# Determination of the nozzle admittance in frequency domain for a generic test case

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In rocket engine combustion systems, thermoacoustic feedback mechanism and conjugated high pressure and temperatur amplitudes may arise to a significant threat to safe operation conditions. To guarantee tolerable dynamic loads on the structure during operation, the precautionary treatment of thermoacoustics within the development process is essential. Nowadays increasing computational capacities allow the application of more and more sophisticated numerical methods to gain deeper insight into the multiphysical discipline of themoacoustics. From these investigations, design tools and design rules can be derived which support the development process in very early stages and therefore reduce expensive and tedious experimental testing to a minimum.

Investigations of thermoacoustics are only possible considering the dynamic interaction of the entire thrust system comprising the propellant feed and injection subsystem, the combustion chamber including the complicated combustion process and auxiliary devices as baffles and dampening cavities as well as the thrust nozzle, which makes the prediction of thermoacoustic stability difficult. At the Institute of Thermodynamics, Technical University of Munich, a divide and conquer approach is developed to face this challenging task [1]. Herein each subsystem is analyzed component wise in its own environment and suitable models are derived which are then recomposed into an overall prediction model for thermoacoustic stability. In general, exciting and dampening subsystems can be distinguished.

The proposed report concentrates on the acoustic scattering properties of the thrust nozzle considering representative flow conditions. The nozzle constitutes the natural outflow boundary of the thrust system and therefore primarily determines a significant part of acoustic dampening. However, properties of exciting transverse modes have also been observed. In terms of numerical computation, the accurate modeling of the interaction of acoustics with the choked conditions in the nozzle throat and present spatial gradients in the flow are crucial and subject of current research.

The acoustic properties of the nozzle are described by its acoustic admittance. It states the ratio between acoustic velocity and pressure. In general, the admittance can be stated for different acoustic modes. For the purpose of preliminary studies the acoustic properties for longitudinal excitation are computed only.

Different approaches to determine the nozzle admittance have been conducted so far. [2] apply conservation laws and finally state an analytical solution for all acoustic modes. [3] use linearized Euler equations (LEE) in a hybrid approach to compute the three-dimensional acoustic response to longitudinal excitation. Single frequency excitation and time step limitations due to the CFL criterion make this approach very time-consuming.

In the proposed report, a new method of determining the nozzle admittance is presented. Similar to the approach by [3], the acoustic field is computed by a hybrid approach. Thus, the steady mean flow state is conducted in the first step using RANS simulations which are performed with the standard solver CFX. In the second step LEE are used to solve for the acoustic field. However, the LEE are transformed into frequency domain first. By this procedure, frequency becomes a input parameter of the system. The solution states the complex acoustic amplitudes in the computational domain which are valid for a single, user-defined frequency. The correlation between frequency and the acoustic field and all derived values is possible directly. Furthermore, time dependency is lost which reduces computational time consumption substantially.

As shown by [6], the numerical discretization is performed utilizing a Petrov-Galerkin finite element method. For its application to the convection dominated problem of determining the nozzle admittance, the discretization is modified by a stabilization technique, the so called streamline-upwind/Petrov-Galerkin approach. By this procedure, numerical stability is achieved and accuracy is increased. Especially, the computation of the acoustic field in the transsonic and supersonic regime within the nozzle is possible. The stabilized finite element technique allows the rapid determination of the nozzle admittance and the investigation of the acoustic fields in detail.

For illustrative purposes, the nozzle admittance of the well-known generic test case "HF2" from the second REST[1] Modeling Workshop 2010 [4] is calculated. The results are compared to experimental results by [5], to numerical results by [3] and to the analytical solution by [2] showing excellent agreement. Furthermore, physical reasoning of the results are given by their detailed investigation.

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## References

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