Mars Science Laboratory Parachute Modeling and Simulation

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Introduction

The Mars Science Laboratory (MSL) is an ambitious mission that will land a 2,000 lbm rover on the surface of Mars in the fall of 2012. MSL will use a 4.5 m aeroshell and a 21.35m reference diameter (D_o) disk-gap-band (DGB) parachute, both the largest ever flown. The parachute is mortar deployed on a velocity trigger at Mach 2.2 and is designed to survive a peak load of 65,000 lbf. The original structural design load case allowed for the possibility that the peak load could be channeled into a single bridle leg, but this was later deemed overly conservative, thus requiring this new loads analysis.

Viking-type DGB parachutes are known to undergo large-scale area oscillations at Mach numbers higher than 1.5 [1]. These area oscillations are typically characterized by a rapid deflation, then re-inflation, and can result in a parachute load which is as large, or larger, than the initial opening load. Multiple load oscillations could occur during MSLs deceleration to Mach 1.5. These large changes in parachute loading can couple with the "wrist mode" of the MSL entry body where, as the two bodies descend, the entry body rotates about its center of mass. If the lander were to rotate to a large relative angle to the chute during a deflation event, the lander would experience a large, off-axis load on re-inflation, knowledge of which is critical to the design of the primary structure.

System Modeling

In order to develop the new load cases, an area oscillation model was developed for incorporation into a 4 degree-of-freedom (DOF) Matlab simulation, illustrated in Figure 1. The three rotational degrees of freedom are modeled, but only the velocity direction is modeled in translation. Relative motion of the body to the chute is calculated using a nonlinear triple-bridle model where the bridle loads are calculated as if they were rigid members of a truss. However, as the bridles may only transmit tension, any members in compression are slack and carry no load. The truss solution is then recalculated with only the remaining tension members; up to two bridles may be slack at any time.

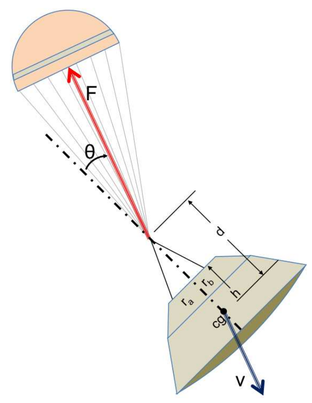

Figure 1: Simulated system model

Viking Parachute Test Data

During the Viking supersonic parachute development, atmospheric test flights were conducted to characterize the supersonic behavior of DGB parachutes. The data from these tests were used to drive the development of the area profile generator, in particular, BLDT AV-4, which was a 16.1 m DGB, deployed at Mach 2.13 [1]. The data taken from the BLDT AV-4 report [1] and provided in Figure 2 shows the total parachute force with obvious dropouts and overinflations.

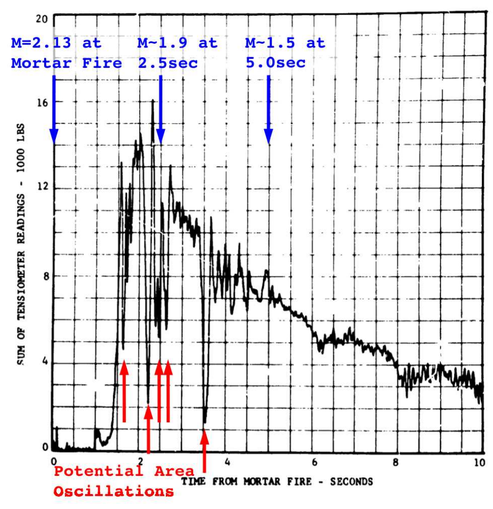

Figure 2: Total Parachute Force: BLDT AV-4

Area Oscillation Model

A randomized generator was used to drive the parachute force model due to the unpredictability of area oscillations, but rules are imposed on the generator such that it creates profiles that are in family with the BLDT parachute force data. Prior to the addition of area oscillations, the simulation uses a Pflanz inflation force profile [2] up to the point of peak inflation, which is always the design load of 65,000 lbf.

A profile is created by stringing together a random number of events (parabolic deflation/inflation pairs) or "wait" periods. A "wait" is simply a period of time, which is given by a uniform distribution, in which there is no event and the parachute force is simply given by qC_DA, with some high frequency noise. One event is always added after initial peak inflation. Subsequent to this, sections are added to the profile which are equally likely to be either wait periods or any additional events, until either the Mach cutoff of $M = 1.5$ has been reached or all events have taken place. Three event magnitude regimes (high, mid, low) were implemented to provide various levels of stress on the system. Governing parameters for the generator and examples are displayed in Figure 3.

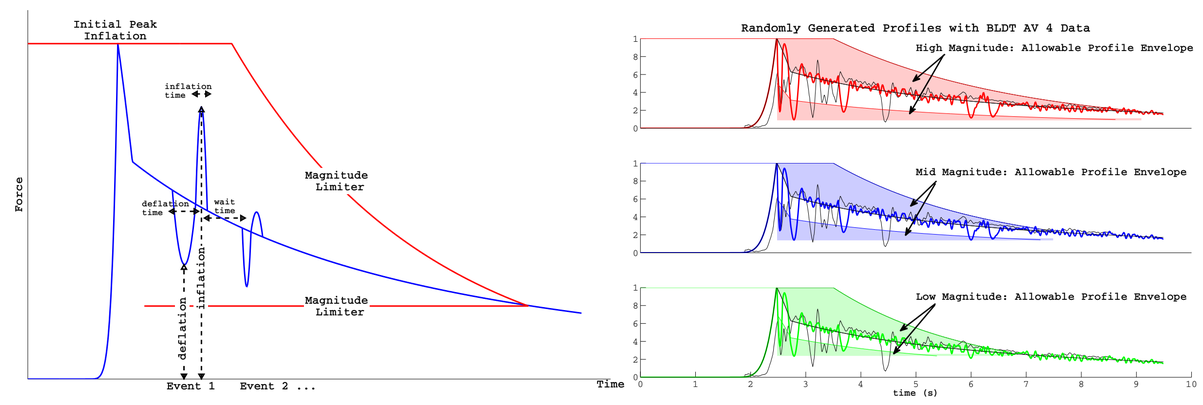

Figure 3: Event Schematic and Example Profiles

Simulation Results

In order to address the sensitivity of the system to the magnitude regimes and the initial attitude at mortar fire, a Monte Carlo simulation consisting of 5000 cases was run at each area oscillation magnitude level. The initial attitude of the entry body was uniformly distributed between $\pm 5°$ relative to the velocity vector to match mission requirements on attitude at mortar fire.

Based on the BLDT AV-4 profile, the low envelope was chosen as the most credible parachute area profile. In order to create new load cases, a bi-linear bound was placed on the low magnitude curve represented by the green lines in Figure 4. In addition, 50% was added to the angle specification in order to carry margin in the loads cases due to the relative uncertainty in the load prediction. These three points (the bounding curve shown in red) represent the new parachute load case.

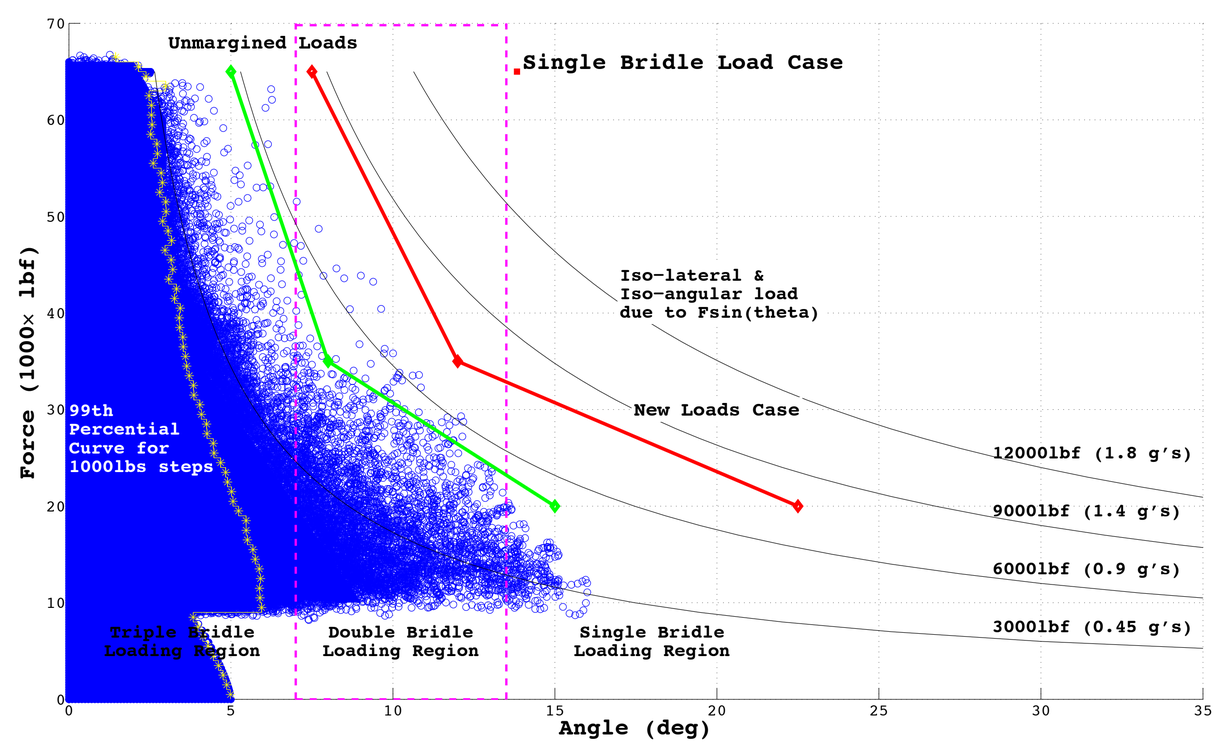

Figure 4: Monte Carlo Simulation Results

Conclusions

The new design loads were shown through simulation to bound the expected dynamics due to supersonic area oscillations. As this load case provides adequate margin suitable for design of the MSL vehicle interfaces and primary structure, these loads have been adopted by the MSL project for vehicle design. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References

[1] Dickinson, D., et al., Balloon Launched Decelerator Test Program, Post-Test Test Report, BLDT Vehicle AV-4, *NASA-CR-112179*, October 20, 1972.

[2] Knacke, T.W., *Parachute Recovery Systems Design Manual*, Para Publishing, Santa Barbara, California, 1992.