Turbine Stator Well Geometry Benefits – Method Validation and Design Optimisation

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Engine components are commonly exposed to air temperatures exceeding the thermal material limit in order to increase the overall engine performance and to maximise the engine specific fuel consumption. To prevent the overheating of the materials and thus the reduction of the component life, an internal flow system must be designed to cool the critical engine parts and to protect them. As the coolant flow is bled from the compressor and not used for the combustion an important goal is to minimise the amount of coolant in order to optimise the overall engine performance.

During a typical flight cycle an aero-engine undergoes different operating conditions which cause varying temperatures, pressures, stresses and displacements to the engine components. From an engineering perspective, it is desirable to be able to accurately predict these behaviours in order to stay within the environmental and safety margins and to maximise component life. This also avoids costly experimental engine tests and increases the competitiveness of the aero-engine company in their market.

Predicting the metal temperatures is of paramount importance as they are a major factor in determining the component stresses and lives. In addition, as modern engines operate in ever harsher conditions due to efficiency requirements, the ability to predict thermal displacements becomes very relevant: on one hand, to prevent damage of components due to excessive rubbing, on the other hand, to understand how much air is flowing internally within the secondary air system for cooling and sealing purposes, not only in the design condition but throughout the engine life-span. In order to achieve this aero-engine manufacturers aim to use more and more accurate numerical techniques requiring multi-physics models, including thermo-mechanical finite elements and CFD models, which can be coupled in order to investigate small variations in temperatures and displacements.

This paper summarises the work carried out during the EU funded research project AMEDEO[1] and shows a practical application and extension of the methodology developed during the five year research programme MAGPI[2]. Extensive use is made of FEA (solids) and CFD (fluid) modelling techniques to understand the thermo-mechanical behaviour of a turbine stator well cavity, due to the interaction of cooling air supply with the main annulus. Previous work based on the same rig showed difficulties in matching predictions to thermocouple measurements near the rim seal gap[3-6]. In this investigation, further use has been made of existing measurements of hot running seal clearances in the rig. The structural deflections have been applied to the existing model to evaluate the impact in flow interactions and heat transfer[7,8].

In addition to a baseline test case without net ingestion, a case simulating engine deterioration with net ingestion is validated against the available test data, also taking into account cold and hot running seal clearances. Furthermore an additional geometry with a stationary deflector plate is modelled and validated for the same flow cases. Experiments as well as numerical simulations have shown that due to the deflector plate the cooling flow is fed more directly into the disc boundary layer, allowing more effective

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use of less cooling air, leading to improved engine efficiency. Therefore, the deflector plate geometry is embedded in a CFD-based automated optimisation loop to further reduce the amount of cooling air[9]. The optimisation strategy concentrates on a flexible design parameterisation of the cavity geometry with deflector plate and its implementation in an automatic 3D meshing system with respect of finally executing an automated design optimisation. Special consideration is given to the flexibility of the parameterisation method in order to reduce design variables to a minimum while also increasing the design space flexibility & generality.

The parameterised geometry is optimised using a metamodel-assisted approach based on regressing Kriging in order to identify the optimum position and orientation of the deflector plate inside the cavity. The outcome of the optimisation is validated using the benchmarked FEA/CFD coupling methodology.

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