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Investigation of tip flow structures of a transonic axial compressor stage based on the harmonic balance method

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Abstract
Compressor flows are prone to separation and stall due to adverse pressure gradients. Tip flows have a major role in stall behavior due to rotor tip clearances and endwall boundaries. Due to these reasons, investigation of stall inception mechanisms and the role of tip flows are still popular in academia. The complex flow dynamics in such a small area make the measurement applications fairly difficult, this explains both the gap and interest towards this field in academia.

Besides experimental efforts, many numerical works have been performed and published in the literature. Since unsteadiness has a huge impact on tip flows, unsteady modeling has been a must for the researchers. Considering computationally large turbomachinery problems with the addition of unsteady modeling, this approach becomes costly and non-applicable to engineering procedures.

There are reduced order models to approximate turbomachinery flows thanks to time periodic nature of the flow problem. The Harmonic Balance Method (HBM) is one of the most popular approaches employed in turbomachinery aerodynamics. Recently, a new solver library has been published by Oliani et al (2022) where they implement HBM in OpenFOAM opensource environment. The implemented multi-frequencial form of HBM accounts for modeling multi-row turbomachinery flows.

This study aims to investigate highly unsteady flows at the tip region of NASA Stage 37 with the help of HBM. Its advantages in computational cost reduction are well known. However, the modeling capability of the HBM in such a specific region is of interest. The work is not limited to the rotor but also includes the stator, to assess the accountability of the numerical method in terms of modeling of the potential flow field around stators and its interaction with the upstream vortices.

NASA Stage 37 geometrical model is constructed with the available public data published by Reid & Moore (1978). A mesh independency study is carried out followed by a validation study with respect to the publicly available experimental data. The validation study is carried out in terms of spanwise total pressure profiles, pitch-wise Mach number plots and blade-to-blade Mach number contours at various span positions. The shock system is also compared and a well match is seen including shockwave boundary layer interaction.

A full wheel unsteady computation was carried out at the design point in order to set the reference baseline for the HBM data. Then, the HBM is employed for 2 and 4 harmonics for the design point. Finally, two datasets based on the

HBM data are investigated with respect to the full wheel unsteady reference data. Vortical structures are visualized by streamlines and Q-criterion allowing the leakage and tip separation vortices to be discriminated.

As a result, the HBM showed a good agreement with the unsteady full wheel computations around the tip region. As expected, a higher number of harmonics allowed a better match with the full wheel unsteady data by ensuring a conformal interface flow behavior and allowing the flow to have higher degree of freedom in terms of unsteadiness. Based on this outcome, thanks to its computational effectiveness, the HBM approach is expected to allow aerodynamics engineers to understand their designs deeper around design point and off-design points where tip flows become even more intense.

References

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