THE UNIVERSITY OF MELBOURNE

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Pushing the boundaries of high-fidelity computational fluid dynamics: surface roughness in turbomachinery

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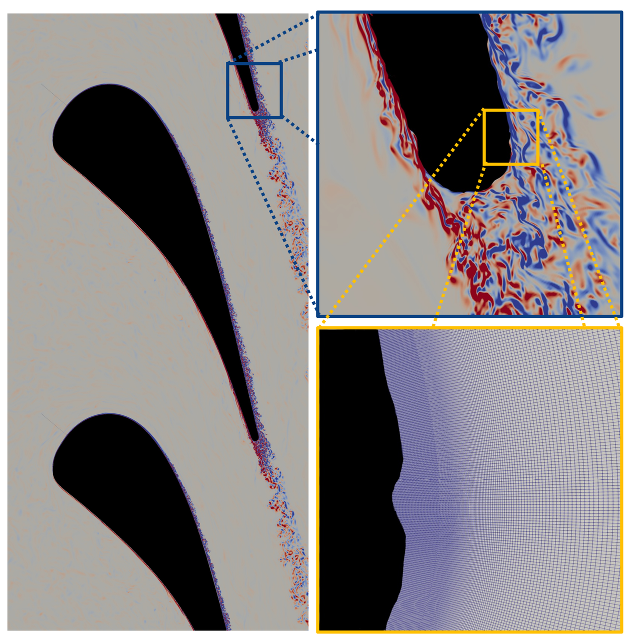
MOTIVATION

- Gas turbines are the most widely-used technology for power generation and aircraft propulsion. Improving their performance means reducing tons of CO_2 emissions and saving billions of dollars every year.
- The high-pressure turbine (HPT), located downstream of the combustion chamber, is subjected to the highest temperatures, pressures and velocities in the engine, which can lead to surface roughness as a result of metal erosion mechanisms.
- It is estimated that just a 2% error in the predicted metal temperature can halve the blade life[1]. Hence the need for high-fidelity tools that can provide insights on the effects of surface roughness on the aero-thermal performance of the blade.

EXTREME SCALE COMPUTATIONAL FLUID DYNAMICS



Details of the turbulent eddies on the blade surface and of the blade grid

High-fidelity simulations need large grids (billions of points) to adequately resolve multi-scale turbulence.

This translates to high computational cost, requiring some of the largest supercomputers in the world.

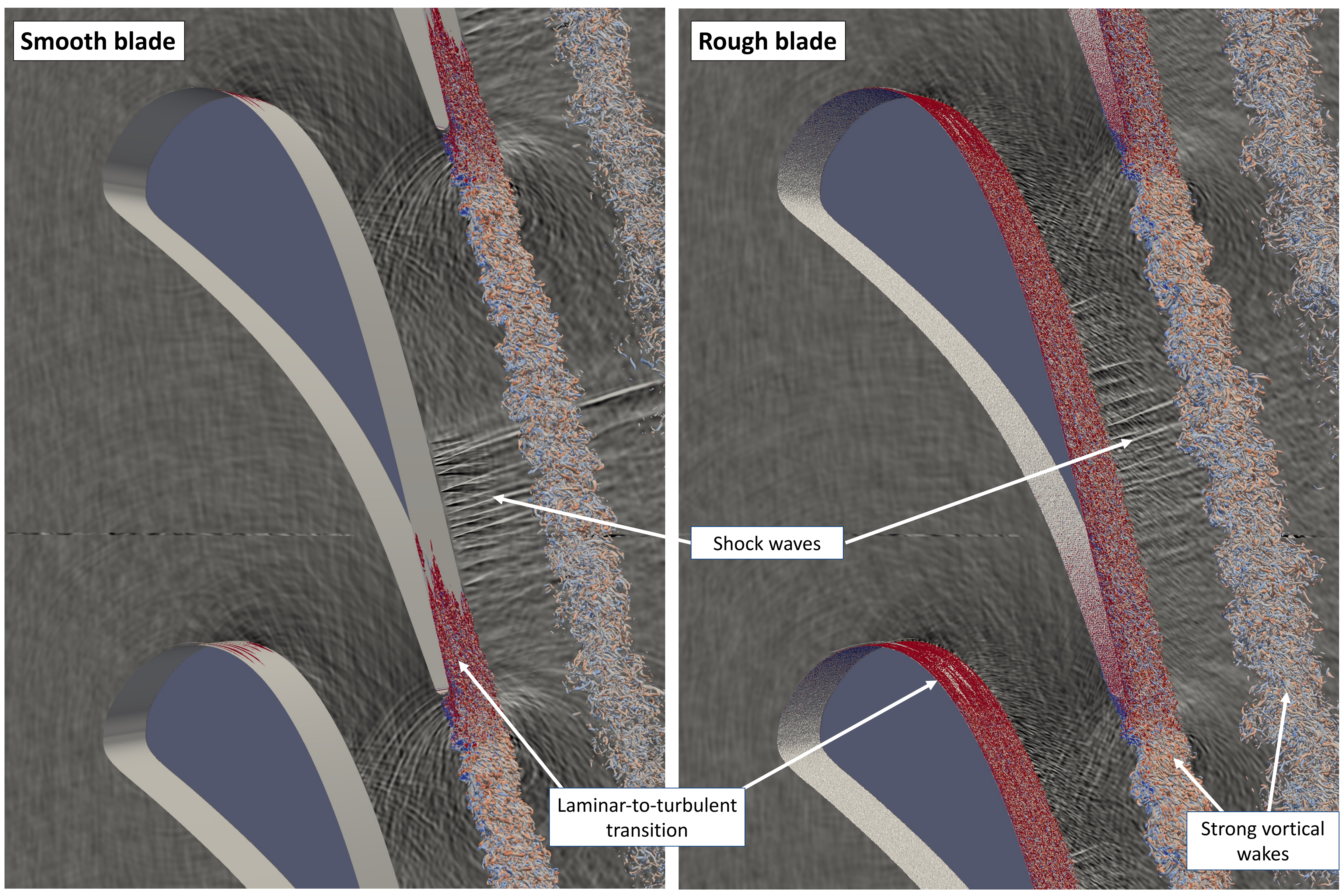
Summit, a world-class supercomputer located at the Oak Ridge National Laboratory

SIMULATING SURFACE ROUGHNESS

A three-dimensional immersed boundary method has been developed to efficiently simulate the complex geometrical features of surface roughness.

A comparison between smooth and rough blade at the leading edge

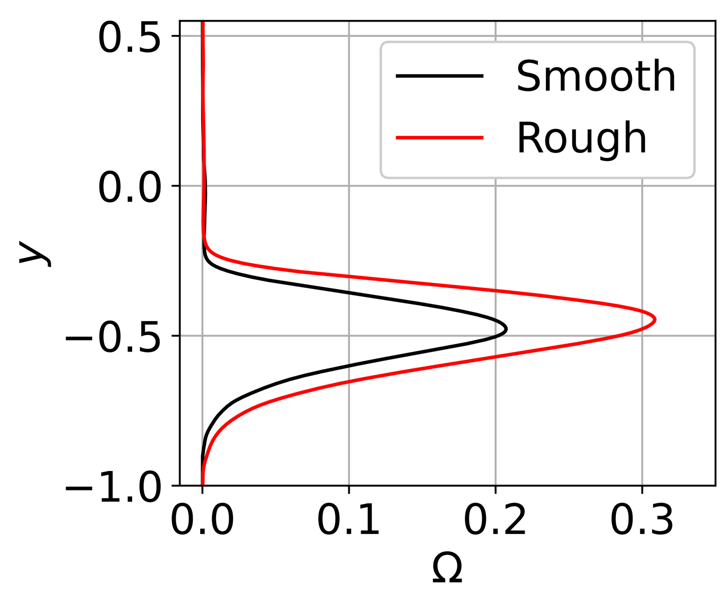
RESULTS



Flows over high-pressure turbine blades present a rich array of complex multi-scale physics

EFFECT OF SURFACE ROUGHNESS

- Promotes boundary layer transition, causing larger turbulence production
- Enhances surface heat transfer and skin-friction
- Increases overall blade loss



Wake loss[3] Ω computed in the pitch-wise direction 0.2 chord lengths downstream of the trailing edge

SUMMARY

- State-of-the-art numerical tools and recent performance improvements of supercomputers are pushing the boundaries of large-scale high-fidelity fluid dynamics, allowing to simulate turbomachinery flows with surface roughness at engine-relevant conditions.
- Surface roughness strongly affects the performance of HPT blades, with strong implications on the design of efficient and reliable engines.

References

1. Han et al., *Gas turbine heat transfer and cooling technology*, 2012
2. Jelly et al., *High-fidelity computational study of roughness effects on high-pressure turbine performance and heat transfer*, 2022
3. Zhao & Sandberg, *Using a new entropy loss analysis to assess the accuracy of RANS predictions of an high-pressure turbine vane*, 2020
4. Schlanderer et al., *The boundary data immersion method for compressible flow with application to aeroacoustics*, 2017