11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

TRANSITION MODELLING FOR HYPERSONIC AIR INTAKE FLOWS IN SCRAMJET APPLICATIONS

Sarah Frauholz[1], Birgit U. Reinartz[2], Siegfried Müller[3] and Marek Behr[4]

[1] Research Fellow, Chair for Computational Analysis of Technical Systems (CATS), Center for Computational Engineering Science (CCES), frauholz@cats.rwth-aachen.de
[2] Research Associate, Chair for Computational Analysis of Technical Systems (CATS), CCES
[3] Professor, Institut für Geometrie und Praktische Mathematik (IGPM)
[4] Professor, Chair for Computational Analysis of Technical Systems (CATS), CCES
RWTH Aachen University, 52056 Aachen, Germany

Key words: *Hypersonic Flows, Scramjets, Transition modelling, Finite Volumes.*

Within the frame of the German Research Group GRK 1095 "Aero-Thermodynamic Design of a Scramjet Engine for Future Space Transportation Systems" a numerical and experimental analysis of a scramjet propulsion engine is being performed. The paper presents an overview of the ongoing work on the numerical simulations of the scramjet intake.

The intake of a supersonic combustion ramjet (scramjet) mostly consists of one or more exterior compression ramps followed by an interior part. Oblique shock waves generated by the ramps and the cowl lip are performing the compression of the incoming flow. To protect the pressure sensitive intake from the back pressure of the combustion chamber the isolator is used. There, the flow adapts to the back pressure using a shock train. Multiple interesting as well as physically complex phenomena may occur, such as shock-boundary layer interaction, laminar-turbulent transition, compressible relaminarization and flow separation. Especially the numerical model of the laminar-to-turbulent transition is crucial to get accurate predictions of the flow field.

A fully three-dimensional intake has been designed at the German Aerospace Center (DLR) in Cologne (see Figure 1). A first test campaign has been performed in 2012 [3] and a second test campaign is planned for 2013. Since experimental measurements are very costly and difficult to perform, numerical computations are necessary to analyse and understand the flow phenomena. Thus, a numerical analysis in cooperation with the German Aerospace Center Cologne is performed.

For this purpose an in-house code QUADFLOW is used. This solver is an h-adaptive and fully implicit flow solver for the Reynolds-averaged Navier-Stokes equations for compressible flow using a fully unstructured cell-centered finite volume method. It follows an integrated concept of surface-based discretization, multiscale analysis, and, on this basis, an h-adaptive grid generation applying B-spline techniques. It has been validated

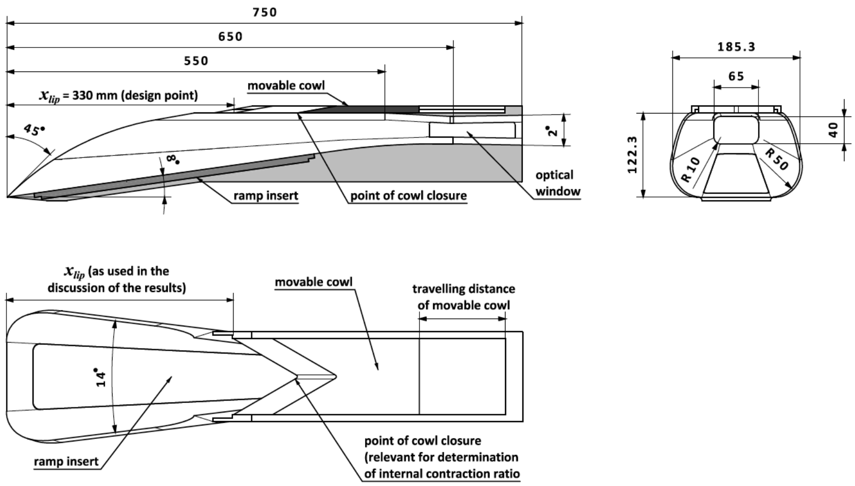

Figure 1: **CAD model of the scramjet intake. Reproduced from Hohn and Gülhan [3].**

extensively against different test cases [1, 8, 4].
Within this paper the influence of the transition modelling is investigated. Therefore multi-level computations with three different approaches to model transition are applied to the scramjet intake: 1.) the Shear Stress Transport Turbulence (SST) model (no transition model), 2.) the SST model with fixed transition point, and 3.) the γ-Re_θ proposed by Langtry/Menter[6, 7] extended with an in-house correlation for for onset and length of transition (SST model with two additional equations for modelling transition) [5]. The numerical results are compared to each other and to experimental data.
Figure 2 shows results for the SST model. Numerical computations using the SST model were presented at the EUCASS conference [2].

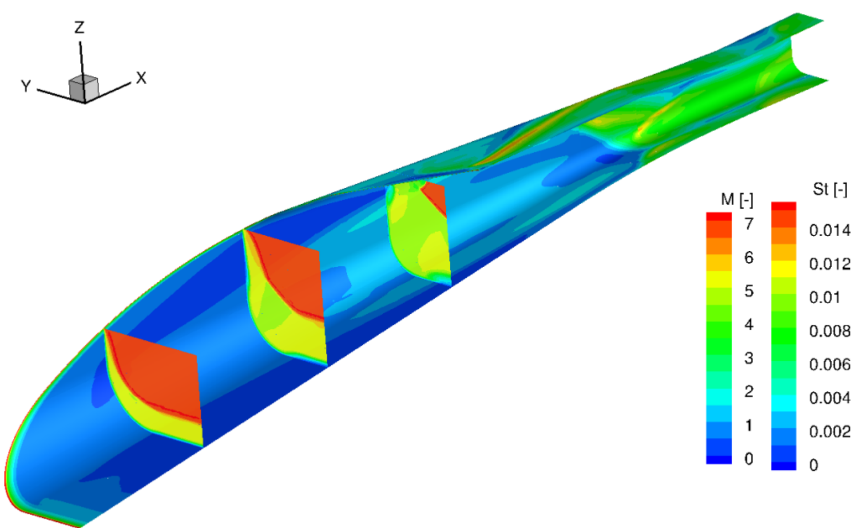

Figure 2: **Half-model of the intake. Mach number distribution at different cross sections of the intake and Stanton number distribution at the intake walls.**

REFERENCES

[1] Frank Bramkamp. *Unstructured h-Adaptive Finite-Volume Schemes for Compressible Viscous Fluid Flow.* PhD thesis, RWTH Aachen University, 2003.

[2] Sarah Frauholz, Marek Behr, and Birgit Reinartz. Numerical simulation of hypersonic air intake flow in scramjet propulsion. In *5th European Conference for Aeronautics and Space Sciences, Munich, Germany, 1-5 July*, 2013.

[3] Oliver M. Hohn and Ali Gülhan. Analysis of a three-dimensional, high pressure ratio scramjet inlet with variable internal contraction. In *18th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Tours, France, 23-27 September 2012, AIAA Paper 2012-5975*, 2012.

[4] Martin Krause and Josef Ballmann. Enhanced design of a scramjet intake using two different RANS solvers. In *26th International Symposium on Shock Waves, Goettingen (OH), Germany, 15-20 July 2007*, 2007.

[5] Martin Krause and Marek Behr. Modeling of transition effects in hypersonic intake flows using a correlation–based intermittency model. In *15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Dayton (OH), USA, 28 April - 1 May 2008*, 2008.

[6] R.B. Langtry. A Correlation-Based Transition Model using Local Variables for Unstructured Parallelized CFD Codes. *Dissertation*, 2006.

[7] F.R. Menter and R.B. Langtry. A correlation-based transition model using local variables part1 - model formulation. *Proceedings of ASME Turbo Expo*, 2004.

[8] Tue Nguyen, Gero Schieffer, Christian Fischer, Herbert Olivier, Marek Behr, and Birgit Reinartz. Details of turbulence modeling in numerical simulations of scramjet intake. In *27th Congress of International Council of the Aeronautical Sciences (ICAS), Nice, France, 19-24 September 2010*, 2010.