Chapter 5
Investigation of the Correlation of Entropy Waves and Acoustic Emission in Combustion Chambers

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Abstract The entropy noise mechanism was experimentally investigated under clearly defined flow and boundary conditions on a dedicated test setup. Previous experimental research on the topic of entropy noise could draw only indirect conclusions on the existence of entropy noise due to the complexity of the physical mechanism. In order to reduce this complexity, a reference test rig has been set up within this work. In this test rig well controlled entropy waves were generated by electrical heating. The noise emission of the entropy waves accelerated in an adjacent nozzle flow was measured accurately and therewith an experimental proof of entropy noise could be accomplished. In addition to this, a parametric study on the quantities relevant for entropy noise was conducted. The results were compared to a one-dimensional theory by Marble & Candel. In a next step investigations on a combustor test rig showed a broadband noise generation mechanism in the frequency range between 1 and 3.2 kHz. The combustor rig was set up with a similar outlet-nozzle geometry like the reference test rig (EWG) and provided therefore outlet-boundary conditions like in real-scale aero-engines (outlet Mach number = 1.0). It was found that this broadband noise has a strong dependency on the nozzle Mach number in the combustor outlet. The summed-up broadband sound pressure level increases exponential with the nozzle Mach number. However, investigations of comparable cold flow conditions did not show this behavior. Since the results of the reference experiment with artificially generated entropy waves did not show this exponential increase with the nozzle Mach number, this leaves the conclusion that this additional noise is generated by the interaction of small-scale fluctuations, e.g. in entropy or vorticity, with the turbulent nozzle flow in the combustion chamber outlet nozzle.

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5.1 Introduction

The total noise emitted by a combustion chamber consists of direct and indirect combustion noise. Only the direct combustion noise is directly related to the combustion process. Indirect combustion noise also called entropy noise is related to the acceleration of gas temperature nonuniformities which result from the unsteady combustion processes. Since the nozzle guide vanes (NGV) of the first turbine stage are choked under almost every relevant operating condition of aero-engines, hot spots passing through the nozzle are connected with mass flow variations (monopole sound source) and also with momentum flux variations (dipole sound source). Gas temperature nonuniformities may cause also broadband noise in all turbine stages, since the related density fluctuations cause pressure fluctuations during the acceleration through each turbine stage.

Entropy noise receives increased interest by the aero-engine industry because it may have a major contribution to the total noise emission of combustion systems. With the noise reducing improvements achieved for other aero-engine components, e.g. low noise fan design and jet noise reduction by high bypass ratios, the noise concern in aero-engine developments also includes the combustion noise issue. Especially at helicopter engines, which emit almost no jet noise, the entropy noise seems to be of high importance.

The generation mechanisms and parameter dependencies of entropy noise are still not completely explained. Hence, this work within the framework of a DFG research unit on combustion noise (http://www.combustion-noise.de) presents in a first step investigations of entropy noise phenomena on a reference test rig called Entropy Wave Generator (EWG), where the parametric dependencies of entropy noise could be evaluated. In a second step combustion noise investigations have been conducted in a downscaled aero-engine model combustor with a similar outlet-nozzle geometry like the reference test rig. The goal of the combustor experiments is to assess if the combustion noise characteristics can be estimated and explained by the entropy noise mechanism.

5.2 Theoretical Background, Test Specification and Data Analysis

The understanding of instationary fluid flow phenomena in a medium at rest as a superposition of different physical modes of perturbation probably goes back to the beginning of modern research in fluid dynamics. The modes are characterized by their physical properties as entropy, vorticity and acoustic mode of perturbation. Later Chu and Kovasznay [20] analyzed the interaction of these modes. They found that in a medium at rest on average, the interaction would be a second order effect [20]. The entropy mode, which is silent in a constant flow may transfer energy to acoustic and vorticity mode and vice versa by the nonlinear interaction. Further-