VG100: INTRODUCTION TO ENGINEERING

Heat Transfer

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Preview

- ReCap: Conduction
- Convection
- Radiation

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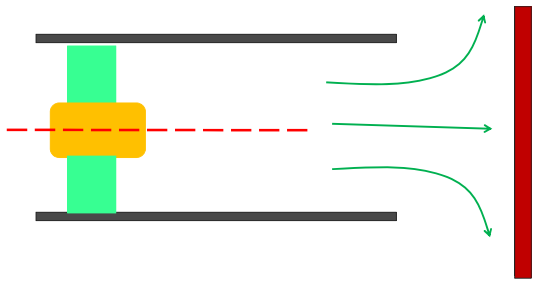
What's Next: **Cooling Performance**



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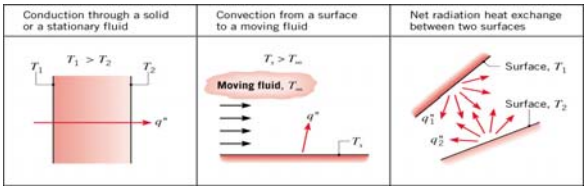
Modes of Heat Transfer



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ReCap: Conduction

Direct transfer of energy via

(i) lattice **vibration**s

(ii) electron movement

(iii) molecular collision

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Convective Heat Transfer

- **Energy transfer at an interface** between different phases:
  - solid and fluid
  - liquid and gas
- No fluid motion = simple conduction.
- With fluid motion, energy is transported both by potential gradients and by the motion of the fluid itself. i.e heat travels by
  - 1. molecular conduction (diffusion)
  - 2. gross fluid movement (advection)

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Convective Heat Transfer

Forced Convection and Nature convection

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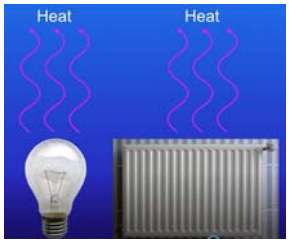
Nature convection



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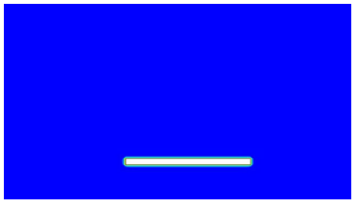
Nature convection



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Nature Convection

Two things are required to induce free or nature convection:

(i) a density gradient

(ii)a body force, such as gravity.

- The fluid motion is driven by buoyancy forces induced by gravity or rotation

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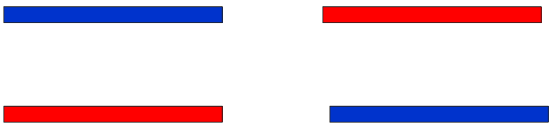
Which case do you feel more stable?



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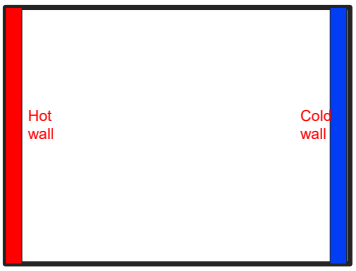
Nature convection



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Forced Convection:

Fluid motion is induced by some external means (pump, fans, etc.)

Oven Example

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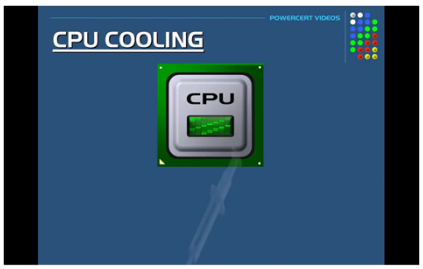
Forced Convection:

Heat Sink Example



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CPU Cooling

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CPU Cooling

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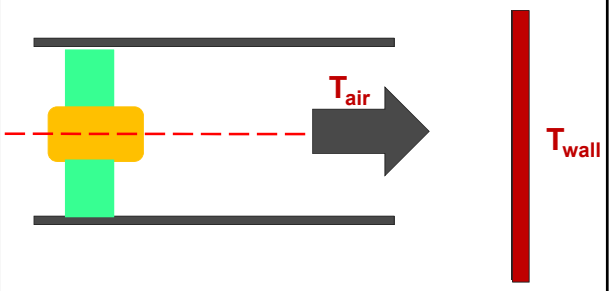
How do you quantify the cooling performance?



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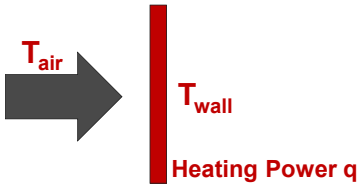
The Heat Transfer Coefficient



$$h = \frac{q}{(T_s - T_{ref})}$$

Still gases (natural convection)	5 to 25
Still liquids (natural convection)	50 to 300
Flowing gases (forced convection)	15 to 250
Flowing liquids (forced convection)	100 to 5000
Boiling liquids	2000 to 50,000
Condensing vapours	2000 to 50,000

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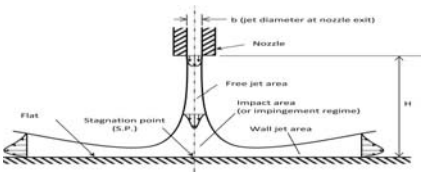

What kind of temperature distribution do you expect ?

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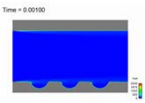
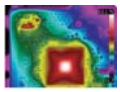
An ongoing research project

Engineering the Time – Novel Thermal Management Concept

- Explore the thermal management design space in time
- Intelligent scan-cooling (UK patent)

Applications:
- Electronic Cooling
- EV battery Cooling
- Energy Storage





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Radiation

- Energy that is emitted by matter due to changes in the electron configurations of its atoms or molecules and is transported as electromagnetic waves (or photons).
- Although radiation originates from matter, its transport does not require a material medium and occurs most efficiently in a vacuum.

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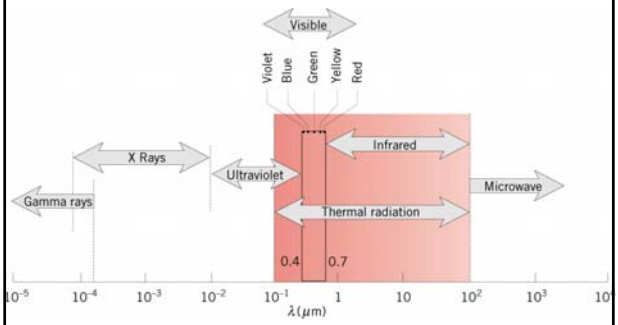
Radiation

The Electromagnetic Spectrum



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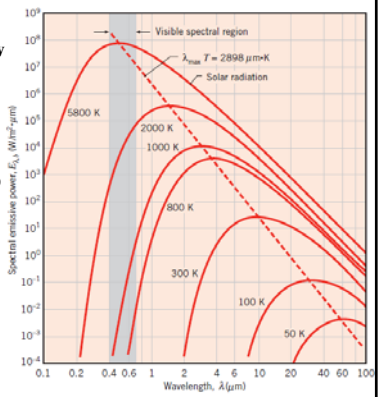
The Spectral (Planck) Distribution of Blackbody Radiation

The Stefan-Boltzmann law

$$E = \sigma T^4$$

$\sigma = 5.67 \times 10^{-8}\, w/(m^2k^4)$



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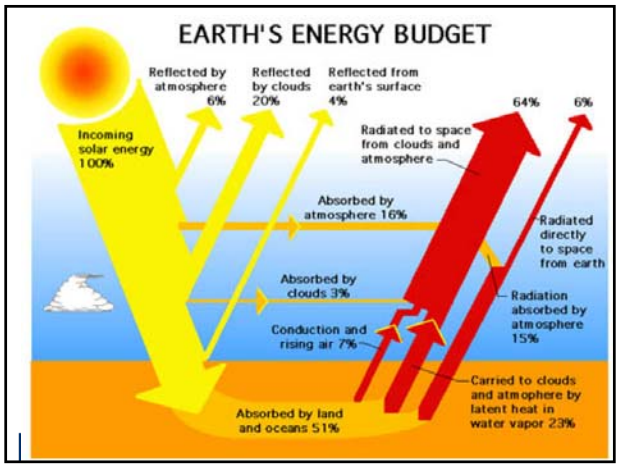

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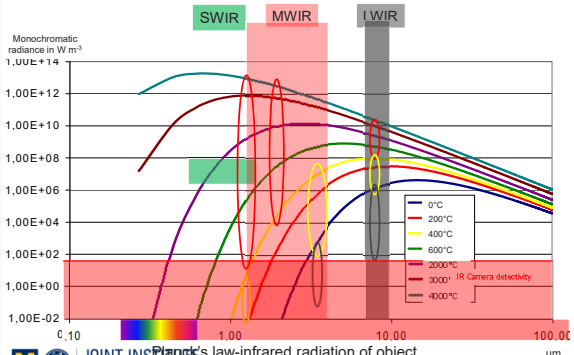
Infrared Camera



Planck's law-infrared radiation of object

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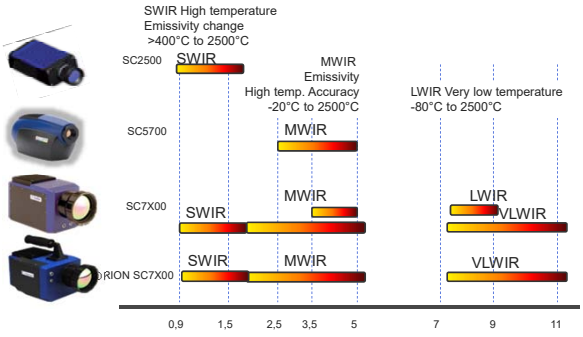
By wavebands



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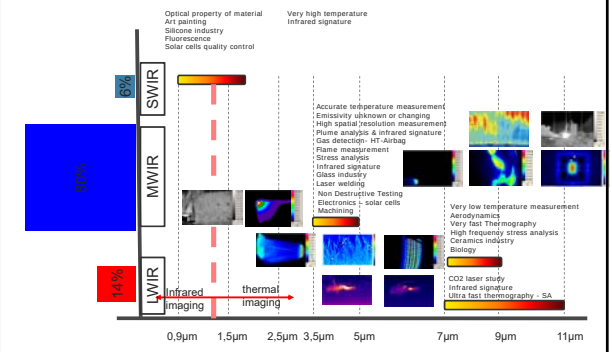
Panel of Applications vs. wavebands



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IR Measurement

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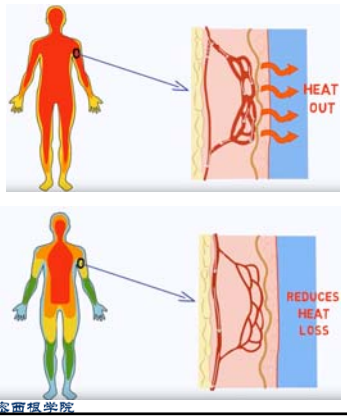
Heat Transfer in our body



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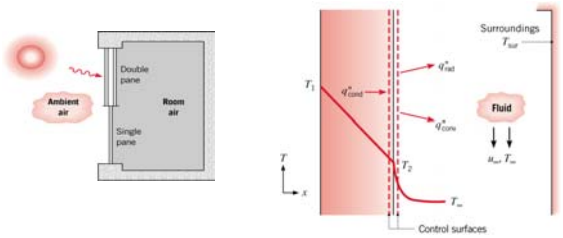
Heat Transfer Example



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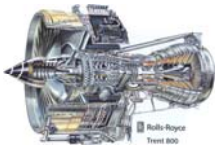
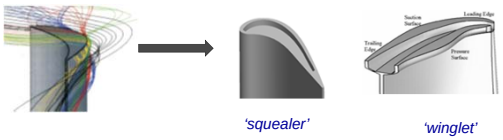
A story in my previous turbine research

Gas Turbine Heat Transfer - a real challenge

Turbine blades can not survive without COOLING!



Blade tip design :



'squealer'

'winglet'

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Tip Research

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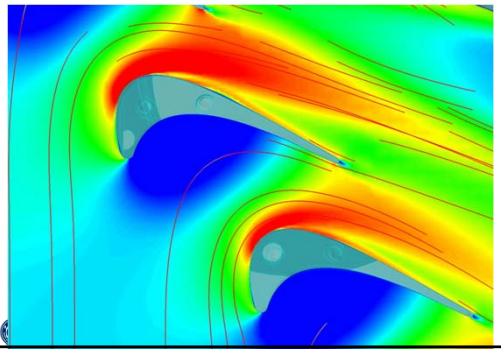
Tip Research

JI Aero-Thermal Laboratory



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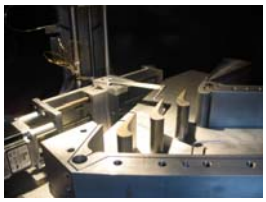
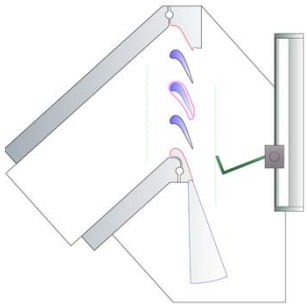
Exit loss measurement





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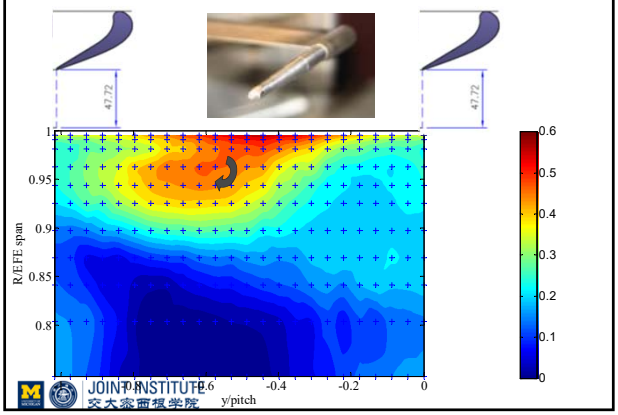
Cp Loss coefficient contour



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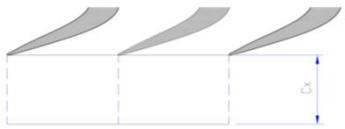
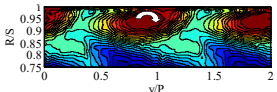
Some Sample Measurement Data

Loss coefficient

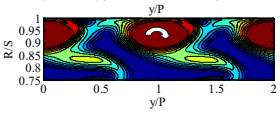
CP_0



Experimental data



CFD



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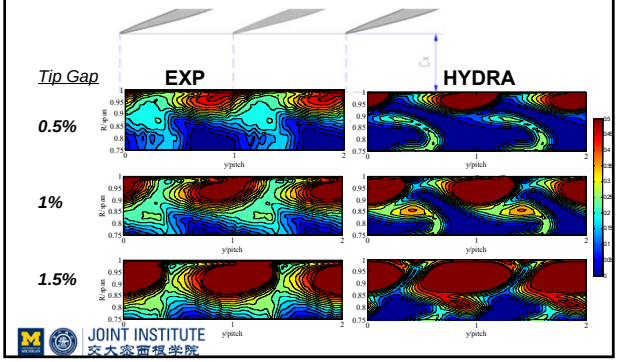
Some Sample Measurement Data

CP_0 Loss coefficient



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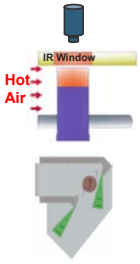
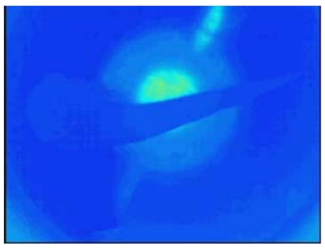
An interesting finding…

Rolls-Royce

IR camera



IR video captured during one blow down test



Flat tip, 1.5% tip gap

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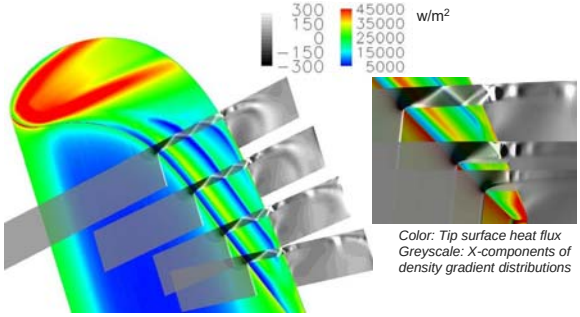
CFD : A virtual Schlieren visualization

Rolls-Royce



Color: Tip surface heat flux
Greyscale: X-components of density gradient distributions

Shock wave signatures !

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Follow-up Project Suggestions

- Suggest to focus on ONE Improvement per team.
- What key physical principles are involved ? What new story can you tell? (**not just some fancy design, again I am not looking for the best performer in testing!**)
- Can your objective be achieved within the budget and time?
- What potential risks?

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Review

- ReCap: Conduction
- Convection
- Radiation

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