Reduced-order body-force modeling for the aerodynamic design of axial compressors

Position PhD
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Context and motivation

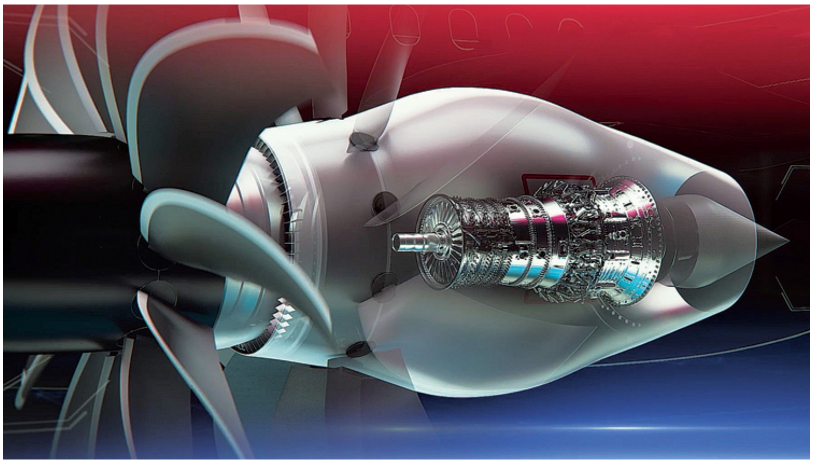
The ambition of lowering aircraft emissions is the key driver for the next generation of engines, and efficient compressor design is an essential part of this process, as engine overall pressure ratio has a first order impact on engine cycle efficiency.

During the preliminary design phase of a compressor, many iterations on the blades' geometry are needed, and the computational cost remains an issue. For this reason, the development of accurate reduced-order modeling methods is still a challenge.

A recent category of reduced-order methods is the body force method. This modeling approach relies on replacing the actual blades by a source term distribution, which reproduces the essential flow features, namely flow turning and entropy rise. This allows a significant cost reduction because the blades are not actually meshed and the resulting computation is steady even for inflow distortion cases.

Over the past years, the scientific community has essentially focused on increasing the fidelity of the BFM approach by resorting to ad-hoc calibration, in the context of integrated simulations. In other words, for a given geometry, calibration against single-blade calculations is performed, and the calibrated model is used for complex simulations, such as inflow distortion or installed engine cases.

In the present PhD, the goal is to develop a body force model for compressor design, where ad-hoc calibration can not be used, and a more general formulation must be developed.



Research program

To achieve this objective, the thesis will be divided into two main research questions: (i) understanding the foundations and main modeling hypotheses, along with the limitations, of existing body force and throughflow models for turbomachines; (ii) creating a new approach which, by exploiting a database resulting from RANS simulations, would be able to overcome such limitations.

The first phase will be devoted to the understanding of the different modeling hypotheses and assumptions, by highlighting their impact on the capability of capturing the most relevant physical phenomena related to the flows in turbomachines. To this end, relevant test cases (both 2D and 3D) will be set up and analyzed to compare the different modeling strategies and identify levers for improvement. Particular attention will be paid to the reliability of such models in the transonic regime.

In the second phase, a campaign of RANS calculations will be set up to generate a database adapted to the creation of the correlations necessary for the targeted model. An offline/online procedure will be used to effectively decouple the generation of the database (performed only once – offline phase), and the simulation of the low order model, which can be executed several times depending on the simulation needs (online phase). Among the reduced order modeling techniques, orthogonal eigenvalue decomposition (POD) with the snapshot approach is probably the most widespread in the calculation of fluid flows. This approach can be compared to other machine learning methods.

The main steps of the thesis will be:

- Literature review of body force and throughflow modeling.
- Analysis of relevant test cases for model assessment.
- Database creation with classical RANS blade simulations.
- Formulation of a new reduced order model and implementation in the elsA code.
- Validation of the new model for axial multi-stage compressors cases of interest for Safran group companies (SAE, SAB etc), through comparisons against higher fidelity and experimental results.

Publication of the results in international journals is expected and participation to international conferences will be encouraged.

Candidate profile

The successful candidate is expected to have:

- A very solid background in turbomachinery aerodynamics and fluid mechanics.
- Good knowledge of CFD and numerical methods.
- Initiative and problem solving skills.

Practical information

The position is for 3 years, staring around September 2024. This PhD work is a CIFRE funding, which means the PhD student will be hired as a SAFRAN employee for a 3-year contract. Time will be shared between SAFRAN and ISAE-SUPAERO in proportions to be discussed. The recruitment process will be handled through SAFRAN website, but information and preliminary contacts can be made using the email addresses given at the top.