A NEW METHOD FOR NUMERICAL SIMULATION OF TWO TRAINS PASSING BY EACH OTHER AT THE SAME SPEED

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(Received February 26, 2010, Revised May 6, 2010)

Abstract: A new method is proposed to numerically simulate problems of trains passing by each other at the same speed, and is implemented in UDF language of commercial software Fluent. Because only a half of the computational domain is required and the dynamic mesh technique is avoided, the computational efficiency is greatly improved. A two-dimensional test case is used for validation, which shows that the flow field and the pressure wave during the train-passing events can be correctly calculated by this new method. This method can be easily extended to three-dimensional simulations, to deal with practical problems.

Key words: trains passing by each other, rotational symmetry, dynamic mesh, pressure wave

1. Introduction

Aerodynamic loads in train-passing problems are becoming more and more important due to the booming development of high speed railways and their effects on the surrounding buildings. Among them the most serious and typical cases are that trains pass by each other at the same speed in a tunnel. Recent investigations mainly focus on real vehicle tests, scaled model experiments and numerical simulations. A series of real vehicle tests were carried out by Takizaw (2 000), Li[1] and Yang[2], during which the basic aerodynamic loads, pressure waves and train winds were measured. Compared to real vehicle tests, numerical simulations require shorter investigation period and lower cost, and most of all, have better ability to simulate extreme conditions which would not occur often in everyday life.

In terms of the computational efficiency, the numerical simulation approaches can be classified into three kinds. The first kind concerns simplified approaches, used for a rapid estimation by solving simplified governing equations or by using engineering empirical formulas, as done by Wang[3] to calculate the pressure pulse on high-speed trains passing by each other. The pressure waves generated by high-speed trains passing by each other in a tunnel were studied by Mei[4,5] with a one dimensional unsteady compressible non-homentropic flow theory. Train-passing problems were simulated by Herrmanns[6] through solving the Laplace equation governing the potential flow with the boundary element method. Solutions can be obtained rapidly with this kind of methods, but they are always used in a qualitative instead of quantitative nature as an engineering estimation.

The second kind of methods is to solve the whole computational domain, in which the dynamic mesh technique is also used[7-13]. The dynamic mesh technique was used by Tian[10], Bi[11], Clarke[12] and Liu[13] to study train-passing problems by solving the whole computational domain. Commercial software Fluent was used by Clarke in his study. Results from
Liu reveal no big difference between a compressible flow computation and an incompressible flow computation, and the results from an incompressible flow computation are even much closer to those of real vehicle tests. Quantitative results from a complicated flow field are usually obtained by this kind of methods, but they always require a very large computational domain, the real time grid updating and a sophisticated computer hardware.

A rotational symmetric point can be found in the above train-passing problems, and with this point being set as the pole point, the flow field of the whole domain is periodic in the circumferential direction, with the period of $\pi$. Calculations can be performed in one period only, which means that one can consider only a half of the domain in train-passing problems.

The third kind of methods is based on the above analysis, and considers only a half of the computational domain, but uses the dynamic mesh technique at the same time. The problem of trains passing by each other in a tunnel at the same speed was studied by Hwang[14,15], Kozo and Takanobu[16] with this approach. This kind of methods keeps a higher computational efficiency with guaranteed precision as compared to the other two kinds of approaches.

The third kind of methods still suffers from slightly low efficiency due to the use of the dynamic mesh technique, especially when the skewness of the grid is sufficiently big. In the present work, a new method is proposed to improve the computational efficiency in simulating trains passing by each other at the same speed. With this method, the dynamic mesh technique is avoided, while only a half of the computational domain is considered, so a better performance can be achieved. For a good applicability, this method is implemented in UDF language by a secondary development of the commercial software Fluent. In order to save computational time but not to lose the generality of this method, a two-dimensional train is considered in this article. Results from two-dimensional test cases show that reasonable pressure waves and flow fields are obtained, which indicate the high efficiency and accuracy of this method.

2. Governing equations

The computational model under consideration is a two-dimensional incompressible flow. The primary transport variables are the flow velocity $u_i$ and the pressure $P$. They are governed by the conservation equations of mass and momentum:

\[ \frac{\partial u_i}{\partial x_j} = 0 \]  
\[ \frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j} \left( \rho u_i u_j \right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] \]  

3. Numerical algorithms

For incompressible Navier-Stokes equations, a SIMPLEC algorithm is adopted in the present work, with an implicit scheme for temporal discretization.

3.1 Boundary conditions

A basic rotational symmetry exists in the problem of trains passing by each other at the same speed, with the rotational symmetric Point O at the middle of the trains and with the period of $\pi$. As shown in Fig.1, with origin of the inertial coordinate system at Point O, Point A and Point A' are the corresponding points and the flow variables and coordinates of Point A and Point A' will satisfy the following relationships:

\[ x_A + x_{A'} = 0, \ y_A + y_{A'} = 0, \ u_A = -u_{A'}, \ v_A = -v_{A'}, \ P_A = P_{A'} \]  

where $x$, $y$, $U$, $V$, $P$ are $x$ coordinate, $y$ coordinate, the velocity in $x$ direction, the velocity in $y$ direction and the pressure, respectively.

Based on the above relationships, a new boundary condition can be specified to consider only a half of the computational domain. A ghost grid line outside the center line is used in the half-domain simulation. Flow variables on the ghost grid line can be deduced from the variables on the interior grid line based on Eq.(3). Studies were carried out in this...