

NUMERICAL STUDIES IN EMBEDDED WM-LES COMPUTATIONS OF THE TRANSONIC SHOCK BUFFET ON AN XRF1-AIRCRAFT CONFIGURATION

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Abstract

Transonic flows around transport aircraft configurations may exhibit complex, unsteady flow phenomena such as transonic shock buffet. In such a case, distinct oscillations of transonic shocks with flow separation arise, which significantly influence the aerodynamics and thus eventually also flight safety. For negative angles of attack, occurring e.g. in emergency descents, transonic shocks at the wing lower surface can be further enhanced by the integration of closely-coupled Ultra-High Bypass Ratio (UHBR) nacelles. These high speed off-design flow phenomena of a commercial aircraft configuration (XRF1) with UHBR engines, are a main research subject of the DFG research unit 2895.

The high geometric complexity and the demanding flow physics require a highly accurate turbulence-resolving method that is also as efficient as possible. In order to meet these contradictory requirements, a novel simulation method was developed specifically for this research project, which combines a RANS model based on Reynolds stress modelling (RSM) with an LES method in the framework of the Improved Delayed Detached Eddy Simulation (IDDES) method [1].

Subsequently, the XRF1-UHBR full aircraft configuration was simulated using the new RSM-IDDES approach. The corresponding computational mesh was refined such that the entire area between pylon, lower wing and fuselage can be simulated with the wall modelled (WM) LES branch of the RSM-IDDES methodology, resulting in a grid size of approximately 800 million points (cf. Fig. 1). With this simulation setup, excellent agreement was achieved compared with dedicated measurements of the configuration in the European Transonic Windtunnel (ETW) [2]. Exemplarily, both, the shock positions and dynamics were precisely captured and a distinct shock buffet was consistently predicted.

Further analysis of the buffet has shown that a particularly strong shock with flow separation occurs in the corner region of the pylon-wing intersection. This raised the research hypothesis that the entire buffet at the lower wing is possibly driven by this corner shock. In this case, the entire shock motion might still persist, even if the turbulence-resolving WM-LES domain is reduced in lateral direction.

To verify this hypothesis, targeted scale resolving simulations are performed in which the WM-LES area is gradually reduced in y-direction. In a first

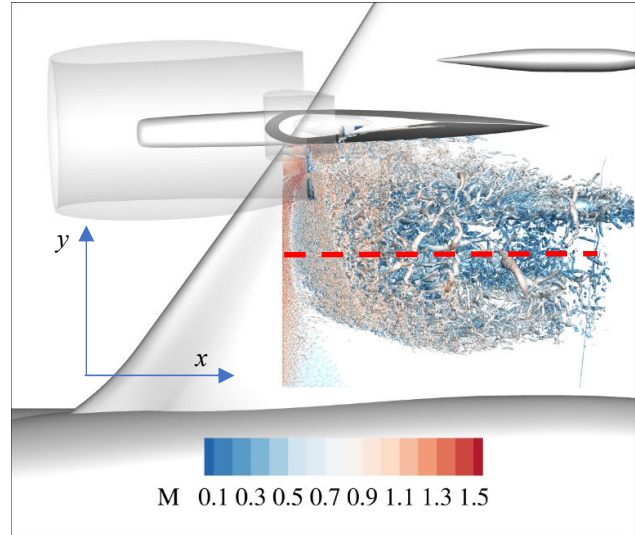


Figure 1: Bottom view of the XRF1 aircraft configuration with UHBR nacelle at transonic flow conditions extracted from [2]. A transonic shock with separated turbulent boundary layer is visualised.

step, this area is reduced by roughly half such that the area from the pylon-wing intersection to the red dashed line in Fig. 1 is captured using the WM-LES mode. The corresponding computational grid is coarsened accordingly and a significant reduction of grid points is achieved. In a further simulation, only the immediate pylon - wing corner flow region is treated with the turbulence-resolving WM-LES enabling a further reduction of grid points.

The final presentation will provide a detailed comparison of these simulations with a reference simulation discussed in [2] as well as with experimental data from ETW tests. Finally, an assessment will be provided on how large the turbulence-resolving region should be as a minimum in order to capture the essential shock buffet phenomena.

References

- [1] Herr, M., Radespiel, R., & Probst, A. (2023). Improved Delayed Detached Eddy Simulation with Reynolds-Stress background modelling. *Computers & Fluids*, 265, 106014.
- [2] Spinner, S., Rudnik, R., Herr, M., Probst, A., & Radespiel, R. (2025). Scale Resolving Simulation of Buffet Effects Induced by Ultrahigh Bypass Ratio Nacelle Installation. *Journal of Aircraft*, published online February 04, 2025.