

Automated design processes with Isight and their requirements regarding modification of CAD-models

D. Otto*, C. Jobusch*

* Department for Design Systems Engineering, Rolls-Royce Deutschland Ltd & Co KG

Abstract: One of the capabilities of Isight is to create processes to involve and control external programmes. Therefore it's possible to embed several commercial and in-house tools and combine them with each other. In this way processes can be generated which contain different disciplines and working focuses. They can support the search for designs which solve given issues, saving time and finding better designs (compared to manual iteration between disciplines). One Example for such a process is the design of a turbo machinery engine disc or a blade integrated disc (so called BLISK). Discs and blisks are critical parts in respect of design and lifing issues and are subject to stringent controls and requirements. They require more detailed investigation of multiple design options to meet all the structural requirements (such as running cycles between overhaul or integrity) while producing a design which meets the engine requirements (for example weight and cost). Automated design and analysis processes contain typically one or more geometry generation tools and one or more analysis tools. Each of these can be a source of errors which can interrupt an automated design and analysis process. This paper considers the CAD-System/CAD-Model as a source of errors in automated processes and discusses the requirements for CAD-Models in respect of automation. It demonstrates the full flexibility of specially parameterised CAD-models and their integration into an automated process.

Keywords: Geometry modification, CAD-System, Isight, Turbo machinery

1. Introduction

Every complex *Isight*-process can contain sources of errors. The errors are manifold but the result is mostly the same: the process is interrupted or produces wrong results. To fix the problems the sources of errors must be identified and fixed, but such a debugging process can be time consuming depending on the source of error. In processes which contain geometry modification and analysis, certain errors are generic and can be avoided in several ways by careful set up of the CAD-model.

1.1 Example for an automated design and analysis process

The following discussion is based on an existing automated design and analysis process for a generic compressor disc or blisk (Figure 1). The goal is to solve issues in respect of e.g. lifing and the existing stresses by combination of low cycle and high cycle fatigue. Therefore an *Isight*-Process has been created, which embeds a CAD-System and an FE (Finite Element) System and contains a fully parametric CAD-Model. All programmes run in batch.

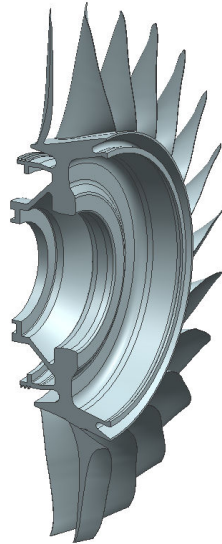


Figure 1. Segment of a blisk-stage.

It is possible to modify the CAD-Model through direct CAD-Parameters and measure discrete geometric parameters, which are effected by the input CAD-Parameters. In the following the CAD-System which is used is *Unigraphics NX 6*. This CAD-System has the possibility to export and import the CAD-Parameters via an Expression-file in ASCII-Format, additionally a direct CAD-kernel interface exist. The FE-Analysis contains two calculations: Firstly a 2-dimensional thermo-mechanical analysis which analyses the desired disc in a fully assembled disc-drum for a complete generic flight cycle (the flight cycle definition contains all boundary conditions (rotational speed, air temperatures and pressures), for all chosen flight conditions e.g. take-off, climb, cruise and landing. The radial and axial movements of the whole drum as well as the temperature distribution in the drum are the results. The second calculation is a 3-dimensional analysis, which uses the 2-dimensional results as boundary conditions among others for the desired disc. In this second calculation the maximum LCF-stresses, HCF-stresses and the stresses due to the worst combination of LCF and HCF are determined and the resulting component life calculated.

The whole *Isight*-process (Figure 2) is splitted into the following steps:

1. modify the CAD-Parameters (via Isight Data Exchanger)
2. modify the CAD-model with the new CAD-Parameters (controlled via Isight OS-Command),
3. measure (and write out) modified geometric parameters (via Isight Data Exchanger),
4. create 2-dimensional and 3-dimensional disc-contour for the FE-Analysis (controlled via Isight OS-Command),

5. run 2-dimensional FE-Analysis (controlled via Isight OS-Command),
6. run 3-dimensional FE-Analysis with results from the 2-dimensional FE-Analysis (controlled via Isight OS-Command),
7. post processing of the FE-results (via Isight OS-Command and Data Exchanger) and
8. restore results.

One run needs ca. 15 minutes on a Windows PC (2.4 GHz, 3.35 GB of Ram). During the initial runs of the described process only a small number of runs passed through the complete process chain and ca. 35% of these successful runs produced equal stress results (that means several design parameter combinations produced the same geometry and, as a consequence of this, same stress results). Such a low number of suitable (or feasible) runs is not acceptable, especially in short timescales.

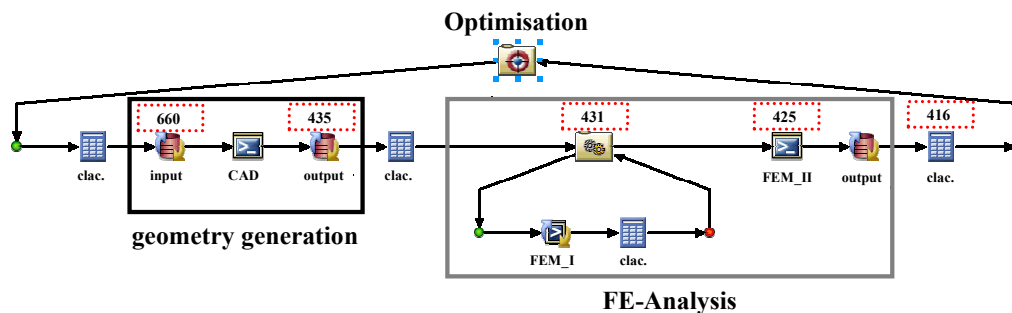


Figure 2. Isight-Process with Geometry modification and FE-Analysis

In particular equal results should not exist, because every design parameter combination should result in a different geometry. Based on the results and an error analysis, the following sources of error could be identified:

- licence issues (no licence for specific tool is available),
- FE-Analysis doesn't converged (as consequence the chosen time limit was exceeded),
- CAD-model crashed (as consequence the chosen time limit was exceeded and no geometry was generated).

The first bullet point (licence issue) can be simply fixed with a licence-checker or a reserved licence. The FE model convergence can be solved with special meshing and analysis procedures (for example with different control files). The CAD-model issues need to be resolved, because the geometry generation is an important initial step for the whole process. Without geometry the FE-analysis cannot be started, with a bad or corrupt geometry the FE-analysis can't be set up correctly (e.g. the boundary conditions can't be applied in the correct area) and with a non-updated

geometry the FE-results will always be the same even though the design parameter have been changed. The next chapter will discuss the described problem in respect of the CAD-model, because the geometry generation is one of the major issues in terms of automated design and analysis workflows.

2. Requirements regarding CAD-models for automation and optimisation

As described in chapter 1.1 the CAD-model is the key part of the process presented as an example. Every CAD-model error or failure results in a process interruption (which mean, the FE-analysis doesn't start and the design parameter combination is labelled as "bad" by a high number of penalty points) or wrong FE-results (as described by Samareh (1999)). The questions "Why does the geometry generation fail?" and "How can the failures be fixed?" will be considered below.

2.1 Reasons for geometry generation failing

There are several different methods within a CAD package to create a complex geometry, like an engine disc. Because of the rotation symmetry of the disc, a sketch can be used (Zeid, 1991). This sketch contains the whole disc contour described with several CAD-parameters. All CAD-Parameters are referred to a reference point or line. Afterwards the sketch is revolved to create a 3-dimensional disc body. This procedure does not provide full flexibility in respect of individual features (like number of drive arms, position and thickness of drive arms, geometry of the diaphragm and bore etc.) or parameter values (like negative values). Due to the referring of parameters many constraints exist and in the event of a constraint conflict, the geometry is not updated. The CAD-System then generates a "new" geometry which is identical with the original geometry. As a consequence of this the FE-analysis produces equal results afterwards. The advantages of the sketch method are the visibility of the dependency of CAD-Parameter among each other and perpetuation of number of lines, edges and faces (which is important for an automated FE-Analysis to apply the boundary conditions and loads to the correct areas). The disadvantages are limited flexibility in geometry changes which results in a small design space and the possibility of unchanged geometry without any error output or exceptions.

Another way to generate a disc geometry is the combination of sketches and solid body modelling techniques. The latter uses the solid body functionality of the CAD-System to create blends and chamfers. New bodies or geometry objects can be created using unite, subtract and intersect between two or more solid bodies. With this geometry generation method, the sketches contain the principal disc geometries (parameterised with additional CAD-Parameters) and some features such as drive arms, but the additional solid body modelling produces the desired disc geometry (with flexible drive arm positions, blends etc.). CAD-Parameters are defined in sketches and for the 3-dimensional shape. Through modification of the CAD-Parameters the positions and shape of the features (like the drive arms) can be modified. This method of geometry generation gives a higher flexibility in respect of the features and disc shape. For an automated design and analysis process, it's necessary that the number of lines, edges and faces remains constant and here the combination of sketches and solid body modelling technique shows some weaknesses. The CAD operations

(blend, unite, subtract, etc) refer to existing lines, edges and faces. If the reference doesn't exist anymore, the CAD-operation cannot be accomplished or the blend cannot be created. In this case the CAD-System produces an error or exception and doesn't generate a disc geometry. The process loop, in which the geometry generation procedure is embedded, stops on this point and the parameter combination, which caused the process interrupting, will be labelled as "bad". Analogue to this the parameter combination gets the same labelling, if a different number of lines, edges or faces are generated and the automated FE-Analysis can't create the calculation model because the boundary conditions can't be applied.

In both cases (geometry generation via combination of sketches and solid body modelling technique or via sketches only) the CAD-System doesn't communicate the source or type of error (e.g. Blend regeneration failed, sketch regeneration failed etc). This is for the process itself not a problematic or necessary issue but for post processing the information is useful to get an overview of geometry failures and the causes. With this information the geometric model can be evaluated in respect of the usability with an automated process and the geometric model can be changed if necessary.

2.2 Parametric modelling in respect of automated design process requirements

One possibility to reduce model failures is more constraints in respect of the CAD-Parameters. The possible ranges for parameter variations are smaller and hence the existing CAD-Model shouldn't fail during regeneration of the geometry. With this approach the design space will however be smaller and an undefined number of designs (which could be better than the current or starting design) will not be found. Reduced design flexibility is another disadvantage.

Another approach is to build up a CAD-model which includes the design and CAD-parameters (Subel, 2001 and Xiong et. al., 2004). The difference between both kinds of parameter is that a single design parameter can control several CAD-parameters. That means that the CAD-model contains dependencies and rules which are described through CAD-parameters which are controlled via design parameters. Design parameters can be identical with existing CAD-parameters or they can be control parameters, which control the shape of the CAD-model, (for example by using integer numbers "0" and "1" whereby some geometry features can be enabled or disabled). Such CAD-models (labelled with "CAD-models for automation" or short "CAD-FA-models") are not like the typical CAD-models for design and manufacturing. CAD-FA-models have a special parameterisation with a strong focus to shape-modification and model stability (in respect of shape-modification). Such models can be created for a particular problem (which should be solved with an automated design and analysis process) or the CAD-FA-model is usable for a group of familiar geometry shapes. Following requirements are typical for CAD-FA-models:

- high grade of design flexibility with a small number of parameters which control the CAD-model,
- CAD-model must be stable in respect of parameter variations in a bigger (untypical) range,

- CAD-model must contain tagged lines edges and faces (or rather the number of lines, edges and faces should be constant), which is important for several automated analysis procedures (like FE or CFD calculations).

3. Special parameterised CAD-models: an example

In the following an example of a CAD-FA-model an engine blisk-model will be shown (Figure 1). blisks are used for compressor rotor stages in several engines. With blisk's the weight of a rotor stage can be reduced because the blade root fixing, which is necessary to assembly blades with a disk, is not required, the number of parts is decreased and the airflow leakages are smaller.

Typically a blisk is assembled through geometry components like rim, shank, diaphragm, drive arms (which are the interfaces to other engine components such as a shaft or another disc/blisk) and bore, Figure 3 (a). For the transition between the blisk parts, blends are used. The model, which is shown, contains a 2-dimensional contour and 3-dimensional geometry, see Figure 3 (b), both are necessary for the two FE-analysis steps.

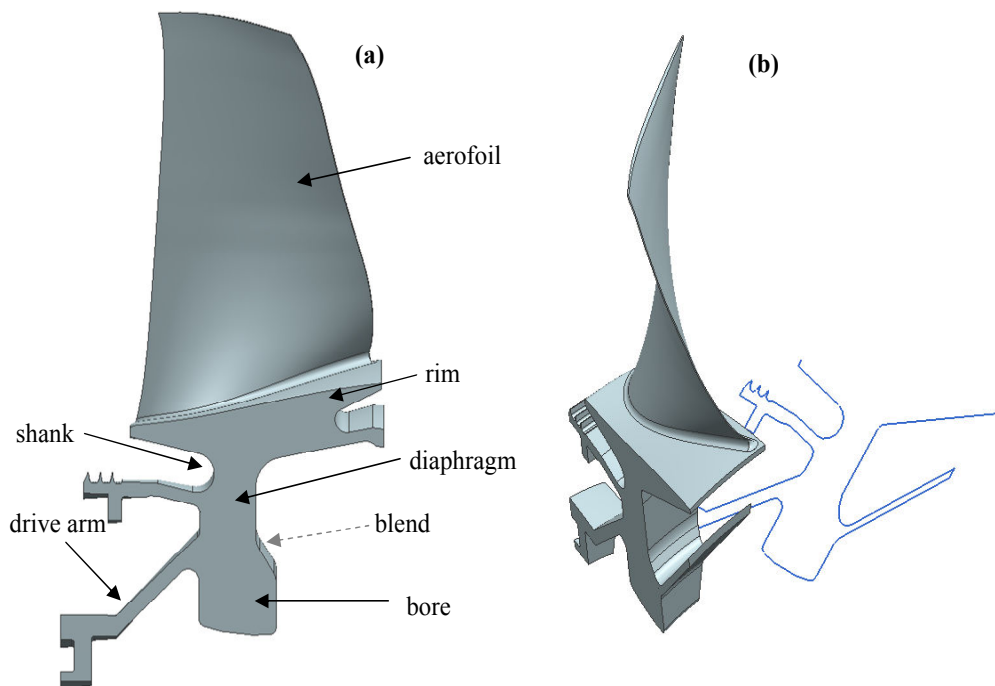


Figure 3. Typical assembly of a blisk (a) and 2-dimensional/3-dimension geometry in one CAD-model (b).

The appropriate CAD-FA-model can generate geometries with different bores (bigger or smaller), diaphragm (thicker or thinner), rim thickness, drive arm thickness and positions as well as number of drive arms. The latter is useful for design studies if the number and/or design of the interfaces are not fully defined. All geometry components and the transitions between the components are controlled via design parameters, CAD-Parameters and design rules, which are implemented direct in the CAD-model. All are stored in a so called expression list. Therewith it's possible to generate several designs with different number of drive arms (Figure 4), drive arm positions while assuring the perpetuation of the interface positions (Figure 5) and the whole blisk design. The formulated requirement in terms of number of lines, edges and faces is achieved. All blends are updated automatically. Figure 4 and Figure 5 show examples for different designs and details of the expression list. The controlling of the number of the rear drive arms is displayed in Figure 4.

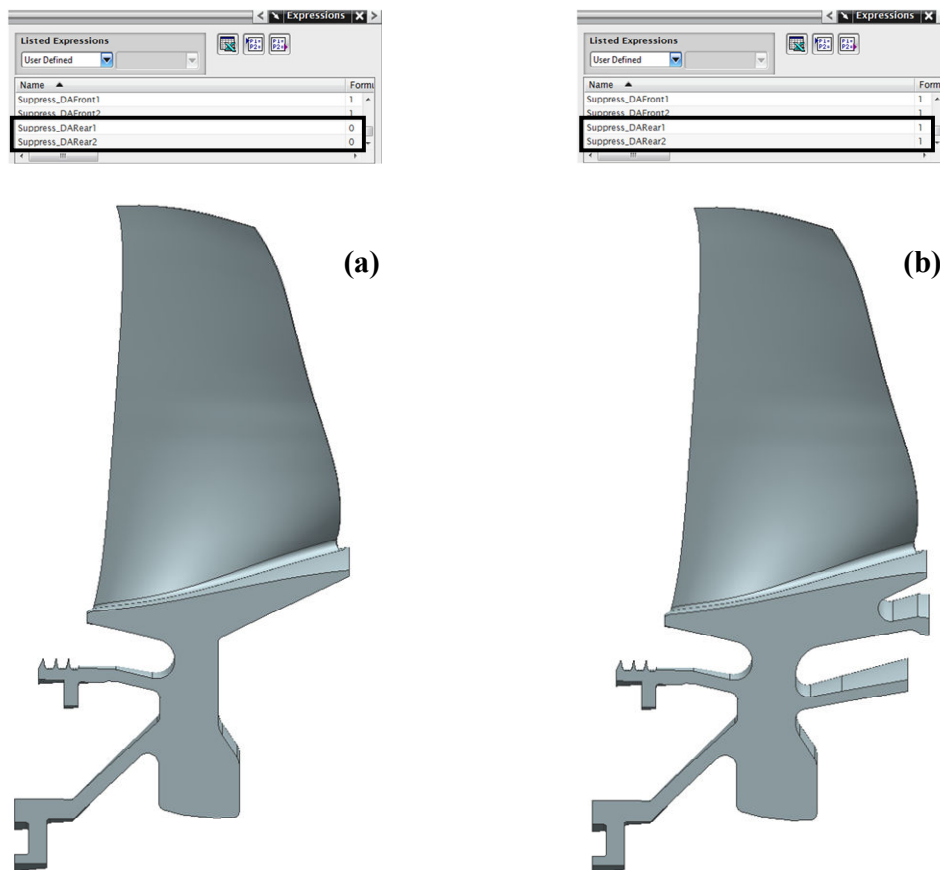


Figure 4. Examples for topology change which are controlled via control-parameters: (a) front drive arms only and (b) drive arms in front and rear.

Through changing of the desired design parameter (e.g. in this case labelled with “Supress_DARear1”) the associated drive arm can be disabled (parameter value equal with “0”) or enabled (parameter value equal with “1”). Figure 5 shows different drive arm positions controlled via CAD-Parameters. By modifying the desired CAD-Parameter the drive arm can move along the rear contour of the disc and the associated blend (or other geometry components) must follow. Also the present CAD-FA-model can generate an untypical or “extreme” design which is shown in Figure 6. Such extreme designs are useful to identify some design, weight or manufacturing (existing forging die) constrains. Additionally the CAD-FA-model generates a text or log file, if a new design couldn’t be created. Therewith the failed sketches or features can be identified in the post processing, and a failed model generation doesn’t result in a CAD-file.

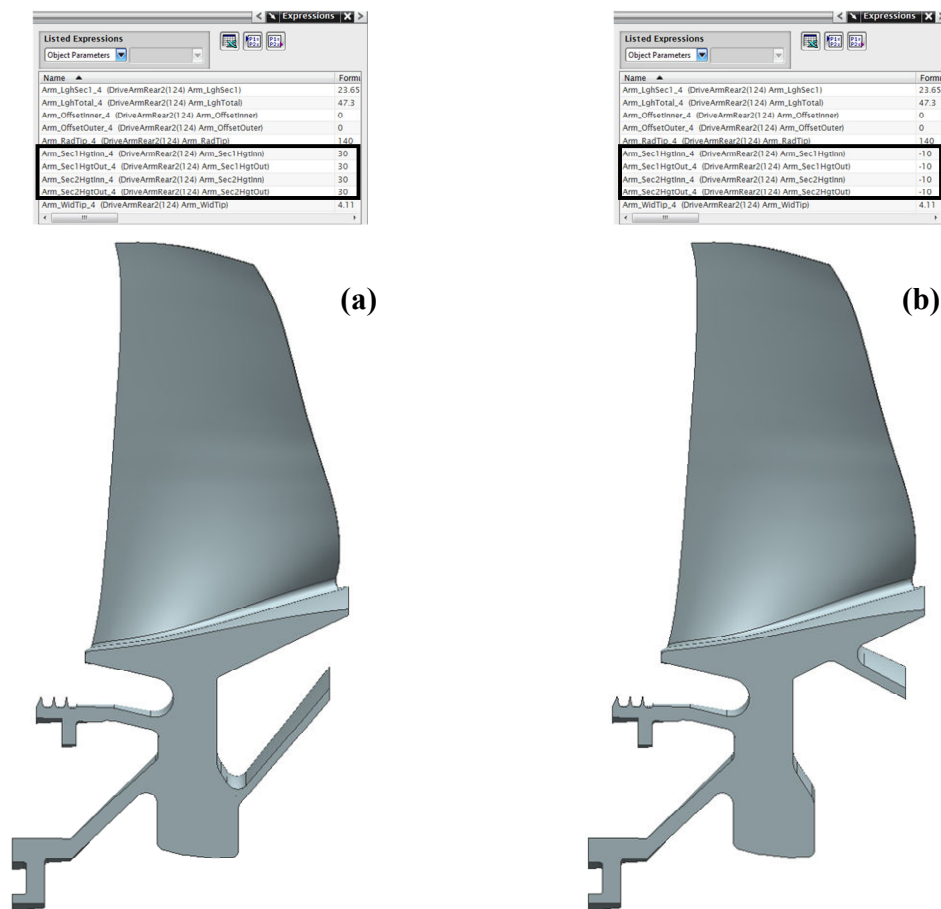


Figure 5. Examples for geometry modification: rear drive arm in (a) lower and (b) upper position.

With this feature, the existence of a modified CAD-file can be checked and communicated in the automated process and the associated Isight-workflow and/or the CAD-FA-model can be modified by the user.

4. Summary

The paper shows the possibilities and flexibility of geometry generation with a particular parameterisation approach. The approach combines CAD-Parameters, design parameters and implemented geometry rules. With such a generic geometry model, it is possible to create different designs of a certain geometry group, e.g. blisks, while keep tagging names and other geometric properties which are important for a subsequent analysis consistent. Additionally the CAD-model communicates more inside an automated design process. Hence a bigger design space can be explored and better design can be found in a given time frame, because the geometry generation process is much more stable (and can be used in an automated design and analysis process) and due to the high flexibility more untypical (not human driven) designs can be evaluated. It was shown that in respect to the example process from chapter 1.1 the number of successful runs (which is based on a modified CAD-model) has increased from 35% to 85% due to the usage of a special parameterised CAD-model (or CAD-FA-model), whereby the given problem could be solved.

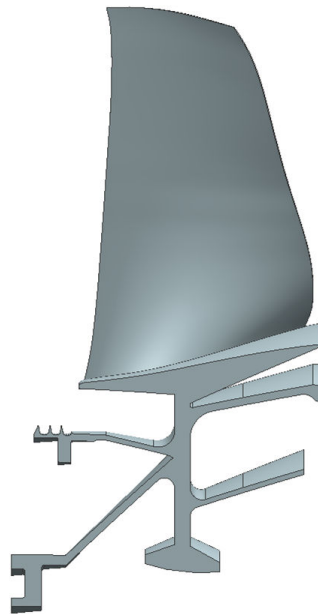


Figure 6. Example for an "extreme" blisk design.

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