Lagrangian Meshfree Particle Method for Modeling Acoustic Wave Propagation in Moving Fluid

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Introduction

Particle-based Computational Acoustics

(PCA)

is a noval branch of computational acoustics that aims to simulate the acoustic phenomenon by Lagrangian meshfree particle methods.

Advantages:

I. eliminate numerical error in computing advection term;

II. easy to handle complex changes of computational domain shape and moving boundaries;

III. easy to track the interface between different media;

IV. computation based on local support domain is suitable for parallel computing.

Governing Equations:

I. Lagrangian fluid dynamic equations (LFDE) [1, 2];

- for direct numerical simulation

II. Lagrangian acoustic wave equations (LAWE) [3, 4];

- for waves in stationary media

III. Lagrangian acoustic perturbation equations (LAPE) [5, 6].

- considering flow-acoustic interaction

Numerical Methods:

I. Smoothed particle hydrodynamics (SPH) [7, 8];

- widely used fundamental particle method

II. Corrective smoothed particle method (CSPM) [9, 10];

- modify SPH with Taylor series expansion

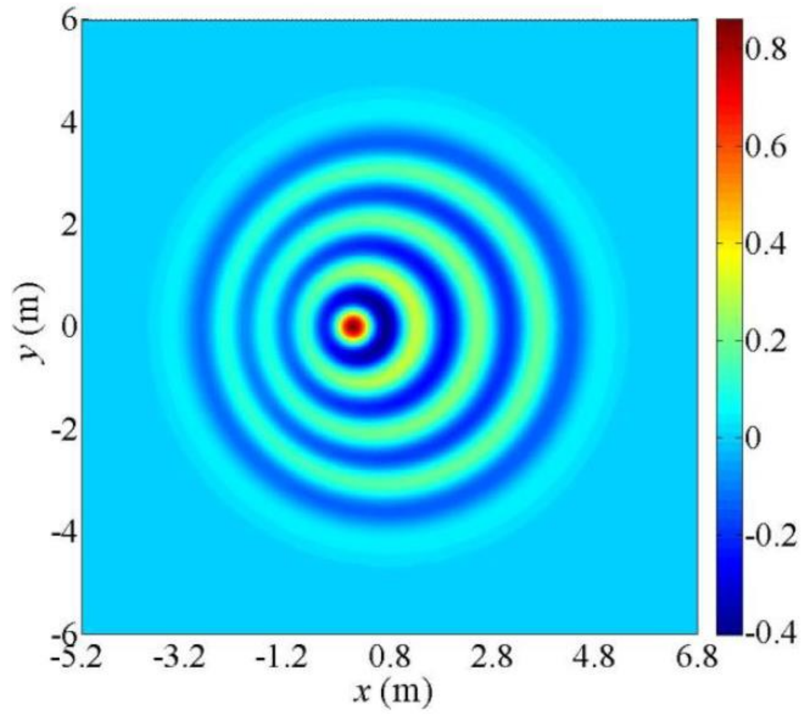
III. Finite difference particle method (FDPM) [5].

- developed from generalized finite difference scheme

Test 1 sound propagation in mean flow

A two-dimensional test is given to validate the CSPM formulations for solving LAPE. In the test, sound propagate through a uniform mean flow. Sound source is

$$\frac{\partial \delta p}{\partial x} = A(x-x_0)e^{-B\left[(x-x_0)^2+(y-y_0)^2\right]}\sin(\omega t)$$



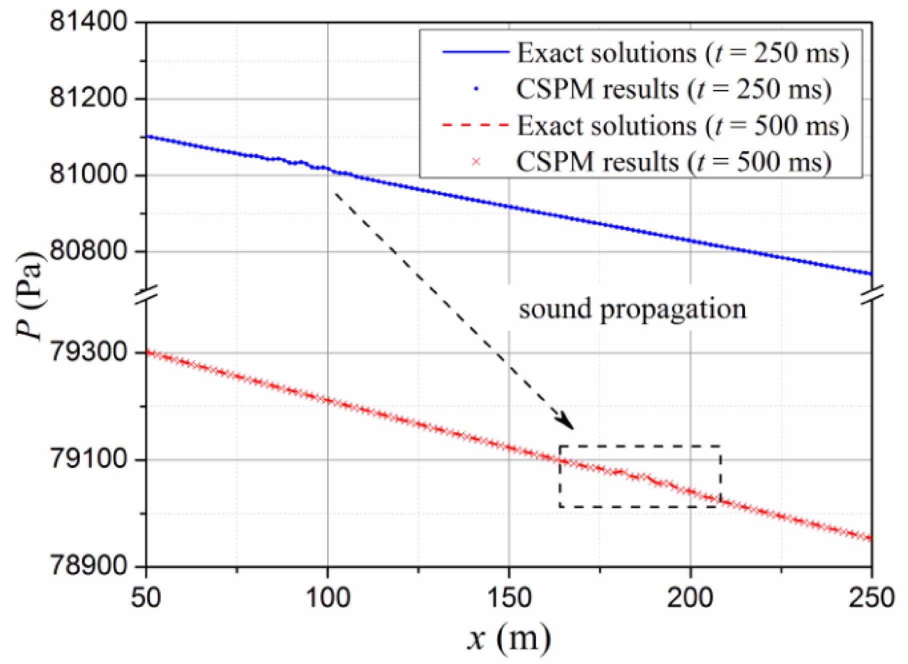
Sound pressure contour after 4.0 s propagation, and the inlet flow comes from left with Mach number as 0.2.

Test 2 sound propagation in turbulent flow

Sound propagate in a tube with turbulent flow is used to test the CSPM formulations for solving LAPE. Velocity and velocity perturbation:

$$u_0 = \frac{2}{\gamma+1}\frac{x}{t}+C_1$$

$$\delta u(x,t=0) = \alpha_1 c_0\left[2+\cos(kx)\right]\exp\left[-\alpha_2(kx)^2\right]$$



Pressure distribution along the tube at different time. Changes of pressure perturbation in the black box is the process of sound propagation.

Test 3 sound scattering in vortex

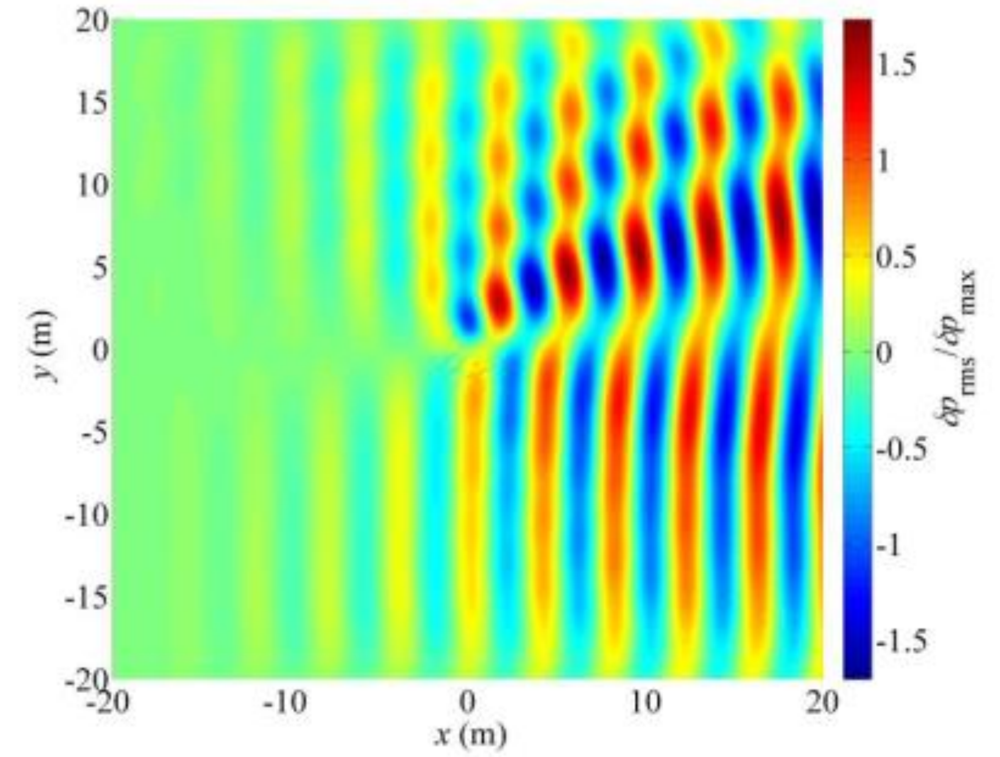
When sound waves propagate through a vortex, the vortical flow affects the sound propagation significantly, and leads to the vortex scattering phenomenon. To model this phenomenon, test 3 uses the FDPM to solve LAPE.

Isentropic vortex field:

$$v_\theta = \frac{\Gamma}{2\pi r}\left[1-\exp\left(-\frac{\alpha r^2}{L^2}\right)\right]$$

Incident sound waves:

$$\delta p_{\mathrm{in}} = \delta p_{\max}\sin(2\pi f t)$$



Vortex scattering sound pressure contour with *Ma* = 0.25.

Conclusions

This work presents a particle-based computational acoustic method for modeling sound propagation in moving fluid. Both CSPM and FDPM are used to solve LAPE which separates the particle motion and acoustic perturbation with two sets of governing equations.

Sound propagation in different flows with different Mach numbers is simulated. Computational results show clear Doppler effects and vortex scattering phenomenon. The present particle-based computational acoustic method demonstrate convergence with exact solutions.

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