AN LIA+EDQNM STRATEGY TO STUDY SHOCKED TURBULENT MIXTURES

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Abstract Direct numerical simulations (DNS) of the interaction of shock waves with turbulent mixtures [3] are only affordable for very low Reynolds numbers. We propose here to couple the Linear Interaction Analysis [2] (LIA) with an Eddy-Damped Quasi-Normal Markovian[1] (EDQNM) model to get inexpensive valuable information at large Reynolds number.

CONTEXT

The interaction of shock waves with turbulent mixtures is a powerful mechanism for turbulence enhancement that is encountered in different fields like inertial confinement fusion, supernovae or scramjet reactors. The modelling of such flows is especially challenging due to the complex structure of the field downstream of the shock front. LIA is aimed at predicting it for upstream statistically homogeneous turbulent mixtures when the wave amplitudes of the Kovasznay decomposition remain weak. This theory predicts strongly anisotropic and out-of-equilibrium turbulence which has to relax to reach its asymptotic decay thereby modifying its properties. DNS of both the detailed interaction process and the non-linear equilibration phase implies a large computational cost and remains affordable only for low Reynolds numbers.

APPROACH

Our goal is to investigate the possibility of coupling LIA and an incompressible axisymmetric EDQNM model to provide useful information for turbulence modelling at a low computational cost but a large Reynolds number. The idea is the following : for a given upstream field, the LIA can predict the (linear) “far field” downstream of the shock front which can itself be injected as the initial condition of an EDQNM computation. However this procedure implies successive simplifications from the basic problem due to the homogneity and Boussinesq approximations included in the EDQNM model. We then must check if we can go :

1. from a spatially evolving turbulent flow including a shock wave to a temporally evolving incompressible homogeneous turbulent flow;
2. from a turbulent flow with fluctuations of an active scalar, the density, to a turbulent flow without scalar fluctuation.

Standard numerical computations are used for these intermediate steps.
To test the first point, we use a single triply periodic box of an upstream mixture at rest that is either periodically injected in a simulation usptream of a Mach 1.25 shock wave or treated according to LIA to give the corresponding far field for entropic and vortical waves but without acoustic fluctuations. Figure 1 shows a snapshot of the fluctuating density field obtained from both computations. The upper part is the spatial computation at a time when a permanent regime has been reached whereas the lower part is made of three instants of the decay from the LIA field. The times are chosen to correspond to the downstream travelling time of the region above in the upper part. Matching is correct indicating that LIA provides the right “initial” condition and that the appearance of non linear effects is well reproduced.
To test the second point, we simply impose a uniform density in the initial field, thereby removing the entropic part of the LIA input and keeping only the vortical one. Figure 2 shows correlations obtained with the three numerical simulations: spatial evolution with computed shock wave, temporal evolution from LIA (entropy and vorticity fields), temporal evolution from LIA (vorticity field only). The last two results are superposed for that special case.
Eventually, this shows that regions exist where using LIA+EDQNM is relevant to shock mixture interaction problems. We will present results obtained with this LIA+EDQNM treatment.

References

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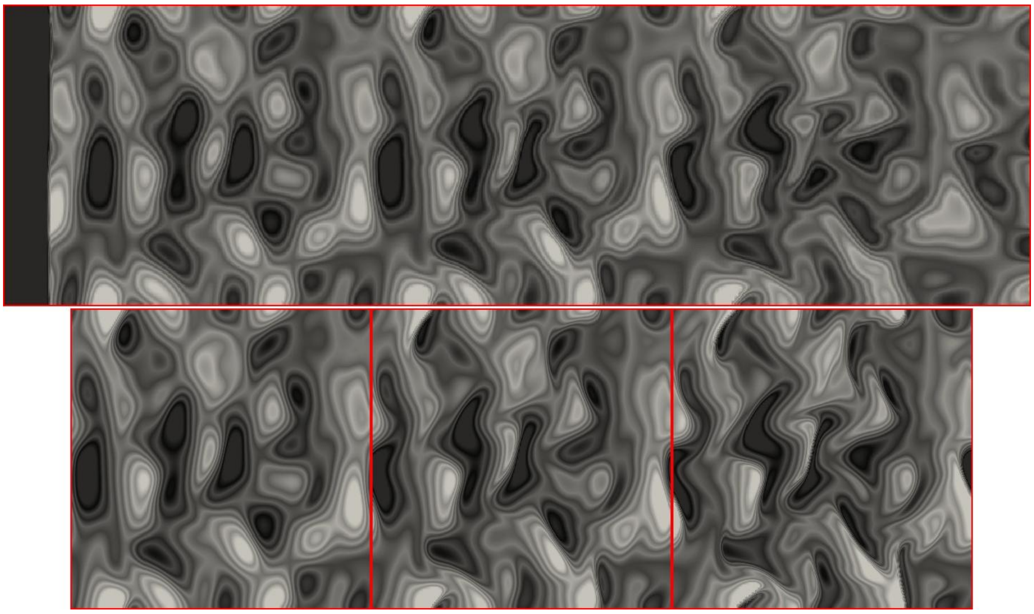

Figure 1. Perturbed density field for interaction of a mixture at rest with a Mach 1.25 shock wave. Upper part : spatial evolution with computed shock wave. Lower part: three snapshots of the temporal evolution from LIA at times corresponding to downstream advection from the shock front.

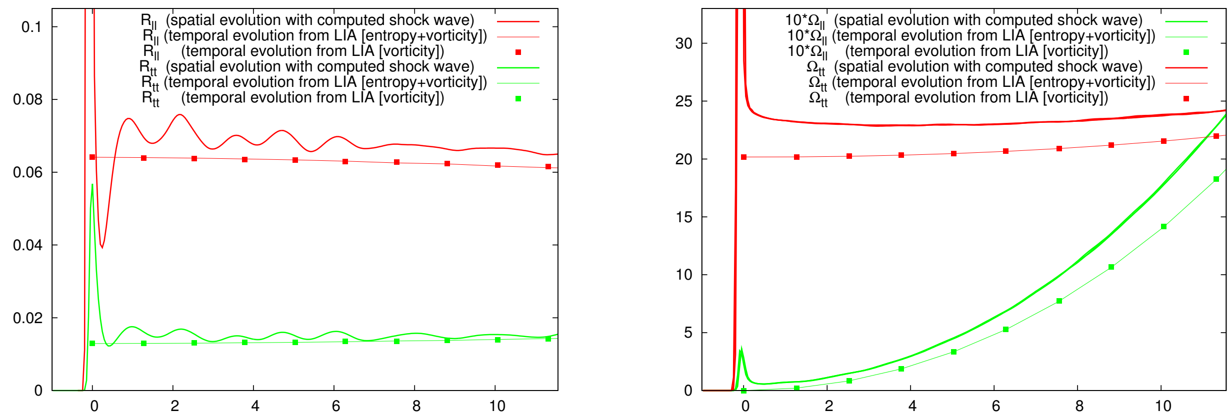

Figure 2. Correlations obtained by the three kinds of numerical simulations. Abscissa : distance from the shock front (for spatial evolution) or time multiplied by downstream fluid velocity (for temporal evolution). Left part: longitudinal R_{ll} and transverse R_{tt} Reynolds stresses; right part : longitudinal Ω_{ll} ($\times 10$) and transverse Ω_{tt} components of the enstrophy tensor.