STUDENT HYBRID THRUSTER TESTING AND RESEARCH

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ABSTRACT

After the first student-hybrid-thruster campaign at DLR-Lampoldshausen in 2011 the Institute of Space Propulsion consequently developed the student-test program. A stronger and improved test rig was fabricated, advanced measurement techniques were applied, more detailed test objectives were defined and testing was accompanied by advanced CFD and thermochemical calculation. In many ways the hybrid thruster appears as an ideal research object for rocket propulsion students. The thruster provides aspects of liquid propulsion, phase transition, solid propulsion, ignition, combustion and rocket nozzle flow. Despite system pressure and temperature in the order of the state of the art of rocket engines the students can fully handle the thruster, rig and testing by their own due to small mass flow and short test duration. Nevertheless the students are introduced to working principles and standards for rocket engine test facilities. The latest test campaign focused on the investigation of the exhaust jet. The experimental studies and advanced measurements were compared to a numerical Navier-Stokes calculation of the flow field.

1. INTRODUCTION

Rocket propulsion science contains an overwhelming variety of research, development and testing subjects. It is a challenge for every scientist and engineer in this field to understand not only a subject itself but as well the overall context in space science. Especially for students of propulsion science the German Aerospace Center (DLR) as an establishment of research and as the national space agency has started a program to support young academics to step into this thrilling technology at the frontier of science.
School pupils are encouraged in school labs to enter space studies and university students are trained in summer schools. A campus and a student test field are in progress [3] and the first students have already practised on a student test rig, laid down their master thesis and stepped into recent research programs. On their way the students learn to apply modern computer codes for computational fluid dynamics (CFD), to use advanced measurement and diagnostic systems and they are trained to prepare and execute hot testing of propulsion systems according to principles and standards for rocket test facilities. In the direct vicinity of the large rocket engine test facilities the students are carefully coached by experienced senior test engineers to conduct their own developments.

2. DEVELOPMENT OF THE TEST PROGRAM

The student testing was developed from a simple thrust suspension point to a comfortable, mobile student test rig with thrust measurement. Also the test specimen, a micro hybrid thruster was modified in order to introduce measurement sensors for combustion pressure and temperature. The next generation of thruster

will allow higher thrust and longer test duration. In the first test campaigns [1,2] the validation of the test rig and measurement system was in the focus as well as the reproducibility of test results. The second test campaign focussed on the expansion process of the oxidiser in the injection element between run tank and chamber. Another subject of the second campaign was the investigation of the regression rate of the fuel package. The results of the third campaign are content of this publication, it has the focus on the characteristic of the exhaust jet.
The students are introduced to test management procedures such as risk management, test readiness validation, failure management, and introduced to test documentation such as test plan, test request, measurement requests and test execution procedures. They are trained to prepare and use the test rig as well as the control and command system of the rig and specimen and the measurement acquisition, recording and processing system.
For each campaign the students establish the test ensemble consisting of mobile components again, but on the other hand they take profit of the progress and results of previous campaigns.

3. OVERVIEW OF STUDENT HYBRID THRUSTER TOPICS

The hybrid thruster provides three main subjects for student research, the liquid oxidiser supply, the combustion of the solid fuel package and the flow downstream the combustion chamber (nozzle flow and exhaust jet).
The oxidiser in this test program is nitrous oxide (N_2O) in liquid state at its saturation point. The supply to the combustion chamber is either liquid with phase transition at the chamber inlet (through the injector) or gaseous N_2O taken from the gas fraction of the storage bottle. The injection of the liquid N_2O is very much alike the injection in large cryogenic rocket engines. Due to the theoretical and experimental work on this subject the students reach a deep and solid understanding of the injection process of modern rocket engines.
The combustion process of the solid fuel offers another package of research subject. The prediction of the pyrolysis, the investigation of the regression rate and the understanding of the recirculation influence to the overall characteristic and performance of the chamber are subjects which contribute to recent work and theories in hybrid and solid propulsion.
The transonic and supersonic flow of the nozzle and exhaust offers another interesting field of research. From one-dimensional flow obtained from NASA programs [4] the student go forward to two-dimensional CFD calculation [5] and furthermore investigate the effect of post combustion and real gas effects, which is a vast package of subjects again when we consider that the flow is composed of several gas species.

4. THERMOCHEMICAL CALCULATION

The thermochemical calculation of the combustion process provides the properties of the gas in the nozzle flow and in the exhaust. In detail specific impulse, flame temperature, exhaust composition will be calculated according to classical thermochemistry.

5. CFD CALCULATION OF THE EXHAUST

The numerical study of the micro hybrid thruster´s exhaust gases under examination is made by using DLR Tau-Code software, whose main modules are the preprocessing, flow solver and adaptation. It is a powerful software to study and predict the viscous and inviscid flows behavior in complex geometries from subsonic to hypersonic flow regime, employing hybrid unstructured grids. Tau-Code, designed for massively parallel computations, is not able to generate a grid but comprises tools for grid modification, adaptation and deformation.
In order to completely describe the flow field, a wide range of turbulence models are available, ranging from simple algebraic approaches to full Reynolds-Stress Transport models [4]. However, Tau does not assume any combustion model for the mixture flow. This is a software limitation which implies the study of a frozen flow along the nozzle without considering any combustion products.
In the case under analysis, to compute the flow behavior a RANS turbulence model is chosen, which represents also the natural mode of operation for Tau-Code. In particular a one-equation model is used, which refers to the Standard Spalart-Allmaras model in order to solve the transport equation. For the discretization of the convective fluxes of the RANS and turbulence equations, the upwind scheme is used. The implicit Backward-Euler method is the scheme for time-stepping solution. Different levels of adaptation (maximum 50% of new points for each one) are applied taking into account the presence of high gradients due to the shocks.

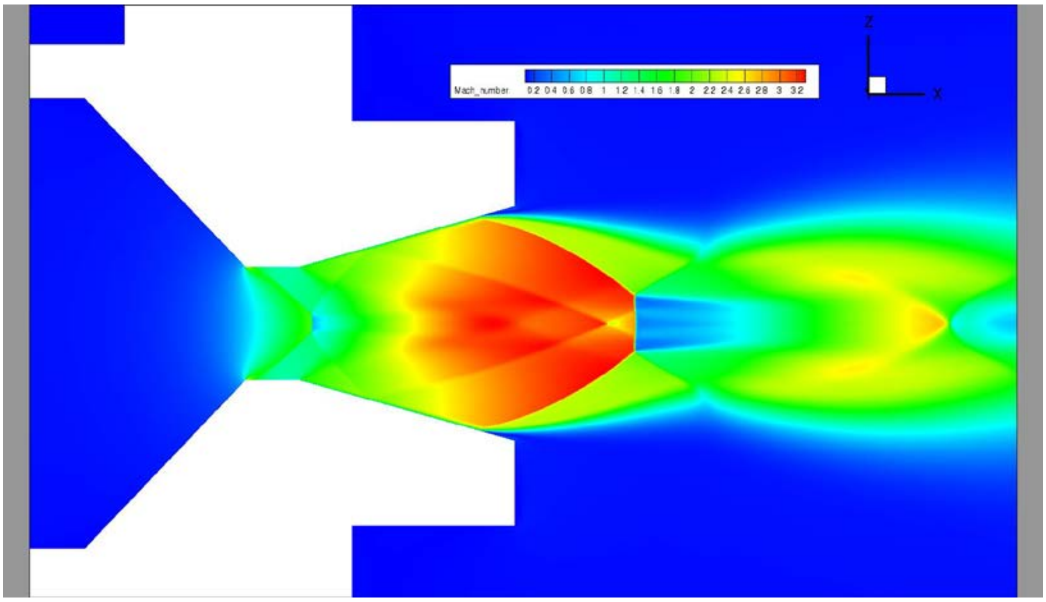

Figure 1 : CFD Calculation of the nozzle flow and exhaust of the hybrid thruster

6. HYBRID TESTING

For experimental investigation the hybrid thruster HT-2 is tested on the test rig P VII at the DLR test center in Lampoldshausen. Laser and optical diagnostic are applied to investigate the flow field of the exhaust. The test are performed according applicable standard (DIN, EN, EC-rules, ECSS) and the test team applies standard testing procedures (test preparation, execution, documentation, risk and failure management e.g.)

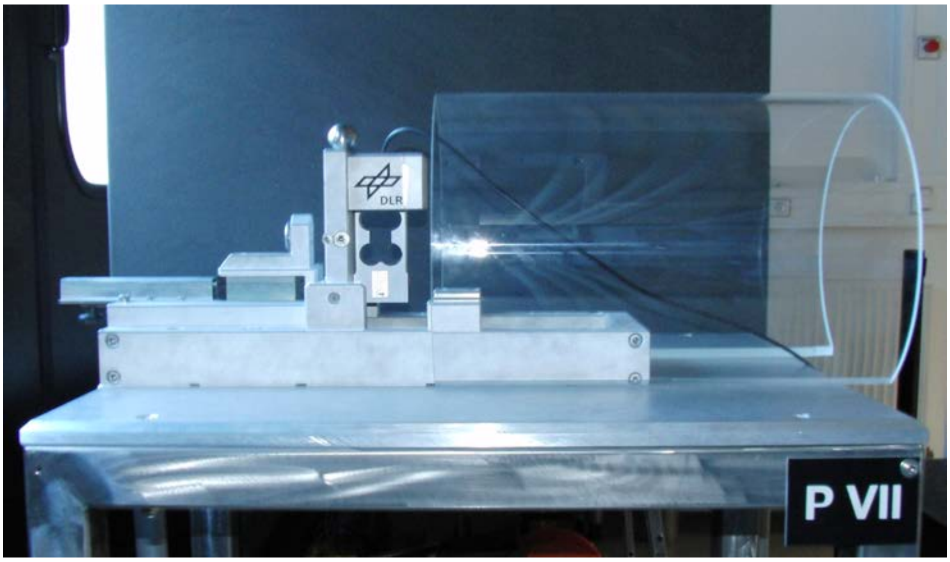

Figure 2 : Test Rig P VII

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