Aerodynamic interaction between multiple parachute canopies

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Abstract

Simulation of airdrop systems in some cases may involve aerodynamic interactions between parachute canopies. These interactions can occur between two separate parachutes when one system enters into the flow field of the other. They also occur between the canopies of a cluster of parachutes. We present results for the interactions involving two separate round parachutes in close proximity to one another, and study at the affect of the separation distance on the aerodynamic interaction. We also present results for the aerodynamic interactions between the canopies in a cluster of parachutes, where we study the affect of varying the number and arrangement of the canopies.

Keywords: Multiple parachutes; Aerodynamic interaction; Clusters of parachutes; Airdrop systems; Unsteady flow; Parachute collapse

1. Introduction

For certain airdrop systems, and under special scenarios, the behavior of a parachute is influenced by its interaction with another parachute (or multiple parachutes). In this paper, we describe a modeling approach and present results for simulations involving the aerodynamic interaction between multiple parachutes. Here, the interaction is assumed to be purely aerodynamic, with fluid–structure interactions playing no role. We focus on two different types of interactions. First, we focus on the interaction between two separate parachutes that interact when coming within close proximity of one another. Results from multiple simulations are presented for different separations between the two parachutes. Secondly, we focus on the aerodynamic interaction between the canopies in a cluster of parachutes. Interactions for three, four, five, and six parachutes in a cluster are studied. These simulations provide initial results on the aerodynamic interactions for multiple parachutes, but they also serve to demonstrate the utility of these modeling tools for application in airdrop applications.

2. Modeling approach

For the problems presented in this paper, we assume that the parachutes are operating at sufficiently low speeds and, therefore, the aerodynamics is governed by the Navier–Stokes equations of incompressible flows. Also, we only focus on the aerodynamic interactions between multiple parachutes (i.e., no parachute geometry changes are accounted for). Therefore, numerical solutions for the fluid dynamics are obtained using a stabilized semi-discrete finite element formulation [1] with the Streamline-Upwind/Petrov–Galerkin (SUPG) [2] and Pressure-Stabilizing/Petrov–Galerkin (PSPG) [1] stabilizations. These methods have been implemented for parallel computing using the MPI programming environment. The results presented in this paper are for simulations carried out on a CRAY T3E-1200 supercomputer.
3. Numerical examples

For each of the simulations we use tetrahedral meshes. The parachute canopy surface is representative of a US Army C-9 parachute system. For the first example, the parachute in the numerical model consists of the C-9 canopy and a paratrooper. In the second example, the cluster of parachutes consist of multiple C-9 canopies.

Fig. 1 shows, for one of the cases, the interior surfaces and a cutting plane through the mesh (left), the parachute canopy surface mesh (center), and the paratrooper (right).

3.1. Interaction between two parachutes in close proximity to one another

A series of simulations were carried out for the interaction between two separate parachutes (i.e., round canopy and ‘paratrooper’) with horizontal spacings ranging from zero radii (i.e., axially aligned) to 5 radii. Vertical spacings are held at a constant value of approximately one meter between the apex of the lower canopy and the feet of the paratrooper. The simulations predict a strong interaction between the upper and lower parachutes for wake for spacings of 1 radius and less. In these cases, the upper canopy ‘loses its wind’ and experiences negative drag, upon which the canopy would risk collapsing. The flow fields for horizontal spacings of 0.5, 2.0, and 5.0 radii are shown in Fig. 2, with the velocity vectors on the left and the vorticity on the right. This figure indicates a strong interaction between the upper canopy and the lower wake for a horizontal spacing of 0.5 radii, with the upper canopy clearly caught in the wake of the lower canopy. In contrast, very little interaction is seen between the two parachute flow fields for a spacing of 5.0 radii. The intermediate case shows clear interaction between the two parachutes, but without the upper canopy being trapped in the wake of the lower one.

The interaction between two parachutes for various horizontal spacings is further clarified when we look at the aerodynamic forces acting on the individual canopies. Fig. 3 shows the time averaged drag for the lower and upper canopies for spacings ranging from 0.0 to 5.0. The values for the upper canopy drag are fit to a curve using cubic spline and assuming that the curve (a) is symmetric at zero horizontal spacing and (b) approaches a constant value as the horizontal spacing is large. The drag for the lower canopy is plotted simply as discrete data points, but for large horizontal spacings the drag is expected to approach the same value of drag as for the upper parachute. This figure shows that the average drag on the upper parachute can become negative for severe interactions between the parachutes, such as for a spacing of 0.5. In these cases, the parachute would risk collapsing. For the intermediate case (i.e., 2.0 radii), the drag on the upper canopy remains positive. However, in this case there is a clear interaction between the two parachutes which could possibly lead to severe structural responses in the fluid–structure interactions of the upper parachute. For 5.0 radii, minimal interaction is seen in the drag history plots.

3.2. Interaction between the canopies in a cluster of parachutes

A series of simulations were carried out for the interaction between the canopies in a cluster of parachutes for
three to six canopies. Two different canopy arrangements were prescribed for the four- and five-canopy clusters. The computed flow field from these preliminary simulations are shown in Fig. 4, depicting the magnitude of the vorticity in two cutting planes for each configuration. The figure shows the vorticity in the $x = 0$ plane (left) and the $y = 0$ plane (right). The center figure shows the arrangement of the canopies in the cluster, as viewed from $z = -\infty$.

These initial simulations demonstrate the interactions between canopies in different cluster arrangements. Further analysis is needed to better understand the other effects influencing the interactions in clusters, such as the preferred arrangements for the canopies, blockage effects due to the finite computational domain, and ultimately fluid–structure interaction effects.
Fig. 4. Interaction between canopies in a cluster of parachutes: vorticity, $x = 0$ plane; cluster configuration, $y = 0$ plane.
4. Concluding remarks

Numerical simulations have been carried out for the aerodynamic interactions between multiple parachute canopies. Interactions between canopies in two separate parachute systems have shown significant interactions for horizontal spacings of less than two canopy radii, which could possibly lead to canopy collapse. Preliminary simulations for the interactions between the canopies in a clustered parachute system have also been carried out for 3–6 canopies and for a variety of cluster arrangements.

These simulations provide initial results on the aerodynamic interactions for multiple parachutes and demonstrate the utility of the modeling tools for application in airdrop applications. These simulations also provide a better understanding of the interactions between multiple parachute canopies and help identify the scenarios under which the interactions are most severe. In the cases of severe interactions, sophisticated fluid–structure interaction models will be required to accurately represent the response of the parachute structure.

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References