TOP DOWN CAD MODELING METHODOLOGY FOR LOW PRESSURE TURBINE DESIGN

Massimo Gallizio*, Gian Paolo De Poli*, Matteo Usseglio**
***Avio SpA - Italy, **Turin Polytechnic - Italy**

Keywords: *CAD, Methodology, Low Pressure Turbine*

Abstract

Top Down is a very well known design methodology in systems engineering, allowing to manage complex systems by creating a hierarchy of information with an increasing level of detail, the result is a structure able to capture the significant parameters of the system. When it comes to CAD, parametric and associative modeling are topics widely known as well, since a vast offer of commercial products able to support these kind of features is available. The point is to put this two concepts together in order to achieve an effective methodology able to implement Top Down modeling in a real parametric and associative CAD environment.

The goal of this paper is to show how a Top Down Design Methodology for a Low Pressure Turbine has been developed at Avio implementing a Control Structure as the backbone of the CAD Design process. Moreover, it will be shown how the Master Model obtained from a Control Structure has been integrated into the analysis loops.

1 Top Down and Control Structure Concept

In the Control Structure, which is a CAD assembly built up on a Top Down logic by means of parametric and associative features, different engineers and designers can work sharing geometric information according to the level of detail they need. Furthermore, by adopting an associative modeling approach, every designer may be aware when the information he (or she) is working on needs to be updated.

The outputs of the process driven by the Control Structure are the 3D Master Models, the complete 3D representation of the items, which reflect the Design Intent defined in the Control Structure.

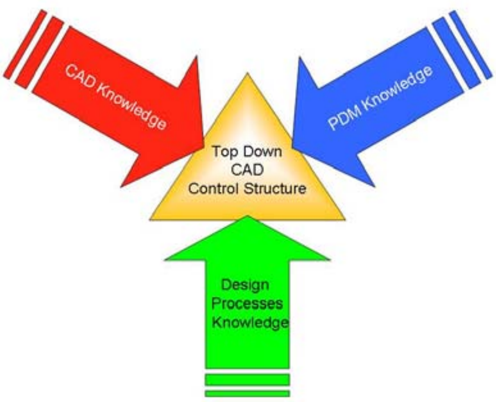


Fig. 1 . Knowledge to build a Control Structure

Implementing a Control Structure requires a deep knowledge of the CAD system’s features in order to be able to select the proper modeling techniques and strategies to implement a Top Down approach. In fact, given the same information to be passed through an assembly structure, different features approaches are available to fulfil the requirement, but only some of them are effective when used in a real design context. Even the choice on the information type, such as numeric parameter or geometry, and which kind of geometry, may affect the effectiveness of the Control Structure.

Since a strict concurrent engineering is necessary in turbine design, data management is also a common issue in the engineering disciplines. It is then fundamental to be able to implement not only pure CAD Top Down techniques, but also feasible PDM data structures in order to manage Top Down information flows and maintaining traceability and consistency. Several different engineers or designers may be working on the same assembly structure and at the same time. It must be clear to everyone which are the reliable information and which is their level of maturity in the design processes.

The third fundamental ingredient to achieve an effective methodology is a profound knowledge of the design processes involved in the turbine design to collect all the requirements and to spread them correctly down the Control Structure. The Mechanical Design process of a turbine receives inputs from many different disciplines such as Aerodynamic, Structural, and Thermal analysis which are to be taken into account and harmonized from a system point of view. Each of these inputs must be allocated at the right level of priority inside the assembly.

2 Aerodynamic and Mechanical Design Control Structures

Since the Aerodynamic data are the primary information to drive the Mechanical Design of a turbine, two different Control Structures have been developed to manage the Design Process. In fact, from an Aerodynamic point of view, only the hot engine conditions are relevant to define the geometry of the blades and the annulus. Shifting to a Mechanical Design point of view, the cold engine conditions are essential to define the shapes of the items to be manufactured.

2.1 Aerodynamic Control Structure

The experience derived from the implementation of the Control Structures on real projects has demonstrated the usefulness of managing the aerodynamic data inside a dedicated Control Structure.

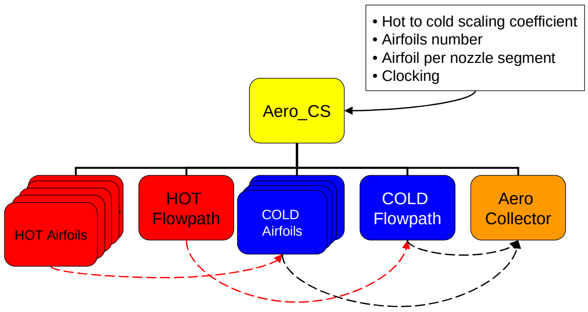


Fig. 2. The Aero Control Structure

The main objective of the Aero Control Structure is to segregate the information related to the specific engineering specialty in order to achieve a more streamlined design process. The assembly structure is then oriented to the management of the aerodynamic data for an entire low pressure turbine, and the requirements taken into account to develop this structure are:

- Separation of hot data from cold data: only aerodynamic experts are allowed to define and edit the hot geometries.
- Possibility to visualize separately hot and cold data, allowing visual comparison in order to verify the effect of hot to cold scaling on the geometries.
- Associativity between cold geometry and hot geometry: after the release of a new revision of the hot data, the cold geometries must adapt automatically.
- Revision traceability: it must be possible to determine which version of the hot geometry has generated a specific cold configuration.

According to this requirements, an assembly structure that receives as an input the geometric definition of the airfoils and of the gas flowpath in hot condition, has been developed. In the main file Aero_CS, the implementation of design rules based on the company knowledge allows to manage the following parameters:

- Number of airfoil per row

- Number of airfoil per nozzle segment
- Airfoil clocking
- Hot to cold scaling coefficients
- Leaning laws for rotor blades

The output of the Aerodynamic Control Structure is then an Aero Collector file where the aerodynamic geometries are available in cold condition and ready to be used into the Mechanical Design Control Structure.

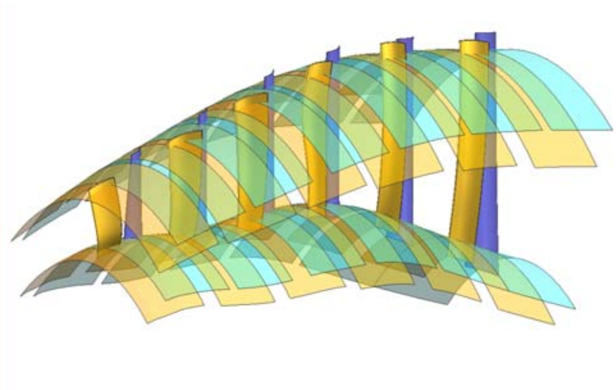


Fig. 3. Aerodynamic Collector from the Aero Control Structure

2.2 Mechanical Design Control Structure

The Mechanical Design Control Structure inherits as an input the geometric information coming from the Aerodynamic Collector file (orange box in **Fig. 2** and in **Fig. 4**.)

These geometries are copied throughout the entire Mechanical Design Control Structure reaching the specific file they are intended for. As an example, the cold airfoil definition of the third stage nozzle is copied to its relative Mechanical Design file in which other details are added. In this way, at the lower levels of the structure, where the component detailed design is carried out, only the needed information is passed. After the Control Structure is set up, only loading the assembly portion related to a specific component is possible. This allow to work on different components to many designers, while the PDM system keeps trace of the evolution of the design requirements. The update of the information are maintained by means of associative links, and the right amount of information is propagated through the structure maintaining it as light as possible. This fact permits to carry out easier design configuration trade off before sharing information to the lower levels in which the more time consuming 3D modeling is performed.

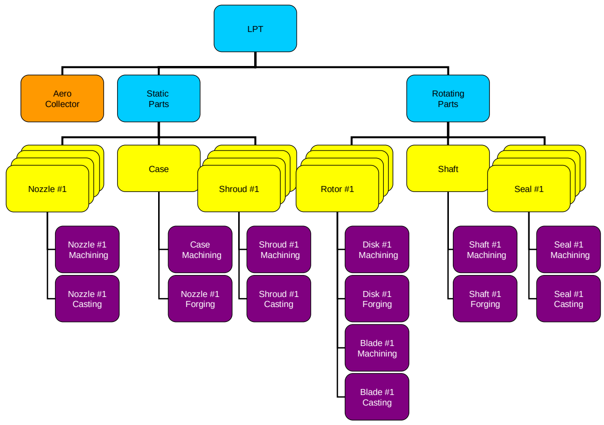


Fig. 4. The Mechanical Design Control Structure

One of the key challenges of creating a Control Structure is the process of formalization of the explicit and tacit knowledge used during the design process. Tacit knowledge is particularly not easy to fix, since every design has its own peculiarity and also the design practices may evolve between different projects, since they are not always clearly expressed. The Control Structure helps then to formalize, at least in the CAD language, a design knowledge that otherwise wouldn't be expressed.

In order to build a Control Structure it is necessary to correctly embed the knowledge used by designers into the CAD assembly. To achieve this goal, many different sets of interviews have been carried out in order to formalize the design processes and to highlight the major criticalities that are encountered during the design phase.
Moreover, the interviews helped to develop a set of guidelines, to aid designers to reach a common behavior in front of different design issues. This means that the design process has

been captured and stored into a structured and coherent way.

This formalization process lead to the clarification on which are the most relevant parameters to be traced during the design process of a Low Pressure Turbine and to organize them into the hierarchical levels of the Control Structure.

A second key factor has been taking into account how the company's organization can influence information ownership subdivision, and hence this affects the PDM system in which appropriate roles and functions must be assigned. On the higher levels of the Control Structure (blue boxes in **Fig. 4**), LPT module parameters are managed by the mechanical design project leader who is responsible for updating the module interfaces and the aerodynamic geometries. In the mid level of the structure (yellow boxes in **Fig. 4**), design specialists, using the information linked from the higher level, define the key geometries to describe the design intent which will be used by the 3D models. Finally, at the lower level of the structure, design engineers model the 3D Master Models linked to the geometries coming from the upper level.

2.3 Control Structure Wizards

Building a Control Structure is a time consuming task especially when no previous structures are available, and even in this case, given the high level of detail managed by a Control Structure, a certain amount of work has to be done. Furthermore, creating the great number of associative links and named parameters requires paying great attention. The knowledge acquired by building these structures has then been collected in order to shorten the time needed to build the two Control Structures, Aero and Mechanical Design. To reduce the possibility of errors and the time necessary to make available a Control Structure, two wizards have been developed to guide the user through the creation process. These tools have been developed using a mix of UG/Open API and Knowledge Fusion languages and they have been integrated into a customized version of UG available in Avio.

The first Wizard, called Aero_Wizard, allows to generate the Aerodynamic Control Structure, adopting as inputs the files with the hot data obtained from the aerodynamic analysis.

The hot geometry is then scaled and repositioned according to the company design rules and the cold aerodynamic definition is then generated. A collector file, containing the cold data, is the final output of the application, and it can be used as the input for the other Wizard, called LPT Wizard.

Fig. 5. Aero_Wizard User Interface

The LPT Wizard takes as input the Aero Collector File and generates an appropriate assembly, linking the correct aerodynamic information into the right components. It also creates the fundamental sketches for the preliminary definition of the geometry of the major items of a LPT. These sketches intentionally don't contain any geometric information and have to be considered just as an empty check list of all information needed for the complete definition of the major items. The designers can now start their work, fulfilling these sketches, with the correct geometry.

A further advantage of the Control Structure created with the Wizards is the global coherence of each feature names that greatly improves the accessibility and the readability of the structure itself.

These wizards have allowed to reduce the time needed to create the Control Structures from nearly two weeks to less than five minutes. The drawback of this work resulted in embedding company design knowledge into the wizards, which are strictly dependent on the CAD system. On the basis of this consideration, a new activity has been started in order to re-define the same knowledge into a more neutral and reusable language as XML is. This is a now an enabler to switch to different CAD system than UG, if needed, and allows to better interact with analysis process, such the optimization ones.

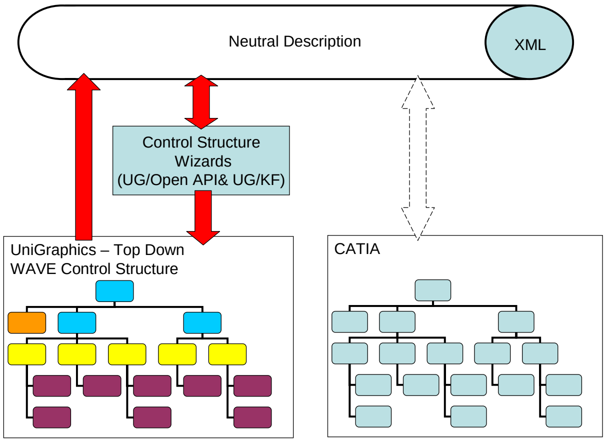


Fig. 6. XML Knowledge Structure

A Control Structure contains a big quantity of different kind of information: parameters, geometries, rules and processes. In order to have a global view of the structure it could be useful to extract all these information and to store them with an appropriate representation. A good choice to achieve this goal is to implement as a container a XML structure, in particular because of its light, extensible, neutral, and very flexible way to organize data.

The first step has been the development of an XML schema. This schema, called XML-CS, is a map of the organization of the data and it doesn't give any information about the data itself. To collect the data, instances of this schema have been created using a general approach that can be used to collect information from assembly of any kind and built with different CAD systems.

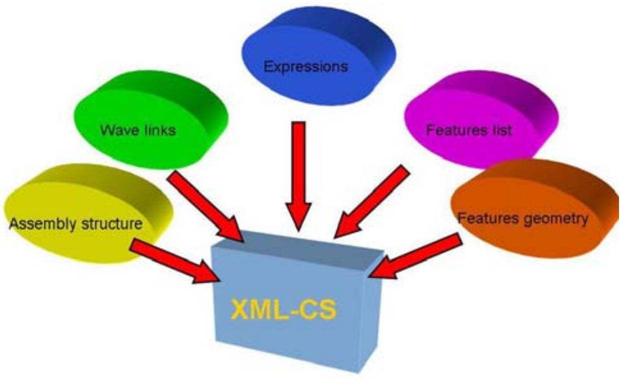
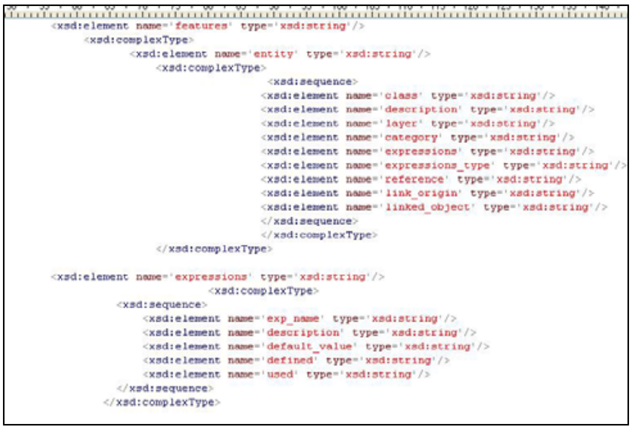


Fig. 7. XML-CS data types

The following step has been the realization of an application that inquires an UG assembly and retrieves, stores and organizes information like assembly structure, features, expressions, associative links into an XML-CS instance of the XML-CS schema.



```
<xsd:element name='features' type='xsd:string'/>
    <xsd:complexType>
        <xsd:element name='entity' type='xsd:string'/>
            <xsd:complexType>
                <xsd:sequence>
                <xsd:element name='class' type='xsd:string'/>
                <xsd:element name='description' type='xsd:string'/>
                <xsd:element name='layer' type='xsd:string'/>
                <xsd:element name='category' type='xsd:string'/>
                <xsd:element name='expressions' type='xsd:string'/>
                <xsd:element name='expressions_type' type='xsd:string'/>
                <xsd:element name='reference' type='xsd:string'/>
                <xsd:element name='link_origin' type='xsd:string'/>
                <xsd:element name='linked_object' type='xsd:string'/>
                </xsd:sequence>
                </xsd:complexType>
            </xsd:complexType>

<xsd:element name='expressions' type='xsd:string'/>
            <xsd:complexType>
    <xsd:sequence>
        <xsd:element name='exp_name' type='xsd:string'/>
        <xsd:element name='description' type='xsd:string'/>
        <xsd:element name='default_value' type='xsd:string'/>
        <xsd:element name='defined' type='xsd:string'/>
        <xsd:element name='used' type='xsd:string'/>
    </xsd:sequence>
    </xsd:complexType>
```

Fig. 8. XML schema sample

The output of the application is a XML-CS structure can be easily accessed from other applications, enforcing knowledge reusability and the possibility to be extended to define CAE interfaces. In fact, other information coming from and going to CAE world, can be easily added to the XML-CS, obtaining a sort of an organized input/output file for analysis.

Finally, it is also possible to use this XML-CS as a “bridge” among different CAD systems allowing from a theoretical point of view, to re-

build into CATIA a Control Structure realized in UG.
The users can choose to use XML-CS only as a container of high level information (e.g. with no information related to geometry), or with a more detailed level of analysis. In this case, XML-CS can be viewed as a neutral parametric CAD format that can be used to communicate geometry parameterization logics between different CAD.

3 Top Down approach for Robust Design

The design process of low pressure turbine can be broken into three phases: conceptual design, preliminary design and detailed design. The conceptual design process focuses on the basic design optimization of features as overall performance, weights and sizes. During the preliminary design, the focus is on the mathematical modelling of the LPT components performance with sufficient accuracy. After this phase, the geometry is frozen and any change could be costly. Detail design concentrates on the actual design of parts to be fabricated.

A design task typically culminates in a design decision – the selection of a technology or component or material, the determination of the best dimensions or parameter values, and so on. One by one, these decisions push the design forward and ideally these decisions are made in the best interests of the customers, both internal and external.

Once the design concept is assembled, a determination can then be made as to whether it is affected by variation.

In recent years, probabilistic design analysis and optimization methods have been developed to account for constant uncertainty and randomness. Fundamentally, robust design is concerned with minimizing the effect of uncertainty or variation in design parameters (variables and constants that appear in a design problem formulation) without eliminating the source of the uncertainty or variation. In other words a robust design is ‘less sensitive’ to variation in uncontrollable design parameters than the traditional optimal design point. A robust design approach helps the designer to find a relationship between the design variables variations and the evolution of performance values.

Consequently, the controllable shape change is crucial. In particular, preliminary design requires timely engineering analysis of large numbers of designs. This leads to the requirement for geometric models to be created both rapidly and automatically. Moreover, created geometric models must necessarily be part of a continuous parametric family of designs, all of which satisfy a large number of shapes and spatial integration requirements for the intended vehicle family.

Beside the management of the Mechanical Design Intent of the entire Low Pressure Turbine system, a further advantage given by the Control Structure is to enforce the re-usability of 2D and 3D models also for CAE analysis. Relying on PDM versioning capabilities, the implementation of the Control Structure and Master Model Methodology has given great benefits in terms of confidence on which version of the geometry has been utilized by the analysis.

In fact, since the analysis are conducted outside the CAD PDM System, an export operation of the CAD 3D models is required in order to do the pre-processing phase of the analysis. This operation implies a partial loss of confidence on the reliability of the model used, since the model is no more traced into the database. Anyway, if the same name defined in the PDM system is applied to the exported model, this potential risk is lowered. Starting from the portion of Control Structure and Master Model extracted from the PDM building again the model for the analysis is no more necessary, while at the same time the correctness of the model is assured. After this step is then possible to build a specific CAE analysis model linked to the original Master Model. The CAE analysis model is derived using associative links to the Master Model and simplifying the geometry according to the requirements of the analysis. By means of this approach is possible to re-use the parameterization implemented to drive the Design Intent of the Master Model also to explore different configuration from the one chosen for the approved design.

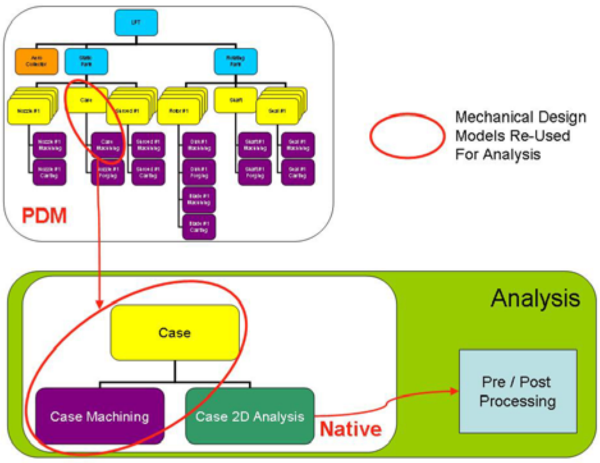


Fig. 9. Control Structure and analysis

The optimization loops are generally composed of a “Process Manager” that leads all the applications, such as CAD, FEM pre and post processor and FEM solver, involved into the analysis process. In order to strengthen the integration of the CAD models into the analysis loops, an application has been developed to allow the batch calling of UG and the remote update of the parameters inside a UG part. This application is called CADGate, and works only in UG environment, but its functionalities can be repeated with any other parametric CAD system. The overall analysis process, in fact, must be considered as a platform independent approach, that allows the integration of different CAD and analysis tools. Following CADGate guidelines it has also been developed a similar application that allows the integration of CATIA into analysis loops.

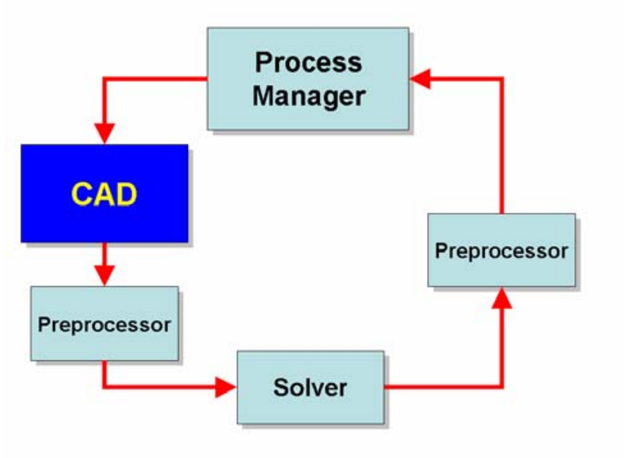


Fig.10. General CAD Process involving CAD

The use of CAD system for geometry modelling in a robust multidisciplinary design optimization environment could potentially save development time.

The choice of the design parameters is of paramount importance, since it is the equivalent to defining the mathematical model of the optimization problem. The possible solutions largely depend on the parameterization, since it defines the nature and the dimensions of the research space.

Parametric strategies combined with optimization can have a big impact on engineering design by automating the individual product development tasks. When parametric tasks and optimization frameworks and methods are combined, theses strategies can be used to make up what is known as a robust multidisciplinary design optimization (RMDO) schema.

The central challenge in this type of analysis is generating the probability distribution for the output parameter. Many different techniques exist, but two of the most prevalent are Sensitivity Analysis and Monte Carlo Analysis. Statistical analyses such as Sensitivity Analysis or Monte Carlo analysis are performed by changing the input parameter values and observing the changes on the output parameter. When a sufficient number of output values have been collected, a probability distribution can be constructed for the output parameter, and this distribution will tell the likelihood of the design satisfying the customer requirement. It is important to note that typically large numbers of output values (on the order of hundreds or thousands) will be required. In an RMDO schema, parametric methodologies are used to execute the design process. Each automated task requires inputs and produces outputs. These tasks are linked together to automate the entire design process

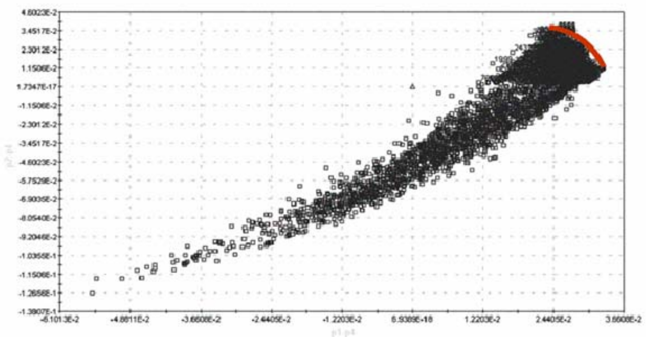


Fig.11. A RMDO exploration

The RMDO framework provides the ability to map the data flow between tasks and to perform stochastic optimization loops. In Fig. 11 the results of a two-objectives optimization have been reported. Here, the geometric parameters have been modified with the aim to maximize two different outputs with a constraint on the standard deviations.

Based on these aspects, we can say that a key step in the process is to use parametric modelling and simulation to create predictive models for design's critical requirements, and statistical modeling techniques can help ensure that the mathematics are explicit and compute quickly. With these models the design can be statistically analysed and optimised to ensure it will perform as expected while being robust to the variation inherent in its production, environment and use.

References

[1] De Poli GP, Fattore L, Frola C, Gallizio M, Mattone M. Multidisciplinary integration and robustness evaluation applied to Low Pressure Turbine casing design, *ASME Turbo Expo Proceedings*, Barcelona, GT2006-90464, 2006.

[2] Gallizio M, Periale P, Pingitore M, A new approach for the preliminary design of an Accessory Gear Box, 9th *CEAS European Propulsion Forum*, Roma, 2003.