

RAPID CREATION OF CFD-CAPABLE CAD-MODELS FOR CABIN AIR VENTILATION SIMULATION

Jörg Fuchte^{*1}, Sergej Rajkowski², Andreas Wick³

¹Air Transportation Systems, German Aerospace Center
Blohmstrae 18, 21079 Hamburg, Germany

²Airbus Operations on behalf of Aerotec Engineering
Kreetslag 10, 21129 Hamburg, Germany

³Airbus Operations
Kreetslag 10, 21129 Hamburg, Germany

Joerg.Fuchte@dlr.de

Abstract

The objective of this paper is to describe a method for rapid creation of cabin CAD (Computer Aided Design) models for usage in CFD (Computational Fluid Dynamics) simulations of cabin air ventilation. The intention is to automate the process of model creation in order to speed up the process and reduce the workload both in CAD modeling and mesh creation. The described method is part of a larger process intended to facilitate the usage of CFD cabin air ventilation simulations for passenger comfort. Thus it serves the long-term objective of increased cabin comfort.

The complete simulation process including flow calculation and post-processing will be detailed in future publications.

1 INTRODUCTION

1.1 Motivation

Increased passenger comfort is one objective of the stated ACARE-goals. Passenger comfort is affected by the climate inside the cabin. Many factors such as temperature, humidity and intensity of airflow do influence the perceived comfort. The individual perception of the climate comfort has become a research subject (see [5] for further details). The cabin represents a confined space with many heat sources like passengers, electronic equipment, windows and monuments. Especially in dense economy class

seating the air has to be circulated constantly. As result the climate inside the cabin depends on factors like seat position and passengers may experience different levels of comfort according to their position inside the cabin. For future cabins both in long and short range operations, passengers will demand higher levels of climate comfort for different operational environments. An experimental simulation of these conditions is nearly impossible.

In recent years CFD-simulations of cabin airflow have become more feasible due to more powerful computers and advances in code (see [1], [2] and [3]). Although the required computer resources still limit such simulations to a small number, in future such simulations will become more affordable. However, the modeling cannot be sped up by simply adding computer resources and might become the bottleneck in increasing the number of scenarios or design iterations.

For that purpose Airbus Operations and the German Aerospace Center launched a project to enhance the modeling process both in required resources and ease of adaption. The presented method is considered a compromise between quick generation and model complexity.

1.2 State of the Art

Any CFD simulation requires a mesh. Usually this mesh is generated from CAD-models using a commercial software. The CAD models can be generated with any established tool. In this case CATIA V5 is the used CAD-software. A CAD-model for mesh generation has to adhere to a number of specific requirements. This makes already existing CAD models intended for different purposes impractical or impossible to use. If these requirements are disregarded a very time-consuming repair process needs to be performed on the generated mesh. Therefore the CAD-models for CFD-simulations need to be specifically created and require specific experience of the subject.

CATIA like most other CAD-tools supports parametric design features. That is, defined dependencies inside the model are connected to user-defined parameters. If the parameter is changed the entire model changes accordingly. This feature allows quick adaption of models with little effort. This has limitations as changed architecture of the cabin or different overhead bin layout may exceed the parametric capability of the CAD-software. The requirements for problem-free meshing also reduce the options of the designer for usage of parametric relationships.

1.3 Overview

The basic cabin layout is calculated external from the CAD-software. This allows usage of more powerful analytical software like Matlab. The resulting geometry is saved as a number of ASCII files that contain raw data and parameters. A number of

functions written in the CATIA-internal script language "CATIA Visual Basic Script" create the model. The entire CAD-model generation does not require additional user input and can be performed in the background. Pre-designed adaptable parts (Powercopy) are used to represent objects with complex geometry like seats and passengers. The model complexity is adapted to the capability of the CFD simulation.

2 TOOL CHAIN DESCRIPTION

The tool chain consists of three different softwares, each responsible of one step in the process. Figure 1 illustrates the dependencies, input and outputs.

1. Cabin layout generation program implemented in Matlab
2. CAD-Model creation using CATIA based on the results of the previous step.
3. Meshing of the CAD-Model using ANSA software

The usage of a third program besides CAD software and meshing tool might not seem rational initially as CATIA already offers far-reaching options for parametric design and scripting. The idea to use a more capable software like Matlab is motivated by the complex dependencies of cabin design. Some basic differences between cabin (like number of classes or placement of monuments) can already exhaust the parametric capability of the software or make modeling very time consuming. Coding the program in CATIA is unattractive due to the limited capabilities of the CATIA programming language.

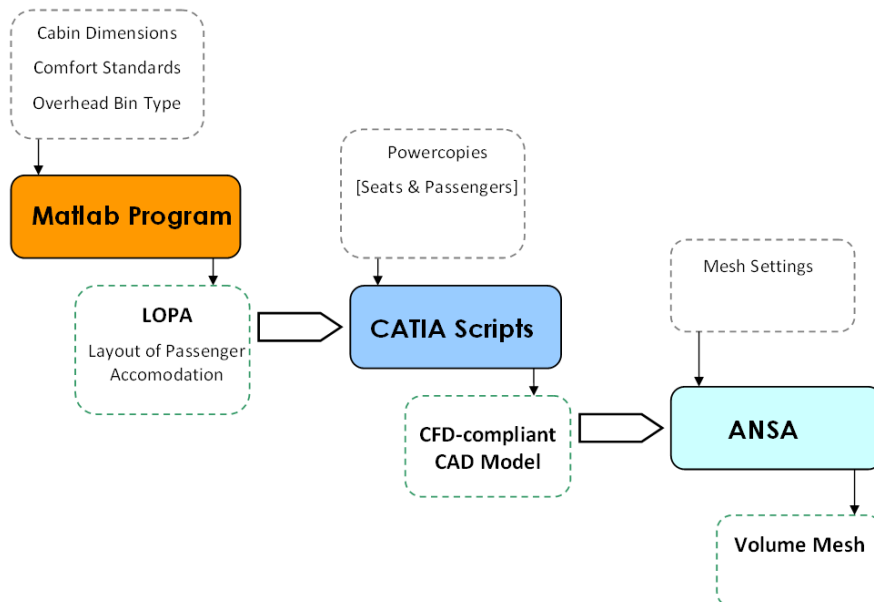


Figure 1: Process Description

2.1 LOPA Generation

The Layout of Passenger Accommodation (LOPA) describes the location of all objects inside the cabin, including seats, galleys and lavatories. Even for the considered single aisle aircraft they can vary considerably between different operators. A Matlab-based tool creates a LOPA depending on user-defined options like comfort standards or seat choice. The layout is adapted to the physical characteristics of the cabin such as the diameter and door position.

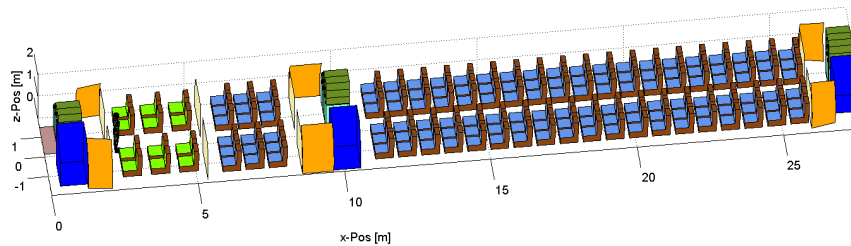


Figure 2: LOPA generated by Matlab Program

The LOPA generator was developed separately by the German Aerospace Center and is also used for other applications. The monument and seat placement is largely based on knowledge-based dependencies, which orient on current state-of-the-art in cabin layout.

The generated LOPA is the basis for the model creation. Besides seat positions the tool also generates 3-dimensional coordinates for the overhead stowage bins and lining of the cabin. These items basically adhere to the limitations of the surrounding structure but are also the result of industrial design considerations. The geometry is consequently difficult to describe with analytical means. To match the actual shape of the cabin lining the geometry is directly imported. Figure 3 illustrates how the lining geometry is calculated as function of the cabin dimensions.

2.2 CAD-Software Interface and Model Creation

The creation of the CAD-model is the heart of the entire process. The program consists of a number of scripts using the CATIA internal programming language CATIA Visual Basic Script (commonly referred to as CATvbs). CATvbs is very similar to the other commonly used CATIA languages. It is based on Visual Basic and uses object oriented programming features. The language allows to perform most of the actions that can be done manually in CATIA, while some limitations exist. It is very powerful when using a large amount of pre-generated data such as the input from the Layout Generator. In the legacy process the CAD user does usually not decide on cabin features such as seat number, lining shape or monument placement. He receives it as input (usually as

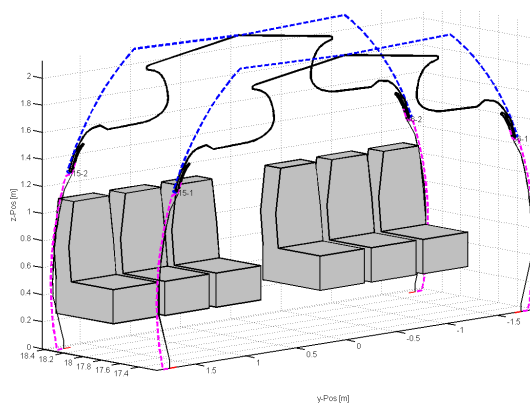


Figure 3: Geometry of Cabin Section

print generated by a specific cabin design software) and translates it manually into a CAD model. Therefore an automated process starting with exactly these parameters does not reduce the autonomy of the responsible engineer.

The CAD-geometry has to adhere to a set of requirements in order to be suitable for mesh generation. The most commonly known requirement is "watertight" design of the geometry. That is, the surfaces of the models are not allowed to have any gaps that can be misinterpreted by the meshing tool. For simple objects the requirement is rather easy to meet, but for more complex models that require a large number of surfaces to be used, the requirement can be tough. Surface joints are the biggest issue. Although usage of "surface split" offer a remedy, their potential has limitations and the processing time is substantial. A number of different approaches have been tested. In the end, a direct surface creation is used and watertightness is provided by careful coordination of neighboring surfaces. Different surface characteristics can be generated by cutting a piece out of a surface but keeping the cut. Figure 4 shows the result in CATIA for the data displayed in figure 3. In that model all surfaces are created as lofts from contours, while the windows are generated using surface splits.

While lining and cabin layout can be efficiently created from scratch using a script-based design, some cabin objects are too complex for this approach. Most importantly the seat rows with the passengers. As the flow characteristics close to the passengers are of primary interest, these objects require more detailed modeling. These items are introduced as pre-designed parts known as "Powercopy" in CATIA. "Powercopy" is a method in CATIA in which parts can be imported so that they adapt to the master part file. The method is most efficient when the master part and the included shape only share a limited number of interfaces. That is clearly the case for the seat rows. Different seat types are available and unoccupied seats can be included wherever necessary. A typical single aisle aircraft features mainly 3-seat rows (rarely 2-seat rows), so that all possible layouts and load factors can be generated using a set of about a dozen seat row models. An example is shown in figure 5. A

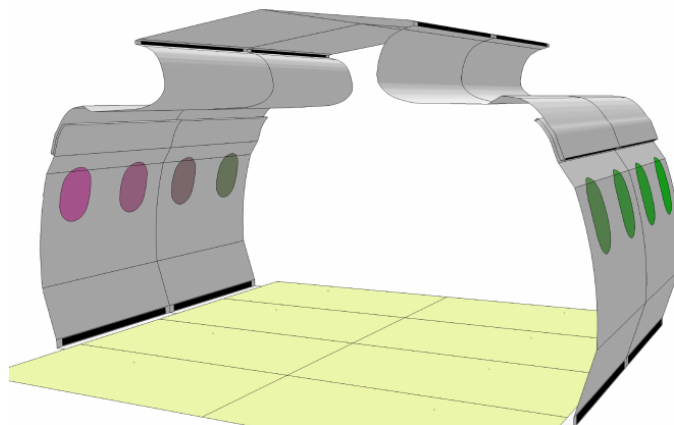


Figure 4: CATIA generated Lining Section from Matlab Input

similar approach was tested for other objects like overhead bin sections but proved uneconomical and unreliable. "Powercopy" is usually time consuming, but it can also be automatized using script.

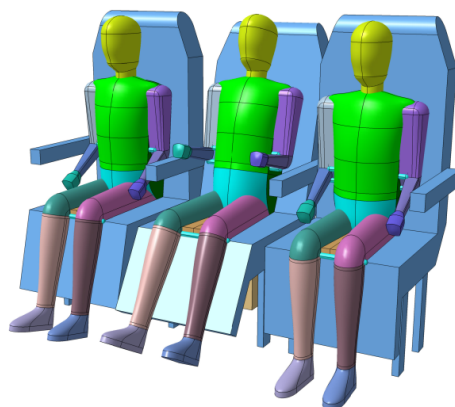


Figure 5: Seat Row with Passengers as "Powercopy"

Monuments are only of limited importance and do not have to be modeled in great detail. They are important as object as they act as barrier for airflow in aisle direction. Galleys may also be an emitter of heat. Monuments are usually placed in the front and aft end of the aircraft, or at the exit rows. The presented approach especially allows to test different monument options with regard to their influence on cabin air ventilation. For successful further processing of the CAD-model a consistent naming of all surfaces is important. Otherwise the meshing tool cannot associate the boundary conditions to the surfaces. This process can be very time-consuming when the model is created manually, especially when several hundred surfaces need to be re-named.

2.3 Transfer to Meshing Software

The CAD-model can be directly read by the meshing software. No usage of common CAD formats such as IGES or STEP is necessary. The software ANSA is used specifically as it provides that feature for models created in CATIA V5 (see [6]). However, growing compatibility between softwares will allow to use other meshing tools if their usage is considered of advantage for the whole process. A well designed CAD model complies with most meshing tools and hence increases flexibility and independence from specific software solutions.

3 RESULTS

For demonstration purposes a set of different monument options in a single aisle cabin is demonstrated. The presented options are typical for different operators. The layout is also shown in figure 2. The shown examples represent possible monument options for the first exit lane.

1. No monuments at all, only class dividers and seats.
2. Single galley and lavatory behind the aisle
3. Full galley installation at right hand side, single lavatory at left hand side.
4. Full galley installation at right hand side, two lavatories at left hand side.

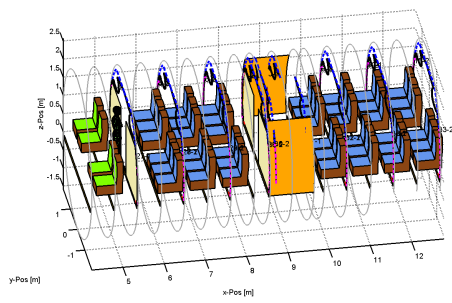
The Layout Generator adapts the seats to the monument positions, which are either determined automatically or can be defined as input in order to create a particular layout.

If limited to the shown number of seat rows the creation takes about 20 minutes each. More seat rows increase the required time. The integration of the Powercopies takes longest, also due to their complexity. Monuments are represented by their outer walls. The subsequent meshing requires a translation of the model using first a model converter and then the main meshing program ANSA. The meshing in ANSA requires about 2 hours, all on standard desktop computers. The duration depends strongly on the desired grid characteristics, which depend on the intended result of the simulation.

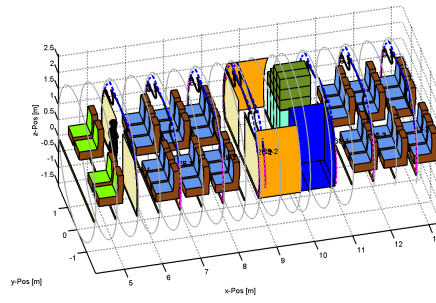
A full CFD-simulation requires a lot of additional information apart from the mesh itself. A good example of a full CFD-simulation can be found in [4].

4 DISCUSSION

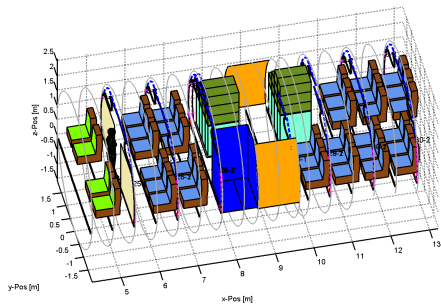
The described process is intended to facilitate cabin air ventilation simulations. Successful CFD-simulations requires careful attention to many different subjects with



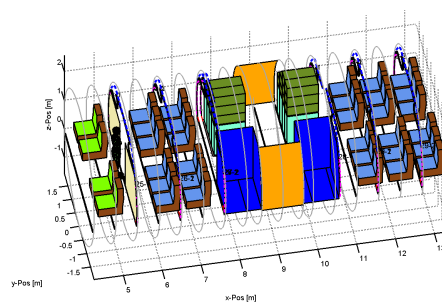
(a) Option 1



(b) Option 2



(c) Option 3



(d) Option 4

Figure 6: Second Exit Lane - Monument Options

modeling being only one of it. However, as soon as a working CFD-simulation process with boundary conditions has been established, the modeling may present a major bottleneck.

Compared to manual creation the described method yields a number of advantages. The main advantage of the tool chain is increased speed of model creation and a reduction in direct man hour expenditure. Large parts of the process do not require direct attention of the designer. The method still yields various opportunities for visual check of the created model. Manual adaption of the geometry model is possible before starting the meshing process, so that the method partly retains the flexibility of the manual creation process.

The tool introduces flexibility in the chosen cabin layout and load factor. That allows to simulate different layouts for various operators and may broaden the spectrum of the CFD-based climate comfort simulations. The automation features exceed capabilities that can be provided by usage of the CAD software internal parametric capability.

The motivation was to reduce the amount of low value design tasks while retaining the ability of the design engineer to check and change the model if required. The quality of the mesh cancels any requirement for repair work, which has added considerable

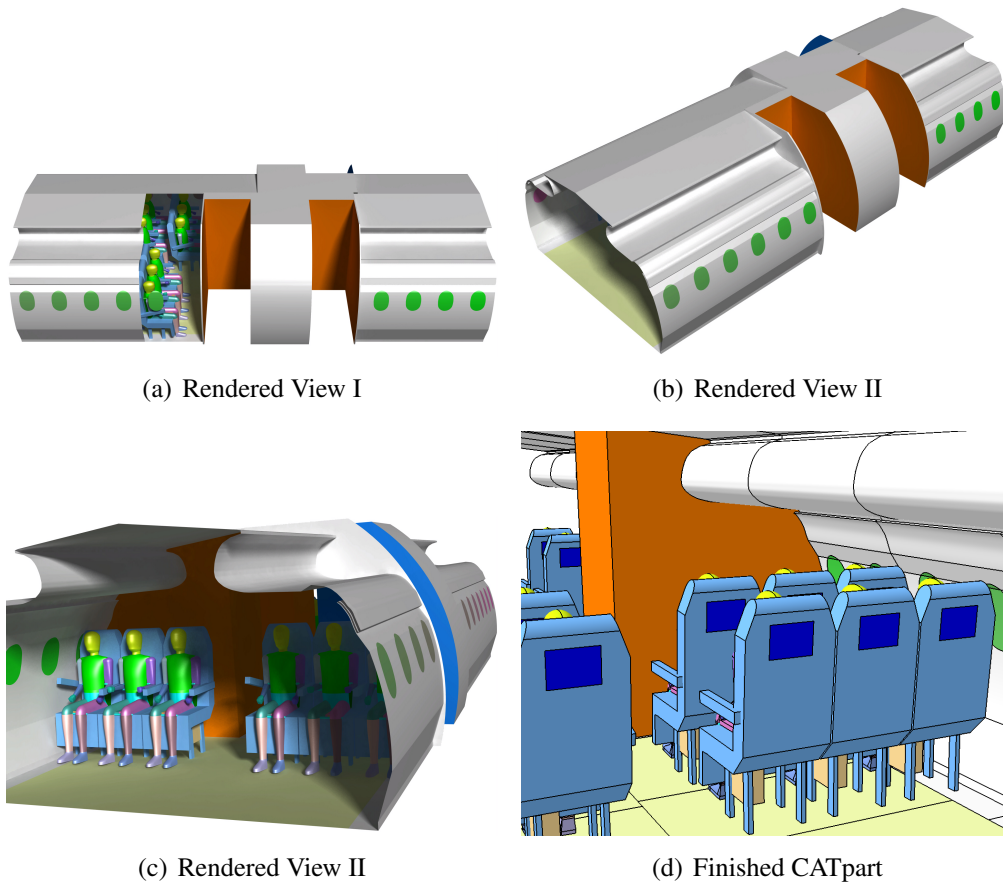


Figure 7: Different Views of Finished CATparts

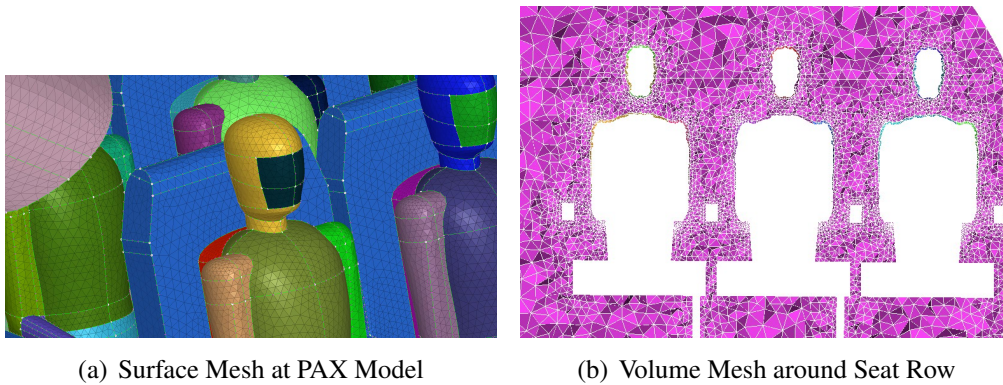


Figure 8: Resulting Mesh for CFD

man hour expenditure in the past.

The usage of an automated process like the presented also introduces limitations. The initial effort to model a fully new cabin design is higher. The overhead bin design needs to be included into the Matlab environment. However, if more than one model is supposed to be created the additional effort is quickly regained.

The model complexity has been limited to ease automated creation. If some details like modeling of the lining in close proximity of the window prove to be of critical importance the geometry creation may be enhanced.

Finally, the different software modules are still in a stage of development and require an experienced user as operator.

5 CONCLUSION

The paper presented an approach to speed up the creation of CAD-models for CFD simulations for cabin air ventilation. The presented method allows a significant reduction in expended time, especially if several different versions of a similar aircraft are required.

While the method represents an enhancement for the current process, it may offer growth potential for future projects. More affordable CFD-simulation resources may allow a verification of different cabin layouts in terms of passenger climate comfort.

The complete simulation process including flow calculation and post-processing will be detailed in future publications.

References

- [1] M. Konstantinov, M. Rütten, M. Lambert, C. Wagner, *Strahlung als wesentlicher Faktor der numerischen Simulation von Flugzeugkabineninnenströmungen für Komfortvorhersagen*. (Deutscher Luft- und Raumfahrtkongress 2009)
- [2] M. Rütten, M. Konstantinov, C. Wagner, *Analysis of Cabin Air Ventilation in the Do728 Test Facility Based on High Resolution Thermography*. (Deutscher Luft- und Raumfahrtkongress 2008)
- [3] J. Bosbach, M. Kühn, M. Rütten, C. Wagner, *Mixed Convection in a Full Scale Cabin Mock-Up*. (25th International Conference on the Aeronautical Sciences, Germany, 2006)
- [4] O. Webel, M. Rütten, M. Lambert, C. Wagner, *Numerical Simulation of a Mixed Ventilation Setup in an Aircraft Cabin*. (Deutscher Luft- und Raumfahrtkongress 2010)
- [5] C. Marggraf-Micheel, J. Winzen, *Ansatzpunkte zur Steigerung des thermischen Komforts in der Flugzeugkabine - Ergebnisse aus dem Do728 Mock-Up*. (Deutscher Luft- und Raumfahrtkongress 2010)
- [6] CAE Systems SA, *ANSA for demanding CFD pre-processing*. Marketing Brochure - www.beta-cae.gr