# Film Cooling Effectiveness of Gas Turbine Blades Using Pressure Sensitive Paint


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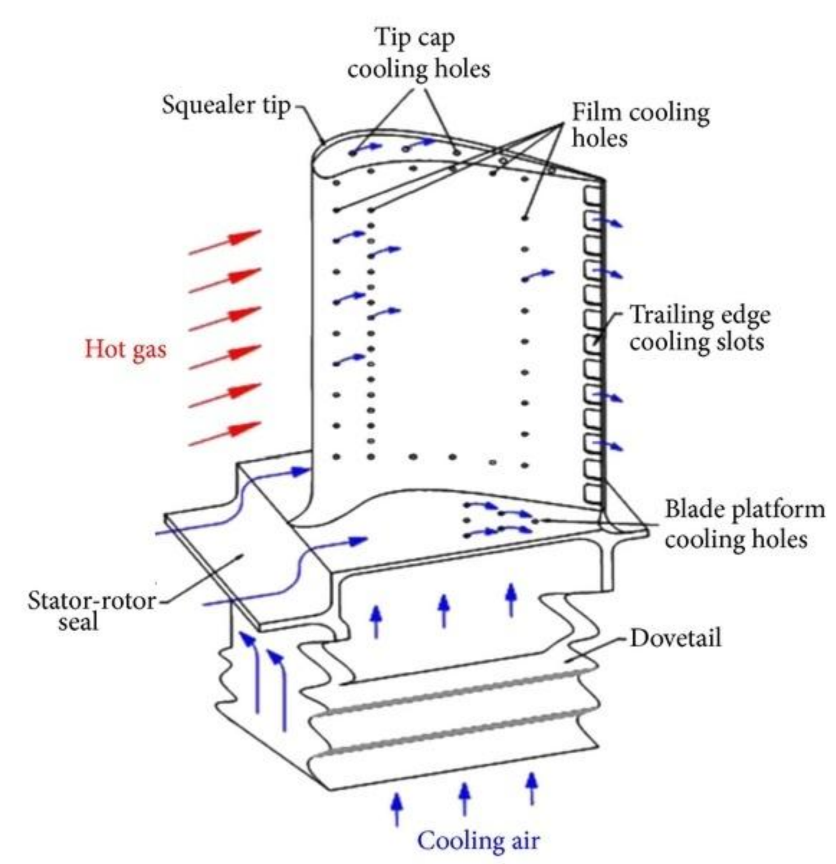
## Motivation

**Gas Turbine engine efficiency and performance**

- Increase through enabling the turbine blades to withstand higher temperatures (Temperatures can exceed 3500°F [1]) using **Film Cooling**.
- Analyze the effectiveness to determine how well the coolant stays attached to the blade.

**Film Cooling**

- Coolant is passed through the turbine blades and ejects out of several strategically placed holes along the blades profile.
- The coolant sticks to the blade, creating a barrier between the high temperature gas and the blade surface.

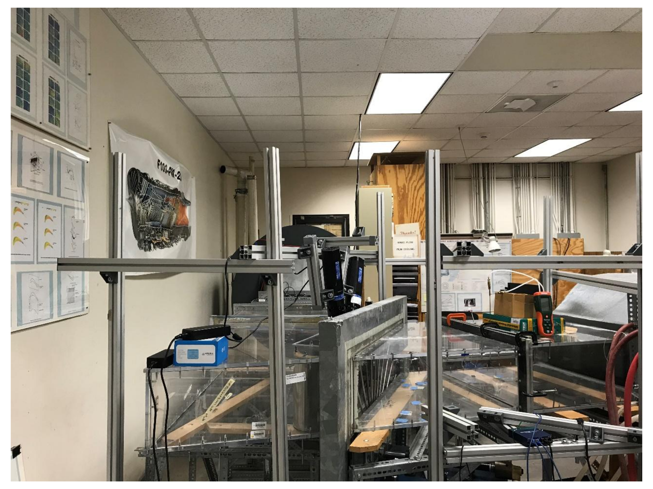



Sample Gas Turbine Blade [1]

## Approach/Methods

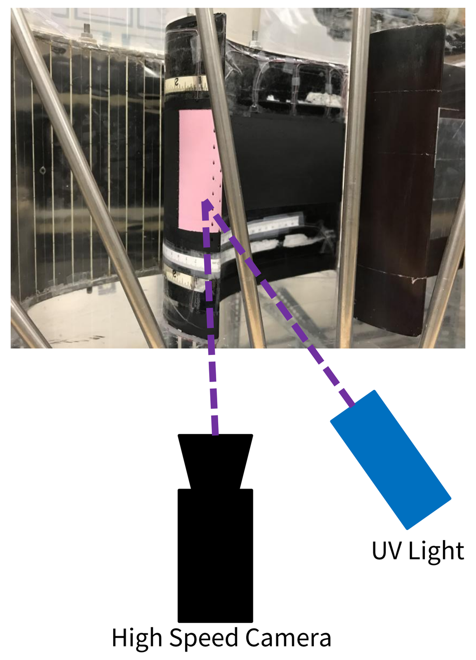
**Verification of Cascade Wind Tunnel functionality**

- Ensured the tunnel could obtain the desired mainstream velocity, measured with a pitot-static tube and digital manometer.
- The wake generator, used to simulate the rotation within the turbine, was verified to reach the desired RPM with a digital tachometer.
- Through several rotameters the desired volumetric flow conditions for the coolant were obtained.



**Data Collection Through Pressure Sensitive Paint (PSP) and High-Speed Camera**

- UV light excites paint causing it to fluoresce.
- The more oxygen present, the dimmer the fluorescence.
  - Using gasses of different densities than air, like Nitrogen, a temperature difference between the coolant and mainstream is simulated.
  - Nitrogen is used as the coolant gas. It is passed through the blade causing the amount of oxygen around the holes to decrease thus causing the PSP to fluoresce.
- Capture 200 images of the blade with a high-speed camera at various conditions (Black, reference, Air and Coolant).

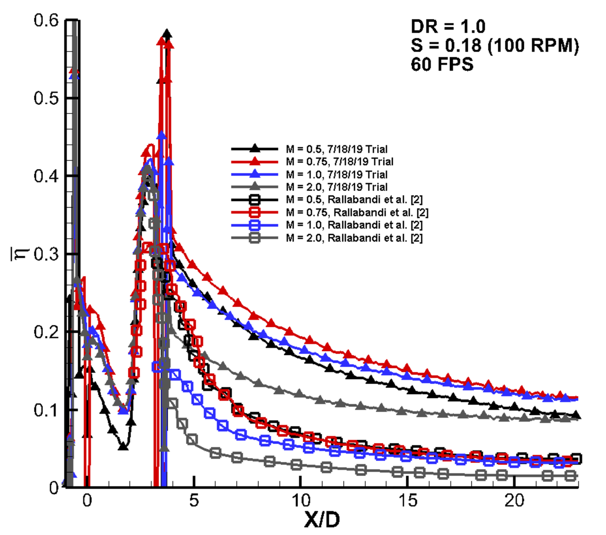



**Analysis of Data Using MATLAB**

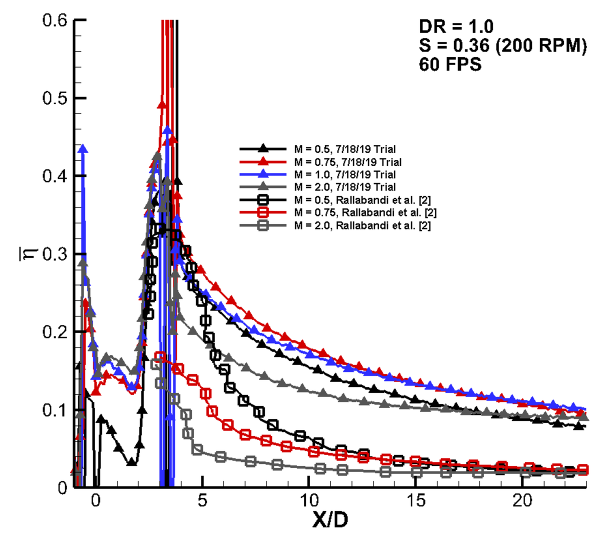
- Process the image sets into average intensity sets across the 200 images.
- Process the intensities into detailed distribution plots and lateral average plots which depict the film cooling effectiveness in the desired region.

## Results

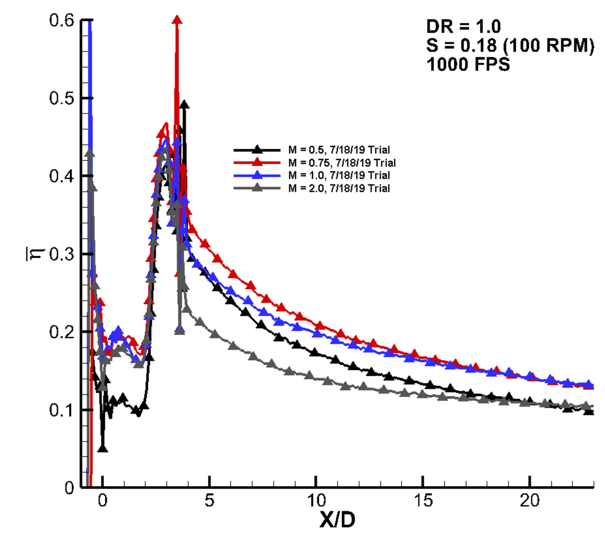
**Lateral Averages** of captured data using Nitrogen, Density Ratio(DR) = 1.0, as coolant.




Lateral Average at 60 FPS and 100 RPM

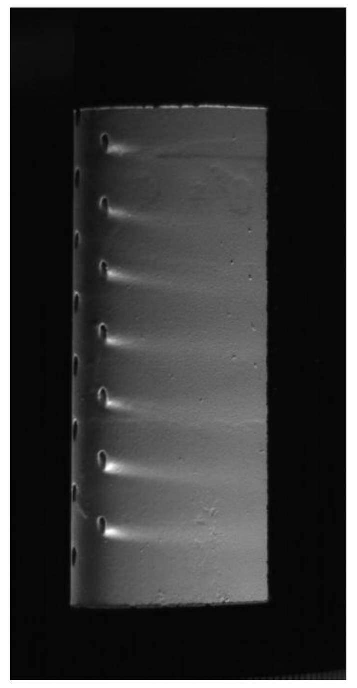



Lateral Average at 60 FPS and 200 RPM

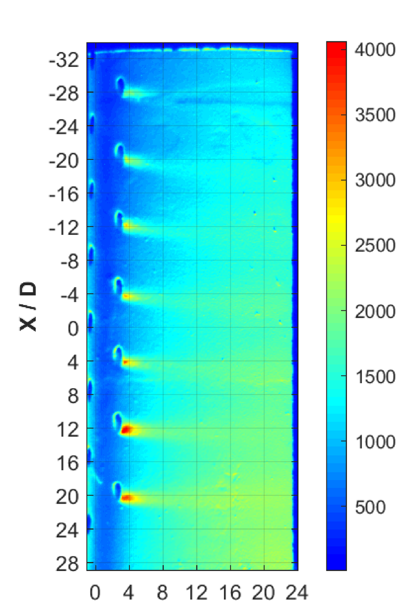



Lateral Average at 1000 FPS and 100 RPM

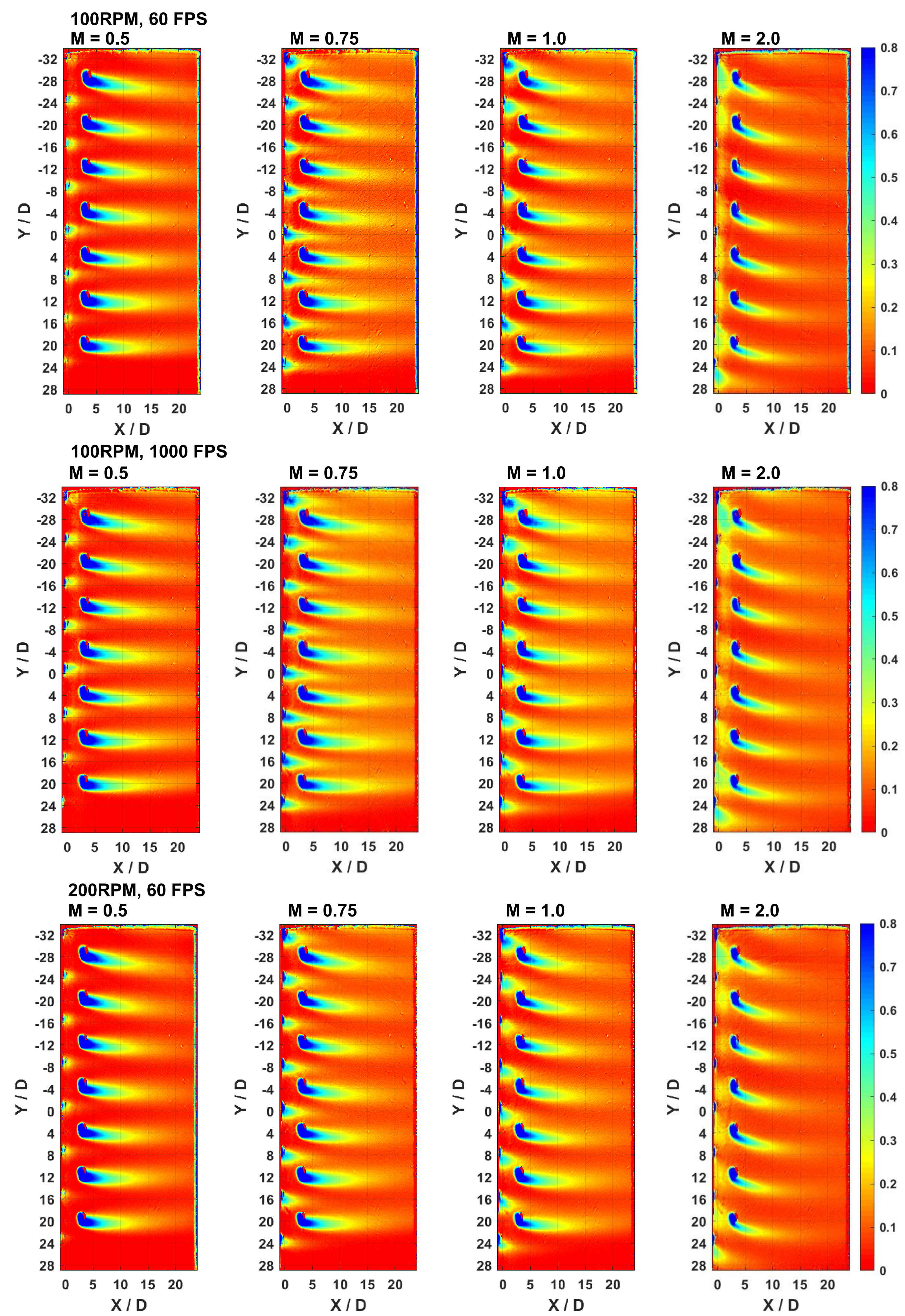
**Detailed Distribution Plots** showing the film cooling effectiveness along the tested surface.

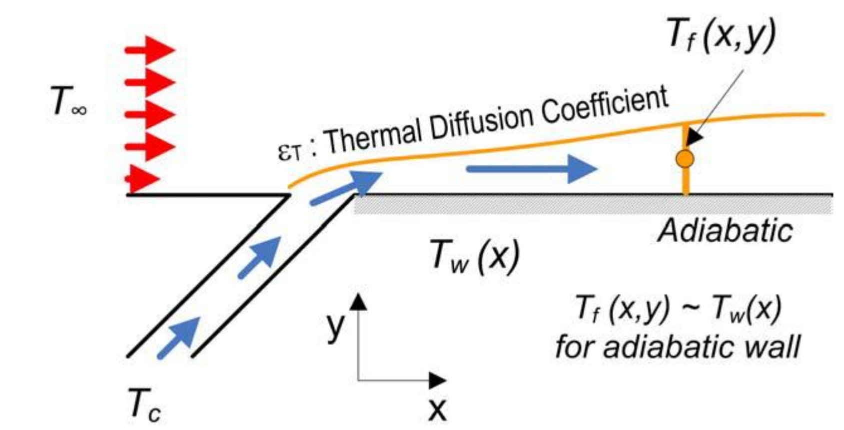


Raw at M = 0.5, 60 FPS, 100 RPM and DR = 1.0




Intensity plot at M = 0.5, 60 FPS, 100 RPM and DR = 1.0




$$\eta = \frac{T_f - T_\infty}{T_C - T_\infty}$$

Desire a Film Temperature that is as close to the temperature of the Coolant to ensure the surface stays intact.

$$\eta = 1 - \frac{1}{\left(\frac{(P_{O_2})_{air}}{(P_{O_2})_{fg}} - 1\right)\frac{W_{fg}}{W_{air}} + 1}$$

Film Cooling Effectiveness Equation

## Conclusion and Future Work

- The wake generator rods were found to skew the data.
  - For each case around 1200 images was captured, of which at least 200 images did not have the rods.
- The data was found to be higher, on average, to that of Rallabandi et al. [2]. However, the data shows similar trends and are within an acceptable range.
  - Looking further into other similar experiments which appear to show trends comparable to the data collected.
- Overall effectiveness remains high in regions immediately surrounding ejection holes and tapers off in the downstream direction.
- There is an optimal blowing ratio to obtain max effectiveness as it decreases with larger blowing ratios.

**Future Work**

- With knowledge that the process functions as expected testing is now ready for a Fast Response PSP and studying a time resolved effectiveness.

## References


[1] J.-C. Han, S. Dutta and S. V. Ekkad, Gas Turbine Heat Transfer and Cooling Technology, New York, NY: Taylor & Francis, 2000.

[2] A. P. Rallabandi, S.-J. Li and J.-C. Han, "Unsteady Wake and Coolant," ASME, p. 10, 2012.


## Acknowledgements


This work is in collaboration with:

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