Computer Modeling and Analysis of the Orion Spacecraft Parachutes

K. Takizawa, C. Moorman, S. Wright, and T.E. Tezduyar

Abstract We focus on fluid-structure interaction (FSI) modeling of the ringsail parachutes to be used with the Orion spacecraft. The geometric porosity of the ringsail parachutes with ring gaps and sail slits is one of the major computational challenges involved in FSI modeling. We address the computational challenges with the latest techniques developed by the Team for Advanced Flow Simulation and Modeling (T★AFSM) in conjunction with the Stabilized Space–Time Fluid–Structure Interaction (SSTFSI) technique. We investigate the performance of the three possible design configurations of the parachute canopy, carry out parametric studies on using an over-inflation control line (OICL) intended for enhancing the parachute performance, discuss rotational periodicity techniques for improving the geometric-porosity modeling and for computing good starting conditions for parachute clusters, and report results from preliminary FSI computations for parachute clusters. We also present a stability and accuracy analysis for the Deforming-Spatial-Domain/Stabilized Space–Time (DSD/SST) formulation, which is the core numerical technology of the SSTFSI technique.

1 Introduction

Various types of fluid–structure interaction (FSI) problems have been addressed and numerous FSI solution techniques have been developed in recent decades (see, for example, [2–11, 15, 17–33, 35, 38, 40, 42–45, 50, 54–57, 59–64, 66–78]). The Team for Advanced Flow Simulation and Modeling (T★AFSM) has addressed many of the challenges involved in FSI modeling of parachutes (see [20,35–37,39,41,45,57–59, 61,66]), with parallel, 3D computations going as far back as 2000. The core technology used in all this FSI modeling is the the Deforming-Spatial-Domain/Stabilized Space–Time (DSD/SST) formulation [46, 47, 51, 52], which was introduced as a
general-purpose interface-tracking (moving-mesh) technique for flows with moving boundaries and interfaces, including FSI. In early years of parachute modeling by the T★AFSM, a block-iterative FSI coupling technique [48] (see [54, 57] for the terminology) was used (see, for example, [20, 35, 36, 45]). The quasi-direct FSI coupling technique was introduced in [56, 57] and became part of the core technology used in the subsequent parachute FSI simulations of the T★AFSM (see, for example, [49, 57, 61, 62]). The stabilized space–time FSI (SSTFSI) technique was introduced in [54]. It is based on the new-generation DSD/SST formulations, which were also introduced in [54], increasing the scope and performance of the space–time FSI techniques developed earlier. The SSTFSI technique is now the core technology used in the parachute FSI computations of the T★AFSM (see, for example, [54, 58, 59]). A number of special FSI techniques were introduced in [54, 59] in conjunction with the SSTFSI technique and the DSD/SST formulation, including the the Homogenized Modeling of Geometric Porosity (HMGP). With the HMGP, we bypass the intractable complexities of the geometric porosity by approximating it with an “equivalent”, locally-varying fabric porosity.

The HMGP and some of the other special FSI techniques were motivated by the task the T★AFSM has undertaken: computer modeling and analysis of the ringsail parachutes to be used with the Orion spacecraft. In this paper we focus on the performance analysis of those parachutes, comparison of different canopy design configurations, parametric studies on using an over-inflation control line (OICL) considered for enhancing the parachute performance, and modeling of parachute clusters. We also describe the FSI technique we have introduced for more effective parachute modeling and analysis, such as techniques for building a consistent starting condition for the FSI computations and rotational-periodicity techniques for improving the HMGP and for computing good starting conditions for parachute clusters. We include a stability and accuracy analysis for the DSD/SST formulation.

2 Starting Condition

A consistent starting condition is essential for making accurate comparisons in many applications using FSI modeling. Starting conditions are especially important when investigating the transient response. A number of techniques for building FSI starting conditions are reported in [58, 66]. These techniques mostly focus on starting the FSI computations gently. The purpose of further influencing the starting condition with the methods introduced here is primarily related to making the starting conditions consistent and matching the physical conditions observed during NASA drop tests. To build an appropriate starting point for comparing performance of various parachute designs, we first analyzed the parachute drop test data and compared the test results to our earlier computations [66]. Based on this, we concluded that a fully inflated parachute with all sails behaves as follows: the parachute exhibits a periodic breathing motion caused by vortex shedding, and this dynamic nature results in a fluctuating descent speed. Furthermore, during drop tests for a given