WALL RESOLVED LARGE-EDDY SIMULATIONS OF THE SPLEEN LOW-PRESSURE BLADE CASCADE

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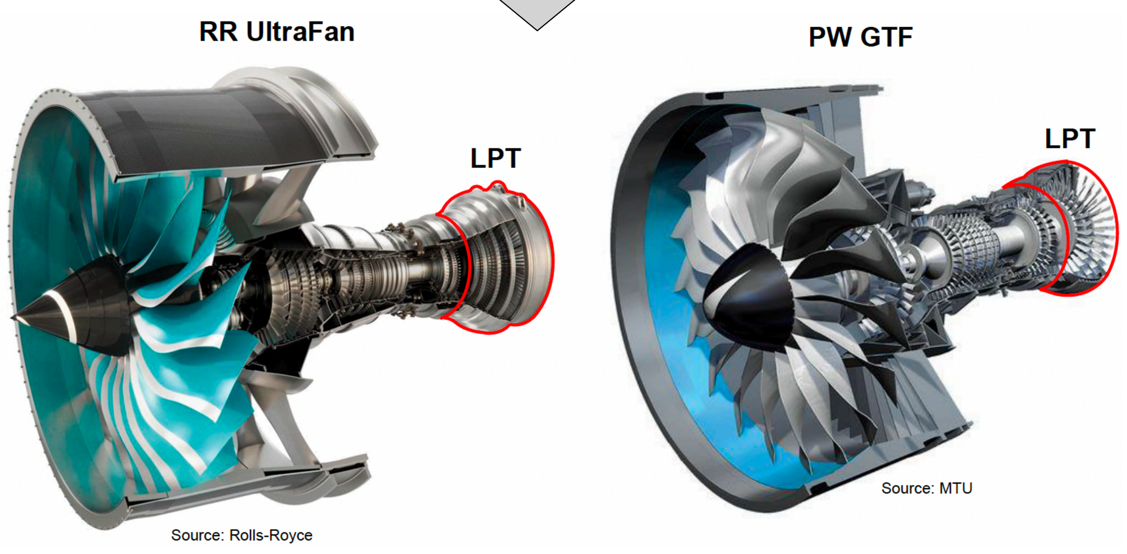
Introduction

The field of aircraft propulsion is currently facing major energy and environmental challenges, requiring faster improvements in engine performance and therefore a better understanding of turbine flows.



- Fan => 80% of the thrust
- Gearbox (Fan & LPT shaft)
- Low Re (50k – 150k)
- Transonic speeds (M_{2s} > 0.8)

Problematics

Complex flows & geometries
➡ Limited Exp. Investigations
➡ Lack of Exp. data

Numerical predictions
Challenge : **Accuracy**

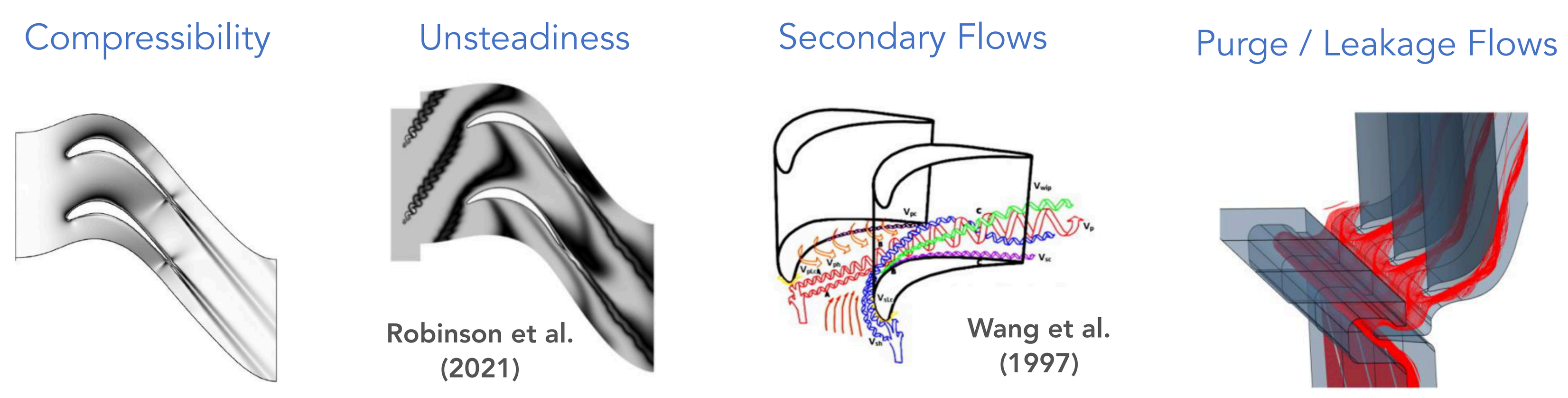
Objectives of the PhD

Numerical investigations of the aerodynamics of transonic low-Reynolds LPT, using High fidelity calculations.

➡ Accurate prediction of :
- the suction-side separation bubble
- the laminar-turbulent transition
- the wake

➡ Wall Resolved Large-Eddy Simulations (WRLES)
- Low Reynolds regimes ($\leq 150k$)
- Transonic flows ($M \geq 0.8$)

➡ Next - generation HS-LPT cascade : **SPLEEN** [1]



Software & features

The **massively parallel (> 32k procs)** code YALES2 [2,3]

- 4^{th} order central **Finite Volume Method** (FVM), 4^{th} order time integration
- Structured, unstructured & hybrid mesh (up to several billion elements)
- **Explicit** density based solver
- **Compressible** N-S equations for turbulent flows

$$\frac{\partial \bar{\rho}}{\partial t} + \nabla \cdot (\bar{\rho}\tilde{\mathbf{u}}) = 0$$

$$\frac{\partial \bar{\rho}\tilde{\mathbf{u}}}{\partial t} + \nabla \cdot (\bar{\rho}\tilde{\mathbf{u}}\tilde{\mathbf{u}}) + \nabla \bar{P} = \nabla \cdot \boldsymbol{t}$$

$$\frac{\partial \bar{\rho}\widetilde{\mathrm{E}}}{\partial t} + \nabla \cdot ((\bar{\rho}\widetilde{\mathrm{E}} + \bar{P})\tilde{\mathbf{u}}) = \nabla \cdot \left((\lambda + \lambda_t) \nabla \widetilde{T} \right) + \nabla \cdot (\boldsymbol{t}\tilde{\mathbf{u}})$$

Perfect gas law

$$\overline{P} = \bar{\rho} r \widetilde{T}$$

- Parallel load balancing & automatic grid refinement
- Automatic reconnection of periodic boundaries
- Parallel interpolator for partitioned meshes

Motivations & Challenges

- Energy transition
- Clean aviation
- Reliable numerical platform for turbomachinery investigations
- Turbulence injection
- Dynamic mesh adaptation
- Purge/leakage Flows simulations
- Numerical reference data for SPLEEN

Test case

- **Exit isentropic quantities** SPLEEN_C1_NC_St000_Re70_M070 [1]

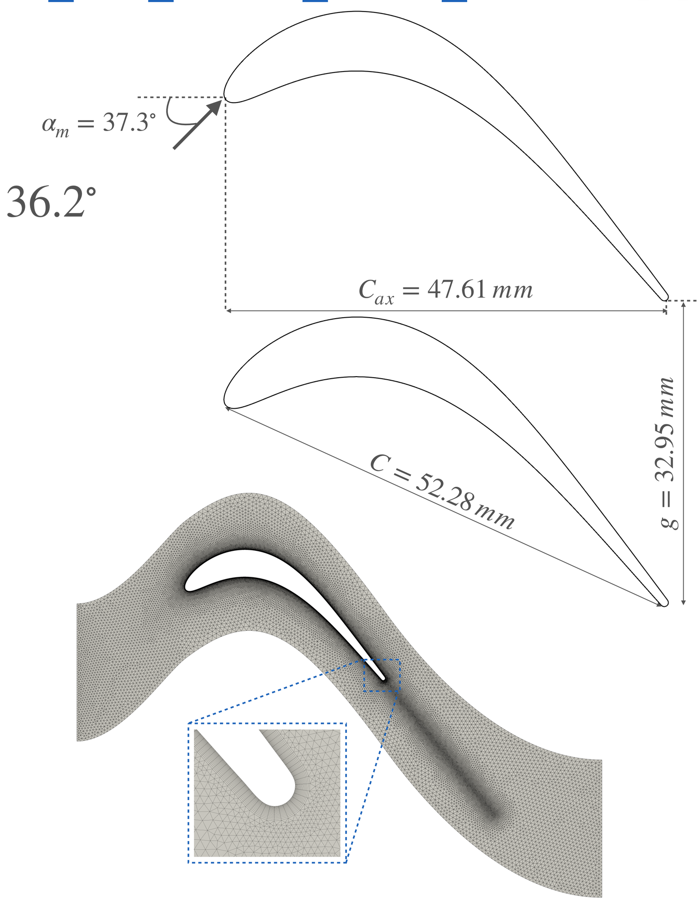
  $Re_{2,is} = 70\,000$ $M_{2,is} = 0.70$

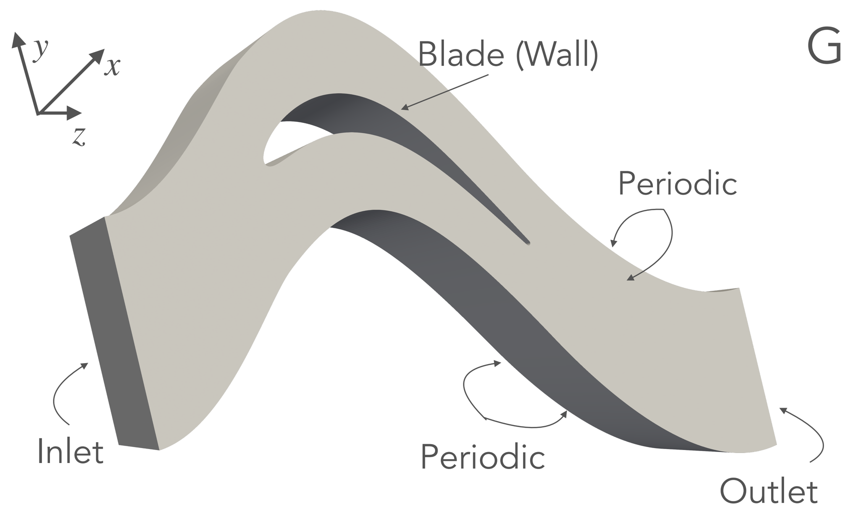
- **N-S characteristic boundary conditions**

  Inlet : $P_{1,t} = 10779.149\,Pa$ $T_{1,t} = 300\,K$ $\alpha_1 = 36.2°$

  Outlet : $P_{2,s} = 7770.989\,Pa$

- **Inflow turbulence :** $TI = 0\,\%$
- **SGS model :** Dynamic Smagorinsky [4,5]
- **Domain and Mesh**





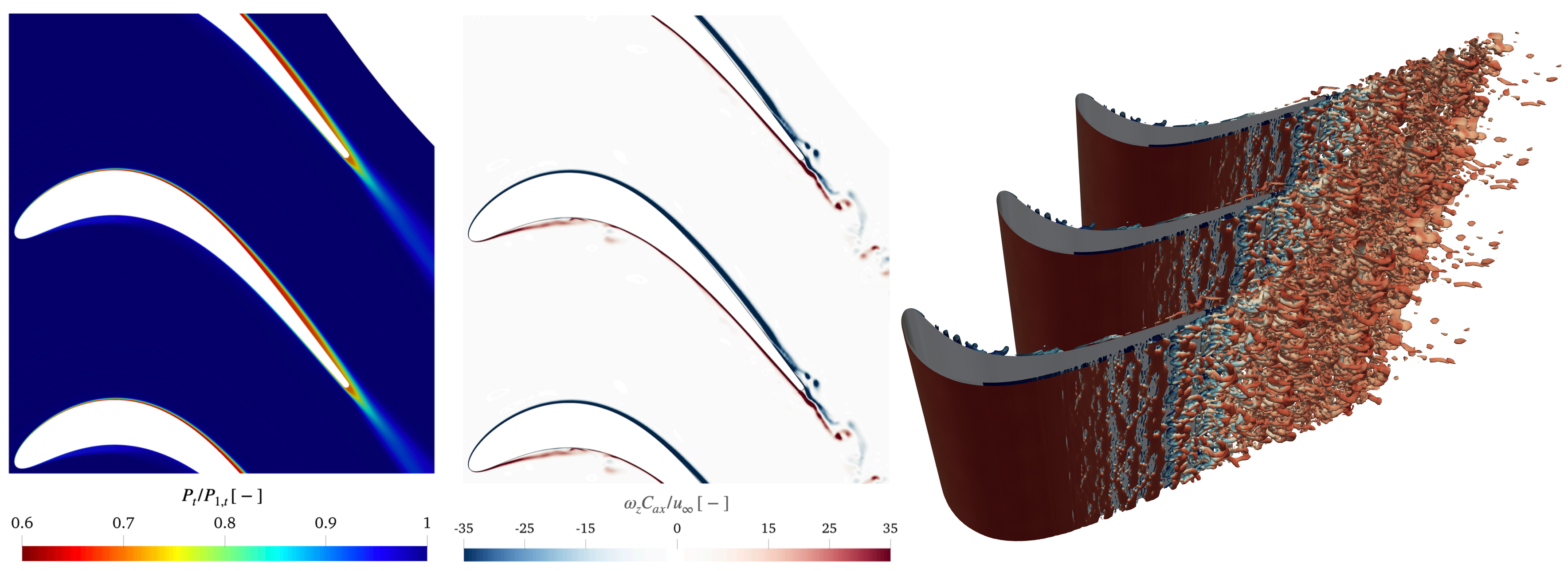
Gmsh [6]

$\frac{Lx}{C} \times \frac{Ly}{C} \times \frac{Lz}{C}$	Δx^+	Δy^+	Δz^+	Total cells
$2.41 \times 1.85 \times 0.5$	≤ 10	≤ 1	≤ 20	$8.3\,M$

Results

Flow fields

Slices taken at mid-span ($z/L_z = 0.5$)
- thinner separated region & wake
- the separated shear layer remains very close to the SS surface
- BL remains laminar after separation
- vortex shedding phenomena & smaller scales in the wake

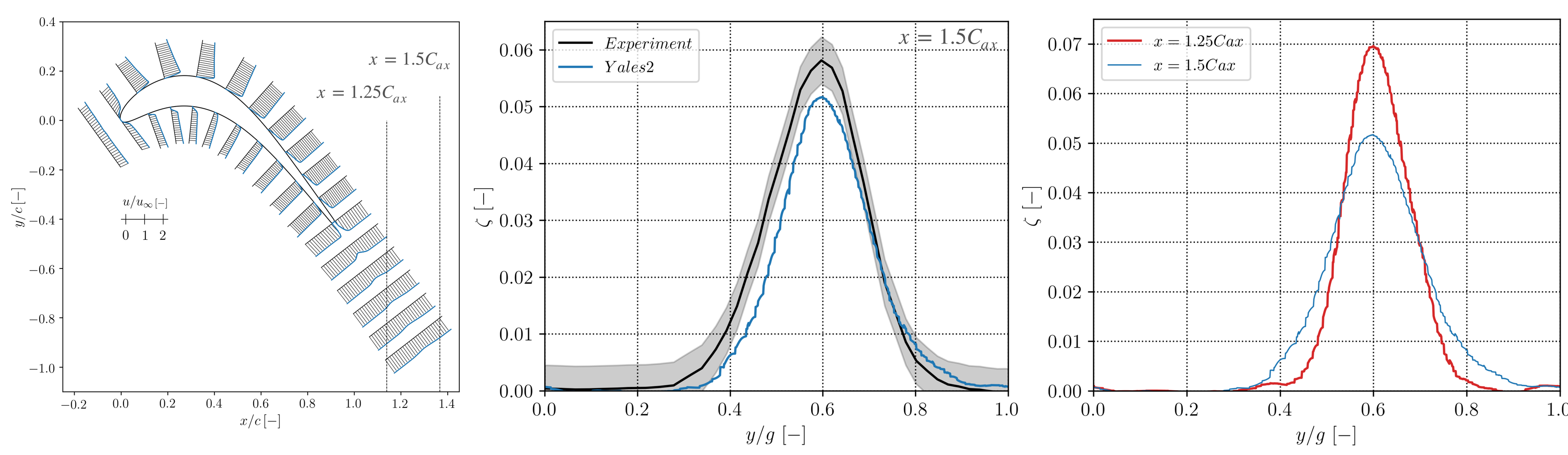


Velocity distribution & Wake losses

$$\zeta = \frac{P_{1,t} - P_t}{P_{1,t}}$$

Velocity profiles in the mid-span ($z/L_z = 0.5$)
- inflexion points in the separated region
- velocity deficits in the wake, images of losses

P_{tot} losses on two downstream planes ($x = 1.25C_{ax}$ & $x = 1.5C_{ax}$)
- underestimation of the peak
- Num. profiles (width) within Exp. uncertainties (grey area)
- widening and flattening of the wake further downstream : **dissipation**



References & Acknowledgements

[1] Lavagnoli et al. 2022, SPLEEN Database, https://doi.org/10.5281/zenodo.7359401
[2] Moureau et al. 2011, Comptes Rendus Mécanique .
[3] Moureau et al., https://www.coria-cfd.fr/index.php/YALES2.
[4] Germano et al. 1991, Physics of Fluids A: Fluid Dynamics. 3(7) 1760-1765.
[5] Lilly et al. 1992, Physics of Fluids A: Fluid Dynamics. 4(3) 633-635.
[6] Geuzaine et al. 2009, International journal for numerical methods in engineering. 3(7) 1760-1765.

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