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Three-Dimensional Aerodynamic Simulations of Jumping Paratroopers and Falling Cargo Payloads

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The aim is to develop computational techniques for studying aerodynamic interactions between multiple objects when an object exits and separates from an aircraft. The object could be a paratrooper jumping out of a transport aircraft or a package of emergency aid dropped from a cargo plane. In all these cases, the computational challenge is to predict the dynamic behavior and path of the object, so that the separation process is safe and effective. Here we have correctly modeled a paratrooper jumping from a transport aircraft and an emergency aid package dropped from a cargo plane. Because these phenomena have been realistically modeled, we can now make model design changes to the aircraft geometry that beneficially affect the falling trajectories, preventing problems such as paratrooper crossover as well as locating the fallen payload. Moreover, these multibody techniques can be extended to other problems, such as the hemological flow of human immunodeficiency virus virions.

I. Introduction

PARATROOPERS jump from a variety of different aircraft weighted with different supplies depending on the mission and experiencing an array of weather conditions. These meteorological conditions, the shape and size of the aircraft, and turbulence caused by nearby aircraft affect the free fall path of the paratrooper.

The U.S. Army has experienced a myriad of problems associated with this situation. Two examples are crossover and wake crossing. With a specific U.S. Air Force aircraft, the U.S. Army has had difficulties whenever paratroopers jump out of both the left and the right doors simultaneously: their paths tend to cross (crossover). This is, of course, potentially injurious. As paratroopers jump out of multiple U.S. Air Force aircraft, they must fall through the wake of the preceding aircraft (wake crossing). If the wake has not experienced sufficient dissipation, casualties could occur due to the difficulty in pulling parachute chords in such turbulent wake.

Obvious solutions include alternating left- and right-door paratrooper jumps and flying all aircraft very far apart. However, the U.S. Army has highly time-sensitive missions during which they need to exit all paratroopers in as short a time as possible using as little air space as possible. Therefore, they prefer to have paratroopers jumping simultaneously and want to know the safest closest distance these aircraft can be flown to avoid wake-crossing casualties.

Cargo drops also present a problem. Often, the U.S. Army may want to make a supply drop to an operative in another country. Alternatively, they want to drop off a shipment to a group of soldiers. In those cases, the U.S. Army wants to be able to pinpoint the location of a drop within a certain radius, so that it can be easily and quickly found. For that reason, cargo drops are also of interest. Some drops use an exit parachute to extract the payload from the cargo bay. Other cargo payloads slide out on frictionless tracks only with the help of gravity. The ability to predict the trajectory of a certain payload and its final target can significantly expedite many operations.

Wind-tunnel experiments can be even more inflexible when dealing with paratrooper jumps. How does one realistically model a falling paratrooper in a wind tunnel? Moreover, experimental data from actual jumps are also hard to obtain. The limitations of experimental research in this area are clear. First, the costs can be prohibitive. These include labor, soldier hours, pilot hours, fuel, aircraft rental, airfield rental, etc. Second, the time can be restrictive. One test jump can be planned for over an entire year. The amount of personnel needed creates inconvenience. Numerical modeling solves all of these problems. It is much cheaper, expends less time for the same experiment, and is more convenient, requiring less people (feasibly one).

Here, we explore simulation and modeling techniques for aerodynamic fluid–object interactions (FOI) between multiple objects. All objects will be treated as rigid bodies. The specific applications of jumping paratroopers and falling cargo payloads from cargo aircraft will be emphasized.

The computational tools developed here are based upon the simultaneous solution of the 3-D time-dependent Navier–Stokes equations governing the incompressible airflow around the aircraft and the separating object, as well as the equations governing the motion of that object. These computational methods include suitable mesh update techniques to be used in conjunction with the deforming spatial domain/stabilized space–time (DSD/SST) formulation [1].

Previously, techniques such as arbitrary Lagrangian–Eulerian formulation were used for moving problems with both finite difference modeling, finite volume modeling [2–5], and finite element modeling [6–9]. Because the relative positions of the aircraft and the separating object are changing in time, the DSD/SST formulation is written over the corresponding space–time domain of the problem and can therefore automatically handle the changes in the spatial domain. This method has been tested on many problems [10–12].

The computations presented use mesh stiffening tactics, remeshing techniques, and projection methods that work well for such a large-scale problem with arbitrary geometries [13]. However, many still have looked to developing alternatives to mesh moving. The fluid–object interaction subcomputation technique (FOIST) is such an alternative [1]. In this paper, we apply it to our problem to determine how well it can approximate the trajectories we seek. A 3-D slip approximation for arbitrary surfaces is applied here as well [1]. Again, the goal is the same.

For now, in this work, we commence with the governing equations for fluid flow. The fluid flow is governed by the Navier–Stokes equations for incompressible flow. Section II is a presentation of those equations with the constitutive relations and the boundary and initial conditions. Instead of directly resolving the turbulent flow features present at the Reynolds numbers of the problems presented in this research, turbulence affects are accounted for by using a zero-equation Smagorinsky turbulence model [14].

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