Automated CFD blade design within a CAD system

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Summary:

The intensified use of CFD techniques for dimensioning and design evaluation of aerodynamic geometries in a jet engine has increased the need for automation of engineering activities. One of the bottlenecks today is the lead time to update the CAD master model based on CFD results. The master model used as a base for the associated context model within different CAE disciplines. The context model is a simplified geometry used for CAE analysis. Another issue is the quality of the geometry representation which must be possible to use in down stream manufacturing processes.

This paper describes a Knowledge Based Engineering (KBE) approach to automate the CFD blade design within a CAD system. The approach has been formalized and an application has been developed as a system support. The application utilizes geometric result from a CFD blade design code and provides a 3D CAD geometry. Output is used both in internal aerodynamic design loops for optimization of the blade profile and to update the CAD Master Model for continuing with the multi-disciplinary iterative design process. The application was developed and tested in an iterative process where domain expertise within CFD and CAD/KBE co-designed the application. The method was implemented using a KBE module from UGS, Knowledge Fusion. The CFD code was an in-house blade design system.

The application, together with a context model and a predefined parametric mesh, has reduced the lead time for trade studies of design alternatives from hours to minutes with an improvement in quality and less sensitivity regarding staff turnover in the engineering expertise. The main benefit is that design iterations previously 'local' to CFD now include a CAD master model update.

The application is designed as a combination of method modules; the advantage is an increased re-usability. An additional benefit with the modular architecture of the blade design application is the possibility to re-use the application in other KBE applications. Similar benefits appear in cost reduction work and production support where engineering work similar to conceptual design work is performed. The approach enables continues improvement, a step towards an integrated methodological toolbox.

Keywords:

CAD, CFD, Automation, Knowledge Based Engineering

1 Introduction

Volvo Aero develops and manufactures high-technology components for aircraft engines, in cooperation with the world's leading engine manufacturers. As a partner in a global project with several large companies, international collaboration is becoming a crucial business capability, both between the OEM (Original Equipment Manufacture) company of the jet-engine module and between other companies who share the same interfaces for the product. New load cases or changes in the geometry definition that has an impact on the design will require a quick response with updated reports of the impact, primarily describing the effect in terms of time and cost for the effected component. Fast and accurate response will shorten the lead-time for the overall project and is often a "Go" or "No go" -factor for an efficient design change. Late design changes cannot be allowed since the time to validate the change using CFD (and others) simulations takes too long time. All arguments above stresses the need for a rapid design process for concept evaluation where design changes are passed through and the geometry is updated according to pre-defined rules.

This paper describes a Knowledge Based Engineering (KBE) [1] approach to create an integrated CFD blade design application within a CAD system with the aim to automatically generate a 3D blade geometry definition.

The aim of the study is to describe an industrial case where Knowledge Based Engineering has been used to automatically generate CFD optimized geometry in the CAD master model. An industrial example will demonstrate a use case where the design lead time has been significantly reduced when used in European development programs.

The paper is organized as follows;

1. An analyze of the current work practice
2. The KBE automation approach to overcome the weaknesses found.
3. A description of the application, together with a use case.
4. Results and conclusion.

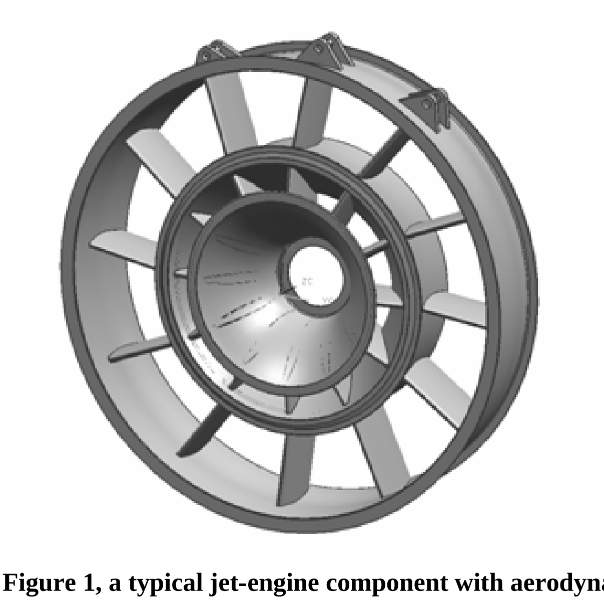


Figure 1, a typical jet-engine component with aerodynamic surfaces interface.

2 Interactive work - a bottleneck

As an initial step in the work to improve the quality and reduce lead-time for design iterations, all design activities are investigated and those activities that has long throughput time and wide spread results in quality key factors are identified as bottlenecks and are candidates for automation.

The aerodynamic design loop typically involves engineers from different organisations. First the blade design is defined by the aerodynamic specialist department specialized in CFD calculations. Then the geometry is created involving resources from departments specialized in CAD definition, using interactive work from skilled CAD modelers. This work is both time consuming and sensitive for staff turnover since the quality of geometric modelling depends on personal experience and modelling style. One effect is that new “best practice” is developed every time for every new situation. As a result; “the wheel is reinvented again”.

In detail; The Nurbs or surface definition is exported from a CFD blade design code to the CAD system, via IGES [2] , STEP [3] or Parasolid [4]. This often requires a complete regeneration of the blade geometry for down stream operations, such as blend operations between blade and the surrounding annular flow path walls. These operations also involve mechanical FEM calculation with iteration back to aero analysis and, when considered necessary, redesign.

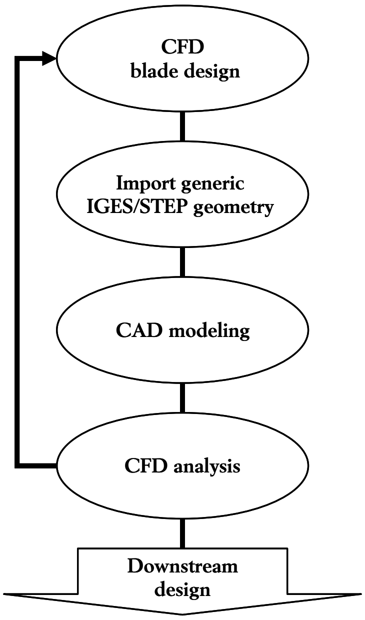


Figure 2, illustration of the design flow from CFD to CAD and back again

Creation of a solid model after the initial CFD blade design is identified as a bottle neck, and has been the target for automation efforts described in this paper.

3 The KBE approach

KBE technology has been an enabler for efficient automation of engineering activities in the aerospace industry during the last decade and large CAD vendors have implemented the technology within the traditional CAD system. Volvo Aero has strategically chosen KBE as one of the methodologies to improve and make engineering tasks more efficient [5] [6] [7].

Generating a KBE application

When a design activity has been identified as a bottleneck and chosen as a suitable candidate for automation the requirement specification work is initiated.

Cross functional meetings are conducted to capture engineering knowledge and set the requirements specification. The outcome of these meetings is then used to build the application followed by several iterative discussions on specific problems.

It is important to involve the users of the application in the system development process in order to achieve a better acceptance and simplify the rollout in business programs.

Automating design activities

The output geometry of the application is used both in internal loops within the aero thermodynamic optimization field for optimization of the blade profile and to update the CAD Master Model for a multidisciplinary iterative design process.

Figure 3 illustrates the design flow with activities to generate aero blade geometry in CAD where the import of STEP, IGES or parasolid has been automated of by a Knowledge Fusion [8], application that also builds up the geometry in the CAD system.

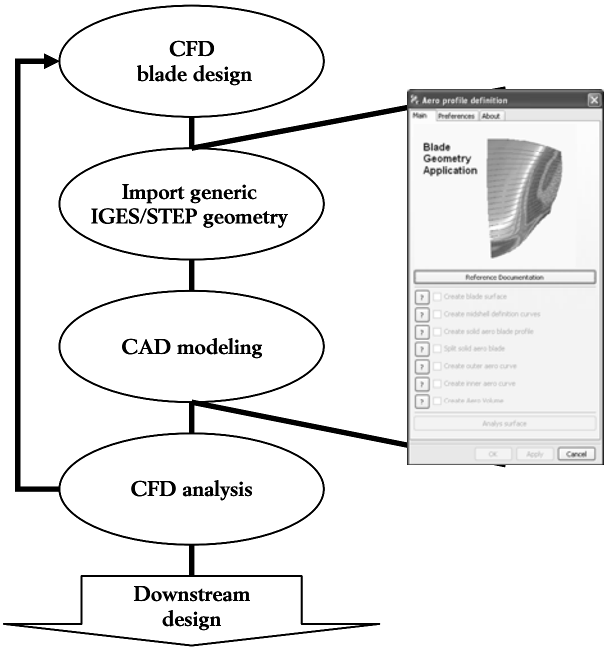


Figure 3, illustrating design flow to generate CAD geometry

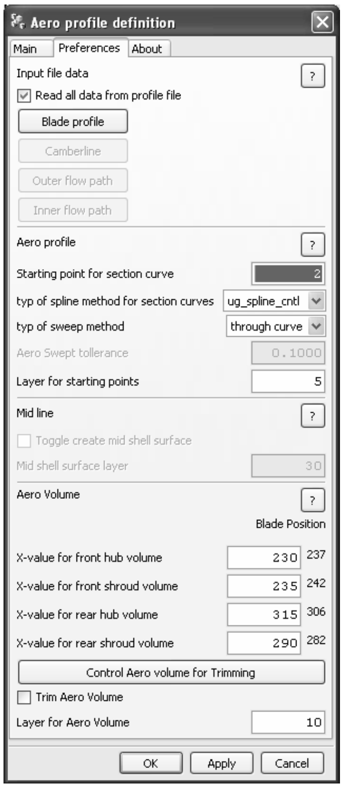
4 Description of application

The main features of the application are described in this section of the document. The application has the capability to vary;

- Geometric representation and resolution (through the input file)
- Geometric dimensions
- Modelling method

User interface

The Graphical User Interface (GUI) is an important part of the application. Iterations between user and the system designer provide an easy to use menu with well organized attributes.



Attributes are grouped together for improved understanding and a manual with reference documentation is implemented.

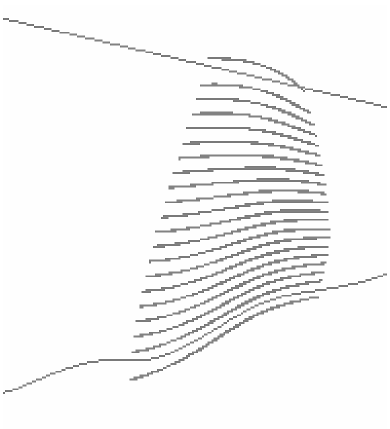
Help buttons provide instant access to content specific areas in the manual.

It is also possible to provide different information depending on a given data file which makes it easier for the engineer to have a good overview with less attributes.

Push buttons are used to link between different menus, making it possible to provide the designer with a workflow that opens up different menus for each activity in the workflow.

The manual of the application is synchronized with company specific best practise documentation for modelling and modelling standard documentation in order to assist the designer in his work.

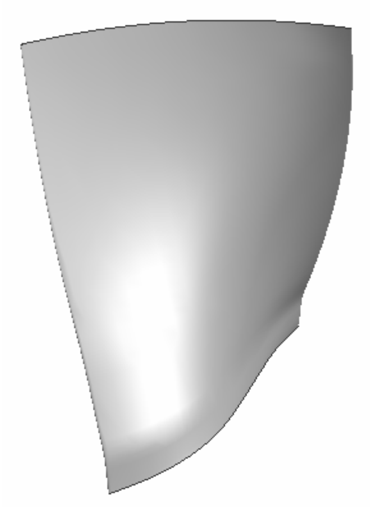
Section curves



Section curves are defined by an in-house CFD blade design code which has an output file with a predefined data set of point data. This data is used to build up the geometry inside the CAD system, without having to import IGES, STEP or other import formats. This simplifies the creation of “native” CAD features, providing a more stable and flexible downstream process.

Section curves can be defined as either a b-spline curve using defined control vertices (poles) with optional weights or as a b-spline curve through defined points using optional slope vectors depending on design factors.

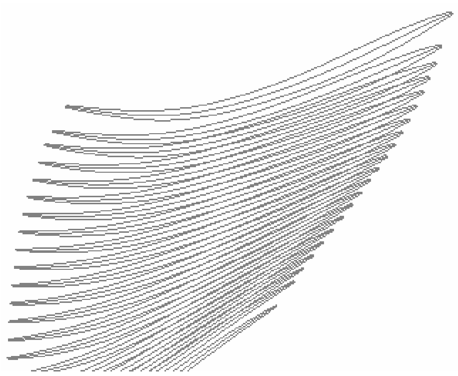
Blade Surface



The sweep method is chosen depending on scale and form of the blade and the designer can manually alternate between two different methods.

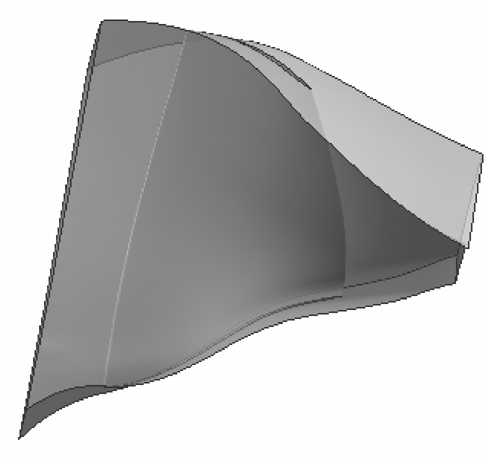
The application also provides a surface analysis tool, ensuring that the surface is within given parameters from the design intent given by the CFD blade design code.

Camber line



The camber line, also provided by the CFD blade design code, is the mid-line between the aero definition pressure side and the suction side. The purpose of the line is originally used in the calculation of the flow path incoming and outgoing angle but it can also be used to support the design engineer with a mid definition curve. This mid curve is then used to build a mid-shell definition in the context model for mechanical FEM analysis.

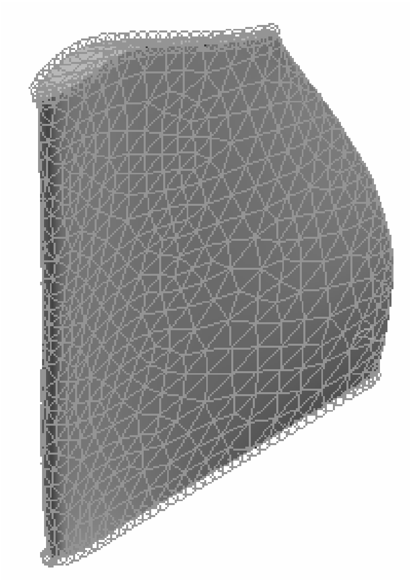
Aero volume



The application is designed to provide an optional aero volume to support CFD calculation tools, i.e. ICEM [9]. This volume utilizes the same surface that builds up the blade geometry and the outer and inner flow channel boundary curves.

There are four parameters that can be varied in this model; inner and outer axial position in the front and inner and outer axial position in the rear.

FEM mesh



A parametric mesh is applied using a FEM module in a CAD system. The mesh can be constrained at different degrees depending on purpose of the analysis, a mesh with less constrains can adapt to more types of different variations of the vane geometry. This is essential in the concept phase where speed is of essence, rather then extreme precision.

If the interfacing geometry between the blade and the outer or inner flow path wall is changing on a configurationally basis, i.e. the number of edges is different or the surface is divided, then the update of the mesh will fail. This type of changes will require a KBE approach to handle different types of meshing scenarios.

5 Results

This application has been used to support engineering work in several ongoing business projects and the time to define new blade geometry in CAD has dropped from hours to minutes. In reality, when taking in to account the limited availability of CAD modelers the gain in lead time is even higher. For local or minor geometry changes the update is nearly instant. For more complex, where the component arrangement is affected, the update is measured in minutes.

The quality of the modeling process is improved, providing a controlled modeling procedure with small variations in the resulting feature tree that builds up the CAD model.

The resulting CAD geometry does not meet all requirements in the downstream design cycle. One of the difficulties arise when mechanical requirements adds modeling features such as varying blend radius between the blade and the flow channel walls. Complex aero definitions representing very small radius on the trailing edge is also an issue. These areas have to be modified manually.

6 Conclusion

It is possible to dramatically improve the lead time for engineering tasks involving CAD modelling by using KBE technology. A system that is defined with a modular architecture enable re-use and efficient re-definition of similar engine components. By using KBE technology, the blade application can also interact with other KBE applications, providing a more flexible and rapid concept evaluation cycle.

The system enables trade studies of design alternatives in conceptual design for product development projects. Similar requirements appear in cost reduction work and production support where engineering work similar to conceptual design work is performed.

There is still work to do in order to improve the down stream usability of the resulting geometry, and as the use of the application increases, the request for improvements and more functionality increases.

7 Acknowledgement

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