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Numerical Aero-Thermal Investigation of Transonic Turbine NGV and Film Cooling Studies - IANC 2023

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Introduction

- This investigation numerically studies the aero-thermal aspects of fluid flow through a nozzle guide vane inside of a high pressure turbine. Experimental data is available for the chosen blade LS-89 designed at VKI for an exit Mach number of 0.9 and an exit Re of approximately 1e+06.
- The methodology was validated with the available experimental data and aero-thermal investigations were carried out hence forth. Film cooling cases have been validated using the available experimental data as well.

Scope of the Project

- Validation of Numerical Data with the available experimental data.
- Aero-Thermal studies of flow through the NGV cascade.
- Establish methodology for future studies.

Methodology

Fig.1. An image of the workflow of the methodology followed

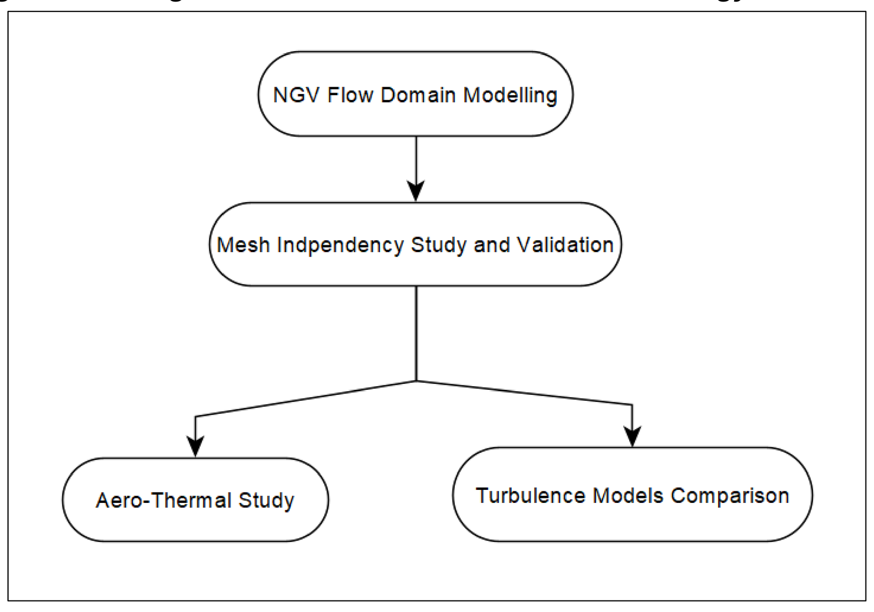


Fig.2. The VKI test case NGV blade geometry

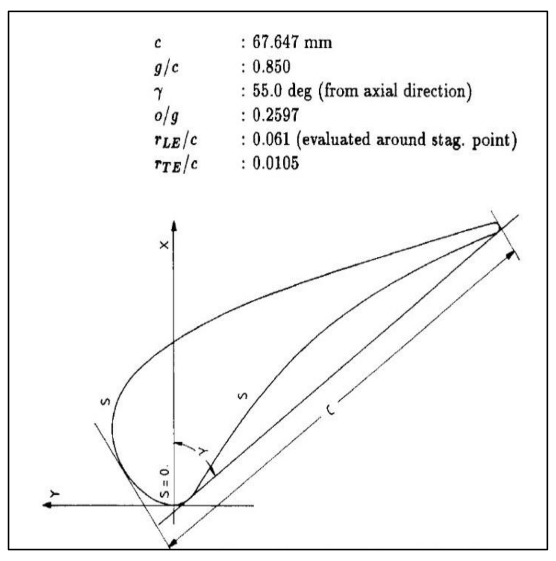


Fig.3. The 2-D computational domain

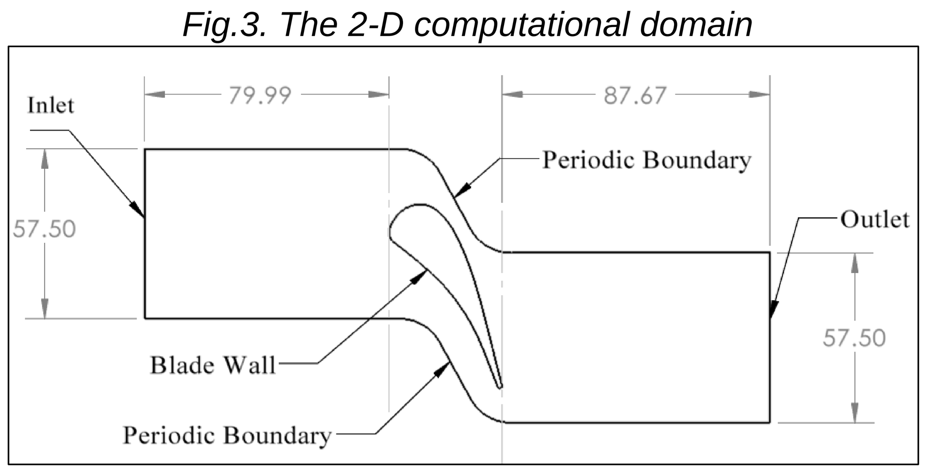


Fig.4. The 2D structured computational grid for the non-cooled case

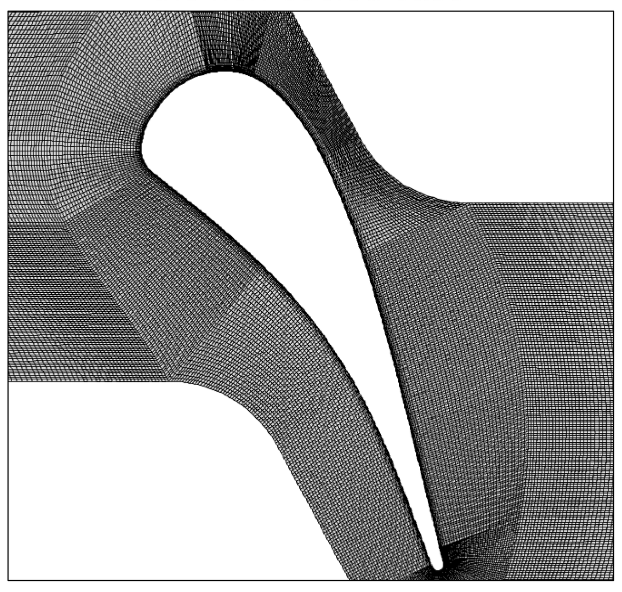


Table. 1. A list of experiments for the validation of the numerical methodology and Aero-Thermal studies

Test Case	Test Type	Exit Re	Exit Mach	Inlet Turbulence Intensity
1	Blade Heat Transfer Coefficient Distribution	5e+05	0.92	1%
2	Blade Mach Number Distribution	1e+06	0.875	1%
3	Blade Mach Number Distribution	1e+06	1.02	1%
4	Film Cooling, Blowing Ratio (BR) 0.45 Suction Side BR 1.5 Pressure Side	1.5e+06	0.8	4.5%

Fig. 5. 3-D computational domain for the film cooling case (No Plume shown)

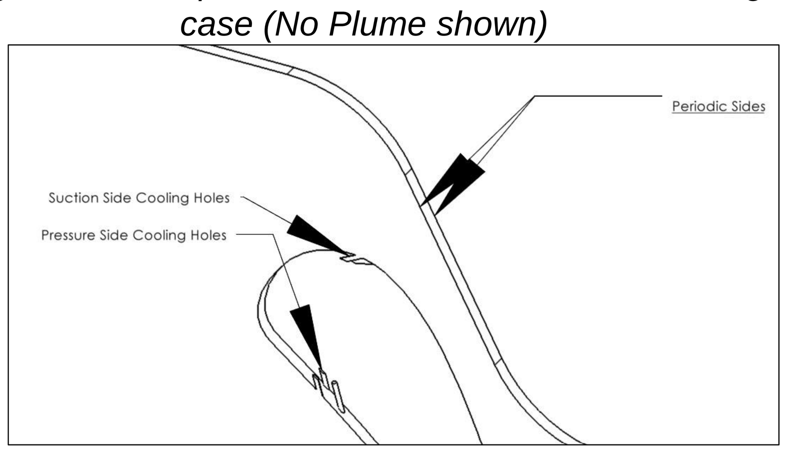


Fig. 6. Film cooling 3-D computational domain without periodicity and plume

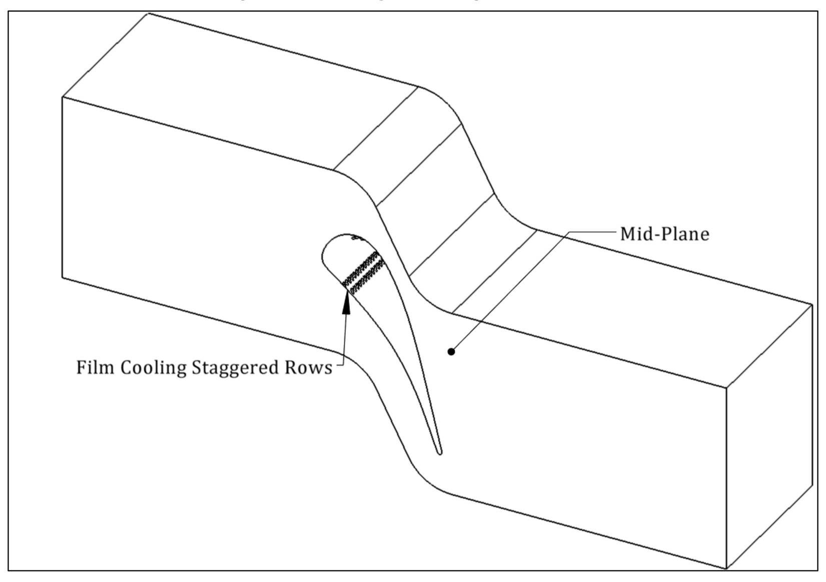
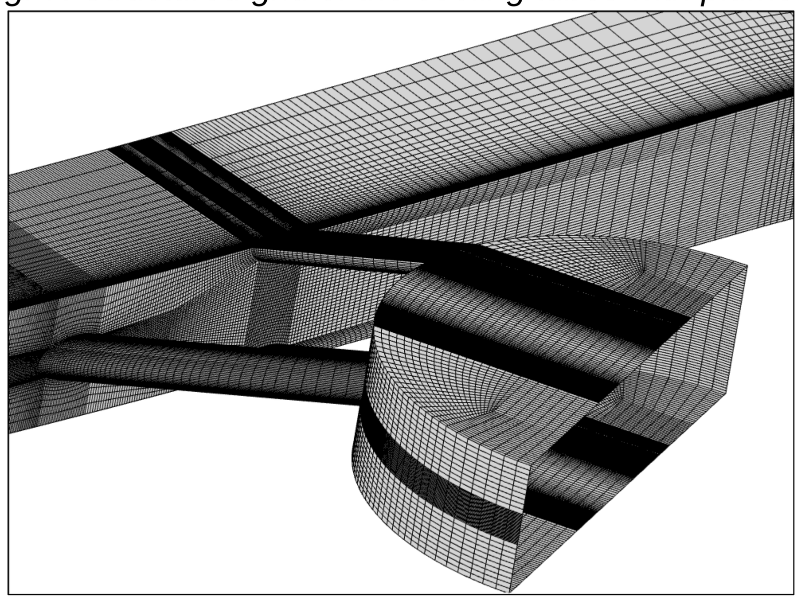


Fig. 7. Structured grid of the cooling tubes with plume



The downstream loss coefficient is given below in **equation 1**.

$$n = 1 - \frac{V_2^{\,2}}{V_{2,is}^{\,2}} \ldots(1)$$

Where V is the velocity,
subscript "2" means exit condition measured in a plane 16mm aft the trailing edge plane, and
subscript "is" means isentropic flow variable.

Results

Fig. 8. Mesh independency and validation study for the Suction Side test case 1

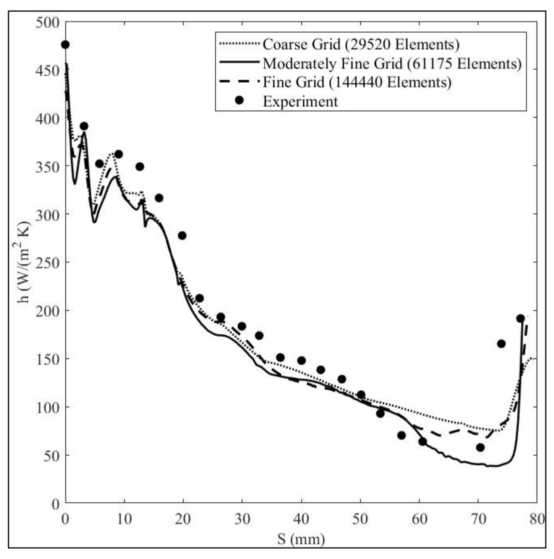
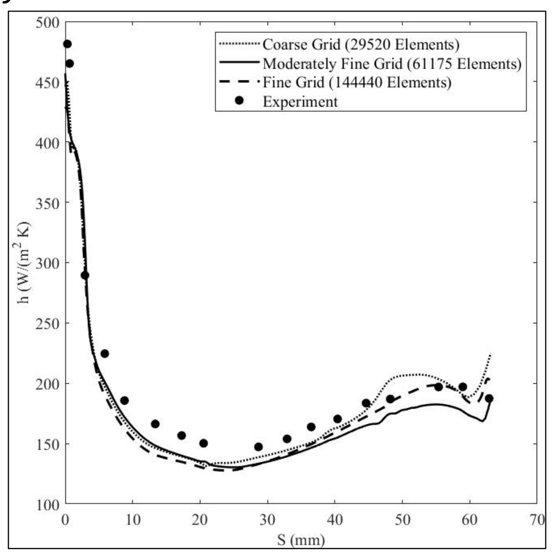


Fig. 9. Mesh independency and validation study for the Pressure Side test case 1



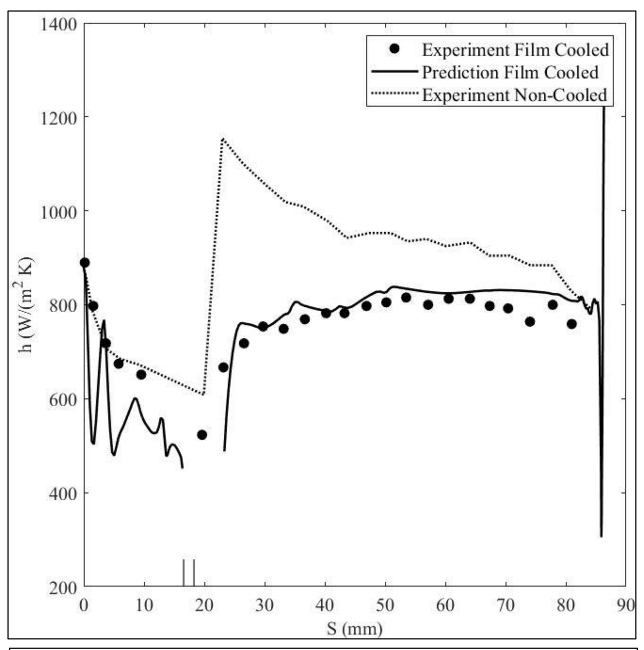


Fig. 10. Comparison of the RANS Trans-SST model prediction with the experimental film cooling data on suction side. The lines on the x-axis represent the cooling hole location

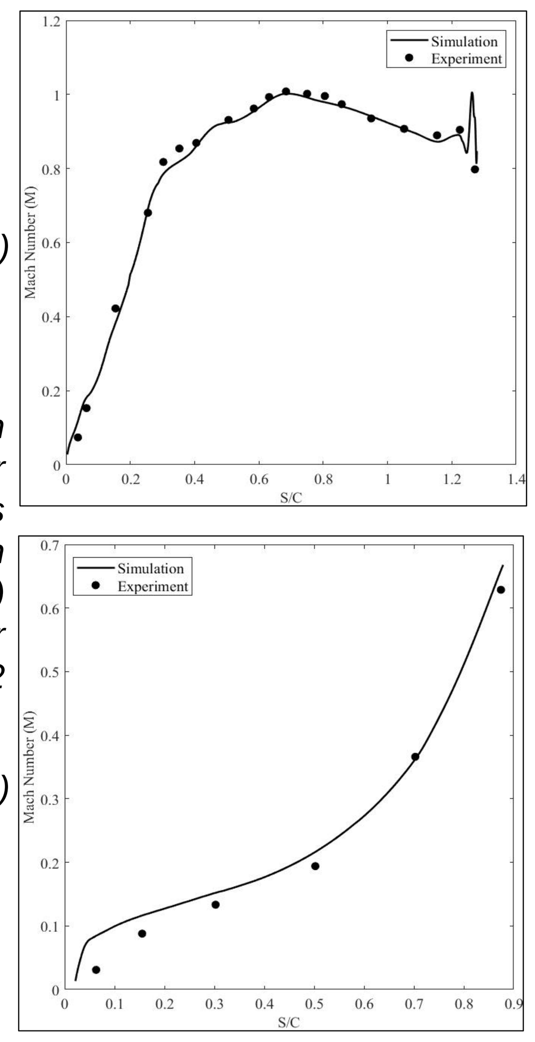


Fig. 11. Mach number distributions along (a) suction side and (b) pressure side for the test case 2

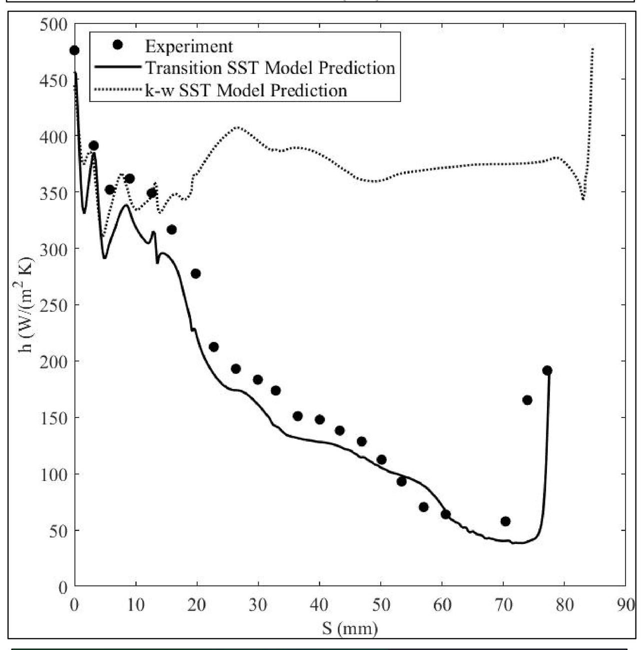


Fig. 12. Comparison of the k-w SST model prediction with the Transition SST model prediction and experimental data

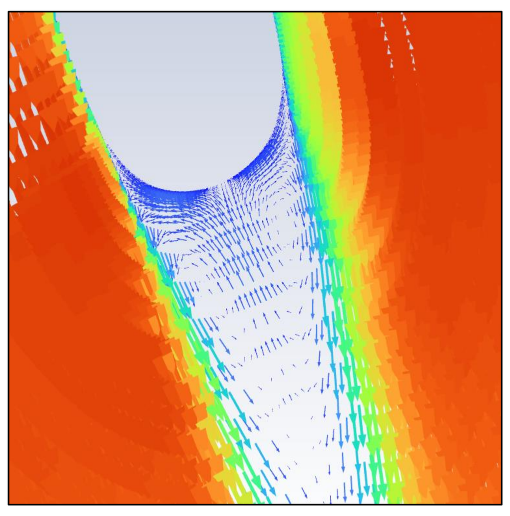


Fig. 13. A velocity magnitude vector plot of the wake region behind the trailing edge

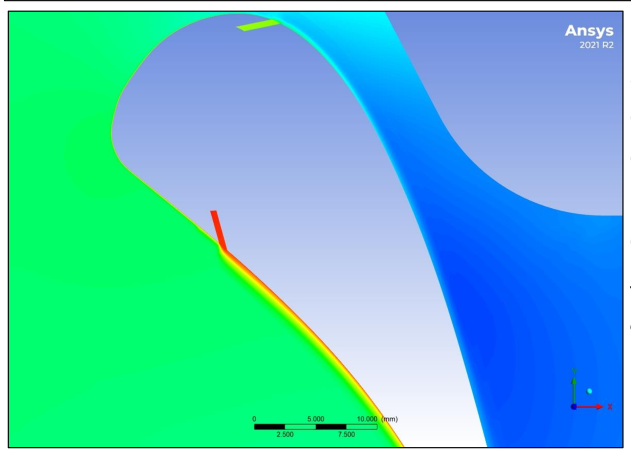


Fig. 14. The density contours for the film cooling case study plotted at mid-plane

Fig. 15. Heat Flux Contours for suction side film cooling

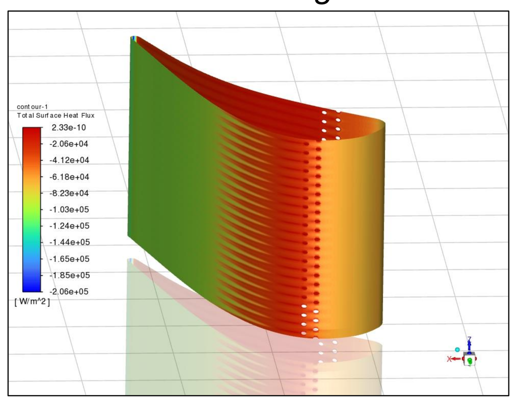
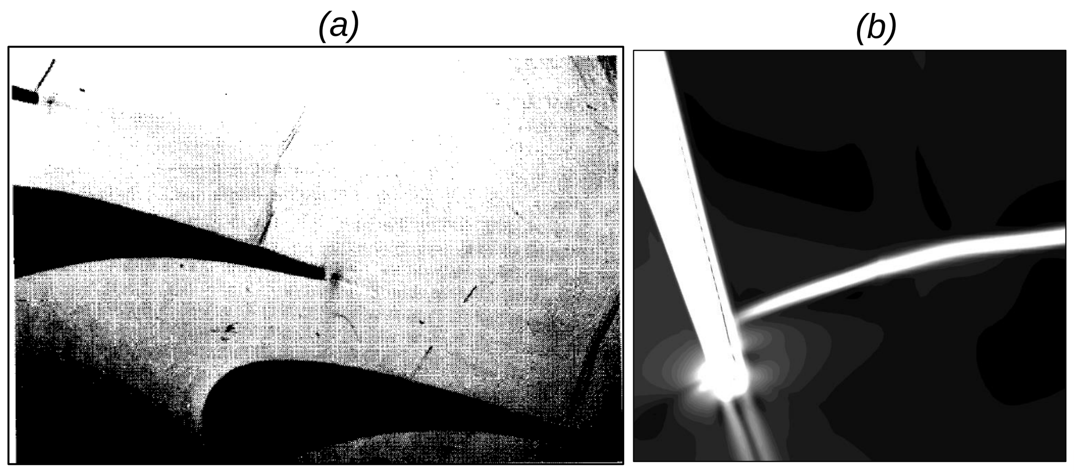


Fig. 16. Schlieren flow visual obtained experimentally (a) and the density gradient based shadowgraph for the test case 3 (b)

(a) (b)



Conclusion

The methodology followed lead to an excellent match with the experimental data. A comparison between the k-w SST and Transition SST model revealed the difference in the results created when predicting transitional boundary layer flows numerically. **The Transition SST model was hence found to predict transitional flows and the non-cooled and film cooled heat transfer distributions along the blade surface very well** in the given transonic NGV. The blade **exit angle** for the heat transfer case was found to be **72 degrees**. **The blade loss coefficient "n" based on equation 1 was found to be 0.2** . With film cooling, the heat transfer reduction can clearly be seen in Fig. 10.

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References: Arts et al. Aero-Thermal Performance of a 2D Transonic NGV.
Fontaneto et al. Aero-thermal performance of a film cooled HPT vane.