Performance and Stability Analysis of a Highly-Loaded Low-Pressure Compressor Under Distorted Inflow Conditions

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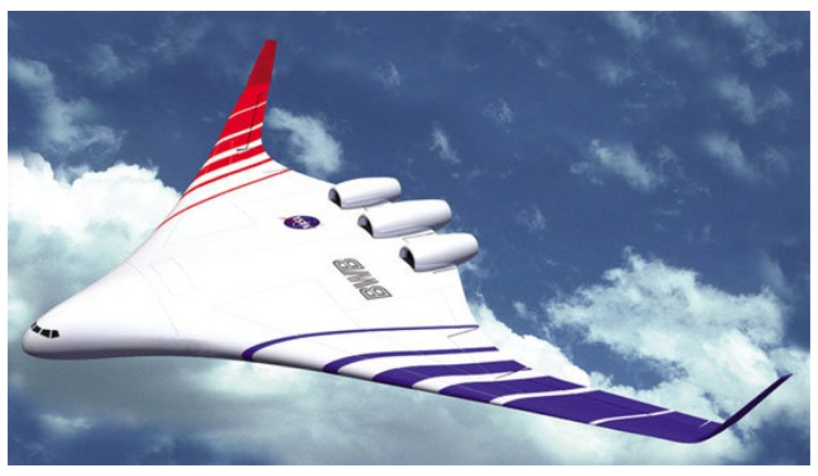
1-Context

Boundary Layer Ingestion (BLI) engines [1] and Geared High-Bypass (GHB) turbofans [2] are considered among the most promising future flight systems to reduce CO2 and NOx emissions. However, they are prone to **inlet flow distortions, leading to reduced aircraft performance and stability** [3].

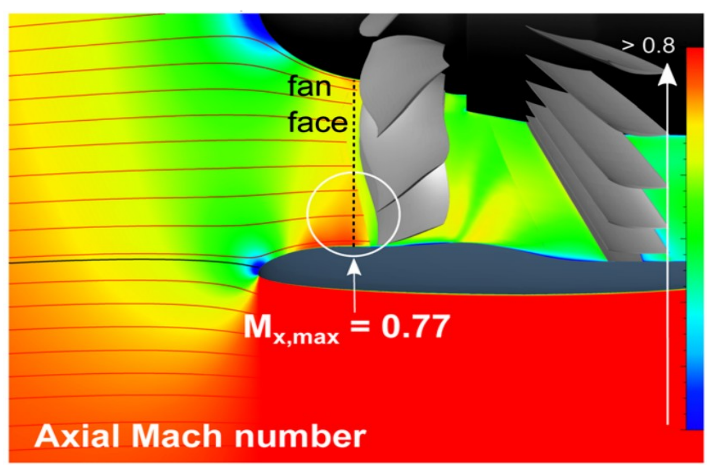
Given its crucial role in the definition of the overall propulsive performance, **the fan has been the only focus of research** on distortion effects induced by shorter inlet ducts and BLI.

Motivation: No information is currently available on the performance and stability of modern low-pressure compressors (LPC), and on the underlying physical mechanisms taking place with distorted inlet conditions.

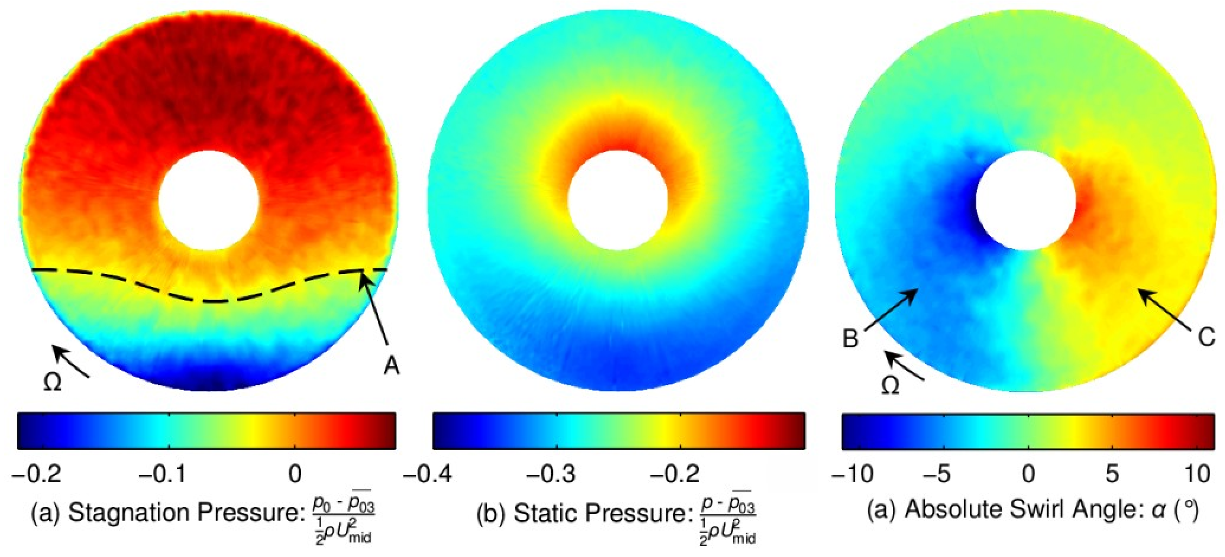
Objective: Provide a comprehensive **description and characterization of the flow topology** involved in the LPC under distortions, highlighting **physical mechanisms driving loss generation, stall inception mechanisms, global performance reduction and post-stall behavior.**



[1]



[2]

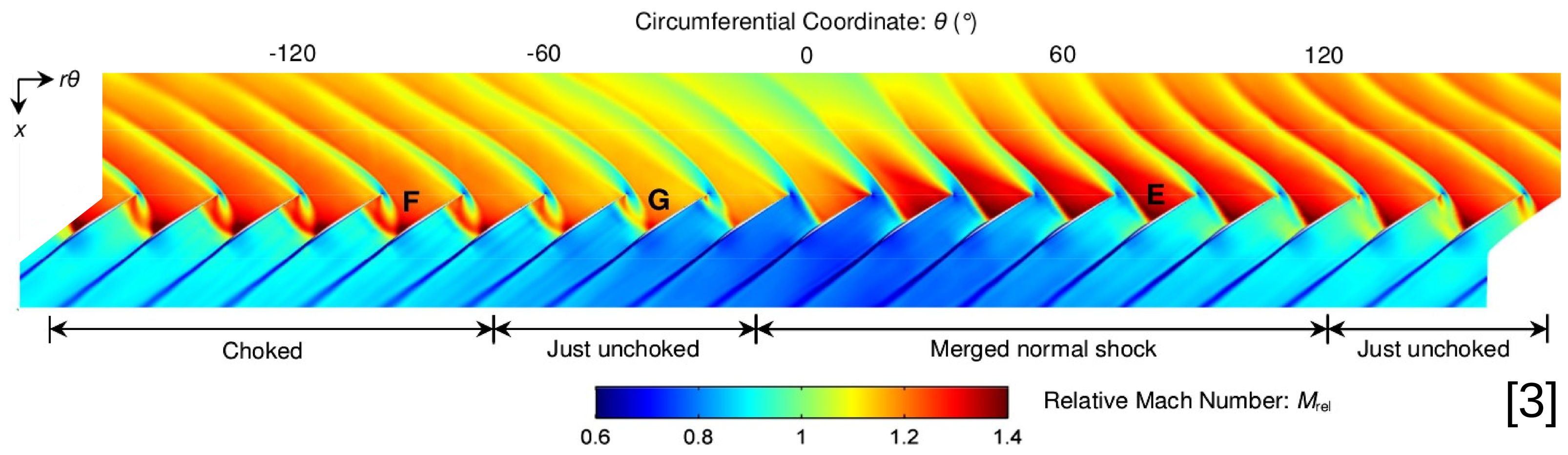


[3]

2-State of the art

In past decades, the studies conducted on the fan were focused on:

- Characterization of performance and stability limit drops;
- Description of loss generation and stall inception mechanisms;
- Development of high-fidelity CFD simulations;
- Development of distortion simulators to reproduce inhomogeneous flows.

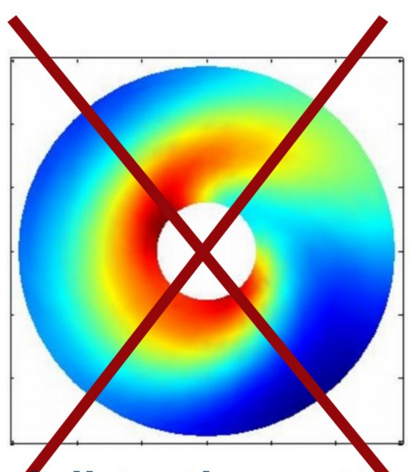


[3]

However, **the aerodynamic and structural design differences do not allow for a direct extension of results** obtained for fan to the LPC.

- No representative geometries and distortions for the LPC.

Modern blade shape



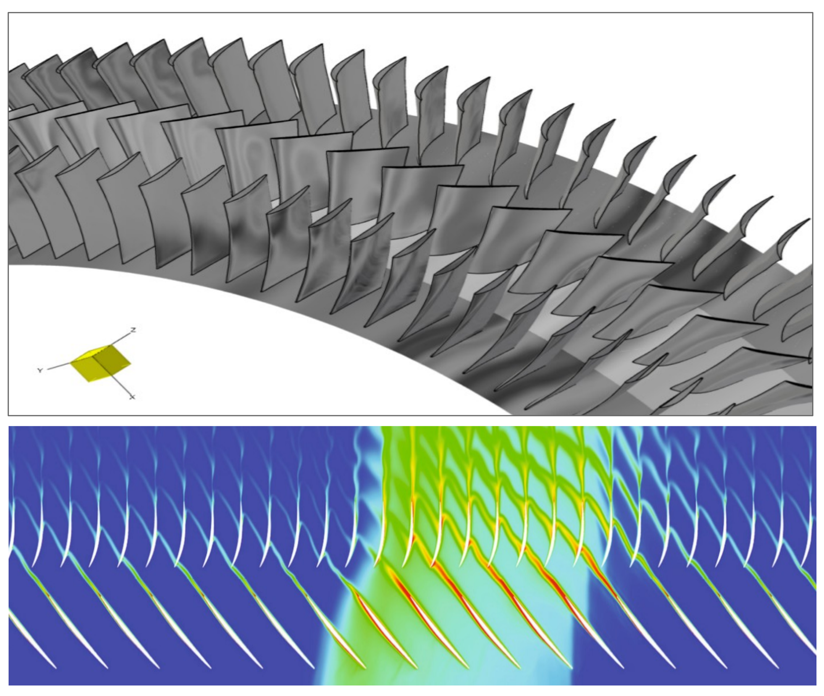
[4]

Real distortion patterns

There is a lack of information on the LPC.

3-Methodology

Complementary development of **numerical and experimental activities.**



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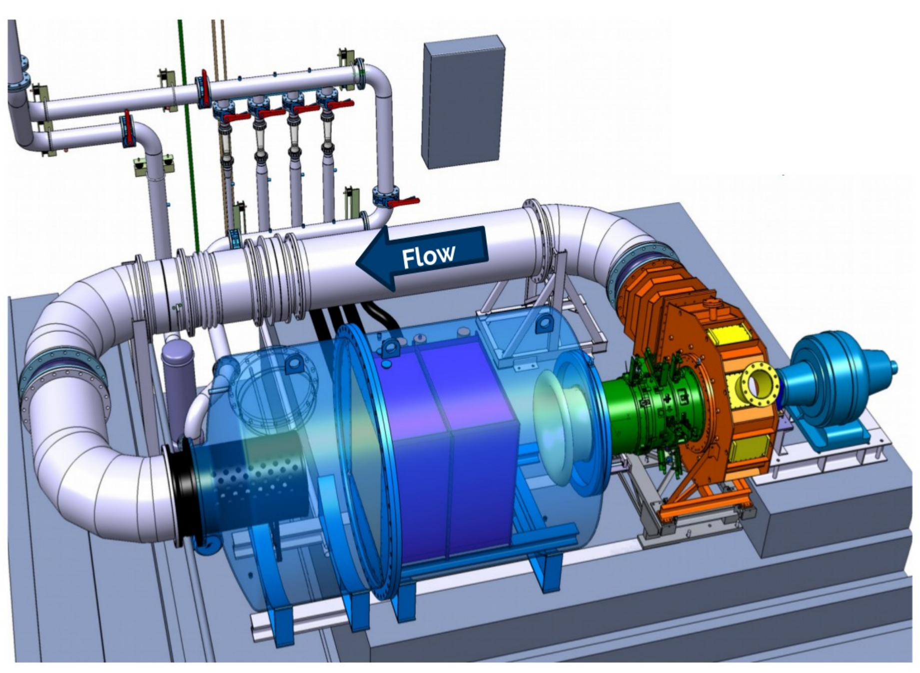


Numerical

- HPC facility;
- Unsteady RANS simulations;
- Full annulus (domain);
- DREAM configuration.

Experimental – VKI R4 facility

- Closed loop compressor test rig;
- DREAM test section;
- Controlled inlet temperature;
- Precision throttling;
- Independent variation of Re and Ma.

4-Research activity

1. Bibliographic survey

- BLI and GHB distortions;
- Most meaningful distortions for the LPC;
- Numerical and experimental feasibility.

Outcome: Distortion at the LPC inlet.

2. Numerical simulations

- Identified inlet distortion as inlet BC;
- Flow characterization;
- Choice of the instrumentation.

Outcome: Design of experiments and numerical flow topology.

3. Measurement campaign

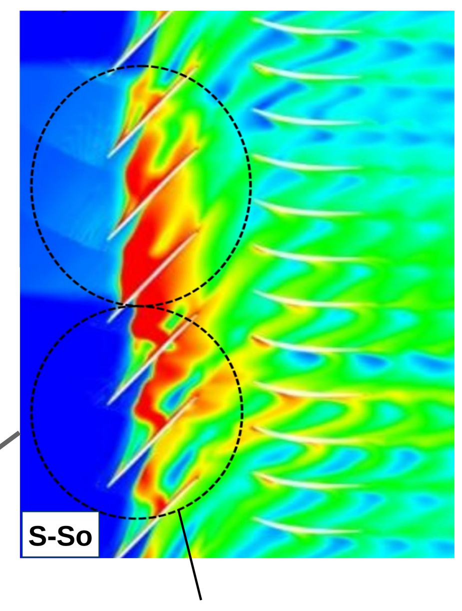
- Adoption of a distortion screen;
- Steady measurements;
- Unsteady measurements.

Outcome: LPC performance and experimental flow topology.

4. Interpretation of the results

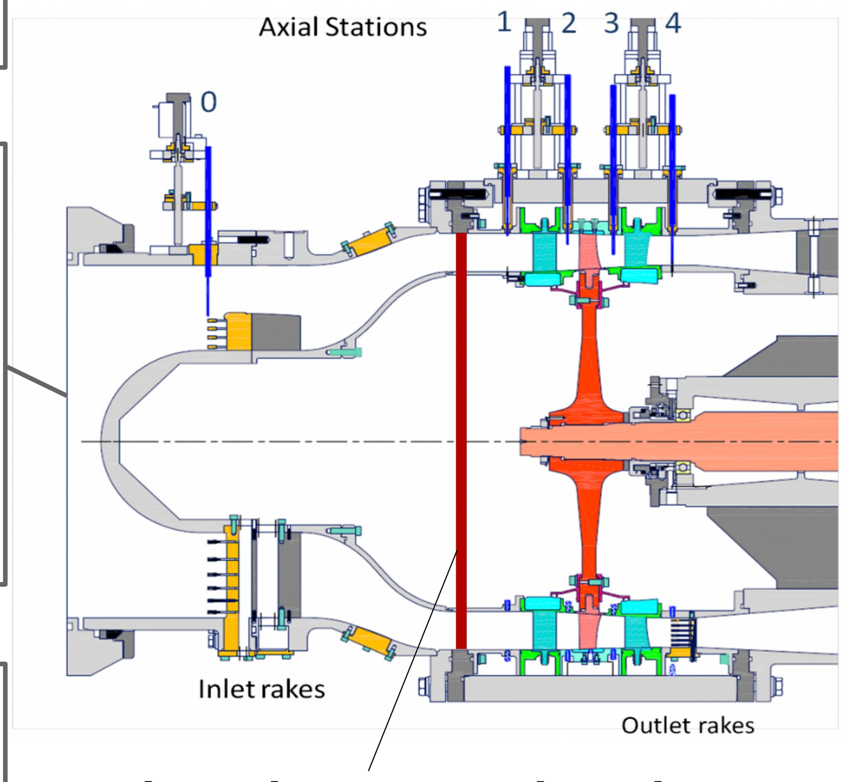
- Performance and stability reduction;
- Role of unsteady effects;
- Stall inception mechanisms;
- Post-stall behavior.

Outcome: LPC behavior under engine like distortions and design guidelines.



[6]

Strong secondary flows: Enhanced resolution of the instrumentation.



Distortion screen location

[7]

5-References

[1] Leiffson L.T. "Multidisciplinary Design Optimization of Low-Noise Transport Aircraft". PhD thesis, Virginia Tech, 2005;
[2] Peters A. et al. "Ultrashort Nacelles for Low Fan Pressure Ratio Propulsors" Journal of Turbomachinery (137(2), 021001, 2014);
[3] Gunn E.J. et al. "Aerodynamics of Boundary Layer Ingesting Fans" ASME Turbo Expo 2014 (GT2014-26142);
[4] Plas A.P. et al. "Performance of a Boundary Layer Ingesting (BLI) Propulsion System" 45 th AIAA Aerospace Sciences Meeting and Exhibit 2007 (AIAA 2007-450);
[5] Barthmes S. et al. "Unsteady CFD Simulation of Transonic Axial Compressor Stages with Distorted Inflow". Symposium on Field of the Research Unit 1066 (FOR 1066 2014, pp. 303-321);
[6] Lesser A. et al. "Transonic Axial Compressors With Total Pressure Inlet Flow Field Distortions" ASME Turbo Expo 2014 (GT2014-26627, pp. V01AT01A036);
[7] Stephens J.E. et al. "Swirl Distortion Using Stream Vanes for Boundary Layer Ingestion Research" ASME Turbo Expo 2019 (GT2019-92073).

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