Low Density Supersonic Decelerator Parachute Decelerator System

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The Low Density Supersonic Decelerator Project has undertaken the task of developing and testing a large supersonic ringsail parachute. The parachute under development is intended to provide mission planners more options for parachutes larger than the Mars Science Laboratory's 21.5m parachute. During its development, this new parachute will be taken through a series of tests in order to bring the parachute to a TRL-6 readiness level and make the technology available for future Mars missions. This effort is primarily focused on two tests, a subsonic structural verification test done at sea level atmospheric conditions and a supersonic flight behind a blunt body in low-density atmospheric conditions. The preferred method of deploying a parachute behind a decelerating blunt body robotic spacecraft in a supersonic flow-field is via mortar deployment. Due to the configuration constraints in the design of the test vehicle used in the supersonic testing it is not possible to perform a mortar deployment. As a result of this limitation an alternative deployment process using a ballute as a pilot is being developed. The intent in this alternate approach is to preserve the requisite features of a mortar deployment during canopy extraction in a supersonic flow. Doing so will allow future Mars missions to either choose to mortar deploy or pilot deploy the parachute that is being developed.

Nomenclature

C_X	=	opening load factor
d	=	test vehicle diameter
D_O	=	parachute nominal diameter
DGB	=	disk-gap-band
LDSD	=	Low Density Supersonic Decelerator
MER	=	Mars Exploration Rover
MSL	=	Mars Science Laboratory
NFAC	=	National Full-Scale Aerodynamics Complex
SPTT	=	Mars Subsonic Parachute Technology Task
SSRS	=	supersonic ringsail
PDD	=	Parachute Deployment Device
PDS	=	Parachute Decelerator System
TPS	=	Thermal Protection System
TRL	=	Technology Readiness Level
V&V	=	verification and validation
x	=	distance behind the maximum diameter of the test vehicle

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I. Introduction

THE Low Density Supersonic Decelerator (LDSD) project has undertaken the task of developing a large Supersonic Ringsail (SSRS) parachute to provide improved capabilities for future Mars landed missions. The need for a new parachute system was identified by NASA to support an increase in payload mass, to target higher altitude landing sites, and to improve landing accuracy. As Mars bound spacecraft continue to get larger and the possibility of future manned missions arises the state of the art in low density supersonic parachutes must also advance. To date, all seven of the successful Mars landings have employed disk-gap-band (DGB) parachutes, which were based on a design that was developed in the 1960's and 1970's for the Viking Mars mission.

The post Viking missions have utilized either geometrically scaled Viking DGB parachutes or Viking derived DGB parachutes, as the design had demonstrated suitable flight characteristics at supersonic conditions that were difficult and expensive to duplicate in test, thus the costs of additional qualification could be avoided. Further, the DGB performance was adequate for the missions that were being flown and additional capability was not necessary. However, the Mars Science Laboratory (MSL) mission pushed the limits of this qualification in growing the size of the DGB to a nominal diameter (D_O) of 21.35 m. For comparision, the Viking parachute of 16.15 m D_O was the largest parachute previously flown on Mars. In fact, the MSL parachute was the largest DGB ever deployed with the second largest being 19.7 m, which was flown as part of the Planetary Entry Parachute Program[1].

While the success of the MSL parachute expands the DGB flight proven size envelope it still falls short of the necessary drag performance expected to be required by future missions. To increase the parachute diameter further requires a new parachute qualification and, to that end, the LDSD project is in the process of developing and flight-testing a planned 33.5 m D_O modified ringsail parachute. This parachute will go through a series of verification and validation (V&V) tests to bring it to Technology Readiness Level (TRL) 6. These tests include scaled parachute testing to provide comparative evaluation between different design features, structural verification utilizing a rocket-powered sled test, and high altitude supersonic flight-tests to demonstrate inflation and aerodynamic performance. At the conclusion of these activities the new parachute system will be advanced to the point where it will be suitable for use in future flight missions.

II. Selection of the Ringsail Parachute and Configuration

The LDSD performed a trade study to determine the class of parachute most appropriate for a large Mars entry systems application. This trade study considered a variety of supersonic parachutes. At the end of this trade two classes were determined as possible candidates, the DGB and the ringsail. The following five factors were the final considerations that led to the selection of the ringsail over the DGB.

1) Improved specific drag performance: The ability to fly a smaller lighter parachute to produce the same drag as a DGB has multiple benefits from improved opening reliability to simply less mass.

2) Inflation reliability: This is thought to be due to the multiple sails catching air and pulling the canopy open.

3) Reefing: Future missions will undoubtedly need the option to add a reefing stage to control spacecraft and parachute loads. There is very little history with supersonic or subsonic reefing of DGBs. The experience that does exist with reefing DGBs shows that it is an awkward configuration with uncertain risks. Subsonic ringsail reefing is standard practice with heritage including all U.S. manned capsule return vehicles.

4) Damage tolerance: Losing a sail or ring section will not compromise the structural integrity or performance of a ringsail as much as it would in a DGB. It is also viewed that the circumferential and meridional skeletal structure adds robustness to the canopy.

5) Reduced opening load factor (C_x): Sources such as Ref. 2 show that ringsails and ribbon chutes exhibit 10% to 30% lower opening load factors compared to the DGB. This reduction would translate directly into lower spacecraft loads and potentially mass.

Once the ringsail canopy was selected, a series of scaled parachute wind tunnel tests were performed.[3] The purpose of these wind tunnel tests was to investigate the stability and drag performance of various parachute canopy designs in order to inform the design of the full-scale supersonic parachute used in the Parachute Design Verification (PDV) and Supersonic Flight Dynamics Tests (SFDT) in the LDSD test program. Multiple sub-scale (35.2%) parachute canopy configurations were tested in the National Full-scale Aerodynamics Complex (NFAC) 80'×120' test section at the NASA Ames Research Center to quantify their relative drag and stability characteristics. Photogrammetry was used to track the parachutes free-motion in the test section in order to back-calculate the parachutes stability coefficients and trim angle of attack. Canopy types included: the Viking scaled DGB parachute, to establish a baseline performance metric, the SPTT scaled ringsail canopy with various gap configurations, and new configurations developed specially for this project. An example test configuration can be seen in Figure 1. The results of this wind tunnel test will be used to select the parachute configuration.

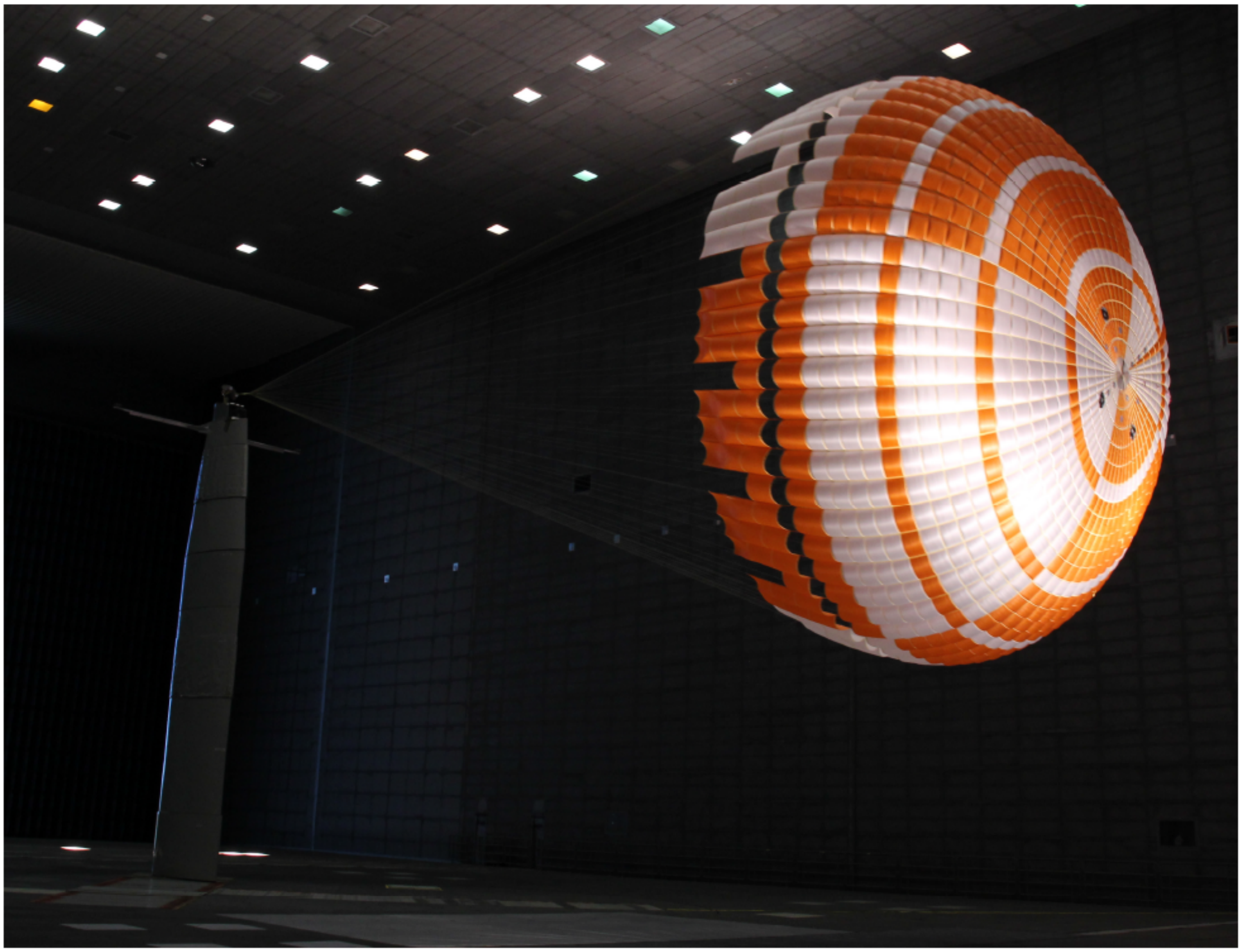

Figure 1: An example of scaled parachute testing in the NFAC 80'×120' test section.

III. Parachute Material Selection

A. Background

A decision was made by the LDSD team to move towards full-scale parachute fabrication using a combination of low-permeability materials consisting of 1.17 oz/yd^2 PIA-C-44378 (often referred to as F-111) and 1.9 oz/yd^2 Diamond Weave Nylon for the broadcloth. Both are Nylon based materials that have been calendared to reduce the overall permeability. The primary alternative under consideration was to utilize another form of Nylon, 1.1 oz/yd^2 Mil-C-7020, Type I. Though both materials are commonly used in parachute applications, all parachutes built for NASA Mars missions since Mars Pathfinder have utilized Mil-C-7020. The primary difference between the two material choices (F-111 and 7020) is the permeability that each material has. By specification, F-111 has a permeability of 0-5 cfm at 0.5" H_2O pressure, while 7020 Type I has a nominal permeability of 100 cfm at the same condition.

The debate between material choices focused on the effect that the different porosities would have on the parachute performance. It is well established that materials with permeabilities similar to 7020 Type I will augment the total porosity of a parachute canopy in a high-density, high-Reynolds number application. However, Lingard[4] has shown that in the low Reynolds number conditions, typical of Earth high-altitude and Mars environments, the contribution of the material permeability to the total parachute porosity, termed the effective porosity, is negligible. Attempts at calculating the effective porosity of 7020 Type I produce conflicting results depending on the set of data used in the process. Furthermore, wind tunnel testing of parachutes[5] built from 7020 and from F-111 have shown that the parachutes fabricated from 7020 tend to have lower drag coefficients and better stability than those fabricated from F-111. Though this is expected for a parachute having larger total porosity, from a preliminary look at recent NFAC testing of subscale parachutes the differences seem to be larger than what would be expected from a low-permeability material canopy with similar total porosity, perhaps underscoring the importance of porosity distribution within a canopy

B. Primary Considerations

A number of points were brought forth in support of both materials and those are summarized here:

1) With the exception of a single test conducted as part of the Subsonic Parachute Technology Task (SPTT)[6,7], low-density parachutes built for Mars flight or high-altitude test have utilized materials with permeabilities similar to 7020. The stability of the parachute tested during SPTT, a ringsail configuration similar to the baseline LDSD configuration, was observed to be very poor at certain high altitudes. However, it is not thought that the material played a significant role in that parachute's behavior, especially given that it was tested at high altitude.
2) There did not appear to be any concerns regarding the lack of space-flight heritage for F-111 fabric. Both 7020 and F-111 are nylon based materials with the primary difference being that F-111 is calendared.
3) The use of a low-permeability material such as F-111 eliminates, or at least greatly reduces, the uncertainty in performance between high-density and low-density test environments. All porosity is geometric porosity. This facilitates high density atmospheric testing since there is no need to modify geometric porosity to compensate for higher fabric permeability.
4) Parachutes of similar configuration but built from low permeability materials exhibit better drag characteristics than those built from materials with higher permeabilities. Unfortunately, this drag benefit generally comes at the expense of reduced stability.
5) Advanced lightweight laminate materials are currently being investigated for use in parachute applications. These materials have even less permeability than F-111 and future adopters would have to similarly adjusted to a low- or zero-permeability material.
6) The use of a low-permeability material constitutes a risk due to the uncertainty of permeability effects in low-density environments. As a technology development project, LDSD should embrace and address this risk rather than leaving it for future adopters to ponder.

C. Final Considerations

The primary reason for using the 7020 material would be the uncertainty associated with how a lower permeability material would perform in Mars like conditions. However, LDSD has acknowledged this uncertainty, and the accompanying risk, and considers the advantages behind using F-111 and the desire to reduce this risk for future users to be compelling enough to move forward with F-111 as the primary canopy material.

IV. Mortar Extensibility

The preferred approach for parachute deployment at Mars is via a mortar as it both removes the uncertainty in dealing with a supersonic wake behind a blunt body and is highly deterministic to test prior to flight. However, due to the Mach 4 speed requirements for the supersonic inflatable aerodynamic decelerator (SIAD) portion of the atmospheric flight test and the limited rocket motor options available, the SFDT vehicle was forced to mount a single Star48 solid rocket motor on its centerline. Unfortunately, this arrangement means that the parachute cannot be deployed using a mortar as vehicle restrictions mandate a significant lateral offset from the center of mass and the resulting angular impulse from the mortar reaction load would tumble the vehicle. Thus, the only means available to deploy the parachute is through the use of a pilot drag device. This parachute deployment device (PDD) is comprised of a (much smaller) mortar-deployed ballute that is staged in its deployed configuration for a short period before it is subsequently released and allowed to lift the parachute away from the vehicle.

The ultimate desire is to use a mortar deployment for Mars flight for the aforementioned reasons. The charge to LDSD is to perform the pilot deployment in a manner that allows test result extensibility to a mortar deployment. That is, the pilot deployment must be sufficiently similar to a mortar deployment that it can be deemed to have qualified a mortar deployment approach without the actual use of a mortar. This is achieved through the use of mortar deployment similarity parameters that include the parachute's packed configuration, Lock number (the ratio of aerodynamic forces acting on the canopy to the inertial forces of the canopy), bag strip velocity, and the parachute's strain energy state at line stretch and bag strip.

The most important aspect of mortar extensibility is that of matching the velocity of the parachute pack from line stretch through bag strip. Ideally the SFDT deployment would emulate the parachute pack velocity profile from a

Mars reference mission. As shown in Figure 2 this can be achieved by cutting the ballute away from the pack at a predetermined position prior to line stretch. To generate the Figure 2 results, both the mortar and pilot trajectories were tuned to achieve a vehicle relative velocity of 35 m/s at line stretch under the high dynamic pressure conditions. Both models were then re-run using the low dynamic pressure to generate the second line. Both the line stretch and bag strip velocities in each dynamic pressure case are within 0.2 m/s. The upshot is that once the ballute has been released from the parachute pack the remainder of the pack flight will be indistinguishable from a mortar launched pack. It is in this manner that the PDD results can be extended to qualifying a mortar deployment.

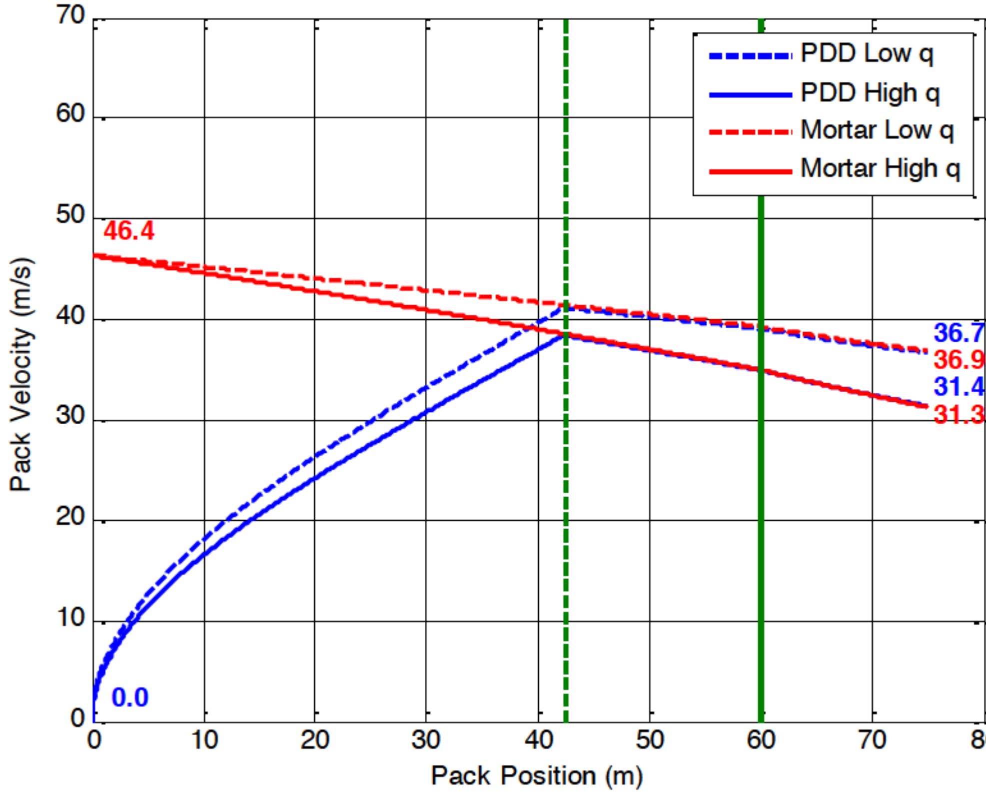

Figure 2: Comparison of the pack velocity versus position for a mortar deployment and an SFDT PDD pilot deployment using a Mars reference mission at both low and high Mars dynamic pressures of 450 and 725 Pa respectively. For these results the ballute is cut away at 42 m (dashed green line) and line stretch and bag strip occur at 60 m (solid green line) and 76.75 m respectively.

Using a PDD for the SFDT actually has one significant advantage over a mortar deployment in that the PDD automatically compensates for uncertainty in dynamic pressure. A mortar has a fixed impulse capability for propelling the pack which works very well for Mars flight where the uncertainty in dynamic pressure at parachute deployment is relatively small and can be controlled to a certain degree through flight software. However, the SFDT involves a significant period of uncontrolled flight which results in a large uncertainty in the dynamic pressure at the time of deployment. This uncertainty translates directly into mortar performance and is difficult to accommodate. However, because the drag on both the vehicle and the ballute are both proportional to the dynamic pressure, the performance of the ballute relative to the vehicle is simply a function of the ratio of their two ballistic coefficients which is largely invariant over the range of uncertainty in Mach.

V. Parachute Decelerator System

The Parachute Decelerator System (PDS) is comprised a supersonic ringsail parachute, mortar fired pilot ballute referred to as the Parachute Deployment Device (PDD), and all the required rigging including thermal protection.

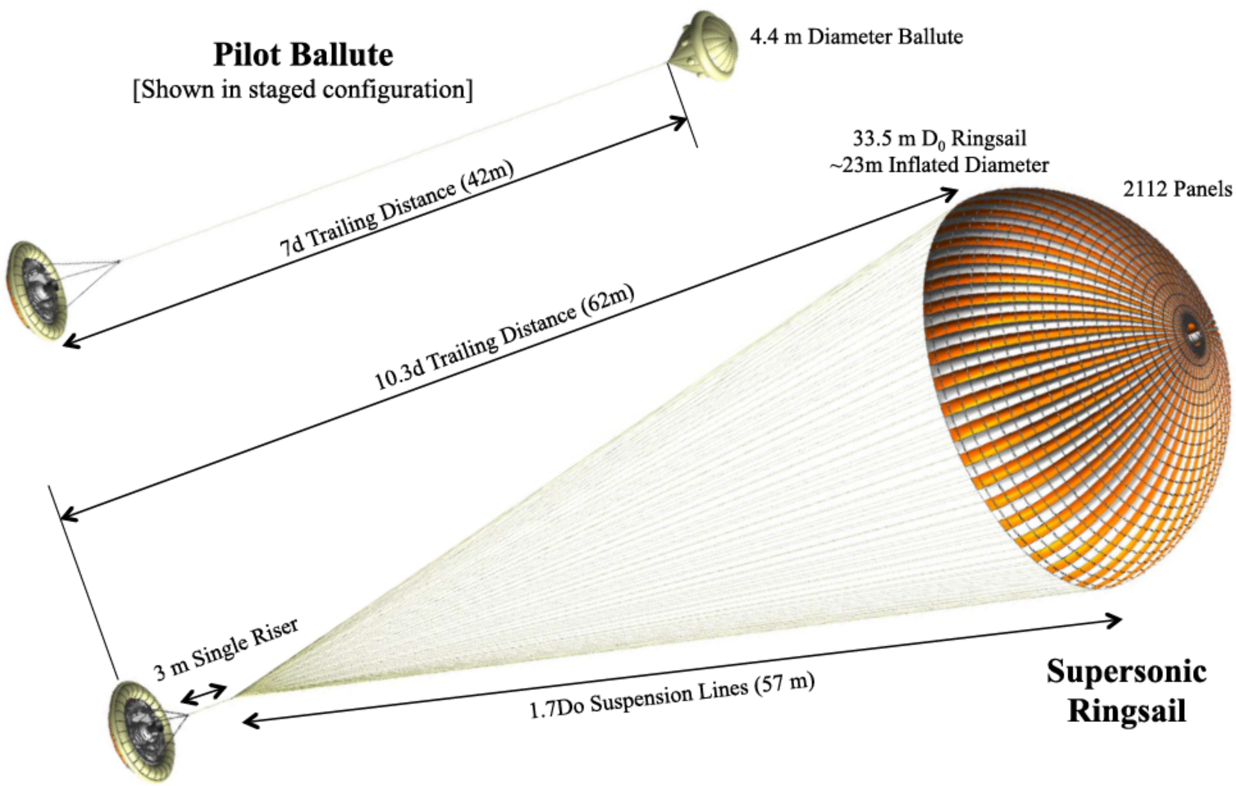

Figure 3: Parachute Decelerator System.

A. Supersonic Ringsail Parachute

The configuration of the LDSD SSRS originates from the Mars Subsonic Parachute Technology Task (SPTT)[6,7] 33.5 m Ringsail. The basic ringsail design consists of 96 gores and 22 rings, which provides a robust structure with a circumferential reinforcement tape at the upper edge of every ring; this allows additional flexibility in design modifications, as any one or more of the many panels or rings can be removed with minimal design impact. As described in Ref. 7, half roll width rings were also chosen to increase the flexibility of geometric porosity distribution, while maintaining reasonable sail fullness.

Figure 4: SPTT Canopy.

Changes to the SPTT configuration at LDSD program initiation included modifications to the structure to accommodate the higher expected inflation loads and lengthening of the suspension lines to 1.7 D_0 which is similar to Mars DGB canopies. Structural modifications included the use of much higher strength structural members, much higher strength suspension lines, and increased strength fabric in the crown region. As with SPTT, the canopy is designed with reefing capability; although unlike SPTT, the reefing system will accommodate textile reefing "rings." At program inception, the suspension lines converged onto 24-12-2 riser legs in a fairly standard cascade arrangement. This arrangement contributes to the robustness of the parachute system, as the loss of a single riser component only creates an 8.3% loss of the parachute structure. However, this arrangement also required the use of a metallic fitting between the resulting two (2) riser leg groups and three (3) bridle legs that attach to the vehicle structure. Due to the complicated dynamics of the deployment process, a metallic confluence fitting is now considered undesirable. Having a point mass attributed to a metallic confluence point results in undesirable snatch loading and decreased tension during extraction of the SSRS suspension lines and rigging. Therefore the LDSD project is developing a "soft confluence" riser-bridle subassembly to eliminate this mass. In eliminating this point mass, snatch dynamics during bridle standup are minimized due to a more continuous linear density of the deployed rigging. Mass is also decreased in the overall bridle assembly.

B. Parachute Deployment Device

Three different approaches were considered at the outset for deploying the LDSD parachute: 1) a pilot ballute, 2) a pilot parachute, and 3) a tractor rocket. From these a ballute was selected primarily because historical data indicates that it has the most stable supersonic flight and that, due to its convex shape, it will track the vehicle wake thus minimizing lateral motions during parachute deployment. This bypasses the risks and uncertainties associated with high Mach stability of a small parachute in a low dynamic pressure environment in the wake of a large blunt body. It is also specifically designed to open in high supersonic flow conditions such as are expected on the SFDT flights. The ballute itself is mortar deployed and then held in its nominal position for a short period before it is then released to lift the parachute pack from the vehicle. By contrast the principal concern with the use of a pilot parachute was the uncertain lateral stability and the unsteady drag that supersonic parachutes are known to exhibit. The tractor rocket approach was attractive as it was more deterministic but it suffered from cost issues and the fixed propulsive impulse that was problematic for deployment in an uncertain dynamic pressure environment where the vehicle could be decelerating over a range of 1 to 2.7 g's. This impulse problem is the same one that would have faced the SFDT flights were a mortar to be used to deploy the parachute.

C. Rigging

Thermal protection of the rigging is also required. During the high-altitude tests, the spin and main motors are a source of thermal flux that, if unshielded, may cause structural degradation to the rigging components in their proximity. The motors are all burnt out prior to the parachute deployment process. The parachute assembly and rigging are heated by their view factor to the plume during the powered flight phase and then by their view factor to the hot motor casing after motor burnout. Due to post burnout chugging of the rocket motor it is anticipated that there will be additional convective heat transfer to the triple bridle and riser of both the ballute and the parachute. There is also risk of direct contact of bridle to thermal sources, such as the main nozzle, during the transient deployment of the rigging when it is in an un-tensioned state. To protect from the thermal flux, aluminized PBI will cover all thermally loaded areas of the rigging. In addition, to protect against head soak from thermal flux or momentary contact, a layer of Nomex will be inserted between the aluminized PBI and the structural members of the rigging.

VI. Deployment Process

The PDS deployment process is a modified pilot deployment. The pilot for the PDS is a ballute, which is also momentarily staged in a drogue configuration prior to SSRS deployment. In a normal pilot deployment, the pilot chute extracts the main parachute bag off of the canopy after line stretch; however, for the PDS the pilot chute is cut free prior to line stretch. The PDS deployment sequence can be seen in Figure 5.

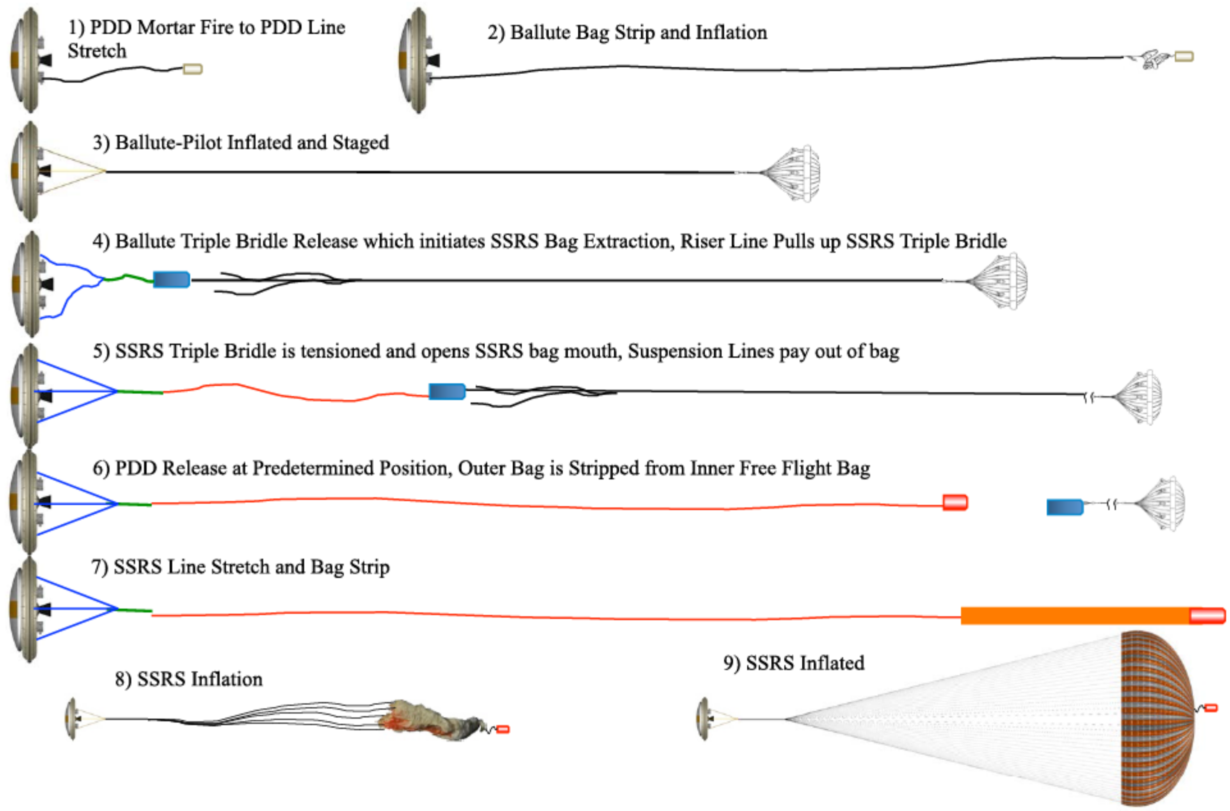

Figure 5: Deployment Process.

VII. Verification and Validation

In addition to the development and qualification of the PDS hardware, the LDSD project is also charged with providing a methodology for verification and validation (V&V) of future parachute qualifications. LDSD will perform all of the typical V&V like radiographic inspection and seam-and-joint testing; however, there are some signification changes in a few critical areas. Missions since Viking have utilized the DGB high-altitude tests, as well as Mars mission on-chute telemetry, to determine the configuration of the parachute to support the mission under development. Structural verification of the parachutes have either been achieved through atmospheric drop testing or through the use of the NFAC wind tunnel to apply the structrual qualification load to a fully inflated parachute. Inflation dynamics and verification have been verified using previous high-altitude supersonic flight data as well as limited utilization of NFAC mortar firings and bag deployments. Rigging deployment was tested in mortar fire tests and packing walkout tests. In all of these areas LDSD is laying the V&V groundwork and methodology for futures missions to follow as past approaches are no longer viable.

A. Parachute Design Verification

Testing in the NFAC wind tunnel is impossible due to the size of the LDSD SSRS. The largest section of the NFAC is 80’×120’ test section, and the projected diameter of the SSRS is ~76 feet. With NFAC insufficient to provide the necessary test section area, LDSD was forced to looked elsewhere for its testing needs. Unlike typical parachute inflation load profiles that see peak loading prior to full open, low-density supersonic parachutes see their peak load at full open. It is this dynamic that made the infinite mass tests in the NFAC facility so desirable. The project traded multiple test design options in order to achieve this full open qualification load state. Typical aerial drops were heavily considered due to the success of qualification of other large ringsail parachute systems; however, the loading profile and repeat costs were undesirable. It was through the success of the LDSD Supersonic Inflatable Aerodynamic Decelerator Structural Design Verification[8] test campaign that the Parachute Design Verification (PDV) architecture was born. Utilization of rocket thrust, which provides nearly constant force, and a rocket sled track, allowed for a test architecture to be conceived. Figure 6 shows a storyboard of the architecture currently being developed. The facility is being built at the Naval Air Warfare Center Weapons Division's Supersonic Naval Ordnance Research Track (SNORT) in California.

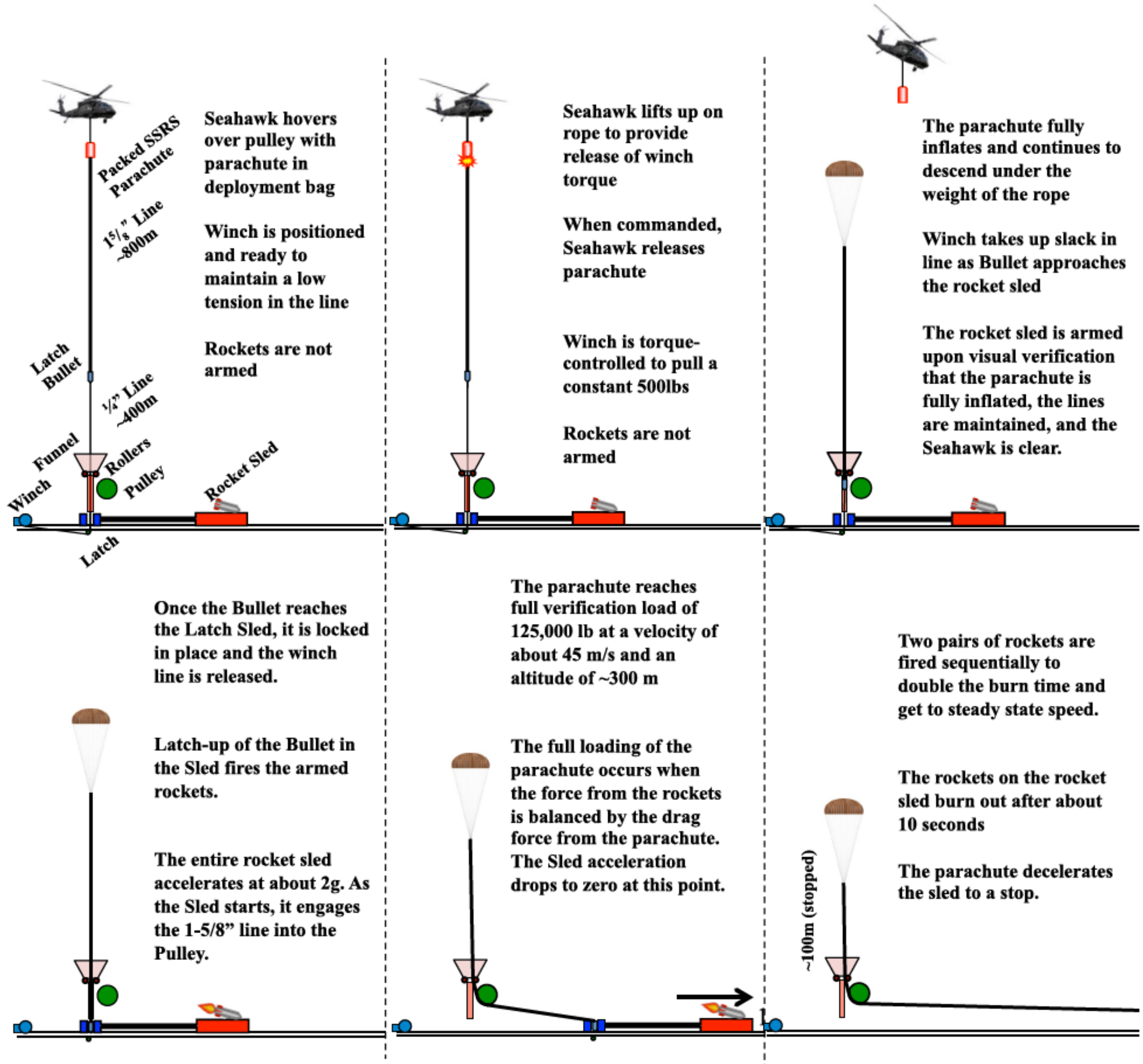

Figure 6: PDV Test Architecture.

Analysis and sizing of all the components has been completed and fabrication of the facility illustrated in Figure 7 is underway. The first test of this facility is scheduled for the summer of 2013. With the completion of this facility, LDSD will be capable of being subjected the SSRS to its qualification load of 120,000 lbs while the parachute is fully inflated. The facility has been sized to allow for future qualification programs up to a load of 200,000 lbs.

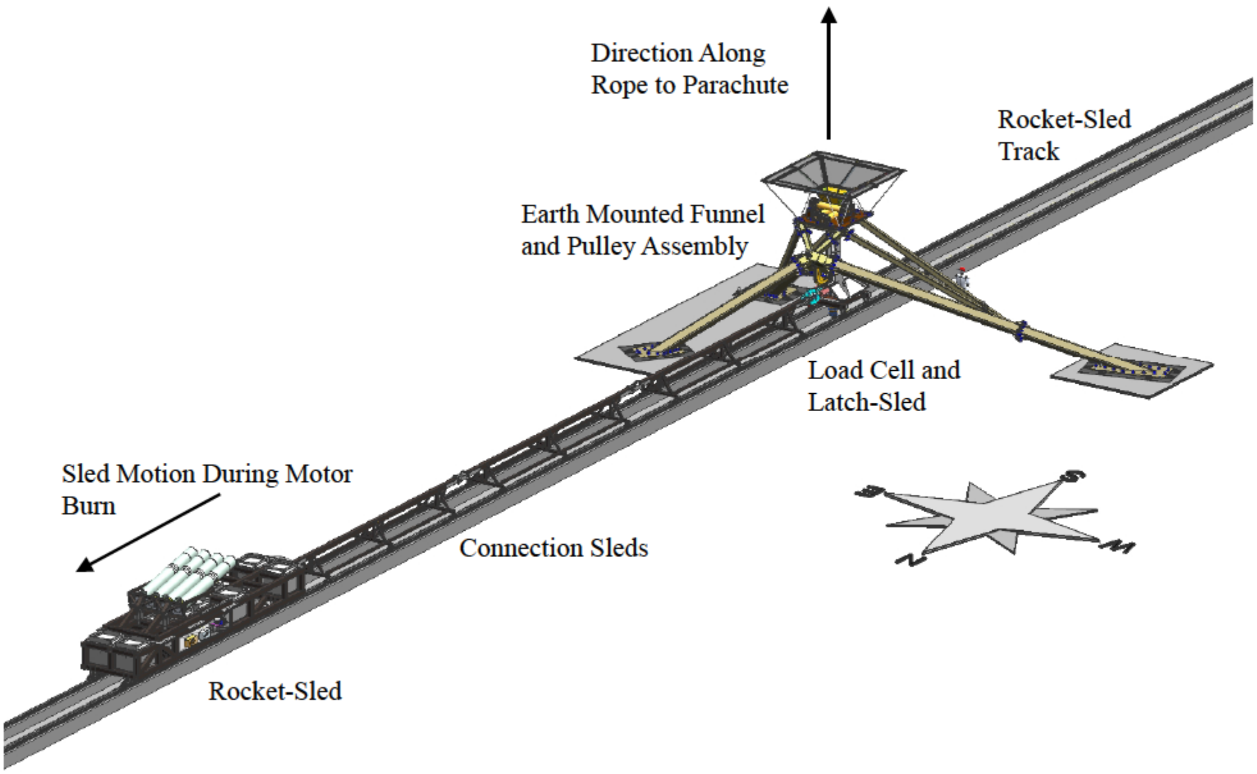

Figure 7: Parachute Design Verification CAD Model.

B. Rigging Testbed

Verification and Validation of this multi-stage deployment process from ballute mortar firing through bag strip will be achieved using a Rigging Test Bed (RTB).[9] This facility will allow validation of the dynamic extraction simulation that was used to size the ballute as well as define the staging distances for the deployment events. Unlike typical parachute extractions, where the forebody is either accelerating or at terminal velocity, the LDSD test vehicle will be decelerating on the order of 1-3 g's. Validation of the simulation model is important, as the tension margin in the bridle and suspension lines during initial extraction is low. If the margins go negative, then the tension will be inadequate to support the deployed rigging and the rigging will start to fall back toward the test vehicle, which means piling up on the aft of the vehicle where thermal damage can occur from the spent motors. In addition, if there is slack in the rigging at the onset of parachute inflation, there will be a significant, and likely unacceptable snatch load as the slack rigging tensions up. The RTB will also provide verification of the adequacy of the rigging onto the aft deck of the test vehicle and all the tie-downs as well as re-contact mitigations during extractions.

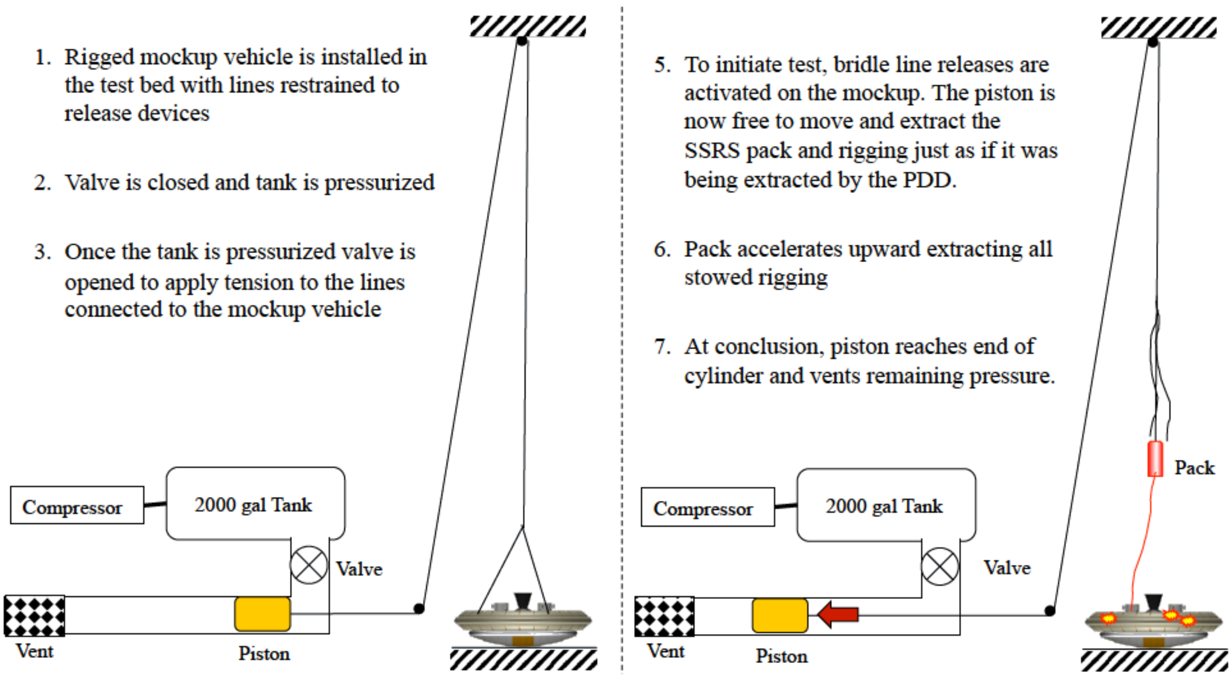

Figure 8: Rigging Test Bed Overview.

The test bed consists of a long pneumatic piston device capable of providing a constant force simulating the ballute drag force for the duration of the 50 m of extraction event. Short pull distance tests will allow for preliminary investigation of sections of the long 50 m extraction stages. These tests will take place inside a high-bay for frequent tests of individual extraction stages. Individually tested stages include parachute "can" extraction, ballute bridle standup, as well as SSRS bridle standup. In all tests a mockup test vehicle will be utilized. This test article will replicate all the rigging tie-off points as well as all the threats to the rigging. Such threats include the Thermal Protection System (TPS) blankets and shields. This TPS hardware will wrap the entire aft part of the vehicle and will not only protect the rigging, but also the test critical hardware including electronics and sensors. The RTB will include these threats during the tests to allow for verification that the threats are adequately mitigated. In addition, hardware such as the rocket nozzle and camera masts will be present, which pose re-contact and entanglement threats on the aft deck of the test vehicle. Angled extractions of the hardware, which will simulate dynamic off-angle extractions, will allow for a measurement of re-contact margin to these items.

Once these short extraction tests are complete, the RTB moves outdoors and employs a mobile hydraulic crane for complete deployment tests from initial SSRS pack pull out to canopy extraction. These tests will measure line tensions and use photogrammetry to track motion of the elements involved. In these full extraction tests all the stages of the deployment process from ballute staging to parachute extraction can be V&Ved. These tests will be performed in a vertical orientation with the extraction progressing upward against gravity. In this orientation the use of Earth gravity partially simulates the apparent deceleration of the test vehicle during the actual SFDT flight tests. This vertical orientation requires a large mobile truck crane to provide the stationary airborne pulley point well above the mock test vehicle, such that a full extraction can be performed without being hindered. The resulting data will be used to validate models and identify potential failure modes to finalize the design of the extraction system on the SFDT vehicle.

C. Parachute Deployment Device

There are a number of elements of the PDD that require targeted V&V activities prior to flight. The first is the PDD mortar function itself, which will be qualified through a series of ground based static firings. The second is the deployment and extraction of the ballute from its deployment bag, which will also be included in the static mortar firings. The third component is ensuring the inflation of the ballute, which is probably the most difficult portion of the PDD V&V. The present plan for this involves the development of an inflation aid that will release a volume of gas into the ballute when it reaches line stretch. The function of the inflation aid would be verified though component level testing with a planned final test in a simulated high altitude atmosphere environment. Wind tunnel and tow testing behind a vehicle are also used to verify that the ballute inlets are sufficient to both initially inflate the ballute and then to maintain its inflated pressure. The ballute material itself will be subjected to a high temperature environment in flight and must be thermally compatible either by specification or as demonstrated through test.

The performance of the ballute is assessed through analysis and currently there are no plans to do any tests at condition prior to the SFDT flights. However, the simulation used to assess the ballute performance will be validated through the RTB as described in Section VII.B. This arrangement will allow for a nearly constant simulated ballute drag that lifts against the 1-g acceleration of Earth, which is representative of the lower end of the expected vehicle accelerations. The very last piece of the PDD V&V is the release and separation of the ballute which must fall behind the vehicle and not re-contact the parachute after it has performed its function which can only be addressed through analysis.

D. Supersonic Flight Dynamics Test

The culmination of the LDSD project is a set of four high-altitude supersonic flight tests that will test the full-scale parachute at Mars relevant conditions. The test approach is similar to that utilized by the Viking Mars Program for the qualification of the supersonic DGB parachute[10] and previously by the Planetary Exploration Parachute Program (PEPP)[11]. Shown in Figure 9 is the SFDT trajectory overview. To achieve the needed test conditions, a full scale 4.7 meter diameter aeroshell is lofted to an altitude of approximately 30 km by a large helium balloon. The aeroshell is released, spun up for stability, and a Star48 main motor is ignited to accelerate the test vehicle to an altitude of approximately 50 km and a Mach number approaching 4. At this point the vehicle is despun and the main test period begins with SIAD deployment. When the vehicle decelerates to Mach 2.6 the ballute is deployed thereby initiating the parachute deployment sequence as discussed in Section VI. The four flight tests will gather high speed and high resolution imagery, bridle forces, test vehicle accelerations, and angular rates. Meteorological sounding rockets will be launched immediately prior to and following each test flight to characterize the velocity and direction of the air mass in which the test takes place. The test conditions have been Mach scaled to reproduce the parachute's drag characteristics as a function of Mach number. However, Mach scaling results in an inability to simultaneously match Mach number and dynamic pressure during the SFDT tests. The SFDT tests will achieve dynamic pressures roughly 25 to 30 percent below those expected in a Mars flight. This is acceptable as the primary objective of the test series is to characterize the parachute's aerodynamic performance. Strength testing is done during PDV. Higher atmospheric temperatures at Earth will result in stagnation temperatures roughly 50-100 K higher than at Mars.

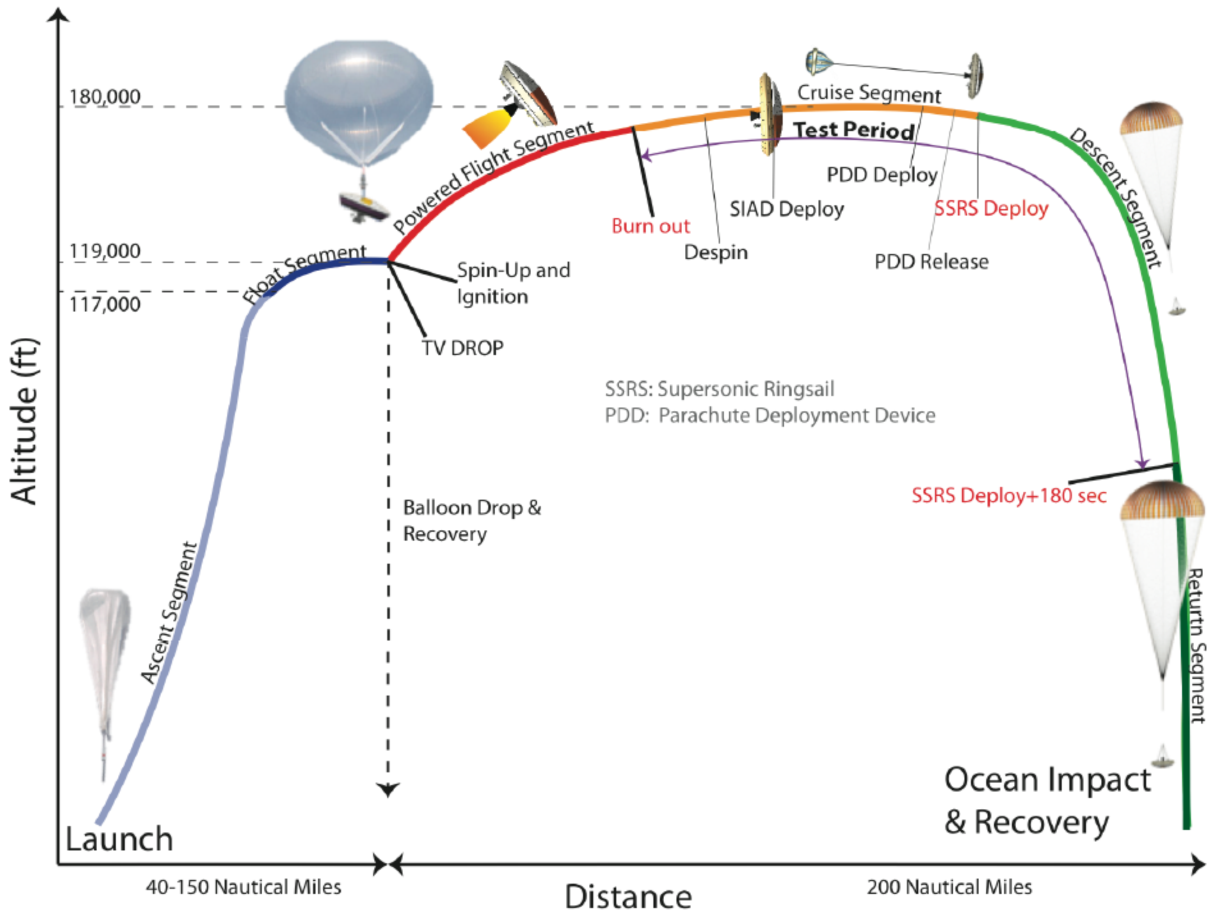

Figure 9: SDFT Trajectory Overview.

Acknowledgments

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