Experimental investigation of waste heat recovery concept in turbine rear structure for a Liquid Hydrogen Gas-Turbine

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Abstract – The increasing governmental restrictions over CO2 emissions have made aviation companies search for another source of fuel to help in this reduction challenge. Liquid Hydrogen is emerging again as a possible clean substitute for conventional aircraft fuel. One of the main challenges is the increase of inlet fuel temperature from cryogenic to a more typical condition, such operation could be done by utilizing the otherwise wasted exhaust heat. This work presents an aerothermal experimental investigation of the outlet guide vanes in the Turbine Rear Structure, for its use as heat exchangers. The experimentation was carried out in the LPT-OGV test facility at Chalmers Laboratory of Thermal Sciences where the convective heat transfer coefficient was evaluated on the surfaces of a new OGV concept with two split-angled coupled vanes using an infrared thermography technique. The results of this study provide valuable insights for further development of heat-management systems in aviation, contributing towards sustainable and efficient aircraft propulsion.

1. Introduction

As a pathway to the European Union's environmental goals of achieving a net-zero CO2 economy by 2050, hydrogen is being considered as a promising sustainable fuel for aviation. The key advantages of hydrogen as a fuel include its CO2-free combustion and high gravimetric energy density. Despite challenges such as lower density and cryogenic storage requirements, the use of hydrogen can potentially enhance heat-management systems in aircraft, through the application of intercooling and exhaust gas heat recuperation.

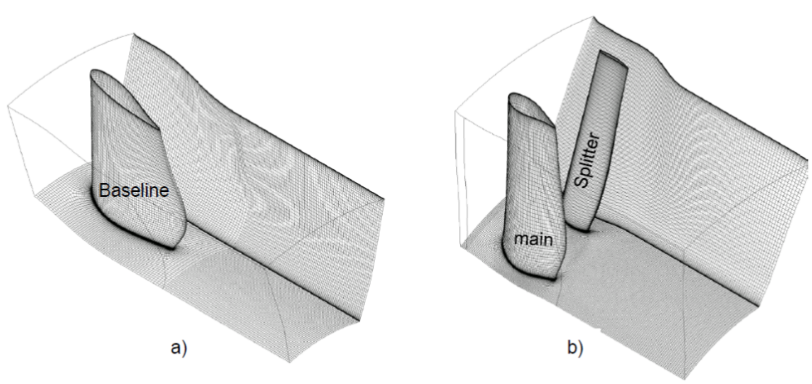

Figure 1: Numerical domains used to simulate the aerothermal performance of the baseline (a) and high-aspect ratio (b) TRS geometries. The high-aspect-ratio configurations includes two separate and different vanes (main and splitter).

This study aims to investigate the potential of utilizing the Outlet Guide Vanes (OGV) in the Turbine Rear Section (TRS) for heat recuperation in the exhaust. The experimental investigation is conducted at Chalmers LPT-OGV test facility under engine representative conditions, evaluating both the heat recuperation capabilities of an engine representative TRS and a GKN designed novel concept for enhanced heat recuperation. The design goal behind such novel concept was to achieve a greater heat transfer, while avoiding an increase of other negative aspects like weight or pressure loses. Higher number of surfaces, increase heat transfer but also weight. Thus, by splitting the baseline vane in two, heat exchange area is increased while weight and solidity is kept almost same as the baseline.
The baseline TRS vane is shown in Fig.1a and the enhanced model in the Fig. 2b, with the latter creating a coupled vane system (main and splitter) dotted with a higher vane inclination angle for aerodynamic purposes.

2. Methodology

A transient technique with radiative heat is used to achieve a steady state temperature on the vane surface, then heat is removed, and surface cooling is measured with an IR camera. For this, a one-dimensional LCM approach was taken to simplify the behaviour of the flow in its 3D form which combined with the RMA method [2] allowed the measurement of the heat convective flux emanating from the surface of the OGV.
Previous experiments carried out on the baseline [3, 4] provided a good frame of reference for the comparation of both concepts. Splitter vane small thickness did not allow a proper integration of hot water channels used in [3, 4] for heating of the vane surfaces. This feature led to the adoption of radiative heating technique for this study.

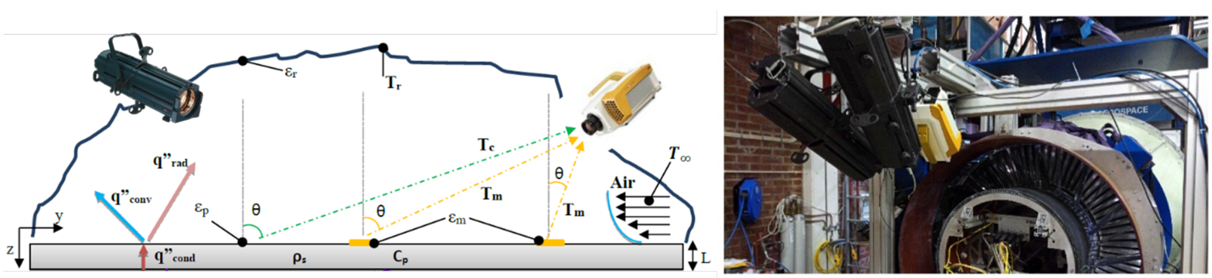

Figure 2: Depiction of the used LCM 1D simplification with IR camera methodology (left) and its implementation on the TRS (right).

3. Experiments

The test campaign for the experimental evaluation of the average Heat Transfer Coefficient (HTC) was designed to provide a map of both Suction and Pressure side for main and splitter vanes. This information was later used for the verification of the computer simulated data. The chosen scenario for the *at design point* (ADP) was same as found on medium size aircraft engines at cruising altitude with some plus minus variations.
The experimental data offered images of the average heat transfer coefficient on the OGV surface as well as additional depictions of the areas with higher temperature fluctuations. The value of these high fluctuating areas is of importance when evaluating boundary layer transition

regions and secondary flows formation. In combination with the HTC images such regions can be point out with high degree of confidence. Interestingly, the experimental evaluation of the same geometry but dotted with a small wire to trigger its turbulent boundary layer (also called "weld"), resulted in a higher average HTC on the Splitter vane than showed in the numerical study as can be observed in Figure 3.

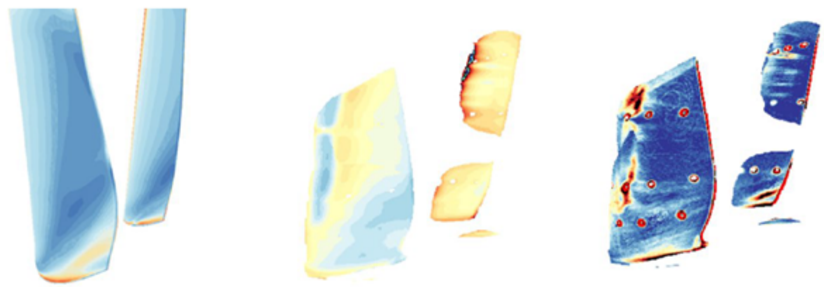

Figure 3: HTC distribution image of numerical simulation (left), experimental (middle), and temperature fluctuations distribution (right) all on OGVs with "weld".

In addition to temperature fluctuation and heat transfer surface mapping, an additional measurement was made to evaluate the total pressure losses encountered in a TRS when its OGVs are fitted with welds. For that, a common upstream plane is used as reference and then compared with the measurements obtained in both of the cases

4. Results

Figure 4: Normalised HTC from numerical simulations (left) and from experiments (centre). Also from experiments, heat transfer and temperature fluctuations (right).

As shown in Figure 4 the experimental results yield a better performance of the HTC than the predicted by the numerical simulation. In particular is noticeable the results with the OGV with triggered turbulent boundary layer, specifically in the splitter vane where such increment is considerably larger. On the contrary with what is observed, in the main vane HTC values are much lower, even when provided with the same triggering mechanism than its smaller sibling. This is likely due to the ineffectiveness of the trip wire to provoke a full turbulent layer over the surface further downstream the leading edge where the trigger is located.

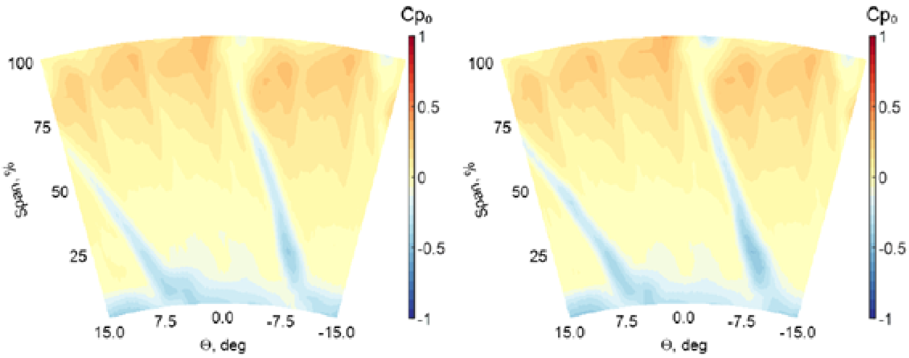

Figure 5: Total pressure coefficient mapping comparative of downstream plane between normal (left) and with weld (right) OGVs

The pressure losses comparation results shown in Figure 5 indicate slight increases in loses, mainly in the mid-low span sections of the geometries, over all in the splitter vane. This confirms the negative effect of a fully turbulent layer. However, when considered with the HTC gained by this phenomena, such increase becomes "tolerable".

5. Conclusions

The new configuration designed, was numerically simulated and implemented in the Chalmers University LPT-OGV test facility. The experimental results agree with the numerical data obtained, supporting the prediction of a 50% increase bearing no substantial loses. The additional evaluation of the OGV version with the boundary layer triggered on the suction side also showed a good agreement between simulation and experimental results, but nevertheless only the splitter vane in the latter achieved fully development over the entire surface which translated in a higher heat transfer than originally predicted. A small increase in total pressure losses of around 10% is observed at mid-span of the geometry, an acceptable number when correlated with the almost 40% extra HTC achieved compared with the non-triggered boundary layer OGVs. Based on the results found in this report it is possible to strongly indicate that the numerical tools used to perform the aerothermal predictions are capable of output confident results for the novel TRS geometries including those with added boundary layer triggering mechanisms.

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