TRANSONIC LINEAR CASCADE

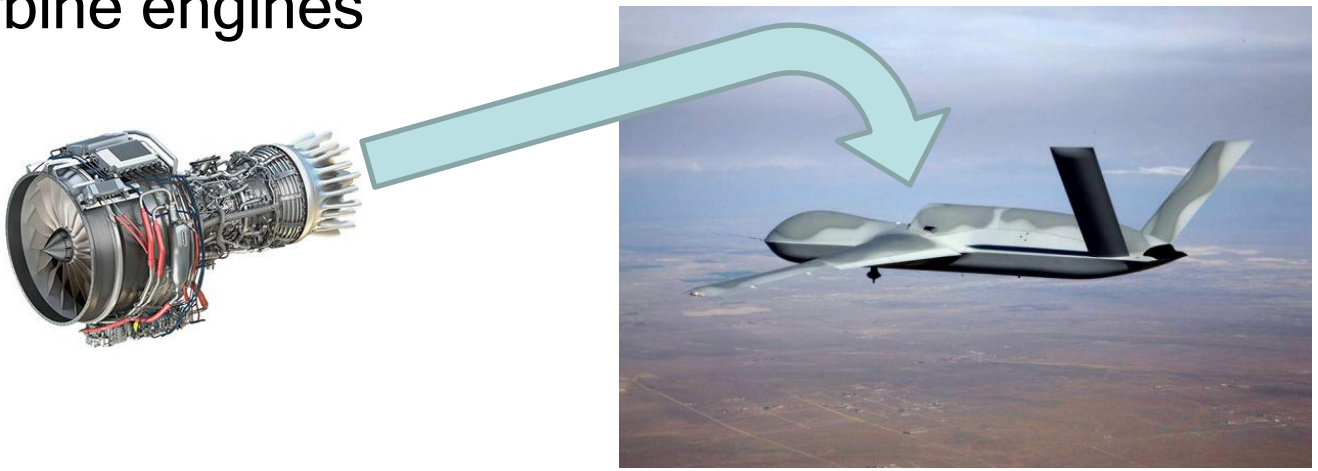
THE 15TH ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES

17/11/2016

Turbomachinery & Heat Transfer Laboratory
Faculty of Aerospace Engineering
Technion – Israel Institute of Technology, Israel

Motivation

- New challenges rise due to increase in demands from small gas turbine engines



- Limited flow velocities yield a decrease in design Reynolds number
  - Viscous forces are increased in relation to the inertia forces – previously not researched fields become priority

Transonic Linear Cascade

- There is market need for compact, low cost and fuel efficient engines which are highly efficient at both design and off design conditions
- Micro dimensions require extensive experimental turbine aerothermal performance studies
- Transonic linear cascade is a tool to conduct test aided design for:
  - Vane aerodynamic performance evaluation
  - Design of advanced cooling techniques

Cascade Investigations

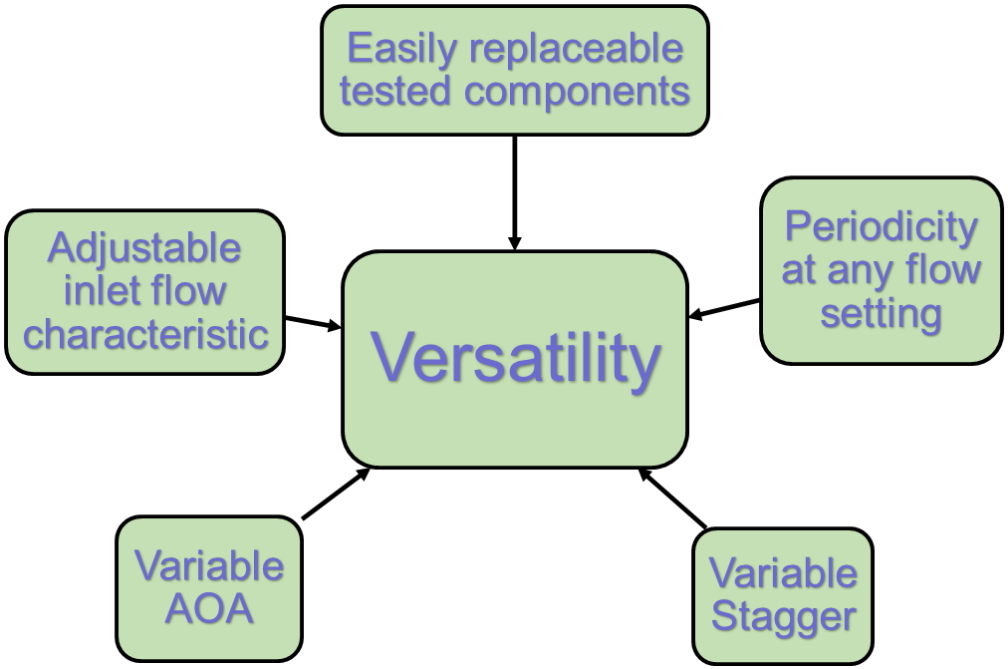
- Turbine Performance Investigation
  - Turbine Airfoil Aerodynamic Testing
  - Improved Transonic Flow Loss Correlations and Design Rules
  - Film Cooling Penalty Measurement
  - Characterization of Downstream Thermal Wakes

- Cooling Investigation
  - Film Cooling Effectiveness Assessment for Various Configurations
  - Internal Blade Cooling Performance Estimation
  - Thermal Barrier Coating Effectiveness and Health Monitoring Evaluation
  - Disk Cavity Cooling – Main Stream Flow Interactions

- Advanced Future Geometry and Cooling Technique Development
  - Effusion, Transpiration Cooling, Variable Stagger Turbines (VST)

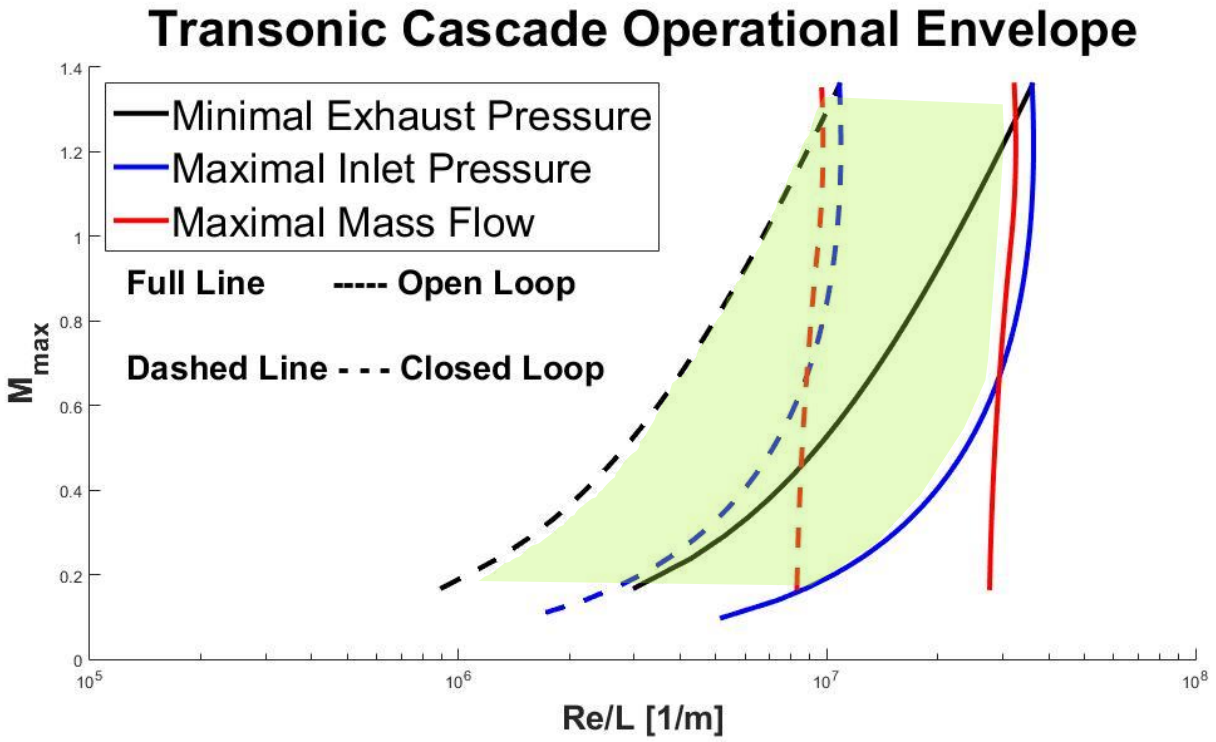
Operational Requirements

- **Versatility**
- Continuous operation at transonic conditions
- Variable angle of attack
  - Off-design studies
- Variable stagger angle
  - Influence of flow turning angle for design optimization
- Periodicity at all operational conditions



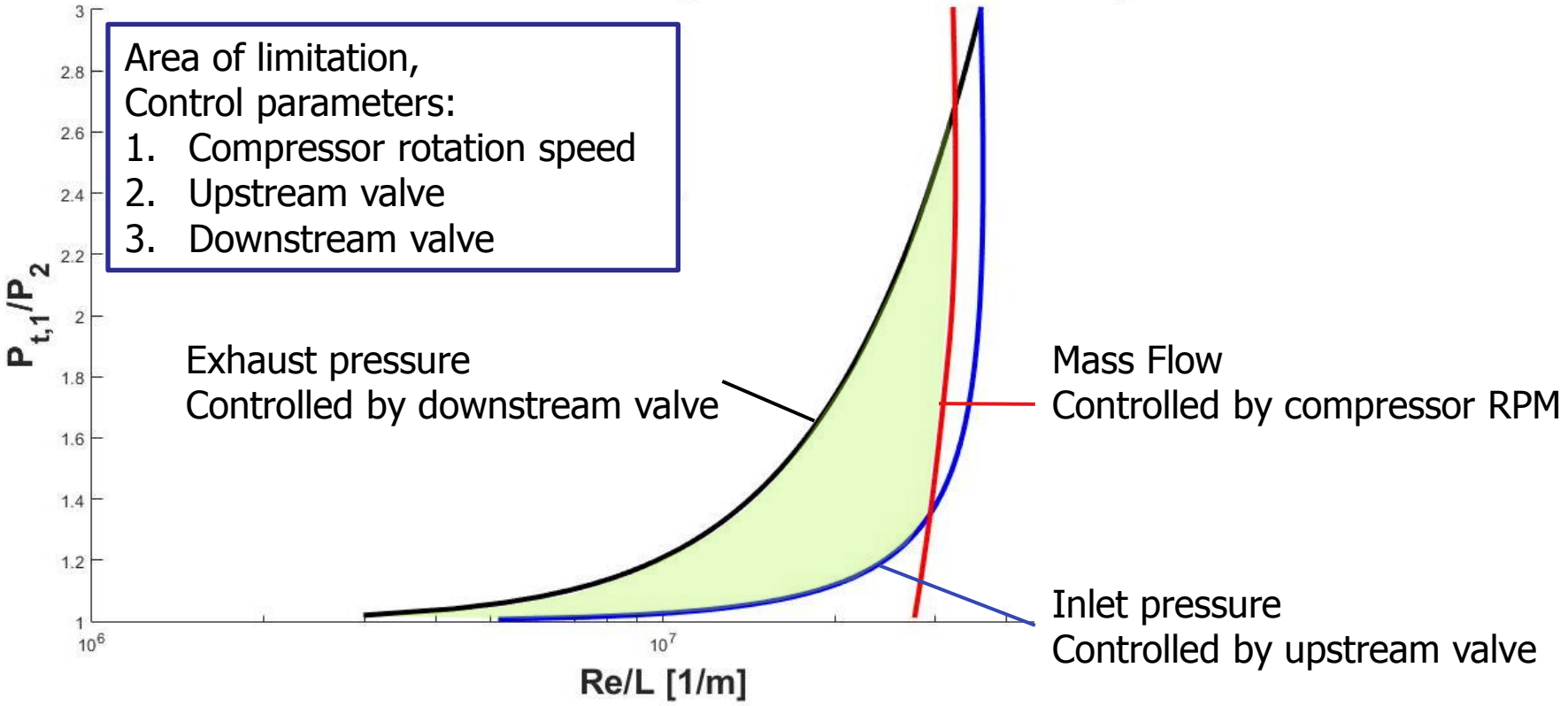
Cascade Operational Envelope M↔Re Independence

- Envelope limited by compressor mass flow
  - Full line ("Open Loop") – 0.9 kg/s (comp. inlet at 1atm)
  - Dashed line ("Closed Loop") – 0.3 kg/s (comp. inlet at 0.3 atm)



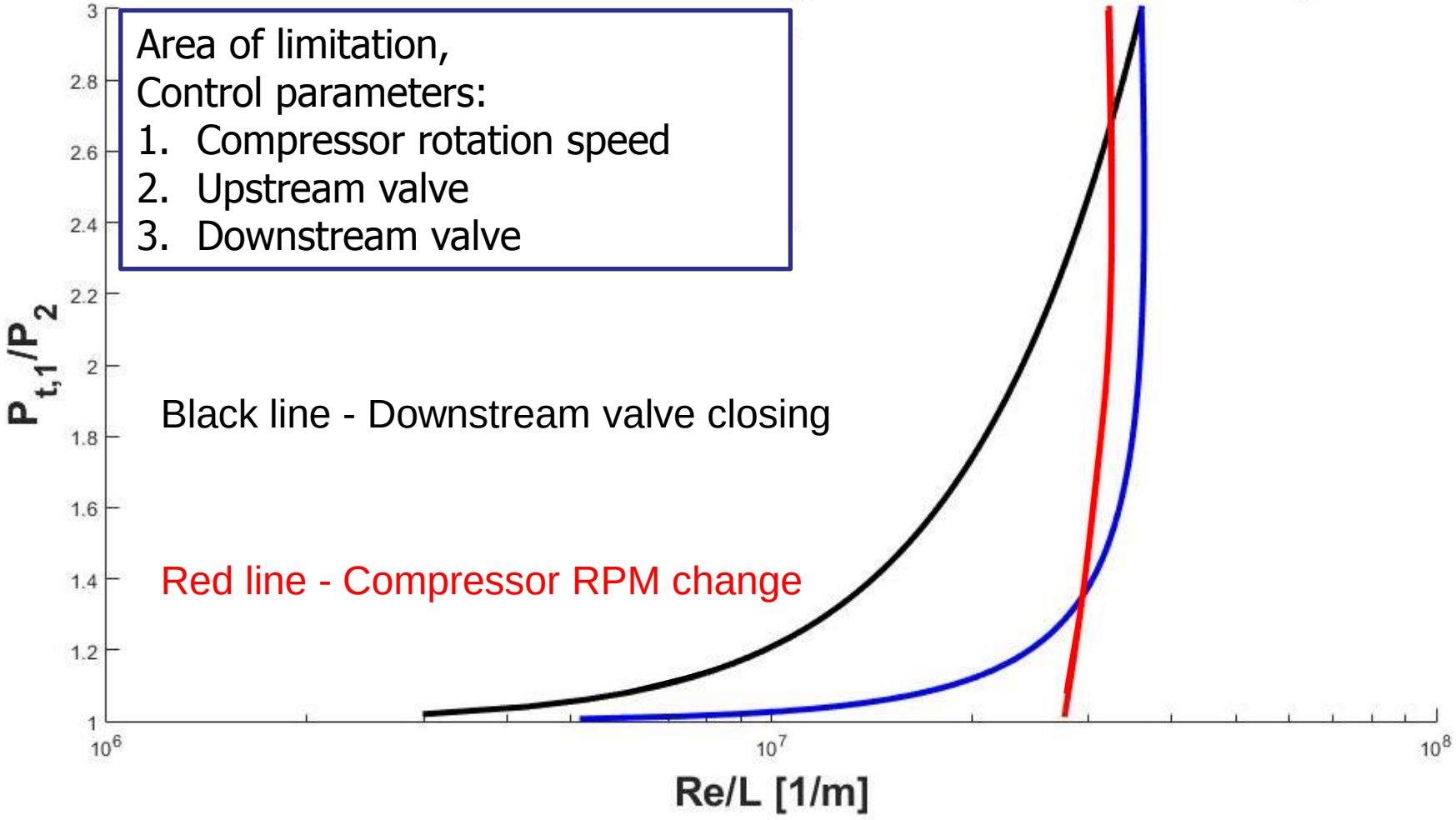
Cascade Operational Envelope Limitation Breakdown

Transonic Cascade Operational Envelope



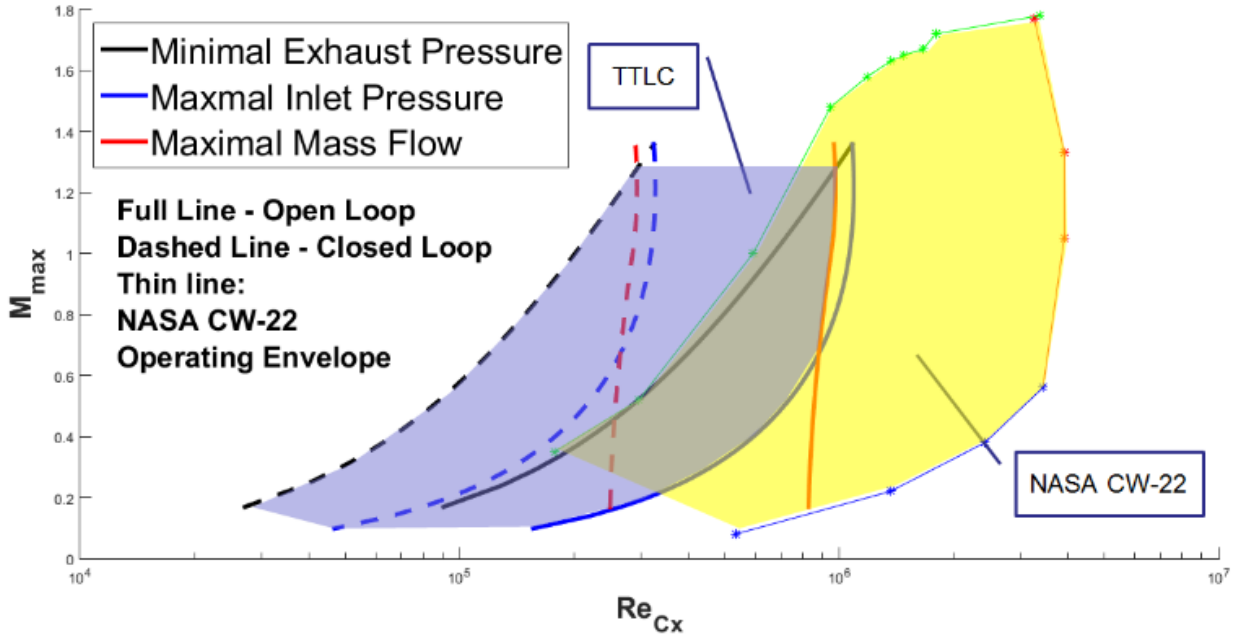
Cascade Operational Envelope Limitation Breakdown

Transonic Cascade Operational Envelope

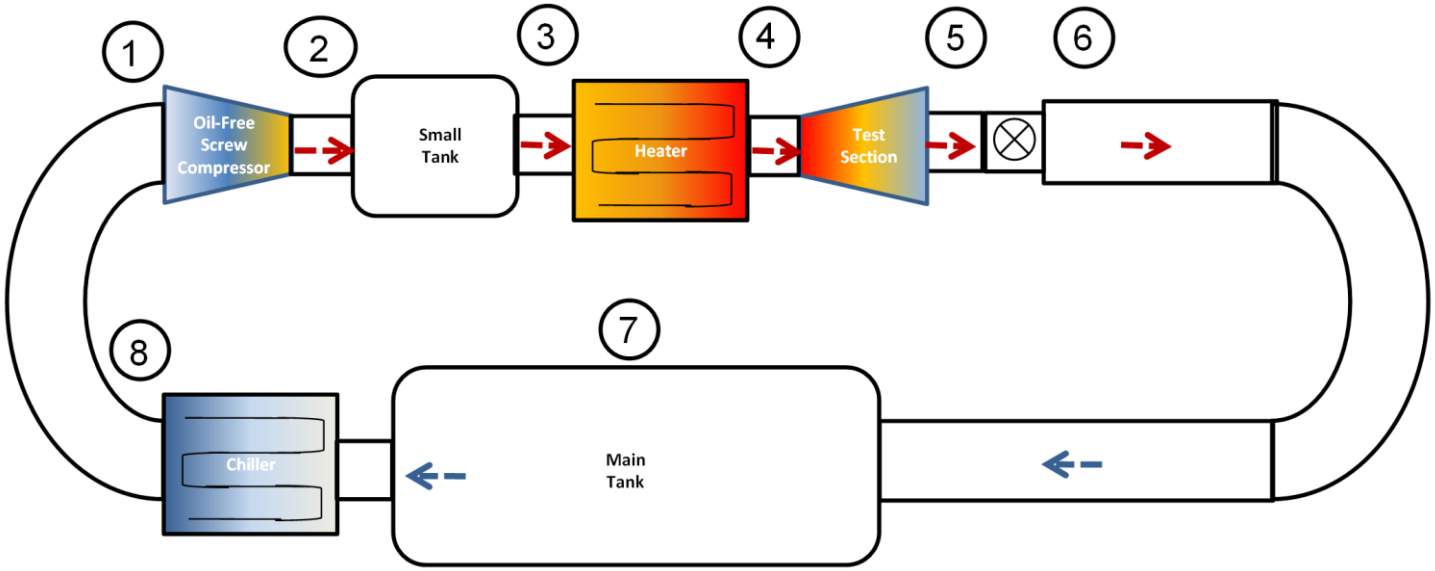


Operational Envelope

- The operational envelope is bounded by:
  - Maximal inlet pressure
  - Minimal outlet pressure
  - Maximal mass flow
- Two modes of operation:
  - Open loop: cascade outlet is atmosphere
  - Closed loop: cascade outlet is fed into the driving compressor

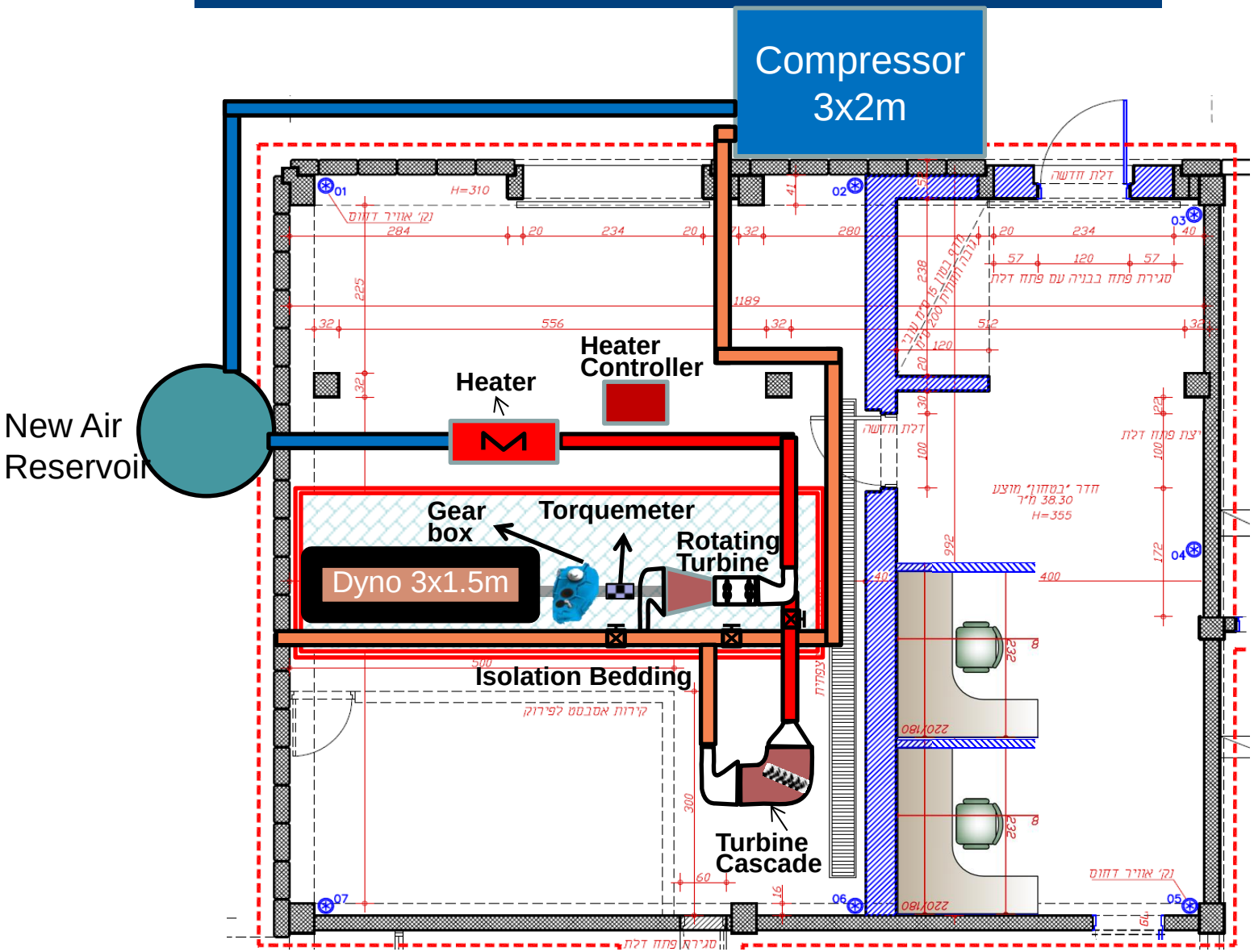


Facility Layout



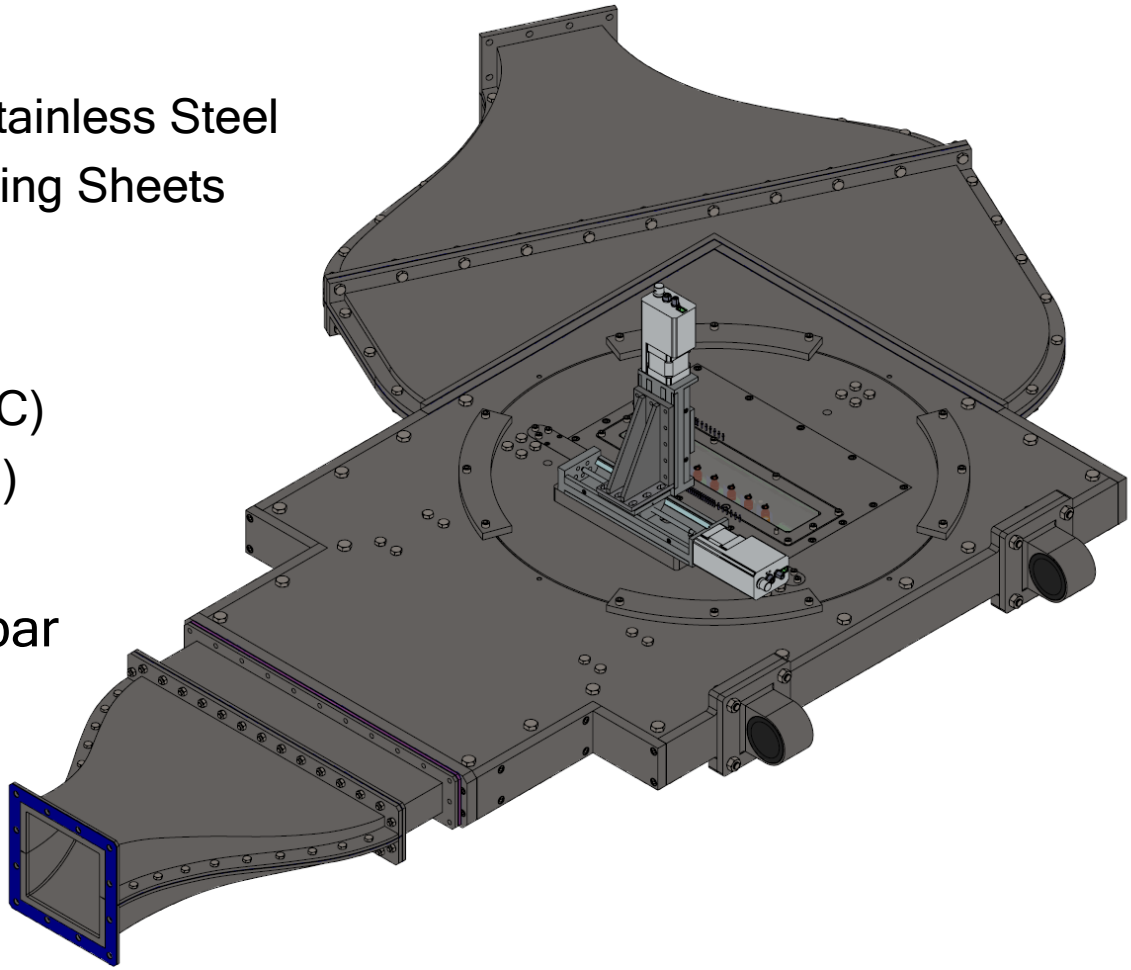
1. Compressor Inlet
2. Small Tank Inlet
3. Heater Inlet
4. Test Section Inlet
5. Valve Inlet
6. Main Tank Inlet
7. Main Tank or Chiller Inlet
8. Chiller Outlet

Room Schematic



Cascade Assembly

- Cascade Properties:
  - Materials:
    - Metal Components: Stainless Steel
    - General Sealing: Sealing Sheets
  - Temperature:
    - Unheated - 350K (80°C)
    - Heated - 650K (350°C)
  - Maximum Pressure: 6 bar
  - Size: 2x1.3x0.07 [m]
  - Mass: 300 kg



Cascade Assembly

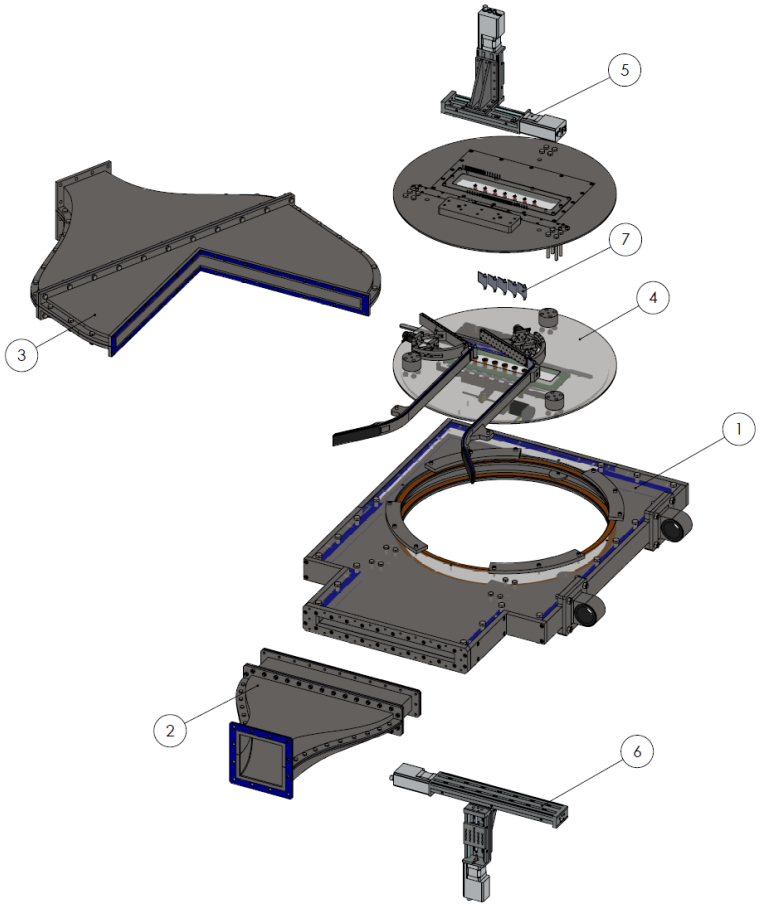
- 4 main sub assemblies:
  - Inlet (2)
  - Main Frame (1)
  - Rotating Disks (4) – test section
  - Outlet (3)

- Inlet pipe diameter: 6 inch

- Outlet pipe diameter: 6 inch

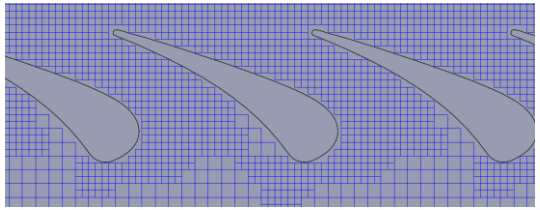
- Inlet and outlet are connected with round-to-square adapter

ITEM NO.	PART NUMBER	DESCRIPTION	Turbine Cascade/ QTY.
1	LCA0040	Main Frame	1
2	LCA0190	Inlet	1
3	LCA0180	Outlet	1
4	LCA0170	Rotating Disk	1
5	LCA0210	Upstream Measurement Stages	1
6	LCA0220	Downstream Measurement Stages	1
7	LCV0010	C3X Vane	5



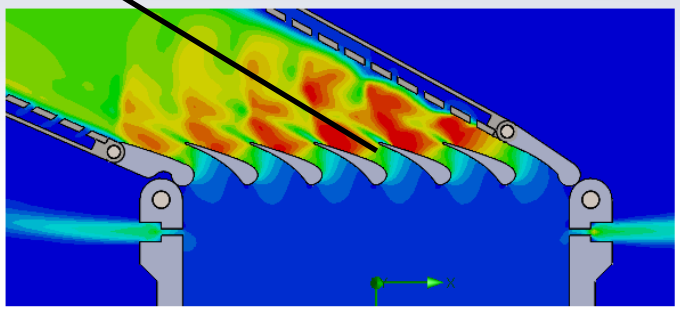
Flow Simulation Results
Mach Number

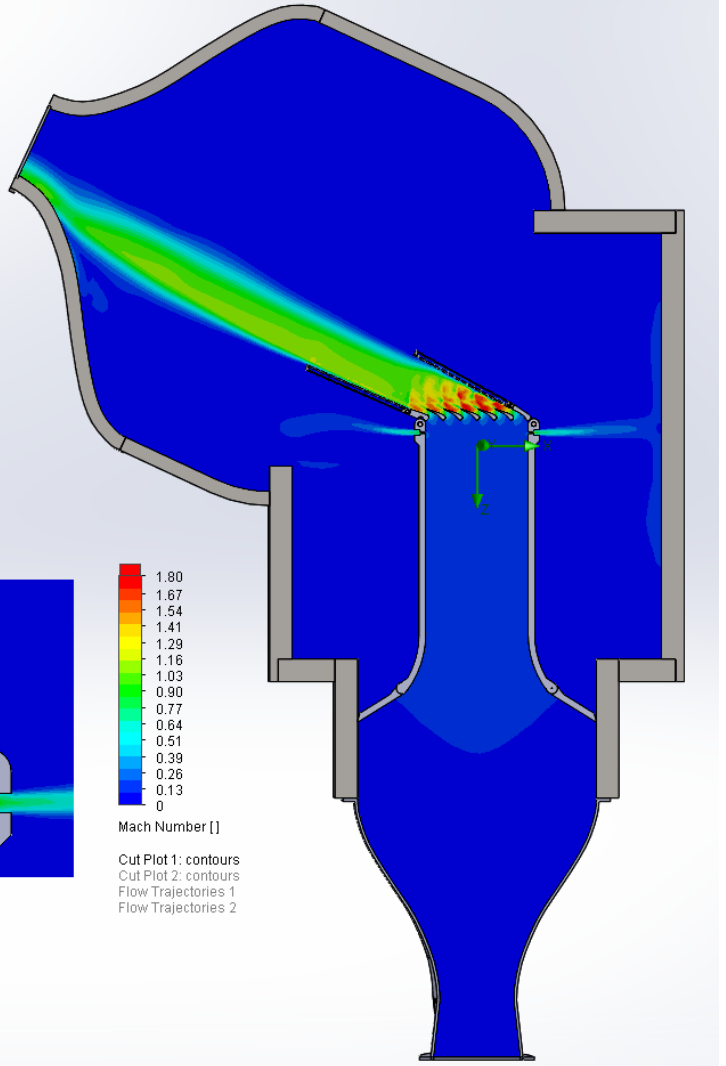
TI = 5%
k-ϵ model
y^+ = 500



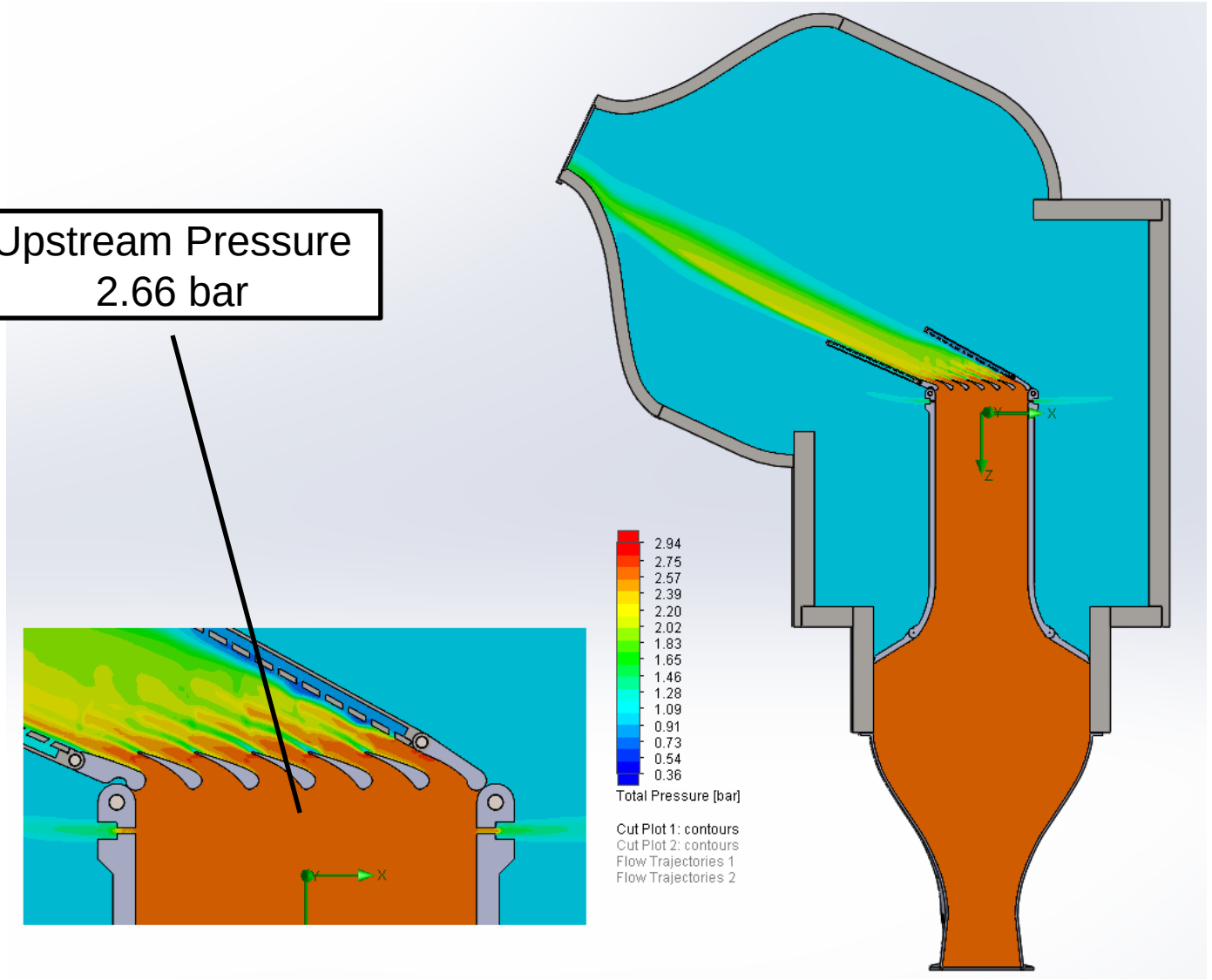
Solved with Mentor Graphics FloEFD Solver (through SW)

Throat Cross-section

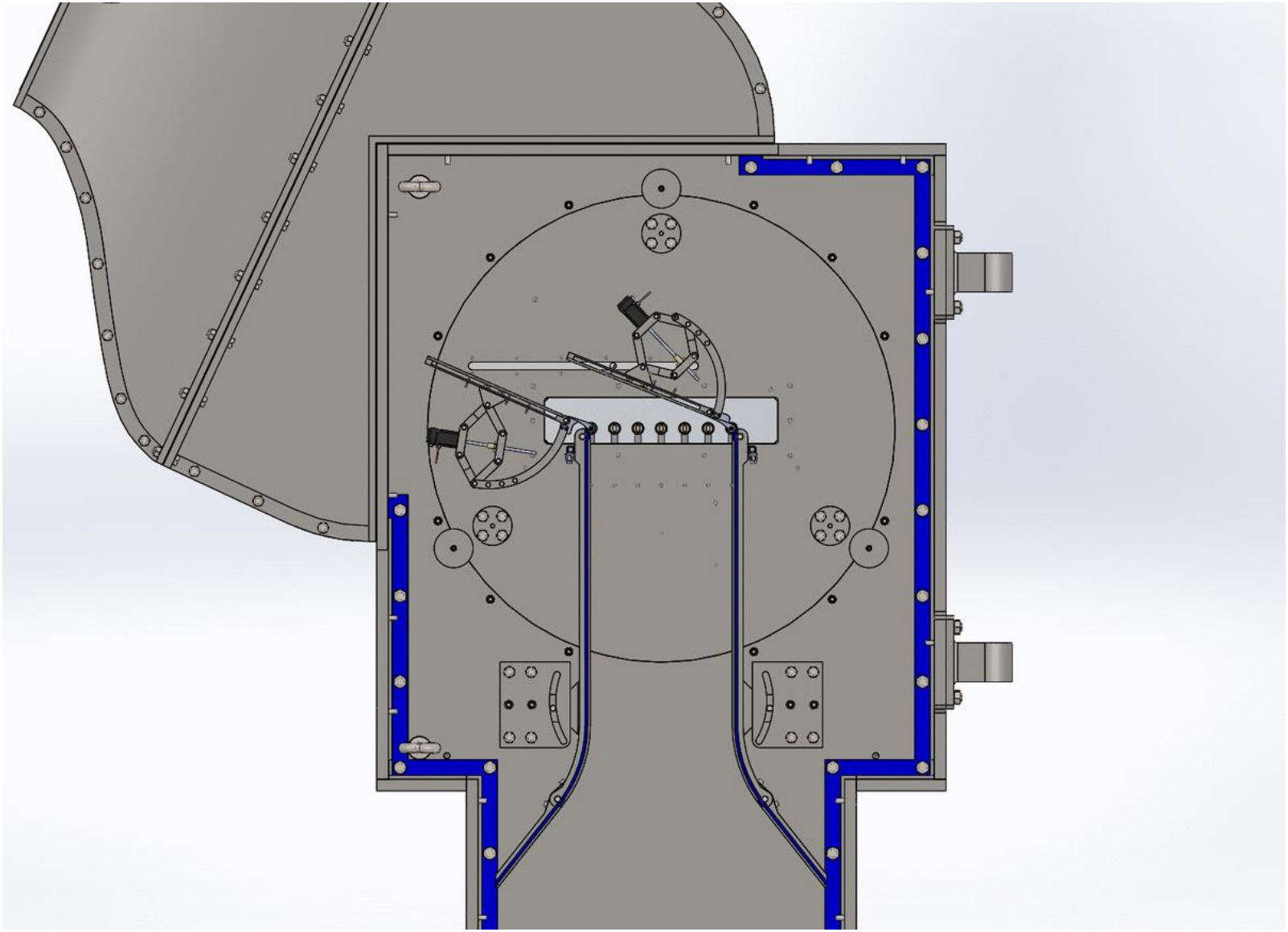




Flow Simulation Results
Total Pressure

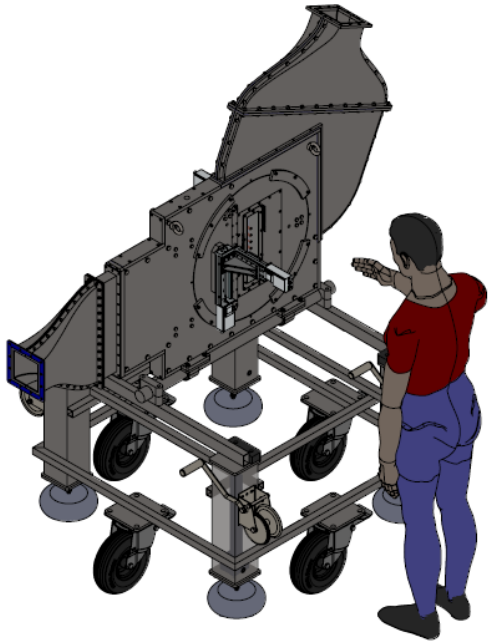


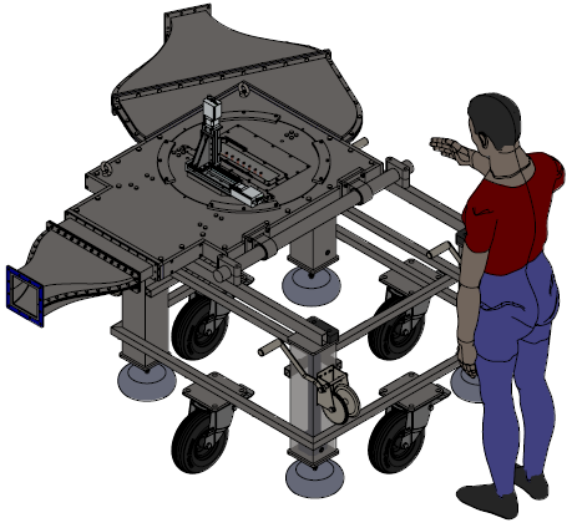
Rotating Disks – Frontboards
Frontboards Movement



Cascade Stand

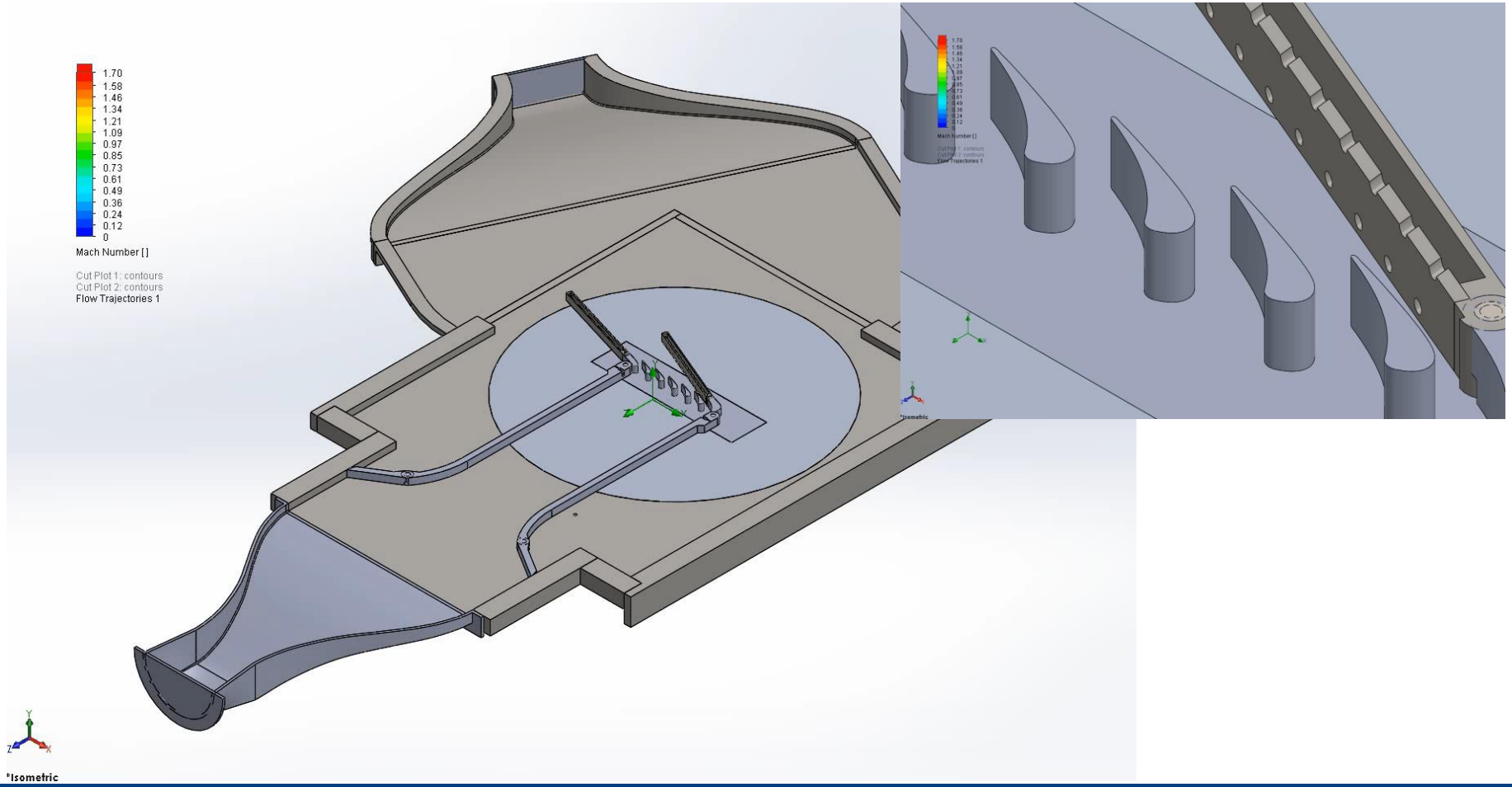
- Horizontal orientation for maintenance and test section replacement
- Vertical orientation for experimental runs
- Orientation control with manual brake winch





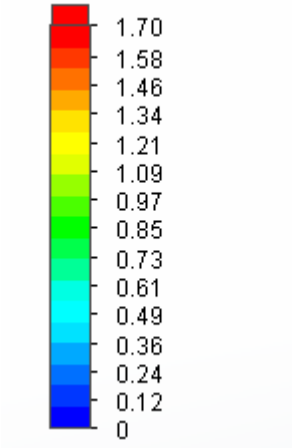
Flow Features From Simulation

- Flow Features From Simulation

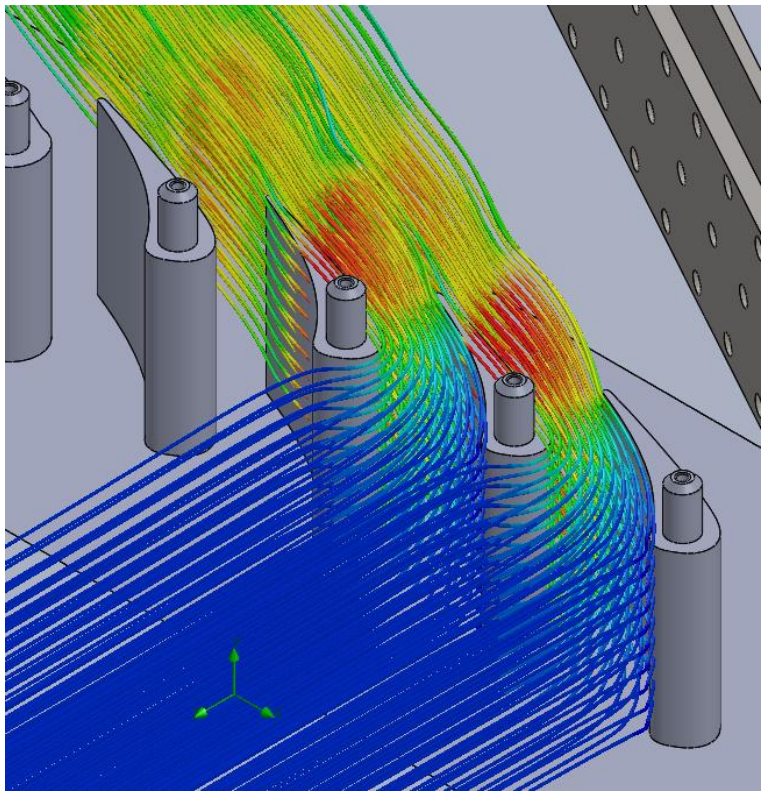


Flow Features From Simulation

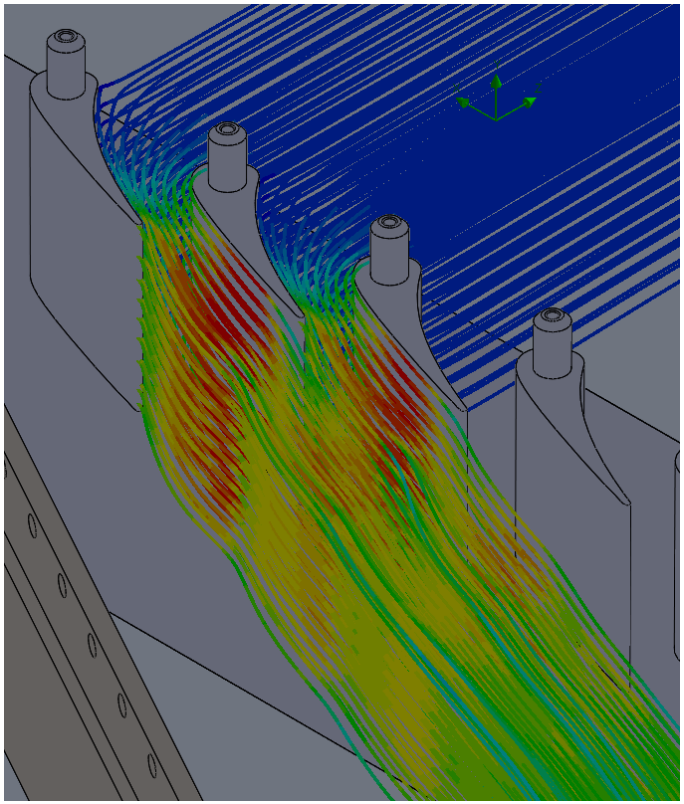
- Flow Simulation – Main Vane



Upstream

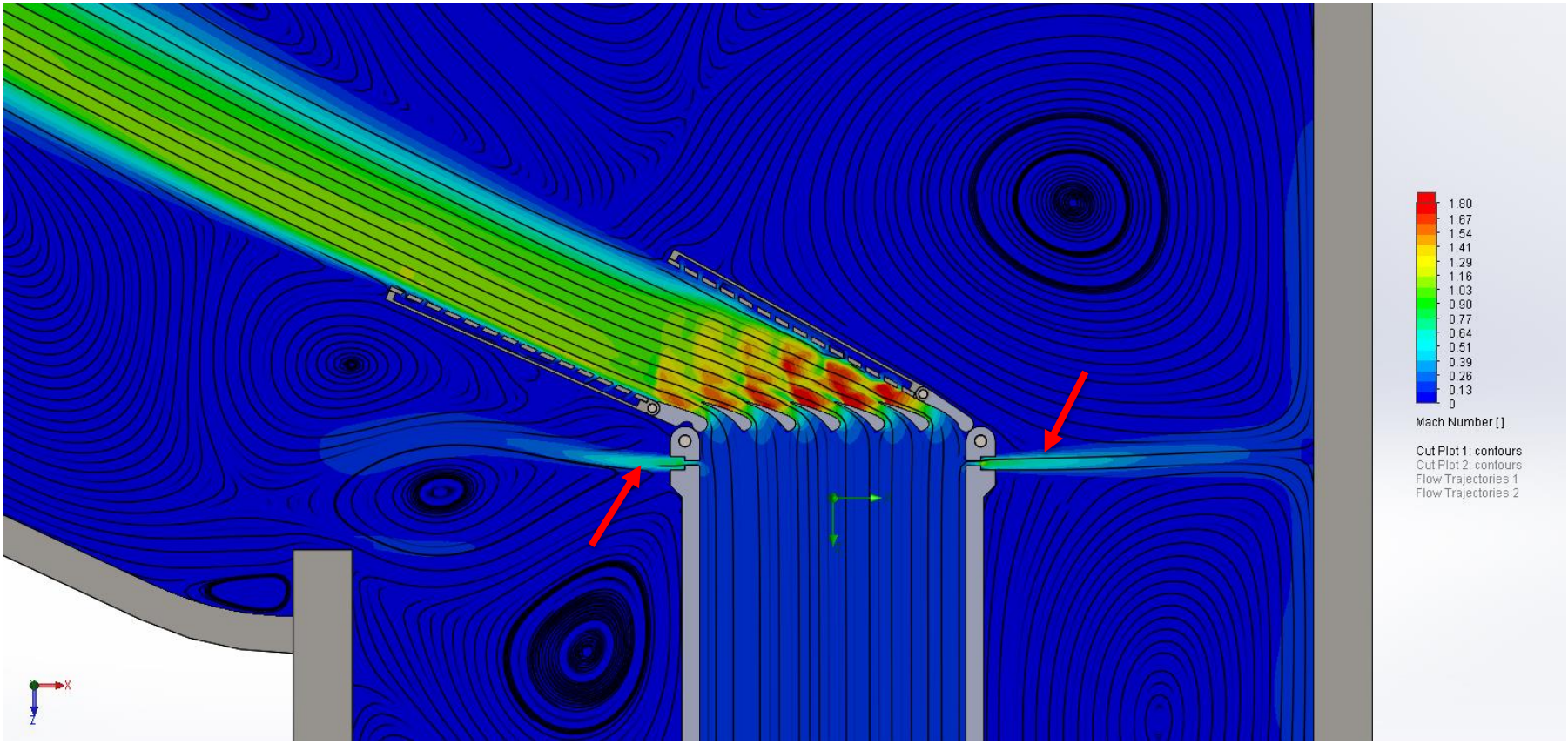


Downstream



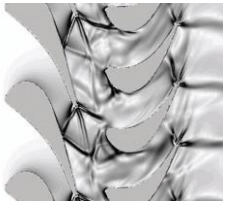
Flow Features From Simulation

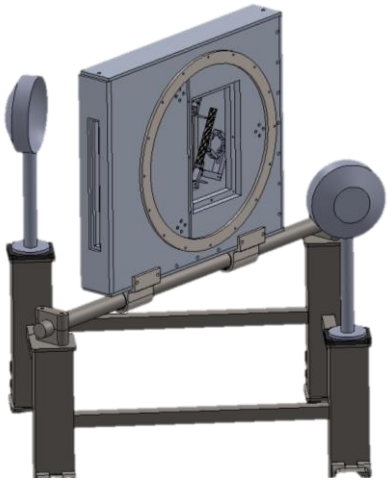
- Flow simulation – Boundary Layer Suction
  - Up to 1.5% mass suction (valve controlled)
  - Suction throat area = 26 mm^2

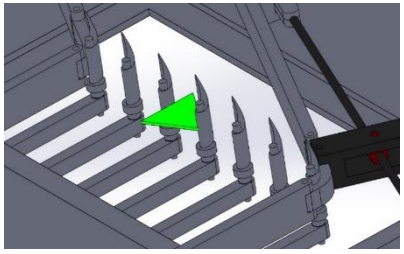


Measurement Review

- Aerodynamic Performance Measurement
  - Integral loss correlation
    - P_0 measurement
  - Total pressure field mapping
    - 5-hole probe traversed upstream and downstream
  - Density field measurement
    - Quantitative Schlieren imaging
    - Shock loss correlations
  - Velocity Field Measurements
    - PIV – Particle Image Velocimetry
    - Endwall loss, mixing loss, profile loss correlations, flow separation assessment

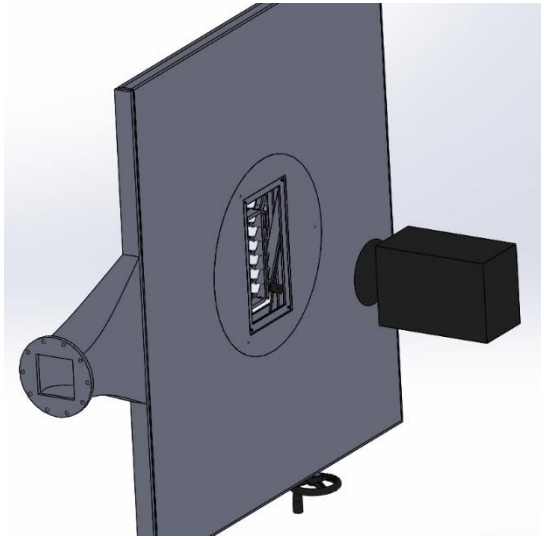


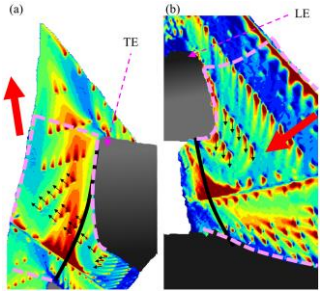


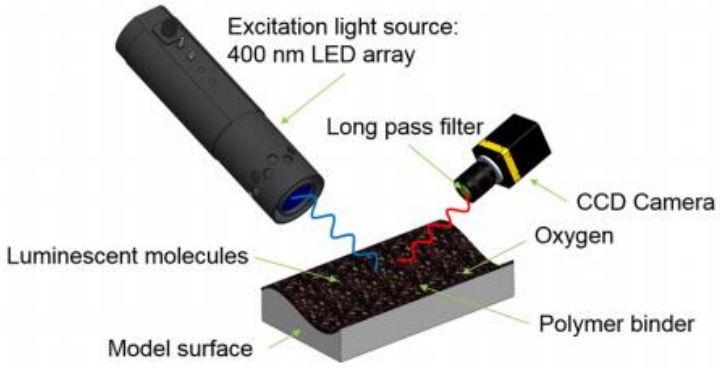


Measurement Review

- Colling Effectiveness Measurement
  - Cooling performance assessment
    - Air heated by compression (350K)
    - Additional heater (650K)
  - IR thermography
    - Surface temperature distribution
  - PSP - Pressure Sensitive Paint
    - Investigation of cooling performance
    - Chemically different gases







Conclusion

- The Technion Transonic Linear Cascade (TTLC) is to become a tool to allow test aided design for the industry
- Re-M independency allows research at a range of Reynolds numbers while maintaining transonic conditions
- The TTLC allows versatility of research over various tested components
- TTLC shall pioneer turbine research in Israel

Questions?

Thank you for your attention!