Research in Internal and External Aerodynamics for the Next Generation of Efficient Aircraft

Huu Duc Vo

Associate Professor

Department of Mechanical Engineering

École Polytechnique de Montréal

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WORLD-CLASS ENGINEERING

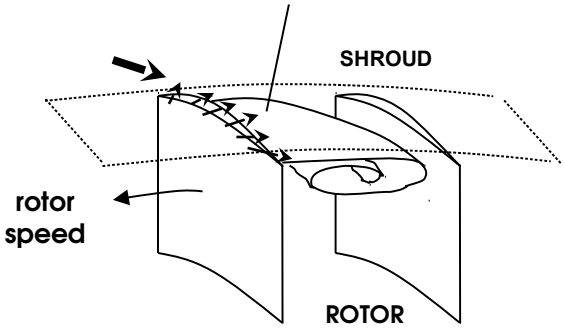
OUTLINE

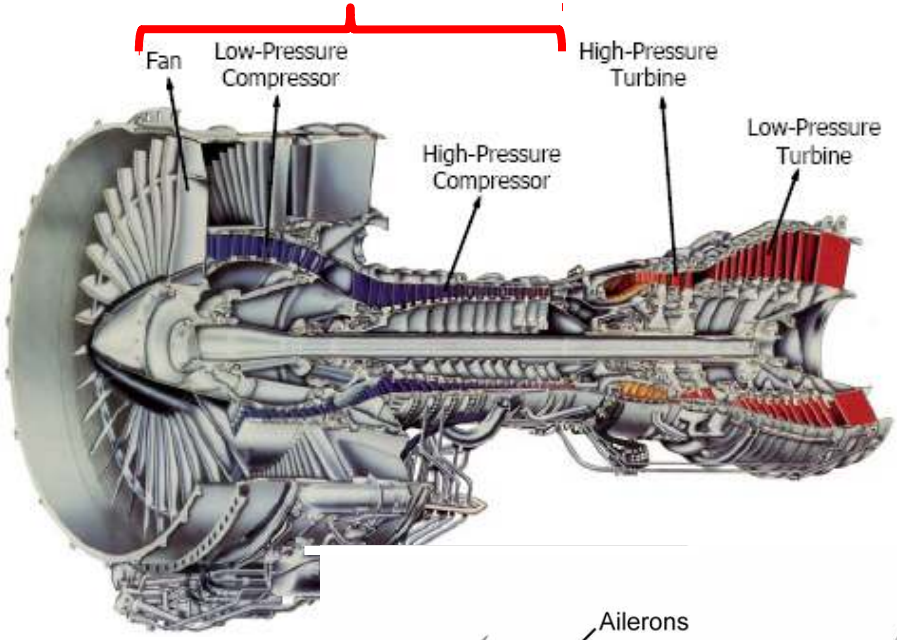
- Research Areas
- Research Approach
- Experimental Facilities
- Internal Aerodynamics Research
- External Aerodynamics Research
- Conclusion

RESEARCH AREAS

I) Internal flows: compressor aerodynamics

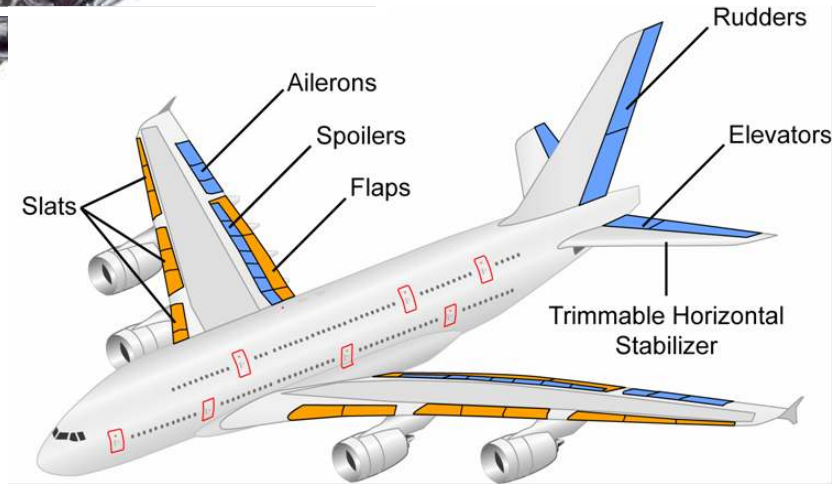
Tip clearance flow





II) External flows:

flight control



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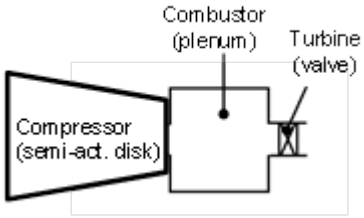
RESEARCH APPROACH

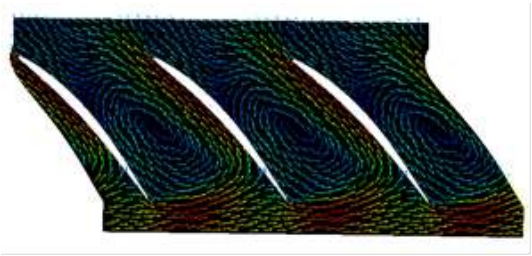
Analytical

- Modeling



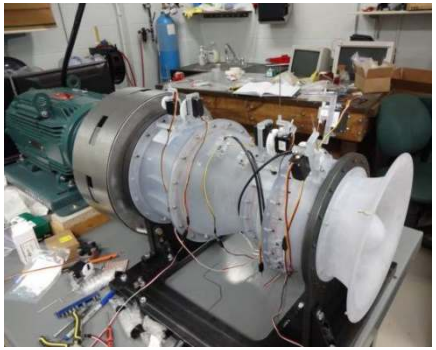
Numerical (CFD)

- Preliminary assessment of concepts
- Elucidate flow physics



Experimental

- Validation of concepts
- Validation of models/flow physics
- Validation of numerical setup



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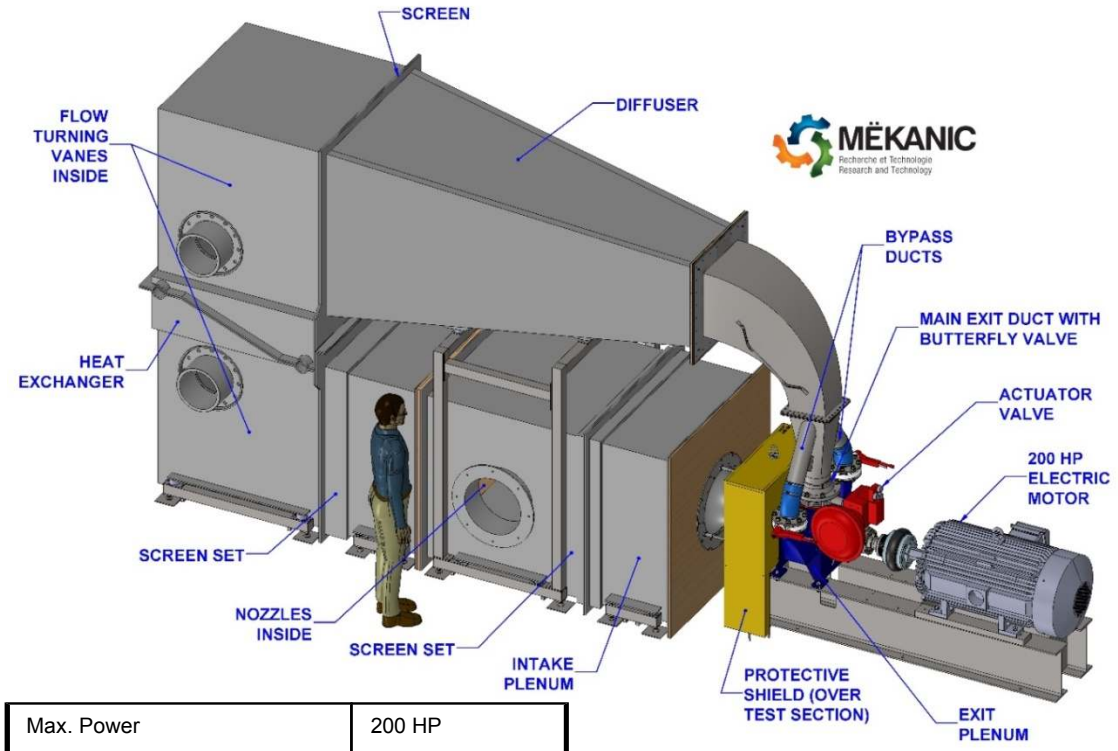
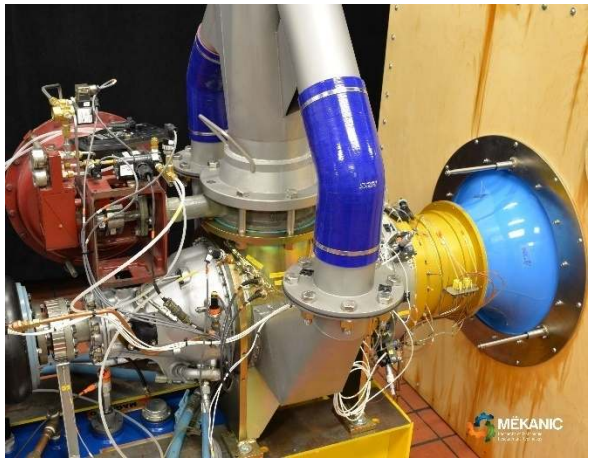
EXPERIMENTAL FACILITIES

1) Transonic compressor test rig





Max. Power	200 HP
Max. Rotational Speed	21 100 RPM
Max. $M_{tip,\ circumferential}$	0.90
Mass flow	~ 8 lbm/s

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Utility: Validate concepts in compressor aerodynamics at realistic speeds

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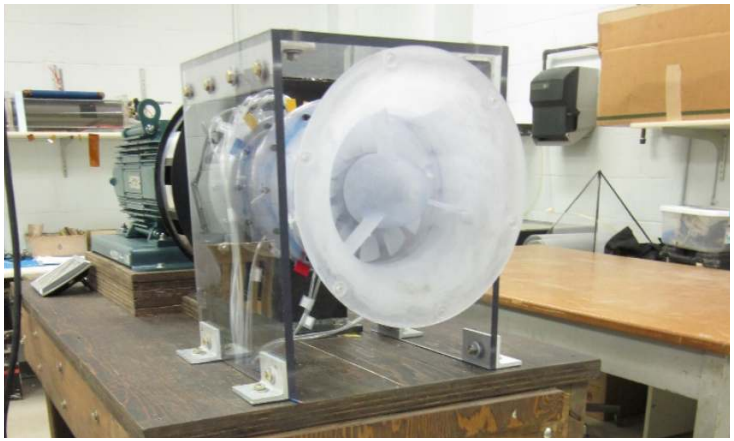
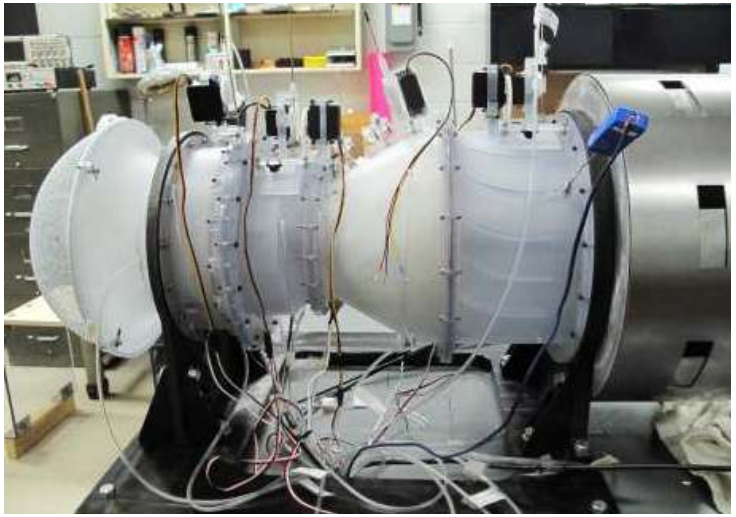
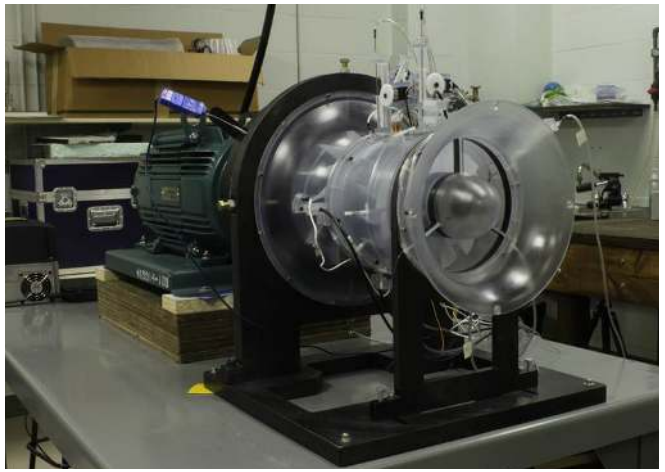
2) Low-speed compressor test rigs







Max. Power	7.7 HP
Max. Rotational Speed	8900 RPM
Max. $M_{tip,\ circumferential}$	0.25
Mass flow	~1-1.2 lbm/s

Utility: Low-cost validation of concepts in compressor aerodynamics

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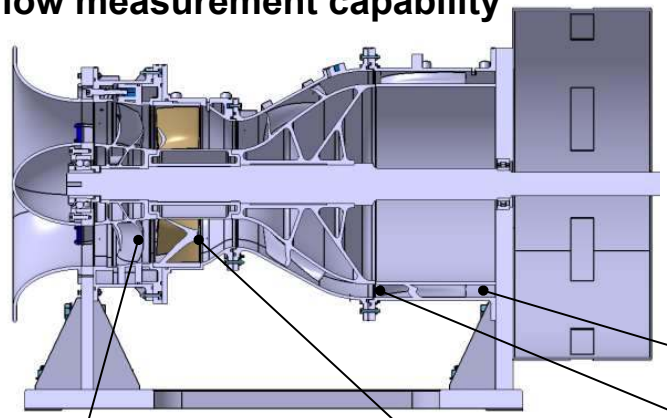
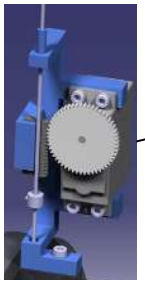
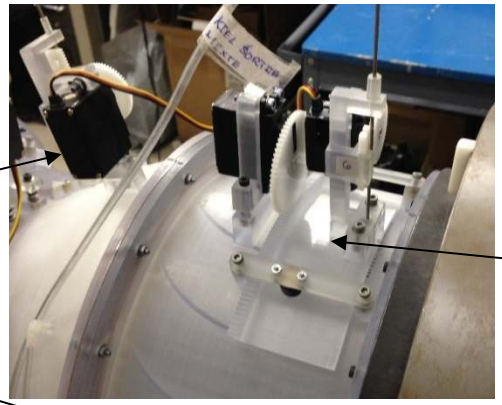
Detailed flow measurement capability

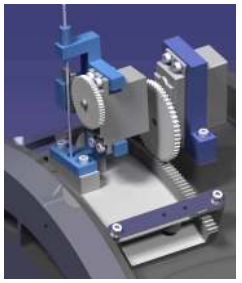


Radial traverse

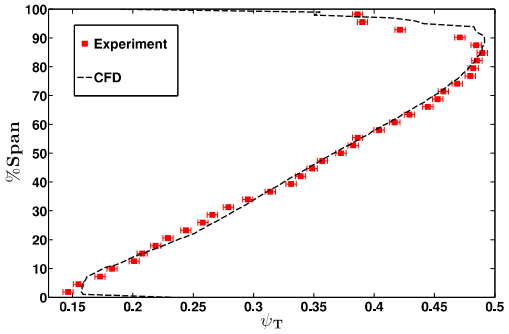




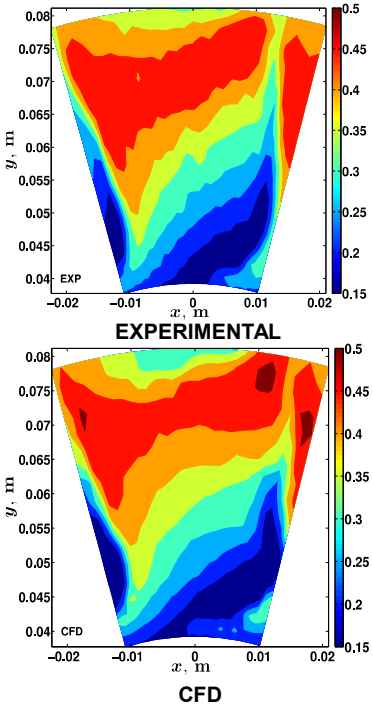
Radial-circumferential traverse



Rotor 1 exit



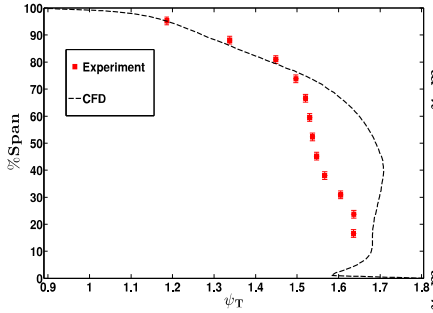
Stator 1 exit



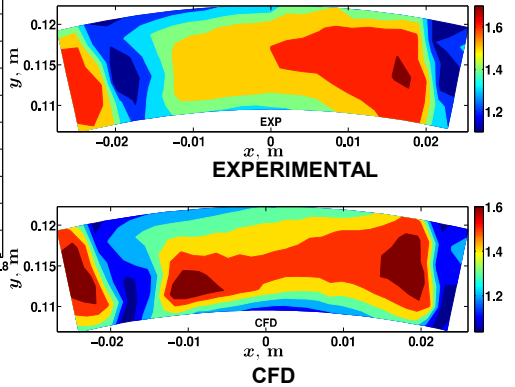
EXPERIMENTAL

CFD

Rotor 2 exit



Stator 2 exit



EXPERIMENTAL

CFD

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3) Closed-Loop Wind Tunnel and Cascade Test Section

24 x 24 x96 inch test section

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Max. Power	200 HP
Max. Speed	91 m/s

Utility: - Low-cost validation of concepts external aerodynamics
- Detailed measurements of blade passage flow in turbomachinery

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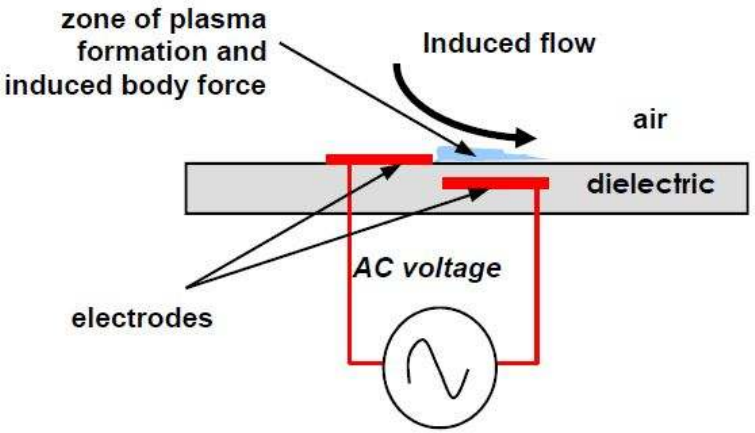
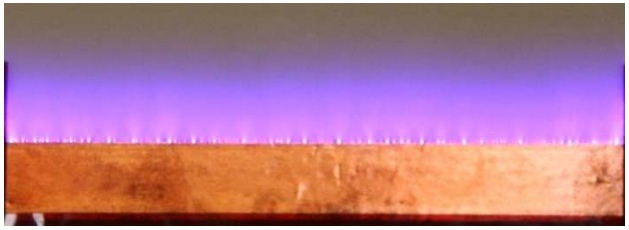
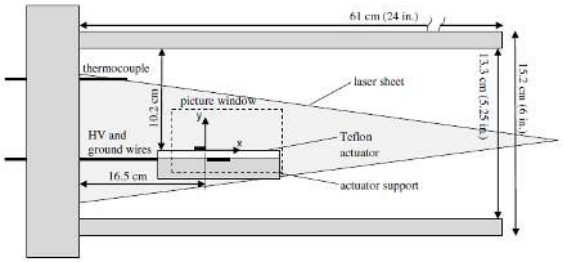
4) Aerodynamic Plasma Actuation

DBD plasma actuator







INTERNAL AERODYNAMICS RESEARCH

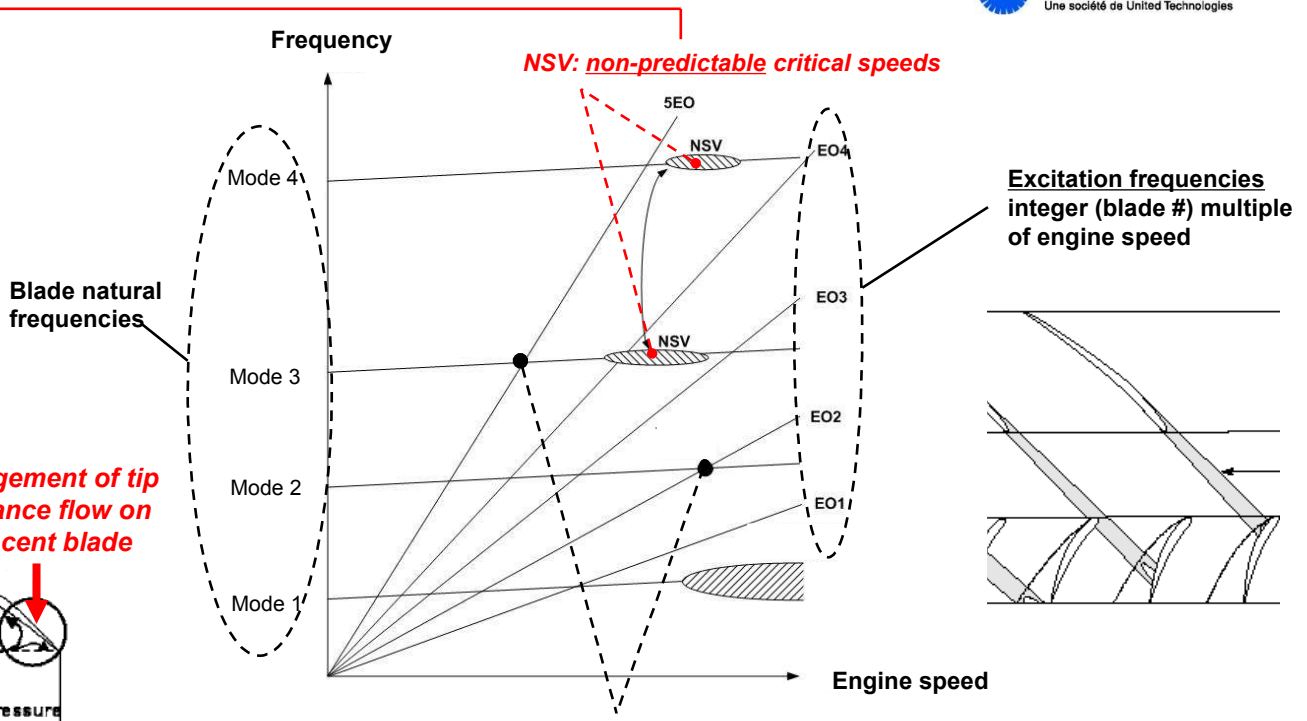
A) Prediction of Non-Synchronous Vibrations (NSV)

<u>Objective</u>: Safe use of lighter aero-engine compressor/fan blades

Pratt & Whitney Canada
Une société de United Technologies

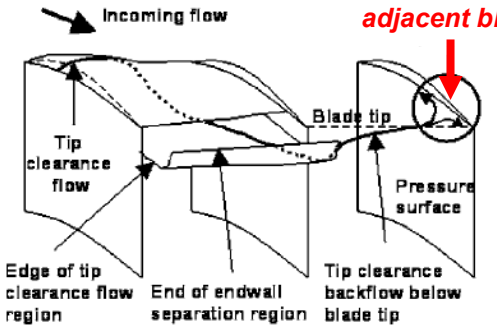
NSV can cause premature blade failure in aero-engine compressors and fans

Original hypothesis to explain NSV



Blade resonance from forced response: <u>predictable</u> critical speeds

impingement of tip clearance flow on adjacent blade



<u>PROBLEM</u>: Resonance of impinging air jets Mach > 0.65 (Ho & Nosseir 1981)
BUT tip clearance flow relative velocity usually < 0.5

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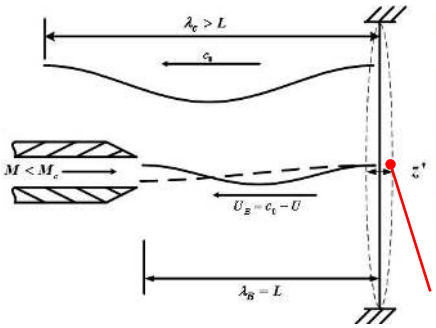
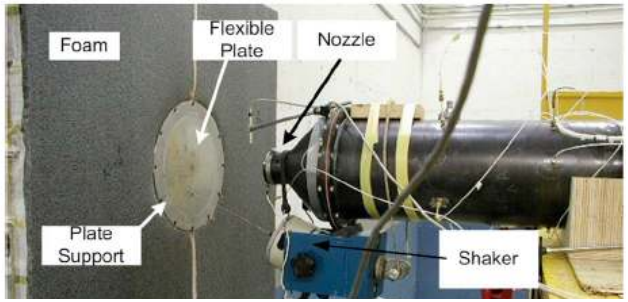
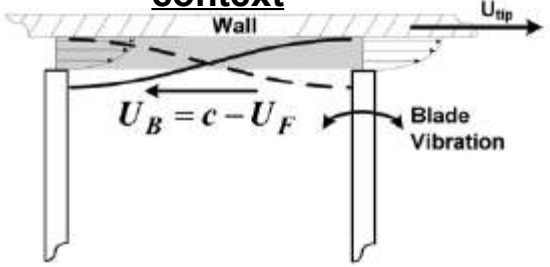
NEW impinging jet behavior proposed and proven experimentally





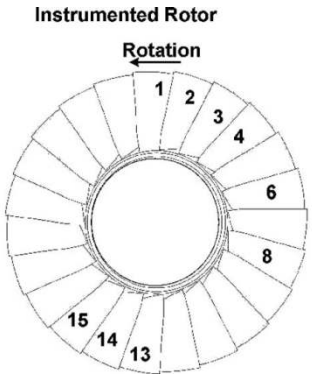
Flexible wall allows for jet resonance well below Mach 0.65

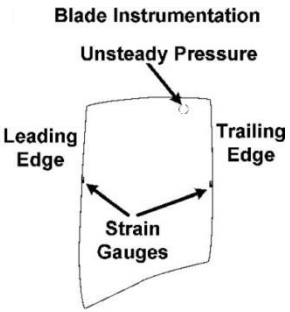
Application to compressor & fan blade context

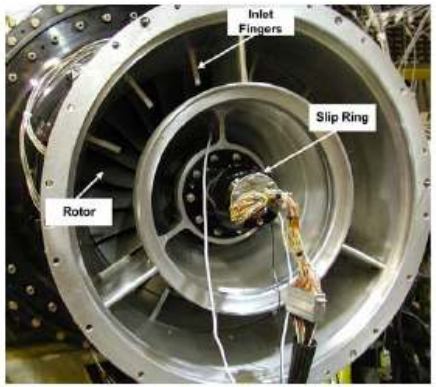


$$\frac{(c - U_F)}{2sf_b} = 1$$

Validated on transonic compressor rig at P&WC





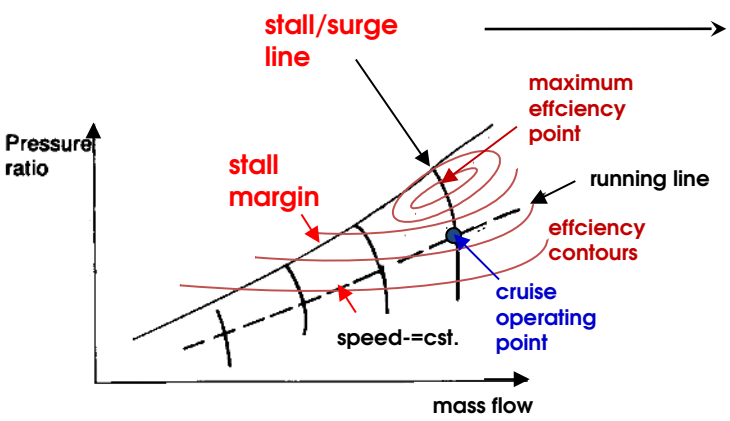


$$\frac{U_{tipc}}{\sqrt{T_{tip}}} = k\left(\sqrt{\gamma R} - \frac{2sf_b}{n\sqrt{T_{tip}}}\right)$$

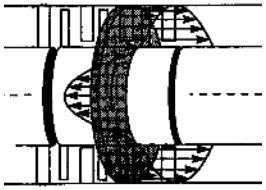
First explanation and predictive tool for NSV

B) Delay of Rotating Stall

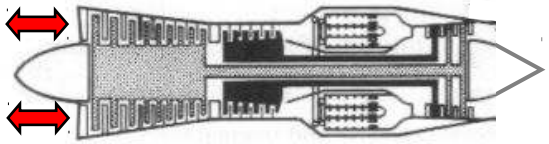
Objective: Improve aero-engine efficiency/operating envelope



rotating stall

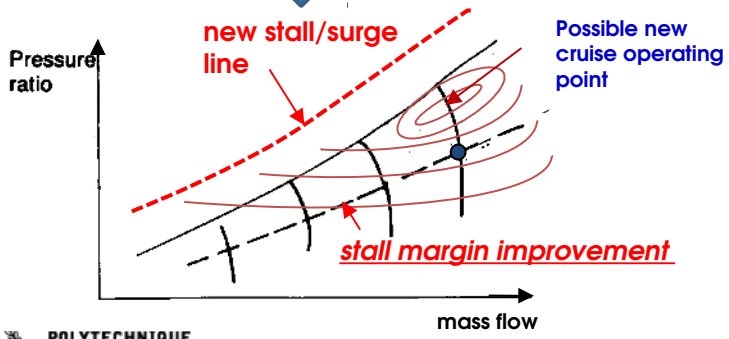


surge



- Sudden loss of power/thrust
- Engine damage

rotating stall delay strategies



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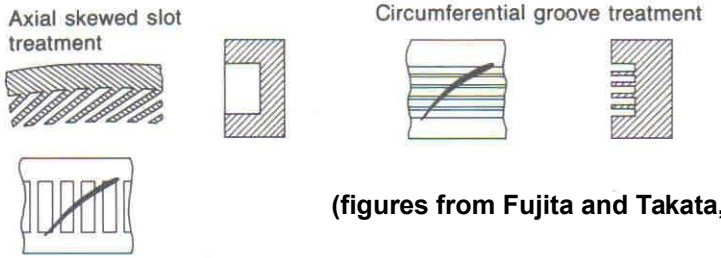
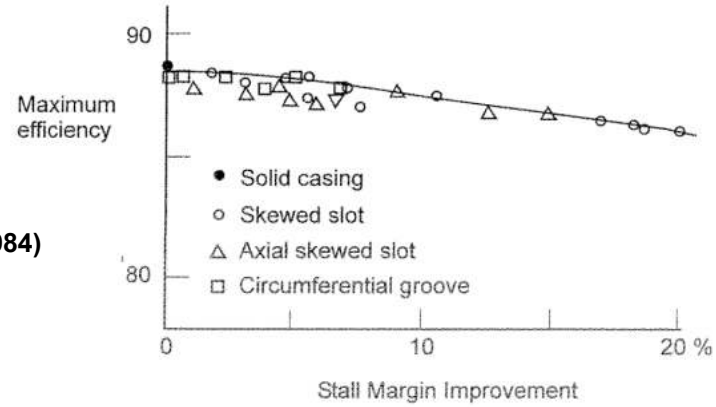
Project 1: Effective and lossless casing treatment

Pratt & Whitney Canada
Une société de United Technologies

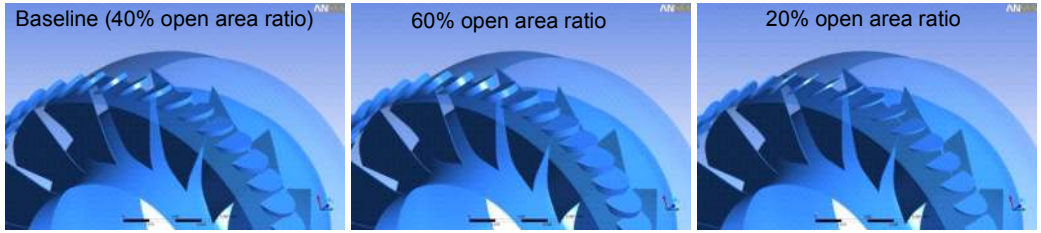
Casing treatment: passive stall margin improvement strategy

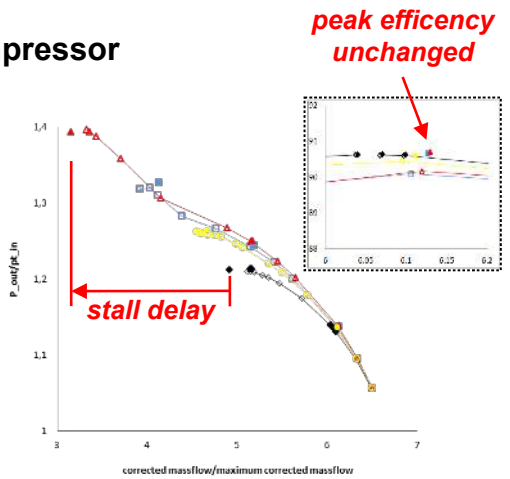


(figures from Fujita and Takata, 1984)



Numerical parametric study for slot casing treatment on mixed-flow compressor





Preliminary geometrical design rules for effective lossless slots casing treatment

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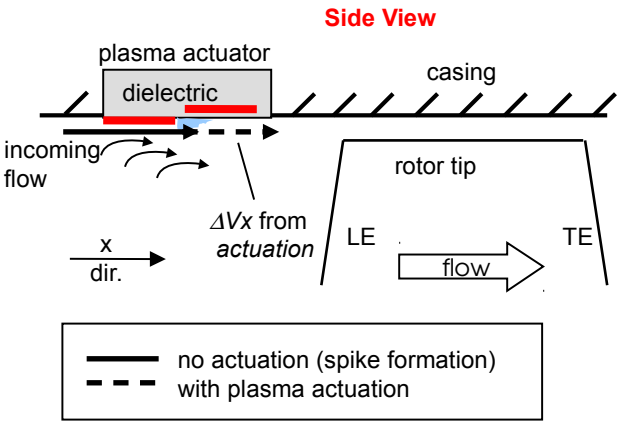
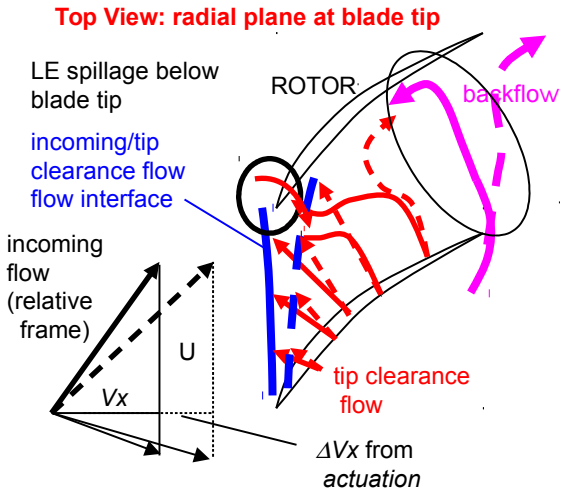
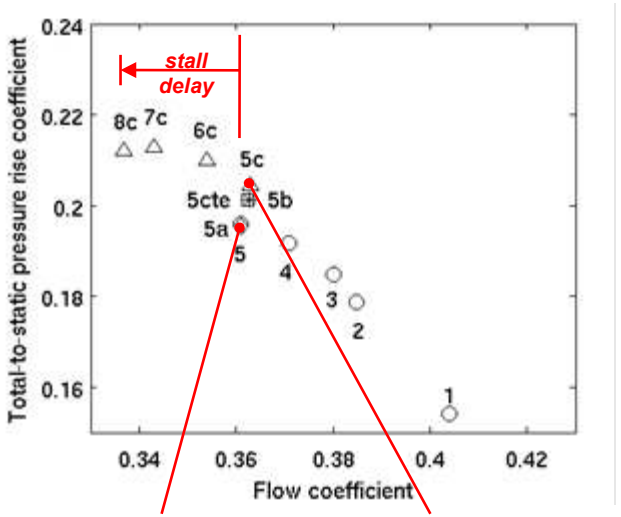
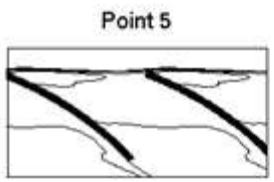
Project 2: Delay of rotating stall with plasma actuators



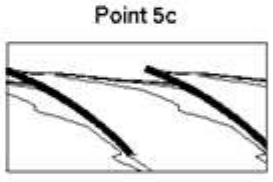


Preliminary numerical (CFD) assessment on low-speed axial compressor





No Actualtion (stall point)



With Plasma Actualtion

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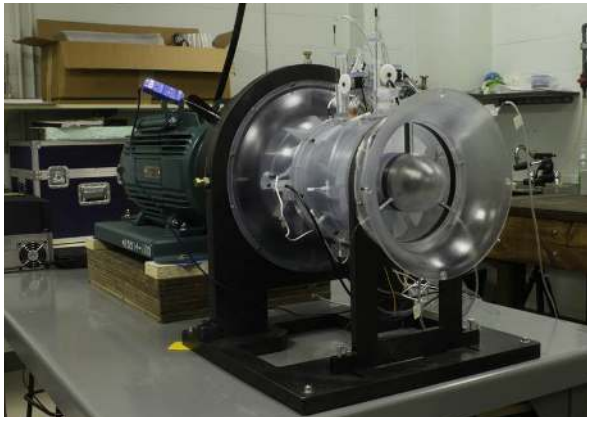
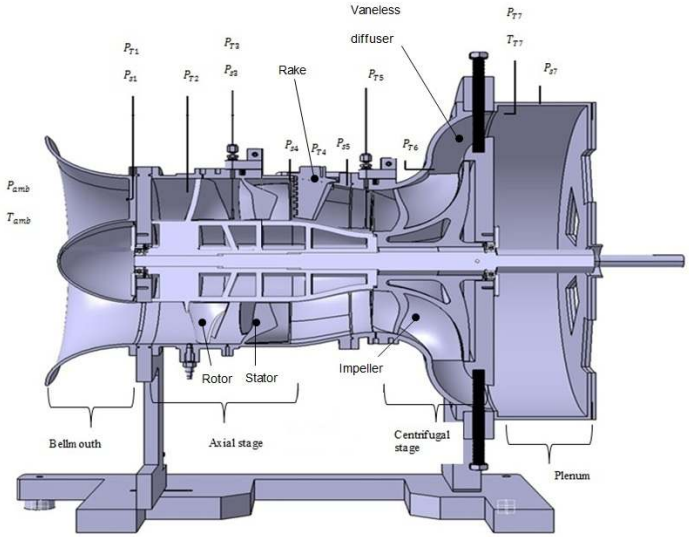
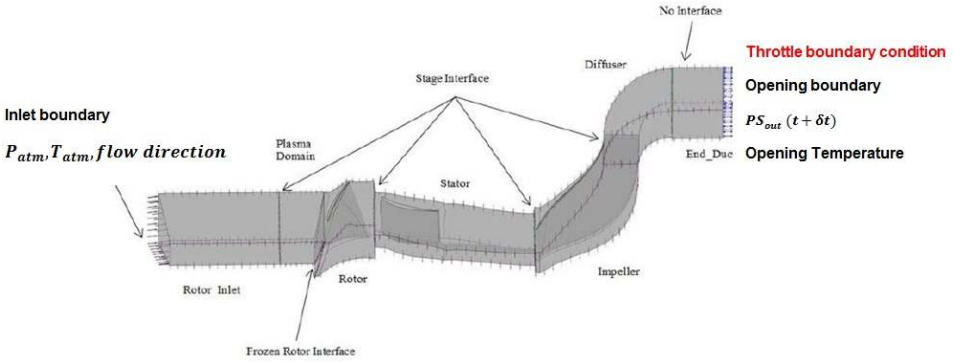
Application to low-speed axial-centrifugal compressor rig



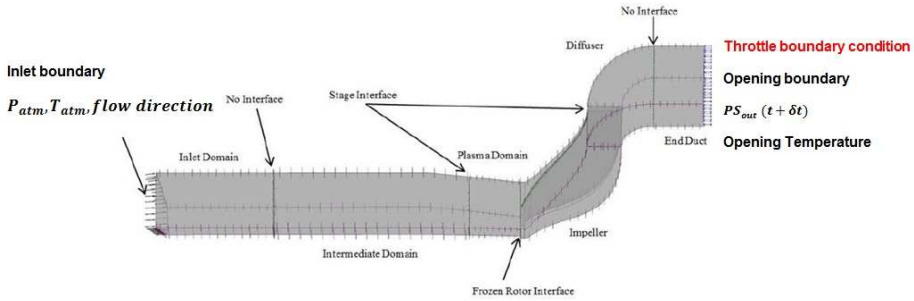


Numerical (CFD) assessment

Configuration 1: Two-stage, actuator on axial stage



Configuration 2: Centrifugal stage only, actuator on impeller



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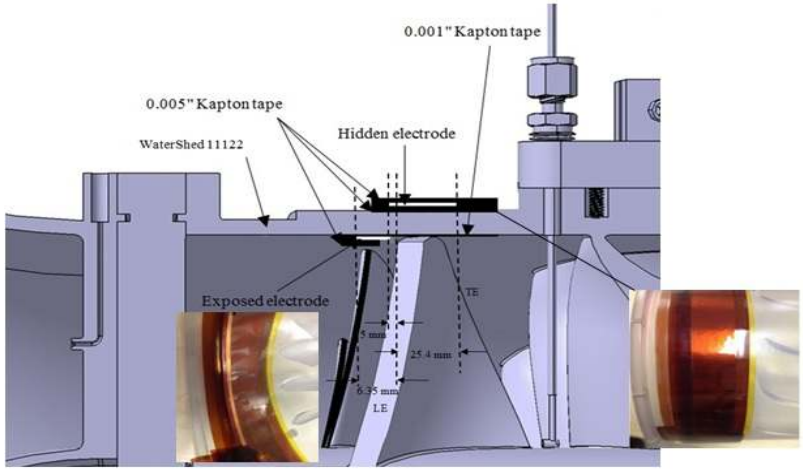
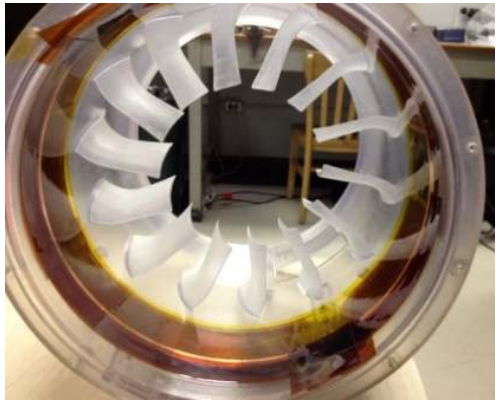
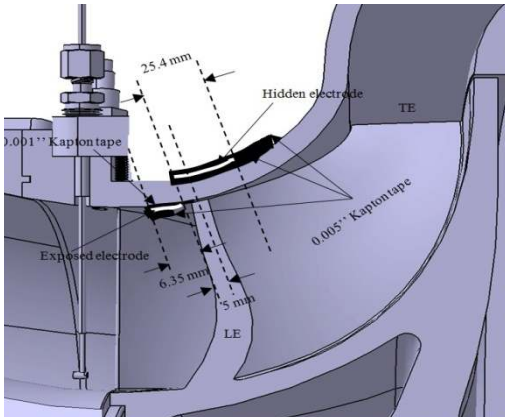
Installation of plasma actuators

Axial stage





Centrifugal stage



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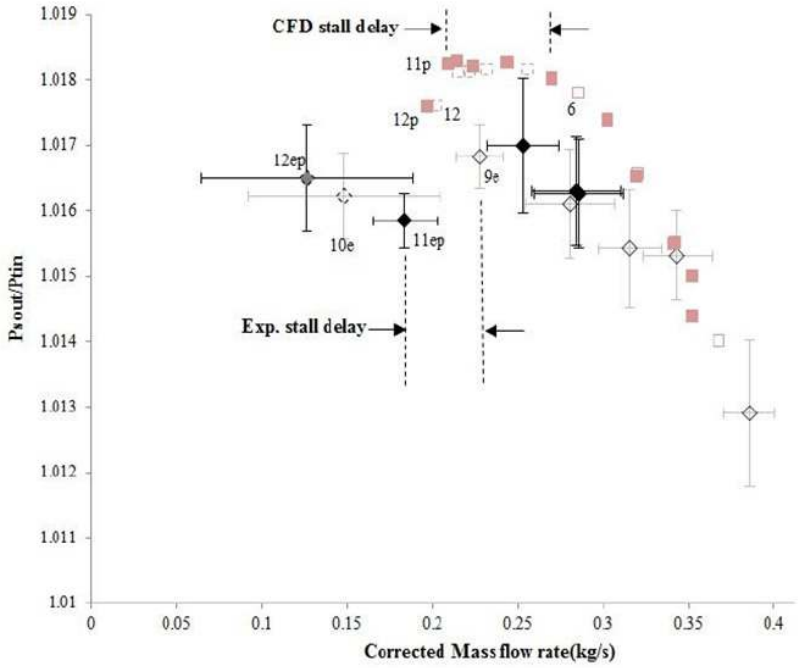
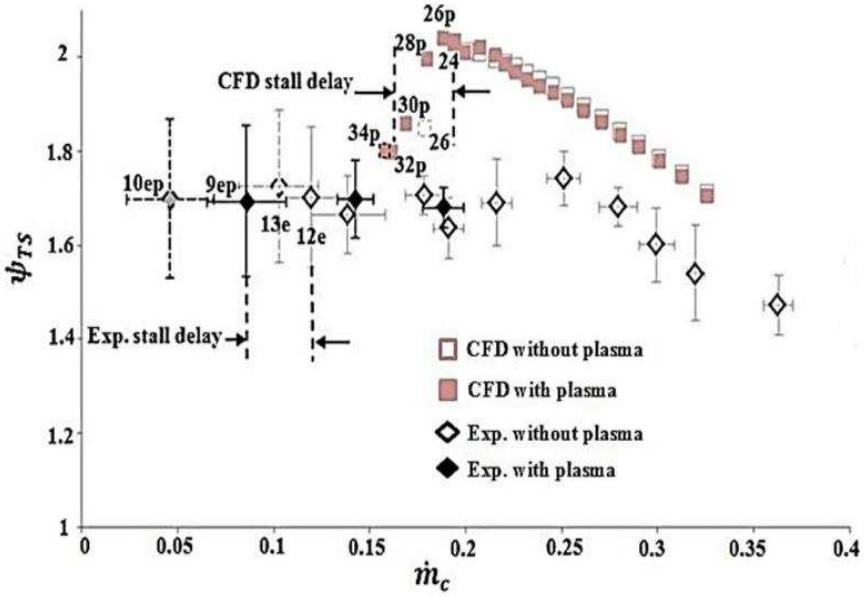
Results

Actuator on axial stage



Actuator on centrifugal stage



Successful demonstration of concept for both axial and centrifugal compressors (first)

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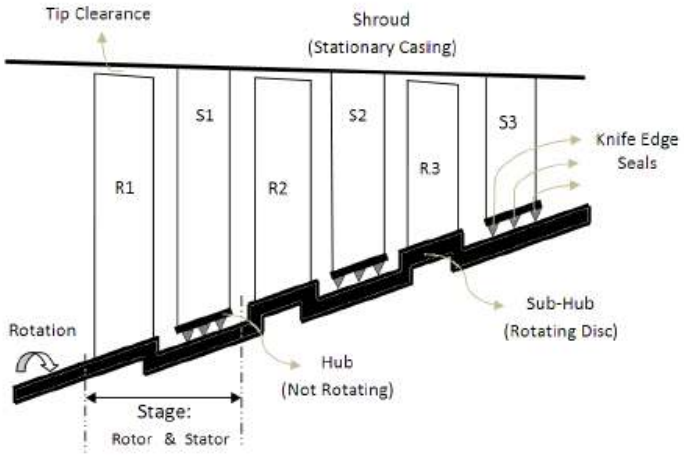
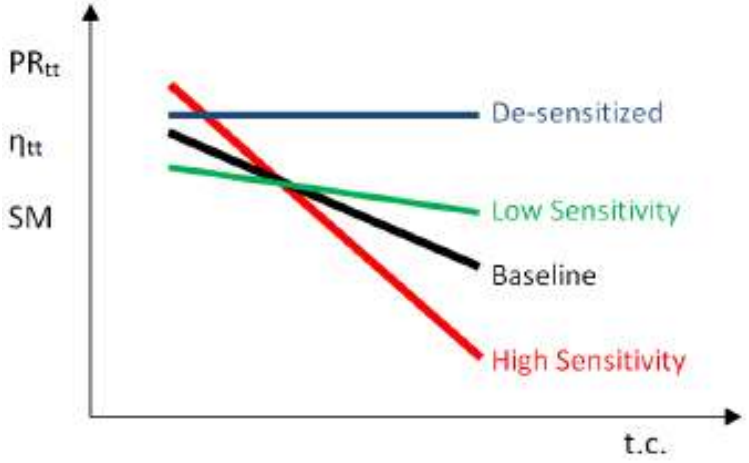
C) Desensitization of compressor performance & stall margin

<u>Objective</u>: Prevent degradation in aero-engine performance and operating envelope with age





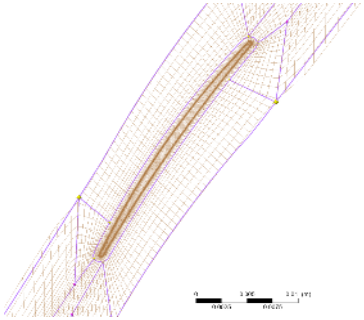
Transient operation → diff. thermal exp. → temp. t.c. increase

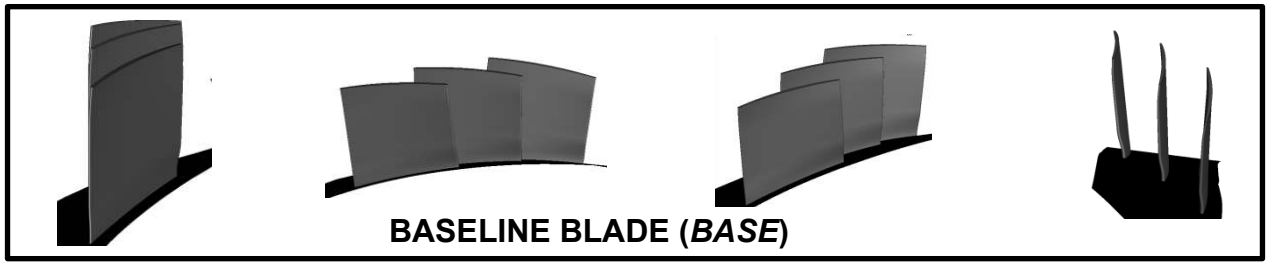
Operational age → rotor tip rubbing → permanent t.c. increase

Fuel consumption ↑

Operating envelope ↓

Extensive numerical (CFD) parametric study of geometric design of axial rotor

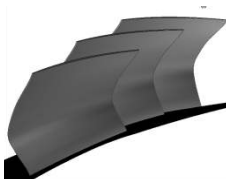




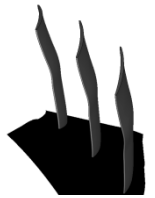
BASELINE BLADE (*BASE*)

Back Axial Sweep

Back Lean

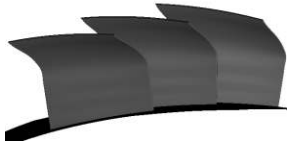


Aft Chordwise Sweep

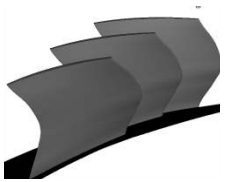


Negative Dihedral

Forward Axial Sweep



Forward Lean

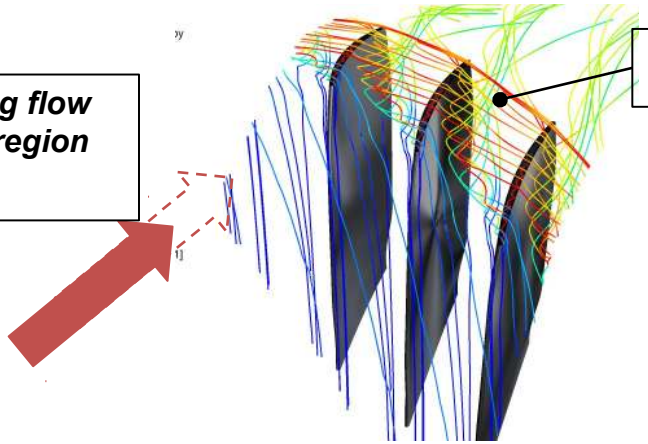


Forward Chordwise Sweep

Positive Dihedral

POLYTECHNIQUE MONTRÉAL

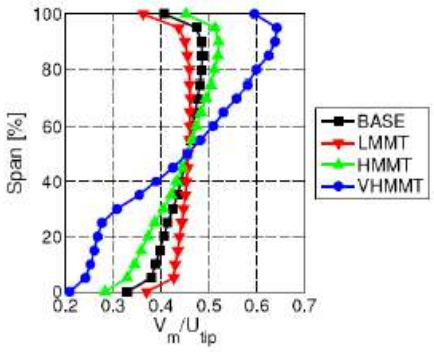
Identification of *two desensitizing flow features*

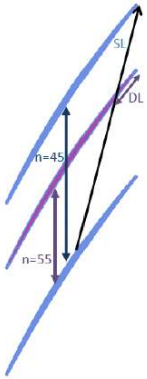


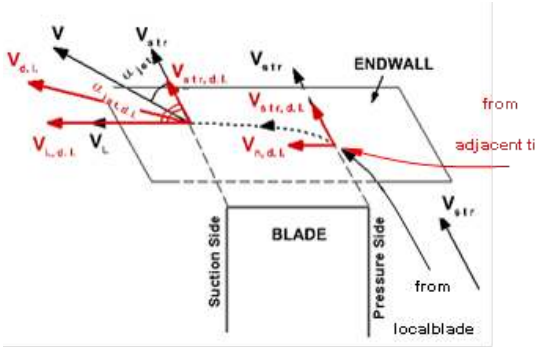
(2) Increased incoming flow momentum in tip region

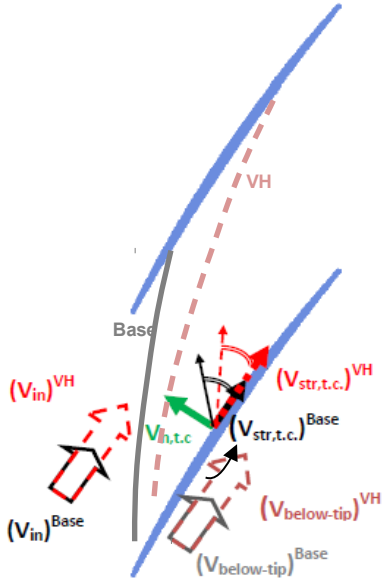
(1) Reduction of double tip leakage

Explanation of associated flow mechanisms



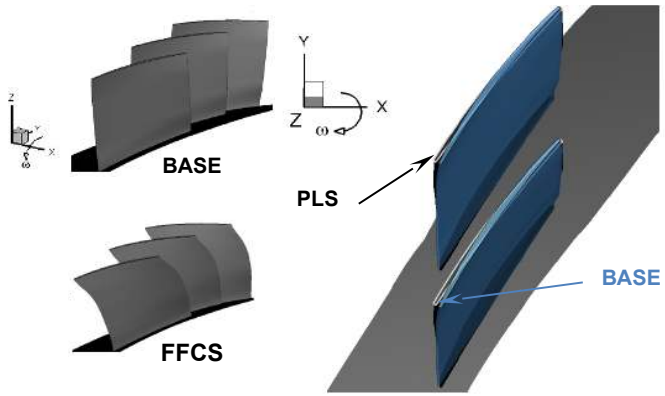


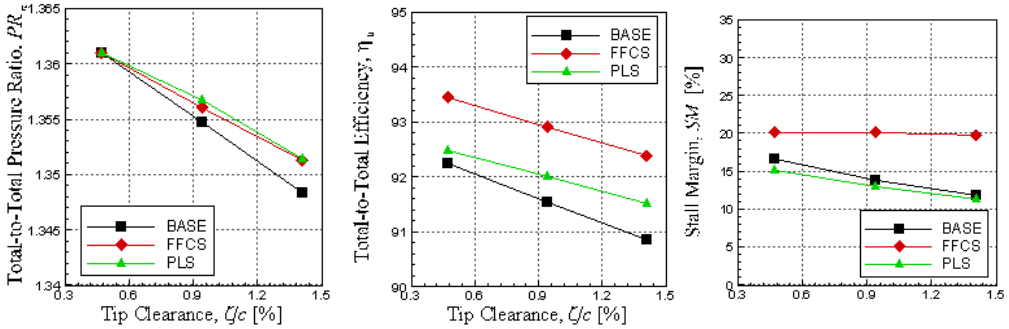




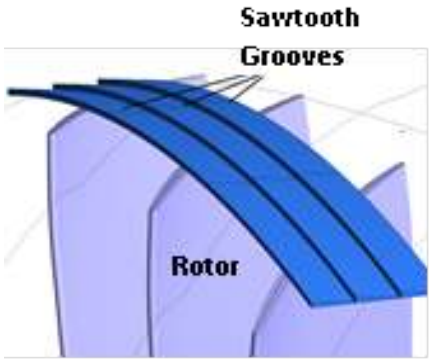
POLYTECHNIQUE MONTRÉAL

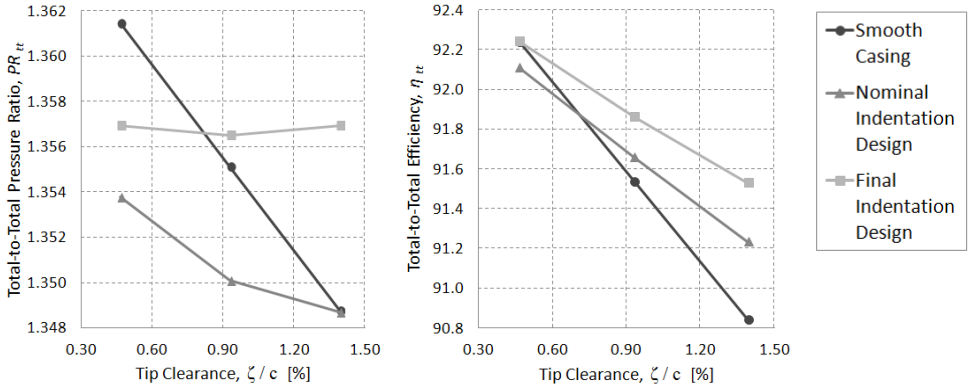
Desensitizing blade design strategies





New desensitizing casing treatment concept





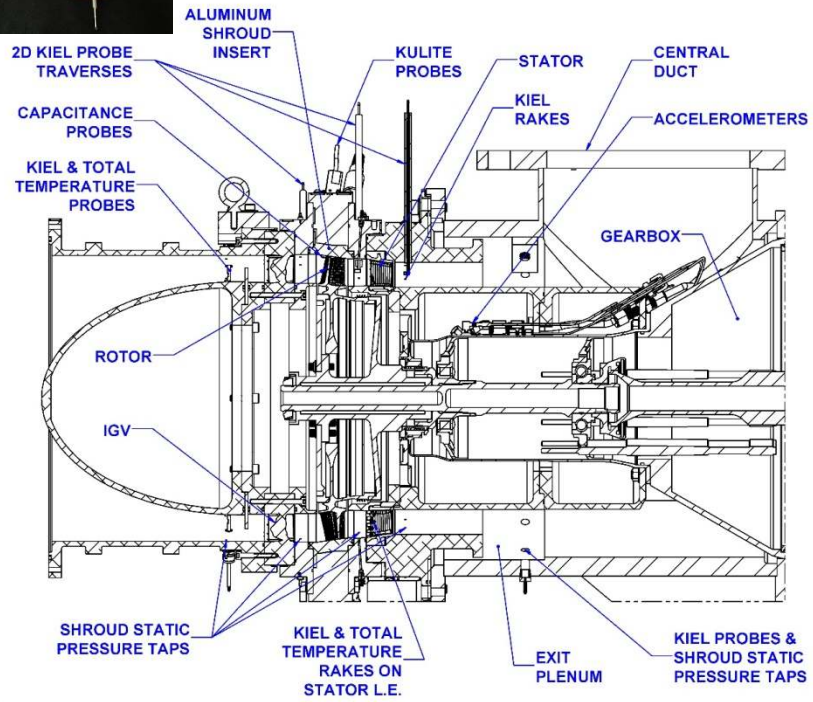
POLYTECHNIQUE MONTRÉAL

Experimental validation on real transonic axial compressor stage at Polytechnique (In progress)

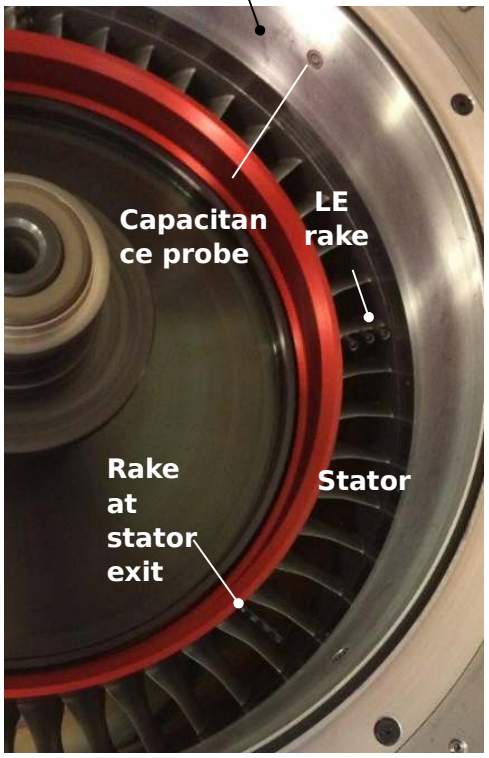
GARDN Green Aviation Research & Development Network

Pratt & Whitney Canada
Une société de United Technologies

MËKANIC
Recherche et Technologie
Research and Technology



Rotor Section



Stator Section

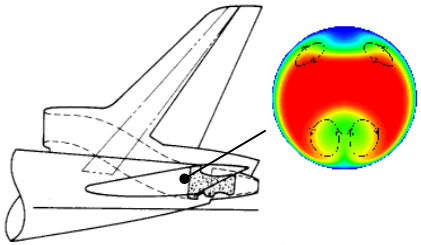
POLYTECHNIQUE MONTRÉAL

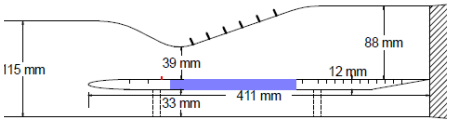
D) Plasma actuation on aero-engine components

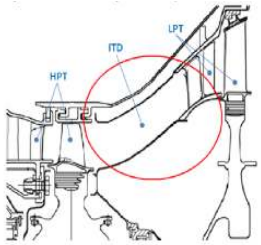
Collaboration with & led by NRC Gas Turbine Laboratory

Project 1: Reduce inlet distortion in non-axial aero-engine intake/inter-turbine duct

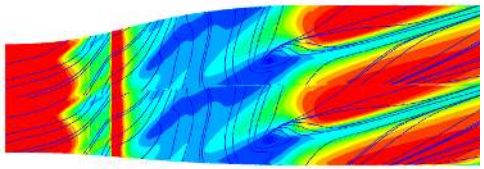
Objective: Improve engine performance/operating envelope & reduce turbine length/weight



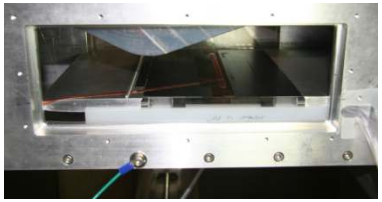




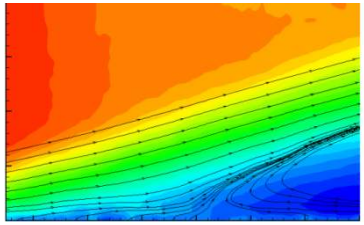
CFD



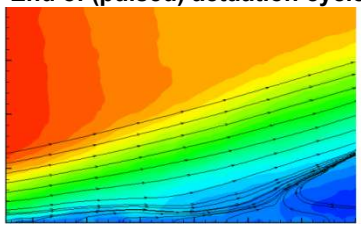
WT test rig at NRC



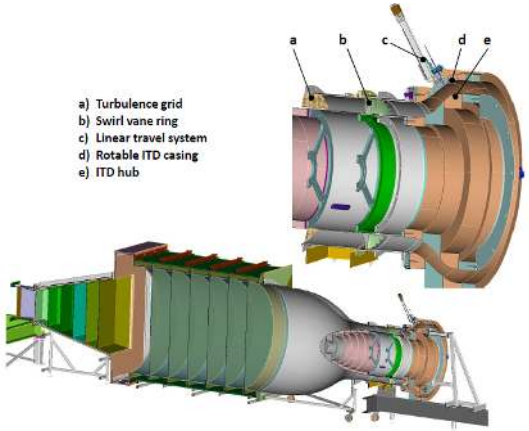
Start of (pulsed) actuation cycle



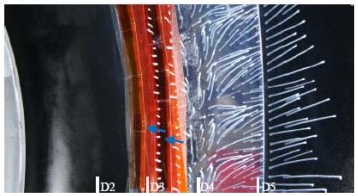
End of (pulsed) actuation cycle



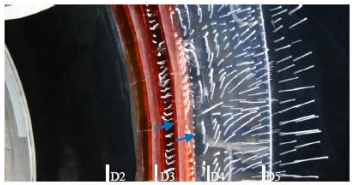
ITD test rig at NRC



No actuation



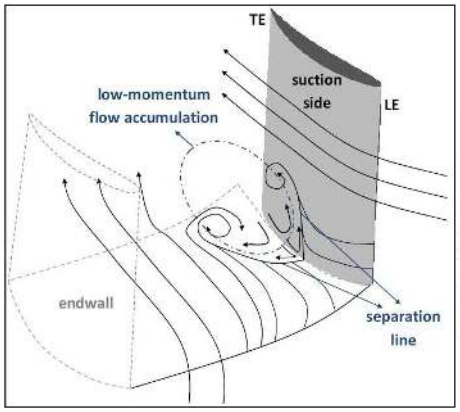
With actuation

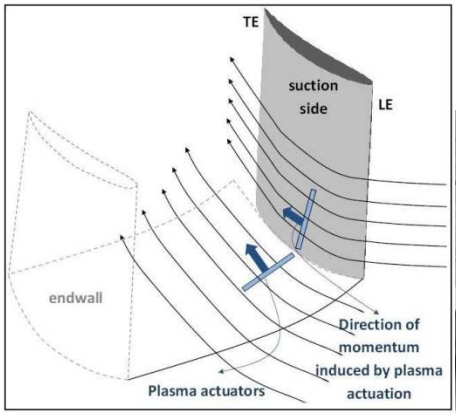


POLYTECHNIQUE MONTRÉAL

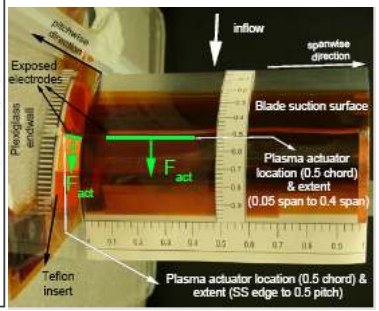
Project 2: Reduce compressor blade corner separation

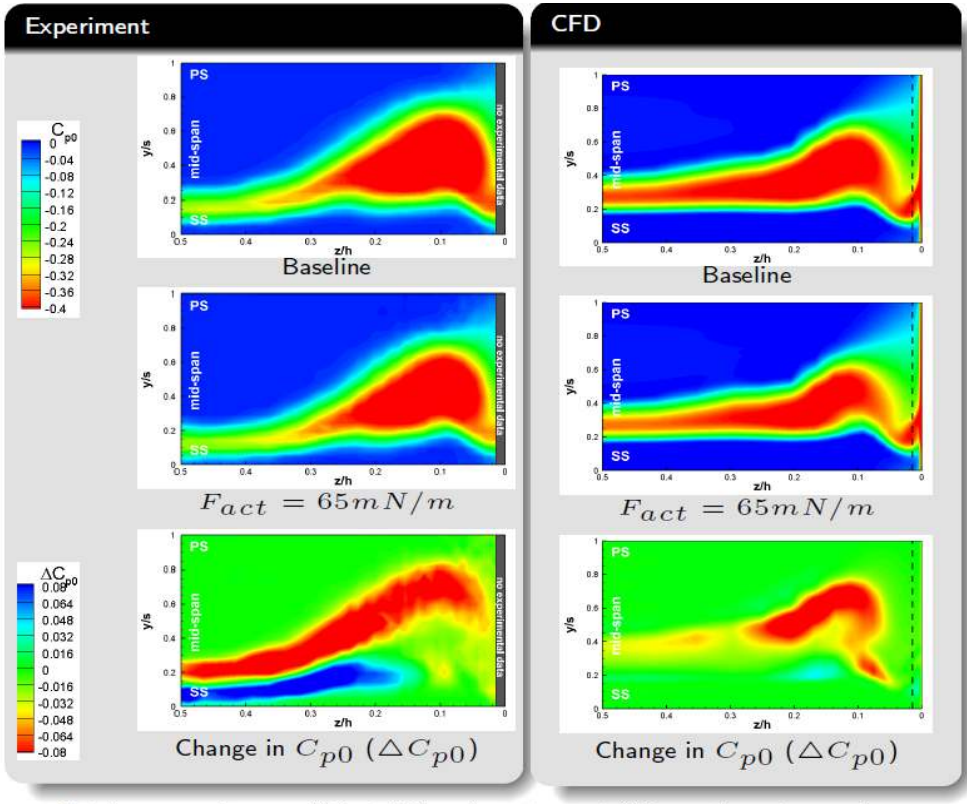
Objective: Improve compressor stage pressure ratio & effciency (reduce # stages)





NRC Cascade WT



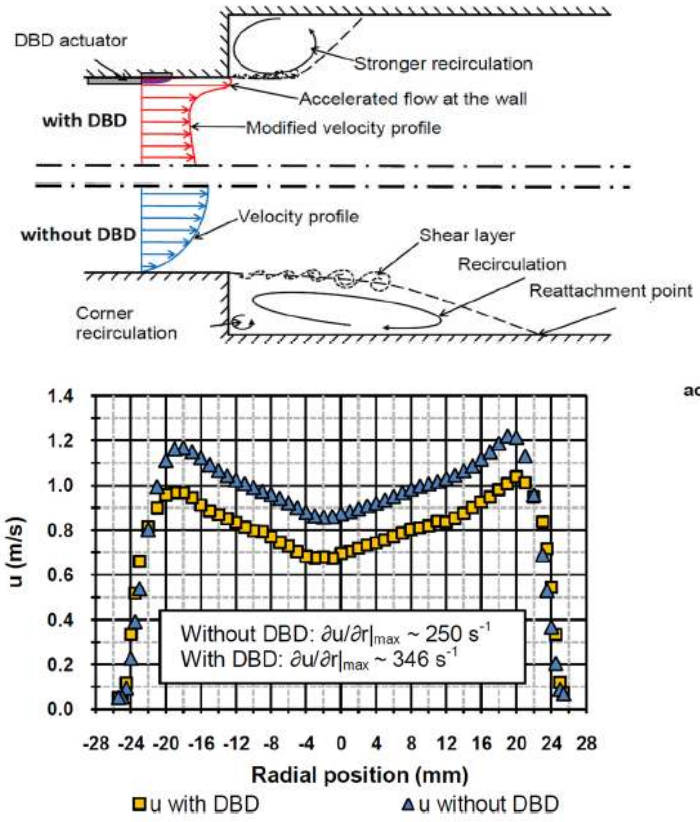


Total pressure loss coefficient (C_{p_o}) contours at 0.4 c_x downstream plane

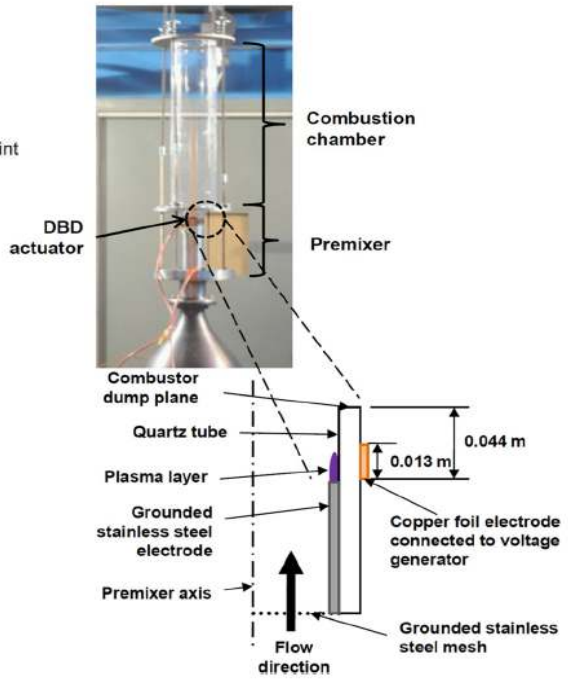
POLYTECHNIQUE MONTRÉAL

Project 3: Flashback control in lean-premixed dump combustor via plasma actuators

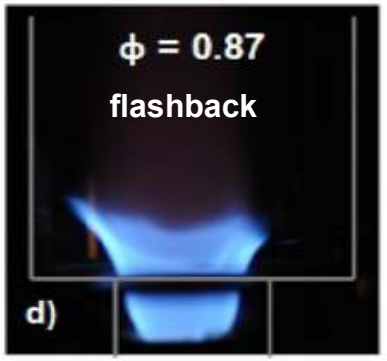
Objective: Improve operability of (low-NOx) lean-premixed dump combustors



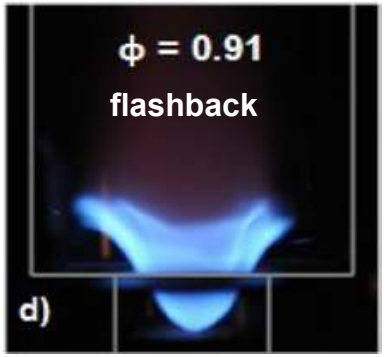
NRC atmospheric combustion rig



No actuation



With actuation



POLYTECHNIQUE MONTRÉAL

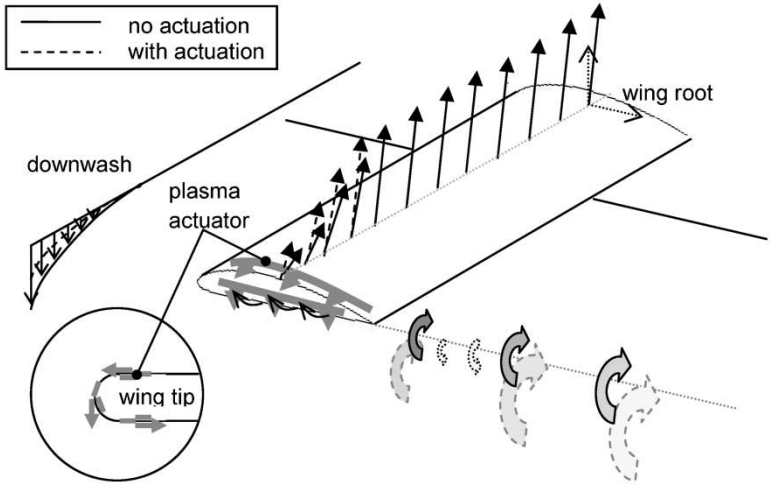
Flight Control with Plasma Actuation

<u>Objective</u>: Eliminate all movable flight control surfaces

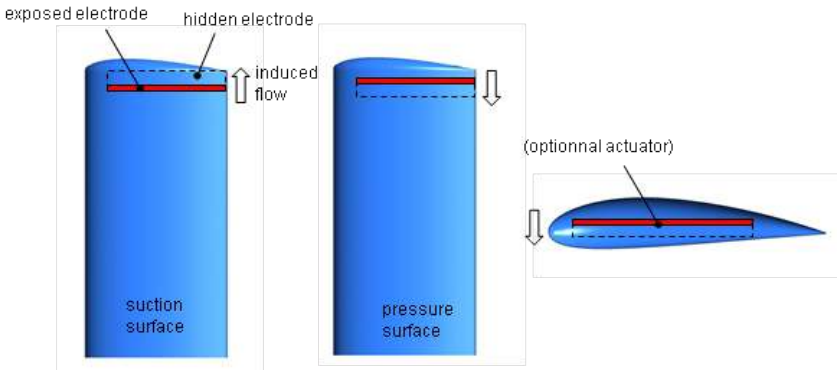
- **Alter lift on wing surfaces**
- **Generate lift on empennages**

<u>Impact</u>: - Reduction of weight and (production/operating) costs
- Increase in range (more fuel volume)

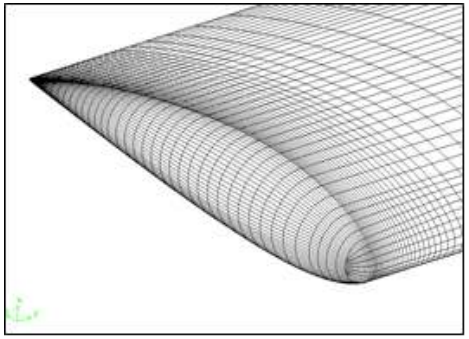
A) Wing tip plasma actuation

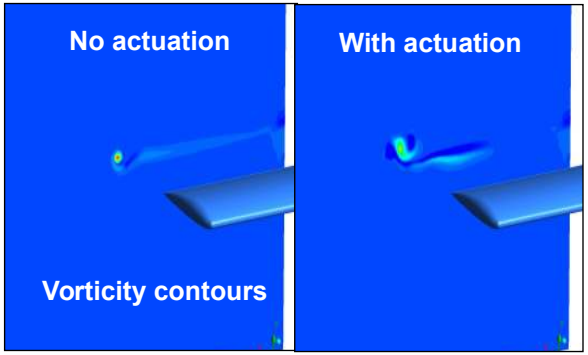


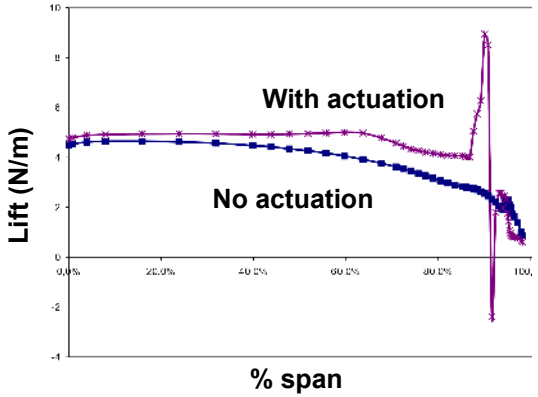
Test Wing Geometry



CFD Simulations

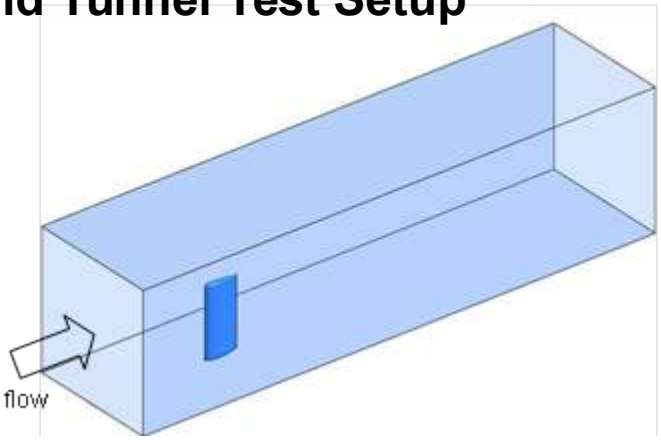


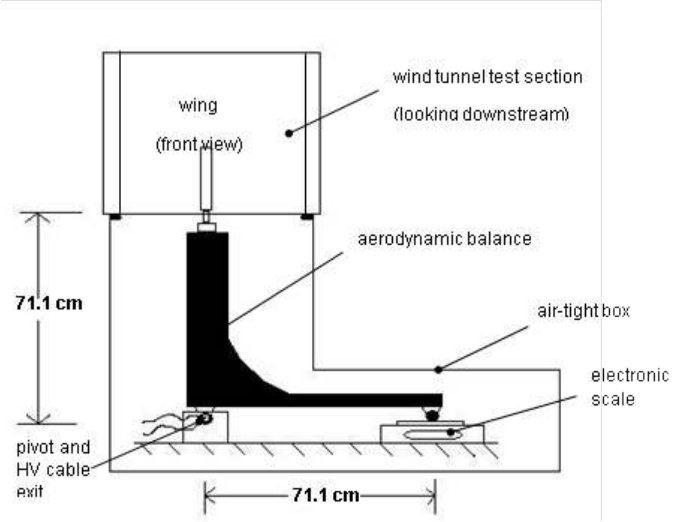




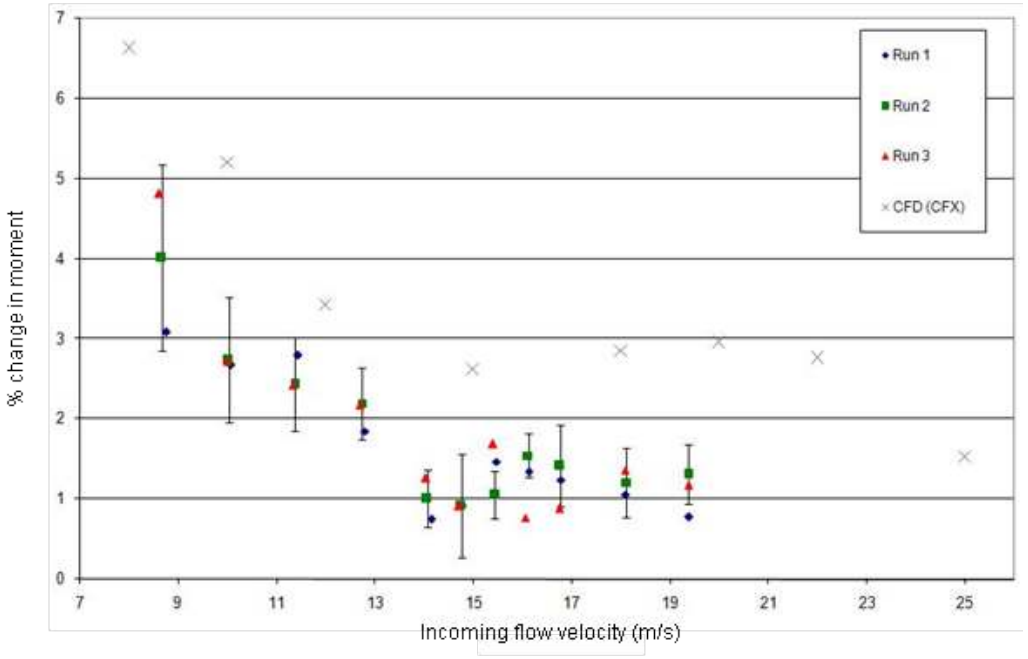
POLYTECHNIQUE MONTRÉAL

Wind Tunnel Test Setup





Results

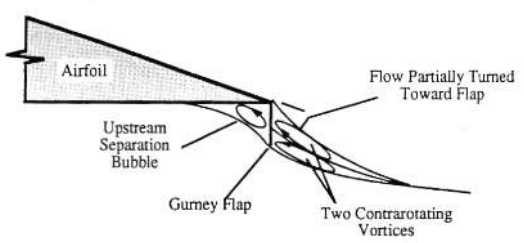


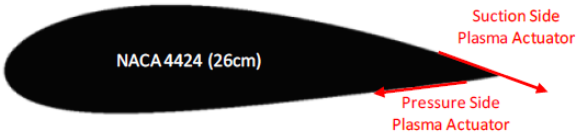
Concept of wing tip plasma actuation can generate sufficient lift change for flight control with sufficient actuator strength

POLYTECHNIQUE MONTRÉAL

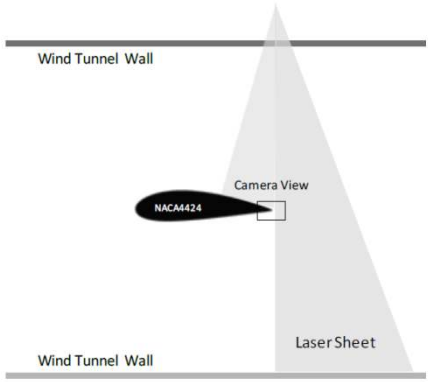
B) Plasma Gurney Flap

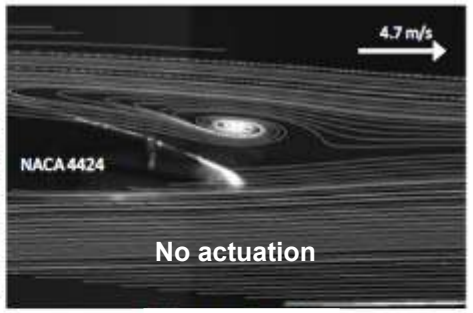
(collaboration with & *led by Prof .N.W. Mureithi*)

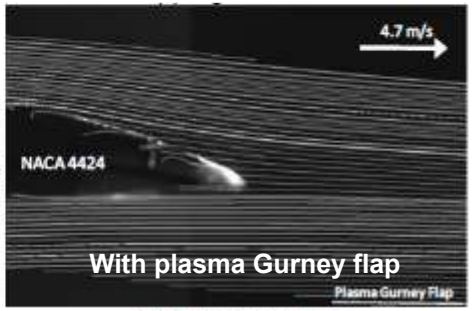


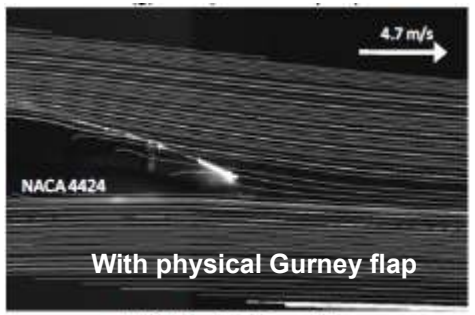


Wind Tunnel Tests with PIV

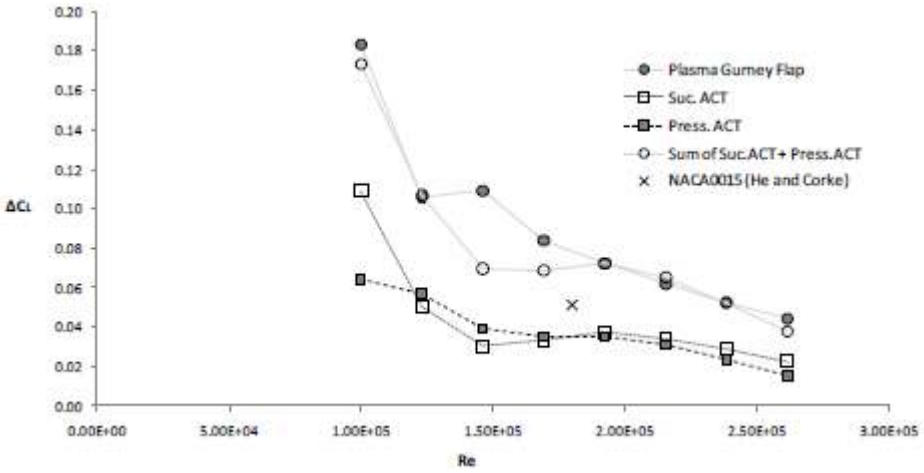






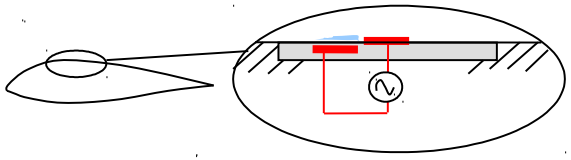


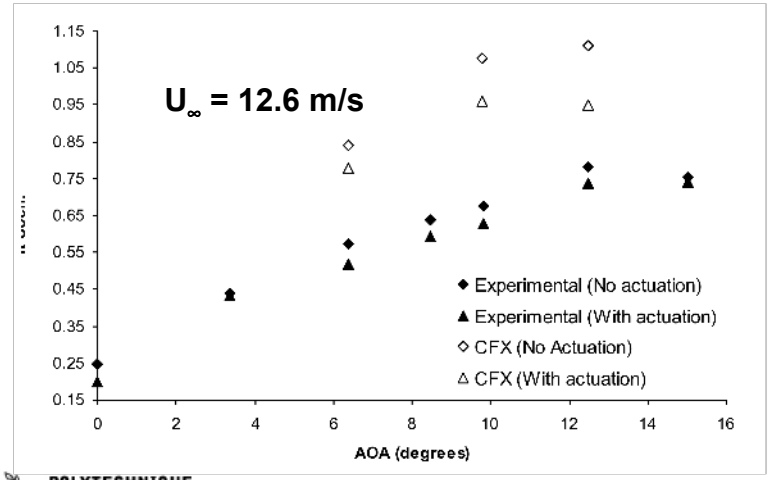
Concept of plasma Gurney flap can work



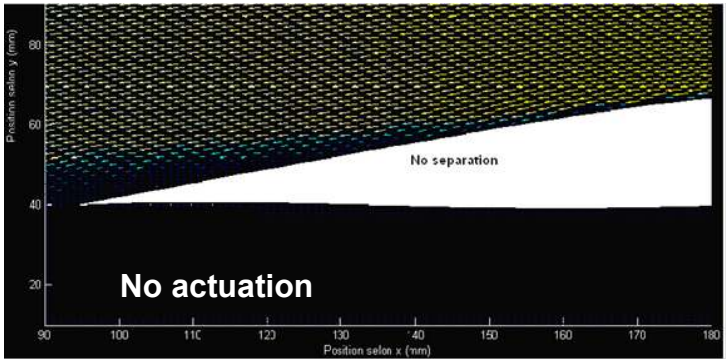
POLYTECHNIQUE MONTRÉAL

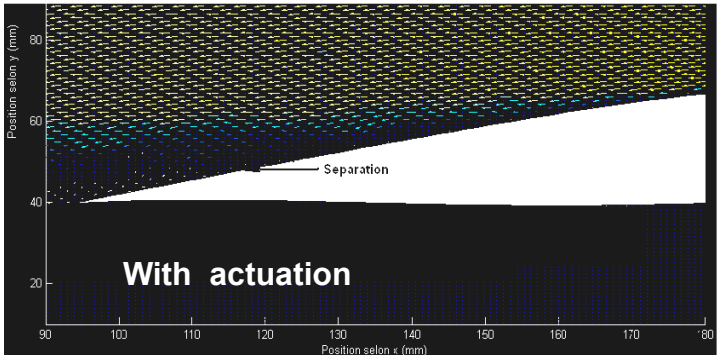
C) Lift reduction with plasma actuation





Measured velocity vectors on suction side with PIV





Concept of 'plasma spoiler' can work with sufficient actuation strength

POLYTECHNIQUE MONTRÉAL

CONCLUSION

- Research on aerodynamics of aero-engine and aircraft wings to make future aircraft more fuel efficient, lighter and mechanically simpler
- Preliminary study of concepts
- Emphasis on understanding of flow mechanism, preliminary numerical assessment/experimental validation of concepts
- Work continuing on further assessment of some of the concepts shown on more realistic geometries/conditions

Thank

You

Question

s?

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