Ultrasonic ice protection systems

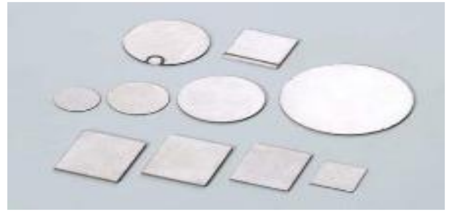
CONTEXT & OBJECTIVES

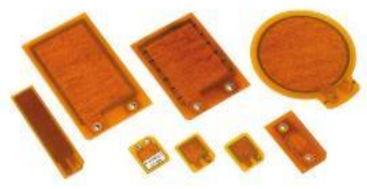
Energetic challenge of icing protection system

- Excluding propulsion, 2° power consumer after Environmental Conditioning System
- Bleed air de-icing systems decreases the performance of reactors
- Electrical de-icing systems currently in use still one of the main power consumer

Objectives of the study

- Investigate low power ice protection system based on piezoelectric technology
- Assess potential benefit at A/C level compared to more classical electrical solutions e.g. electro-thermal





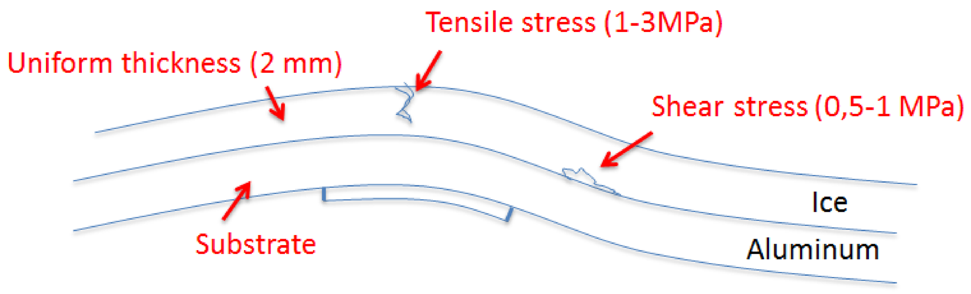
DuraAct™ Patch Transducers - PI Ceramic

METHODOLOGY

Main design drivers for piezoelectric deicing systems

- Thickness and shape of ice
- Form and dimensions of the substratum to protect
- Boundary conditions
- Stress at the interface ice/substrate leading to delamination and cracking

Modeling assumptions



Test sample

Design methodology

Modal analysis with FEM simulation or analytical model:

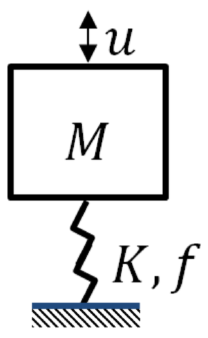
- to link mode type, displacements and stress
  ⇨ required displacement to delaminate
- to compute the electromechanical coupling between the actuator and the substratum
  ⇨ required voltage and current to delaminate

THEORETICAL RESULTS

PZT actuators and structures can be modeled by 2 equations:

- Mechanical equation ➔ $M\ddot{u} + f\dot{u} + Ku = NV - F$
- Electrical equation ➔ $q = Nu + C_0V$

with N the electromechanical coupling

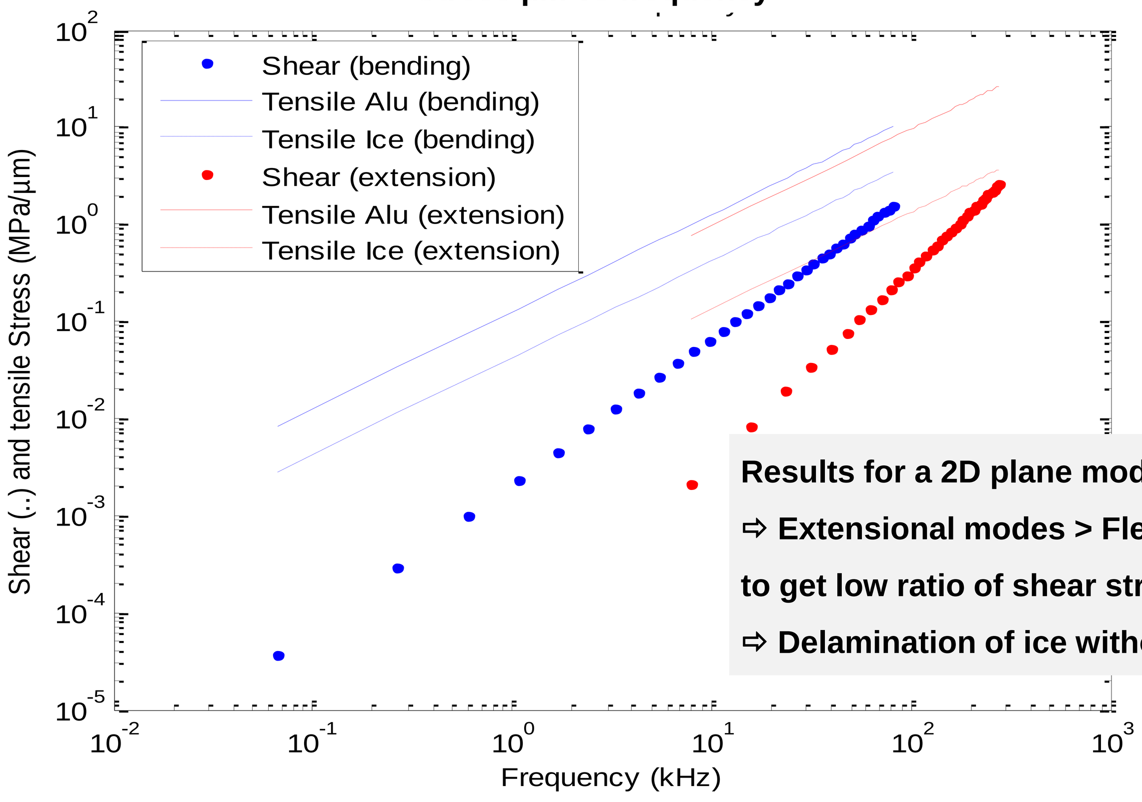


At resonance frequencies and for $F = 0$:

$$\cancel{M\ddot{u}} + f\dot{u} + \cancel{Ku} = NV - \cancel{F} \;➔\; V \approx \frac{f\dot{u}}{N} = \frac{M\omega^2 U_0}{NQ_m}$$

with Q_m the mechanical quality factor of the vibrating structure and U_0 the required displacement for delamination

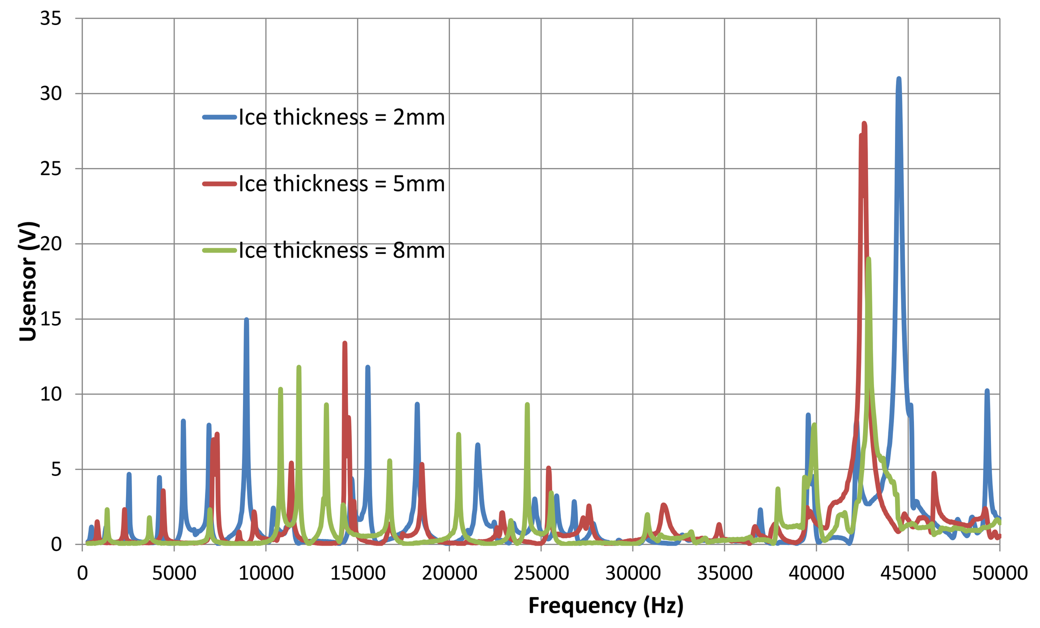
Stress/µm vs frequency



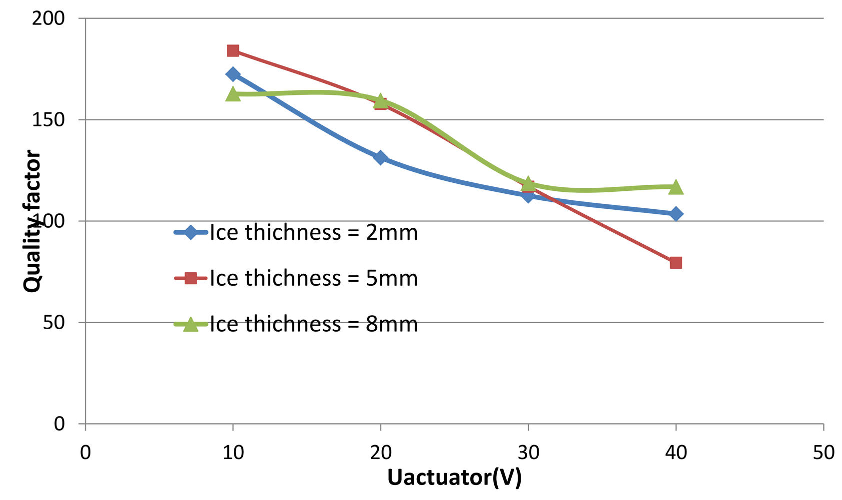
Results for a 2D plane model:
⇨ Extensional modes > Flexural modes
to get low ratio of shear stress/µm
⇨ Delamination of ice without damaging the actuator

PRACTICAL RESULTS

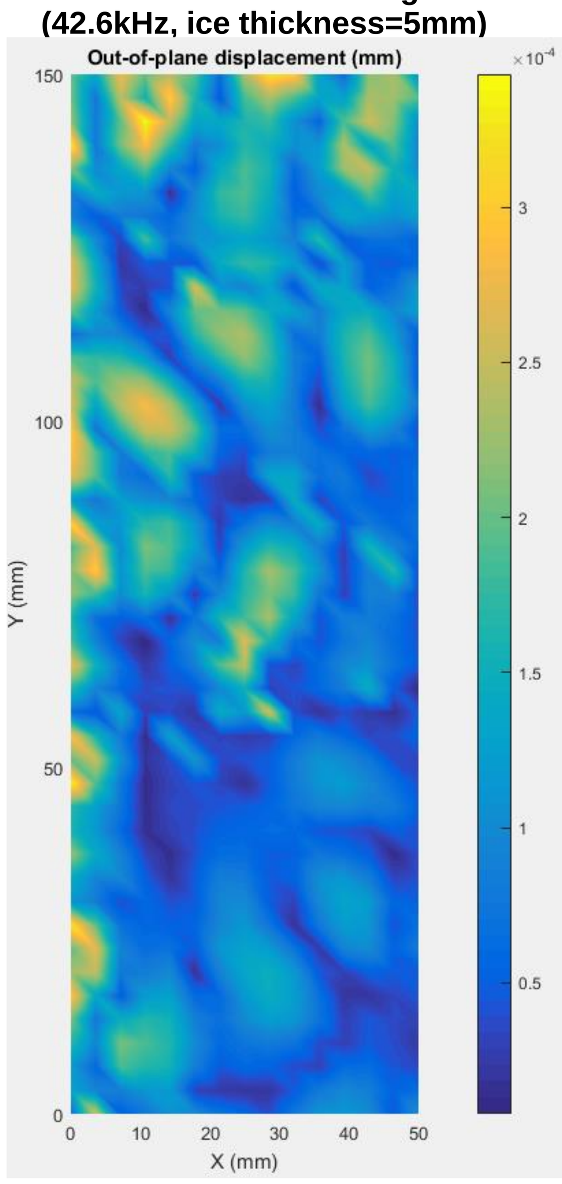
Voltage of the sensor vs Frequency



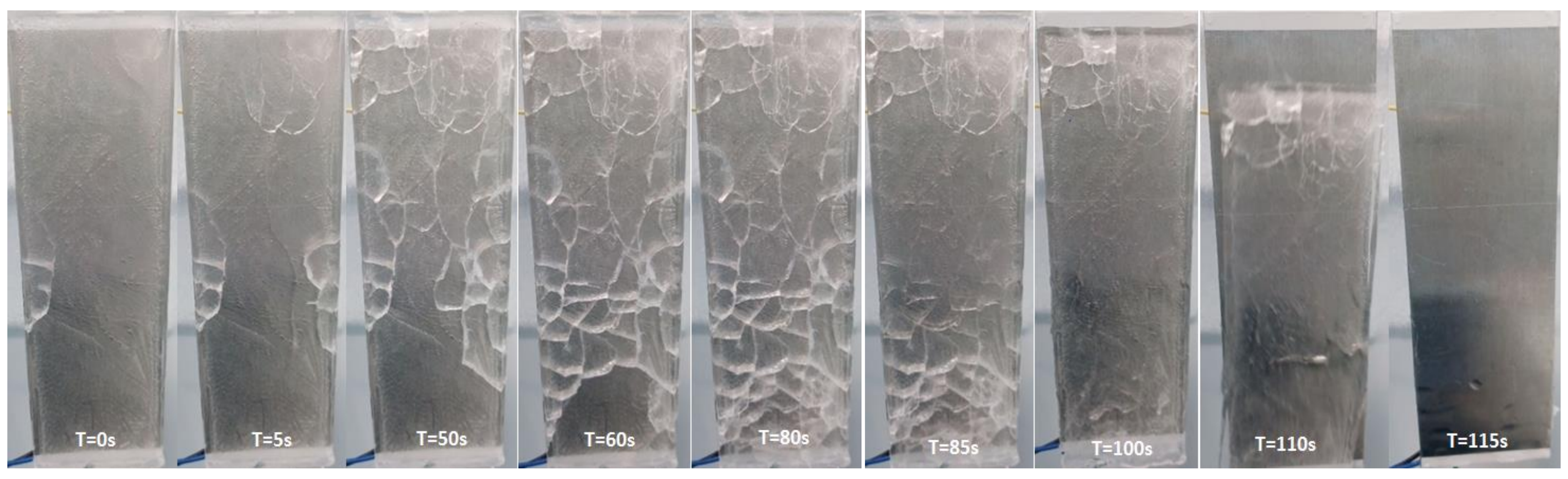
Quality Factor vs actuator voltage at 42.6kHz



Displacement measured by vibrometer scanning (42.6kHz, ice thickness=5mm)



Deicing test (42.6kHz, 80V, 08A, ice thickness=5mm)



PERSPECTIVES

- Next tests on small leading edges in an icing wind tunnel
- Use of pre-stressed piezoelectric actuators to avoid damage of piezoelectric systems
- Control of the resonant piezoelectric actuators to optimize the consumption
- Assessment of the piezoelectric deicing systems at aircraft level
- Investigation of coatings for decreasing the required shear stress to delaminate and thus the required electrical power (collaboration with Carleton University)

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