Introduction

Designs of inertial fusion reactor chambers, such as the LIBRA-SF, involve rows of cooling tubes to absorb energy from the fusion reaction as well as target debris. The reaction also results in a hydrodynamic shock wave in the low pressure blanket gas that spherically radiates from the center of the chamber out to the rows of cooling tubes. A shock tube has been used to model experimentally the interaction of a shock wave with two rows of cooling tubes. The shock tube studies have been repeated in a computational environment and the numerical results compare favorably with the experiments. The numerical studies are now extended to a bank of cylinders, consisting of five rows, with the goal of understanding the most favorable geometrical spacing of the cooling tubes for structural design purposes.

Key Features of the Numerical Code

The code solves the Euler equations in two-dimensions using an exact Riemann solver and a fourth-order accurate (spatial) piece-wise spline method (PWSM). The Euler equations in conservative form are:

\[ U_t + F_x + G_y = 0 \]

where the conservative variables (U) and fluxes (F and G) are:

\[ U = (\rho, \rho u, \rho v, \rho e)^T \]

\[ F = \frac{\rho u}{\rho} (\rho u^2 + p) \]

\[ G = \frac{\rho u}{\rho} (\rho u v + p) \]

The total energy per unit volume is \( \rho e \) and the calorically perfect gas model is used:

\[ e = \frac{p}{\gamma - 1} \]

A splitting scheme is employed for the system in two spatial dimensions and the unstructured mesh. The code is parallelized with the virtual mesh component, vmeso. A two-step process scheme is used to accomplish the integration in time via a Godunov scheme.

The PSM and following steps follow similar to those described by Bai et al. (2018), are used for the reconstruction of the conservative variables for the local Riemann problem solutions at cell interfaces to achieve fourth-order (spatial) accuracy:

\[ U^i_+ = U_0 + \frac{\delta}{8} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

\[ U^i_- = U_0 - \frac{\delta}{8} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

\[ U^i_0 = U_0 + \frac{\delta}{8} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

\[ U^i_4 = U_0 + \frac{\delta}{4} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

where \( \delta \) and \( \delta u \) are the first and second spatial derivatives of the conservative variable. The reconstructed variables are used with the Pse exact Riemann solver to evaluate the flux terms at the interface.

Numerical Study of Shock-Cylinder Banks Interactions

The total energy per unit volume is \( \rho e \) and the calorically perfect gas model is used:

\[ e = \frac{p}{\gamma - 1} \]

A numerical scheme is employed for the system in two spatial dimensions and the unstructured mesh. The code is parallelized with the virtual mesh component, vmeso. A two-step process scheme is used to accomplish the integration in time via a Godunov scheme.

The PSM and following steps follow similar to those described by Bai et al. (2018), are used for the reconstruction of the conservative variables for the local Riemann problem solutions at cell interfaces to achieve fourth-order (spatial) accuracy:

\[ U^i_+ = U_0 + \frac{\delta}{8} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

\[ U^i_- = U_0 - \frac{\delta}{8} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

\[ U^i_0 = U_0 + \frac{\delta}{8} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

\[ U^i_4 = U_0 + \frac{\delta}{4} \frac{\partial}{\partial x} \left( 9 u + 2 \delta u \right) \]

where \( \delta \) and \( \delta u \) are the first and second spatial derivatives of the conservative variable. The reconstructed variables are used with the Pse exact Riemann solver to evaluate the flux terms at the interface.

Results and Discussion

Four test cases, A-D, are presented with vertical force traces on each of the five rows of cylinders for a 0.275 in shock in argon. Each of the plots, the uppermost cylinder is labeled 1 while the lowest row is 5. It is seen from the force plot that the maximum force occurs on the second bank of cylinders while for cases B, C and D the maximum force occurs on the third row of cylinders. The maximum force seen in all of the simulations is for the third row of cylinders in case C which is likely due to the fact that the radius of each cylinder is largest in this case. In all cases, the first cylinder bank is subjected to the lowest vertical force loading due to the shock strengthening that occurs as the shock wave traverses the gaps between the cylinders. The shock strengthening effect is seen to lessen as the shock reaches the fourth and fifth rows of cylinders due to the numerous shock reflections that have occurred by this time. For the actual cooling tubes in an IFE reaction chamber it will be necessary to consider the force loading on each row in the structural design, that is, if the geometry of case A is used then the second row will have to be stronger than the others, while in cases B-D, the third row of tubes would require the highest strength.

Numerical Study of Shock-Cylinder Banks Interactions

S. P. Wang, M. Anderson, J. Oakley and R. Bonazza
Department of Engineering Physics, University of Wisconsin-Madison, Madison, WI 53706