A shock stable and contact preserving convective pressure split Riemann solver for computation of compressible high speed flows

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1. INTRODUCTION & OBJECTIVE

Computation of high speed gasdynamic flows continues to be a major challenge in CFD. Complexities arise in terms of strong shocks, expansion fans, shear waves and their interactions. Amongst various classes of upwind schemes that exist heretofore, approximate Riemann solvers have been quite promising in their ability to accurately resolve these complex flow features. These approximate solvers can be further classified into non contact preserving and contact preserving solvers. While most schemes belonging to both these categories can handle shocks and expansions fans satisfactorily, only the contact preserving variety is designed to admit linearly degenerate waves that carry information regarding shear and entropy features. Such a distinct ability favors contact preserving Riemann solvers to be used for discretizing the convective fluxes in a practically significant Navier-Stokes code. However robustness of almost all contact preserving Riemann solvers have been questioned due to the occurrences of one or the other form of numerical shock instabilities. These instabilities results in production of various impractical numerical artefacts like distorted shocks, erroneous stagnation heat transfer values, kinked Mach stems, negative internal energies etc [1].

Recently, several contact preserving Riemann solvers based on the philosophy of Convective-Pressure Split (CPS) methods have found appreciable success in dealing with high speed gasdynamical flows. The basic idea of CPS schemes was first pioneered in [2] wherein the total flux vector is seperated into its convective and pressure components which are then treated distinctly based on their respective propagation speeds. HLL-CPS scheme [3] is the most recent addition to this category. Unlike AUSM family of schemes which are based partly on Flux Vector Splitting ideology, HLL-CPS utilizes a Flux Difference type discretization for both convective and pressure parts. Contact preservation is achieved by modifying the dissipation vector of the pressure flux using isentropic relations. Using appropriate choice of wave speeds, the discretized convective and pressure fluxes are coupled to each other. Although reported to be stable on several test problems concerning shock instabilities, closer investigation reveal that the behaviour of this scheme can be largely influenced by the choice of wave speed selection. It has been observed that choice of Roe averaged wave speeds (HLL-CPS-Z_{Roe} version) render the scheme prone to shock instabilities on fine meshes.

In this work, a new low diffusion scheme based on CPS framework is proposed. In a certain sense it can be considered as an improvement to the standard HLL-CPS method. Like HLL-CPS, the new scheme uses HLL type discretization to deal with convective and pressure fluxes. It also retains Roe averages in wave speed selection that enables exact shock capturing ability as suggested in [4]. However unlike HLL-CPS, contact preserving ability in the new scheme is achieved by introducing an antidiffusion term derived from the classic HLLC scheme. To cure

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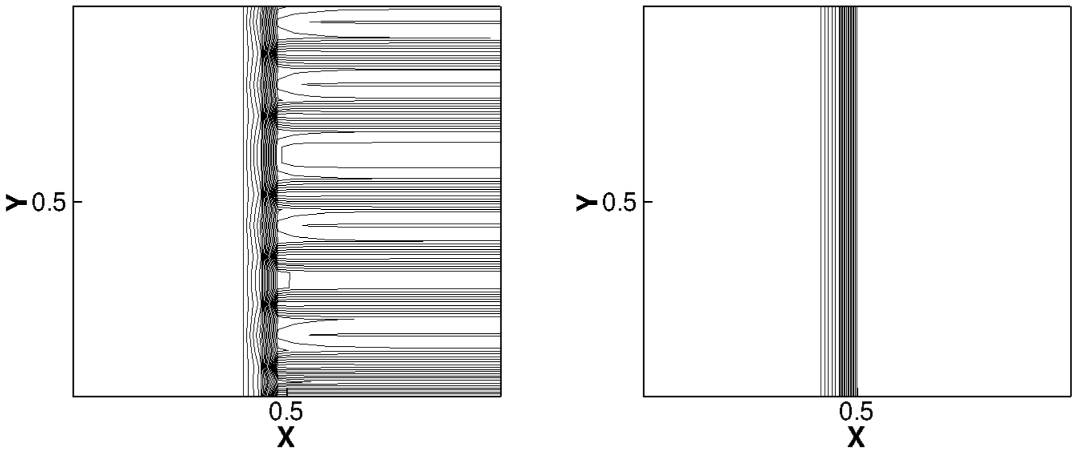
the new scheme of shock instabilities, a pressure based sensor is used to smoothly control the amount of antidiffusion near strong shocks. Results from numerical experiments shows that the new scheme is not only accurate but also performs better as compared to HLL-CPS-Z_{Roe} when dealing with strong shocks.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

Simplest test case to investigate the proneness of a numerical scheme to shock instabilities is one which concerns with the stability of a stationary strong normal shock [5]. A normal shock of strenght M=7 is located in the middle of a unit dimensional domain. The domain is divided into 26×26 Cartesian cells. Ideally such a shock solution should be preserved without any change. However it has been observed that if a scheme is susceptible to shock instabilities, random numerical errors in the computed solution may be amplified to produce a completely distorted shock profile and contaminated post shock values. Figure 1 shows the results of this experiment carried out using both HLL-CPS-Z_{Roe} and the newly proposed scheme. Thirty density contour lines equally spanning values from 1.0 to 7.4 is shown. From the Figure, it is evident that HLL-CPS-Z_{Roe} scheme produces this variant of shock instability while the new scheme is compeletely free of this. This simple yet revealing test problem demonstrates the efficacy of the new solver.



(a) HLL-CPS-Z_{Roe} (b) New scheme

Figure 1: Density contours for M=7 standing shock instability problem.

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