Effusion Cooling Design for Jet Engine Blade

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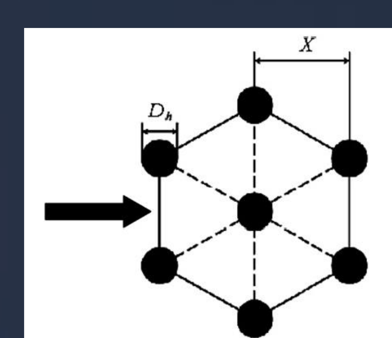
MOTIVATION

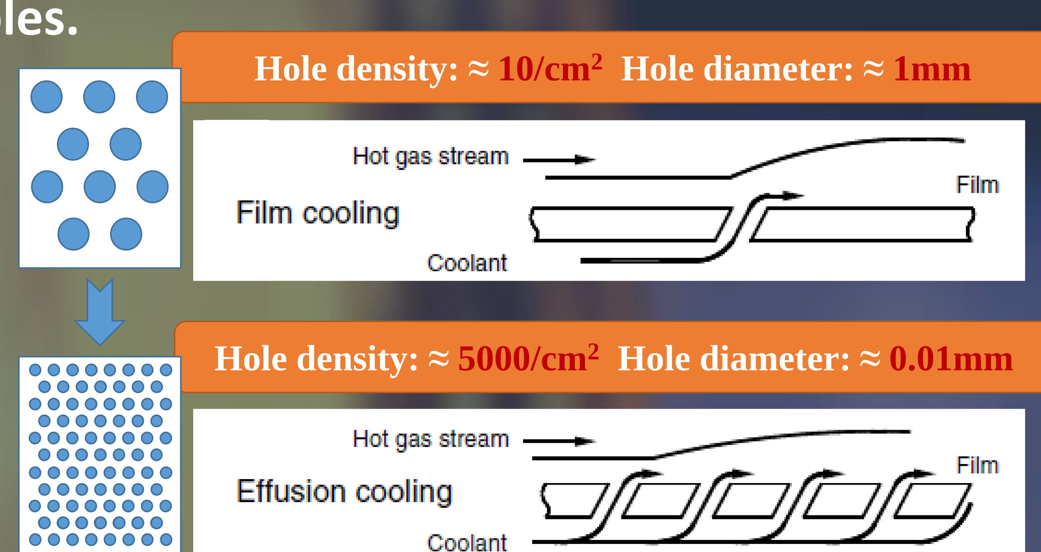
Increasing turbine inlet temperature (TIT) is desirable for achieving higher jet engine efficiency, and thus reducing specific fuel consumption and increasing thrust-to-weight ratio. However, TIT is restricted by blades' melting temperature. Current study develops blade effusion cooling system using optimization tool. Design is then validated via aero-thermal study in linear cascade facility.

BACKGROUND - EFFUSION

- Full coverage micro holes array is a method for mimicking porous medium and is potentially much more effective than film cooling.
- These days, drilling capabilities are constantly improving and allow to manufacture large amount of extremely small cylindrical holes.
- This large number of holes generates thin convective wall protection over whole blade, and reduces separation and pressure losses, when compared to conventional film cooling.

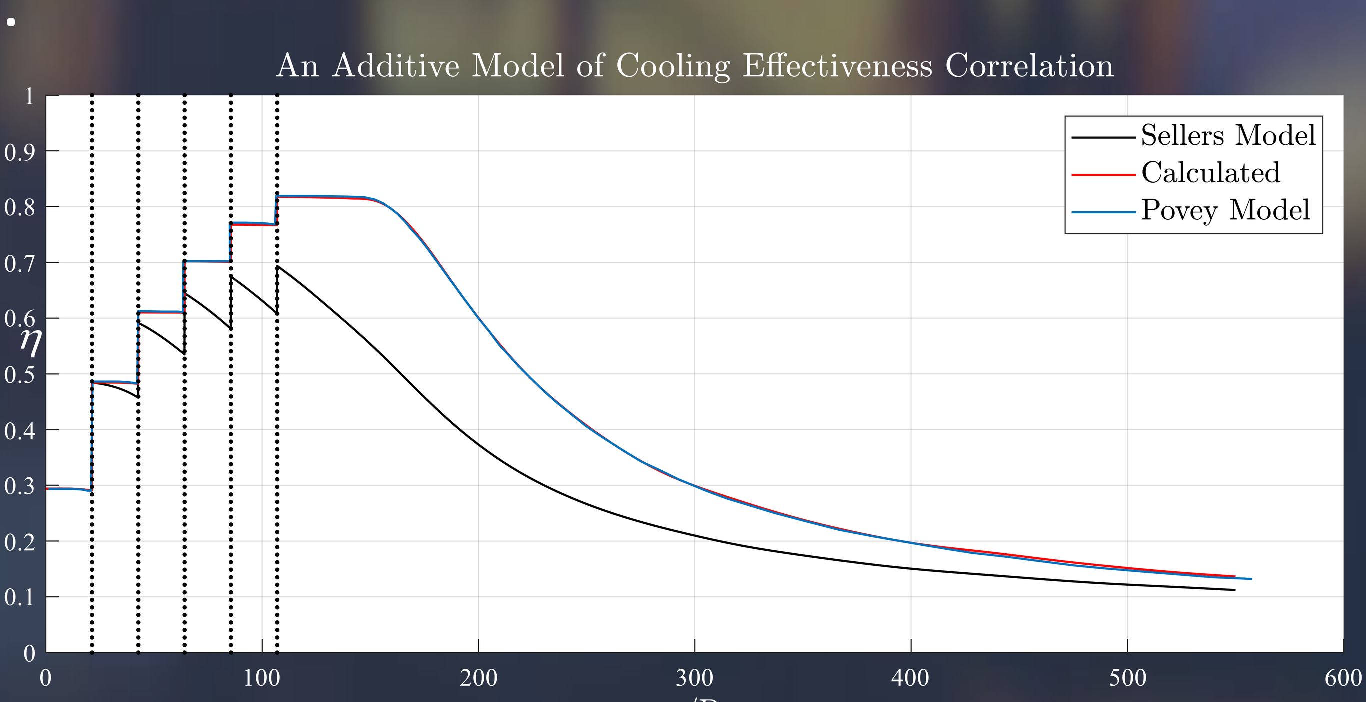


Hexagonal hole distribution

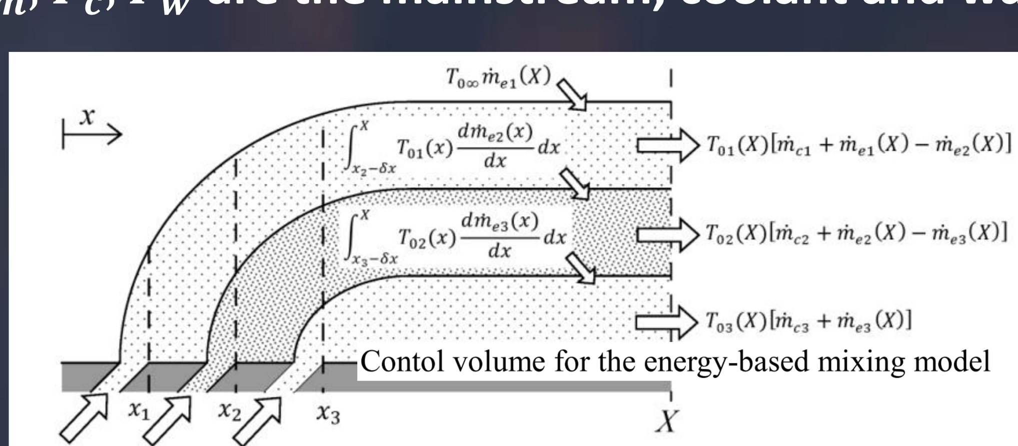


3D – NUMERICAL SOLVER

Solver includes reduced models of external flow, through-holes and internal flows. External flow solver is based on cooling effectiveness correlation and on energy-based method for predicting additive effect of multiple film cooling rows [1].



Higher and uniform cooling effectiveness ($\eta = \frac{T_m - T_w}{T_m - T_c}$) is desirable. T_m, T_c, T_w are the mainstream, coolant and wall temperatures respectively.



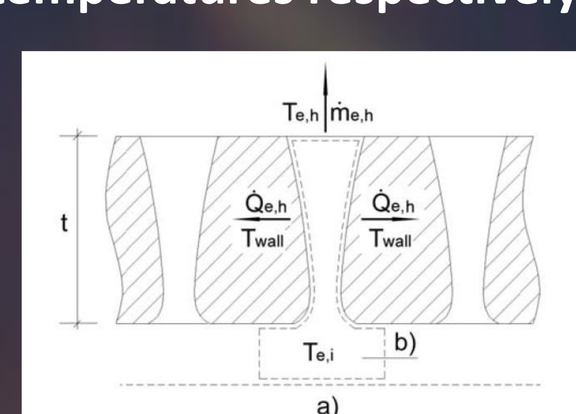
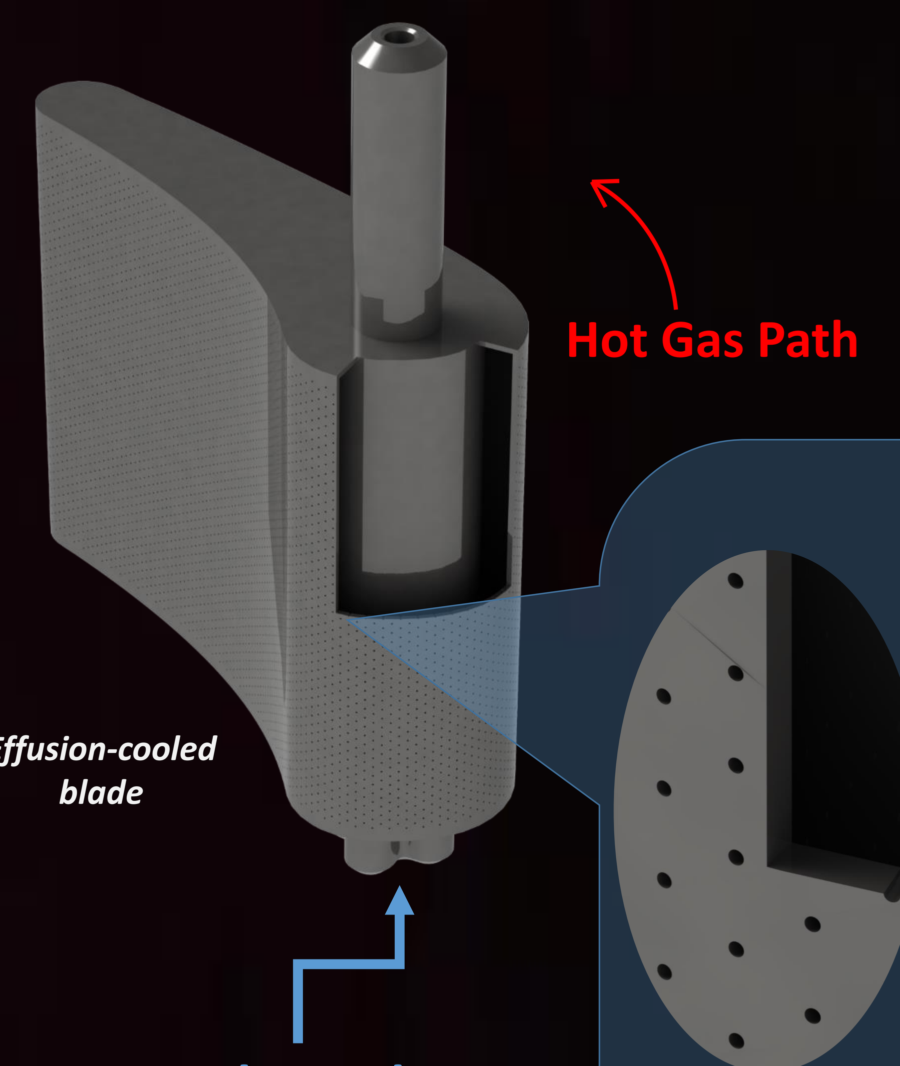


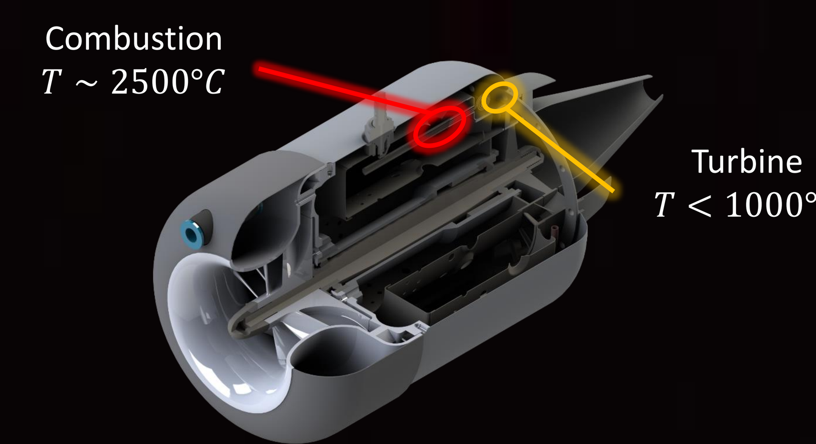
Fig. 5: Control volume relative to the single hole – b)

Internal flow solver is based on mass, momentum and energy conservation. Through hole flow analysis takes into account hole discharge coefficient.



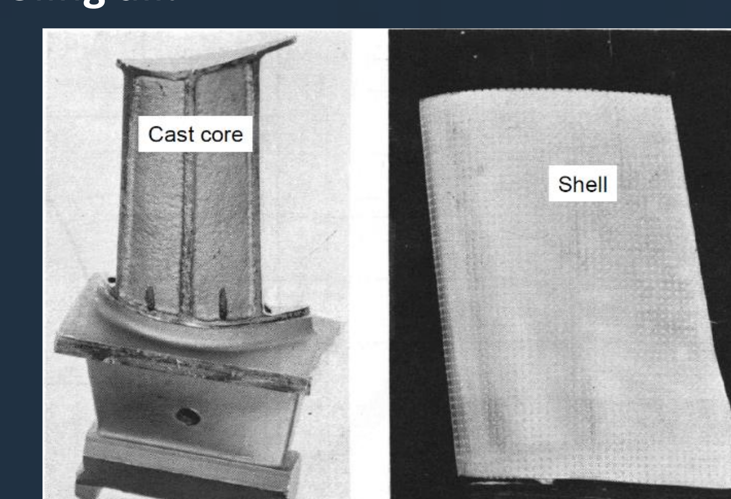
Effusion-cooled blade

Shell with effusion holes



Blade

Comprised from a core and a shell. Holes are arranged in hexagonal arrays, resulting in best surface coverage by cooling air.



GEOMETRY OPTIMIZATION USING NUMERICAL SOLVER

In order to decrease coolant flow leaving the compressor, the optimization objective is to minimize mass flow rate ($\dot{m}_c$) with respect to:

- hole diameter (D_h)
- hole density distribution $\left(N_h \left[\frac{holes}{m^2}\right]\right)$
- channel width (W)

Constraints are:

- constant wall temperature ($T_w = const$)
- bounded blowing ratio $\left(BR = \frac{\rho_c V_c}{\rho_m V_m} < const\right)$
- bounded hole diameter ($D_{min} < D_h < D_{max}$)

CFD analysis is almost impossible to perform and optimize due to problem complexity.

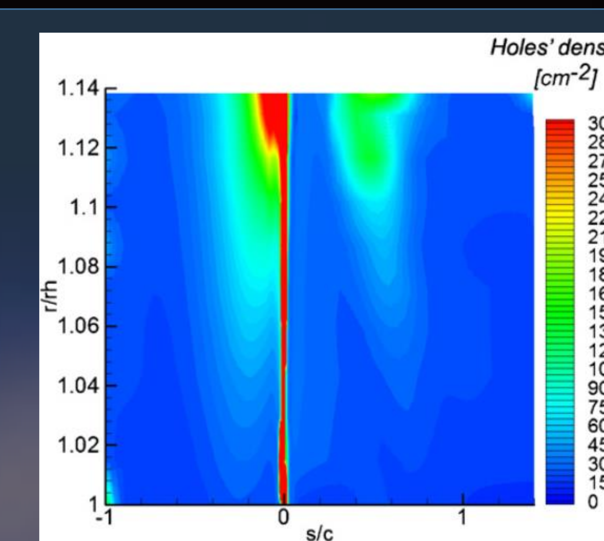


Fig. 5. Surface distribution of hole density.

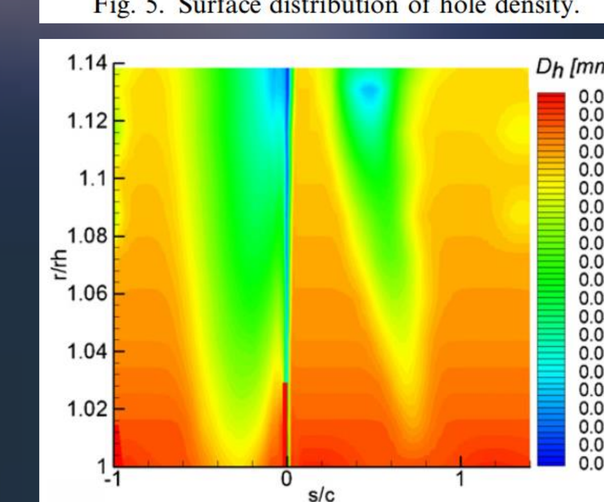


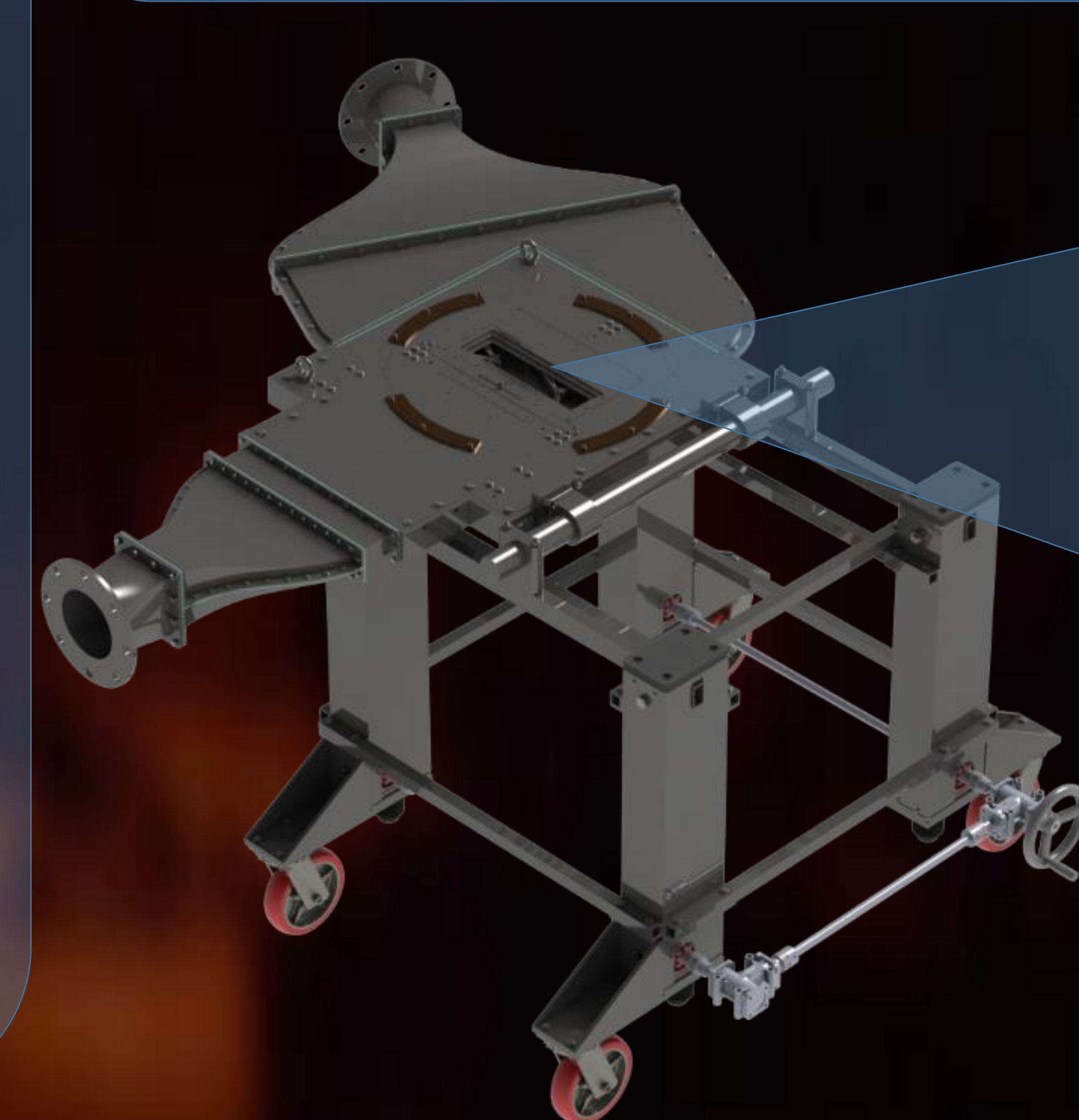
Fig. 4. Surface distribution of hole diameters.

[2] Cerri et al. (2007)

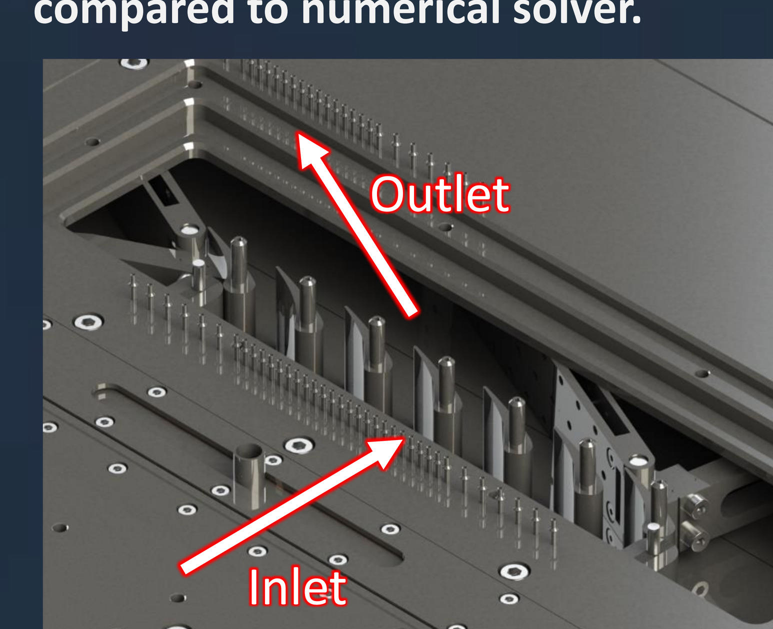
Experimental Setup

Using existing linear cascade testing rig [3], both uncooled and cooled blades will be tested.

Optimization process will be based on uncooled blade experiment results. Cooled blade experiment will be compared to numerical solver.



Linear cascade test bench



Close-up on blades area

CONCLUSIONS

Overall, effusion cooling for nozzle guide vane/turbine is suitable in many applications, and particularly fits micro jet engines where it has significant potential to increase TIT and overall efficiency, while decreasing development cost.

FUTURE WORK

- Assembly and operation in test rig
- Durability and reliability experiments

[1] Kirollos, Benjamin, and Thomas Povey. "An Energy-Based Method for Predicting the Additive Effect of Multiple Film Cooling Rows." Journal of Engineering for Gas Turbines and Power 137.12 (2015): 122607.

[2] Cerri, Giovanni, et al. "Advances in effusive cooling techniques of gas turbines." Applied Thermal Engineering 27.4 (2007): 692-698.

[3] Yakirevich, E., Miezner, R., Leizeronok, B., Cukurel, B., "Continuous Closed-Loop Transonic Linear Cascade for Aero- Thermal Performance Studies in Micro-Turbomachinery", ASME Journal of Engineering for Gas Turbines and Power, Vol. 140, No. 1, 2018.