INTEGRATED PARAMETRIC AIRCRAFT DESIGN

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Abstract

Driven by the inspiration to develop a new aircraft that incorporates all fields of aeronautical engineering, the focal point of this design-approach is the geometric modelling. Since innovative technologies need to be included in novel configurations, every new idea has to be modelled in a comprehensible manner. Feedbacks coming from the analysed models are easily integrated in the next iterative cycle.

In the complex process of airplane design the primary aim is to investigate the configuration as a whole. Consequently, there should be just one geometric model that is frequently updated and to which each discipline has access with its individual tools. For this purpose a parametrical geometric model is built for the following disciplines in order to keep the effort of development of the required interfaces as low as possible.

In this approach the aircraft is broken down into logical components which reflect the used modules of an aircraft. These components are successively divided into subassemblies until the obtained aircraft parts can be described with useful parameters. To reach the required factor of detail, this step can be repeated down to the rivets, which includes a large amount of effort, know-how and computing power due to the parameterised interconnections.

1 Introduction

Market studies, competition and economical requirements demand the airframe constructor to evolve new ideas for new aircrafts. These requirements consist of goals such as flying higher, faster and longer, or the airline driven demand to fly less noisy because of increasingly strict noise abatement rules, or to fly more economical because of the rising costs and not to forget that the final customer demands more and more comfort during the flight. Many more of these drivers depending on market requirements exist. New technologies available for the above mentioned requirements are researched and chosen by the engineer. Therefore for example a scenario process [1] could be performed in order to ensure a configuration, which points out to the most predictable future or even to a new or unconventional thought.

These thoughts could then be the start for an initial preliminary sizing [2] with either new assumptions for unconventional airplanes or statistic measures from older aircrafts with related tasks. Until now this was done iteratively in all levels of detail by spread sheet calculations and 2D-drawings. Now this could be the point to start with not much difference in effort, in an early step of the iteration, with 3D-configurations and numerical analysis.

The conceptual design phase of a new aircraft project is characterised by a large potential of design modification and a high degree of information missing about the aircraft. To minimize overall design costs and development risks, there is a strong need to shift more design and development expenditures to the concept and definition phase (Figure 1). Simultaneously a more balanced cost distribution during the aircraft design process will arise [3].

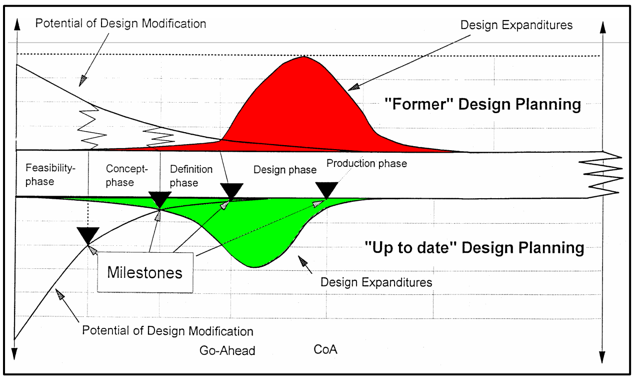

Figure 1

Thus an aircraft design process is needed which gives the engineer from the very beginning of the development an idea of the project and his characteristics on the part of all necessary disciplines which are involved in the process (e.g. aerodynamics, flight mechanics etc.). To meet the demands on this side, the Institute of Aeronautical Engineering is developing a new approach to aircraft pre-design in which at a final stage all disciplines will be integrated.

2 Conception

Within the concept phase of the preliminary aircraft design process a basic aircraft concept will be developed and it will be rated to alternative concepts. Therefore each concept has to be designed and calculated by all the special disciplines of aircraft design like the aerodynamics, flight-mechanics, weight & balance, structures, etc. This is the point where the new method in form of *Pad3D* (**P**arametric **a**ircraft **d**esign **3**-**D**imensional) shall be installed into the process.

Until today, every special discipline of aircraft design uses its own methods and tools. That means every discipline also uses its own specific parameters and the results of the calculations are returned to the main process as a sum of values. That leads to several different geometric models which are generated by each of the disciplines. This is of course a time consuming and expensive procedure. As there are no direct data transfer interfaces installed between these models, they deviate in detail which always leads to a falsification of specific results. The falsification always has to be compensated and that leads to a more complex procedure.

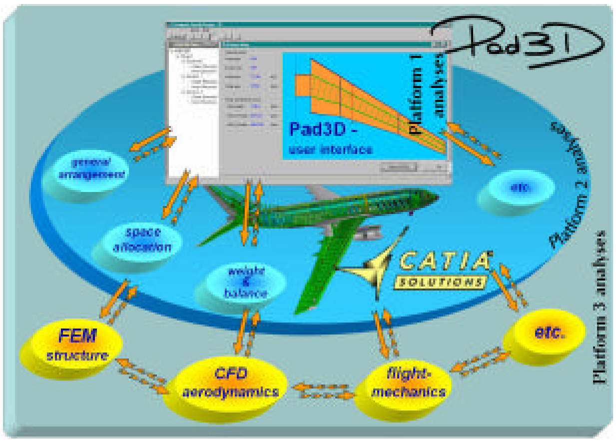

Figure 2

In contrast, the new approach of *Pad3D* is a common geometric modelling for all the disciplines of aeronautical engineering. This does not lead to a loss of data at the interfaces and also compensates cost and time, as all disciplines operate with the same consistent database.

The combination of all relevant disciplines of aeronautical engineering enables to point out interdependencies of these different disciplines and of course also interdependencies of aircraft components on the geometric side. With this knowledge-based concept, the effects on the whole aircraft project could be determined which arise due to a modification of one or more components. This is also valid for impact studies, belonging to a variation of parameters in specific disciplines.

Driven by the inspiration to involve all fields of aeronautical engineering already in the first project design of a new aircraft, the focal point of this design-approach is the geometric modelling. This is realised in *Pad3D* by feeding a certain amount of specific parameters which are essential to generate the 3D-geometry into

CATIA V5. Thus the aircraft designer has a first sketch of the project from the beginning.

3 Parametric Geometry

In this approach the aircraft is separated into reasonable components which reflect the modules applied of an aircraft (see Figure 3). These components usually are again separated into subassemblies to split up the aircraft in parts which can be described in useful parameters. To reach the required factor of detail, this step can be done down to the rivets, which includes a large amount of effort, know how and calculation performance because of all the parameterised connections. In this concept it will be done to show the useful advantage of this method in the pre-design process.

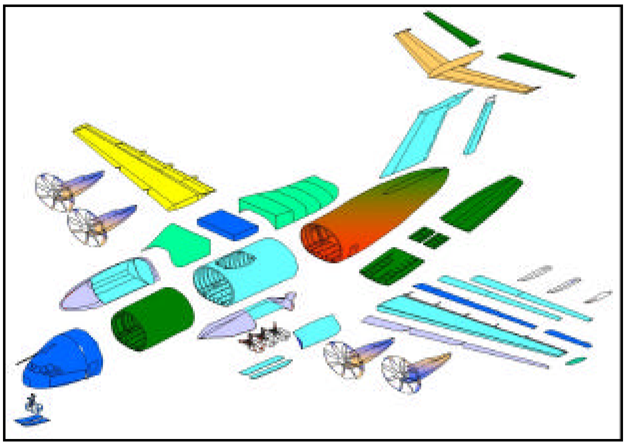

Figure 3 [4]

Table1: ***Main Aircraft Components***	
Fuselage	- Cockpit section - Constant Section - Rear Section
Wing	- Sections - Wingtip Devices
Stabilizer	- Horizontal Stabilizer - Vertical Stabilizer
Engine	- Fan - Hull Frame - Inlet - Nozzle
Pylon	
Fairings	
Landing Gear	
Etc…	

Every above mentioned component is then divided into different parameter groups:

- Outer Structure
- Inner Structure
- Cosmetics

The ***Outer Structure***, which is responsible for the bounding geometry, reflecting the configuration of that part, gives an arrangement of all parts, a first feedback for the designer of the overall aircraft configuration. The second group is the ***Inner Structure***, which contains all the parts indicating the structure devices in between the above mentioned bounding geometry. ***Cosmetics*** is the third group in the pre-design subdivision. This group contains all items which are not necessary for the main geometry but useful to see their dimensions, orientations and other properties like colour, material etc.

All above mentioned groups are input groups. This means that they contain parameters which have to be derived from the idea for a new aircraft or by drafts, pictures or datasheet from a recreation, and fitted by the user into the matching part. Parameters which are depending on others can just be fed into the program automatically, if these have been set before. Inside this method, there is one more group in which ***Characteristics*** parameters are shown. These parameters are more or less calculated numbers out of the groups mentioned before. To compare the new design with aircrafts already built, the parameters from this group are needed. It is possible that parameters of that group could be just taken out of the other three groups, but only if they reflect a feeling of the design to the engineer.

4 Program, Modules and Data Handling

In-, output and the data handling is controlled by the user-interface *Pad3D*. This front-end is developed in order to use it as a construction set in which it is always comprehensible, what parts have already been created, how detailed, and what could or should be added to the actual configuration (Figure 3). For most parts, the input of data can be visually controlled in a preview window and the others are controlled by maximum and minimum measurements within which range these parameters should normally lie. Therefore almost every wrong input will be checked, before the process "Create in CATIA" brings out senseless or faulty results. Figure 4 displays an input window of the *Pad3D* Engine-Module [17]. The automatically created 3 dimensional geometric result in CATIA V5 is shown in Figure 5.

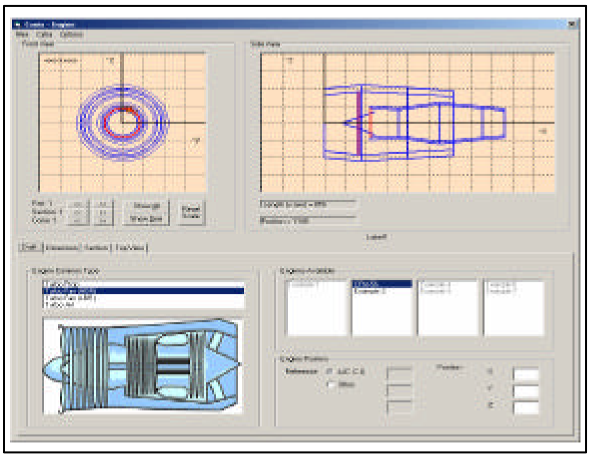

Figure 4

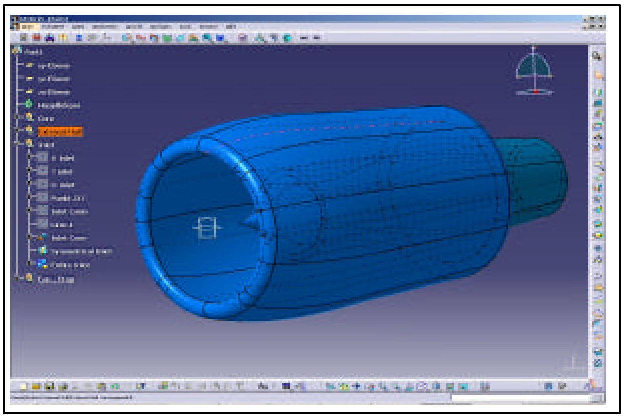

Figure 5

A "fundus"-database is also included, which contains several completed configurations. A derivative configuration can be developed by taking one of these and add missing or additional components or to scale the desired dimensions. In the tree view it is shown very clearly how the parts are connected to each other (left side of Fig.2). For every part which is parameterised, it is always possible to add new ones.

There is also a capability to use external input. A self created module called *Cabin Generator* uses the output of the program *Pacelab Cabin* [5], which is very useful to create a payload- respectively a cabin-configuration. This input can then be used to automatically build up the 3D geometry of all monuments inside the fuselage. Figure 6 shows an example of an aircraft project with a completely filled cabin.

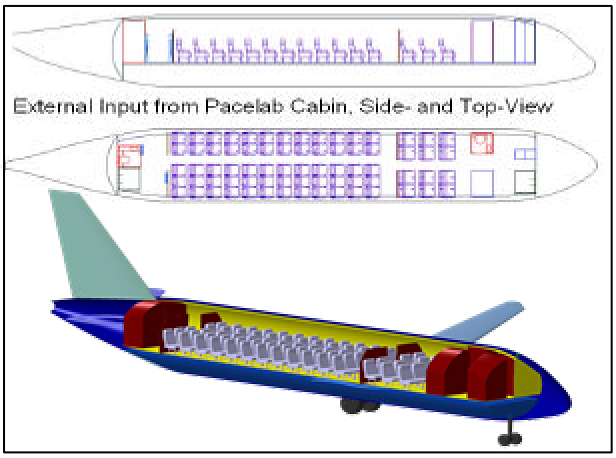

Figure 6

4 Implementation in CATIA V5

Microsoft Visual Basic routines can be executed in order to show the input in the 3D CAD-System given before. Either the single components or the total configuration can be processed by these VB-CATIA scripts.

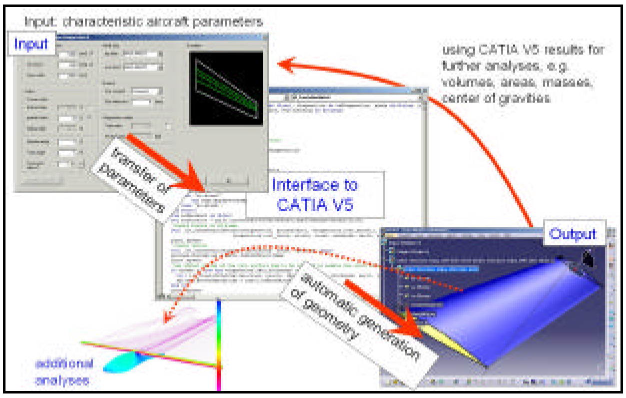

Figure 7

To get the result can take from seconds up to several minutes, depending on the amount of data which has to be displayed and the requested level of detail. The final result will be shown on the screen and is the beginning of the Digital Mock Up (Figure 6).

The construction tree already mentioned is then realized in the CAD-System and gives again a clear view of the configuration structure. External objects, which have not yet been parameterised, could also be added to the configurations by *Pad3D*. As long as the implementation is made by the user interface, all data can be exchanged bidirectional between these two tools. The advantage is the use of parameters which are calculated by the CAD-System. This is a big gain of time, because sometimes it is very painful to get surfaces, volumes or resulting weights out of complex geometry. The information received can then be a new input for own or external analysis methods.

5 Analysis

In this approach the greatest effort is dedicated to design the aircraft geometrically with respect to investigation. In the aircraft pre-design process it is not needed to investigate every detail of the aircraft. Much more suggestive is to take a set of analytical methods, which always have about the same relative percentage of variation as the given input. The use of handbook-methods in aerodynamics will be sufficient as long as the factor of detail in the geometry is not better than 10%. It is not feasible to use FEM-methods like NASTRAN if there is no *Inner Structure* available. All methods and tools available should be supported by the geometry mentioned in previous chapters. Sometimes it is just a lot of work to connect the different methods. Therefore it is useful to integrate standardised interfaces which are already validated with the applied tools. In special cases or for not very common methods, the needed interfaces have to be written. The most important thing is to receive, if the interface already exists, or to define the in- and output-lists for the interfaces which have to be developed. To integrate a new method, a clear description of that method should be attached as information to the user.

Below three platforms of analysis, with methods for all levels of detail, will be described and distinguished.

5.1 Platform 1 Analysis

Platform 1 Analysis includes all the methods which could be implemented into the *Pad3D*:

- Visual feedback in 2D previews
- Simple geometrical calculations, i.e. to get parameters out of the *Characteristics* group.
- Semi - analytical methods which use the results of the platform 2 and platform 3 analysis as noted below.

All these methods can be used without interfaces. They will be integrated directly into the *Pad3D*-System and user interface as modules which could be changed very easily. These procedures are always found on the data which is stored in the aircraft configuration databank.

Methods out of platform 1 analysis support the engineer at the beginning of a design with helpful data to do a reasonable input. After having done analysis, evaluation modules like NETSIM, an aircraft fleet simulation [6], he can compare with other aircrafts and competitors. Fundamentally, all data out of the other platforms are collected and combined to a standard performance sheet and other statements about the design. A typical weight & balance diagram, shown in Figure 8 also stands for a Platform 1 Analysis.

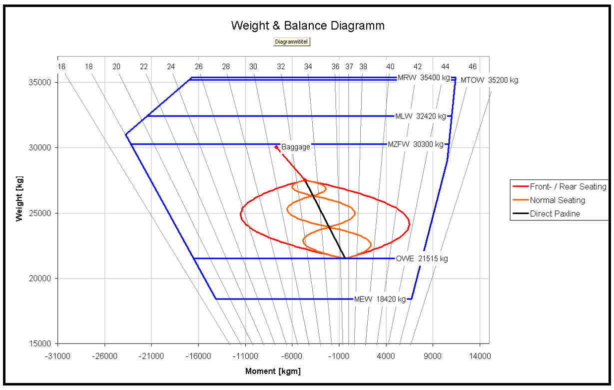

Figure 8

This self created tool [15] calculates the variation of the centre of gravity, respectively the additional moment which caused from the payload itself, respectively the loading process.

5.2 Platform 2 Analysis

The second platform contains tools or methods, which are included in the CAD-System itself. All of these can be used directly by using the CATIA-data without any interfaces between the analysis. As long as the tool is controlled by the *Pad3D*-system, all the data are stored in this databank. Within the release V5R8, the CATIA CAD-System contains over 80 different moduls which support a large number of necessary disciplines in aircraft design.

All of these tools can be controlled by Visual Basic scripts or C++ Code. Therefore, procedures like geometrical changes, because of wrong results in early iteration steps, can be carried out automatically until a special value or optimum is reached. Inside these tools there are functions which are very useful to have. These functions for example calculate surfaces, volumes, weights, the centre of gravity, moments of inertia etc. out of parts and assemblies. These parameters are usually very complicated to create with individual methods but they are important inputs for other analysis. To finish a configuration study it is also always essential to have a good documentation and presentation. Having the 3 dimensional geometry of the aircraft project from the beginning incorporates the possibility to create any kind of pictures and presentation background at this stage.

5.3 Platform 3 Analysis

Platform 3 Analysis is are external methods which have to be connected to the other two mentioned before. Every discipline has its own specialists who are continuously developing better and more precise methods and tools. These tools are normally fed by self made geometry models. The special geometry modelling has to be made to get the right input for the special analysis tools and it is often not possible to use the output of the CAD-System. To connect these platform 3 analysis methods, it is then obligatory to define interfaces which transfer the basis-data from one system into the other and back.

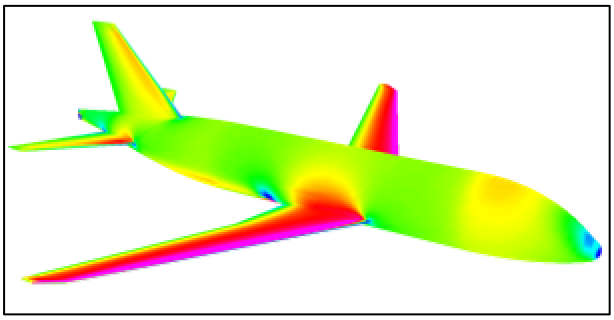

Figure 9

Inside this platform, there are methods which analyse the aircraft configuration in the same discipline but with different levels of detail. This is necessary to study the aircraft in every stage of the process with appropriate accuracy. Because every method or tool has its special features and results of same are not always comparable. This could be a very useful technique to compare results with other configurations.

For example in the discipline aerodynamics at the beginning of the process handbook methods exist which are precise enough. For more detailed statements, the use of numerical tools is needed. Therefore different codes like Panel-, Euler- or Navier-Stokes codes and their additional tools can be used. Until now, there are two special tools which are integrated or intended to be integrated. The first is the VSAERO [7] which is a Panel-code and commercially used by most aircraft manufactures in the pre-design phase (Figure 9 shows the result of an aerodynamic calculation with VSAERO). To compare and validate this method, HISSS [8], which is also a panel-code used by EADS and several research institutes, is used. For more precision and if a very high level of detail is required, FLUENT, a Navier-Stokes code can be applied,.

The concept described above can be realized in every required discipline with every requested level of detail. It has to be mentioned, that in this case, the numerical methods will take longer and need more sources. Also it is not always possible to control these tools from other systems so that there may cause some problems with the automation and in further steps with optimization. Often it is necessary to have a very special know how about the handling, the inputs and results of these tools.

In cooperation with the Institute of Flight Mechanics and Flight Control of the Technical University of Munich another module of *Pad3D* is in the development phase, which calculates and analyses the flight performances of the aircraft project [14]. At the present stage the results of this module are for example:

- maximum flight path angle over altitude
- angle of attack for maximum flight path angle over altitude
- flight path angle over speed for different altitudes
- etc.

6. Interfaces

Interfaces are needed for all the analysis methods out of platform 3 analysis. Here there are three different kinds of interfaces. First there are interfaces which are standardised by the industry, like STEP, IGES and STL. These are file formats which are normally implemented in the CAD-System as im- or export interfaces. The second category of interface includes all commercial tools which transfer data from one system into another essential system. Gridgen [9] is the tool here used which transfers data from the IGES export interface of CATIA, to an input file for VSAERO, HISSS and Fluent (Figure 10).

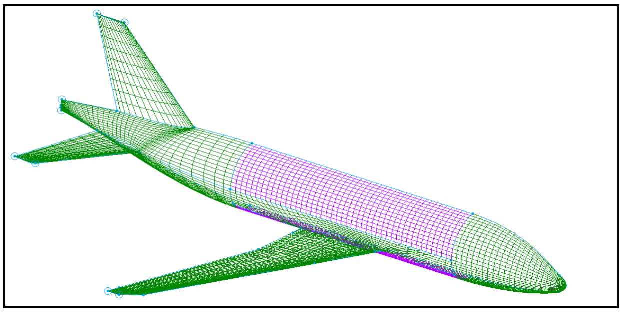

Figure 10 [12]

The great advantage is that these interfaces have already been proven by the software manufacturer. The interfaces in the third category have to be coded by the *Pad3D* developers. For every special tool which cannot be fed by the first two categories, the interface has to be self developed. The most important task therefore is to define exactly what kind of data and in which format the method is required.

Usually all analysis tools save their results in files which are used for post-processing. These results can then be read into the *Pad3D* and could be used for the next iterative loop of the analysis

7 Conclusion

With this approach, aircrafts can subsequently be designed up by permanent three dimensional visual control. The qualification of an aeronautical engineer is still fundamental, but not a specialist in all disciplines of the airplane design is essential. The way in which the design process is performed is not much different to the ones described by Roskam [2], Torenbeek [10] or Raymer [11], but a lot of the steps are automated in an engineering way. The main difference to previous approaches is to work in a three dimensional sketch from the beginning.

The major advantages in this process are that all of the used methods get their input from one single data basis, which guarantees that several analysis are performed on the same set of data. Another advantage is that the conclusions drawn from the configuration in the early feasibility or concept phase can be used directly as input to the next phase like e.g. the definition phase. This is only possible because the new CAD-System CATIA V5, the basic 3D-tool employed by many aircraft manufactures, is definitely in used from the beginning of the airplane design process.

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