Session:

Mixed Fidelity Modelling of Fan Flows with Zonalized LES Near Tip Region

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There is a continuous drive for ever more efficient aircraft engines, driven by economical as well as environmental concerns. The efficiency improvement is mainly achieved by increasing the engine bypass ratio. In the next generation aeroengine architecture, the bypass ratio will be pushed to 15. It is referred as ultra-high bypass-ratio (UHBPR) engines. Fan component plays a more important role in this UHBPR engine system, because it will deliver more than 90 percent of propulsive thrust and dominate the engine noise. It is crucial to predict the fan turbulence accurately for an efficient and quiet engine design.

(U)RANS methods struggle to provide satisfactory predictions at off-design points where massive separation occurs. As the fan operating at a very high Reynolds number ($\sim 1\times 10^7$), wall resolved LES of a full-span fan will reach around 1×10^{10} grid points [1]. It is impossible at the current computational level. Hybrid LES-RANS methods provide most realistic solution forward. In this paper, mixed fidelity modelling will be used to simulate fan flows. Zonalized LES is used to simulate the flows near fan tip where tip leakage and separation occurs on the suction side and also used to resolve the downstream wake regions. The rest flow domain is computed using RANS methods. A low-order smeared geometry body force model [2] is used to simulate downstream OGV and ESS and further reduce the computational cost. The mixed fidelity modelling strategy is shown in Figure 1.

Hybrid structured-unstructured mesh is used to adapt to the requirement of mixing-fidelity modelling in different regions. The near wall region is meshed with hexaheral elements. The grid density is refined to meet LES grid standard in the blade tip and wake region to resolve large scale eddies with tetrahedral elements and coarsen to RANS level in the other region and even coarsen in the low-order body force region. The Spalart-Allmaras RANS and WALES LES stress are blended using a user defined function $f(d)$ of a modified wall distance d [3]:

$$\tau_{ij}^{turb} = f\tau_{ij}^{SGS} + (1-f)\tau_{ij}^{RANS}$$

Session:

where f is 1 and modified wall distance is 0 in the LES region.
The preliminary results are shown in Figure 2. The separated flows are resolved on fan blade suction surface and the downstream wake flows are directed correctly as OGV is present. The computation is still in progress and more analysis on turbulence wake spectra and comparison with experimental data will be shown in the full manuscript.

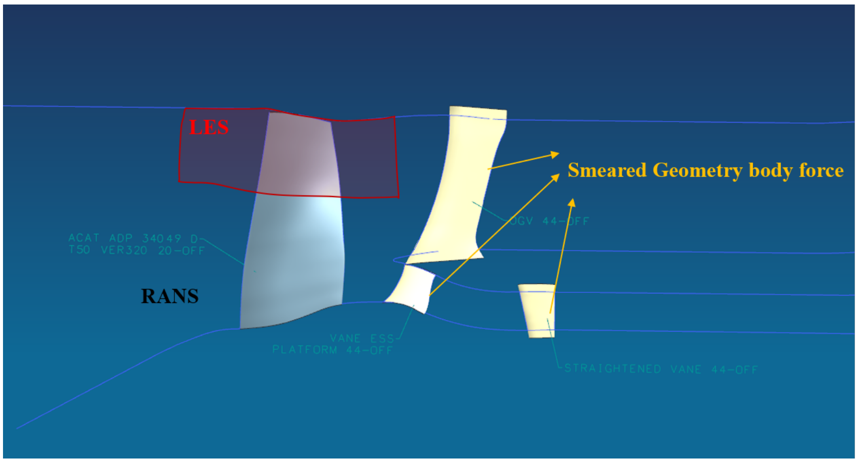

Figure 1 Mixed fidelity modelling of fan flows

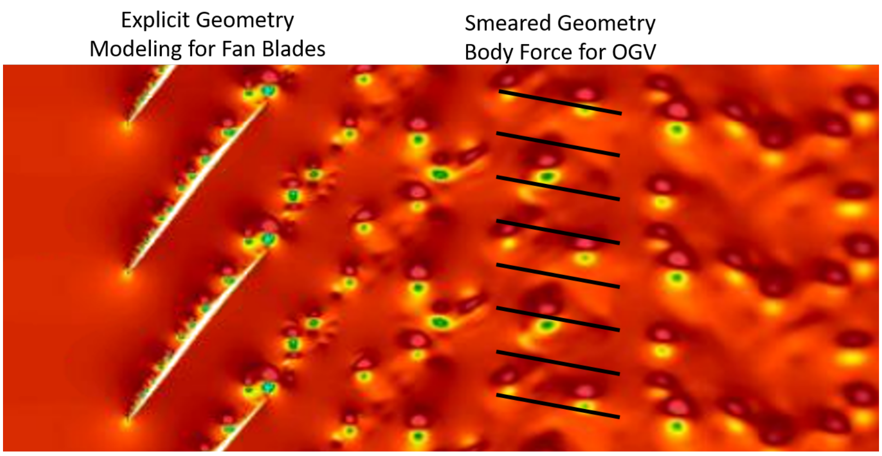

Figure 2 Preliminary results in the fan tip region

Session:

References

[1] Tucker, P., 2011, "Computation of unsteady turbomachinery flows: Part 2—LES and hybrids," Progress in Aerospace Sciences, 47(7), pp. 546-569.
[2] Cao, T., Hield, P., and Tucker, P. G., 2017, "Hierarchical immersed boundary method with smeared geometry," Journal of Propulsion and Power, pp. 1-13.
[3] Wang, Z.-N., Tyacke, J., and Tucker, P. G., 2018, "Hybrid LES/RANS predictions of flows and acoustics from an ultra-high-bypass-ratio serrated nozzle," Note on Numerical Fluid Mechanics and Multidisciplinary Design: Progress in Hybrid RANS-LES Modeling, pp. 465-478.