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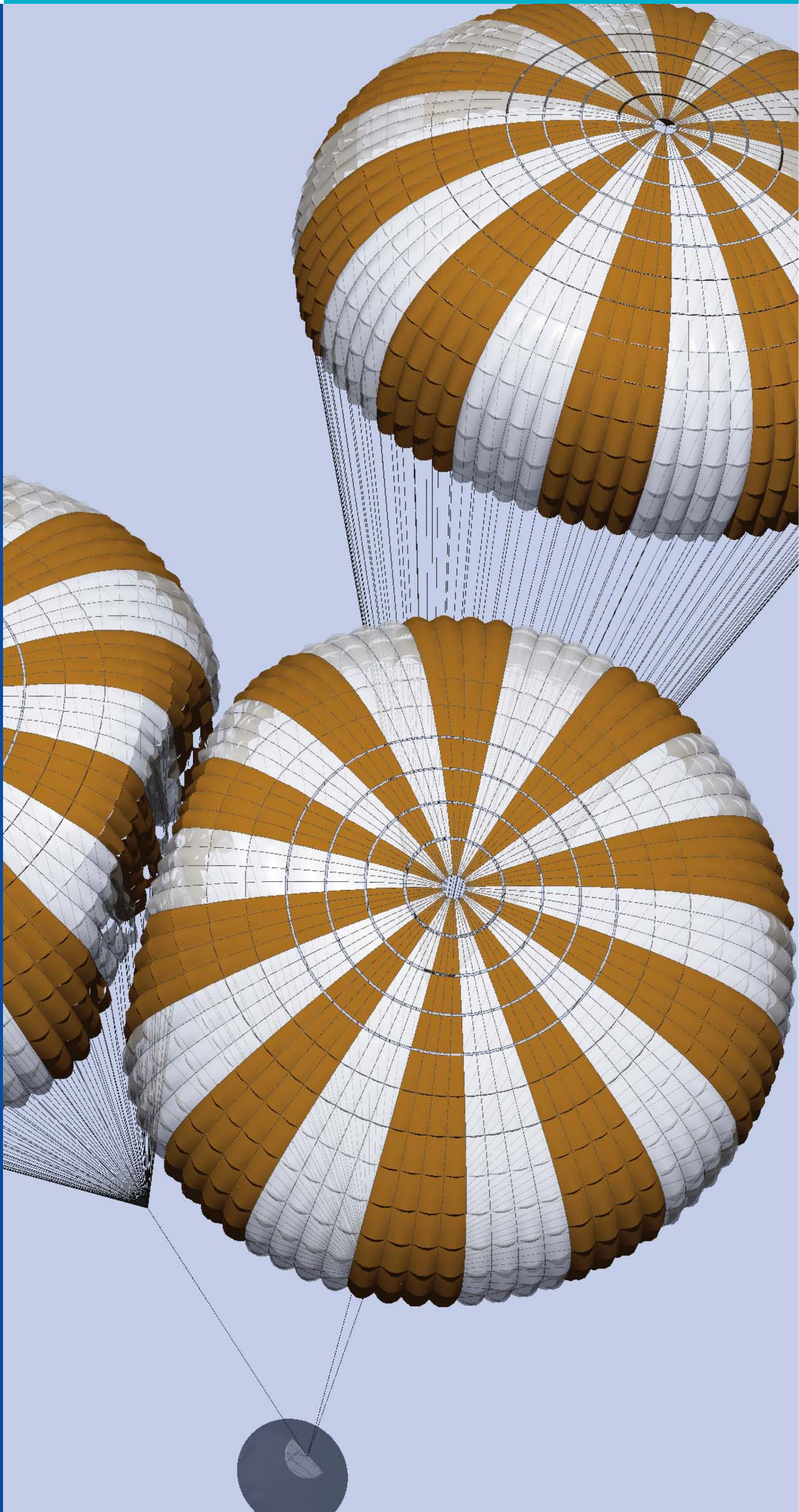

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FSI Modeling of Spacecraft Parachutes

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Computer modeling of parachutes involves all the numerical challenges of fluid–structure interaction (FSI). The aerodynamics of the parachute depends on the canopy shape and the deformation of the canopy depends on the aero-dynamics forces, and the two systems need to be solved in a coupled fashion. Because the parachute FSI is in a category where the structure is light (compared to the air masses involved in the parachute dynamics) and very sensitive to changes in the aerodynamics forces, the coupling technique, which determines how the coupling between the equation blocks representing the fluid, structure, and mesh moving is handled, requires extra care.

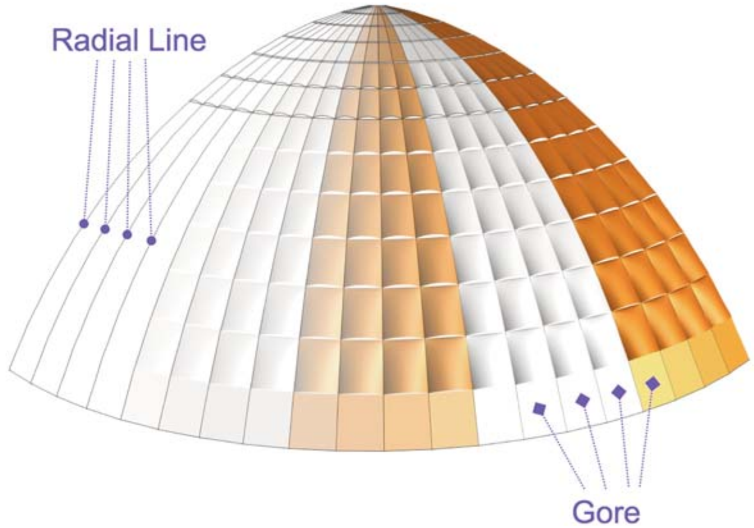


Figure 1: *Parachute radial lines and gores*

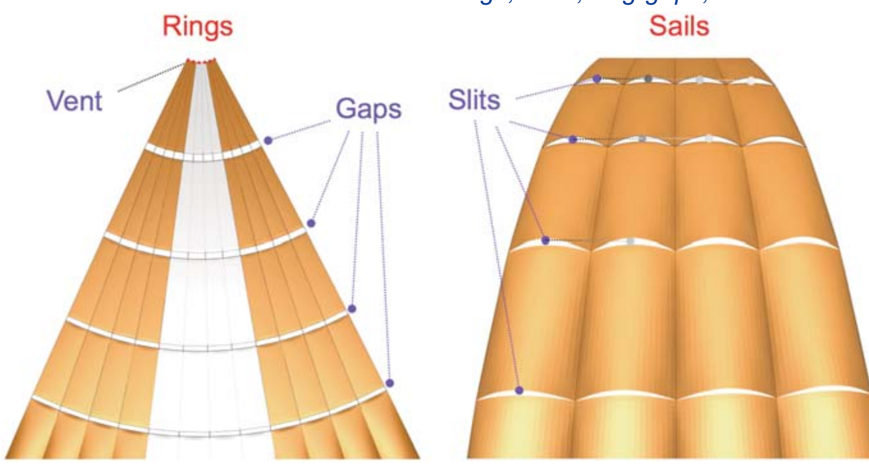


Figure 2: *Rings, sails, ring gaps, and sail slits*

Spacecraft parachutes are typically very large ringsail parachutes that are made of a large number of gores, where a gore is the slice of the canopy between two radial reinforcement cables running from the parachute vent to the skirt (see *Figure 1*). Ringsail parachute gores are constructed from rings and sails, resulting in a parachute canopy with hundreds of ring gaps and sail slits (see *Figure 2*). The complexity created by this geometric porosity makes FSI modeling inherently challenging.

Spacecraft parachutes are typically used in clusters of two or three parachutes (see *Figure 3*), and the contact between the parachutes is a major challenge specific to FSI modeling of parachute clusters.

The core technology used in the parachute FSI computations of the Team for Advanced Flow Simulation and Modeling (T★AFSM) <www.tafsm.org> <www.jp.tafsm.org> is the Stabilized Space–Time FSI technique [1].
The T★AFSM parachute FSI computations started as early as 1997 with axisymmetric computations and goes as far back as 2000 for 3D computations. In the early years of parachute modeling with the space–time FSI technique, the coupling technique was block-iterative (see [1, 2] for the terminology), and later a more robust version of that, which significantly increased the coupling stability (see [2]). In 2004 and later, the space–time FSI computations were based on the quasi-direct coupling and direct coupling techniques [1, 2], which yield significantly more robust algorithms for FSI computations where the structure is light. These techniques are for the general case of nonmatching fluid and structure meshes at the interface, which is what we prefer in parachute computations, but reduce to monolithic techniques when the meshes are matching. Today, the quasi-direct coupling is the favored coupling tech-nique in the FSI computations of the T★AFSM.

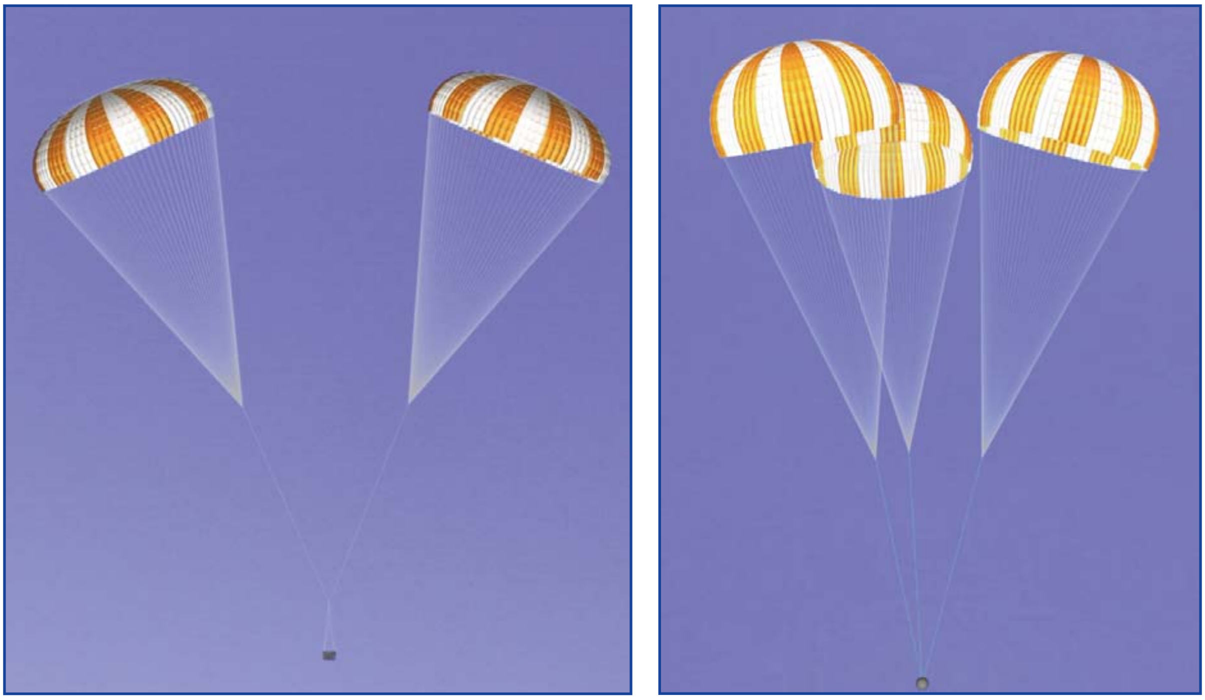


Figure 3:
Clusters of two and three parachutes

The Homogenized Modeling of Geometric Porosity (HMGP) was introduced in [3], and its new version, "HMGP-FG," was introduced in [4]. The HMGP helps us bypass the intractable complexities of the geometric porosity by approximating it with an equivalent, locally varying homogenized porosity, which is obtained from an HMGP computation with an n-gore slice of the parachute canopy. *Figures 4 and 5* summarize the HMGP-FG. For details, see [3, 4]. Even in the fully open configuration, the parachute canopy goes through a periodic breathing motion where the diameter varies between its minimum and maximum values. The shapes and areas of the gaps and slits vary significantly during this breathing motion (see *Figure 6*). It was shown in [5] that the porosity coefficients have very good invariance properties with respect to these shape and area changes.

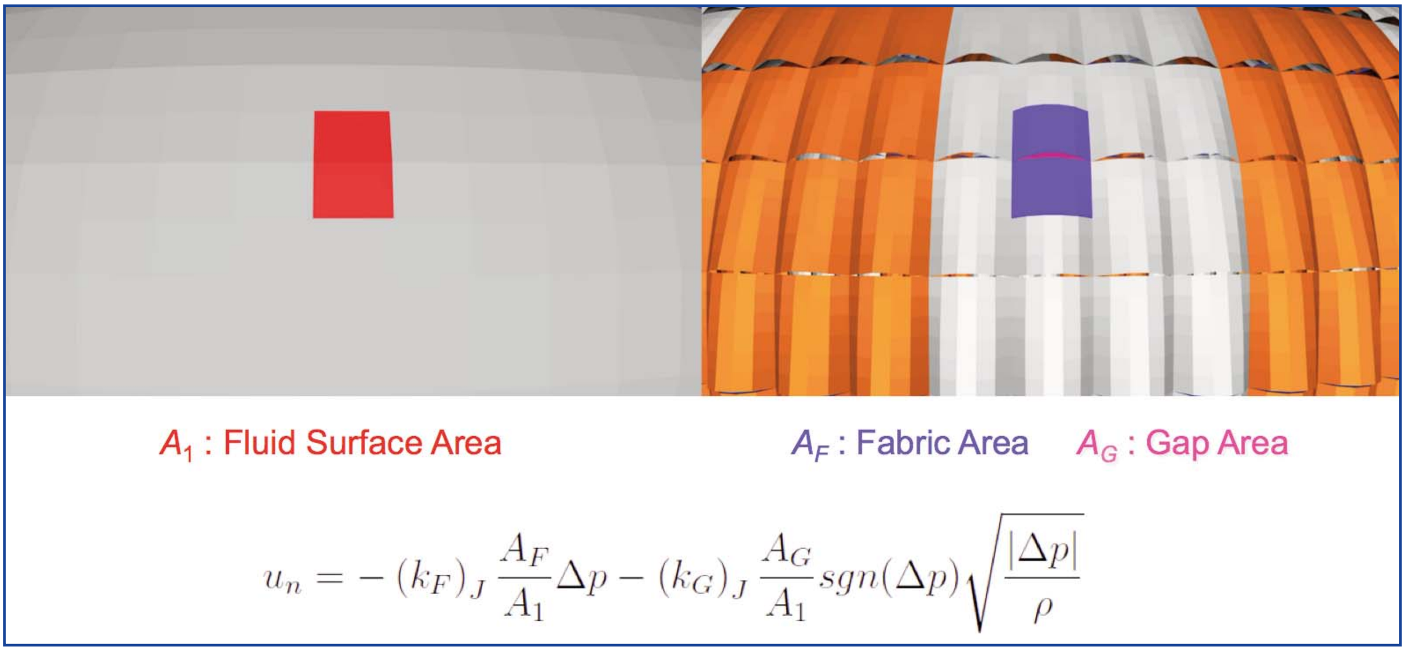
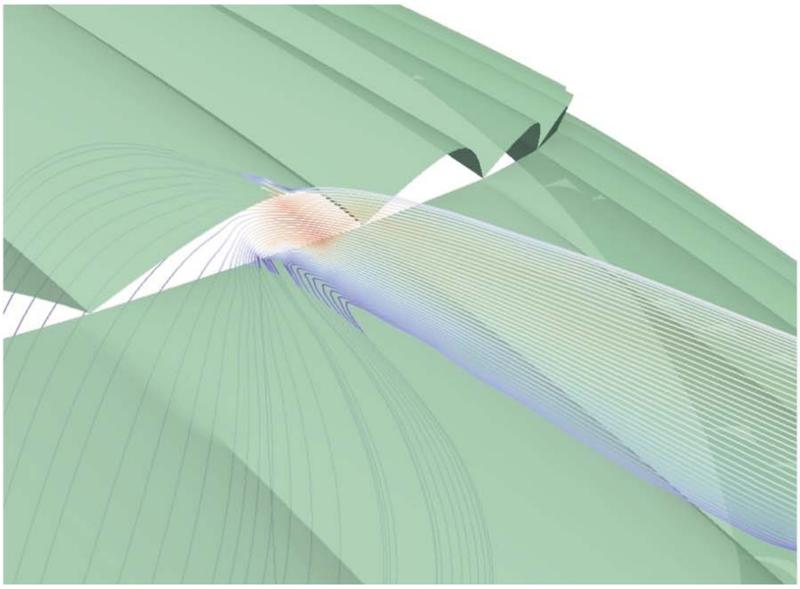


Figure 4:
In the HMGP-FG, the normal velocity crossing the parachute canopy under a pressure differential $\triangle p$ is modeled by using two homogenized porosity coefficients $(k_F)_J$ and $(k_G)_J$. For details, see [3, 4]



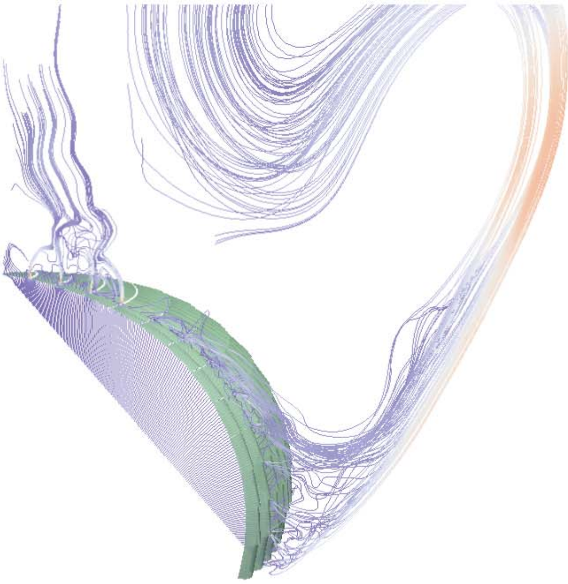


Figure 5:
The two porosity coefficients are calculated from a one-time fluid mechanics only computation with an n-gore slice of the parachute canopy, where the flow through all the gaps and slits is resolved

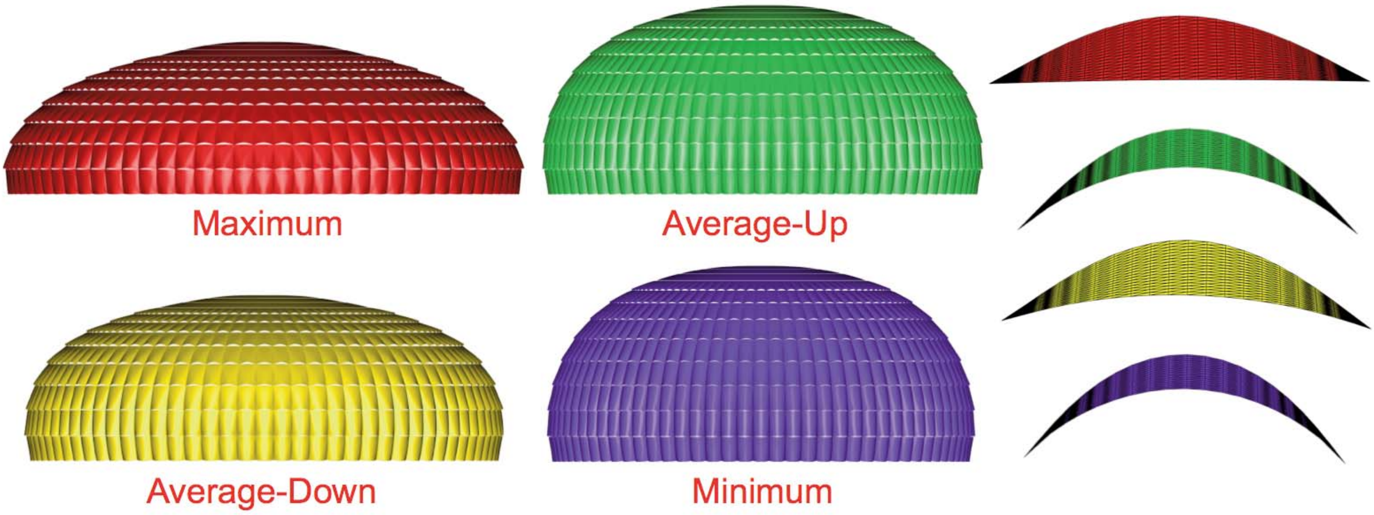


Figure 6:
The shapes and the areas of the slits vary significantly during the canopy breathing motion

	Descent Speed (ft/s)	Relative Horizontal Speed (ft/s)	Breathing Period (s)	Swinging Period (s)
Test Data	<10% Diff	Comparable	<10% Diff	<10% Diff
Computation	21.4	4 to 13	6.7	16.4

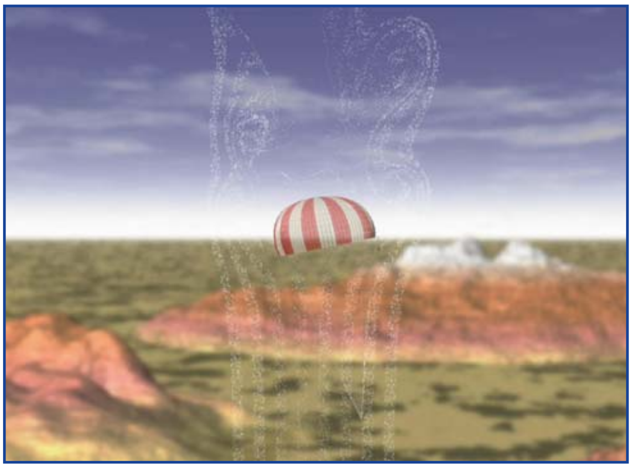


Figure 7:
Parachute and flow field at an instant during the computation and the comparison with the test data

Comparing our computed results to data from drop tests with a base parachute design helps us gain confidence in our parachute FSI model. *Figure 7* shows the parachute shape and flow field at an instant during the computation and the comparison with the test data.

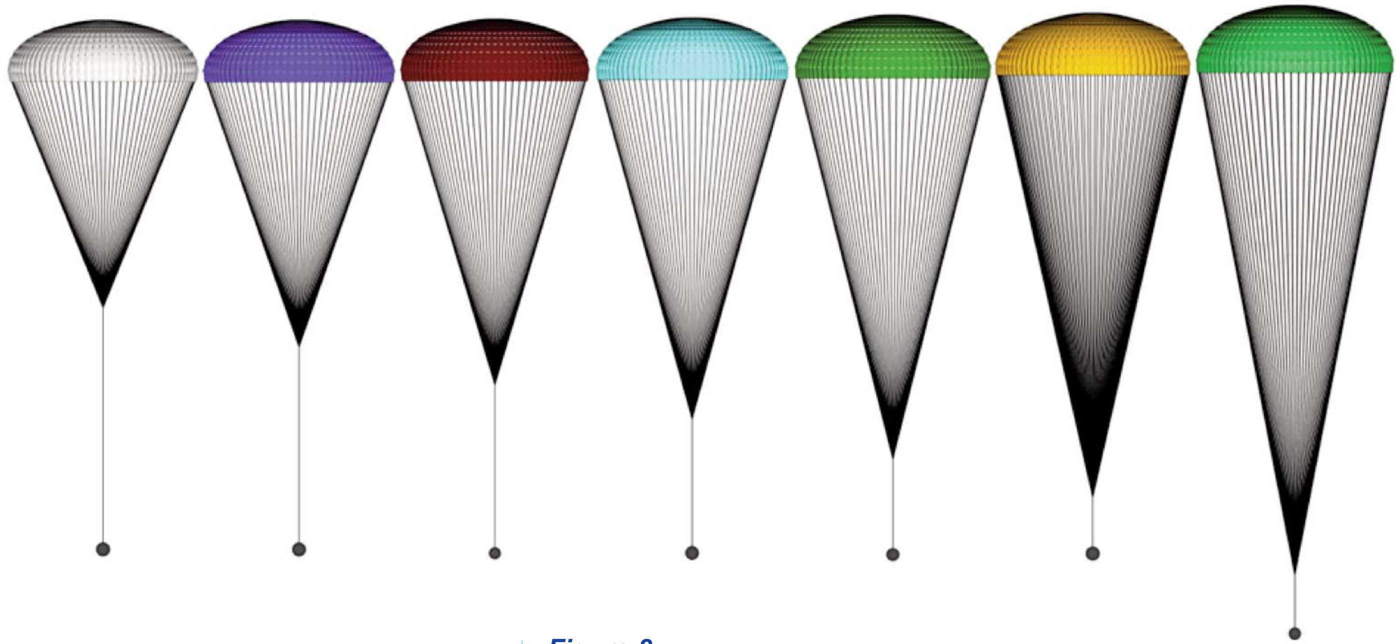


Figure 8:
A simulation-based parachute design study, where the objective is to evaluate the aerodynamic performance of the parachute as a function of the suspension line length. See [6] for details of the study

With confidence gained from comparing our results with test data, we can carry out simulation-based parachute design studies [4, 6], such as evaluating the aerodynamic performance of the parachute as a function of the suspension line length (see *Figure 8*) or in response to removing one of the sails of the canopy (see *Figure 9*).

Figure 9:
A simulation-based parachute design study, where the objective is to evaluate the aerodynamic performance of the parachute in response to removing the 5th sail. The virtual smoke shows the vortex patterns in the parachute wake. See [4] for details of the study

The contact between the canopies of a spacecraft parachute cluster is a computational challenge that we have addressed recently (see [7, 8]) with a contact algorithm where the objective is to prevent the structural surfaces from coming closer than a minimum distance. The Surface-Edge-Node Contact Tracking technique was introduced in [1] for this purpose, in [7, 8] evolved into a conservative version that is more robust, and is now an essential technology in the parachute cluster computations we carry out. *Figure 10* shows a cluster of two parachutes at an instant during the FSI computation when the parachutes are in contact, and *Figure 11* shows a cluster of three parachutes at three different instants during the FSI computation, with contact between two of the parachutes. See [7, 8] for details.

This article shows that parachute FSI modeling can contribute valuable information and analysis to the spacecraft parachute design process, and in particular the parachute cluster computations show that spacecraft parachute modeling can now be done under actual conditions.

A comprehensive review of the core and special space–time FSI techniques used in spacecraft parachute modeling can be found in [9]. The readers can also find material on this subject, and some movies, at our Web sites <www.tafsm.org> <www.jp.tafsm.org>.

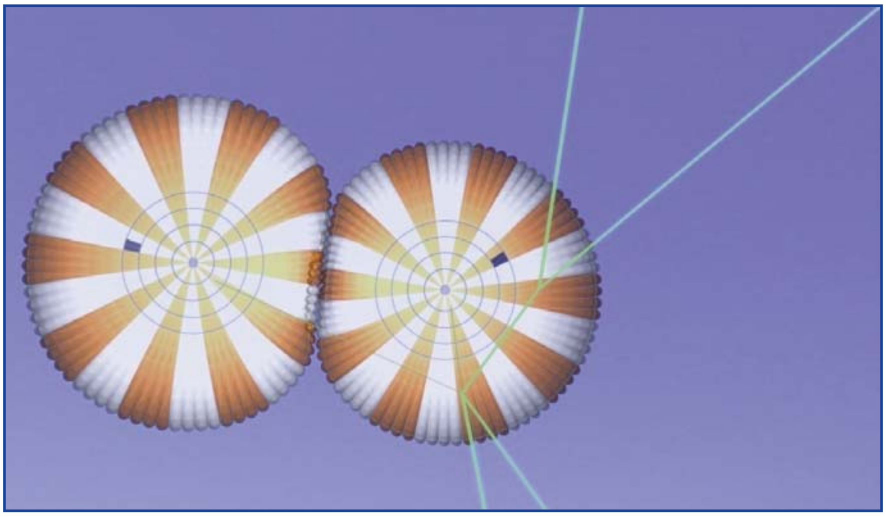


Figure 10:
A cluster of two parachutes at an instant during the FSI computation. See [7, 8] for details

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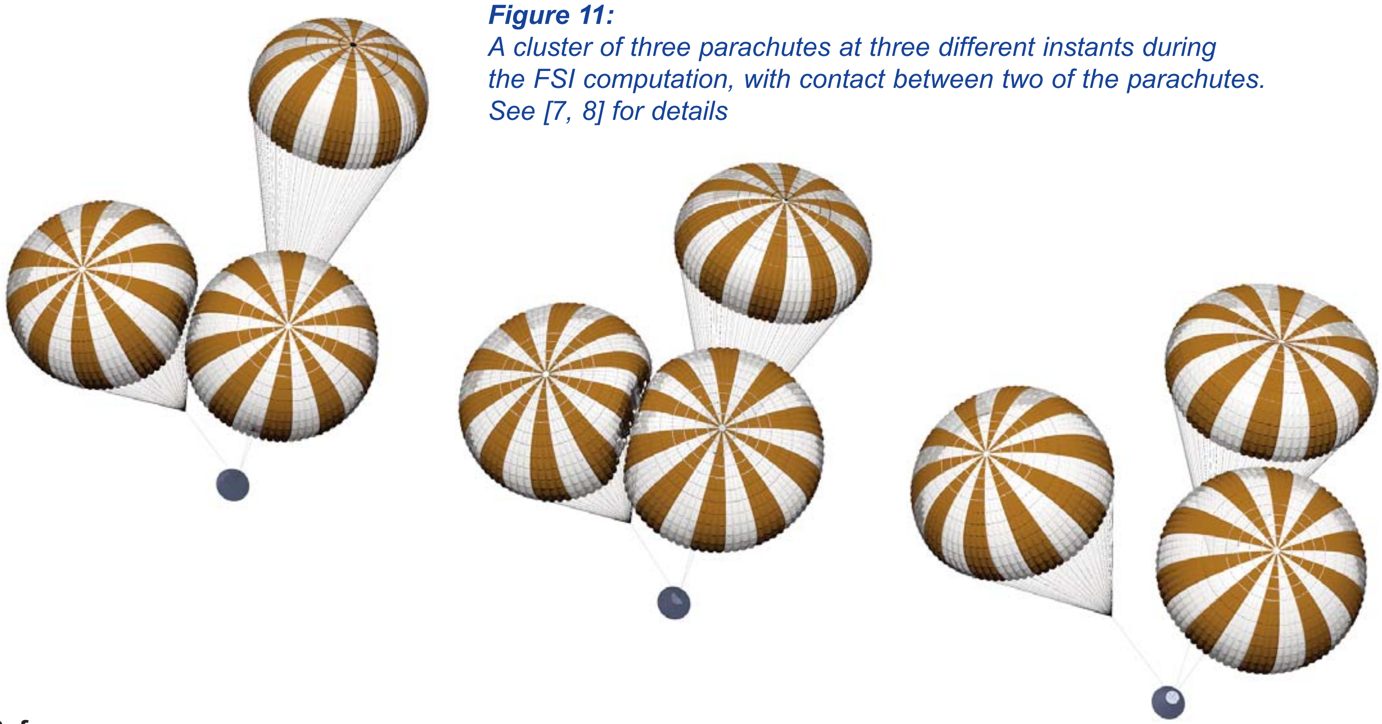

Figure 11:
A cluster of three parachutes at three different instants during the FSI computation, with contact between two of the parachutes. See [7, 8] for details

References

[1] *T.E. Tezduyar and S. Sathe*, **Modeling of Fluid-Structure Interactions with the Space-Time Finite Elements: Solution Techniques**, International Journal for Numerical Methods in Fluids, 54 (2007) 855-900.

[2] *T.E. Tezduyar, S. Sathe, R. Keedy and K. Stein*, **Space-Time Finite Element Techniques for Computation of Fluid-Structure Interactions**, Computer Methods in Applied Mechanics and Engineering, 195 (2006) 2002-2027.

[3] *T.E. Tezduyar, S. Sathe, J. Pausewang, M. Schwaab, J. Christopher and J. Crabtree*, **Interface Projection Techniques for Fluid-Structure Interaction Modeling with Moving-Mesh Methods**, Computational Mechanics, 43 (2008) 39-49.

[4] *K. Takizawa, C. Moorman, S. Wright, T. Spielman and T.E. Tezduyar*, **Fluid-Structure Interaction Modeling and Performance Analysis of the Orion Spacecraft Parachutes**, International Journal for Numerical Methods in Fluids, 65 (2011) 271-285.

[5] *T.E. Tezduyar, K. Takizawa and S. Wright*, **Fluid-Structure Interaction Modeling of Spacecraft Parachutes**, Extended Abstracts of the 61st National Congress of Theoretical and Applied Mechanics, Tokyo, Japan, 2012.

[6] *K. Takizawa, T. Spielman, C. Moorman and T.E. Tezduyar*, **Fluid-Structure Interaction Modeling of Spacecraft Parachutes for Simulation-Based Design**, Journal of Applied Mechanics, 79, 010907 (2012).

[7] *K. Takizawa, S. Wright, C. Moorman and T.E. Tezduyar*, **Fluid-Structure Interaction Modeling of Parachute Clusters**, International Journal for Numerical Methods in Fluids, 65 (2011) 286-307.

[8] *K. Takizawa, T. Spielman and T.E. Tezduyar*, **Space-Time FSI Modeling and Dynamical Analysis of Spacecraft Parachutes and Parachute Clusters**, Computational Mechanics, 48 (2011) 345-364.

[9] *K. Takizawa and T.E. Tezduyar*, **Computational Methods for Parachute Fluid-Structure Interactions**, Archives of Computational Methods in Engineering, 19 (2012) 125-169.