Spray Drag Effect of Fluidized Sand for a Supersonic Vehicle

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This paper deals with fluidized sand simulation in order to estimate the impact of sand particle motion on the BLOODHOUND SuperSonic Car (SSC) drag forces, such phenomenon is known as a spray drag effect. A gas-particle model is used to simulate the sand particles that rise from the ground because of the strong shockwave-desert surface interaction. A finite volume scheme is used to discretise the continuous model with a special treatment of the solid phase equations. An indefinitely differentiable and anisotropic limiter to reinforce the method stability and reduce any excessive smearing is applied. To estimate the area where sand particles are detached from the ground, a criterion based on pressure change is proposed. The model is first validated on a curved 90^0 bend test case with comparison to experimental results and then applied to the supersonic car.

Keywords: Gas-particle mode, Drag forces, Navier-Stokes equations, finite volume method, HLLC solver.

1. INTRODUCTION

The BLOODHOUND SSC (*Supersonic Car*) Project [1] was publicly announced in October 2008, with the objective of constructing a vehicle to take the World Land Speed Record to 1 000 mph, see figure(1) for an artist's impression of the car. To successfully achieve this feat, many major technological problems have been tackled. The aerodynamic design of the vehicle is one of them, and for this project it is exclusively based on computational fluid dynamic (CFD) simulations. This paper concentrates on one aspect, the study of the sand particle motion and impact with the vehicle on the drag forces (spray drag). As BLOODHOUND SSC travels at supersonic speed, the shockwaves created around the body of the car interact with the surroundings disturbing the desert surface. This causes sand and dust particles to rise up from the ground under the influence of pressure forces and these particles will then be moved up into the air by resistive drag forces. As the particles accelerate, their velocity overtake the velocity of the air resulting in a local air acceleration. Therefore, a critical amount of particles could significantly affect the flow and then create additional resistive forces acting on the car which are not typically accounted for in traditional CFD analysis. A Gas-Particle model (see for instance [2, 3, 6]) is proposed to simulate this phenomenon. In addition to the classical Navier-Stokes equations, a typical continuity equation of particle volume fraction is solved as well as a momentum equation where drag forces and gravity are considered for coupling. The numerical scheme is implemented within the FLITE package (see [4, 5, 11, 33]). This package consists of a Delaunay mesh generator and a cell-centred finite volume flow solver. For the fluid phase, fluxes are estimated using a *Harten-Lax-van Leer-Contact* (HLLC) Riemann solver with a sigmoid-based limiter belonging to C^∞, the space of indefinitely differentiable functions (the derivatives of any order exist and are continuous), for better stability and convergence and with anisotropic action to reduce excessive smoothing. For the solid phase, a centred scheme is used. To stabilize the momentum equation we propose adding artificial viscosity with an orientation control coefficient that allow diffusion mostly in the streamline direction mimicking the *Streamline upwind Petrov-Galerkin* (SUPG) approach. The model is validated against experimental results from a 90^0 curved bend provided in [36]. Finally the model is applied to the BLOODHOUND SSC. To estimate the area where sand particles detach from the ground and entering the calculation domain, a criterion based on pressure change and gravity is proposed and applied to define the boundary condition on the ground for the particles volume fraction variable.

FIG. 1: BLOODHOUND SSC artist's impression

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