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INVESTIGATION OF THE MECHANISM OF SASI IN CORE COLLAPSE SUPERNOVAE USING SIMPLE TOY MODEL SIMULATIONS

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Abstract. We perform numerical simulations of a toy model proposed by Foglizzo (2009) to explain the mechanism of the standing accretion shock instability (SASI), and confirm the results of the linear analysis. Three types of simulations have been performed, measuring (i) the acoustic feedback resulting from the advection of entropy/vorticity in a region of deceleration, (ii) the advected wave generated at a shock perturbed by an acoustic wave, and (iii) the growth rate and oscillation frequency of the dominant advective-acoustic cycle in the linear regime. The results of the simulations agree with the linear analysis within 5% when the mesh size is 1% of the distance between the shock and the deceleration region, with a numerical error dominated by the numerical treatment of the shock. This simple toy model can be used as a benchmark test for numerical codes dealing with SASI simulations.

1 Introduction

The standing accretion shock instability (SASI) takes place in the collapsing core of a massive star, when the shock stalls $\sim$ 150 km above the nascent neutron star (Blondin et al. 2003). This $l = 1$ instability may be responsible for the asymmetric character of core-collapse supernova explosions (e.g. Marek & Janka 2009). The physical mechanism of SASI advocated by Foglizzo et al. (2007), Scheck et al. (2008) is an advective-acoustic cycle (AAC). A simple toy model has been proposed by Foglizzo (2009) (hereafter F09) in order to improve our understanding of the AAC. The purpose of this study is to check the results of the perturbative analysis of F09 through numerical experiments, thus providing concrete examples of the coupling processes involved.

2 Setup of the simulations

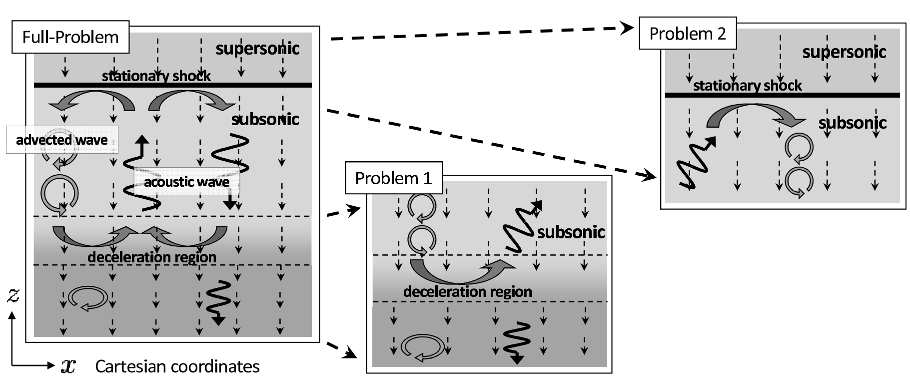

Fig. 1. Schematic view of the toy model of the advective-acoustic cycle, separated into two sub-problems. Advected perturbations are noted as circular arrows, while acoustic waves are noted as wavy arrows.

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The AAC is due to the interaction of the accretion shock and a deceleration region. The toy model of F09 is studied through three types of simulations in the linear regime, illustrated by Fig. 1. In “Problem 1” , we measure the acoustic feedback δp produced by an entropy/vorticity wave δS advected from the upper boundary to the deceleration region (Fig. 2a). In “Problem 2”, we measure the advected entropy/vorticity wave δS generated at the shock by an acoustic wave δp propagating against the flow from the lower boundary (Fig. 2b). The “Full-Problem” involves both the shock and the deceleration region. This flow is linearly unstable. We measure both the growth rate ω_i and the oscillation frequency ω_r of the most unstable mode (Fig. 2c). The details of the simulations are described in Sato et al. (2009).

3 Results

In Fig. 2a and 2b, Problems 1 and 2 are solved for different frequencies ω_0 and mesh sizes (Δx, Δz). The good agreement between the simulations (symbols) and the linear analysis (solid line) confirms the validity of both the linear analysis and the numerical simulation. The convergence to the analytical formula in Problem 2, however, is much slower than in Problem 1 (Sato et al. 2009). The growth rate and oscillation frequency in the Full-Problem are displayed in Fig. 2c for different mesh sizes Δz. An accuracy of 5% is reached for a mesh size of 1% of the distance $r_{\rm sh} - r_{\nabla}$ between the shock and the deceleration region.

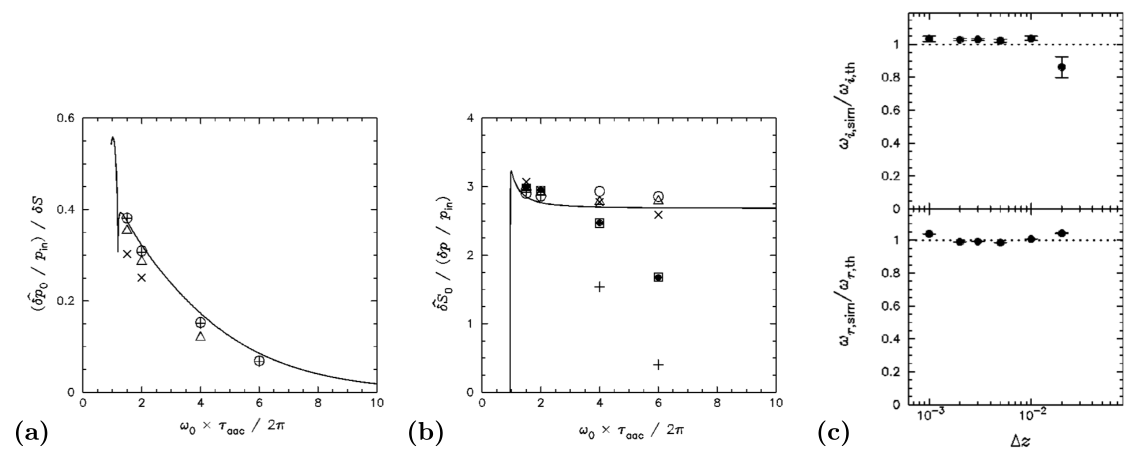

Fig. 2. (a): Efficiency of the production of acoustic waves by the deceleration of advected waves as a function of frequency in Problem 1, deduced from the numerical simulations (symbols) and compared to the perturbative analysis of F09 (solid line). $\tau_{\rm aac}$ is a normalization timescale associated with the AAC in 1D (F09). The different square mesh sizes, measured in units of $r_{\rm sh} - r_{\nabla}$, are $\Delta x = \Delta z = 5 \times 10^{-2}$ (crosses), 2×10^{-2} (triangles) and 10^{-2} (circles). The results for $\Delta x = 2 \times 10^{-2}$, $\Delta z = 10^{-2}$ are also shown (pluses). **(b)**: Dependence of the entropy production on the frequency in Problem 2. The different mesh sizes are $\Delta z = 2 \times 10^{-2}$ (pluses), 10^{-2} (squares), 5×10^{-3} (crosses), 2×10^{-3} (triangles) and 10^{-3} (circles), with $\Delta x = 2 \times 10^{-2}$, and $\Delta x = \Delta z = 1 \times 10^{-2}$ (filled points). **(c)**: Growth rate $\omega_{i,\rm sim}$ and oscillation frequency $\omega_{r,\rm sim}$ of the most unstable mode ($n_x = 1$) measured in numerical simulations of the Full-Problem, compared to the values $\omega_{i,\rm th}$ and $\omega_{r,\rm th}$ obtained from F09 (dotted line).

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