Abstract submitted to The Third National Symposium on Shock Waves

Reynolds stress budgets in canonical shock-turbulence interaction

Russell Quadros[1], Maloth Thirupathi[1], Johan Larsson[2] and Krishnendu Sinha[1]

[1] Department of Aerospace engineering, Indian Institute of Technology Bombay

[2] Department of Mechanical engineering, University of Maryland

Shock turbulence interaction is a important and commonly observed phenomenon in high speed flows. This phenomenon results yields regions of high pressure and high thermal loads with significant impact to the flow topology also. Correct predictions of properties such as heat flux, wall pressure and skin friction in regions of such a phenomenon is essential from a design perspective. However, due to the complex nature of interaction, it has been a challenging task to predict such flow properties experimentally or numerically[1].

A simplified case of shock-turbulence problem is the interaction of an isotropic turbulence with a normal shock. This problem has been extensively studied in the past experimentally[2], numerically[3],[4] as well as theoretically[5]. Some of the recent numerical studies were performed by Larsson et al. who carried out DNS for the case of purely vortical turbulence interacting with a normal shock[6].

In their study, simulations were performed for 20 cases, each varying in either upstream Mach number, turbulent Mach number or Reynolds number. Upstream Mach numbers ranged from 1.06 to 6. Turbulent Mach number for these cases were between 0.15 and 0.38. Further, two cases of upstream Reynolds number based on Taylor-scale, were considered for study. These cases highlight the effect of shock strength, upstream turbulent intensity and viscous mechanisms on the shock-turbulence interaction.

An important quantity of interest is the Reynolds stress which is a defining characteristic of the turbulence. Reynolds stress R_{ij} is defined as $\overline{u_i' u_j'}$ where u_i' is the fluctuating velocity component in the i^{th} direction with the overbar representing Reynolds averaging. Correct prediction of Reynolds stresses across the shock, forms the basis of prediction of other important flow properties such as wall pressure and wall heat flux in RANS modeling[8]. Larsson et al. study the effect of mean Mach number M, turbulent Mach number M_t and Reynolds number Re_λ on the evolution of Reynolds stress across the shock.

In this study, we take a closer look at the Reynolds stress budget equation for streamwise Reynolds stress R_{11}, transverse Reynolds stress R_{22} and the trace of the Reynolds stress tensor R_{kk}. The budget equation highlights the mechanisms affecting the evolution of Reynolds stress in the post-shock region. The effect of M, M_t and Re_λ on each of these mechanisms is studied and important observations are highlighted.

References

[1] Xiao, X. and Hassan, H. A., "Modeling scramjet flows with variable turbulent Prandtl and Schmidt numbers," *AIAA Journal*, Vol. 45, 2007, pp. 1415

[2] Barre, S., Alem, D. and Bonnet, J. P., "Experimental study of a normal shock/homogeneous turbulence interaction," *AIAA Journal*, Vol. 34, 1996 , pp. 968.

[3] Lee, S., Lele, S. K. and Moin, P., "Direct numerical simulation of isotropic turbulence interacting with a weak shock wave," *Journal of Fluid Mechanics*, Vol. 251, 1993, pp. 533.

[4] Mahesh, K., Lele, S. K. and Moin, P., "The influence of entropy fluctuations on the interaction of turbulence with a shock wave," *Journal of Fluid Mechanics*, Vol. 334, 1997, pp. 353.

[5] Mahesh, K., Lele, S. K. and Moin, P., "Shock turbulence interaction in the presence of mean shear: an Application of rapid distortion theory," *31st Aerospace sciences meeting and exhibit,AIAA Reno, NV*, 1993

[6] Larsson, J., Bermejo-Moreno, I. and Lele, S. K., "Reynolds- and Mach number effects in canonical shock-turbulence interaction" *Journal of Fluid Mechanics*, Vol. 717, 2013, pp. 293.

[7] Larsson, J. and Lele, S. K., "Direct numerical simulation of canonical shock/turbulence interaction," *Physics of Fluids*, Vol. 21, 2009, pp. 126101.

[8] Sinha, K., Mahesh, K., and Candler, G.V., "Modeling the Effect of Shock Unsteadiness in Shock-wave / Turbulent Boundary Layer Interactions," *AIAA Journal*, Vol. 43, 2005, pp. 586