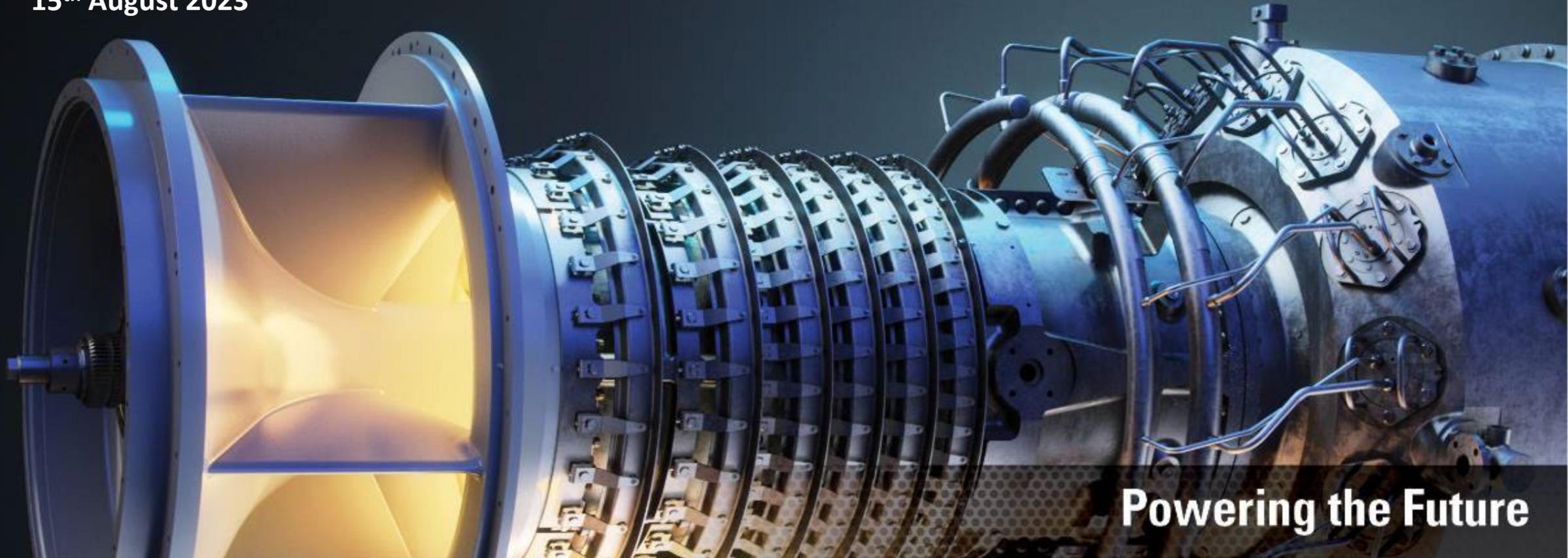


# Internship Exit Presentation

15<sup>th</sup> August 2023

Adil Riahi



Powering the Future

**Solar Turbines**

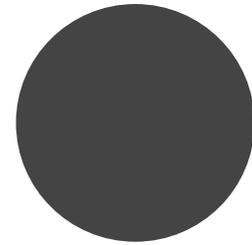
*A Caterpillar Company*

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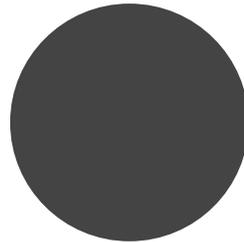
# Agenda



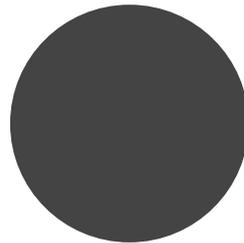
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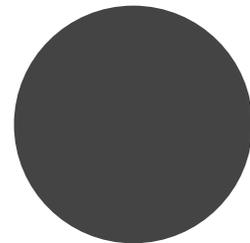
*Background*



*Solar Projects*



*Takeaways*



*Acknowledgements*





AA – Valencia College – Spring 2018



BS - Mechanical Engineering

- University of Central Florida – Fall 2020



MS – Mechanical Engineering

- University of Central Florida – Spring 2023



PhD Candidate – Thermo-fluids Track

- University of Central Florida – Spring 2024

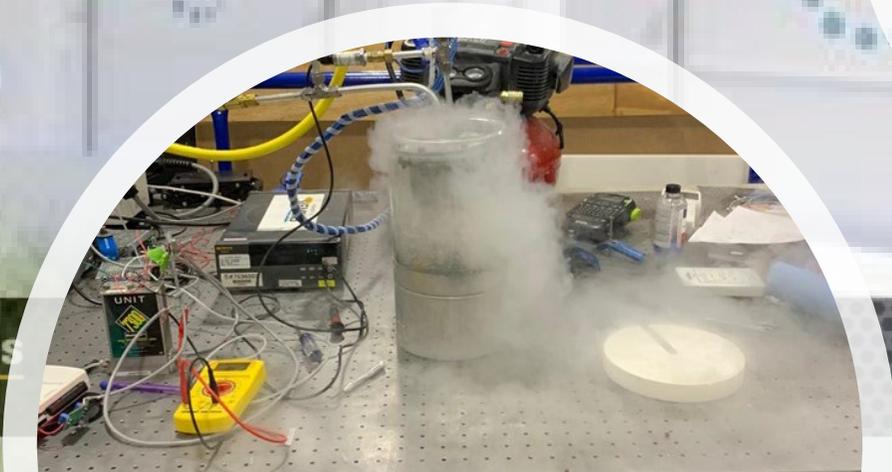
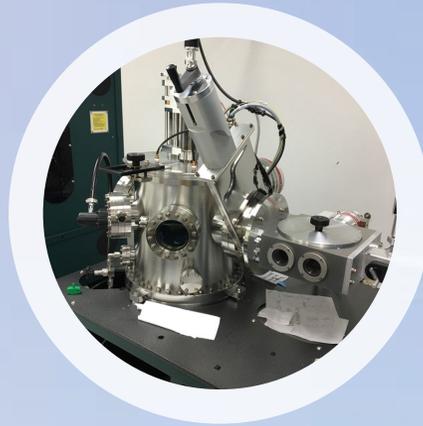
# NOOR Solar Station

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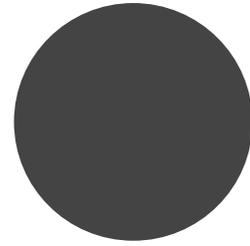


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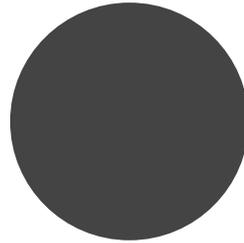
# Hydrogen Storage



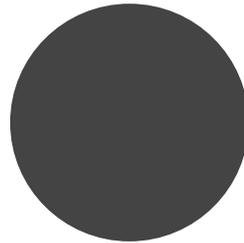
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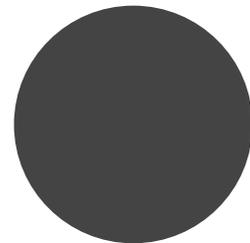
*Background*



*Solar Projects*

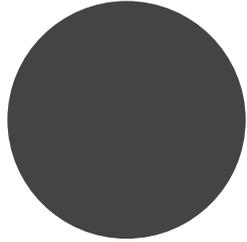


*Takeaways*



*Acknowledgements*



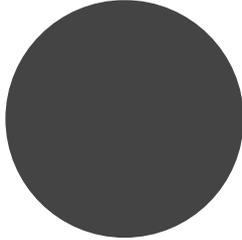


# Solar Projects

- Film Cooling Effectiveness
- Engine Cycle

## Agenda





# Solar Projects



## Film Cooling Effectiveness

- PSP Data Reduction
- Step-By-Step Instructional Document

Next step: digitize contour to create the correlation curve for design purposes.

# Agenda

*Theory & Procedure*

*Raw Data Acquisition*

# **PSP Film Cooling**

*Data Reduction & Cleaning*

*Data Post Processing*

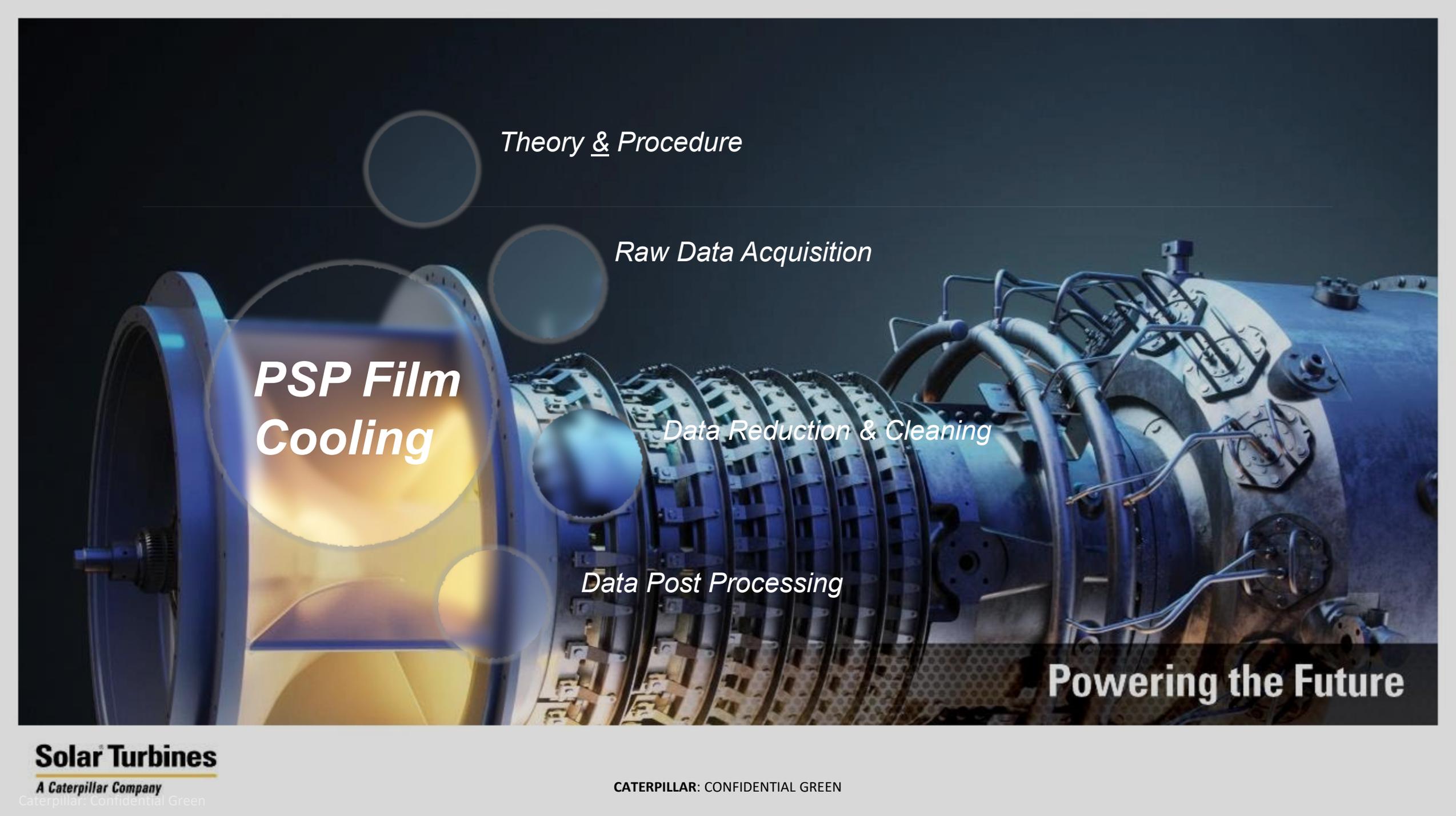
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*Theory & Procedure*

*Raw Data Acquisition*

**PSP Film  
Cooling**

*Data Reduction & Cleaning*

*Data Post Processing*

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# Turbine Blade Cooling Techniques

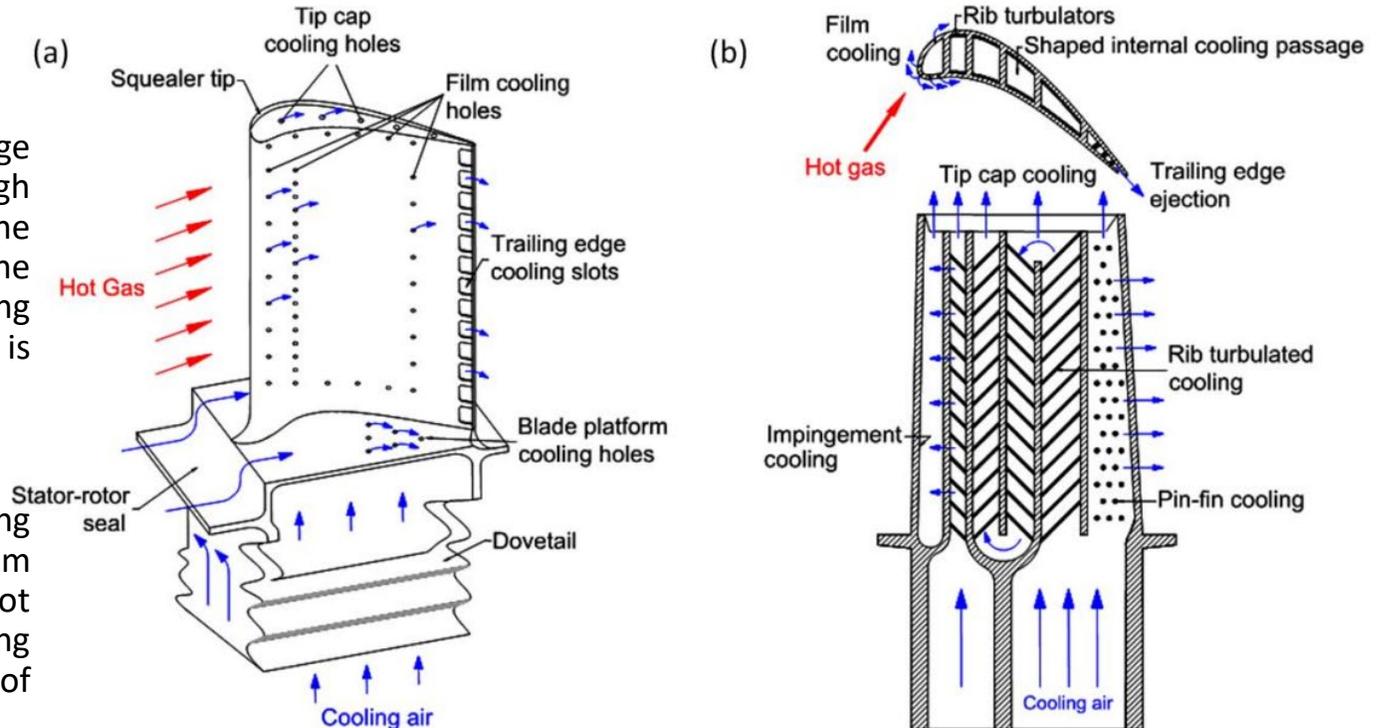
Advanced cooling technologies include blade internal cooling (Fig. b) and external cooling (Fig. a)

## Internal Cooling:

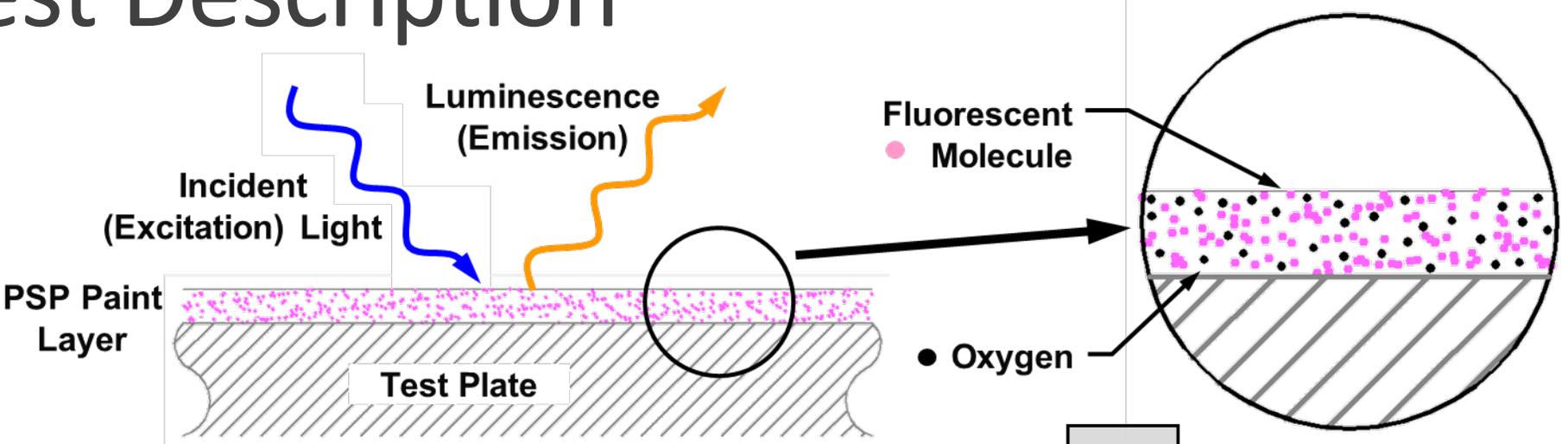
Secondary coolant air is bled from the turbine compressor stage (typically at a much lower temperature). This air is ducted at high Reynolds numbers through cooling channels inside the blade/vane which are equipped with rib turbulators to remove heat from the blade. Channels roughened with pin-fins are used in the trailing edge region of the blade; the heavily loaded leading-edge region is cooled by jet-impingement cooling.

## External Cooling:

External cooling of the turbine blade is achieved by film cooling and the provision of an insulating thermal barrier coating. Film cooling involves the secondary fluid being discharged into the hot mainstream through holes drilled into the internal cooling passages. The goal is to form an insulating film reducing contact of the blade material with the hot mainstream.

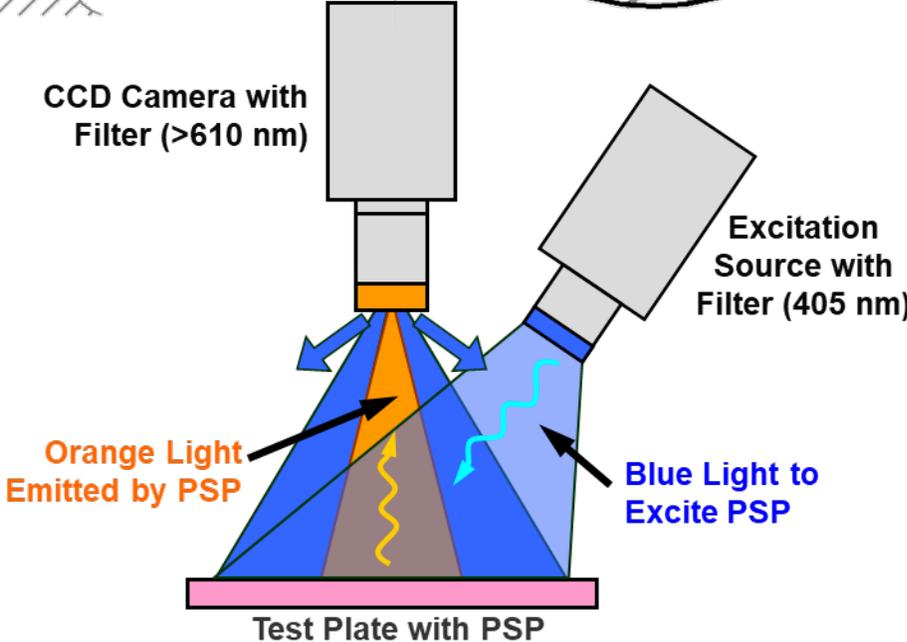


# PSP Test Description

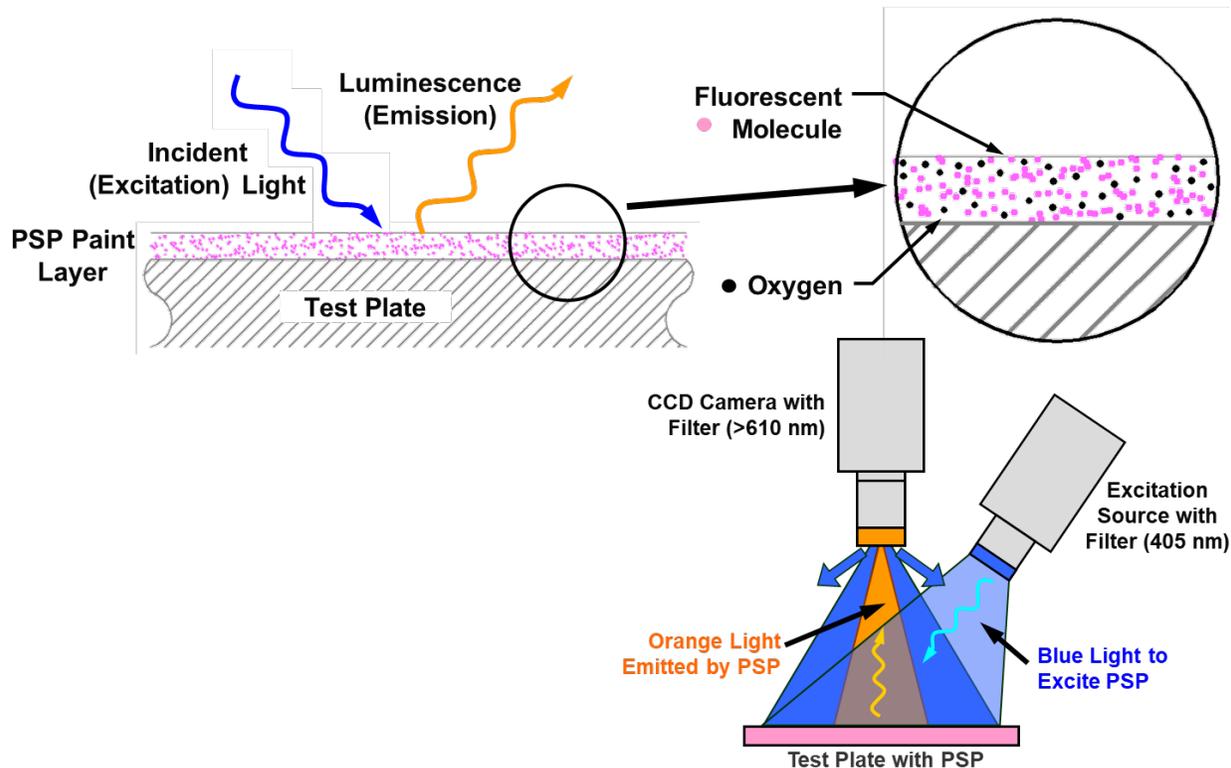


Oxygen Quenching:

Luminescent intensity decreases with the increasing partial pressure of oxygen



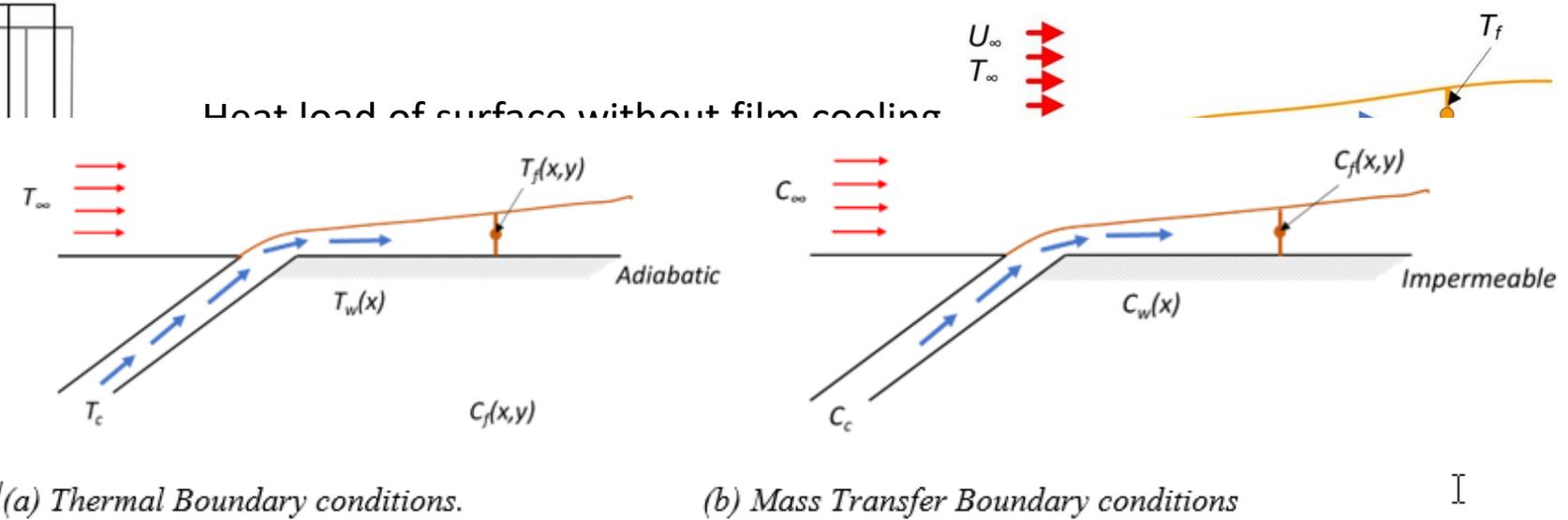
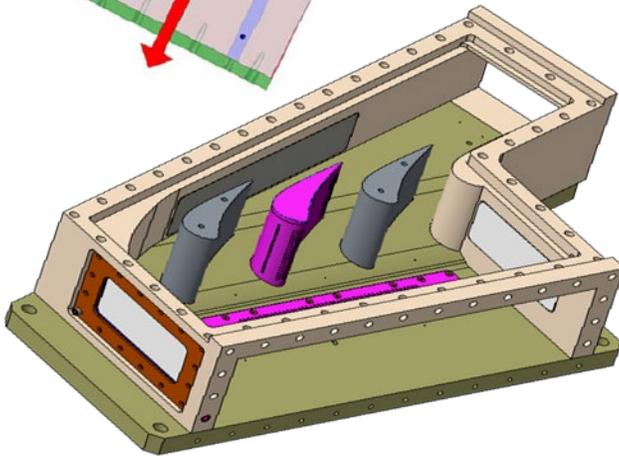
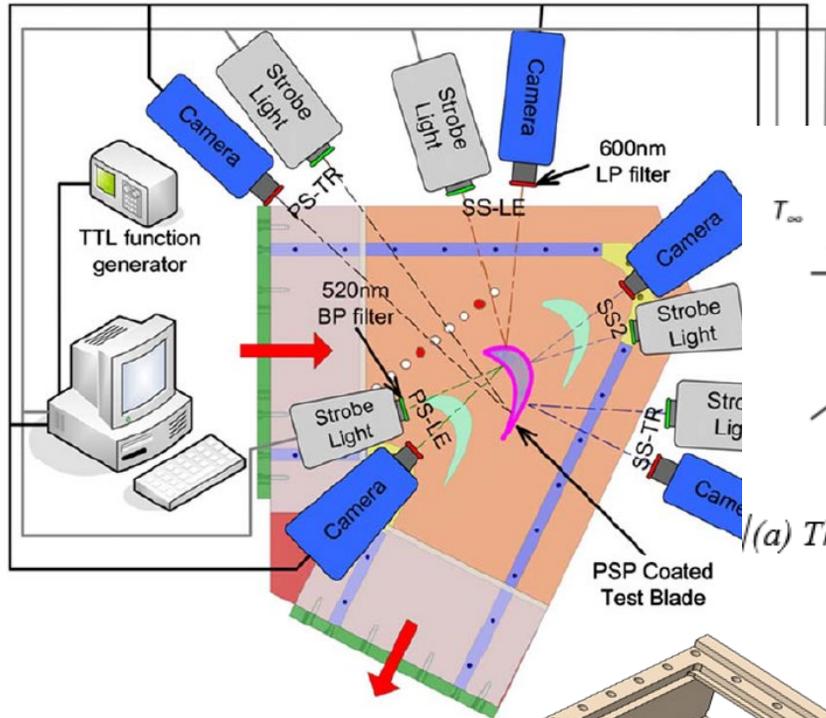
# PSP Test Description



- Photo-luminescent molecules and an oxygen-permeable polymer binder, both dissolved in a solvent
- Excited by a LED light source with a wavelength of 400 nm
- Luminescent molecules in the paint emit photons at a wavelength around 650 nm

# Film Cooling Effectiveness Using PSP

Film cooling two-layer Model



Film cooling effectiveness

$$\eta = \frac{T_f - T_\infty}{T_C - T_\infty} \approx \frac{T_{aw} - T_\infty}{T_C - T_\infty} \quad \eta \approx \frac{C_w - C_\infty}{C_C - C_\infty} = \frac{C_{O_2,fg} - C_{O_2,air}}{C_{O_2,C} - C_{O_2,air}} = 1 - \frac{C_{O_2,fg}}{C_{O_2,air}}$$

$$\eta = 1 - \frac{C_{O_2,fg}}{C_{O_2,air}} = 1 - \frac{1}{\left(1 + \left(\frac{P_{O_2,air}/P_{O_2,R}}{P_{O_2,fg}/P_{O_2,R}} - 1\right) \frac{W_{fg}}{W_{air}}\right)}$$

# Film Cooling Effectiveness Using PSP

Heat load of surface without film cooling

$$q'' = h_o(T_\infty - T_w)$$

Heat load of surface with film cooling

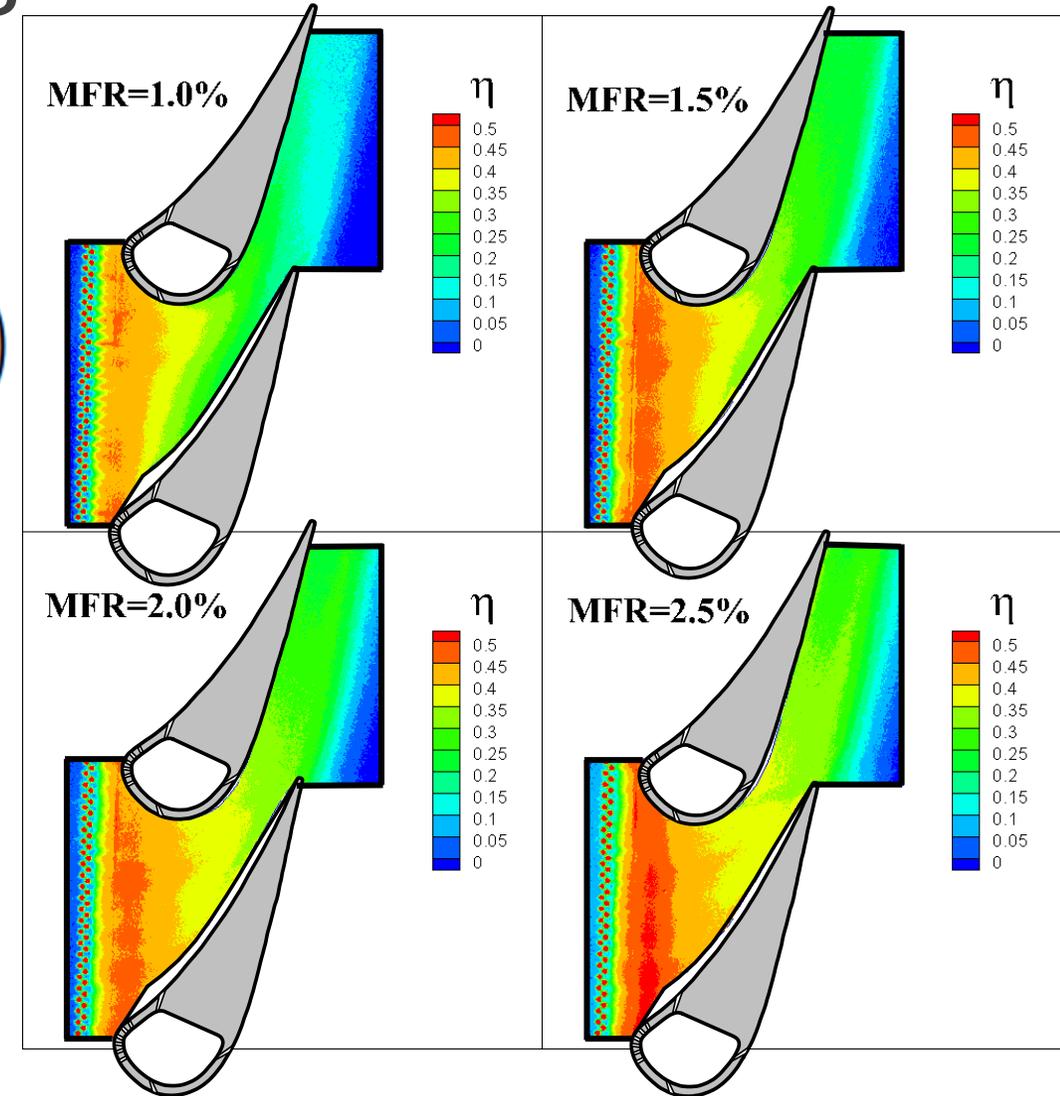
$$q'' = h(T_f - T_w)$$

$$\frac{q''}{q''_o} = \frac{h}{h_o} \left( 1 - \eta \frac{T_\infty - T_c}{T_\infty - T_w} \right)$$

Film cooling effectiveness

$$\eta = \frac{T_f - T_\infty}{T_c - T_\infty} \approx \frac{T_{aw} - T_\infty}{T_c - T_\infty} \quad \eta \approx \frac{C_w - C_\infty}{C_c - C_\infty} = \frac{C_{O_2,fg} - C_{O_2,air}}{C_{O_2,c} - C_{O_2,air}} = 1 - \frac{C_{O_2,fg}}{C_{O_2,air}}$$

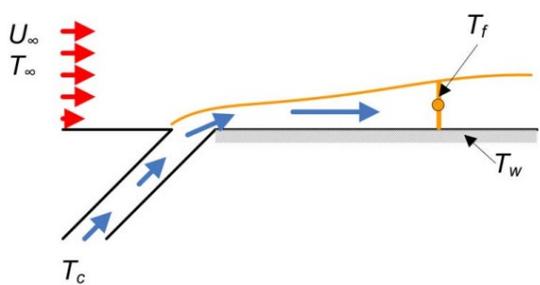
$$\eta = 1 - \frac{C_{O_2,fg}}{C_{O_2,air}} = 1 - \frac{1}{\left( 1 + \left( \frac{P_{O_2,air}/P_{O_2,R}}{P_{O_2,fg}/P_{O_2,R}} - 1 \right) \frac{W_{fg}}{W_{air}} \right)}$$



# PSP Testing Procedure

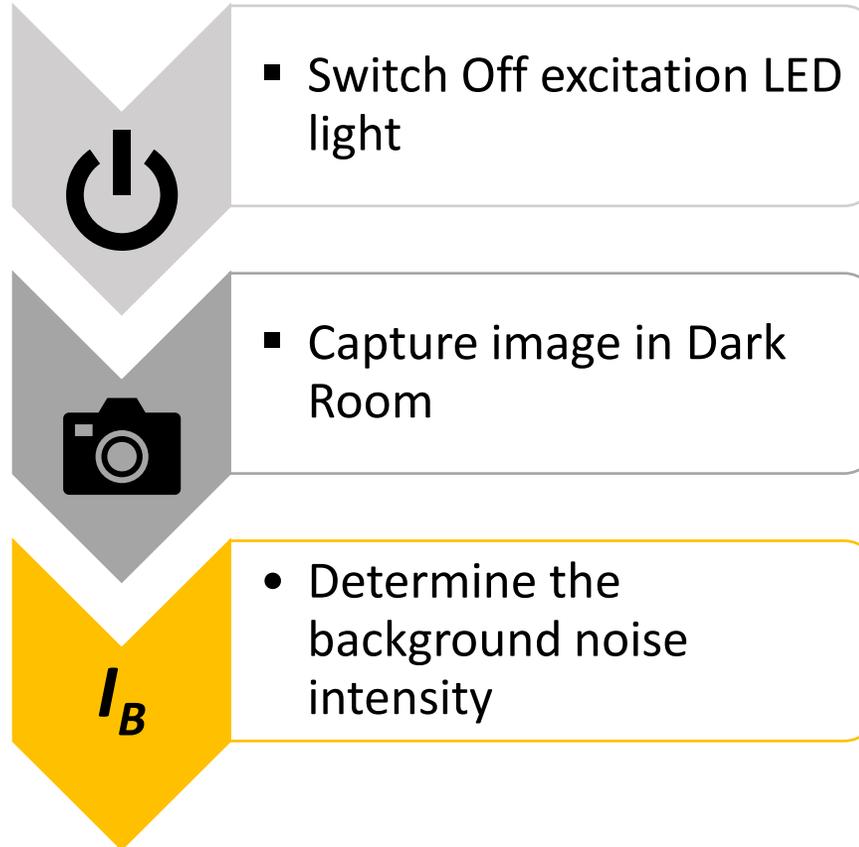
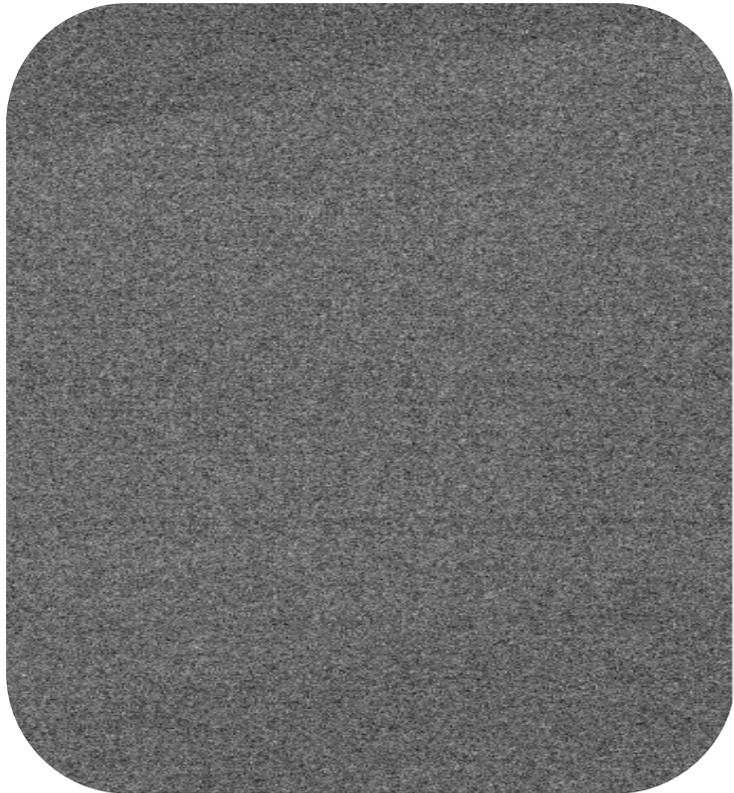


Black Image



# PSP Testing Procedure

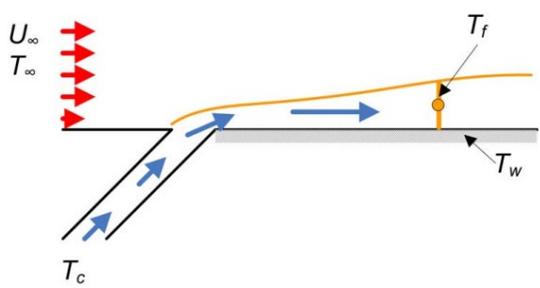
## Black Image



# PSP Testing Procedure



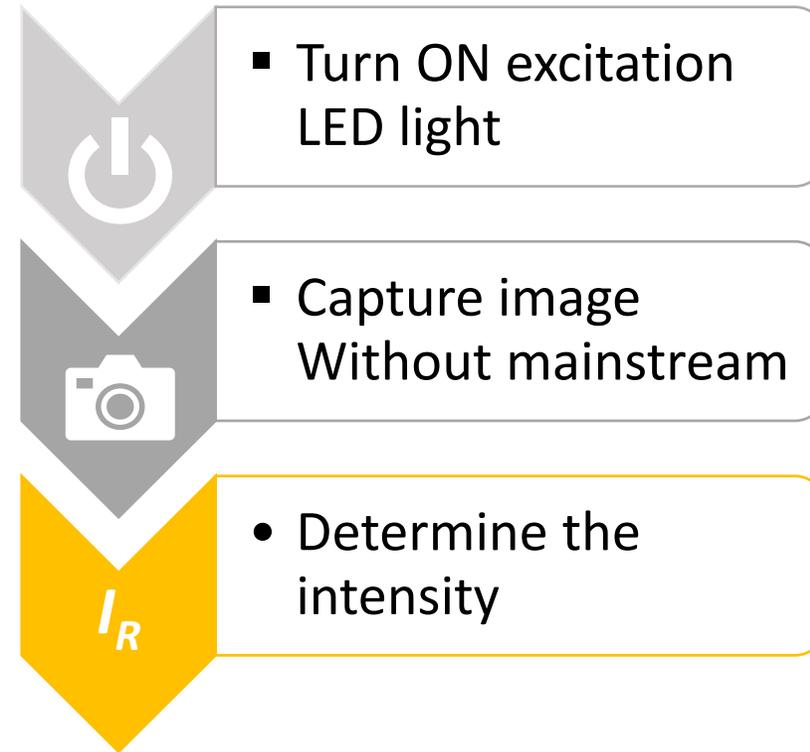
Reference Image



# PSP Testing Procedure



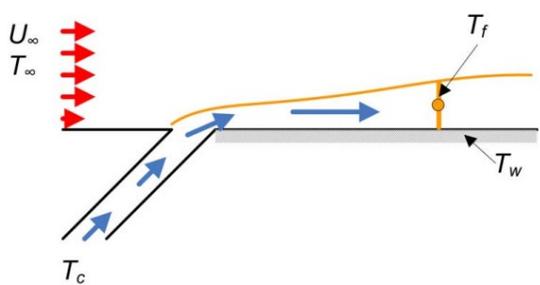
## Reference Image



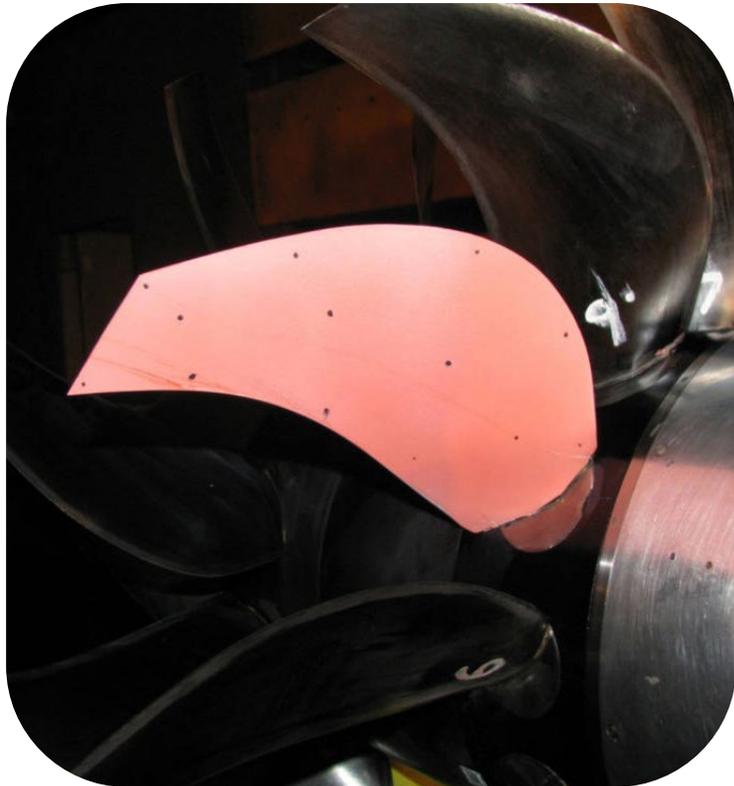
# PSP Testing Procedure



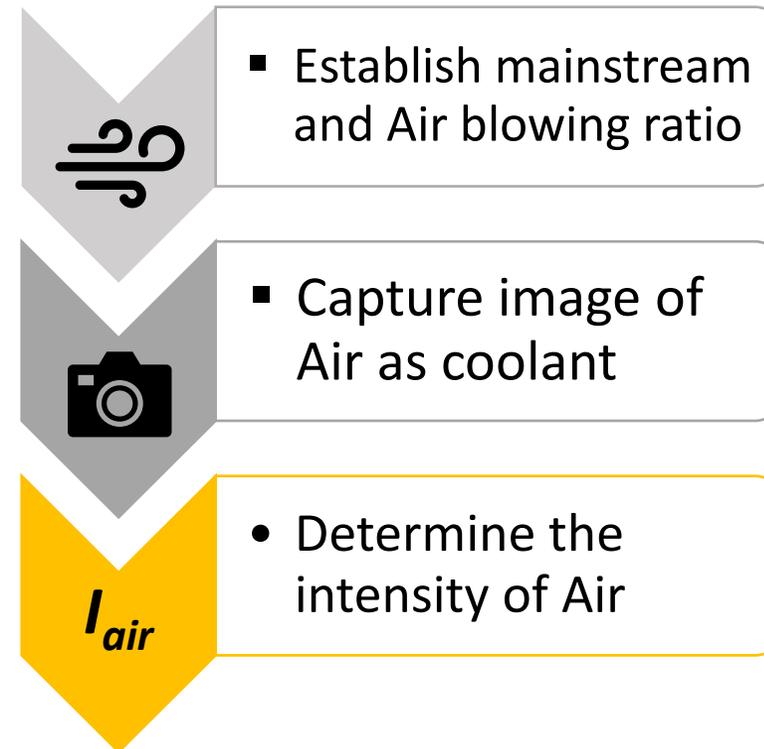
Air Image



# PSP Testing Procedure



## Air Image

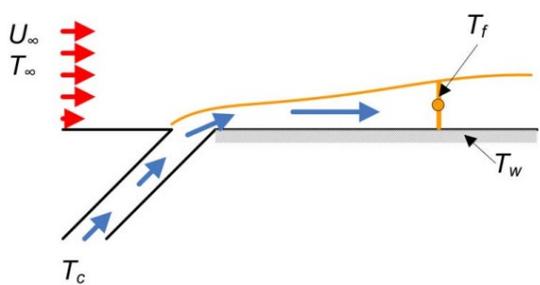


$P_{O_{2,air}}$   
 $C_{O_{2,air}}$

# PSP Testing Procedure



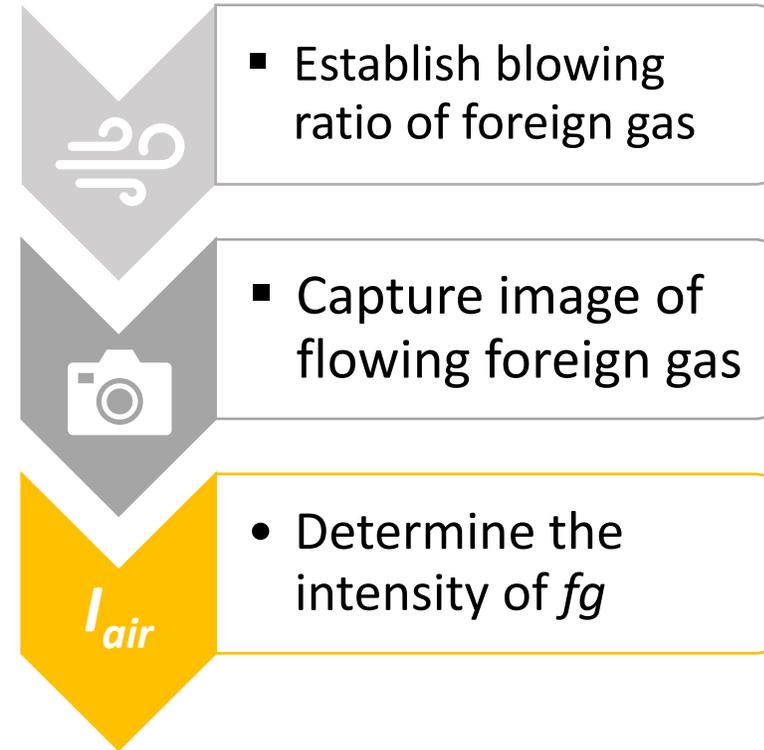
Coolant Image



# PSP Testing Procedure



## Coolant Image



$P_{O_{2,fg}}$   
 $C_{O_{2,fg}}$

# Raw Data Acquisition – Calibration

A calibration can be performed to quantify the pressure and temperature sensitivity of the paint

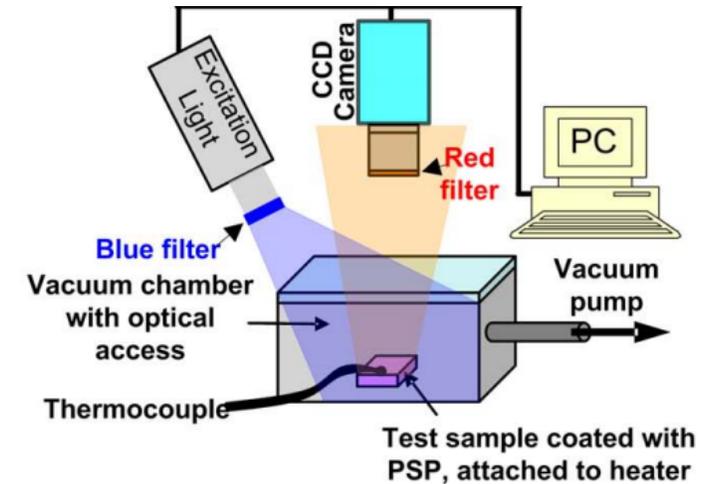
Calibration Parameters are obtained by curve fitting the data generated by the calibration setup

*Stern-Volmer equation*

$$\frac{I_R - I_B}{I - I_B} = A(T) + B(T) \frac{P_{O_2}}{P_{O_2,R}}$$

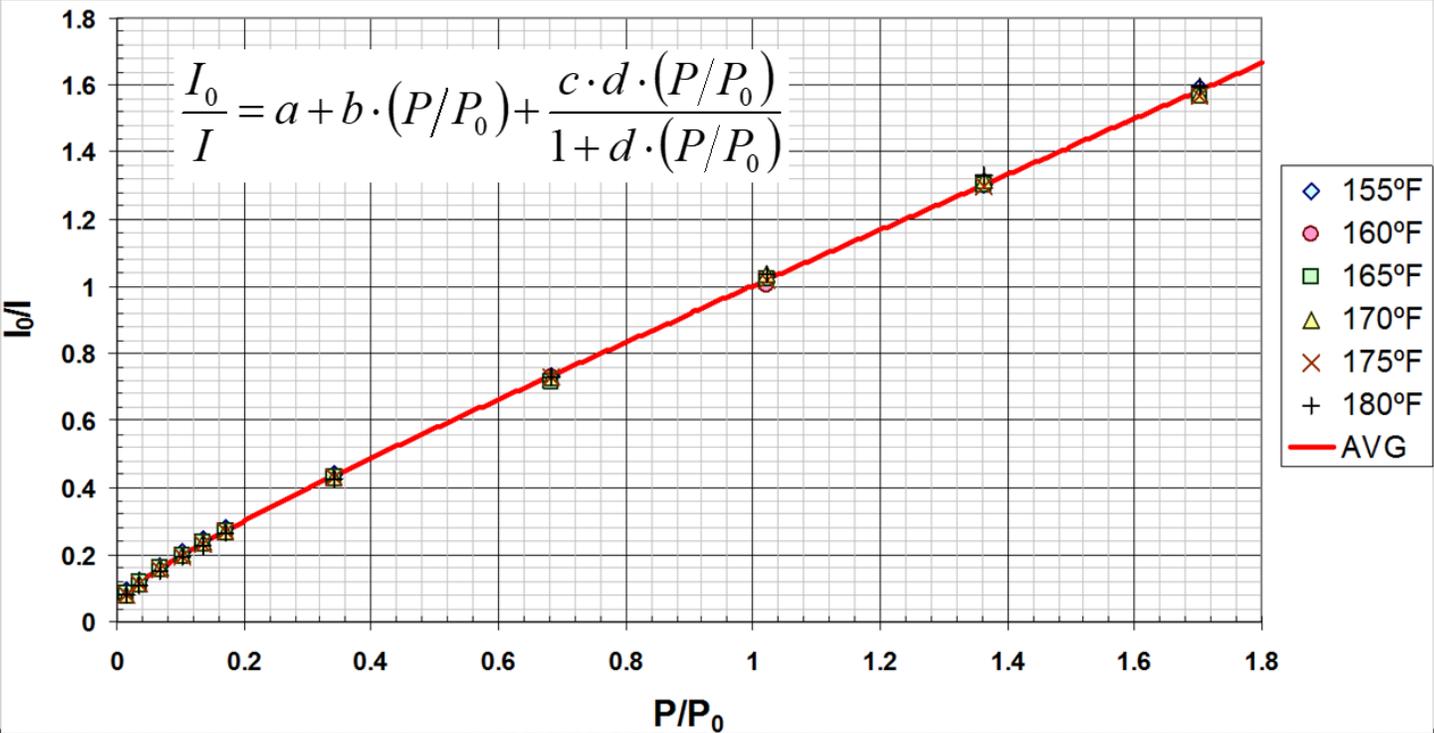
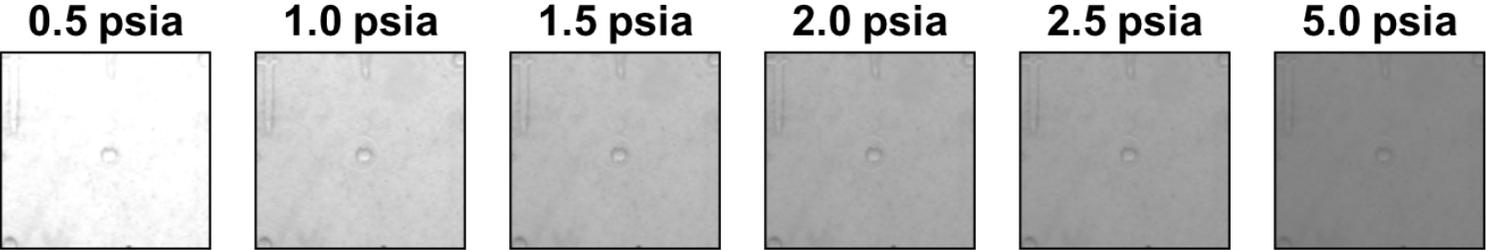


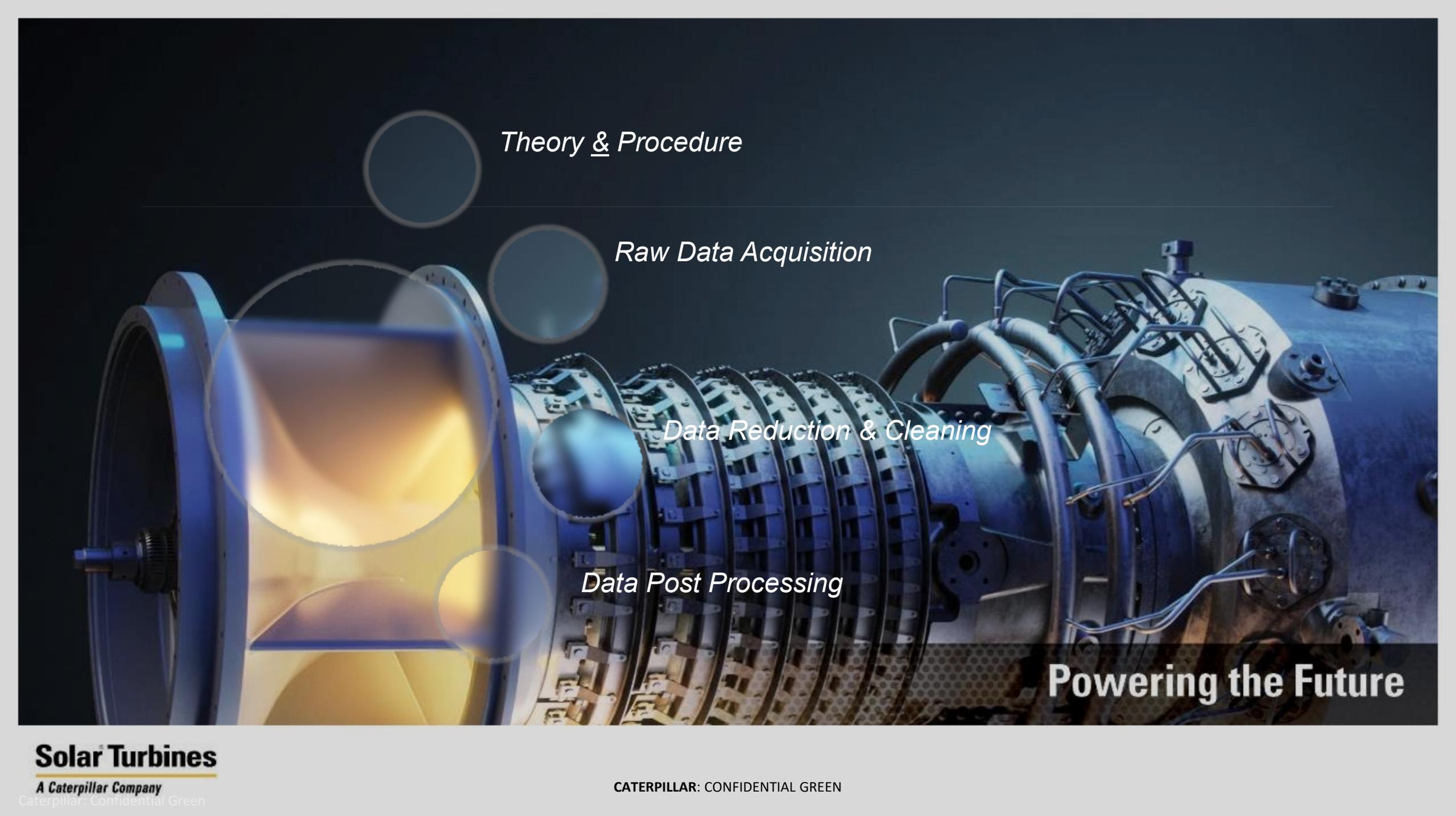
Courtesy of Kevin Liu



Courtesy of [DOI: 10.5098/hmt.v1.1.3001](https://doi.org/10.5098/hmt.v1.1.3001)

# PSP Calibration





*Theory & Procedure*

*Raw Data Acquisition*

*Data Reduction & Cleaning*

*Data Post Processing*

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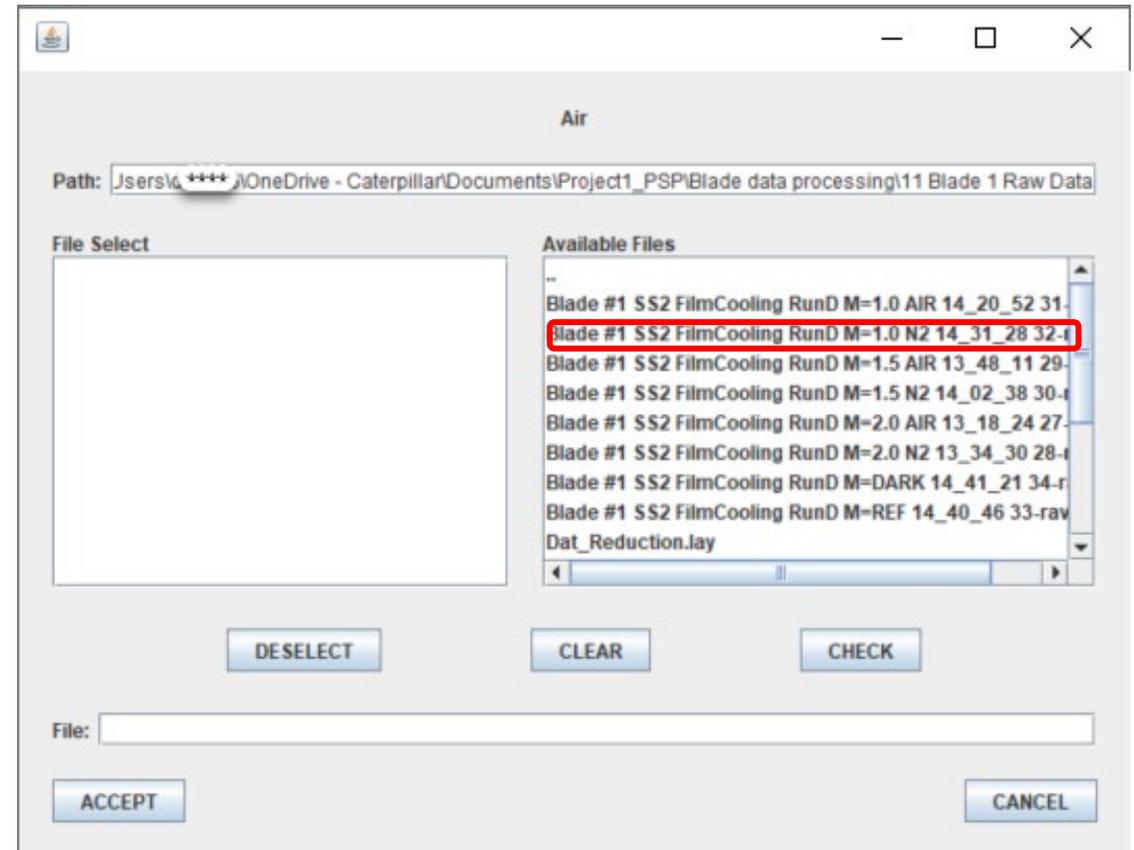
# Raw Data Acquisition– Four Modes

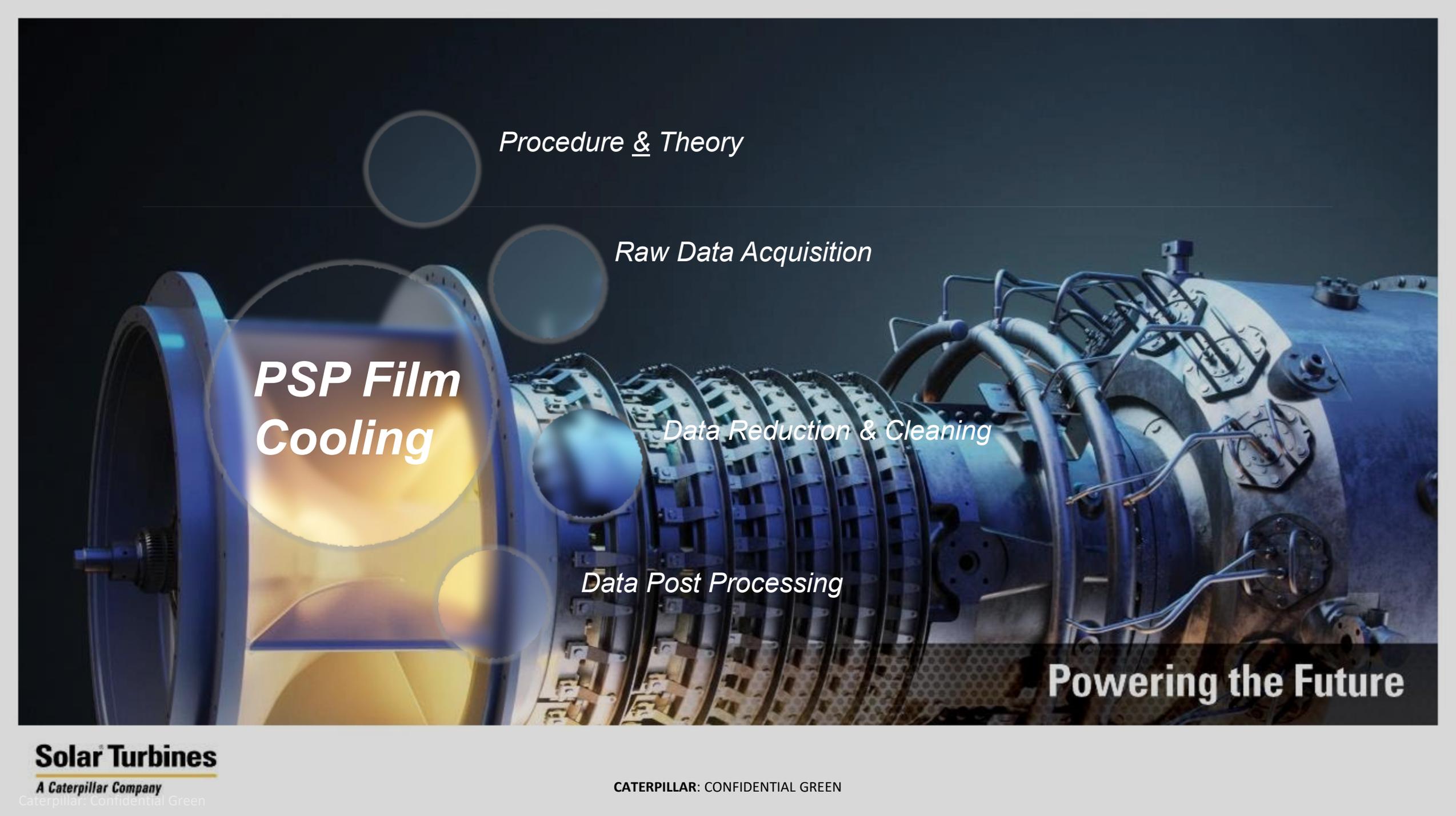
❑ Use in house Java code to process data from the superposition of images.

❑ Choose the corresponding image to each mode with its specific blowing ratio M.

- First, choose images for the same M on the same data processing.
- Then, choose image for Air.
- Then choose image for Reference.
- Then choose image for Coolant.
- Then choose image for Dark.

$$M = \rho_c v_c / \rho_\infty v_\infty$$





*Procedure & Theory*

*Raw Data Acquisition*

***PSP Film  
Cooling***

*Data Reduction & Cleaning*

*Data Post Processing*

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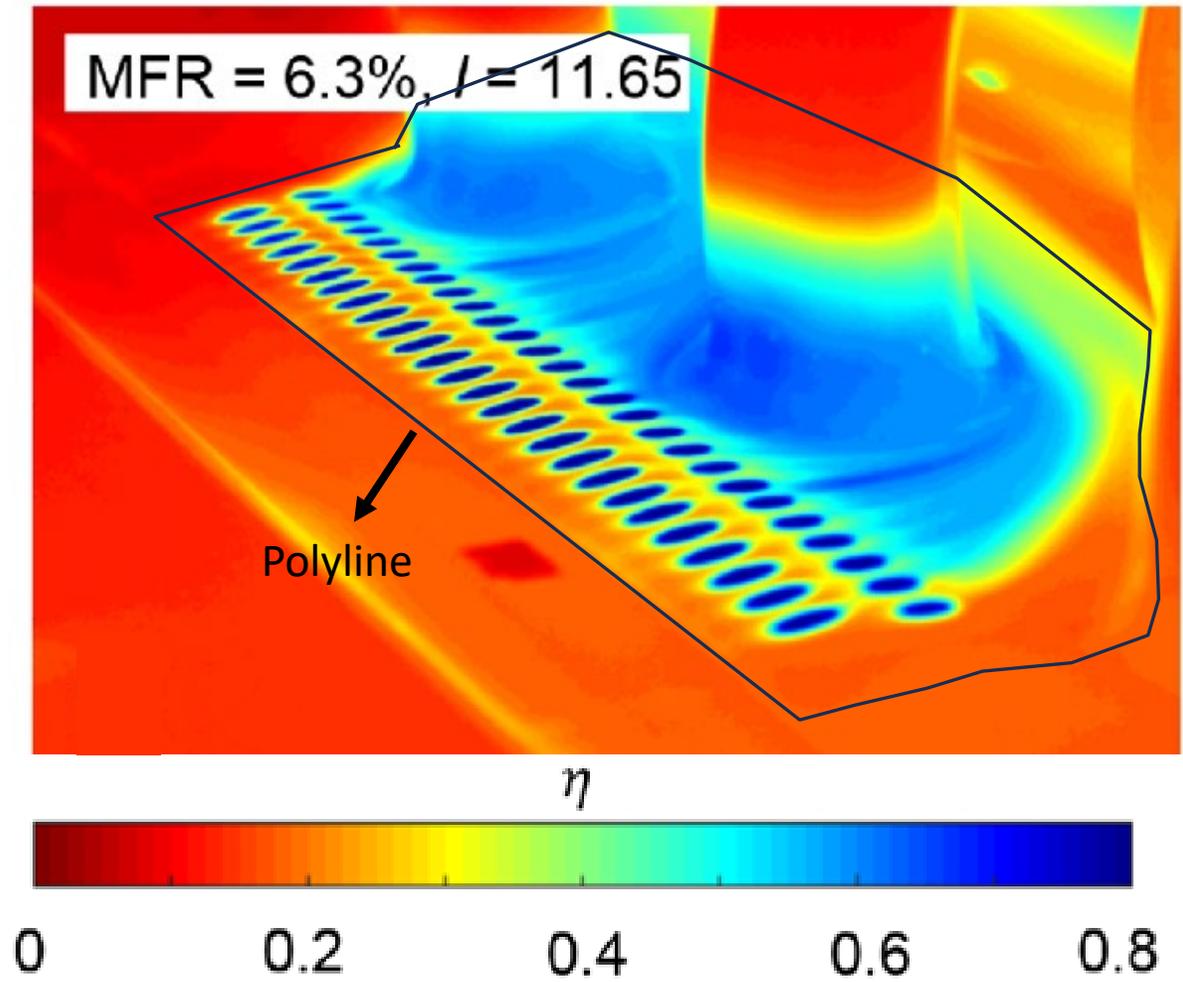
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# Data Reduction – Tecplot 360

- ❑ **Tecplot 360** is a Computational Fluid Dynamics (CFD) and numerical simulation software package used in post-processing simulation results
- ❑ The reduced data is processed by creating a polyline to get rid of the noise surrounding the testing section of concern (i.e., Blade).

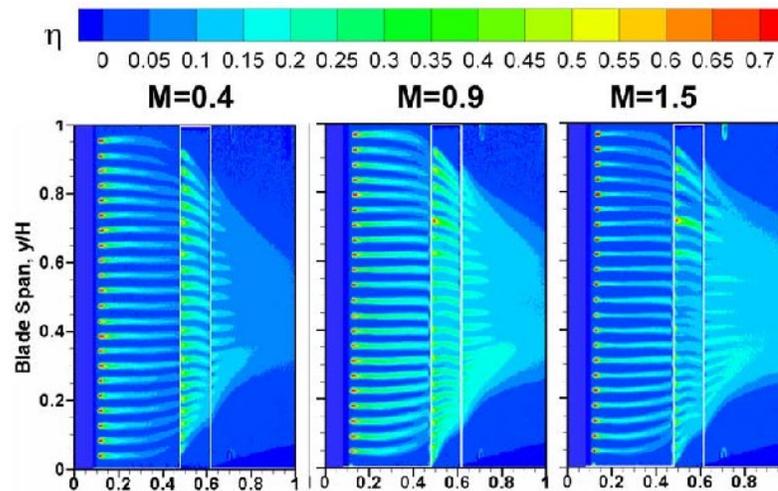
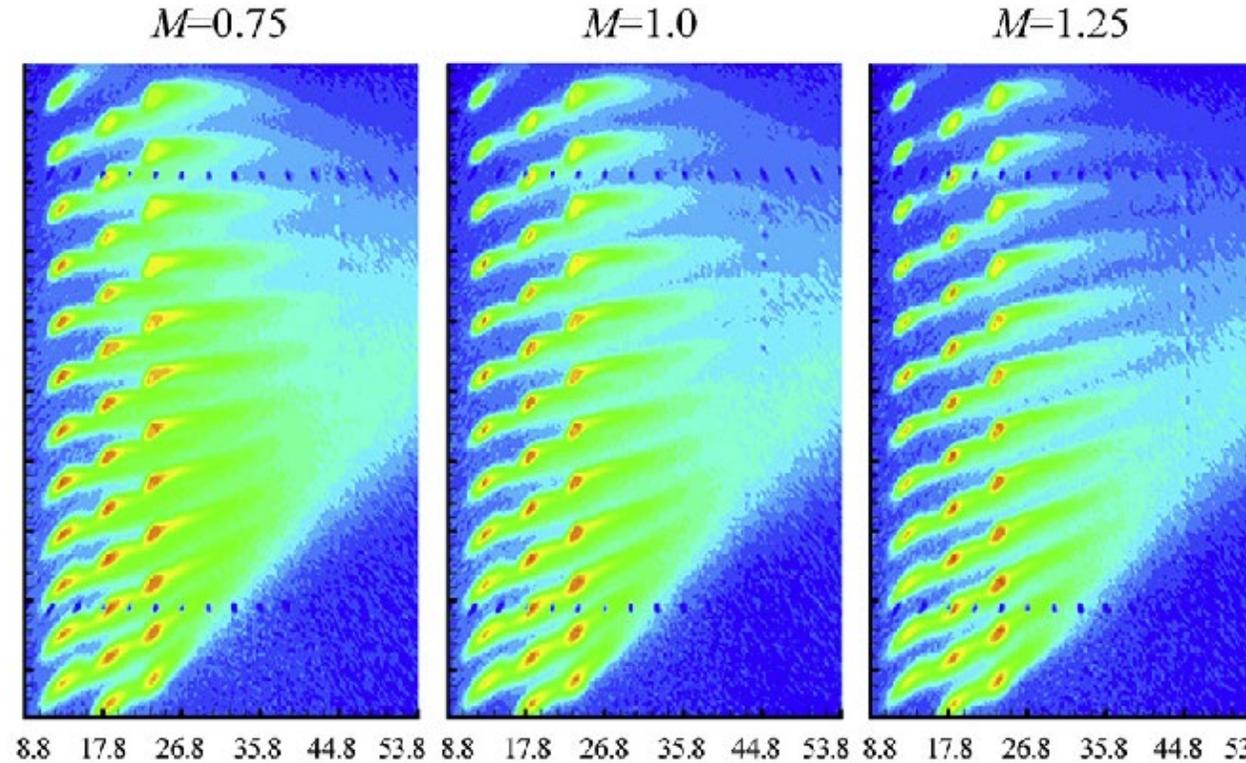
Sample Contour Plot



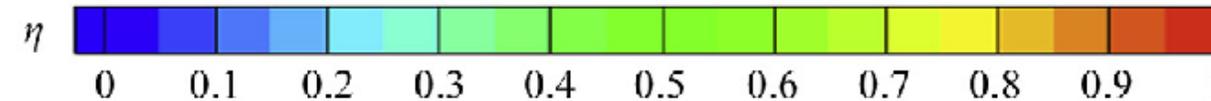
# Film Cooling Effectiveness Using PSP - Results

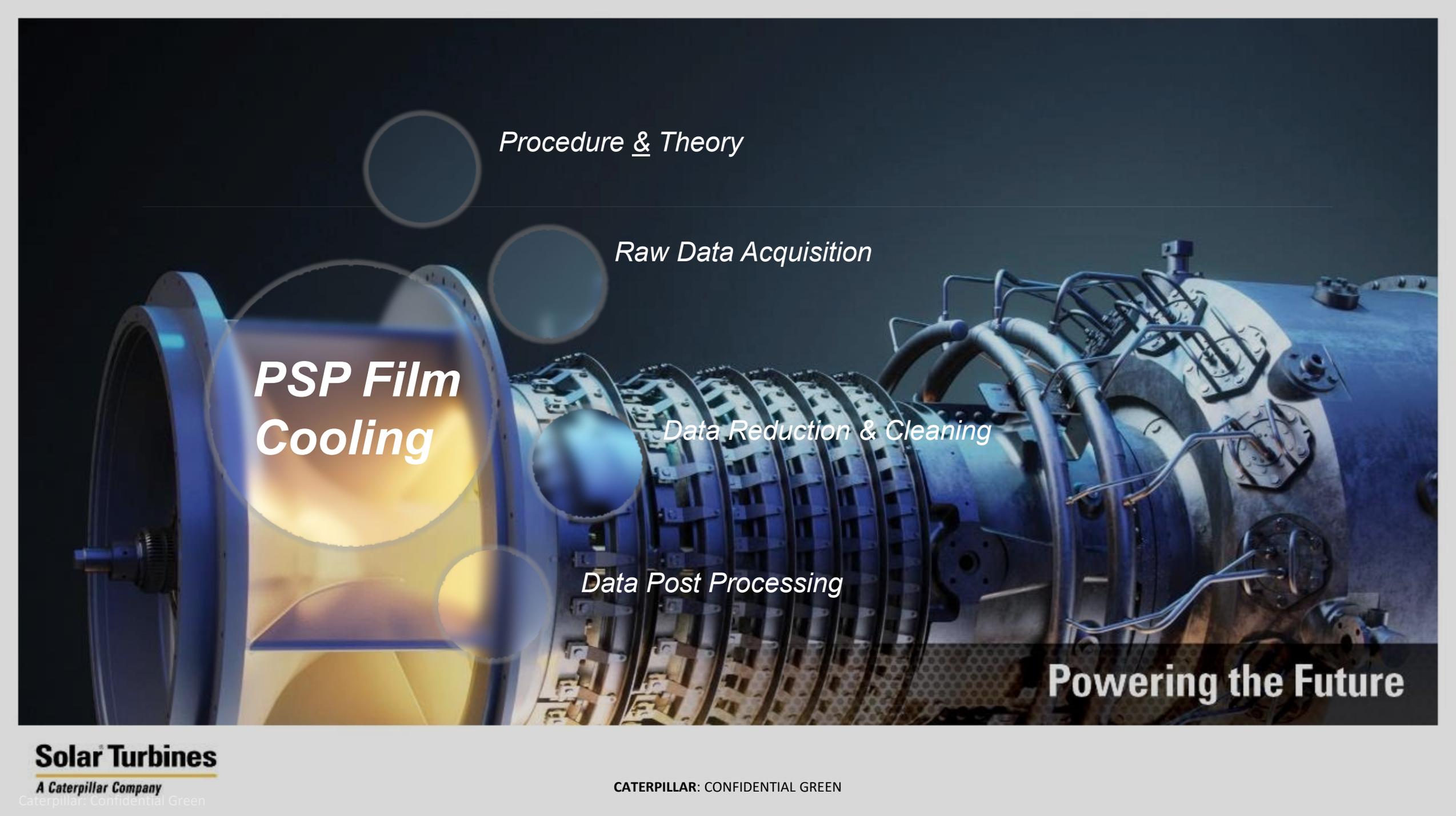
- Several blowing ratios are investigated
- A lower blowing ratio does not create an effective film cooling
- Also, a very high blowing ratio creates lift off which makes the cooling fluid mix with the mainstream. Film cooling effectiveness is achieved with an optimal Blowing ratio

Sample Data



Sample Data





*Procedure & Theory*

*Raw Data Acquisition*

***PSP Film  
Cooling***

*Data Reduction & Cleaning*

*Data Post Processing*

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# Data Post Processing – Overview

- Data cleaning using a Matlab code.
- Visualize data using a contour display mode from TECPLOT 360.
- Plot exported as a TIFF image.

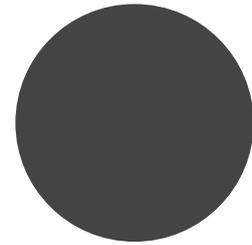
# Agenda

## ● Solar Projects

### ● Film Cooling Effectiveness

- PSP Data Reduction
- Step-By-Step Instructional Document

# Agenda



## Solar Projects



### Film Cooling Effectiveness



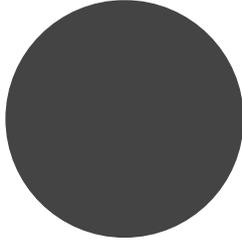
Step-By-Step Instructional Document



## Data Record



- Documented the PSP procedure into Engineering Design Memo (EDM).
- Elaborated a step-by-step interactive instructional document for film cooling effectiveness data processing.

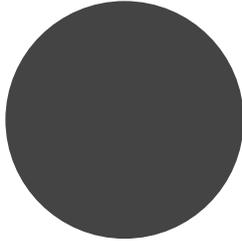


# Solar Projects

- Film Cooling Effectiveness
- Engine Cycle

## Agenda





# Solar Projects



## Engine Cycle

- T250 Cycle Analysis
- Scale Boundary Conditions

Next Step: Conduct an ANSYS computational analysis and compare to engine test 1XB16.

# Agenda



## Engine Cycle

# Test Objectives

- Collect data during a full load transient run in Gen Set mode with 2-hour heat soak and during a fast stop shutdown.
- Collect data at part load points from Idle to 100 percent load at 10 percent increments.
- Perform 2-3 bearing oil parametric study.
- Cold engine starts to full load testing.

# Project Objectives

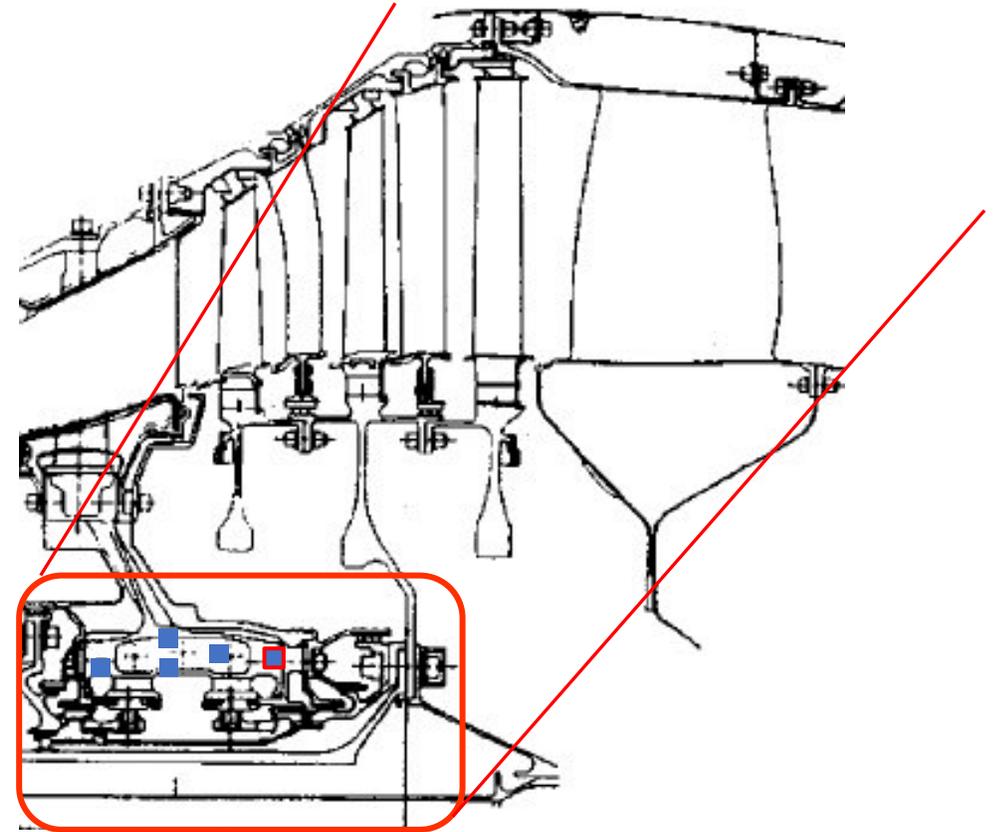
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## Engine Cycle

- Generate the engine cycle (simplify from the trend data) (My part of the project)
- Serves to run our ANSYS thermal analysis following the engine condition
- Compare to the engine test data and validate the Simulation Modeling

# Engine Cycle – Project Objective

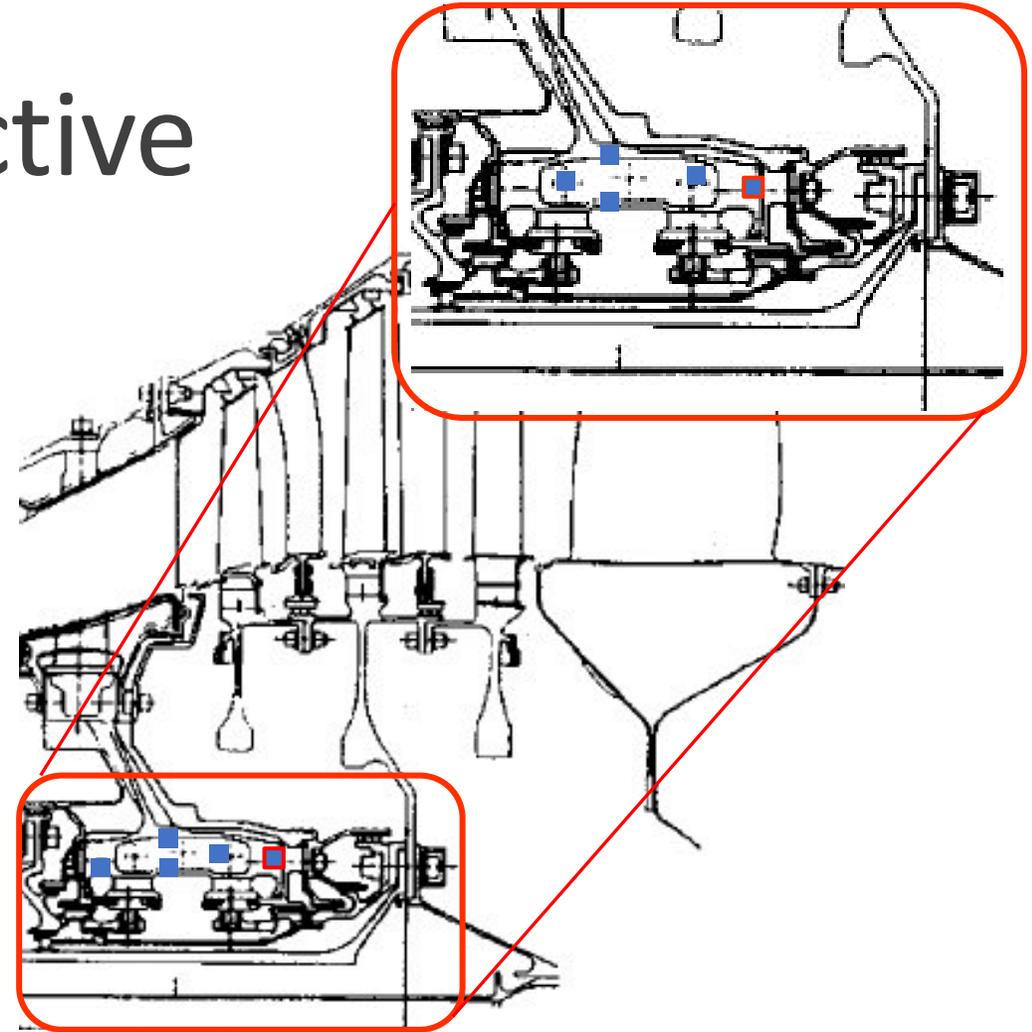
- ❑ Generate the engine cycle (simplify from the trend data).
- ❑ Serves to run ANSYS thermal analysis following the engine conditions
- ❑ Compare to the engine test data and validate the Simulation Modeling



Sample Engine Layout w/ instrumentation

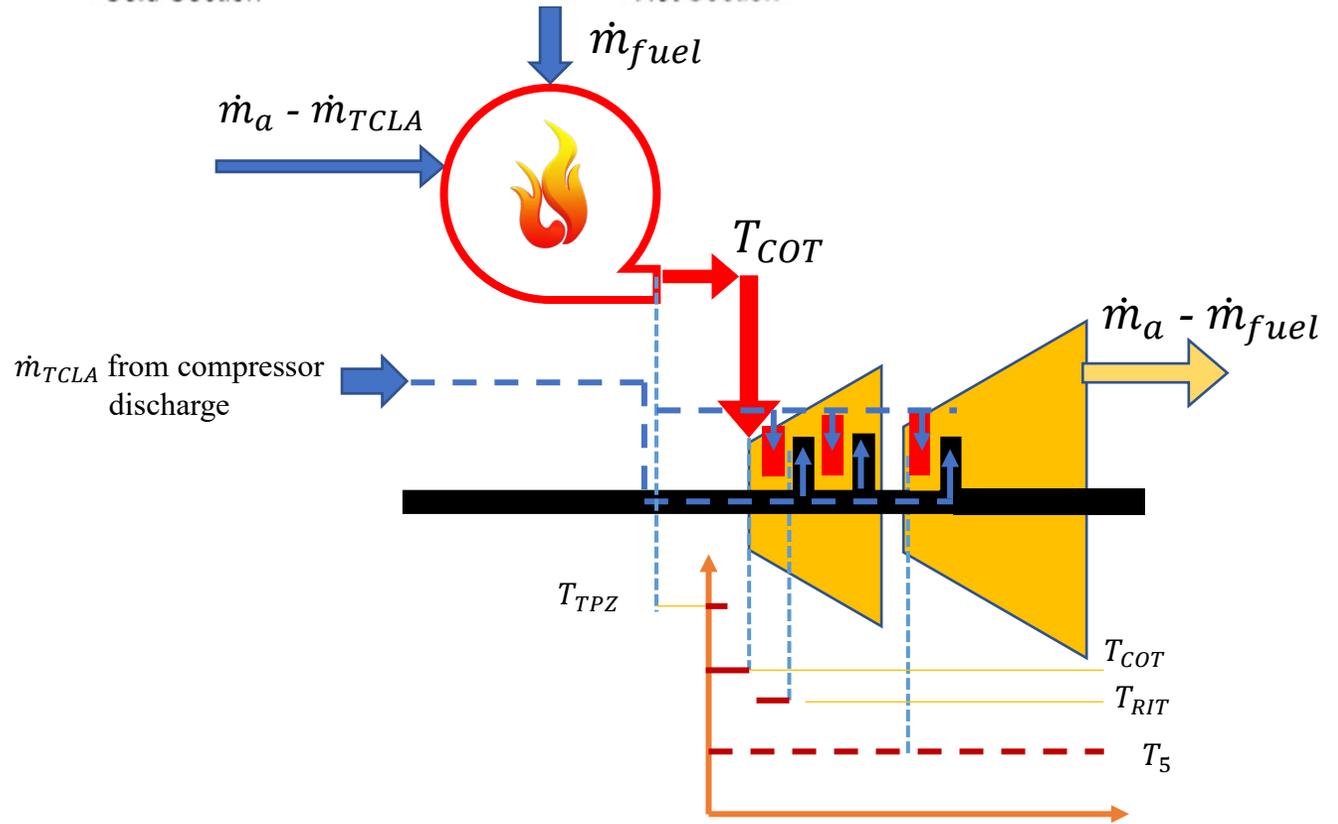
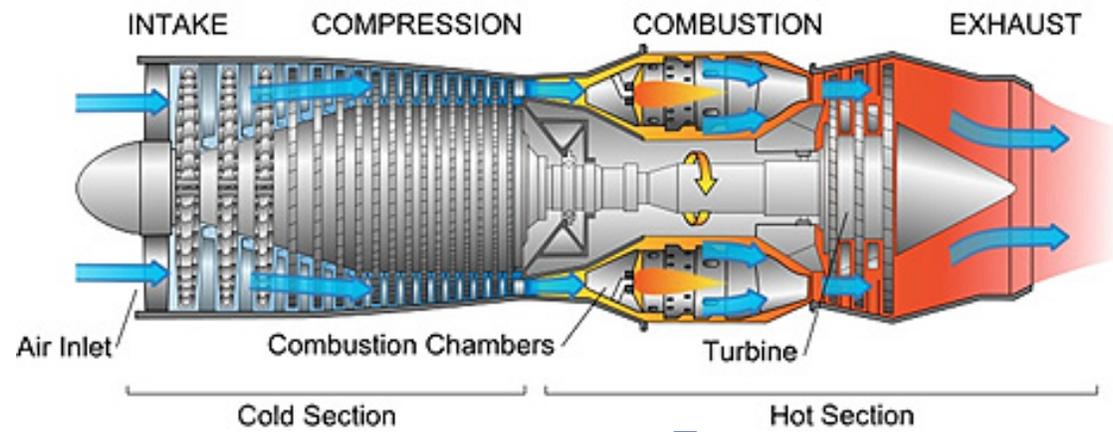
# Engine Cycle – Project Objective

- ❑ Generate the engine cycle (simplify from the trend data).
- ❑ Serves to run ANSYS thermal analysis following the engine conditions
- ❑ Compare to the engine test data and validate the Simulation Modeling



Sample Engine Layout w/ instrumentaion

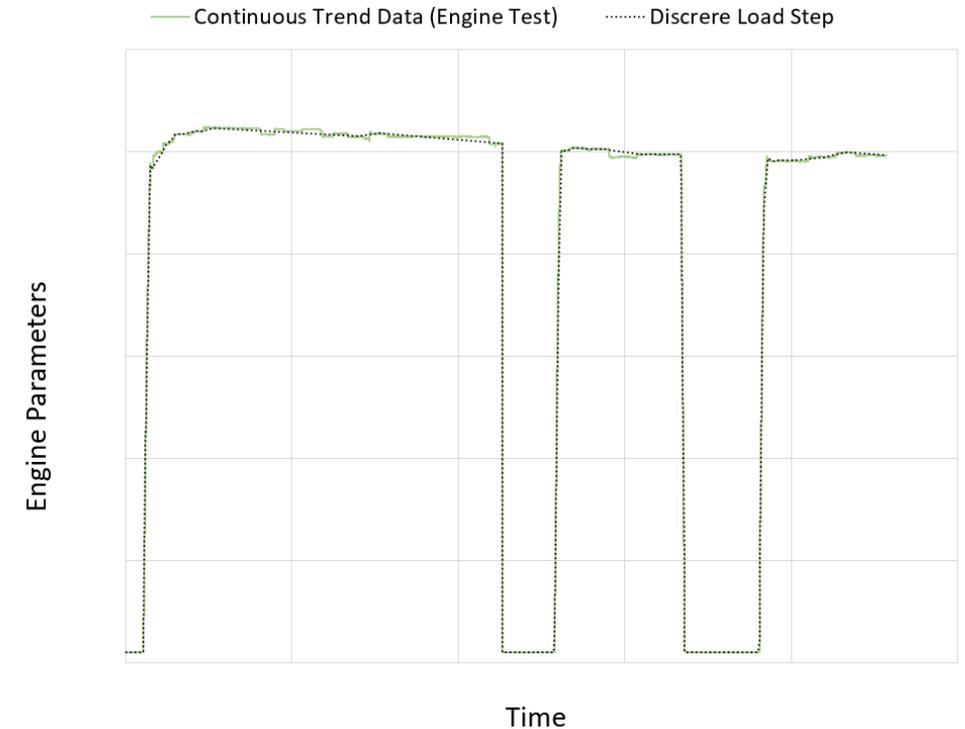
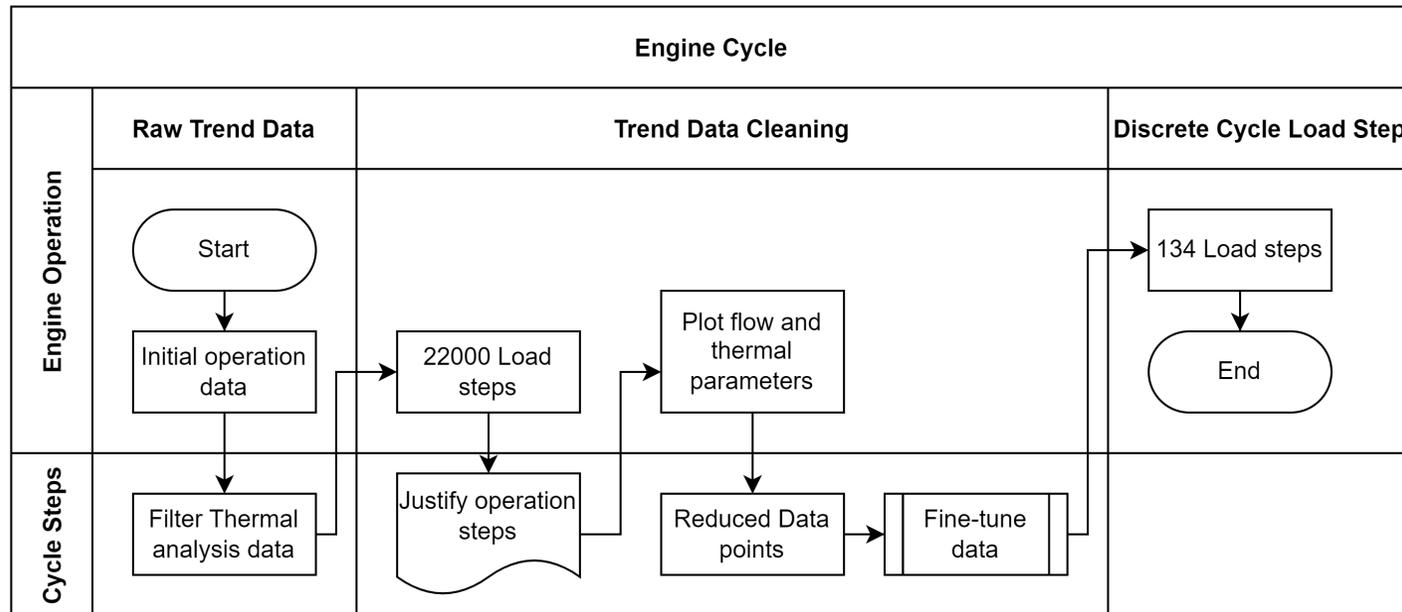
# Power Turbine Temperatures

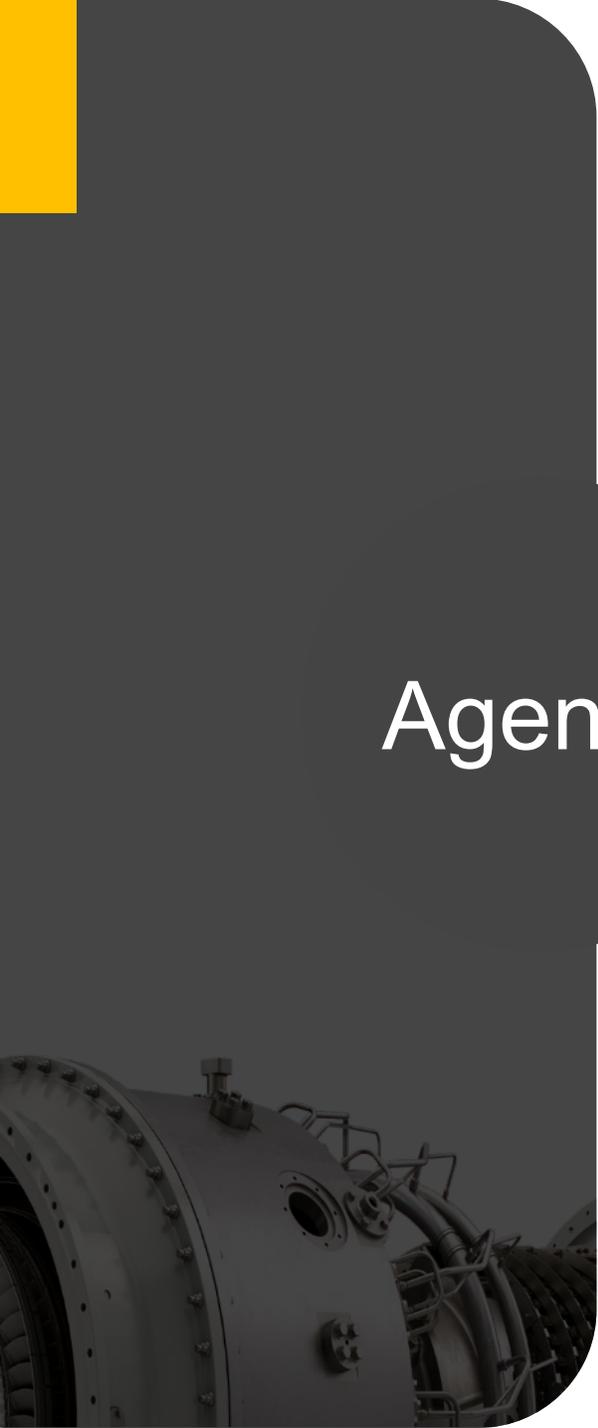


# Engine Cycle Process

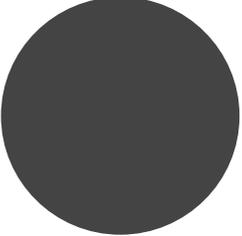
## Notes

- Raw Data containing several data points of the test
- Filtering data pertinent to the engine cycle
- Justifying cycle operations and steps
- Reducing to a minimal discrete data points

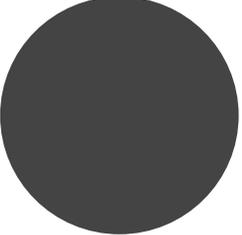




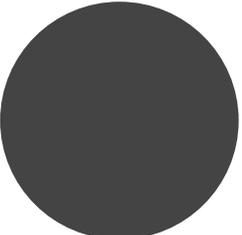
# Agenda



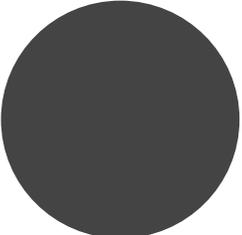
*Background*



*Solar Projects*



*Takeaways*



*Acknowledgements*

# Takeaways

## Technical

- Cooling techniques
- Engine Cycle
- Gas Turbine: Parts and Operations

## Facility tours

- Additive Manufacturing
- Injectors
- IMTK crystals
- Thermal paint

## Relational

- Communication
- Teamwork
- Networking
- Collaboration

## Safety Protocols

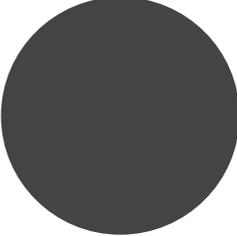
- Emergency Procedures
- Protective Glasses
- Shop Access

## I wish

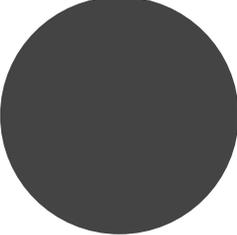
- Engine assembly
- Engine Test
- Lab test



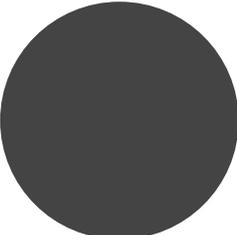
# Agenda



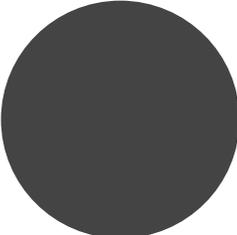
*Background*



*Solar Projects*

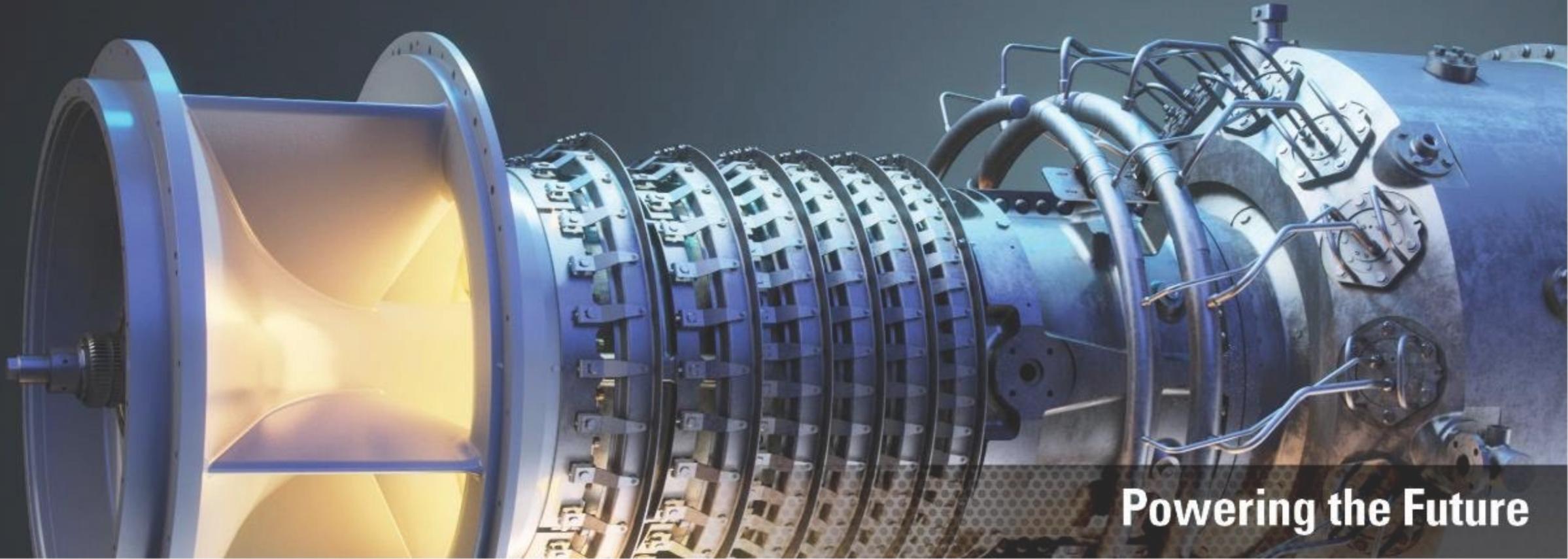


*Takeaways*



*Acknowledgements*

# THANK YOU



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