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Multi-Parameter Optimization of Gas Turbine Blade Snubber

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Mechanical and Aerospace Engineering

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Work supported by Siemens

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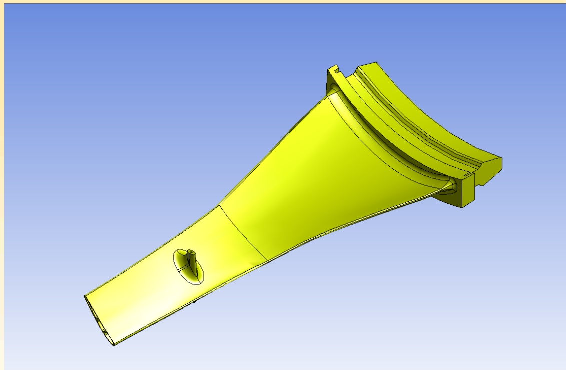
Introduction



- Turbine blades can be long at the latter stages
- Snubber necessary for damping the blade vibrations
- The cross-sectional shape of the snubber was circular in Siemens original design
- Here, we modify it to elliptical-like to achieve better performance in terms of reduction of drag and structural stress.
  - Multi-parameter optimization with Isight
  - Integrated CFD and structure analysis with ANSYS/Fluent
  - Experimental effort on heat transfer analysis

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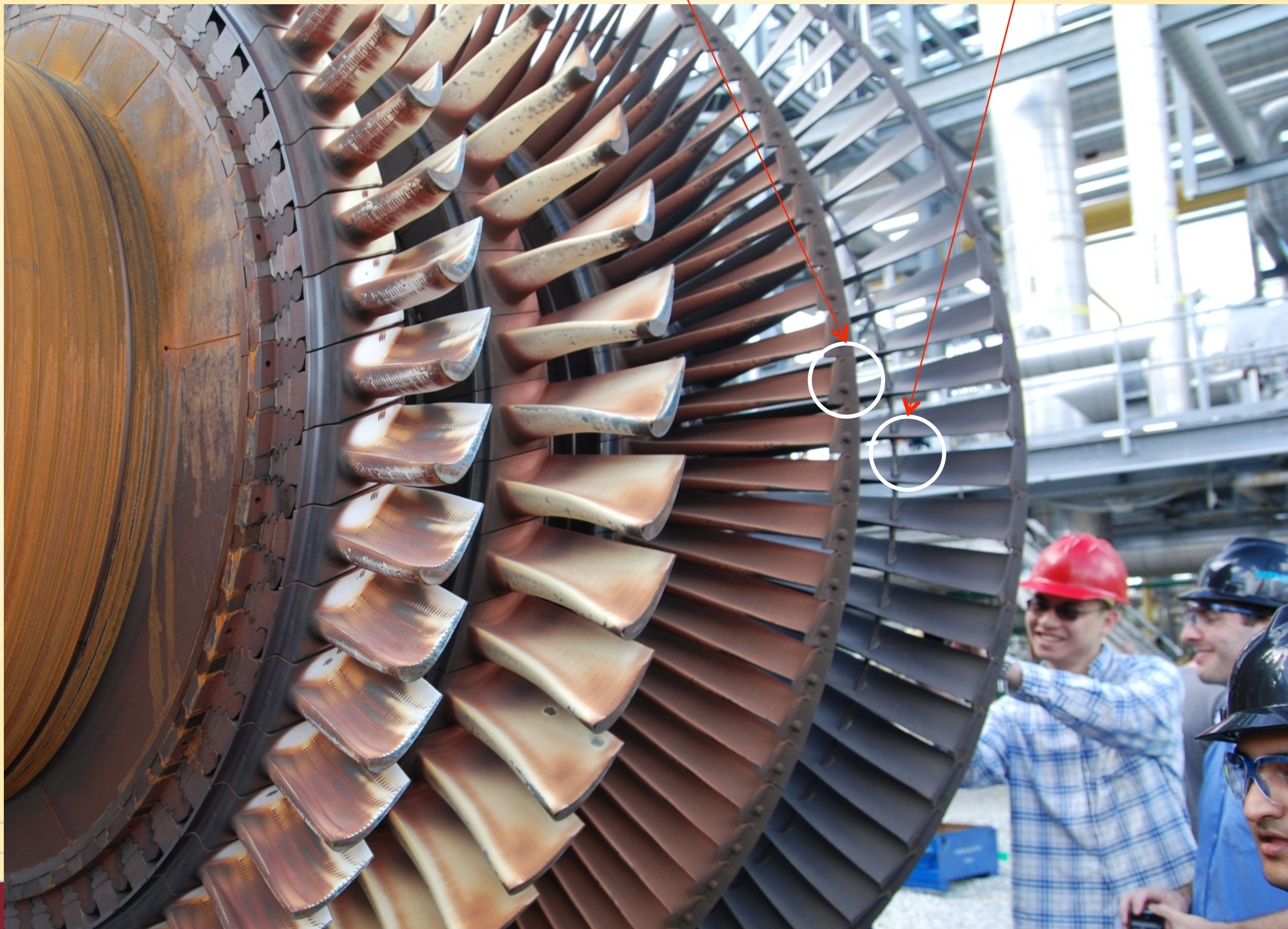

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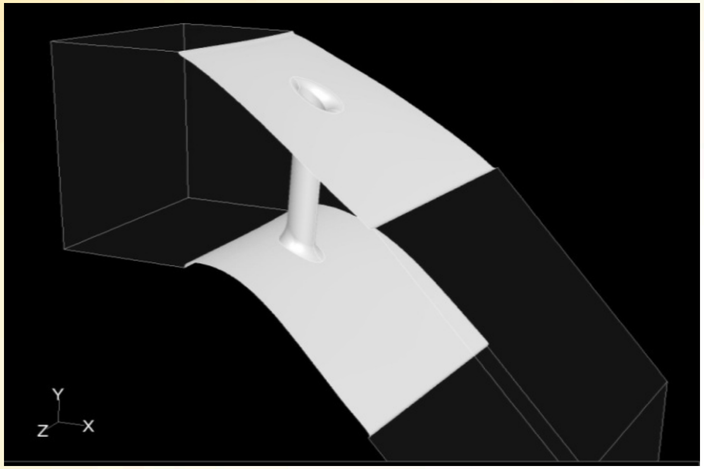
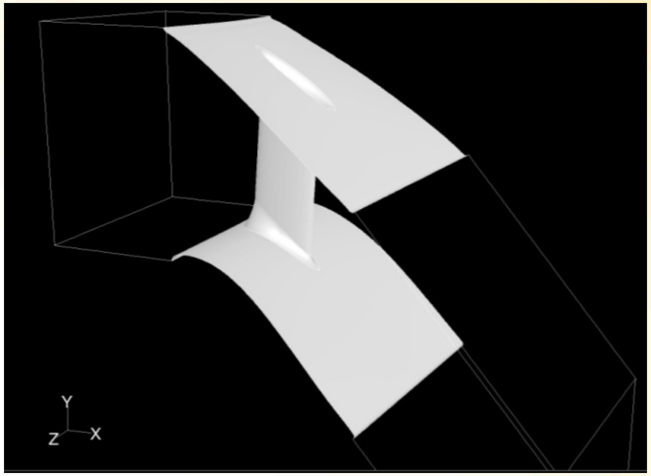
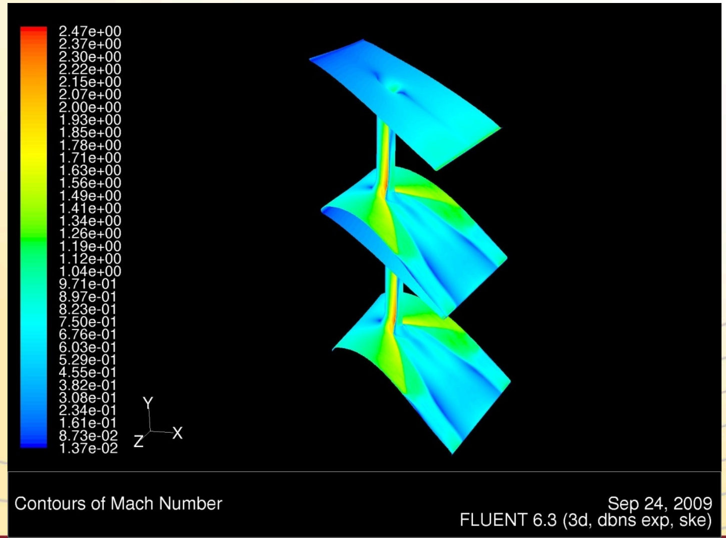
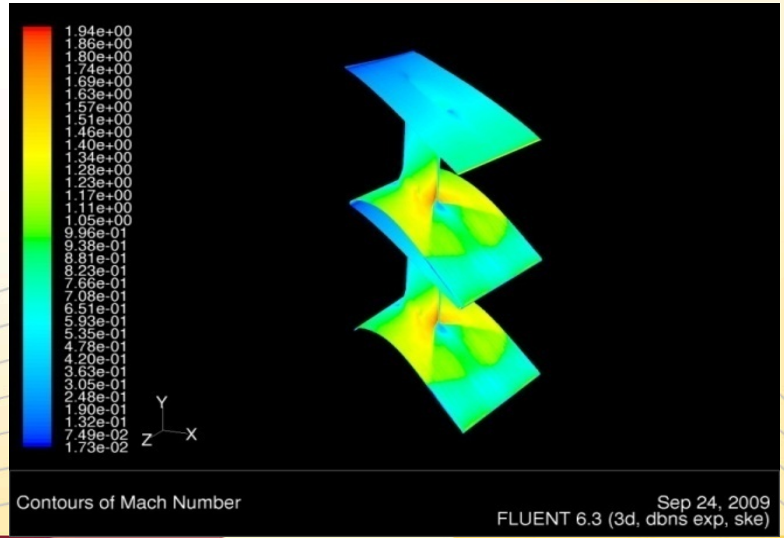
Performance Improvement by Redesigning the Snubber Cross-sectional Shape from Circular to Elliptical

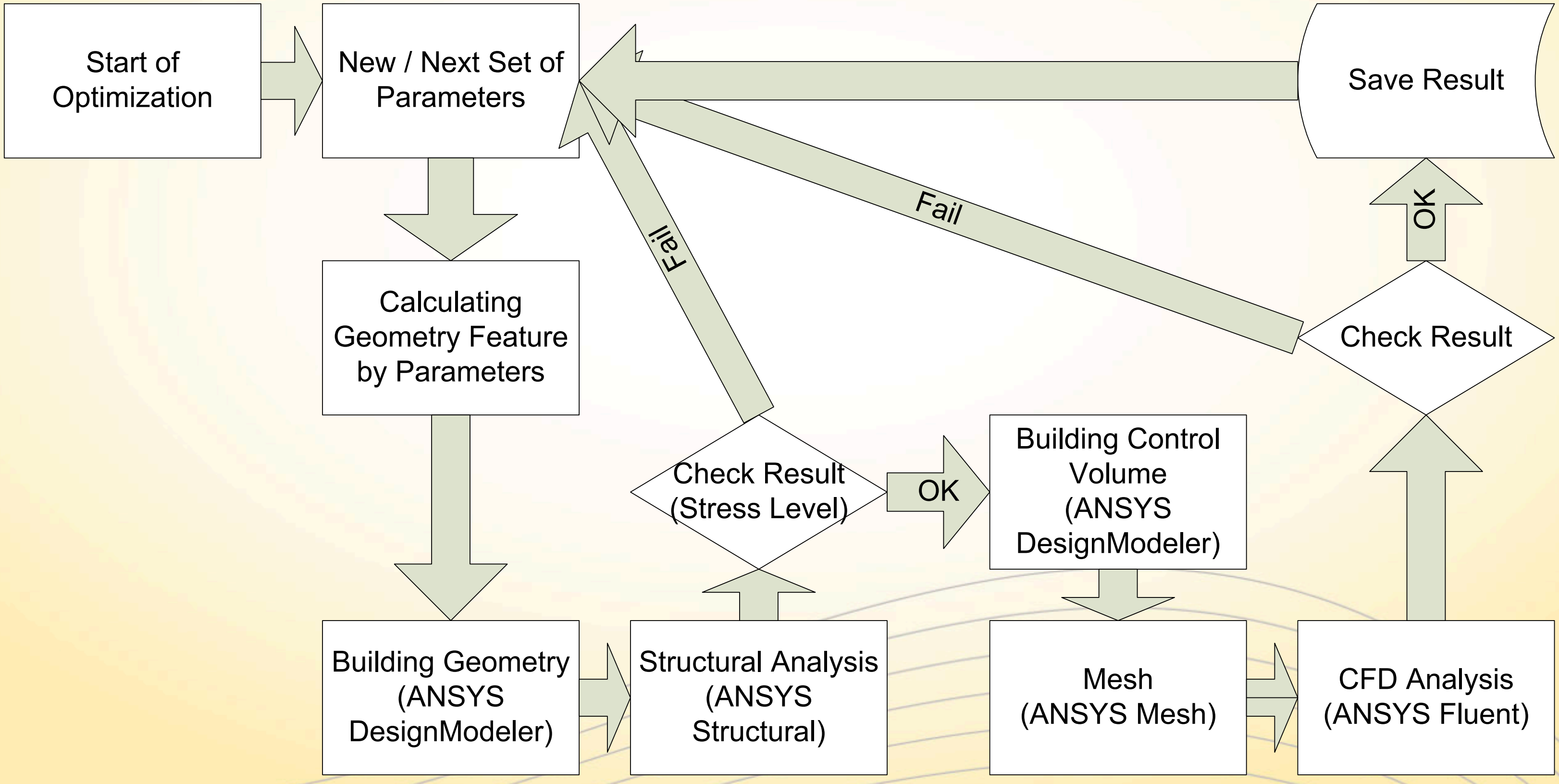




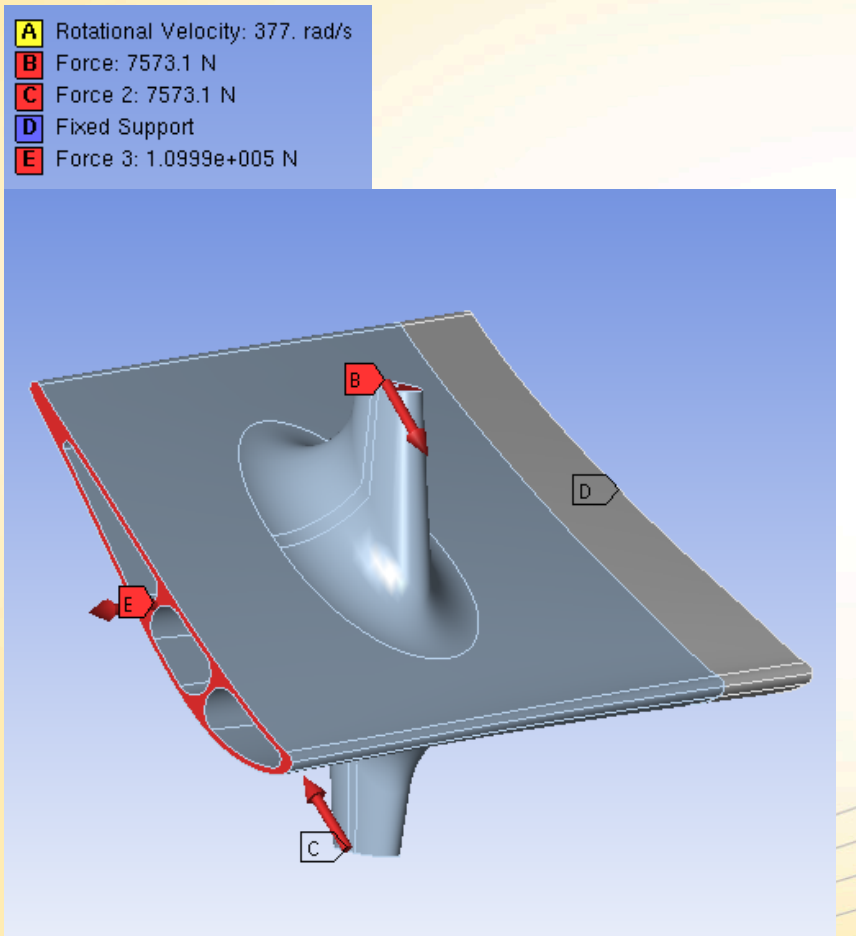




Isight Optimization Engine Flow Chart



Structure Analysis Condition



- [A] Rotational Velocity
- [B],[C] Contact force on end of snubber
- [D] Fixed support on sub-model blade root

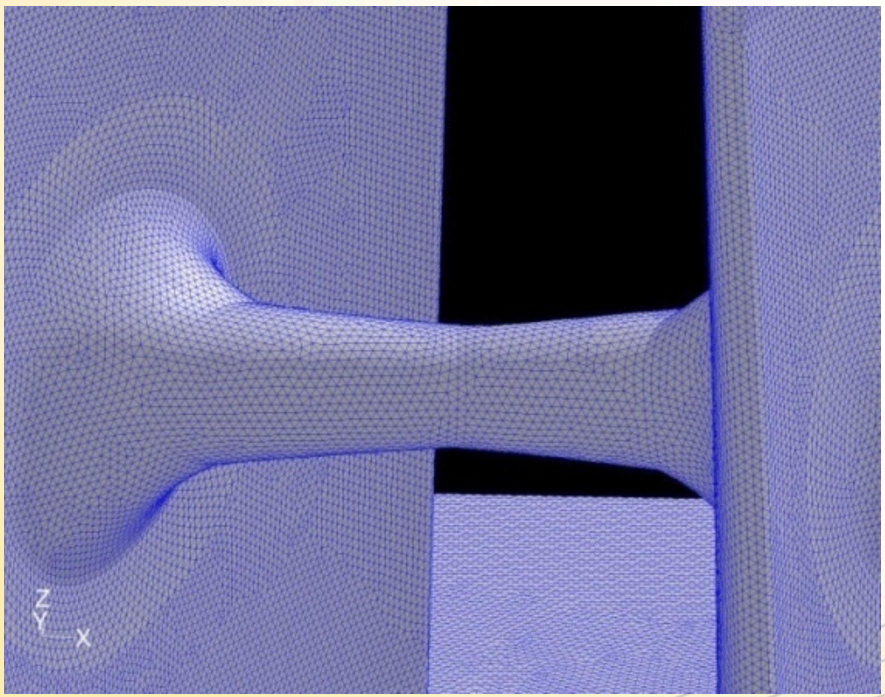
  (Displacement = 0)
- [E] Centrifugal force on blade tip of sub-model

  $F = mR\omega^2$

  109,988 N

  = 0.518 kg × 1.493 m × (377 rad/sec $)^2$

Computational Fluid Dynamics (CFD) Analysis Condition



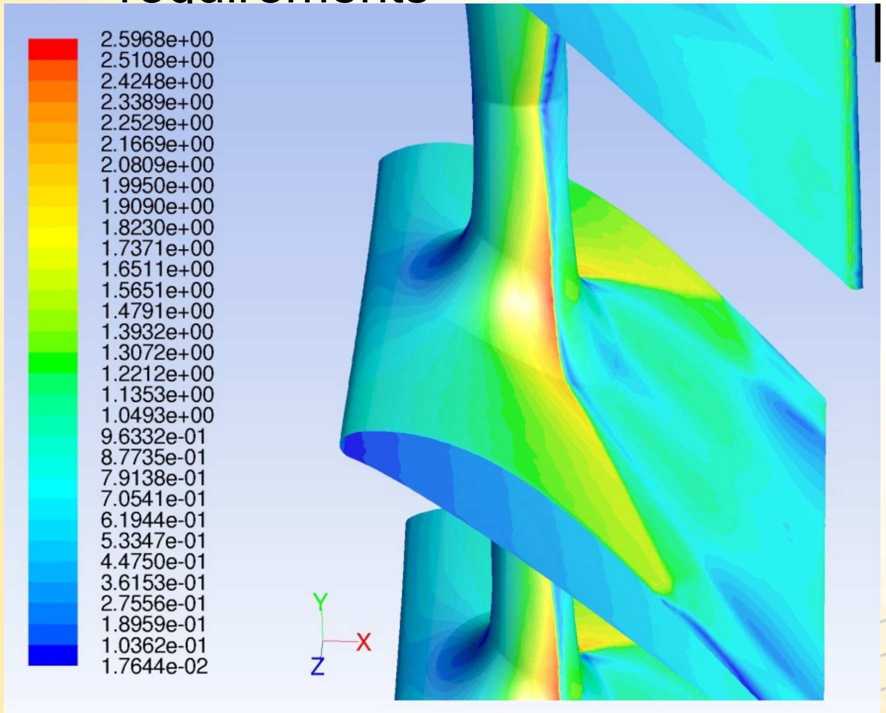
T-grid mesh

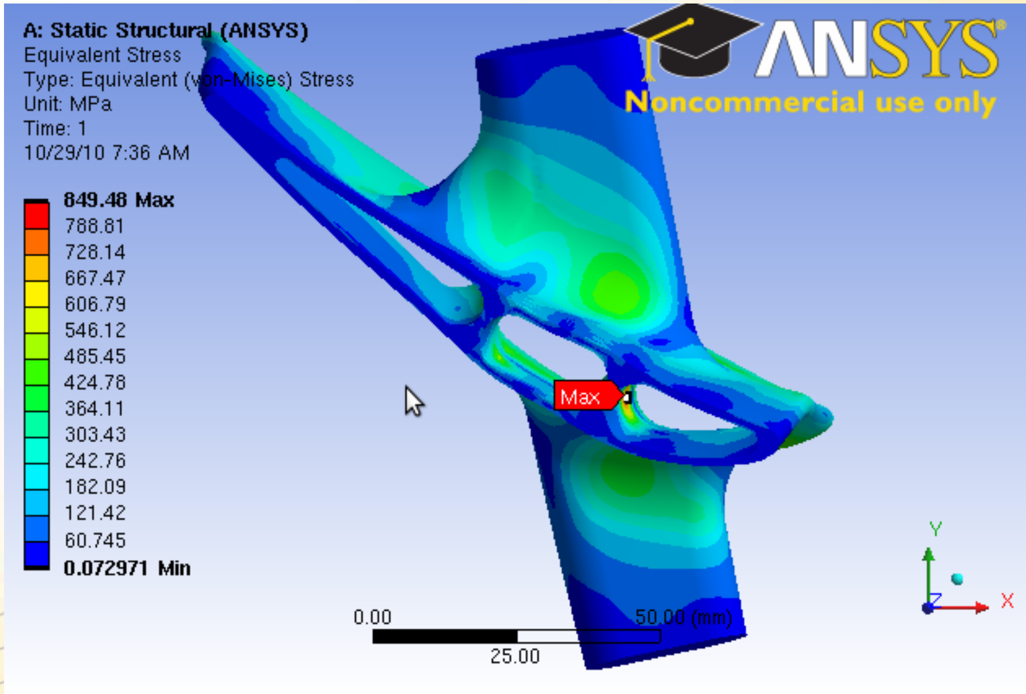
- Control volume analysis between 2 parallel blades.
- T-grid mesh (Unstructured)
- k-ε turbulence model (2-equation model)
- Solved with energy equation

Inlet Total pressure	1.8435 bar
Outlet Static Pressure	0.823 bar
Operating temperature	1121. 2 K
Average inlet Mach Number	0.31

Gas Turbine Blade Component Design Optimization via Integrated Aerodynamics, Heat Transfer, & Structure Analyses

- Integrated Fluent and ANSYS Structure software tools under Isight
- Geometry parameters and constraints optimized with gas turbine design requirements





Contours of Mach Number

Contours of Stress (MPa)

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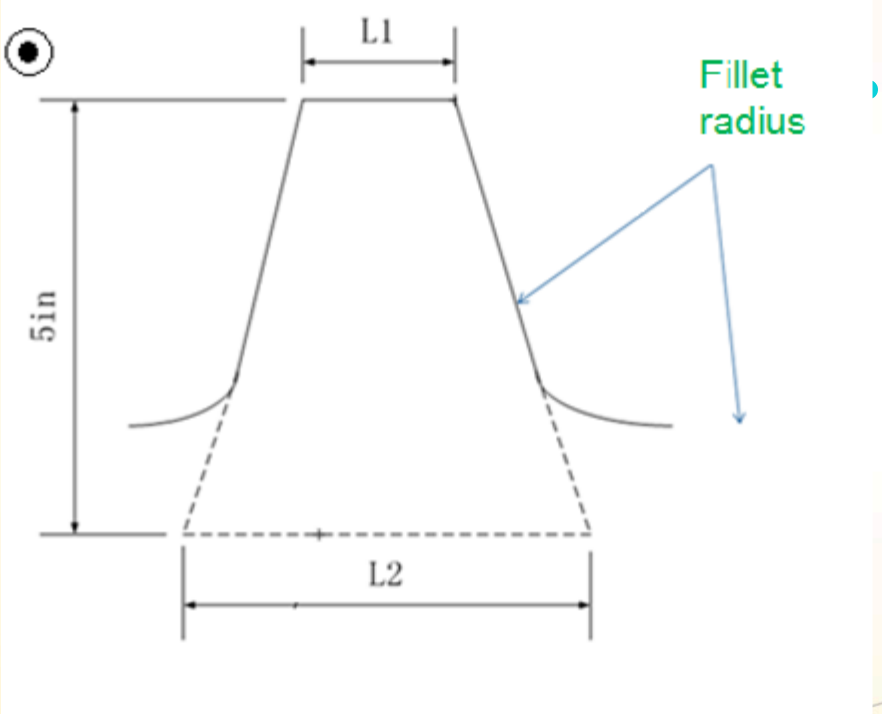
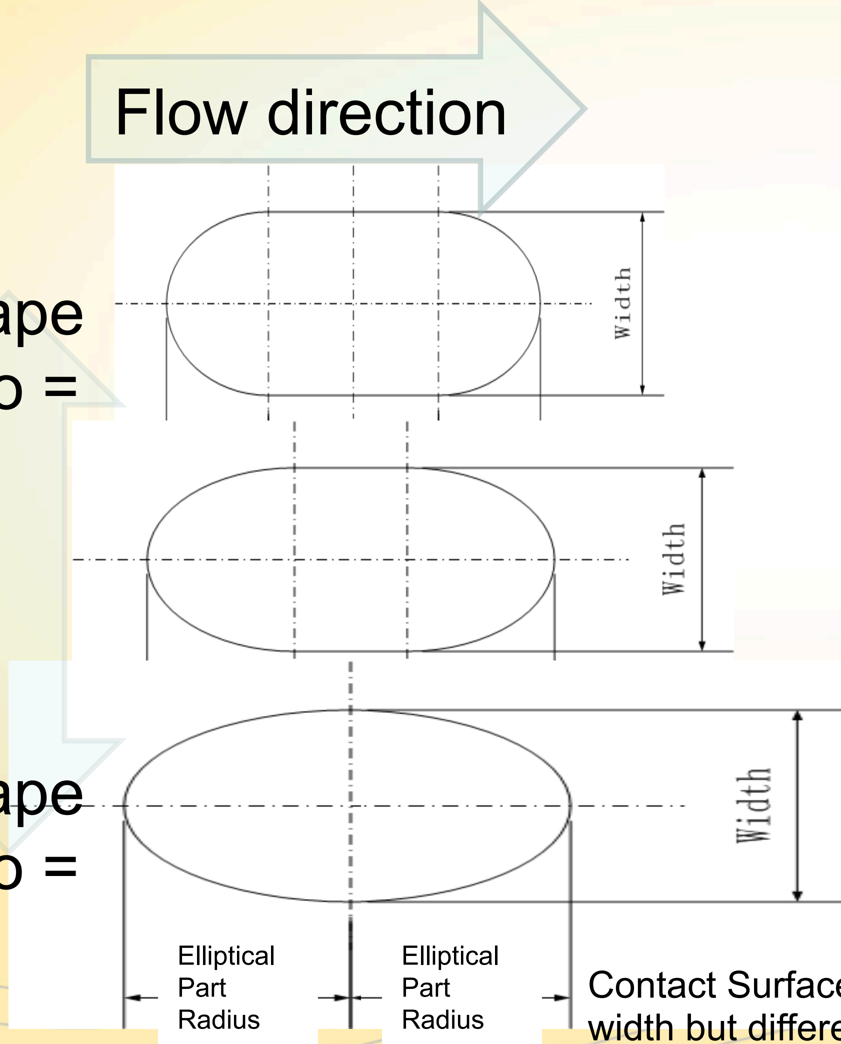
5-Parameter Geometry Model



Front view of snubber

- 5 parameters:
  - 1. Taper ratio = L_1 / L_2
    - L_2 is length on the projection plane, which is 5 inch below contact surface
  - 2. Pressure side fillet radius
  - 3. Suction side fillet radius

5-Parameter Geometry Model



Shape ratio = 0.5

Shape ratio = 1

Contact Surface with constant width but different shape ratio

- 4. Contact Surface Width
- 5. Contact surface Shape Ratio

$$= \frac{Elliptical\_part\_radius}{Elliptical\_part\_radius_{Max}}$$

- Note: *Elliptical_part_radius* is equal to *Elliptical_part_radius*$_{Max}$ when straight line segment goes to zero (total area keeps the same)
- When *Shape_ratio* = 1, contact surface is totally elliptical
- When *Shape_ratio* = 0, contact surface is a rectangle.

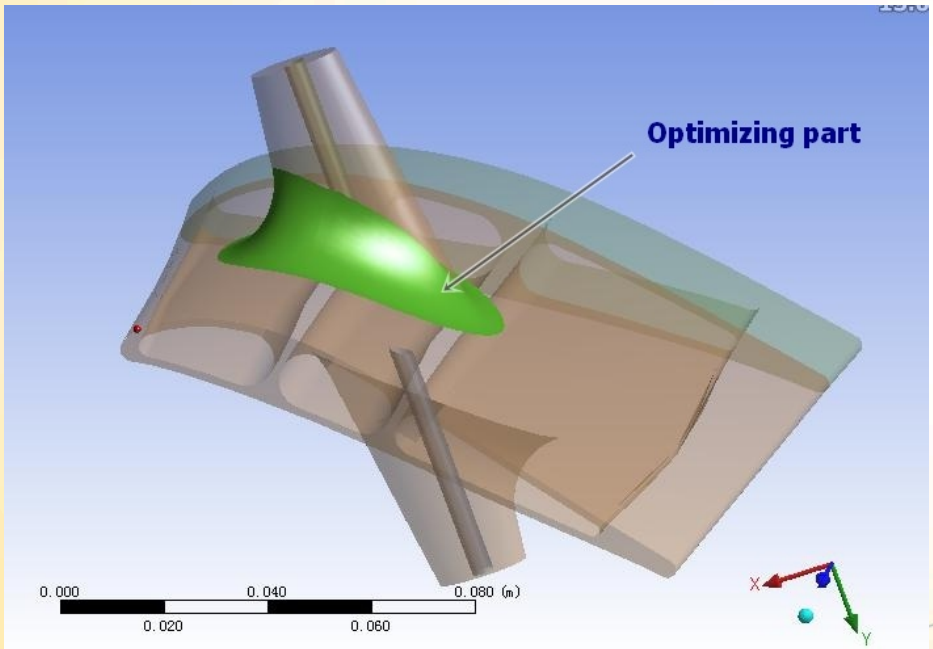
Contact surface area

= 178 × cos45° mm^2

(Constant, calculated by contact needs)

Recent Development

Flow direction



Side view of snubber

- Use the best result of 5-parameter study

Fillet Radius of PS	17.154 mm
Fillet Radius of SS	17.651 mm
Shape Ratio	0.8151
Taper Ratio	0.3732
Snubber Width	9.322 mm

- Add two parameters on fillet radii of each side (see next slide)

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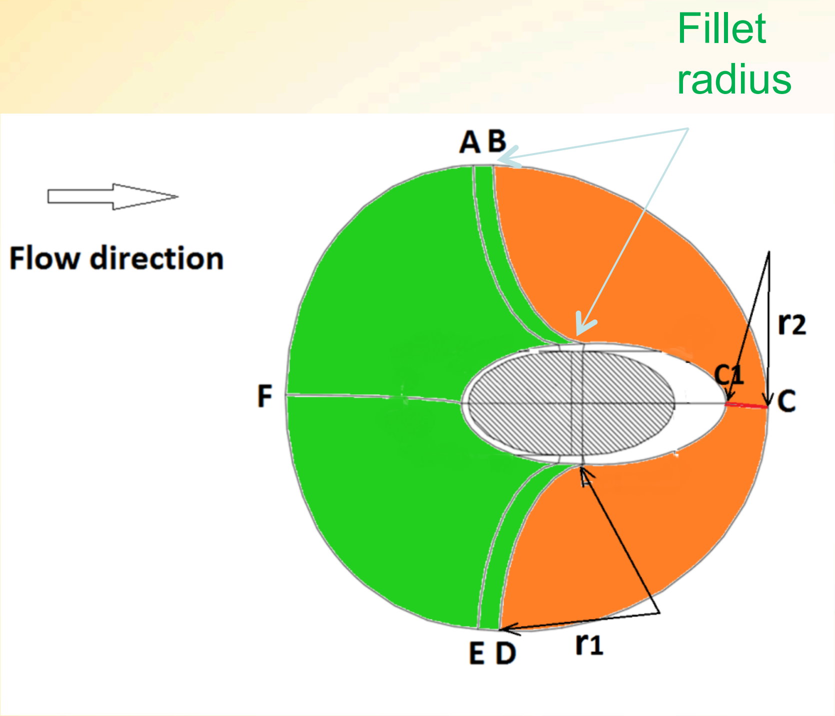
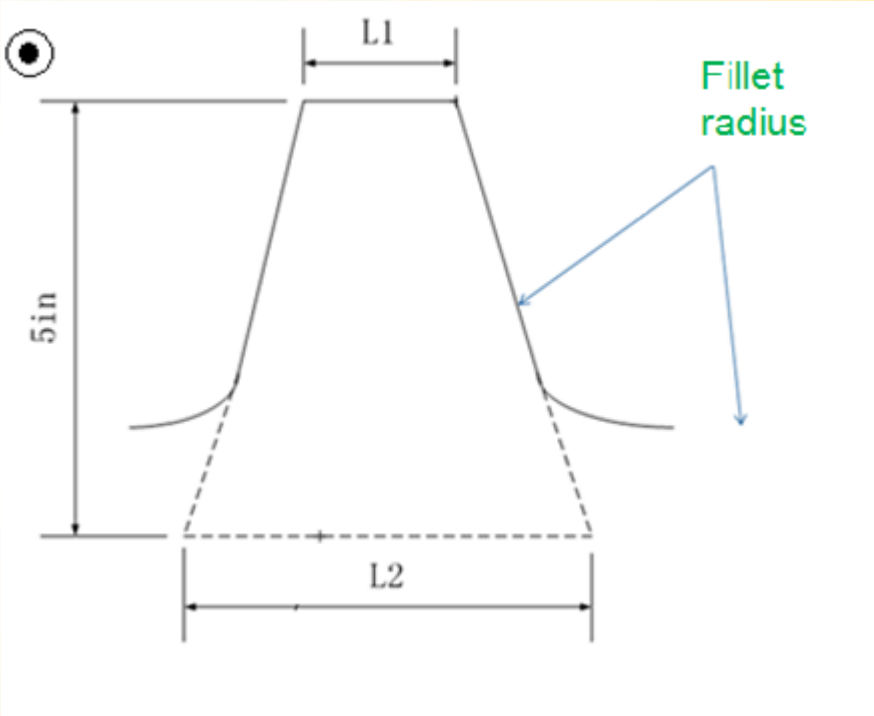
The New Geometry Model





B-A-F-E-D (the green area), same radius, r_1

D-C and B-C (the orange area), the radius linearly changes from r_1 to r_2

Objective Function

$$obj = -\left(\frac{\left(\frac{\sigma}{k}\right)^{\frac{1}{m}} - \left(\frac{\sigma_B}{k}\right)^{\frac{1}{m}}}{\left(\frac{\sigma_B}{k}\right)^{\frac{1}{m}}} - \frac{\bar{v}D - \overline{v_B}D_B}{v_B D_B} \right)$$

- *Obj* Objective function
- σ Maximum equivalent stress
- *k, m* Constant between stress and blade life cycles
- *D* Drag force on 5in section
- *v* Mean velocity cross blade and snubber
- σ_B 400 MPa (Baseline)
- D_B 800 N (Baseline)

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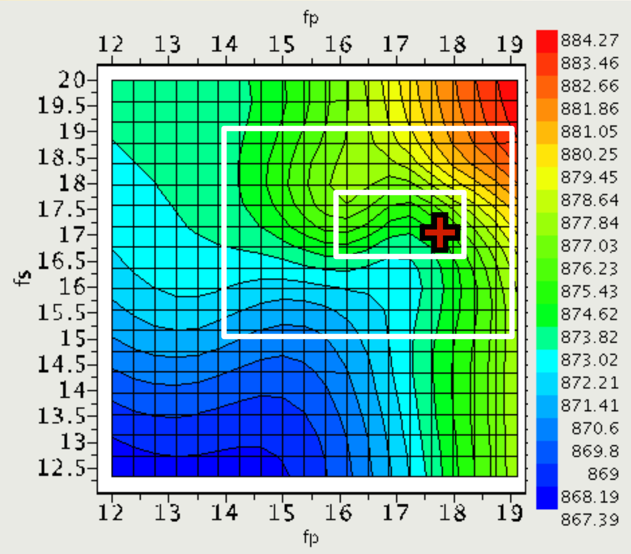
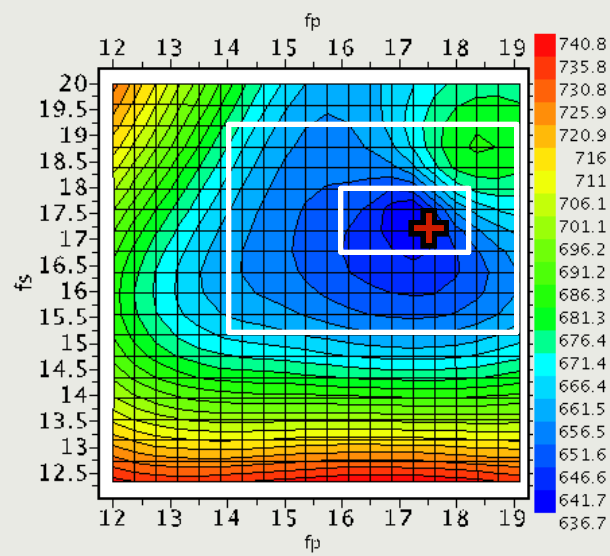
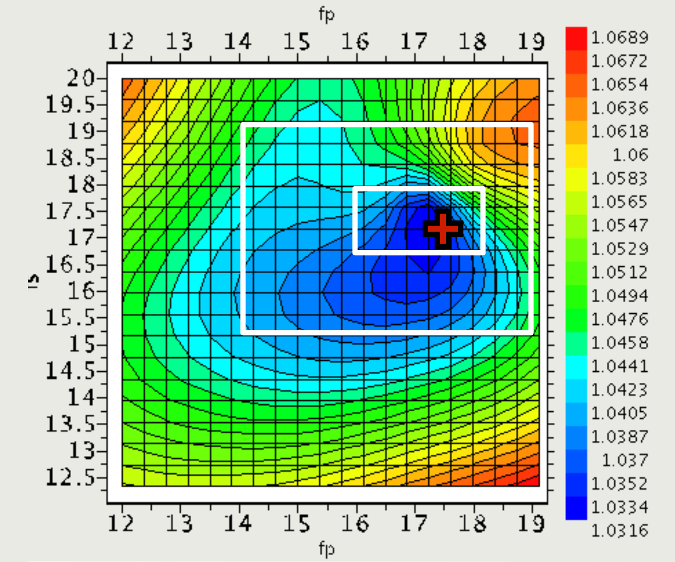
Optimization of Snubber Geometry to Reduce both Drag Force and Max Equivalent Stress







- **Drag Force (N)**
- **Max. Eq. Stress (MPa)**
- **Objective Function**

✚ Best Result of DOE search

Optimization Results

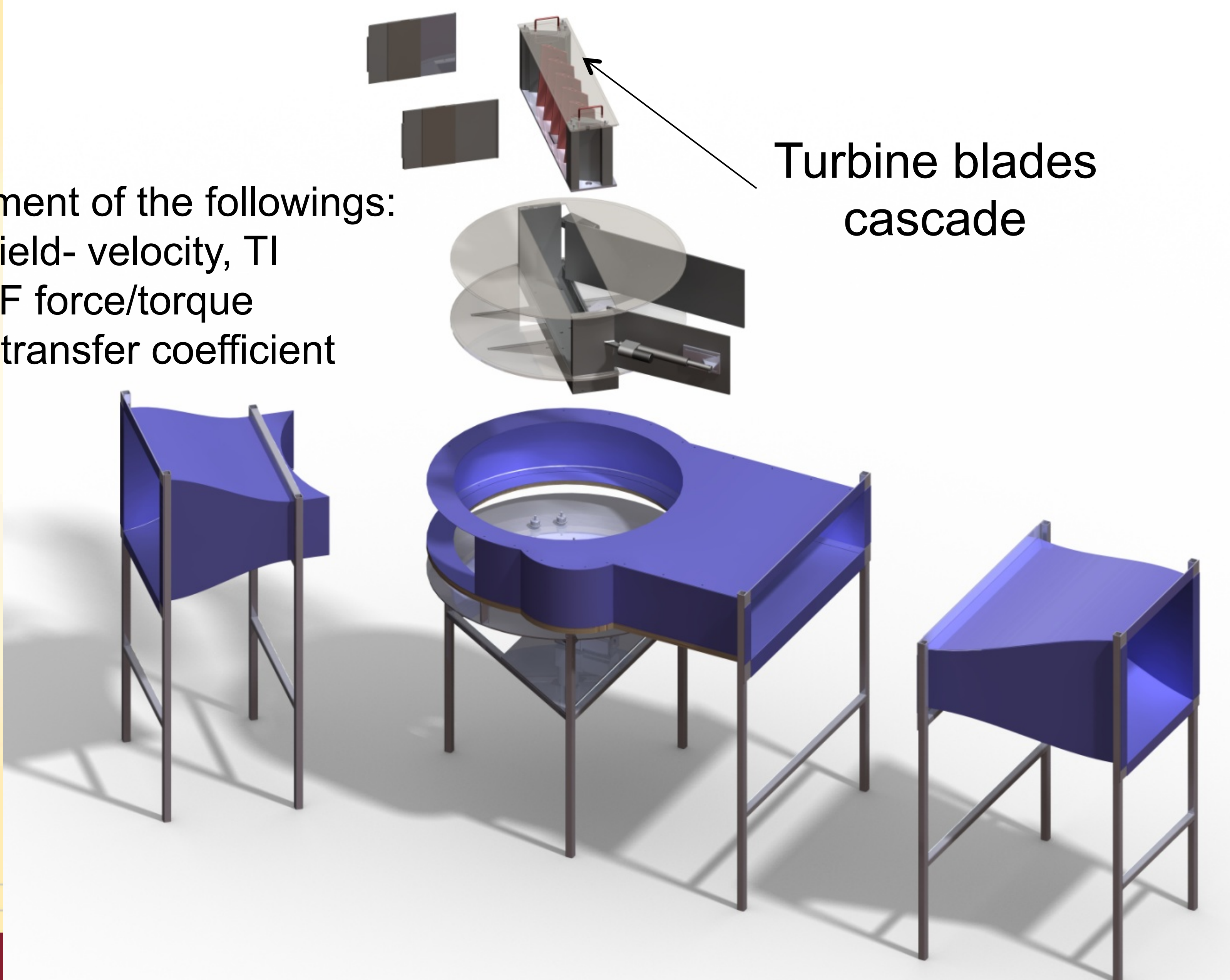
	Drag Force (N)	Max. Stress (MPa)
Original Siemens Design	894	752
5-parameter	867	643
New model	859	621

Drag Reduction	Stress Reduction
4%	16%

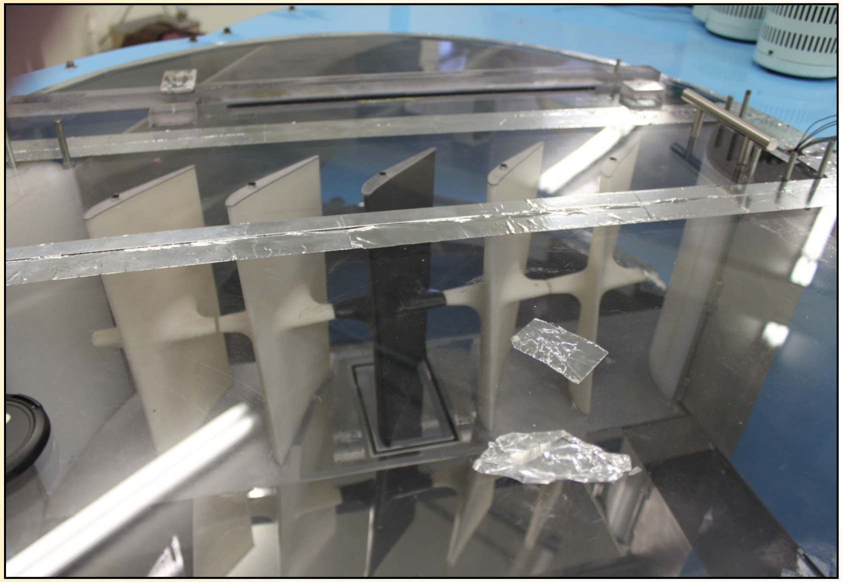
Wind Tunnel Testing

Measurement of the followings:

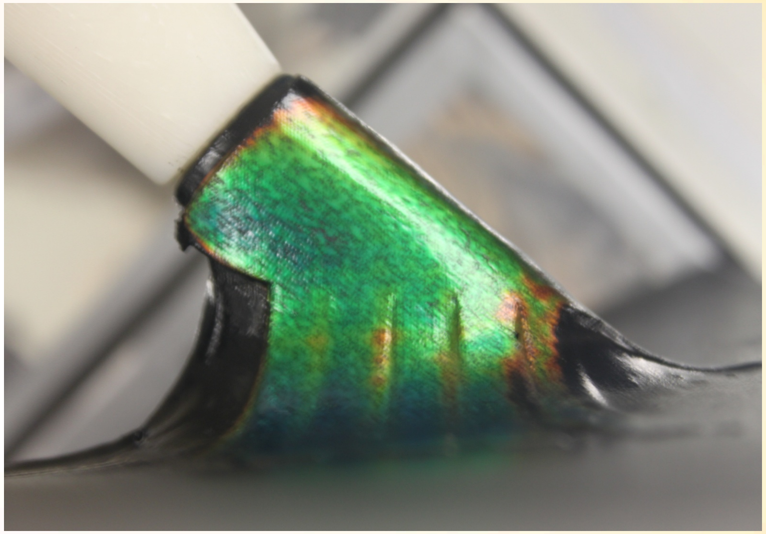
1. flow field- velocity, TI
2. 6 DOF force/torque
3. Heat transfer coefficient



Heat Transfer Experiment



Test Section



Thermochromic liquid crystal coating on top of heater covering snubber

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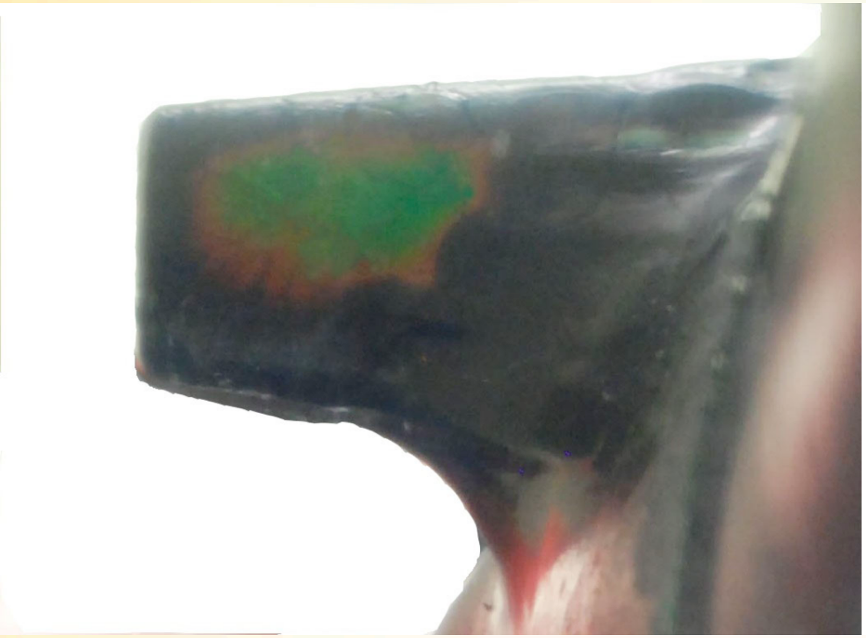
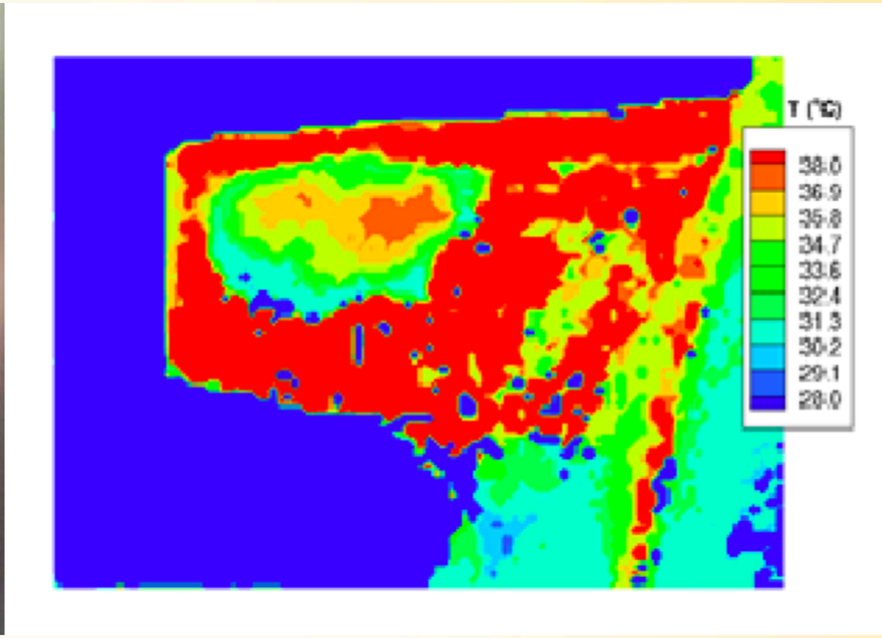
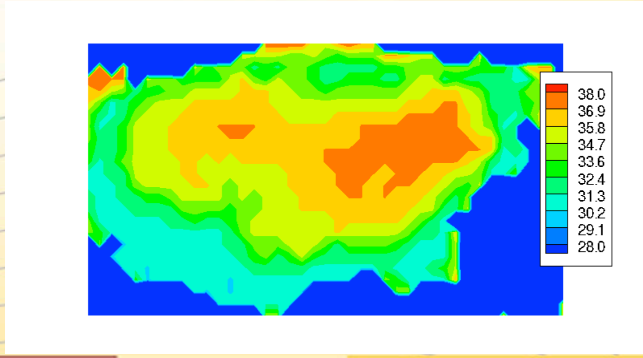
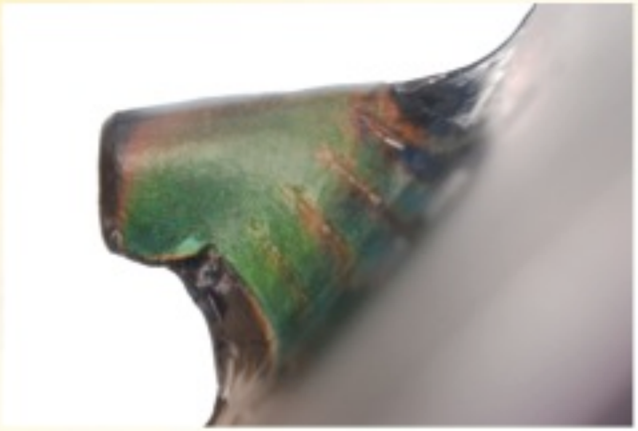
Image Processing

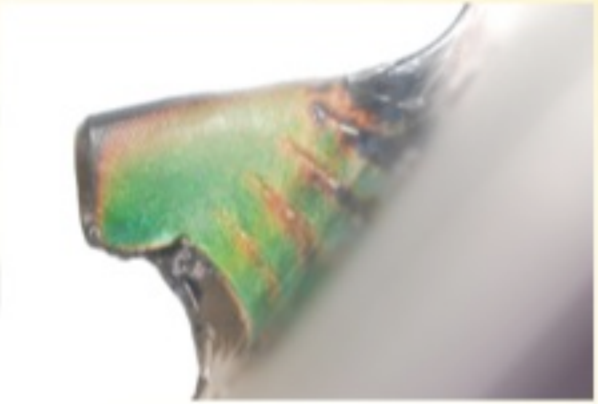


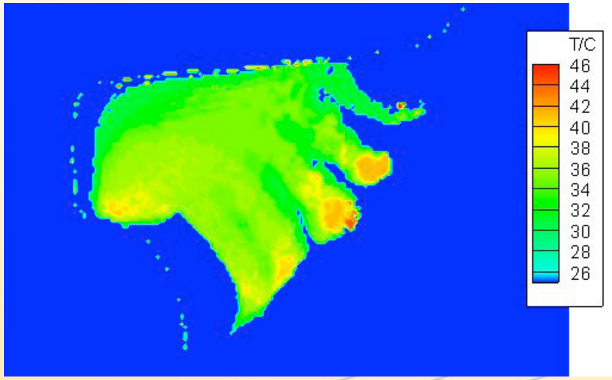


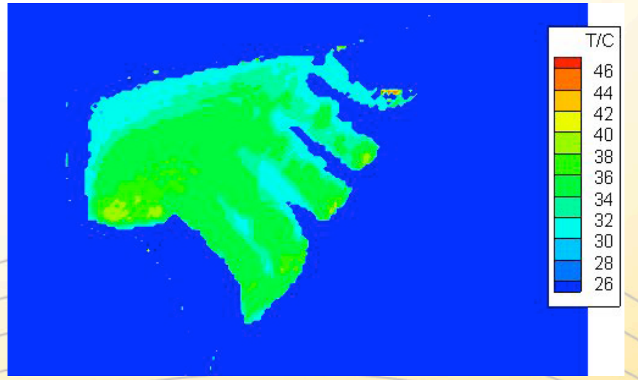


Wind speed: 17 m/s 20 m/s









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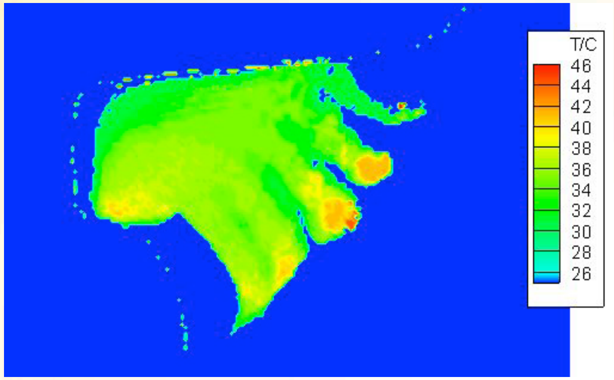
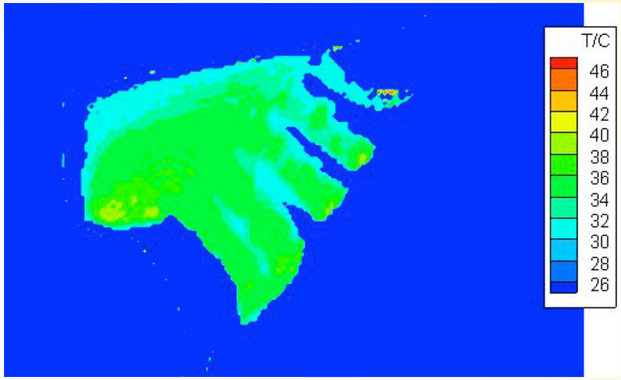
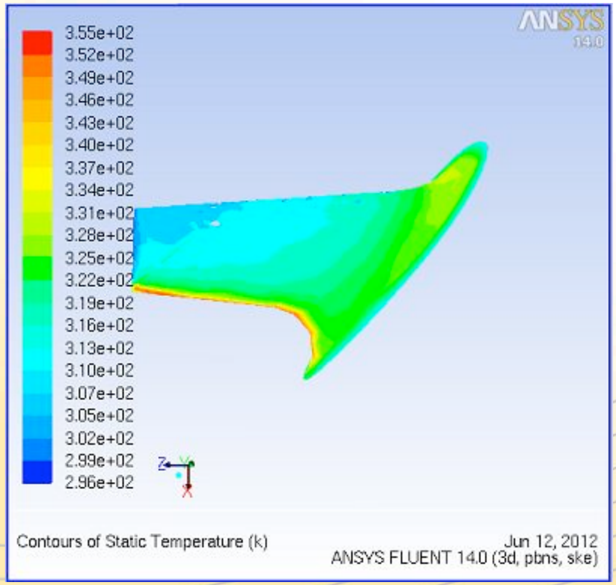
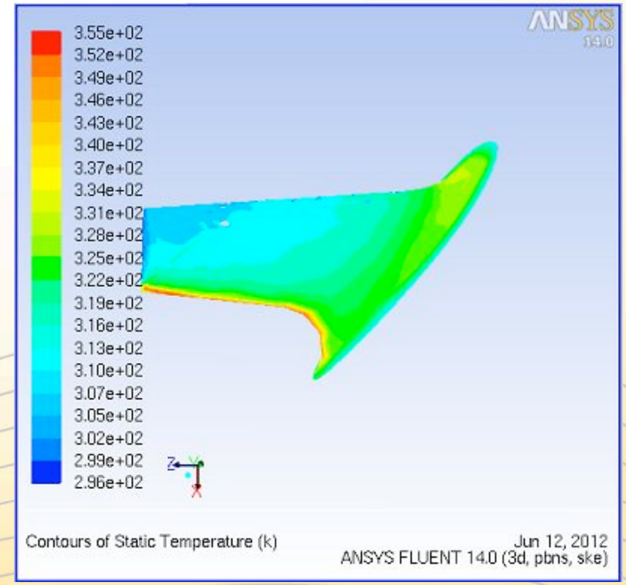
17 m/s

20 m/s









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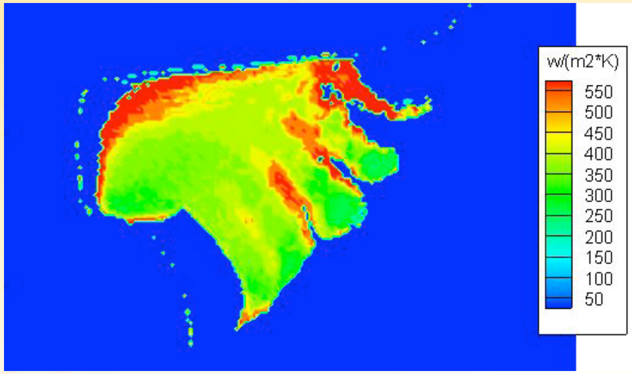
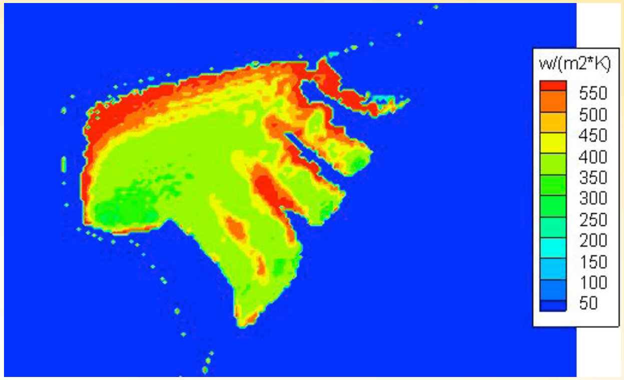
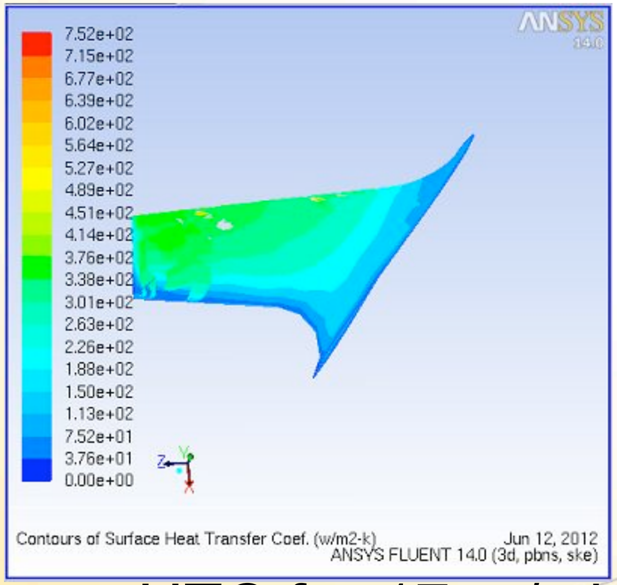
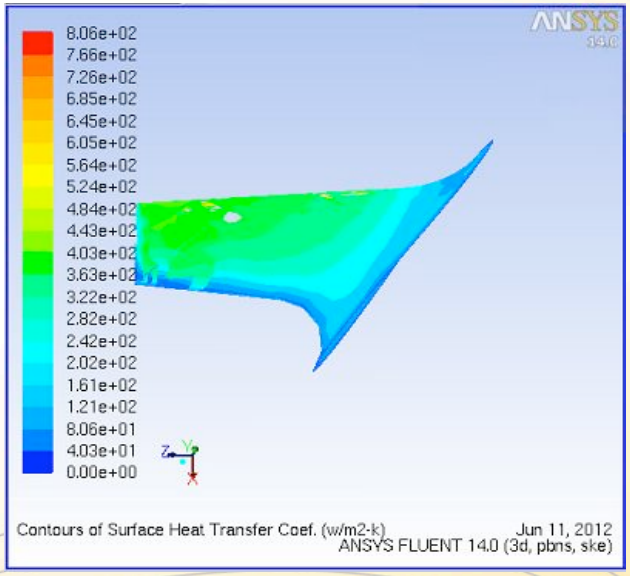




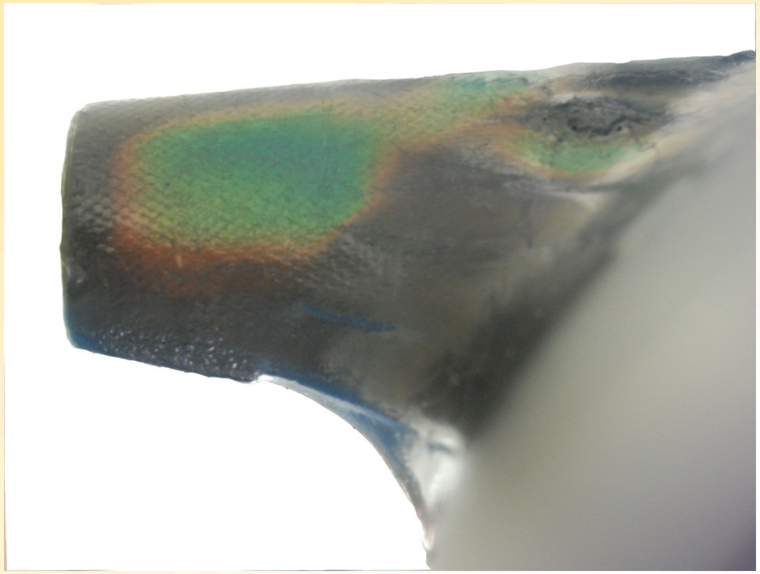




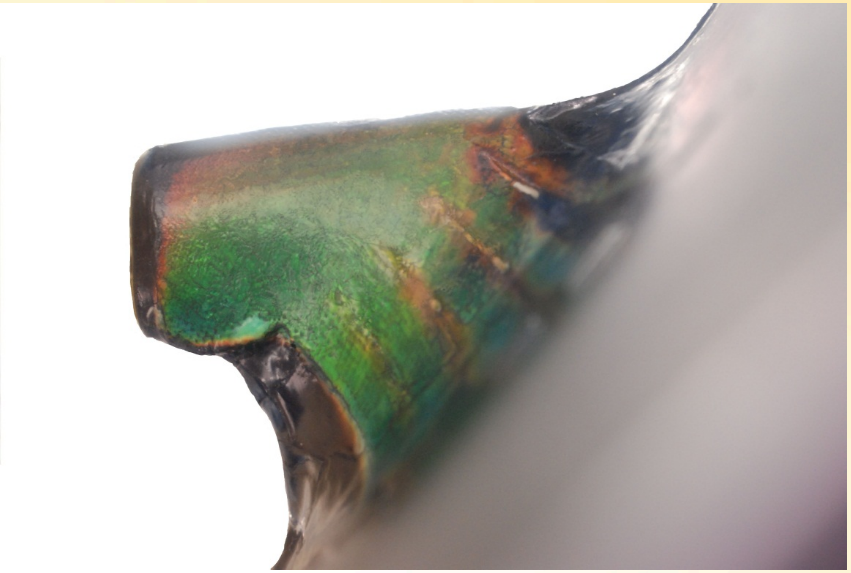
The average HTC for 17 m/s inflow:

Experiment: 395.3, suction side, 378.3 w/(m^{2}K), pressure side

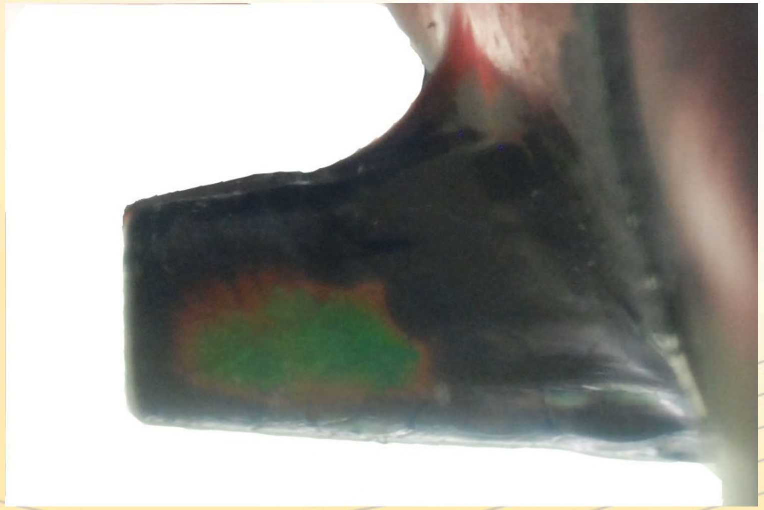
Numerical: 315.1, suction side, 309.1 w/(m^{2}K), pressure side.



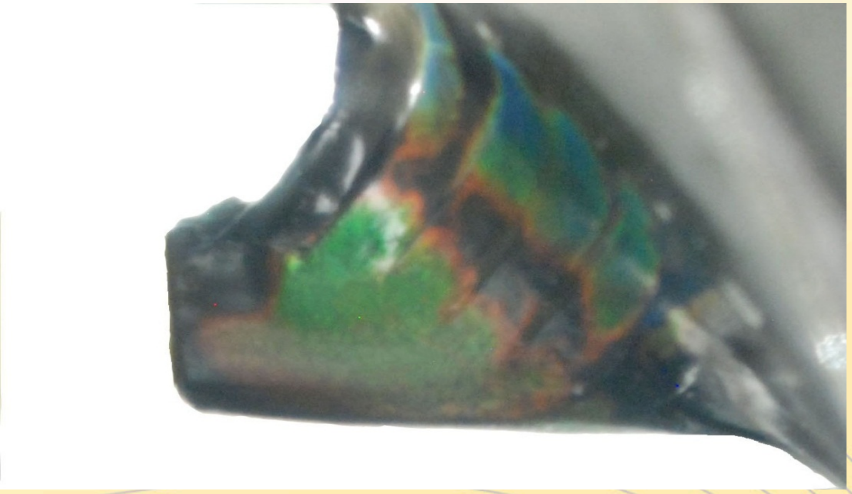
suction side , top view



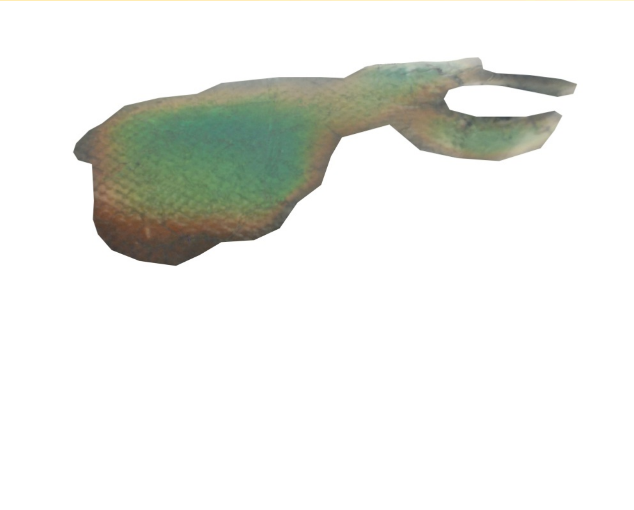
Pressure side , top view



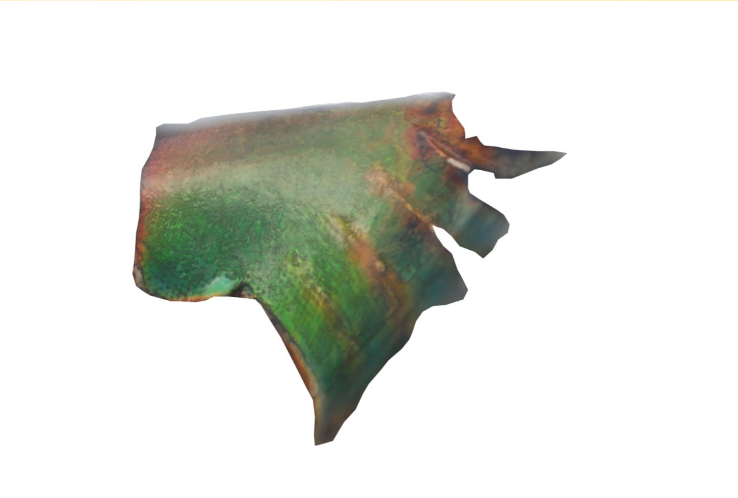
suction side , bottom view



Pressure side , bottom view

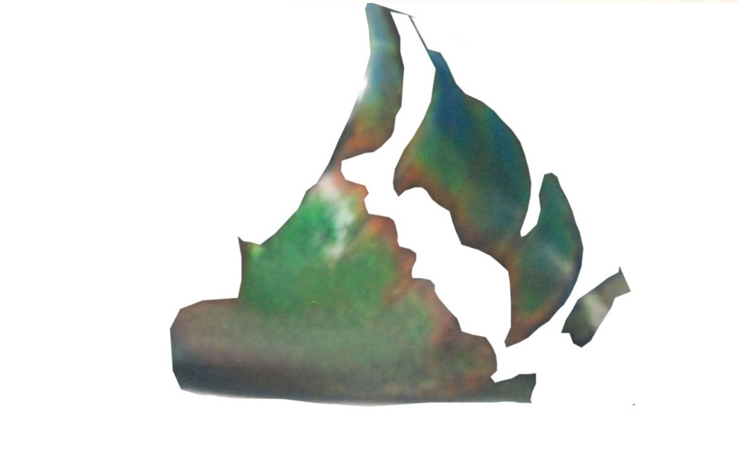


suction side , top view



Pressure side , top view

suction side , bottom view



Pressure side , bottom view

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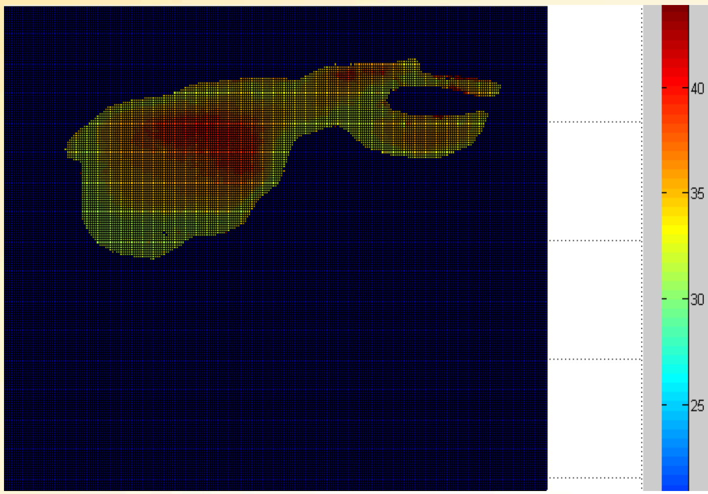
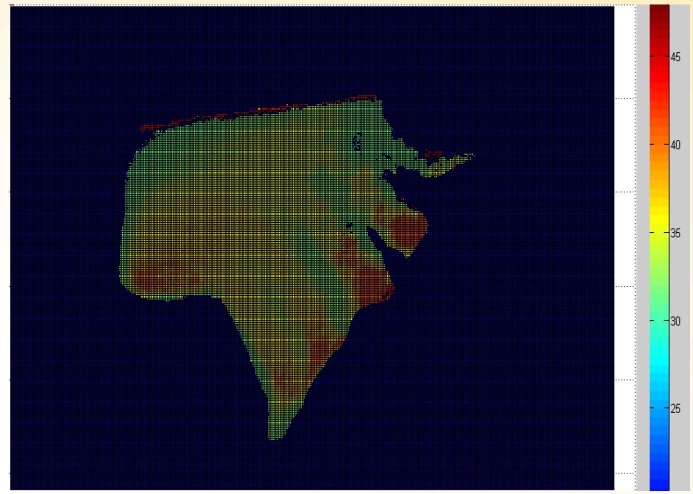
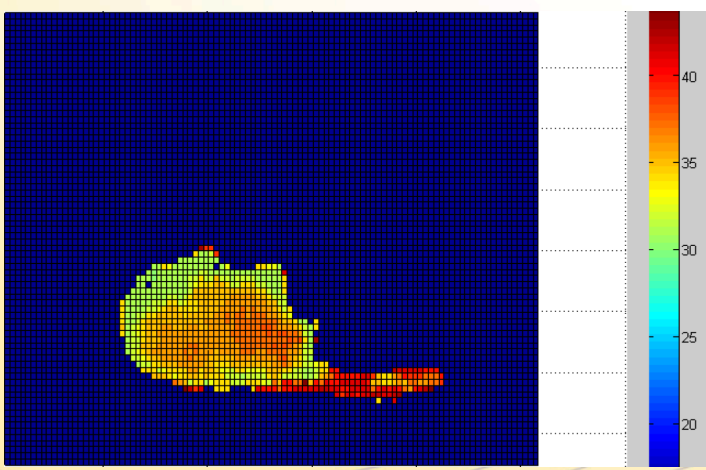
Temperature Distribution



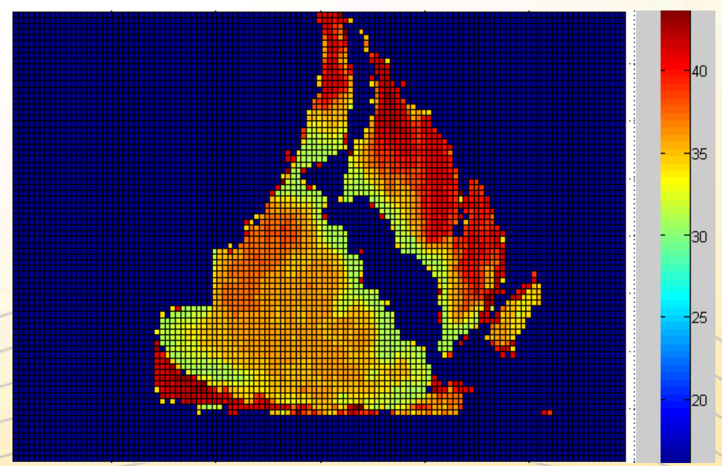
suction side , top view



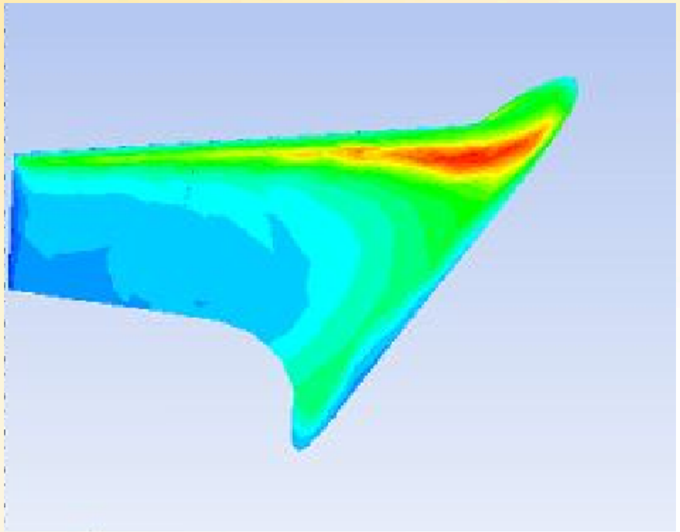
Pressure side , top view



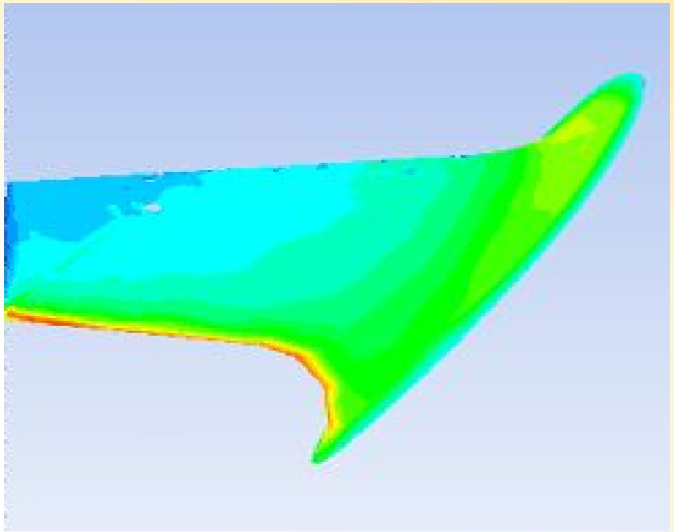
suction side , bottom view



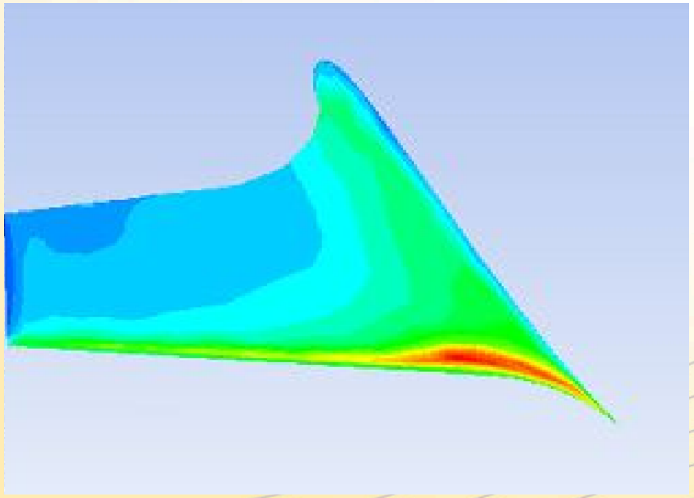
Pressure side , bottom view



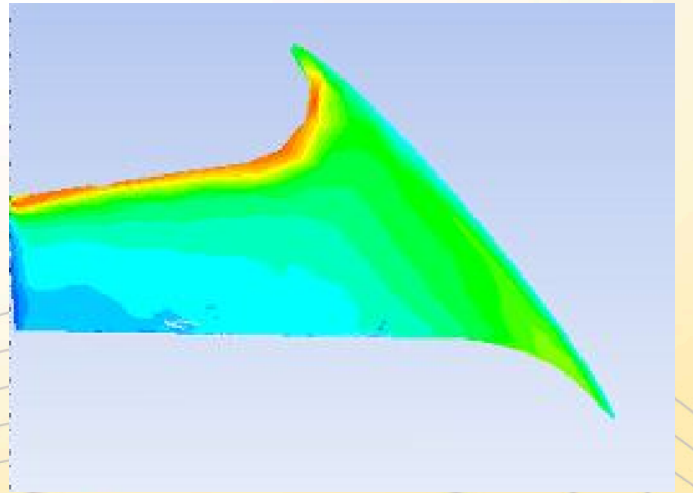
suction side , top view



Pressure side , top view

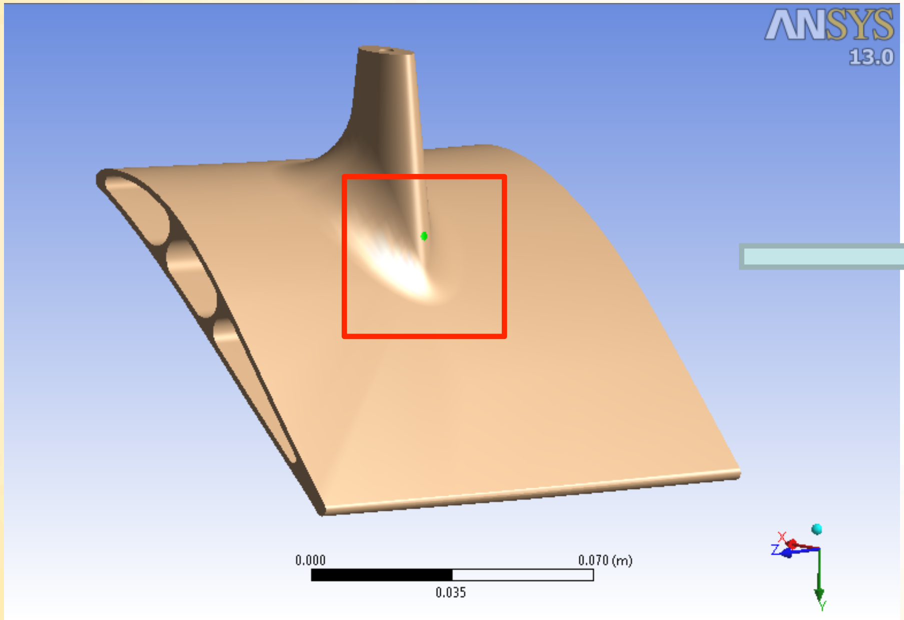


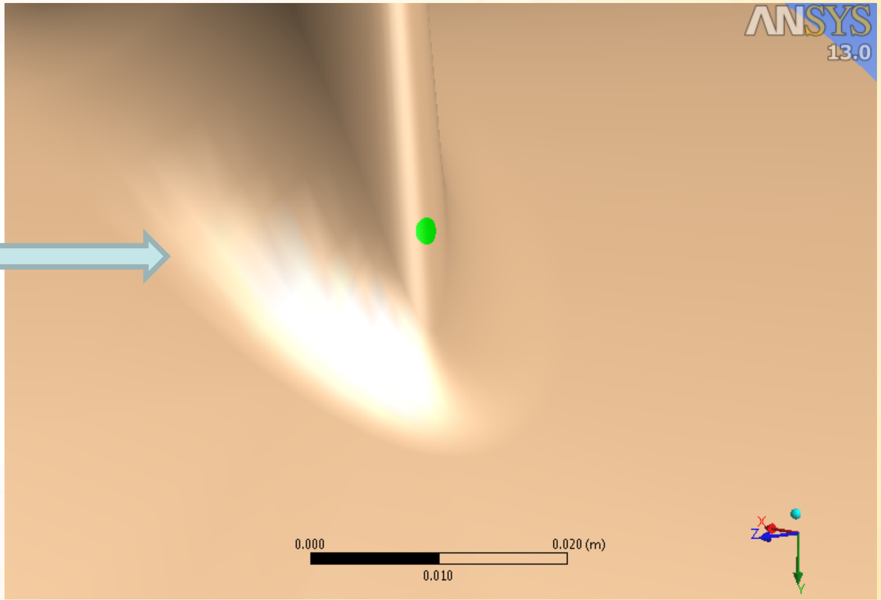
suction side , bottom view



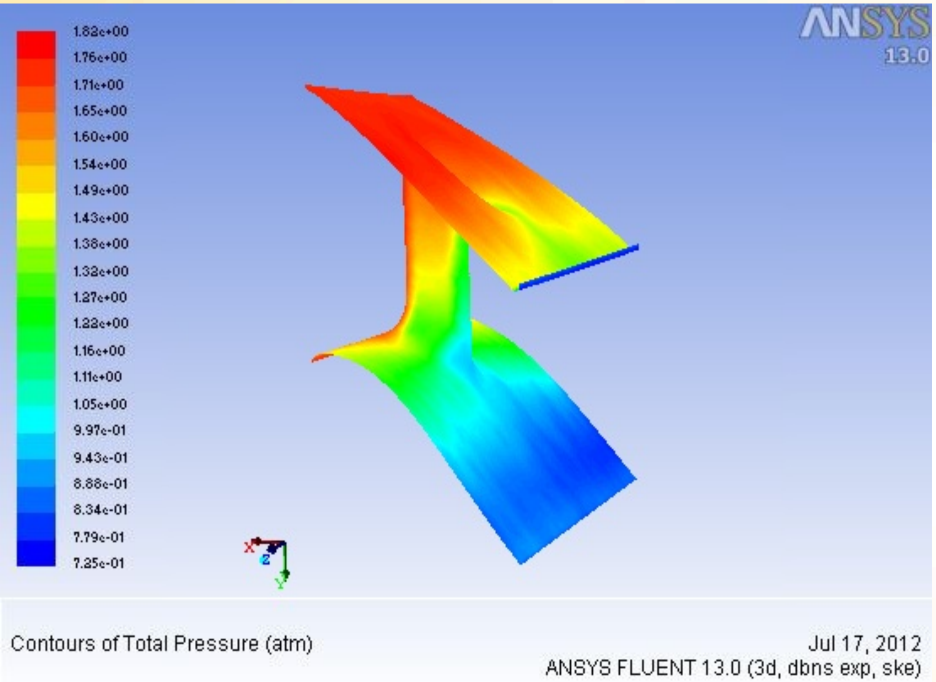
Pressure side , bottom view

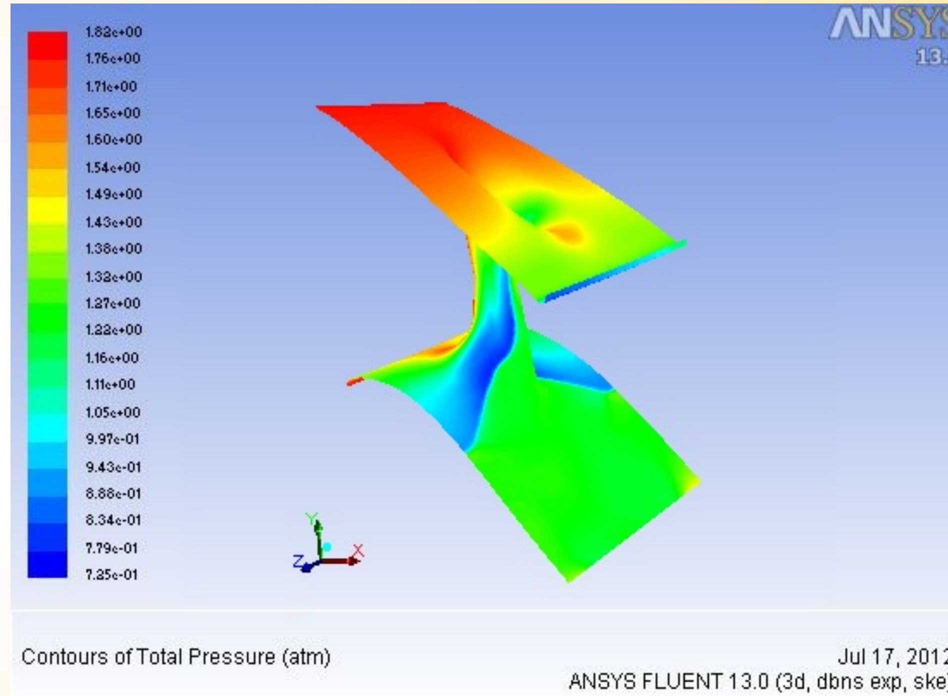
Simulations with Injecting Holes





Total Pressure on the Blade





Simulation case without injecting hole

Simulation case with injecting hole