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CFD SIMULATION OF THREE-DIMENSIONAL AIRFLOW OVER A VEGETATED SOIL SURFACE

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ABSTRACT

The PAR3D code [1] represents a continuation of work that began with the MAC3D code [2] which was developed for simulating flow and transport in deep water. PAR3D retains the original capabilities of MAC3D, but it also incorporates parallel processing, which reduces CPU time and increases allowable resolution (problem size).

Since water and air can both be regarded as incompressible fluids at flow velocities much less than the speed of sound, PAR3D has been extended to facilitate simulations of air flow and heat transfer over irregular terrain. PAR3D is limited to incompressible flow in particular, which means that the fluid density may be altered slightly by temperature but not by pressure. Variations in density create buoyant forces for which PAR3D employs the Boussinesq approximation. Thus, density variations are neglected in the continuity equation but not in the momentum equation.

The code uses a finite-volume scheme with curvilinear marker-and-cell (MAC) grids to compute the transport of mass and momentum through flow regions of arbitrary shape. The MAC designation indicates that vector components are computed normal to the cell faces, while scalar quantities are computed exclusively at the cell centers. The grids are subdivided into multiple components called grid blocks, and each block is assigned to a single processor. Shared information is communicated between processors via the standard message-passing interface (MPI) library discussed by Gropp et al. [3].

PAR3D uses a time-marching scheme to solve the Reynolds-averaged Navier-Stokes (RANS) equations. A Poisson equation for pressure, obtained by combining the momentum and continuity equations, is solved iteratively during each time-step to supply the pressure gradient needed for conservation of mass. The influence of turbulence is incorporated via the standard $k-\varepsilon$ turbulence model developed by Launder and Spalding [4].

In recent applications [1, 5] PAR3D has been used for the simulation of air flow and aerosol dispersion in complex man-made enclosures. The current application of PAR3D

involves the simulation of air flow over a hypothetical, irregular, vegetated ground surface. The domain of interest is 10 m wide, 10 m long and 2 m deep, discretized on a computational grid with a nominal spacing of 4 cm between grid nodes. The grid itself was divided into 50 blocks, with each block residing on a single processor. The bottom boundary for the grid was generated from topographic data for representative semi-arid terrain.

Stones and other objects were included as impermeable obstacles, and plants were incorporated as semi-permeable regions of the grid. Although the scene is synthetic, the surface shape, surface roughness, and vegetation geometries used were derived from field data collections. Realistic inflow boundary conditions are still under development, but the provisional inflow conditions used for this study include a logarithmic velocity profile with uniform turbulence energy. Constant (but distinct) values of temperature were specified along the inflow and bottom boundaries, respectively. Values for all computed variables were extrapolated from upstream values along the outflow boundary. Using a time-step of 0.05 seconds, steady state was achieved after 10 minutes of simulated time.

Spatially variable wind speeds and air temperatures produced by these simulations will drive surface heat exchange functions within soil and vegetation models. The resulting surface temperatures will feed models that approximate atmospheric and sensor effects on infrared signals. The end product is high-resolution, synthetic, infrared imagery of realistic soil surfaces. Such images permit the exploration of meteorological, hydrological, and geological influences on the performanceof infrared sensors.

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