Development of Inflatable Entry Systems Technologies

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ABSTRACT

Achieving the objectives of NASA's Vision for Space Exploration will require the development of new technologies, which will in turn require higher fidelity modeling and analysis techniques, and innovative testing capabilities. Development of entry systems technologies can be especially difficult due to the lack of facilities and resources available to test these new technologies in mission relevant environments. This paper discusses the technology development process to bring inflatable aeroshell technology from Technology Readiness Level 2 (TRL-2) to TRL-7. This paper focuses mainly on two projects: Inflatable Reentry Vehicle Experiment (IRVE), and Inflatable Aeroshell and Thermal Protection System Development (IATD). The objectives of IRVE are to conduct an inflatable aeroshell flight test that demonstrates exoatmospheric deployment and inflation, reentry survivability and stability, and predictable drag performance. IATD will continue the development of the technology by conducting exploration specific trade studies and feeding forward those results into three more flight tests. Through an examination of these projects, and other potential projects, this paper discusses some of the risks, issues, and unexpected benefits associated with the development of inflatable entry systems technology.

1.0 INTRODUCTION

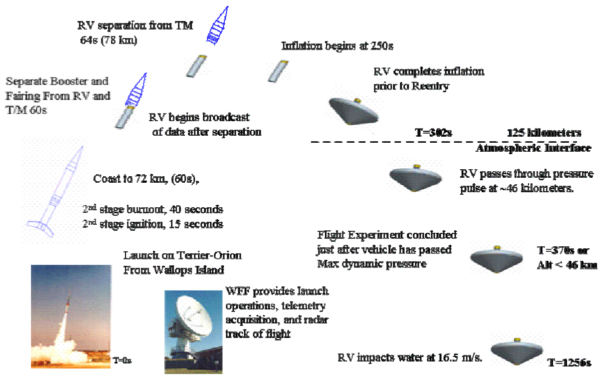
Inflatable aeroshells provide a low-volume, low-mass, modular alternative to rigid aeroshells for the purpose of aero-assisted planetary entries. Furthermore, the very nature of an inflatable allows it to be deployed at much larger sizes than are realistically possible with rigid aeroshells without on-orbit assembly. If validated through a focused and well-planned technology development process, inflatables will surpass the capabilities of rigid aeroshells in a multitude of ways: increased payload mass and volume fraction, post launch vehicle integration payload access, use of Entry, Descent, and Landing (EDL) or mission systems during the in-transit phase of the mission, access to higher altitude landing sites upon entry, provide a more benign payload thermal environment during entry. Significant research and analyses [1, 2] have already been done in the development of this technology. Now the technology has matured to the level of conducting flight demonstrations.

The purpose of these flight demonstrations is to move the inflatable aeroshell from a Technology Readiness Level of two (TRL-2) to TRL-6, and eventually, TRL-7. At TRL-6 the technology has been demonstrated in a mission relevant environment [3]. Achieving a mission relevant environment for planetary entry systems is very difficult, especially within the constraints of low cost and short schedule. This paper describes a proposed technology development process for the maturation of the inflatable aeroshell technology from TRL-2 to TRL-7, and states the current status of the projects associated with that process. This technology development process addresses the mission relevant environment issue through multiple flight tests, ground tests, and analyses.

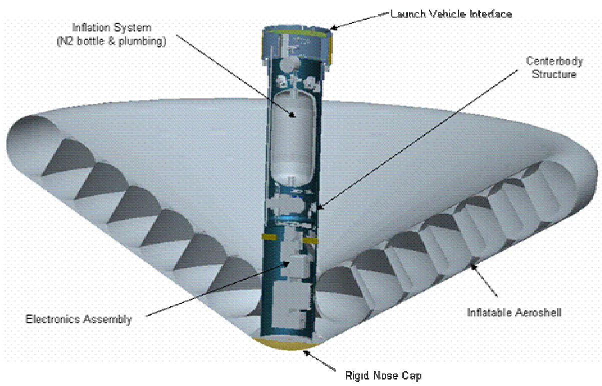
2.0 PROJECTS UNDERWAY

2.1 Inflatable Reentry Vehicle Experiment

NASA Langley Research Center (LaRC), in collaboration with NASA Wallops Flight Facility (WFF), is developing inflatable aeroshell technology through the Inflatable Reentry Vehicle Experiment (IRVE) project. The project will conclude with a flight demonstration in December 2005. The flight experiment will demonstrate packaging efficiency, inflation, and structural integrity and aerodynamic stability throughout the flight regime [4]. IRVE will use a Terrier-Improved Orion sounding rocket, provided by WFF, as its launch vehicle. The rocket will carry the IRVE Reentry Vehicle to an altitude of 111 km. The Reentry Vehicle will continue on to an apogee of 185 km. The Reentry Vehicle will initiate inflation of the aeroshell after apogee at an altitude of 160 km, and perform a ballistic entry and descent. The flight experiment will conclude at ocean impact, approximately 20 minutes after launch. The vehicle will not survive the water impact, and therefore there are no plans to recover the vehicle at this time.



IRVE Flight Test Timeline



IRVE Reentry Vehicle

In flight, structural integrity and structural response of the aeroshell will be verified through video and photogrammetric measurements of the back side of the aeroshell. Aerodynamic stability as well as drag performance will be verified with on board inertial measurements and radar tracking from multiple ground radar stations. Surface and in-depth temperature distribution will be measured via thermocouples embedded within the aeroshell itself. Thus, in addition to demonstrating the inflatable aeroshell technology, IRVE will serve to validate structural, aerothermal, and trajectory modeling techniques for the inflatable [5].

2.2 Inflatable Aeroshell and Thermal Protection System Development

Inflatable Aeroshell and Thermal protection system Development (IATD) [1] is an Exploration Systems Research and Technology project initiated in January 2005 in direct support of the Vision for Space Exploration. IATD is a NASA Johnson Space Center managed project being supported by LaRC, WFF, and NASA Ames Research Center. The purpose of IATD is two-fold. First, IATD will conduct studies and analyses to determine the feasibility of the inflatable aeroshell technology for use in specific exploration applications. Secondly, IATD will conduct three flight tests to continue the inflatable aeroshell technology maturation.

The IATD exploration application studies are currently underway. These studies will examine the feasibility of using an inflatable aeroshell for the following eight mission applications: 1- Earth return of International Space Station (ISS) payload mass in the post-Shuttle era, 2- Earth aerocapture of a trans-lunar injection stage, 3- Earth aerocapture of a vehicle returning from the moon, 4- Crew Exploration Vehicle stability augmentation, 5- direct entry of Mars science payloads, 6- direct entry of massive Mars payloads (as precursor to Human Mars missions), 7- Earth aerocapture of a trans-Martian injection stage, 8- Earth aerocapture of a vehicle returning from Mars. The approach to these studies is to independently investigate three major aspects of aeroshell design: the trajectory to be flown, the aerodynamic and aerothermal loads to be incurred in-flight, and the aeroshell structure and system configuration, and then to complete high-level conceptual designs of inflatable aeroshell systems that meet the requirements of each mission. This process will drive out some subsystem elements and aeroshell configurations that show utility across the range of exploration missions. This will result in a focusing of the flight tests, and the technology maturation process as a whole, on those elements of the technology that appear to have the most promise. This phase of the project will be completed in September 2005.

The IATD flight tests will build upon the heritage of the IRVE design. The sounding rockets to be used in IATD are more capable than the Terrier-Improved Orion, and will therefore provide a more severe reentry environment for the aeroshell. While the final objectives of each of the IATD flight tests will not be defined until the conclusion of the application studies, these flight tests will demonstrate lift generation and controllability, increased size (8-12 meter diameter aeroshell), and survivability at higher heat rate, heat load, and aerodynamic load than demonstrated with IRVE. The schedule for the IATD flight tests is October 2006, August 2008, and October 2008.

3.0 PROPOSED PROJECTS

3.1 Inflatable Re-entry Vehicle Experiment II

LaRC is currently in discussion with WFF for a follow-on flight test to IRVE. This flight test will accelerate the development of the inflatable aeroshell technology as well as provide risk reduction for the IATD project. Currently IATD flight tests two and three are scheduled to use a Talus-Oriole sounding rocket. The Talus-Oriole has significantly more payload volume, and can provide a much more energetic trajectory than the Terrier-Improved Orion. However, the Talus-Oriole has yet to be flown, and a launch failure on either of IATD's final two flight tests would severely impact the development of the inflatable aeroshell technology. IRVE II will flight demonstrate an 8-meter diameter inflatable aeroshell. The aeroshell is to be launched on a Talus-Oriole into a ballistic trajectory. IRVE II will provide further risk reduction for IATD by providing for the initial development of a larger scale aeroshell and its associated inflation system. Finally, since the IRVE II project would be independent of the ESR&T program, it provides the technology development process with some insulation against ESR&T programmatic risks and issues. The proposed schedule for IRVE II is for a flight in Fall 2006.

3.2 Proposed TRL-7 Flight Test

LaRC has proposed an inflatable aeroshell as a candidate for a secondary payload aboard geosynchronous satellite mission. The proposed mission is to deploy the aeroshell payload in the geo-transfer orbit. The payload will inflate a 4-meter aeroshell and re-enter the atmosphere at approximately 10 km/s. This mission would be the first flight of an inflatable aeroshell at conditions relevant to ISS and Lunar return missions.

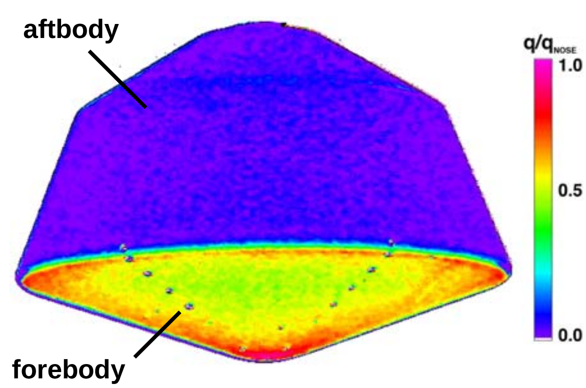
4.0 ANALYSES

As the inflatable aeroshell technology develops, a set of analysis techniques and methodologies will mature along with it. The flight demonstrations will not only demonstrate the capabilities of the technology, but will also serve as a series of testbeds to validate the analysis methods and tools used in the design of the flight vehicles. There a number of aspects of the inflatable aeroshell that need to be characterized prior to the design of an "operational" system including surface temperature distribution due to aero- and radiative heating, in-depth aeroshell heating due to that heating environment, aeroshell aft-body heating distribution, aero-elastic (and potentially aerothermal-elastic) affects, and aeroshell stability throughout the flight regime. Each of these must be predicted and accommodated within an operational inflatable aeroshell system. Therefore, the techniques and methodologies used to predict and analyze these issues must also be developed and validated during the technology development process. Two methodologies currently under development at LaRC as part of the IRVE and IATD projects are further discussed below.

4.1 Aft-body heating

As stated previously, one of the benefits of the inflatable aeroshell is that significantly larger diameters (and surface areas) can be realized than with rigid aeroshells. In other words, the scale of a given payload relative to the aeroshell diameter is reduced. In such a situation, the payload is effectively tucked close behind a sufficiently large aeroshell. The aerothermal environment that this payload experiences is reduced relative to a smaller diameter aeroshell. This reduction may be large enough to eliminate the backshell altogether. However, the actual aft-side heating is difficult to measure or predict for a vehicle in this configuration. The benefits realized by eliminating the need for a backshell are mass savings, volume savings, and the ability to use payload subsystems throughout the mission. New testing or analysis techniques for predicting aft-body heating need to be developed to realize these potential benefits.

LaRC is currently developing a methodology for predicting accurate measurement of the aft-body heating on concave blunt body entry vehicles. LaRC is using a technique called Thermogrpahic two-color, relative intensity, phosphor thermography phosphor to provide a global heat-transfer mapping of the flow around a blunt entry body during a hypersonic wind-tunnel test. Phosphor thermography has been successfully employed in numerous hypersonic test programs to date, however, for aft-body measurements, the challenge is develop a system with greater sensitivity to measure the very low heating-levels generally experienced by the aft body. LaRC is currently conducting proof-of-concept testing on several notional entry body configurations including the IRVE aeroshell and payload.



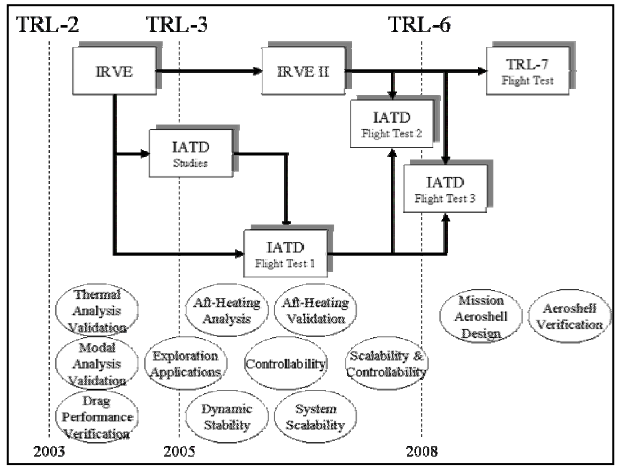
Heating on Notional Mars Entry Vehicle Geometry

In this method [6-9], wind tunnel models are coated with a phosphor compound that fluoresces in two separate regions (green and red) of the visible light spectrum. During a wind tunnel run, the phosphor-coated model is illuminated by ultraviolet (UV) light sources, and the resulting fluorescent intensity of the model is recorded and digitized through a three-color CCD (charge coupled device) camera. The fluorescent intensity is dependent on both the intensity of incident UV light and the local model surface temperature. The intensity dependence on the incident UV lighting is removed by taking the ratio of the green to red intensity images. Surface temperature distributions can be determined from this ratio through prior calibrations. Images are acquired before the wind tunnel run and after injection of the model to the tunnel centerline during a run. Global heat-transfer distributions can then be determined from the temperature changes between the two images using onedimensional, constant heat-transfer coefficient conduction theory.

4.2 Dynamic Stability

Historically, projects such as Viking, Pathfinder, MER, Genesis, Huygens, and Stardust have quantified dynamic stability using wind-tunnel testing or free flight testing. LaRC, in support of IATD, will combine forced-oscillation wind-tunnel testing with ballistic range testing (free flight) and numerical analysis to determine dynamic stability derivatives. The three techniques will be used to compliment each other. Forced oscillation testing is the common method in the aircraft world to generate dynamic stability data. However, for blunt body vehicles, the dynamics are heavily influenced by the aft-body shape, and therefore the measurements obtained via wind-tunnel testing are biased by the presence of the sting holding the model in place. Ballistic range and other forms of free flight testing can be used as a method for generating dynamic stability data that is free of the complications of wind-tunnel testing. Unfortunately, free flight tests can be expensive, and, depending on the type of testing conducted, may generate only a few data points that must be interpolated before the dynamic stability derivatives are calculated. The goal for IATD is to generate and validate numerical analysis methods through wind-tunnel and ballistic range testing as well as through the flight tests. If successful, the project will create a method to analyze blunt-body dynamics that reduces the dependence on wind-tunnel and free flight testing required. The generation of such a methodology will advance the inflatable aeroshell technology, as well as rigid aeroshells, by reducing cost and risk associated with system development.

5.0 SUMMARY



Overall Technology Development Process

A focused technology development plan has been constructed for the development of inflatable aeroshell technology. Because of the difficulty of duplicating the planetary reentry environment, this process uses an approach that demonstrates significant system capabilities in sequential flight tests. No single flight demonstration prior to the TRL-7 flight will entirely duplicate the reentry environment; however each test will demonstrate key system compatibility and operability. In parallel, a set of analysis methodologies and techniques that predict the thermal, structural, and aerodynamic performance of the inflatable aeroshell will be developed. The sequence of flight demonstrations will validate each of those techniques. Finally, the TRL-7 flight test will conclude the technology development by verifying our ability to predict the reentry environment, predict the inflatable aeroshell system performance within that environment, design and build the system, and conduct a mission relevant flight demonstration.

This technology development process successfully addresses the problem of demonstrating an EDL technology in a mission relevant environment. This plan provides some mitigation against programmatic risk to the technology by providing parallel development paths, however the paths are integrated sufficiently that each flight test can help provide technical risk reduction for the others. And by reducing technical risk, each flight test helps increase the programmatic health of the subsequent tests. By continually reducing both programmatic and technical risk, this technology development plan provides a sustainable maturation process for the inflatable aeroshell technology.

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