Ultrasonic ice protection systems

**CONTEXT & OBJECTIVES**

- **Energetic challenge of icing protection system**
  - Excluding propulsion, 2nd 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

**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**

- **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 \( M\ddot{u} + f_u + Ku = NV - F \)
  - Electrical equation \( q = Nu + CuV \)
  - with \( N \) the electromechanical coupling

- **At resonance frequencies and for \( F = 0 \):**
  \[
  M\ddot{u} + f_u + Ku = NV - f \quad \Rightarrow \quad V = \frac{f_u}{N} = \frac{M\omega^2 u_0}{NQ_m}
  \]
  - with \( Q_m \) the mechanical quality factor of the vibrating structure
  - \( u_0 \) the required displacement for delamination

**PRACTICAL RESULTS**

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

**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)