Experimental study and analysis of labyrinth seals in space engine

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Context: Labyrinth seals are a wide diffused mechanical component of space engines turbopumps (*Figure [1],[2]*) which role is to guarantee more efficient engine performance by reducing flow leakage and by limiting recirculation through rotor/stator gap in pumps and turbines (*Figure [3]*). The high fluctuations of pressure and velocity deriving from labyrinth seals operation, together with the necessity for light structures, make them subject to aeroelastic instabilities (*Figure [4]*). The latter are object of in-depth investigations in order to prevent failures caused by fatigue and provide safer turbopumps.

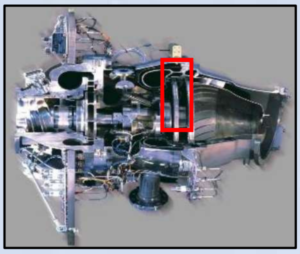


Figure 1: *Vulcain 2 LOX Turbopump*

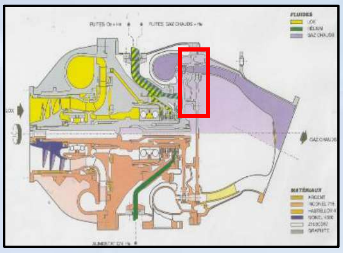


Figure 2: *Vulcain 2 LOX Turbopump - scheme*

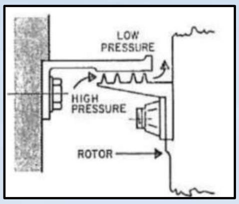


Figure 3: *TOR labyrinth seal*

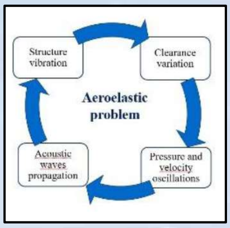


Figure 4: *Aeroelastic problem loop scheme*

Objective: Studying labyrinth seals aeroelastic instability, as well as the related phenomena, through an experimental campaign on a work bench reproducing the characteristics of a real turbopump, using air as working fluid. The deriving experimental data would constitute the means to validate the refinement and upgrade of existing analytical models reproducing labyrinth seals behaviour in specific working conditions.

Approach and application: The present analysis involves two aspects:

- The development of an accurate **analytical one-dimensional model** of the fluid-structure coupled system (*Figure [5]-[7]*) through the improvement of existing simplified models, in order to properly describe the aeroelastic problem.
- An **experimental campaign** on an existing and consolidate work bench (*Figure [8]*), reproducing realistic working conditions. The in-depth analysis of the innovative experimental data would allow to understand the phenomenon and validate the results given by the analytical model.

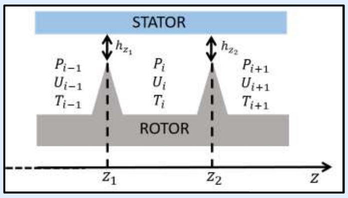


Figure 5: *Cavity 2D CV (for fixed θ)*

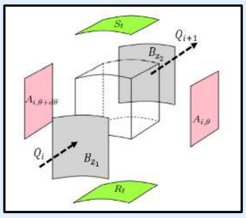


Figure 6: *Cavity 3D CV*

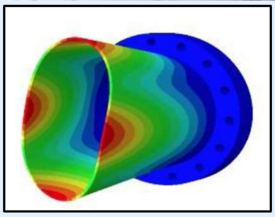


Figure 7: *Stator structural model*

Figure 8: *Minotaur work bench*

Results:

- Sensitivity of the fluid-structure coupled system stability to different design parameters and working conditions (*Figure [9a],Figure [9b]*) together with the particular relevance of including the energy equation in the fluid behaviour modelling (*Figure [10a],Figure [10b]*).
- Consistency between the analytical results and the experimental data obtained from a previous campaign on the work bench

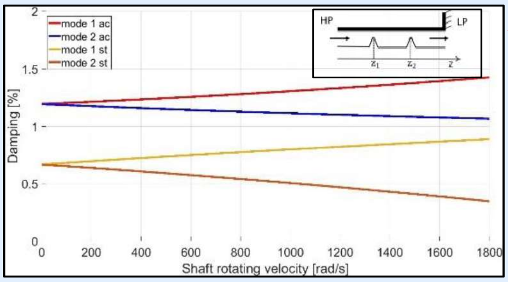
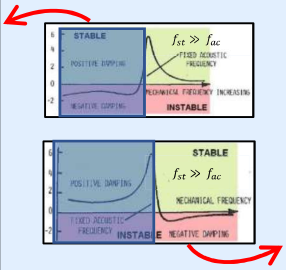


Figure 9a: *Coupled system damping ratio variation for stator supported in LP zone*



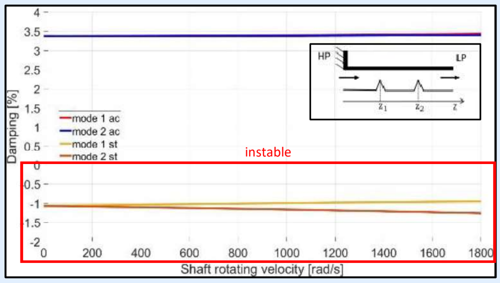


Figure 9b: *Coupled system damping ratio variation for stator is supported in HP zone*

P_{in} [bar]	3
T_{in} [K]	293
U_{in} [m/s]	0
P_{out} [bar]	1.01
ND	2
ζ_{st}	0 %
c_{in} [µm]	150
Stator support location zone	LP

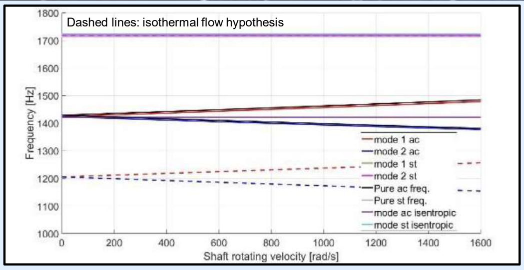


Figure 10a: *Coupled system frequency variation with shaft rotating velocity for different fluid model hypothesis*

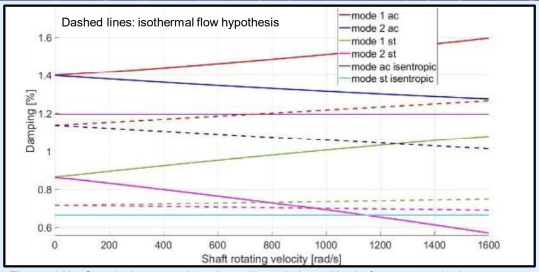


Figure 10b: *Coupled system damping ratio variation with shaft rotating velocity for different fluid model hypothesis*

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