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Design optimization schemes to reduce Tip clearance uncertainties in Gas Turbine Engines

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Introduction

The lead time required in designing a gas turbine engine configuration and structure is enormously long. The design process involves stages such conceptual, preliminary and detailed design. Design also involves the use of a number of software tools (CAD/CAM/CAE). Integration of these tools could lead to the automation of some of the iterative processes involved in the design process. Figure.1 illustrates a process designed to achieve an optimized gas turbine engine structure that satisfies design objectives such as weight, stress, stiffness and fuel efficiency by using high and low fidelity FE analysis.

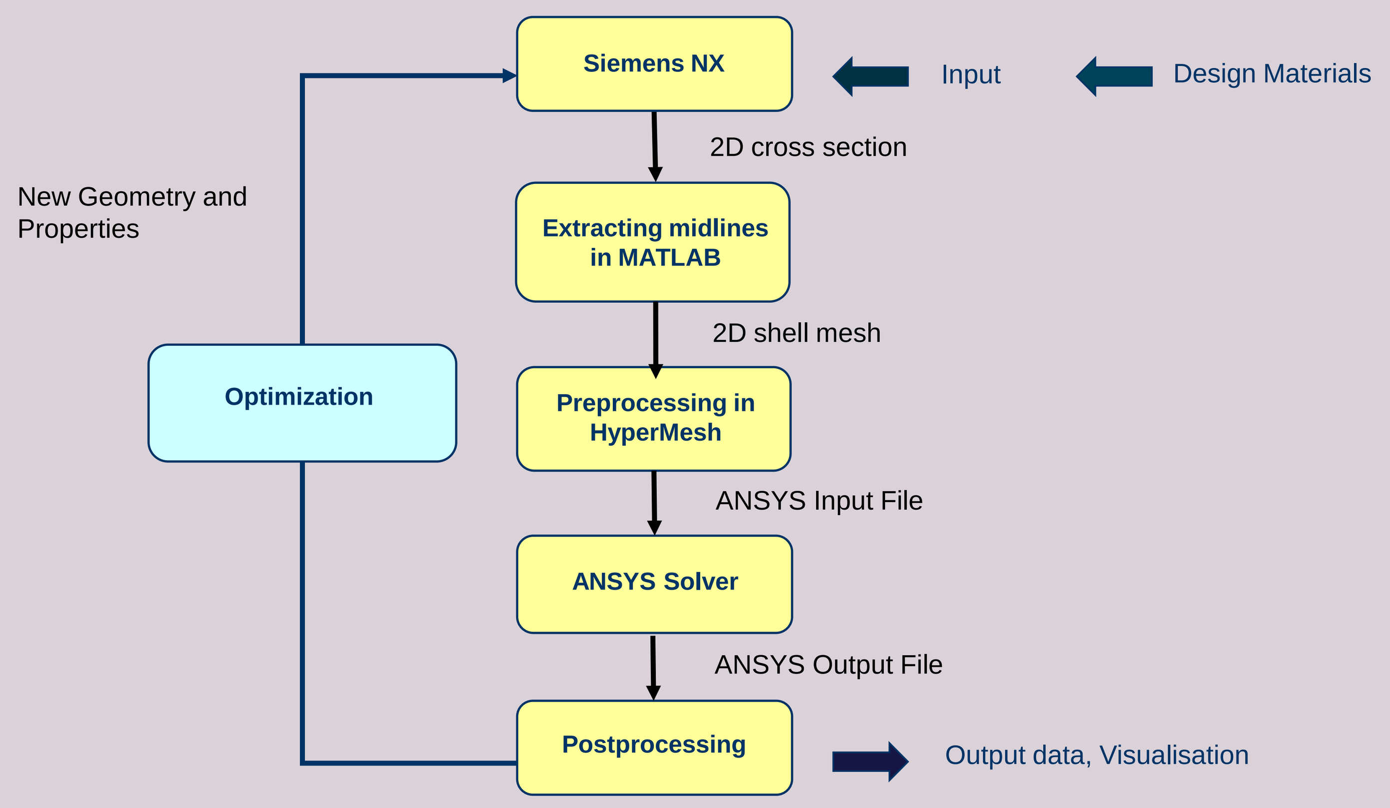

Figure 1: Process to obtain an optimized aero engine casing structure

Geometry Modelling for Finite Element (FE) Analysis

A 2D general arrangement/cross-section is the starting point of most gas turbine geometric models. One approach is to use this cross-section to create 3D FE models by meshing the 2D geometry and revolving to form the 3D FE model. In order to have at least 2-3 elements through the thickness, fine 3D meshes have to be created which in turn leads to large run times. On the other hand, if the solid model is represented using midsurfaces, fewer elements can be used to build an FE model which represents the actual 3D model more closely. The work presented here deals with approach. A cut section of a typical gas turbine engine model used to create midsurfaces is as shown in Figure 2, while a typical 3D FE mesh is shown in Figure 3.

By approximating a 3D geometric model into a 1D or 2D FE model, information of the many intricate and critical features is lost. Therefore, using midsurfaces and retaining the original stiffness of the geometry is a very important requirement. 2D mesh on the midsurfaces of a full engine general arrangement can be done in batch mode using HyperMesh. However, the midsurface or midline extraction tools within HyperMesh or Siemens NX have limitations when handling complex 3D/2D geometries. The midsurfaces extracted using such commercial tools requires a lot of manual intervention to stitch and sew the extracted midsurfaces for the purposes of creating a good quality mesh.

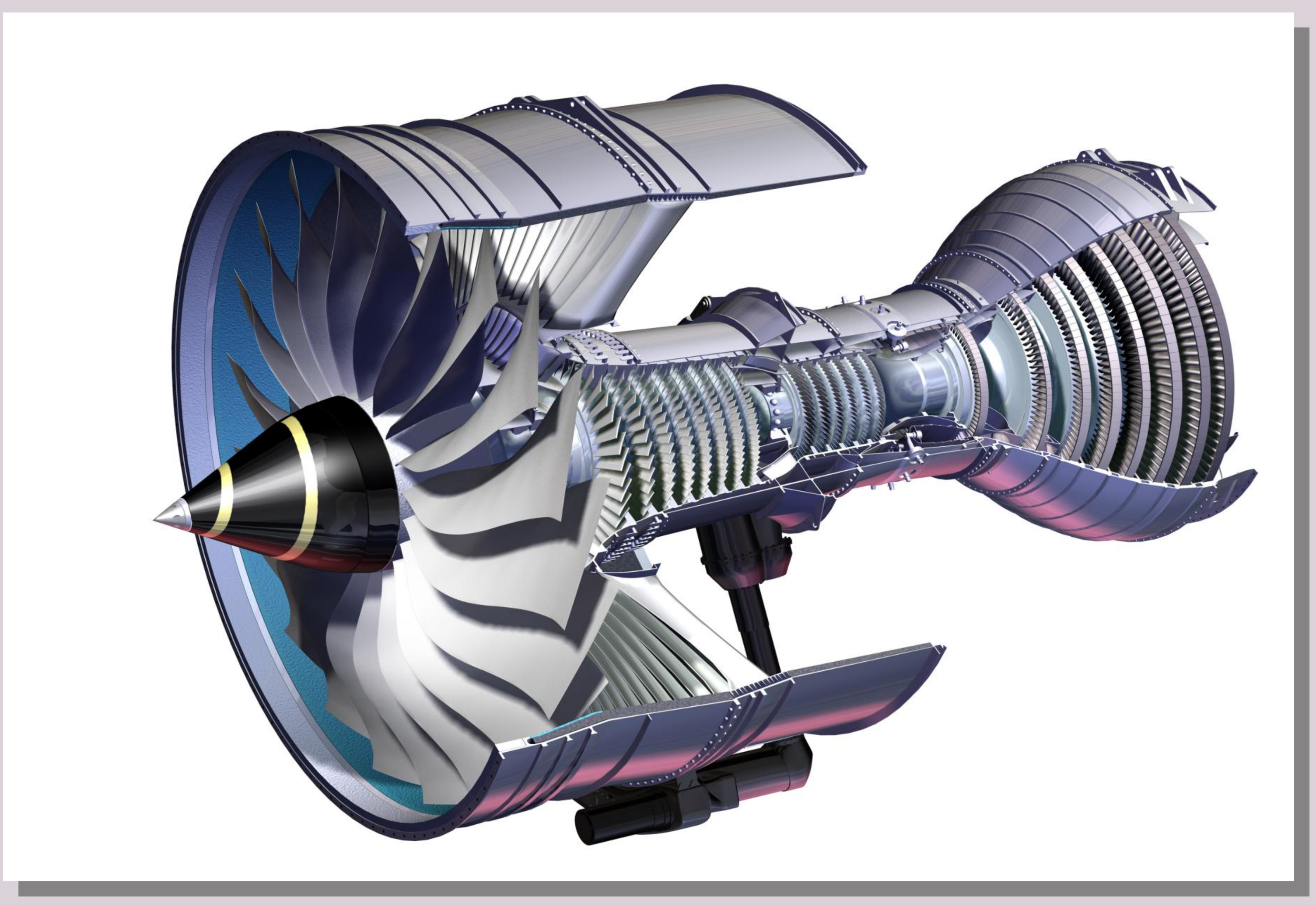

Figure 2: Cross section of a typical gas turbine engine

Medial Axis Transforms

The concept of Medial Axis Transform (MAT) has been implemented here using Matlab to extract the midlines of 2D cross-sections and revolve these midlines to create midsurfaces. These midsurfaces can then be meshed using 2D elements and represent a 3D model when an appropriate thickness is defined. One such midline extracted using the MAT code for a typical High Pressure turbine casing is as shown in Figure 4. The 2D meshes created using these midsurfaces are comparable to solid models for most parameters, i.e. mass, center of gravity (CoG), natural frequencies and stiffness. These critical parameters from the 2D model (midsurface model) have to match closely (error less than 10%) with the solid model for use in Tip clearance studies. An error of <=10% is acceptable since these low fidelity shell models will be used along with High fidelity solid models and co-Kriging during the optimization runs. Generally the mass of the shell model produced using MAT midlines is higher when compared to the solid models. This is due to the branches that are created by the MAT code. These branches add extra mass into the system. In order to match the shell model mass with the mass of the actual geometry, density correction is needed. By doing so, mass error can be virtually eliminated.

However, density correction does not change the CoG of the shell model. Mass balancing is needed to correct the CoG of the shell model to match the CoG of the solid model. If the mass distribution along the geometry is not as per the solid model, the CoG's of the shell and solid models will differ. This difference can lead to erroneous results when loads involving gravity (maneuver loads) are used for FE analysis. The FE model created based on the MAT midline (Figure 4) is as shown in Figure 5. The midsurface shell model's mass, CoG and first 10 natural frequencies here differ from the solid model by 0.29%, 1.2% and less than 2.5% respectively.

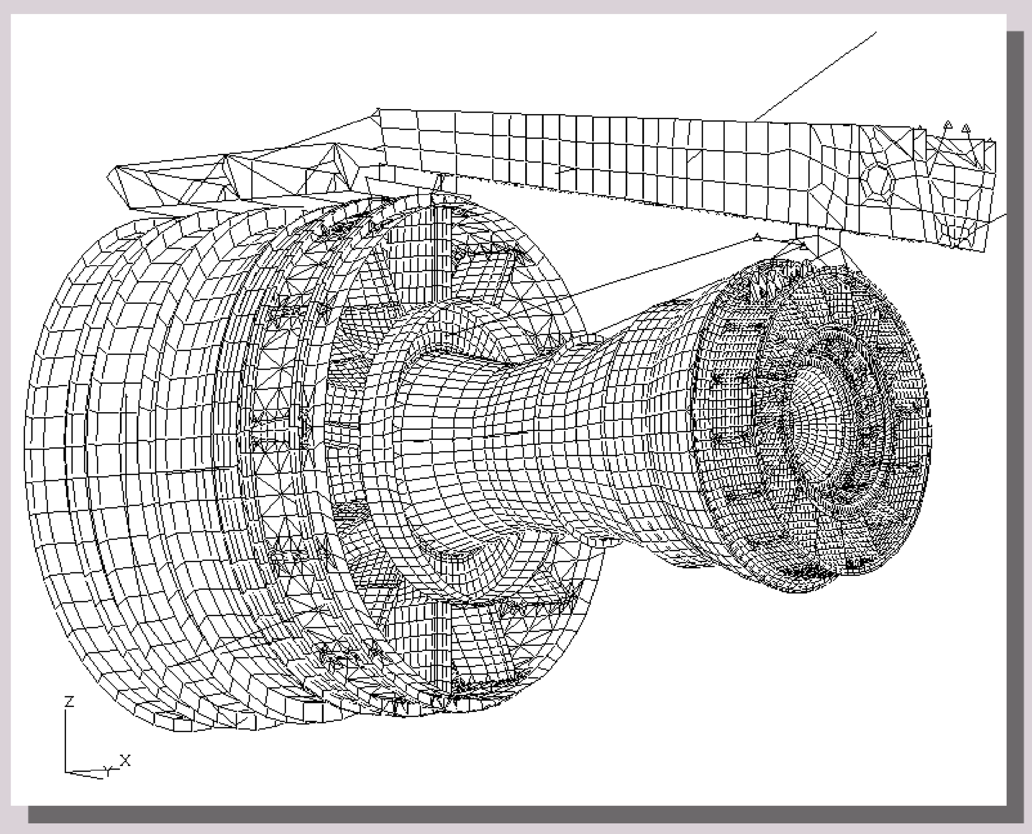

Figure 3: 3D finite element model of the full engine

Design Optimization

In a general design environment, the manual iterative process would take months before an optimal design can be decided upon. By subjecting such design processes to the multi-objective optimization cycle, a robust design with tradeoffs made can be achieved more efficiently. Multiobjective optimization can also lead to a considerable reduction in the design lead time of the full engine model. In a general design environment, many groups are involved while designing a part and these interactions between groups can be integrated by using computational approaches to design. The knowledge base held within these groups can be used to parameterize the geometry and define rules which form the core of Knowledge Based Engineering (KBE).

In order to search the design space for optimum tip geometry, the geometry needs to be changed and its behavior studied. The time taken to prepare a 2D finite element model of the HPT case discussed in Figure 5 is around 12 man hours. The same task when performed in batch mode using the Matlab code needs less than 5 min to create and does not require any manual intervention. Potentially significant savings in terms of time and money can be achieved by adopting the MAT based Matlab code when optimizing the load bearing casings of an aeroengine.

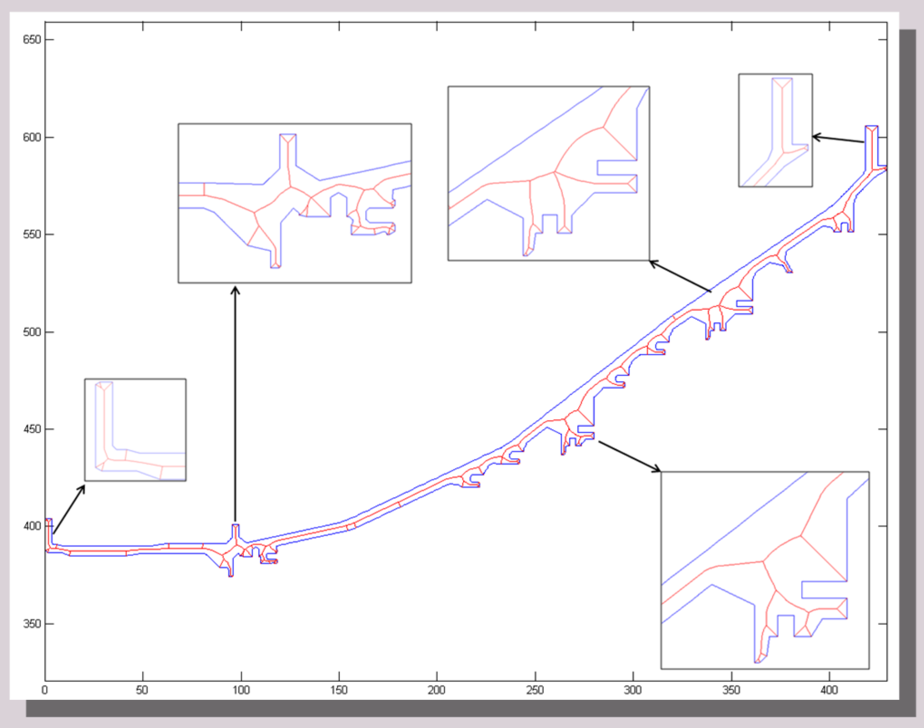

Figure 4: Midline of the HPT case extracted using the MAT Matlab code

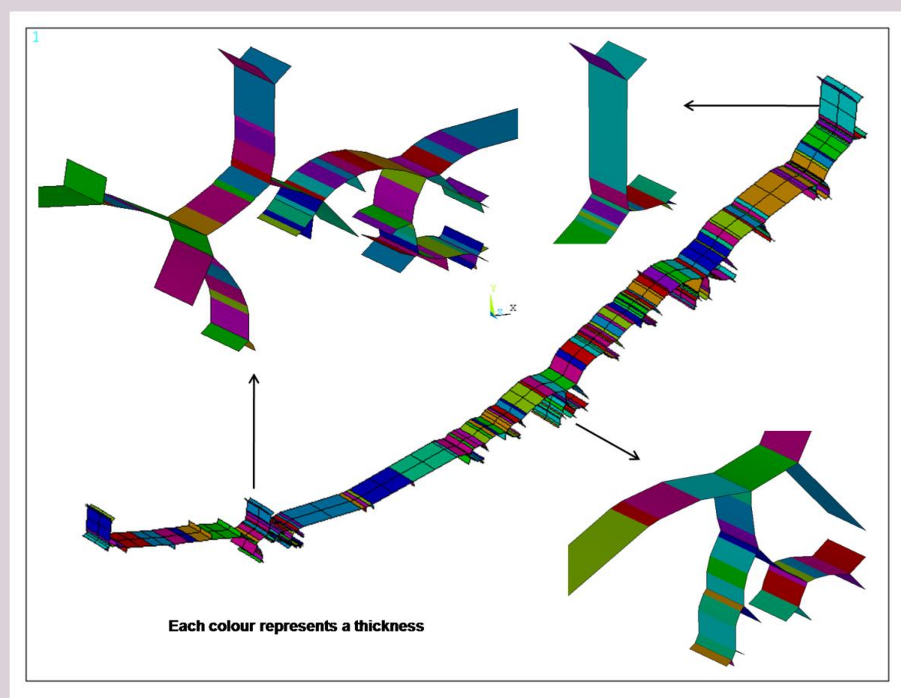

Figure 5: 2D finite element model of the HPT case

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