in dotted line in Fig. 8). There also exists another reference area method to choose from such as

Double delta, Gross Method and Wimpres Method. The RAPID area method uses the trapezoid area as a reference, after instantiating required number of partitions the chord at each airfoil can be modified to obtain different wing shape as shown in Fig. 8.

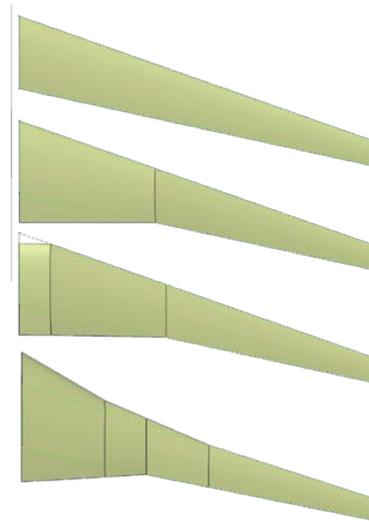


Fig. 8 Different wing shapes modified after instantiation of partitions

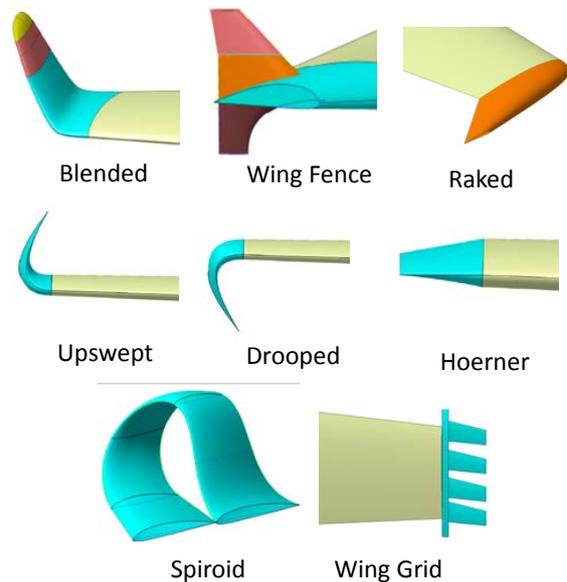


Fig. 9 Different types of Winglets [15]

Each partition is made up of two airfoils joined by a surface. The airfoils are generated using third-order Bézier curves. The same

partition template is used for horizontal tail, vertical tail and canard. Since the airfoil is parametrically defined, it can be used to obtain “n” number of airfoil shapes [14]. Different types of winglets and wing tip devices can be chosen. The wireframe is first instantiated and later number of wing partitions are instantiated. The projected areas of each partition are summed up automatically to give the final area of the wing and winglets.

4.1.3 Engine Sizing

Two types of engines turbofan and turbojet can be sized in RAPID. Thrust, Specific fuel consumptions (SFC), Weight, Length, Diameter and By-pass ratio are the key parameters that size the engine. Turbofan engine is sized to suit commercial aircrafts engine dimensions with a bypass ratio from 3 to 20; turbojet engine to suit the dimensions of business jets and military engines with no after burner engines from 0.1 to 15.

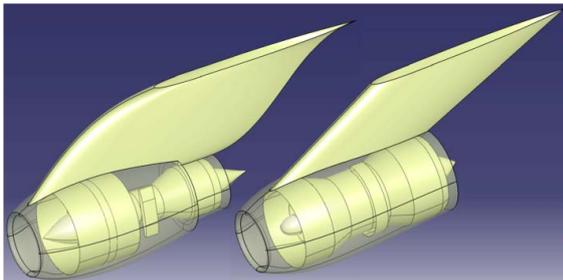


Fig. 10 Turbofan (left) and turbojet engine (right) [11]

Mixed-flow and separate-jet are two kinds of nacelles available; straight and smooth pylon types can be chosen. Nacelle design depends on the type of engine and various parameters can be changed to obtain the desired contour. Pylon is designed in context with nacelle, start and end values are changed accordingly. Air inlet and duct for military application is a work in progress.

4.2 Interior Design

Comfort is the privilege that a passenger craves for while travelling. Aircraft Interiors is a major part of the Aircraft Design process. Cabin space has to be utilized in a intelligent fashion

using most of the space, identifying the comfort factors for passenger, able to accommodate the maximum number of passengers according to the requirement. FAR 25 rules have been implemented in cabin design.

4.2.1 Cockpit Design

The cockpit design consists of windshield design, cockpit layout and ergonomic study. Flat panels and blended windshield can be generated. The wing shield uses the visibility pattern as the wireframe and later number of panels can be instantiated shown in Fig. 11.

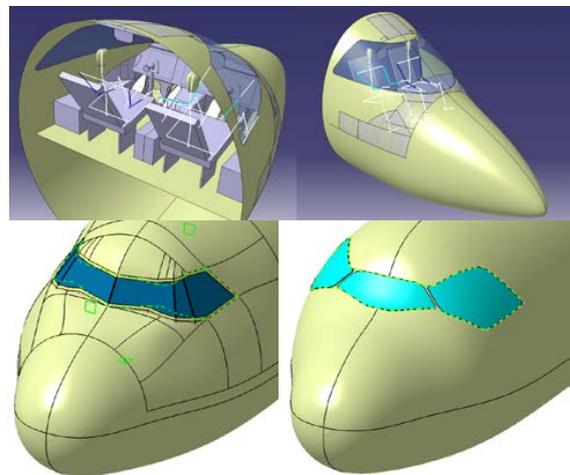


Fig. 11 Cockpit and Windshield model [16] [17]

4.2.2 Cabin Layout

Seating layout, Doors, windows, galley, lavatory, and containers can be configured from the cabin interior layout. FAR rules have been applied to all the entities listed above. The overall length of the cabin needed is computed and the user will know the cabin length available at all times. Depending on the number of passengers; type of galley, number of galleys, and number trolley in each galley and number of food trays needed are computed. The weights of first class, business class and economy seats are computed after instantiation.

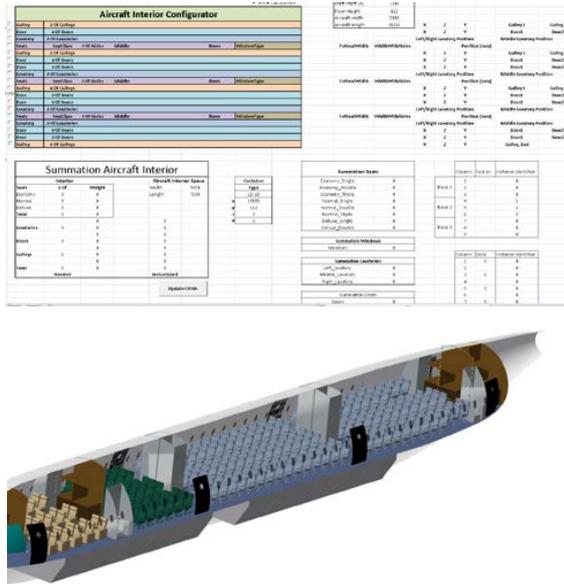


Fig. 12 Cabin Layout Interface and Cabin Interior

5 Applications

5.1 The Jet Family Project

In the course “Aircraft Conceptual Design” assignment was to design a family of turbofan powered aircraft according to FAR 25. The aircraft family includes three family members. The number of seats range from 75 to 110 (design payload), at 32 inch pitch, but high density versions had to allow two more rows of seats and seat pitch of 28 inches. In addition to this a two class internal layout had to be studied. The two classes were business and economy. 15% of the passengers in each version had to be seated in business class and the rest in economical class. The seat pitch in business class was 34 inches and in economy class, 30 inches. The family of aircraft had to be equipped with one and the same wing. The assignment also includes a study on how an optimal aircraft should be designed (for each family member) and how much you lose in weight and efficiency by keeping the wing unchanged. Interior design for this assignment was very important (as for all designs) as it leads to the length of the cabin. It includes a study on the number of doors and sizes required for different family members.

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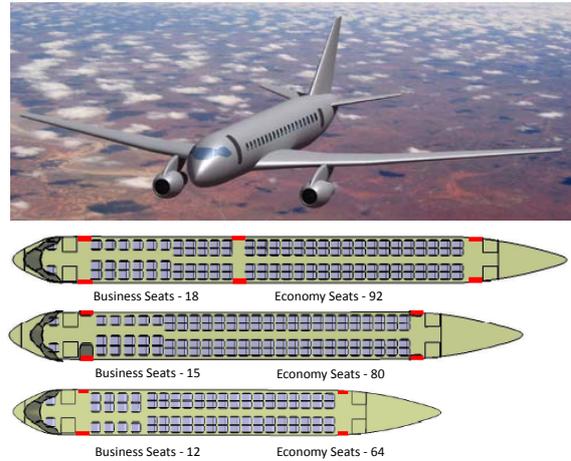


Fig. 13 One of the student aircraft and interiors with two class seating configurations and an artistic view of the aircraft.

It is also important to provide the required spacing at the emergency exits for evacuation. Number of toilets, galleys and the number of cabin crew required for the different family members also needs to be figured out. Where to put and access passenger luggage and cargo on the aircraft needs to be addressed. Also to consider all kinds of ground handling while on the ground, i.e. the possibility to service the aircraft by means of different vehicles during ground stop.

- M_{des} : 0.82 at 35000 ft for all family members
- Range : 2500 NM at design payload for in-between member of the family
- Reserves : 200nm + 30 min holding
- T-off field length (SL, ISA +20) max : 1900 m for all members
- Landing field length (SL, ISA +15) max: 1500m for all members
- Individual passenger weight (including luggage) : 110 kg
- Pilots including personal luggage : 104 kg each
- Attendants (including personal luggage) : 100 kg each

5.2 The Mid-Jet aircraft Project

The Mid-Jet project was to build a aerobatic, aesthetic, striking and overwhelming single seat

sport jet. To test and demonstrate the flight performance and characteristics a scaled model was built. As a first part of the project, a study was conducted on the existing single seat sport jets and later came up with different concepts. Many different concepts were studied from each team in the group, finally one concept was chosen for further studies. A conceptual design had been performed for full scale version. The initial model was built in RAPID. Later on many different features had been added during the detail design process. A demonstrator was built and tested with a scaled down version.

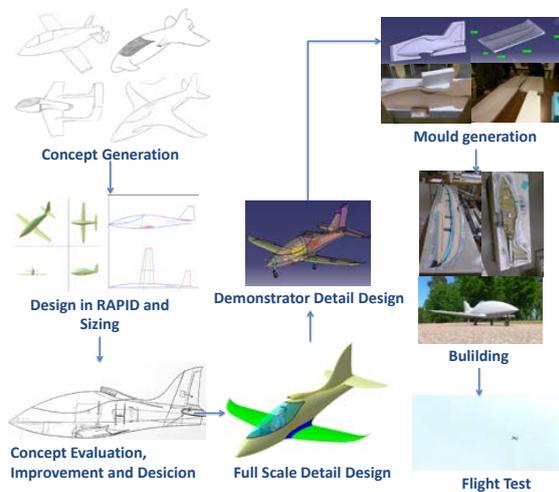


Fig. 14 Mid-Jet aircraft project process

6 Conclusion and Future work

This paper shows it is possible to communicate between the analytical tool and the CATIA environment and doing it both ways. Knowledge based automated design of RAPID is presented along with its applications. Different types of aircraft configurations can be obtained with less effort. As RAPID is developed based on relational design, any changes made to the geometric model will update the entire design. Different cross-sections and airfoils can be obtained for fuselage and wing like features respectively. An initial size of the engine is obtained from the engine sizing, nacelle and pylon can be shaped accordingly. The geometry model is well defined to carry over to the preliminary design.

Details such as cockpit model, windshield, fairings, winglets, interior layout can be observed at early stages of design. An XML database is used to save the design data and also communicate with Tango.

Future work includes weight estimation, drag calculation, structural design, optimization. An improvement in the existing structural model and aerodynamic model is needed to update the mesh automatically so that it can be used in optimization framework.

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