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Applications of the Artificial Wind Schemes and Adaptive Unstructured Grids to Compute Shock Wave Interactions in Water

○ E.V.TIMOFEEV, K.TAKAYAMA, Shock Wave Research Center, IFS, Tohoku University
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan, E-mail: timo@ceres.ifs.tohoku.ac.jp
K.NAGAYASHI, Chugoku Kayaku Co. Ltd.
5-1-1 Etajuma-cho, Aki-gun, Hiroshima 737-21, Japan

Recently proposed Artificial Wind concept allows constructing of simple, accurate and efficient upwind schemes being suitable for a variety of hydrodynamic problems without any generalizations for each particular case. In the present paper we show how the Artificial Wind schemes implemented on locally adaptive unstructured grids work for computing unsteady high-speed flows in water. The Euler equations with the Tait equation-of-state underlie the mathematical model. Two problems have been considered here: (a) long-distance shock wave propagation in the World Ocean as a hypothetical scenario of mass marine life extinction caused by an impact of a celestial body; (b) underwater shock wave reflections induced by the explosion of mild detonation fuses.

Recently Sokolov & Co-Authors ([1]) have elaborated a new approach to construct upwind schemes. The main idea is to avoid the splitting of perturbations, the key and most cumbersome part of any upwind scheme, at all and make them all propagating in the same direction depending on our choice, thus facilitating the upwinding. This can be achieved by various means: by changing the frame of reference, by moving control volume faces during a time step, by considering a spatial-temporal invariance of an arbitrary hyperbolic system of conservation laws. All the ways are physically equivalent (they result from the Galilean invariance) and interrelated. They all introduce an additional velocity which is called Artificial Wind velocity to emphasize that its value is a matter of our choice and that it is introduced to facilitate upwinding. The resulting schemes are very simple in construction, at least as accurate as traditional upwind schemes, and efficient. They retain the same and simple form for a wide range of hydrodynamical systems.

The main objective of the present paper is to demonstrate how easy the Artificial Wind schemes may be applied to compression waves' propagation in water assuming that the Tait equation of state is valid and employing the previously developed locally adaptive unstructured 2D and 3D Euler codes by Voinovich [2].

In fact, exactly the same formulas as those for perfect gases can be used. For a face $i+1/2$ with the left and right states denoted by "l" and "r", respectively, the Artifical Wind flux may be written as follows:

$$\mathbf{F}_{i+1/2} = \mathbf{F}[\xi^* \mathbf{U}_r + (1-\xi^*)\mathbf{U}_l] + d \cdot (\mathbf{U}_l - \mathbf{U}_r)$$

where $\mathbf{U}$ are the conserved variables, and the weighting coefficient ξ^* is given by a simple iteration procedure involving the Artificial Wind velocities $\widetilde{D}^L$ and $\widetilde{D}^R$:

$$\widetilde{D}^L = \frac{1}{2}[\min(v_r - c_r, 0) + \min(v(\xi^*) - c(\xi^*), 0)],$$

$$\widetilde{D}^R = \frac{1}{2}[\max(v_l + c_l, 0) + \max(v(\xi^*) + c(\xi^*), 0)],$$

$$\xi^* = \widetilde{D}^L/(\widetilde{D}^L - \widetilde{D}^R)$$

with subsequent calculation of the diffusion coefficient

$$d = \max[\xi^* \widetilde{D}^R, (\xi^* - 1)\widetilde{D}^L] \quad .$$

The only difference is that the full energy and the speed of sound should be computed as follows from the Tait equation-of-state: $\rho e = (p + \tilde{\gamma} B)/(\tilde{\gamma} - 1) + 0.5\rho \mathbf{u}^2$, $c = \sqrt{\tilde{\gamma}(p+B)/\rho}$, where $\tilde{\gamma} = 7.415$ and $B = 296.3$ MPa are parameters of the Tait equation.

Two problems are considered: (1) long distance propagation of a shock wave produced in the ocean by an impact of a celestial body; (2) the interaction of underwater shock waves induced by an explosion of mild detonating fuses (see Fig. 1; this 3-D problem was also studied experimentally and our CFD results are in good agreement with the experimental data).

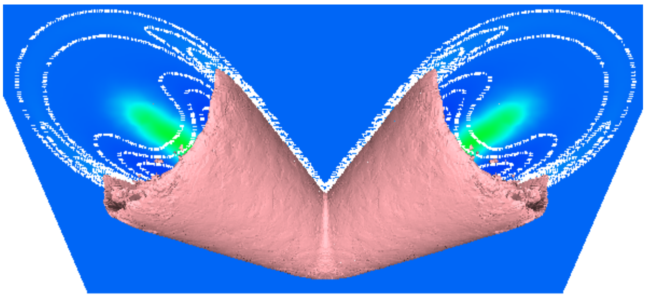

Fig. 1: Two submerged segments of mild detonation fuse are attached to each other at $2 \times 43°$ angle and ignited simultaneously at the opposite ends. The detonation wave propagates along the explosive wires and induces axisymmetrical underwater shock waves which, upon the detonation is completed, interact with each other (see the isosurface). Pressure contours and shading according to density values are shown on the plane of symmetry

References

1. Sokolov, I.V., Timofeev, E.V., Sakai, J., and Takayama, K., "Development and application of Artificial Wind schemes for hydrodynamics, MHD and relativistic hydrodynamics, CD-ROM Proc. 13th Japanese National CFD Symp., Tokyo, (1999), paper Nr. E01-5.
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