1. Publishable Summary

The third Reporting Period of the Engine Representative Internal Cooling Knowledge and Applications (ERICKA) project has progressed broadly according to plan, although with certain delays which have resulted in a request for a one-year extension..

Rolls-Royce UK has led the project with the support of the ERICKA Project Office and appropriate approval from the Management and Steering Committee. ARTTIC has also set up a popular internal web site which has been used with success to communicate data, geometries and results between the beneficiaries.

WP1 involves all of the SMEs who are tasked with optimising specific cooling technologies. During the present reporting period, this work package involved significant interaction between the WP1 leader and all of the industrial partners engaged in the experimental Work Packages - specifically WP2, WP3 and WP4. The CFD evaluation work is focussed in WP5 which, as the project progresses and results become available, will adopt a similar interface role. WP6 has concentrated on producing a workable dissemination plan which has resulted in the ERICKA website (www.ericka.eu).

A summary of the technical progress of ERICKA is given below.

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WP1

The principal aim of WP1 of the ERICKA project is to implement a set of tools and methodologies, to improve the thermal behaviour of turbine blades by optimising internal cooling component. In this project 3 types of internal cooling systems are being investigated:

- Leading edge impingement
- Radial cooling passages
- Radial cooling passages with U-Bend

During the previous reporting period, partners implemented new advanced strategies in their software to account for robust mesh (re)generation and to improve robustness and reliability of CFD convergence to reduce the computational cost of optimisation while maintaining CFD reliability. Each partner verified and validated the reliability of the CAD/Meshing/CFD solutions used in his computational loop.. Automated post processing tools and methodologies have also been tested prior to optimisation. EnginSoft and Cenaero finished their optimisations. An optimisation on the leading edge impingement geometry is currently running at Cambridge Flow Solutions, while Numeca implemented conjugate heat transfer (CHT) in their computational loop to optimise the RRUK, ITP and Snecma geometries.

Optimisation work performed by EnginSoft was successful, managing to produce a leading edge impingement geometry that was able to increase the heat transfer coefficient per unit of radial length by 29% while decreasing the coolant mass flow requirements by 12%. Optimisation work carried out by Cenaero led to a drastic increase in heat transfer coefficient both on the static MTU configuration and on the rotating Snecma geometry, while controlling the head loss. Cenaero formulated several guidelines to run such optimisations and provides the partners with optimisation methodologies and major trends observed on the different configurations.

Optimisations running at CFS and Numeca already show promising trends.

WP2

In Task 2.3 a design optimised model was generated based and delivered. For Avio's optimized geometry, configuration changes in fins and holes geometry and relative position were chosen. According to experimental results shown on C3 baseline, a shift of the jet holes was proposed. Moreover, to further explore possible optimisation, a shift in fin location was experimentally investigated.

For ALSTOM's optimized geometry the configuration changes in impingement hole position, angle as well as the hole shape, according to experimental and numerical results from task 2.2 and WP5 CFD investigations.

All experiments on optimized geometries were done successfully.

RHR test campaign in task 2.4 continued. Due to consistency checks unplanned 80rpm rotational runs were implemented to validate the benchtop test (with 0rpm) at the beginning of the measurement test campaign. The post processing of the results is on-going. In addition the first set of RHR tests (80-1550 rpm) 4-6 out of 17 runs were done. The post processing of these results is also still on-going

WP3

During reporting period 3, the work on WP3 has concentrated on tasks 3.2, 3.3, 3.4 and 3.5.

Task 3.2 was concerned with the tests on static geometries typical of current and future engines at UOXF. As noted in the report for PR2, the outcome was key in understanding the impact on the flow of the features of the channels.

The work assigned to task 3.2 during PR3 consisted in the development of the iterative technique to obtain detailed distributions of heat transfer coefficient over the ribs. It was not formally part of Task 3.2 but was a very useful outcome of the work undertaken using the results of Task 3.2.

Task 3.3 comprised the work, at IMP PAN, on static geometries typical of current and future engines as well. This task complemented the work in Task 3.2 by making detailed measurement of hydrodynamic parameters. Heat transfer measurements, directly comparable to those obtained at UOXF were obtained and provided a good challenge to the measurement technique. Task 3.3 also incorporated the test work on an 'optimised' geometry to be carried out at IMP PAN as well. The new geometry was agreed between IMP PAN and RR at the end of M35 and design work commenced immediately.

Task 3.4 comprised the work on 'optimised' static geometries at UOXF. The geometries and conditions for test were agreed between UOXF and RRUK by M33. The tests were completed and a final report was being prepared at the time of writing.

Task 3.5 comprised the work, at RRUK, on rotating radial cooling geometries, typical of current and future engines. The campaign of rotating heat transfer tests was completed with the exception of a very high speed test that had always been envisaged as desirable but not essential. The results are being processed with a view to releasing them during the early part of PR4.

WP4

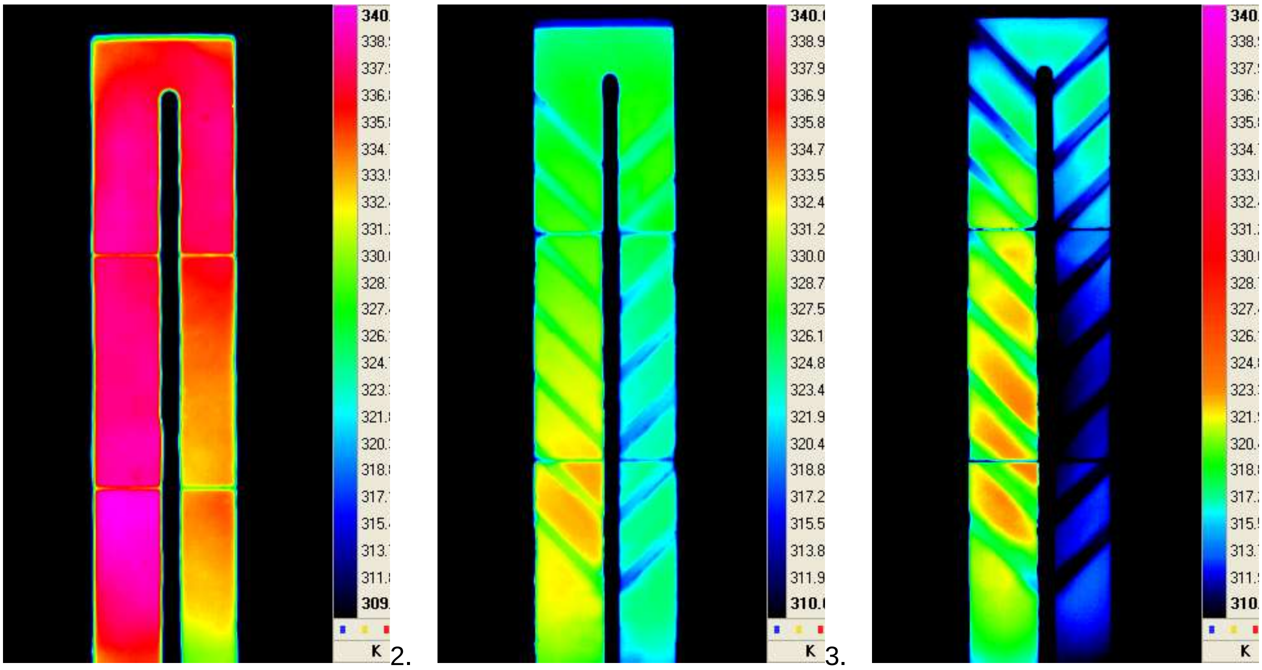
Task 4.1 :

The objective of the Task 4.1 is to generate an experimental database for the high pressure turbine geometry defined by Snecma. Tests are performed by ONERA using the BATHIRE facility.

Three configurations were tested on the BATHIRE rig (smooth channels, ribs only in the channels and ribs in the channels and bend). Only one wall is heated and ribbed to allow for optical access. For each configuration, three Reynolds numbers (15000; 25000; 35000) based on the inlet channel passage were tested. The impacts of heating power value and rotation number were also investigated.

Infrared thermography measurements were performed in static and rotating conditions to obtain the temperature maps on the heated wall for all the tests conditions.

The following figures shows temperature maps measured in static condition for each configuration.



1. 2. 3.

4. No ribs
5. Ribs in the channels
6. Ribs in the channels and the bend

Fig. 1: Re = 25000 ; P = 200 W ; Static

Lastly, the experimental results were post processed to obtain heat transfer coefficients repartition on the heated wall.

The following figures shows Nu/Nu_0 distribution maps in static condition for each configuration.

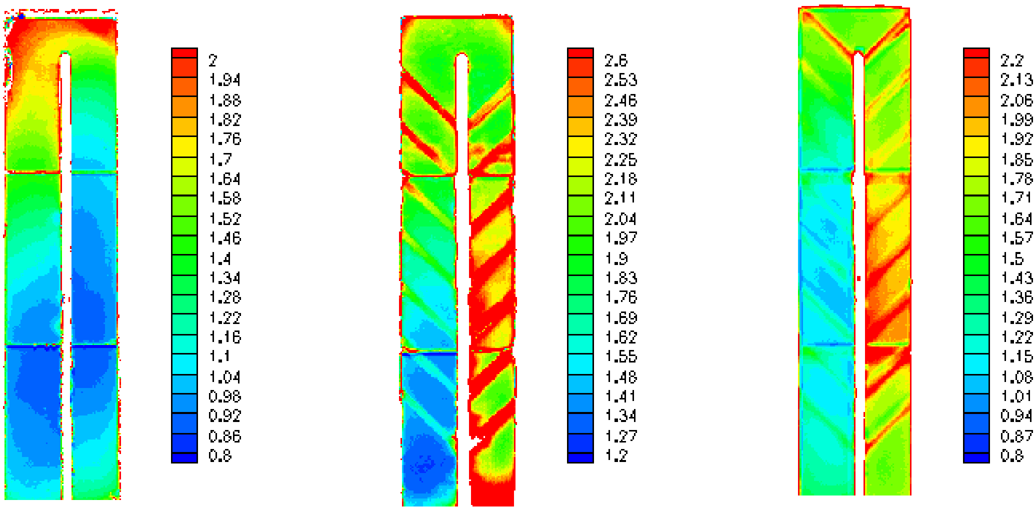


Fig. 2: Nu/Nu_0 *for Re = 35000 ; Static cases*

Task 4.2 :

The objective of the Task 4.2 is to generate an experimental database for the low pressure turbine geometry defined by MTU. Tests are performed by ONERA using the BATHIRE facility.

One configuration was tested on the BATHIRE rig. Only one wall is heated and ribbed to allow for optical access. Two values of the heating power were applied. Four Reynolds numbers based on the inlet channel passage were tested. The impact of rotation number was also investigated.

Infrared thermography measurements were performed in static and rotating conditions to obtain the temperature maps on the heated wall for all the tests conditions.

Task 4.3 :

The objective of this task is to obtain experimentally high quality local heat transfer information for engine representative turbine blade internal cooling configurations using optical measurement techniques. These data are supporting the validation of CFD-methods to be used for optimization processes. Thereby, the experimental results are analysed and evaluated in close integration between experiment and numerical simulation.

The tests campaign of the starting geometry was conducted by USTU during the period two of the project. Then, the first optimised geometry was defined by MTU. Compared to the starting geometry, the rib configuration (rib angle, rib shape) was altered. The passage cross section was unchanged.

Fig. 3 shows the installation of the Perspex model on the test rig.

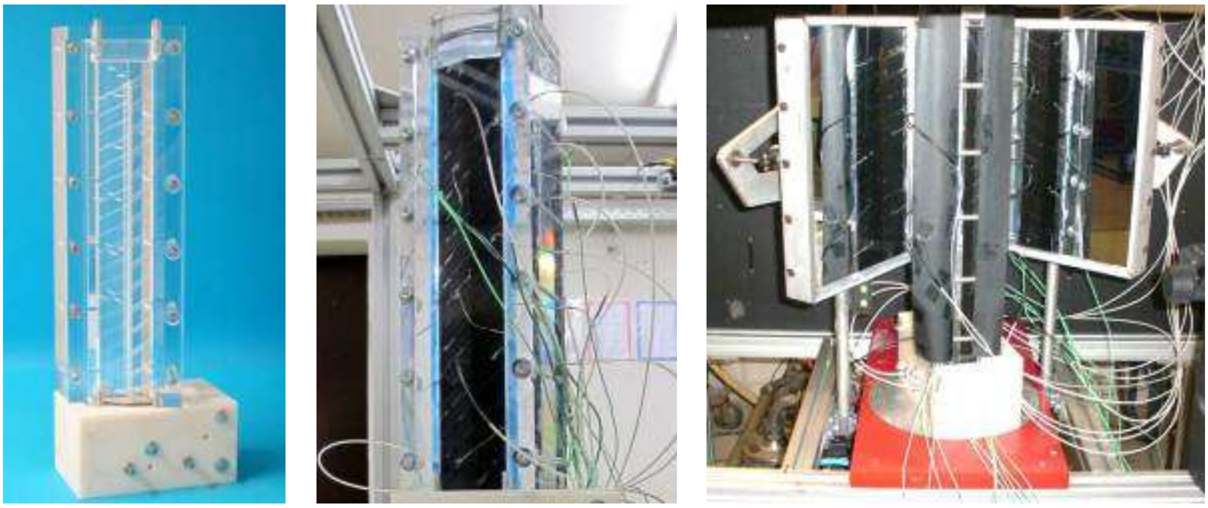


Fig. 3: Assembled Perspex model on base block (left), TLC coated and instrumented model (middle), installed model on test rig (right)

Several improvements to the test rig were implemented. A new bypass valve unit close to the model allows preheating of the air supply passages. This way, steeper fluid temperature gradients for a better approximation of an ideal fluid temperature step change is achieved. The unit also contains a flow straightener directly upstream of the model base block. A new base block was designed with an improved inlet geometry compared to the base block used for the starting geometry.

The base block of the starting geometry has an inlet passage with an expanding cross-section (see Fig. 4). Numerical investigations by MTU showed that this caused a deflection of the flow towards the leading edge resulting in inhomogeneous temperature profiles in passage 1 of the model. The inlet passage of the new base block – version 2 has a constant cross-section and is a direct extension of the trapezoidal cross-section of pass 1 of the Perspex model.

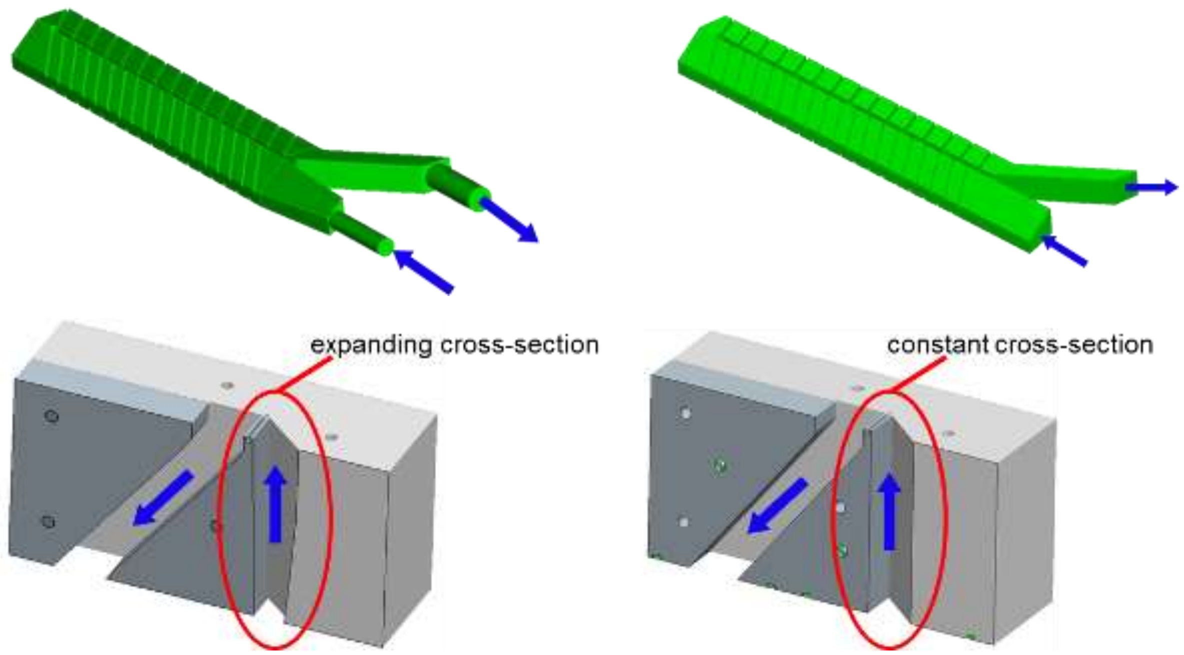


Fig. 4: Base block for starting geometry (left) and first optimised geometry (right)

USTU tested the first optimised geometry using the transient Thermochromic-Liquid-Crystal (TLC)-technique for five Reynolds numbers between Re=10000 and Re=40000. The results were obtained according to the evaluation processes and data reduction methods used for the starting geometry. USTU used the normalized Nusselt number Nu/Nu0 to present the heat transfer enhancement with respect to a smooth channel. Fig. 5 shows the result for Re=20000, where the three heat transfer surfaces: pressure side (top), leading edge (middle) and suction side (bottom) are illustrated in a single contour plot.

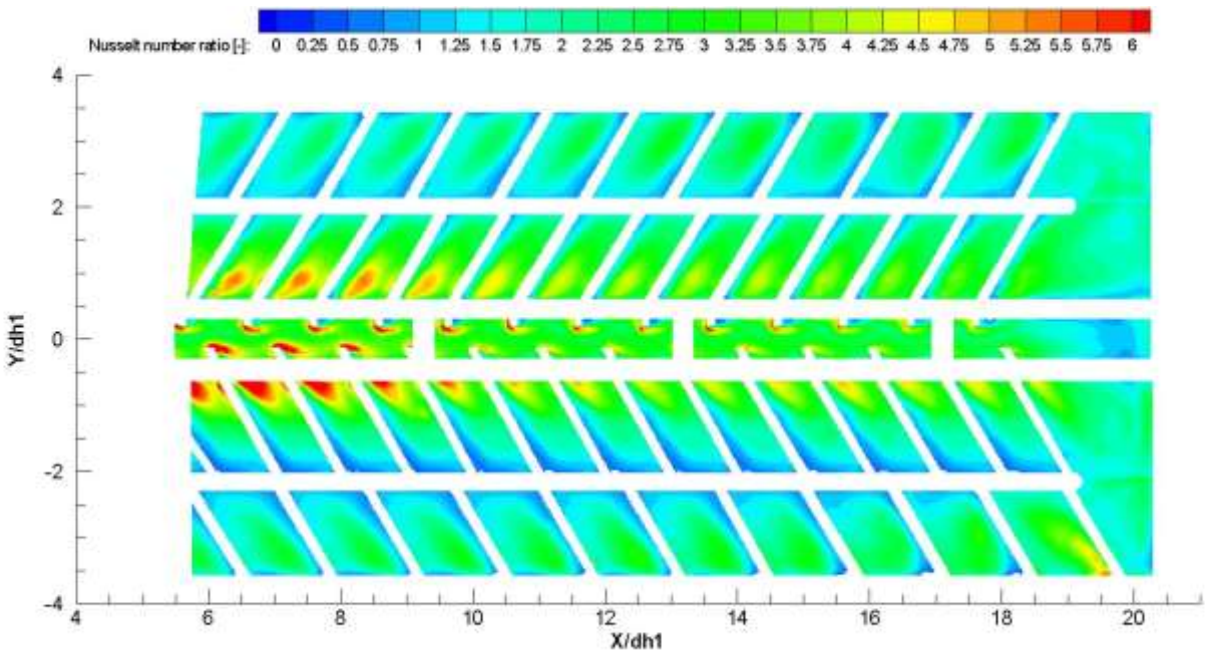


Fig. 5: Heat transfer enhancement (local Nu/Nu0-distribution; Re=20000; Nu0=57.5)

Furthermore, the local data was reduced to segment averaged data by area-averaging rib segments of the pressure side and suction side as shown in Fig. 6. The segments are numbered in flow direction, where negative numbers indicate segments in passage 1 and positive numbers indicate segments in passage 2.

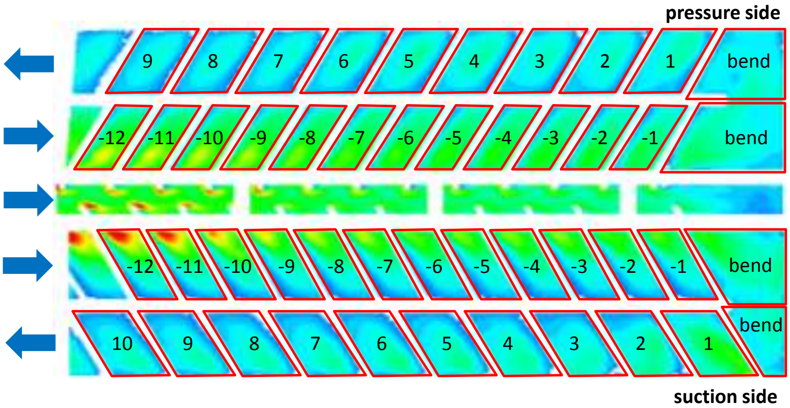


Fig. 6: Segment numeration

The results for Re=20000 are given in Fig. 7. MTU derived the results of their numerical investigations similarly. Thus this representation allows a fast comparison of the experimental (USTU) and numerical (MTU) results.

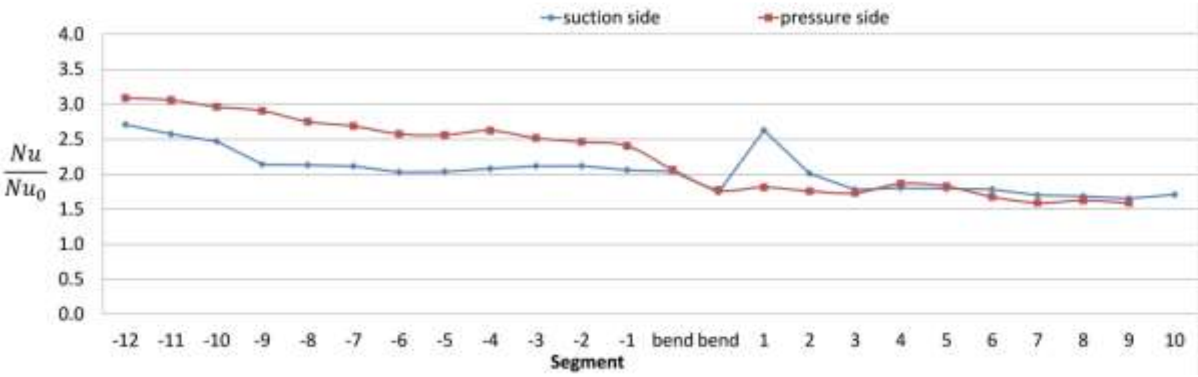


Fig. 7: Segment averaged Nu/Nu0 (Re=20000)

Another form of data reduction is shown in **Error! Reference source not found.** where averaging lines parallel to the ribs are used. The averaged values are then plotted vs. the dimensionless streamwise distance s/dh$_1$.

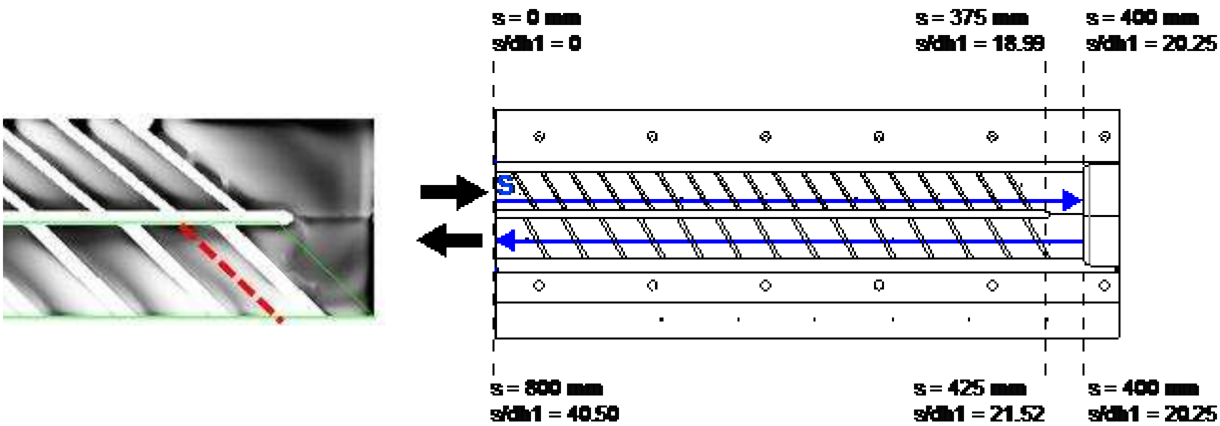


Fig. 8: Line-averaging method, averaging lines parallel to ribs (left), definition of dimensionless streamwise distance (right)

The results for the suction side and pressure side for Re=20000 are given in Fig. 9

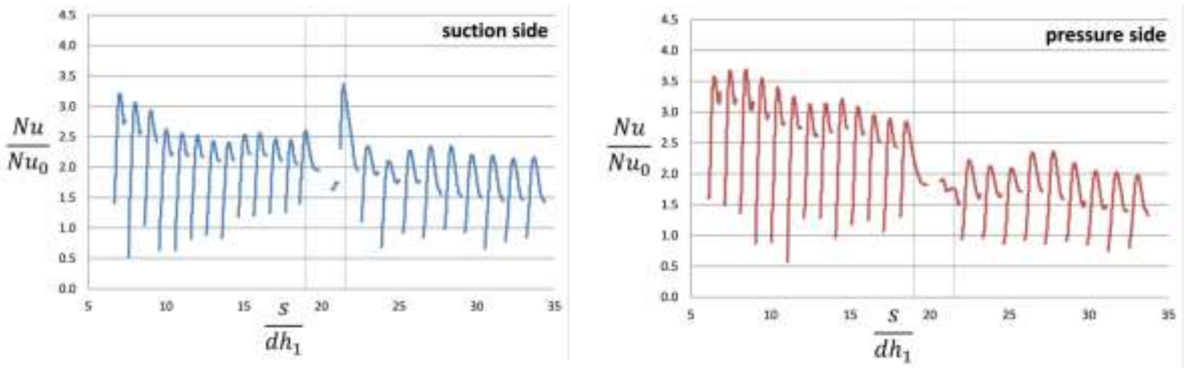


Fig. 9: Line- averaged Nu/Nu0 for Re=20000, suction side (left), pressure side (right)

In this representation the influences of the local rib arrangements on the local heat transfer distribution are apparent.

Based on the experimental results gained so far, MTU performed additional CFD calculations to finalize the second optimized geometry to be tested in the ITLR lab at USTU.

A database of the first optimised geometry has been achieved and provided for download on the ERICKA internal website. The database contains spatially-resolved, area-averaged and line-averaged heat transfer data as well as pressure loss measurements for the five investigated Reynolds numbers.

WP5

As measurements made within experimental workpackages WP2, WP3 and WP4 arrive, computational fluid dynamics studies are performed. One of the objective is the determination of applicable methodologies for industrial processes during conception phase. Besides, complementary informations on the performances of the tested cooling configurations can be extracted from the computations.

Recently, numerical studies on ribbed passages have proved the relevance on actual CFD codes for non rotating configurations. For example, results obtained by UOxF, MTU and NUMECA on the leading and traileing edges wrap rib passages tested at UOxF demonstrated the ability of classic RANS two-equations models to simulate heat transfers in such configurations with a reasonable level of accuracy. Likewise, complex static configurations of trailing edges impingement cooling systems such as those tested at UNIFI have been successfully simulated by ALSTOM with standard RANS modelisations. Further studies are in progress to explore effect of rotation on the numerical predictions.

Expected Final Results and Project Impact

The main outcome of the ERICKA project will be the reduction of CO2 emissions by 1% compared to year 2000 reference engines. This will be achieved by a combination of the improved use of cooling in the turbine and the enabled uplift in the turbine entry temperature. Blade cooling technology will be advanced through the following objectives:

- The new heat transfer data and computer modelling strategies will enable turbines to be designed to cope with low NOx combustors.
- The improved modelling and computer methods will reduce the time required to design the turbine by 20%. This will reduce engine time to market and engine cost significantly.
- In more detail, the main results from ERICKA will be:
- Acquisition of engine representative Rotating HtC data.

- Development of optimising software for internal cooling
- Creation of a database of detailed HTC data from a broad range of stationary internal cooing geometries.
- Development of CFD strategies used by the partners to predict internal flows.
- Experimental evaluation of optimiser codes
- Development of cooling system design methods suitable for future low emission and green fuel combustors.
- Enhance competitiveness of the EU aero-engine industries

ERICKA will deliver an impact on the environment through the reduction of emissions. Combustion emissions such as CO2 and Nox are deleterious to the local and global environment and need to be reduced. CO2 reduction will be achieved by using a combustor running hotter than the existing one and by reducing the required amount of cooling air. The technologies to be generated in ERICKA will be key enablers of low Nox combustion though the reduction of the amount of cooling used in the turbine, enabling more compressor air to be used in the burner stage of the combustor which has the effect of reducing peak temperatures and hence Nox emissions.

An additional impact of ERICKA will come from the work done on CFD codes and CFD analysis which should reduce aircraft development costs by 50%, create a competitive supply chain able to halve time to market and reduce travel charges.