Computations of Complete Flow Fields in an Axisymmetirc Scramjet Using Accurate Anti-Diffusive WENO RANS Solvers

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Abstract - The description of geometrical configuration and design consideration are the most important requirements for understanding the aerophysics of scramjet, one of the very widely developed hypersonic air-breathing engines. A typical scramjet propulsion system consists of five major engine and two vehicle components: internal inlet, isolator, combustor, internal nozzle and the fuel supply subsystem. The key performance parameters can be determined from the CFD analysis are thrust, viscous drag, specific impulse and combustion efficiency. In addition configuration optimization using multi-variant optimization method can be performed for the design of scramjet.

Here, to conduct basic study of the hypersonic scramjet in a moderate scale, we adopt the CFD approach. We developed an implicit anti-diffusive weighted essestially non-oscillatory (WENO) scheme for the compressible Navier-Stokes equations with suitable turbulence model and applied the method to simulate the complex shock-shock/shock-boundary layer interactions inside the flowpath of an axisymmetric scramjet (CIAM/NASA), where flight and ground test as well CFD analysis have been available [1, 2]. Another configuration will be considered is [3] where some pressure data was available. The anti-diffusive WENO schemes [4,5] developed have been tested and validated in 2-D airfoils and 3-D wings aerodynamic flows [6-8] and accurate shock capturing and good slipline resolution have been demonstrated. Here, we also adopted suitable turbulence models [9-11] to better model the complicated shock-shock/ shock-boundary layer interactions and laminar-to-turbulent flow transition [12-14]. The complete flow fields of a hypersonic axisymmetric CIAM/NASA scramjet have been computed using the inhouse developed accurate CFD code. Comparison with available data and other computations indicate that the present superior contact discontinuities capturing capability does offer advantage in such a complex multiple shock-on-shock and shock boundary interactions where multiple contact discontinuities exist in one single flow. A good computational tool and suitable grid system (such as mult-domain) are

adopted to treat the complex and practical geometry and the high Mach number flows. A geometric parameter study will be carried out to optimize the flowpath geometry. The basic CIAM/NASA scramjet is shown in Fig. 1. Some results using high resolution TVD, WENO2 and WENO3 are given in Fig. 2 to Fig. 4. A brief report on the recent development in scramjet R & D at CSISI will be covered. More detailed results and analysis will be included in the full paper.

REFERENCES

[1] Voland, R.T., Auslender, A.H., Smart, M.K., Roudakov, A., Semenov, V., and Kopehenov, V., CIAM/NASA Mach 6.5 Scramjet Flight and Ground Test, AIAA 99-4848, 1999.

[2] Rodriguez, C. G., CFD Analysis of the CIAM/NASA Scramjet, AIAA Paper 2002- 4128, 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Indianapolis, Indiana.

[3] Henry, J.R., Andrews, E.H. Jr., Pinckney, S.Z. and McClinton, C. R., Boundary Layer and Starting Problems on a Short Axisymmetric Scramjet Inlet, NASA Langley, pp. 481-508, 1969.

[4] Bouchut , F. An Antidiffusive Entropy Scheme for Monotone Scalar Conservation Law. *Journal of Scientific Computing*, 2004; **21**: 1-30.

[5] Xu, Z. and Shu, C.W. , Anti-diffusive Flux Corrections for High Order Finite Difference WENO Scheme, *J. Comput. Physics* 2005; **205**:458-485.

[6] Yang, J.Y., Perng ,Y.C. and Yen, R.H., Implicit Weighted ENO Schemes for the Three Dimensional Compressible Navier-Stokes Equations. *AIAA J.*, 2001; 3**8**:p.464.

[7] Huang, J. C., Lin, H. and Yang, J. Y.,Implicit preconditioned WENO schemes for steady viscous flows, *J. Comput. Phys*, **228**, pp. 420-438, 2009.

[8] Yang, J.Y, Hsieh, T.J. and Wang, C.H. Implicit Anti-Diffusive Weighted ENO Schemes for the Three-Dimensional Compressible Navier-Stokes Equations. *AIAA Journal*, 47, No. 6, 2009, pp. 1435-1444.

[9] Wilcox, D. W., Formulation of the k-ω Turbulence Model Revisited, AIAA J., Vol. 46, No. 11, 2008, pp. 2823-2838.

[10] Roy, C. J. and Blottner, F. G., Review and Assessment of Turbulence Models for Hypersonic Flows, Progress in Aerospace Sciences, Vol. 42, 2006, pp. 469-530.

[11] Rumsey, L. C. Compressibility considerations for Two-Equation Turbulence Models in Hypersonic Boundary Layer Applications, NASA-TM April, 2009.

[12] Ungewitter, R.J., Ott, J.D., Ahuja, V. and Dash, S.M., CFD Capabilities for Hypersonic Scramjet Propulsive Flowpath Design, AIAA-2004-4131.

[13] Curren, E. T. and Murthy, S.B.N., Ed., Scramjet Propulsion, AIAA Progress in Astronautics and Aeronautics, Vol. 189, p. 452.

[14] Andreadis, D., Scramjets Integrate Air and Space, The Industrial Physicist, 2004.

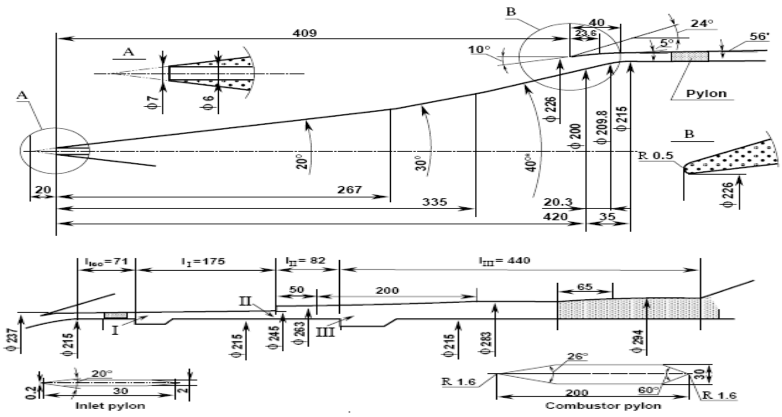

Fig. 1, Congifuration of the CIAM/NASA Scramjet [1].

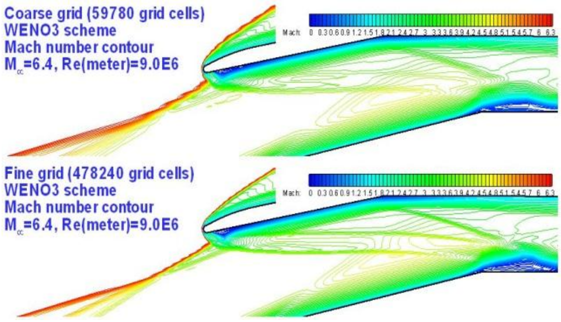

Fig. 2. Hypersonic Inlet flow analysis – A grid refinement test for anti-diffusive WENO RANS solver.   Note that the original M=6.4 case will not completely enclose the cowl lip.

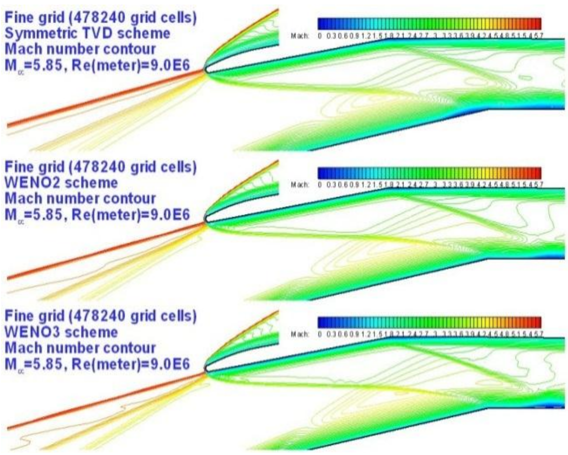

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Fig. 3. Hypersonic inlet flow analysis – A comparison of different high resolution schemes. Note that our analysis reveal that M=5.85 will give better performance of the inlet.

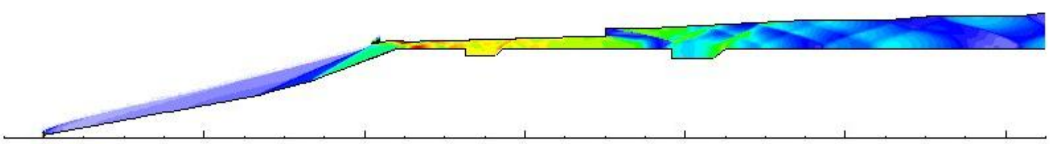

Fig. 4. Complete flow fields of a CIAM/NASA Scramjet using anti-diffusive WENO RANS solver.