Ares I
First Stage Booster Deceleration System: An Overview

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In 2005, the Congressional NASA Authorization Act enacted a new space exploration program, the "Vision for Space Exploration." The Constellation Program was formed to oversee the implementation of this new mission. With an intent not simply to support the International Space Station, but to build a permanent outpost on the Moon and then travel on to explore ever more distant terrains, the Constellation Program is supervising the development of a brand new fleet of launch vehicles, the Ares. The Ares lineup will include two new launch vehicles: the Ares I Crew Launch Vehicle and the Ares V Cargo Launch Vehicle. A crew exploration vehicle, Orion, will be launched on the Ares I. It will be capable of docking with the Space Station, the lunar lander, Altair, and the Earth Departure Stage of Ares V. The Ares V will be capable of lifting both large-scale hardware and the Altair into space. The Ares First Stage Team is tasked with developing the propulsion system necessary to liftoff from the Earth and loft the entire Ares vehicle stack toward low Earth orbit. The Ares I First Stage booster is a 12-foot diameter, five-segment, reusable solid rocket booster derived from the Space Shuttle's four-segment reusable solid rocket booster (SRB). It is separated from the Upper Stage through the use of a Deceleration Subsystem (DSS). Booster Tumble Motors are used to induce the pitch tumble following separation from the Upper Stage. The spent Ares I booster must be recoverable using a parachute deceleration system similar to that of the Shuttle SRB heritage system. Since Ares I is much heavier and reenters the Earth's atmosphere from a higher altitude at a much higher velocity than the SRB, all of the parachutes must be redesigned to reliably meet the operational requisites of the new launch vehicles. This paper presents an overview of this new booster deceleration system. It includes comprehensive detail of the parachute deceleration system, its design and deployment sequences, including how and why it is being developed, the requirements it must meet, and the testing involved in its implementation.

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Nomenclature

BSM	=	Booster Separation Motor
BTM	=	Booster Tumble Motor
CDR	=	Critical Design Review
DSS	=	Deceleration Subsystem
FSE	=	Forward Skirt Extension
ISS	=	International Space Station
MSFC	=	Marshall Space Flight Center
NASA	=	National Aeronautics and Space Administration
PDR	=	Preliminary Design Review
Q	=	Dynamic Pressure
SRB	=	Solid Rocket Booster

I. Introduction

THE Constellation Program was established to implement the new civil space policy articulated by the president and enacted by Congress in the NASA Authorization Act of 2005. The broad principles and goals of the policy are for NASA to retire the Space Shuttle after completing construction of the International Space Station (ISS). It will be replaced with a new system, whose mission is not simply to support the space station, but also to enable human return to the Moon to establish a sustained lunar presence, and pave the way for future exploration missions to Mars and beyond. A major piece of the Constellation Program is the Ares I Crew Launch Vehicle. Its development is being managed by NASA's Marshall Space Flight Center (MSFC) in Huntsville, AL. Ares I is an in-line two-stage launch vehicle. Its function will be to deliver the Orion crew capsule to low Earth orbit to service the International Space Station and/or staging for a lunar mission. The backbone of the Ares I launch vehicle is the First Stage, a 12-foot diameter, five-segment, reusable solid rocket booster (SRB). It provides the main thrust, enabling vehicle liftoff from the Earth.

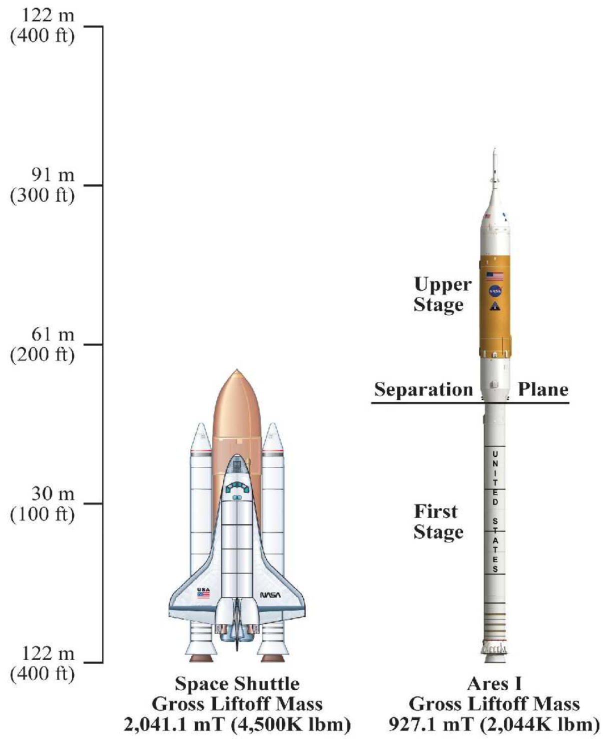

Figure 1. Shuttle and Ares I compared.

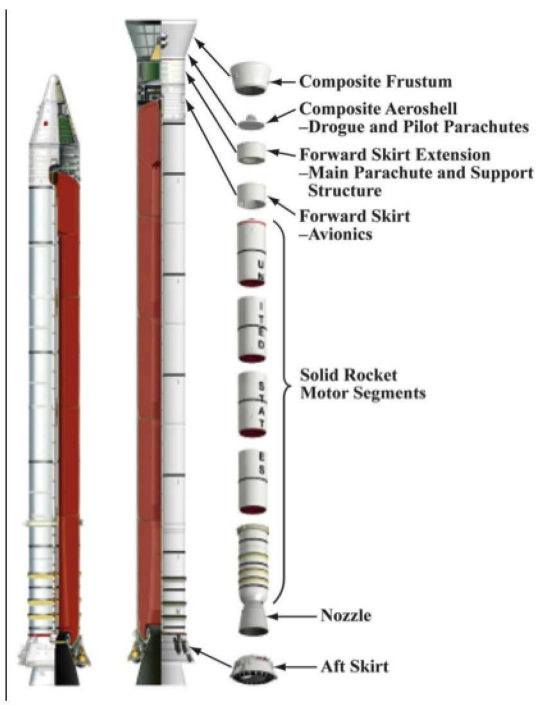

Figure 2. Shuttle 4-segment SRB (left) compared to Ares I 5-segment First Stage.

The second, or Upper Stage, uses a single liquid propulsion engine to complete the task of putting the Orion crew capsule into low Earth orbit. The First Stage separates from the Upper Stage approximately 130 seconds after launch at an altitude of about 190,000 feet. After separation, the spent First Stage booster will continue on its flight path to an apogee of approximately 325,000 feet before it starts its journey back to Earth to splash down in the Atlantic Ocean. The Ares I First Stage is longer and heavier, and it reenters the Earth's atmosphere from a higher altitude, at a much higher velocity than does the Space Shuttle SRB. Consequently, a redesigned reentry Deceleration Subsystem (DSS) is required for the safe recovery of the Ares I First Stage booster. A side-by-side comparison of the Shuttle and Ares I is shown in Figure 1. A comparison of the Ares I First Stage and the Shuttle SRB are shown in Figure 2. A more detailed DSS configuration can be seen in Figure 5.

II. Basis for Design

The Ares I First Stage DSS redesign will be developed using the Shuttle's heritage system as a baseline. This will include the parachute deployment sequences and consequently take advantage of the past 25 plus years of successful SRB recovery experience. Barometric pressure is collected from external ports during reentry and averaged in a plenum chamber. The barometric pressure reading from the plenum chamber will trigger a preset altitude switch assembly, which will initiate the firing of pyrotechnic pressure cartridges to eject the aeroshell at an altitude of approximately 16,000 feet. Although the geometric profile is slightly different, the aeroshell is similar to the SRB nose cap. It uses a bridle attached to the pilot deployment bag to pull and deploy the pilot parachute. Immediately upon inflation, the pilot parachute deploys the multi-stage drogue parachute. The drogue parachute is the workhorse of the system and its job is to provide the initial low altitude deceleration and stabilization of the booster in a tail down attitude for safe deployment of the three large multi-stage main parachutes. The cluster of three main parachutes will provide the final deceleration of the booster to achieve its safe splash down terminal velocity. A graphical representation of the First Stage reentry and parachute deployment sequence is shown in Figure 3.

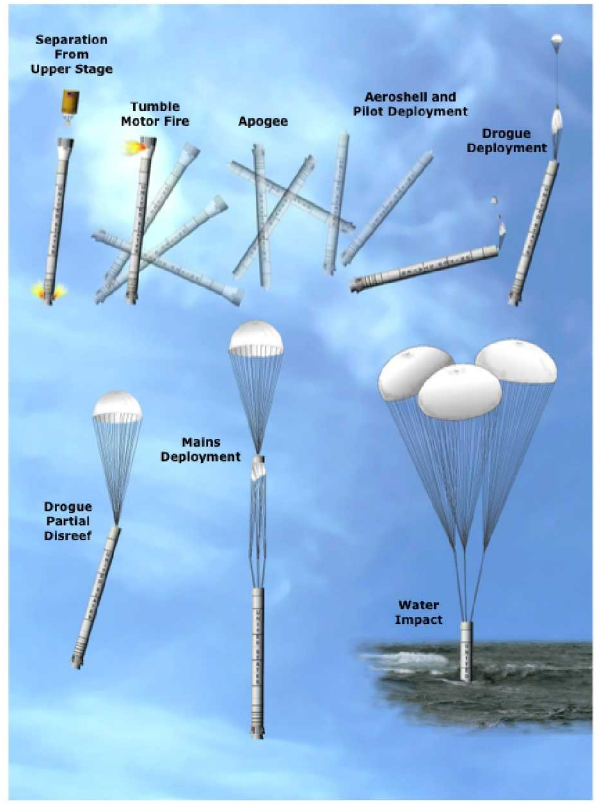

Figure 3. First Stage reentry and parachute deployment sequence.

The driving program requirement for the Ares I First Stage DSS is that the booster be recoverable for refurbishment and reuse, while maintaining the same or less hardware attrition as experienced with the Shuttle's SRB. The first key design factor for the DSS was to establish the allowable water impact velocity required to meet this recoverability and hardware attrition requirement. To help establish the allowable nominal vertical velocity of the First Stage booster at water impact, the following goals were established:

- Goal #1: The main parachutes should be sized to provide a vertical velocity at water impact such that damage to the First Stage booster is not expected to exceed damage currently experienced by the SRB at water impact.
- Goal #2: The main parachutes should be of sufficient size to meet Goal #1, but not so large as to introduce deployment and inflation challenges that result in an unacceptable risk of recovering the First Stage booster.

Goal #1 can only be accomplished if the loads that cause water impact damage are understood, however water impact loads are caused by a combination of forces and pressures that are difficult to define. The history of water impact damage to the Shuttle SRB hardware leaves further uncertainty in the relationship between vertical velocity and water impact loads damage. The three primary water impact loading events that can inflict hardware damage during the Shuttle's SRB water impact include: 1) initial water impact, 2) cavity collapse, and 3) slapdown. These impact loading events are illustrated in Figure 4. These same impact loading events are expected to occur during the Ares I First Stage splash down impact.

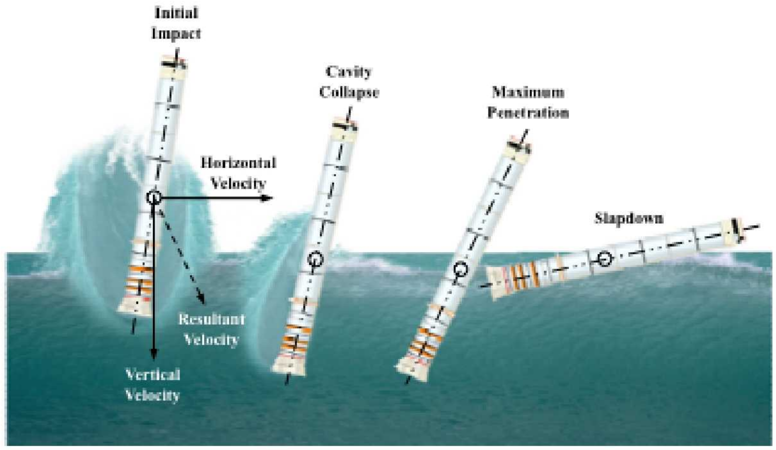

Figure 4. The same primary water loading impact events encountered by Shuttle SRBs will affect the Ares I First Stage.

Three different approaches were examined to establish a safe splash down velocity that would simultaneously meet both goals. Given that the 5-segment Ares I booster is heavier than the 4-segment SRB of Shuttle, irrespective of method; larger diameter main parachutes would be required. The first approach was to maintain the same water impact velocity as the SRB since this would require the least amount of size increase. This approach was ruled out because splash down damage caused by cavity collapse loads is considered to be influenced by impact kinetic energy and not velocity. Although it would require the greatest increase in the size of the parachutes, the second approach was to maintain the same equivalent momentum as the SRB at water impact. This approach was also ruled out due to the increased risk of deploying an extremely large parachute compounded with the fact that there is no evidence that controlling impact momentum mitigates damage any more than impact kinetic energy. The third approach was to maintain the same equivalent kinetic energy as the SRB at water impact. Kinetic energy, used as a guideline rather than a requirement, was chosen as the best approach to provide a water impact vertical velocity that meets the damage control goal. Each of the three main parachutes would require a minimum of 147-feet in diameter to achieve the water impact velocity derived from this equivalent kinetic energy method. The final design size was increased to a diameter of 150 feet to provide margin for booster mass growth. Team experts believe that issues associated with designing main parachutes as large as 150 feet in diameter are workable and will not introduce excessive risk for successful deployment and inflation.

A parachute deployment analysis was conducted to determine the maximum set of initial parachute deployment conditions that would still allow the Ares I First Stage DSS to operate successfully from aeroshell separation, through pilot, drogue, and main parachute deployment, to water impact. Reentry simulations were run with an analytical model using peak parachute loads, lateral loads, and event time intervals as inputs. The final results were defined in terms of a maximum allowable 95th percentile dynamic pressure (Q) at aeroshell separation. The 100^{th} percentile, or all of the possible trajectories, was not considered as a valid design requirement. Designing a system for 100% of all possible trajectories would be technically challenging and too expensive. High values of Q at aeroshell separation can produce velocities that interfere with the correct sequence of events occurring in the right order throughout parachute deployment. Those same high levels of Q can produce loads on the new parachutes and reacting structures that exceed structural capability. The full set of acceptance criteria must be met if that target Q is to be deemed acceptable. This analysis was used to establish the maximum allowable aeroshell deployment Q. This is a major design requirement for the DSS parachutes and for support structure loads development.

After the design requirements for safe aeroshell deployment Q were established, it became evident that some form of additional aerodynamic drag would be essential to create high altitude deceleration before the booster could achieve the 95th percentile maximum dynamic pressure for aeroshell deployment. The Shuttle 4-segment SRB decelerates during its reentry to a satisfactory velocity less than Mach 1 before the booster recovery system is deployed. This natural deceleration is due to the aerodynamic drag on the booster, which is a complex function of Mach number and angle of attack. The 5-segment booster of Ares I will be heavier and its separation conditions produce a more severe reentry than that experienced by the SRB. This results in a higher separation altitude, greater separation velocity, and a higher apogee. Consequently, the Ares I booster, reentering at approximately Mach 6, will not have sufficiently decelerated at 16,000 feet to allow for a successful deployment of the aeroshell and the parachute system.

A trade study was conducted to evaluate and select a system that would provide the means to decelerate the First Stage booster during the high altitude portion of its reentry to an acceptable velocity and dynamic pressure to allow for the successful deployment of the aeroshell and parachutes. This trade study used both quantitative and qualitative data to determine the best option. Some of the options considered were fixed and deployable fins, various ballute configurations, supersonic drogue chutes, and induced pitch tumbling following separation from the Upper Stage. The main ground rules were that the deceleration had to take place before an altitude of 16,000 feet and 95% of the reentries had to be recoverable. Additionally, the aerodynamic force and moment coefficients were assumed to be the same as for the Shuttle SRB, but the aero damping coefficients for the Ares booster were increased by 43% of those of the SRB. The induced pitch tumble option adds drag to the reentering booster by increasing its pitch rate (tumbling about the body pitch axis). The booster tends to trim at a high angle of attack, but the added tumbling will delay the achievement of this high trim angle. The tumbling forces the booster to spend more time near a broad side angle of attack and this attitude increases the drag and thus causes more deceleration.

The pitch tumble option was selected for its performance and design maturity. The Shuttle uses Booster Separation Motors (BSMs) to push the SRB away from the External Tank at separation. To induce the pitch tumble following separation from the Upper Stage, Ares I will use these same heritage motors as its Booster Tumble Motors (BTMs). The trade study concluded that a tumble rate of 12 to 16 degrees per second was necessary to achieve the required high altitude deceleration. Ares I will use four of these existing motors mounted on the inverted frustum to create the desired tumble rate. These BTMs will fire at approximately three seconds following separation from the Upper Stage. As the BTMs fire, the wake effects of the departing Upper Stage, and the plume effects of the ignited Upper Stage liquid engine will also have an effect on the tumble rate. A booster tumble analysis incorporates and combines the effects of all three of these events and hands it off as initial conditions for the reentry analysis. The frustum assembly, along with the BTMs, will be ejected after the first 180 degrees of tumble and will not be recovered with the First Stage booster. The configuration of the DSS components, including the BTMs, is shown in Figure 5.

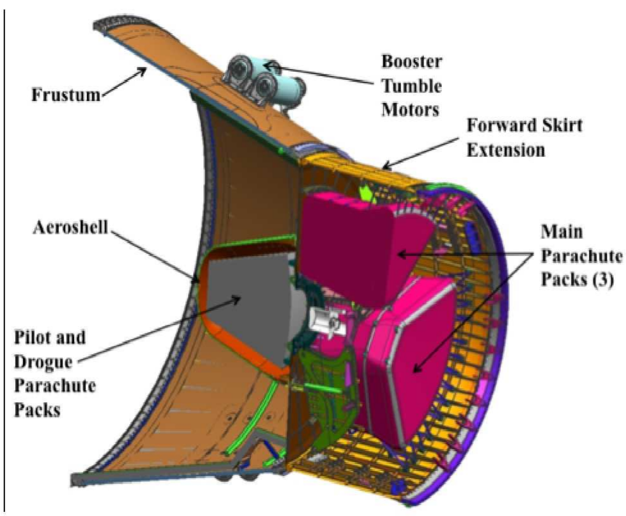

Figure 5. Ares I First Stage deceleration subsystem (DSS).

III. Design Changes

Vehicle performance constraints imposed by Constellation and the Ares I program on the DSS design are that the pilot, drogue, and main parachute packs cannot exceed the pack weights and pack volumes of their

Shuttle SRB counterparts. The DSS design challenge was to produce larger and stronger parachutes within the same weight and volume envelopes as the SRB. To achieve these objectives, stronger and lighter materials would be required as well as advanced construction techniques. The SRB heritage parachutes, designed in the 1970s, have used nylon materials in their construction. A survey was conducted of the newer materials currently available for parachute manufacture. Kevlar was selected for all of the structural axial load-bearing members, such as radials, suspension lines, reefing lines, skirt band, and vent hoops. Kevlar has a higher strength to weight ratio than nylon, which helps save both weight and pack volume for the new stronger and larger drogue and main parachutes. In most cases, a narrower webbing and fewer plies of the Kevlar material are needed for a higher Ares I loading application than would be required if using nylon.

The Ares I DSS is taking advantage of newer construction technology and over 25 years of large parachute experience in the SRB program. Whereas the SRB pilot, drogue, and main parachutes were all constructed with a cut gore design, all of the Ares I First Stage parachutes utilize continuous ribbon construction. Continuous ribbon reduces the overall parachute weight by about 8% just by avoiding the horizontal ribbon overlaps when sewing the gores together. Continuous ribbon also increases the parachute strength since the horizontal ribbons pass through the radials without joints. See Figure 6 for a side-by-side comparison of the two construction techniques.

Figure 6. This is a side-by-side comparison of Shuttle's SRB cut gore construction (left) and the Ares I continuous ribbon construction (right) techniques.

The SRB parachutes were built using a 20-degree conical construction, whereas the Ares parachutes are built utilizing a quarter-spherical canopy profile. The quarter-spherical construction produces a canopy that is seen to match its inflated shape more closely than the conical construction. This closer conformance between constructed shape and inflated shape produces a parachute that provides more drag performance for a given diameter, and creates a uniform distribution of stresses in the canopy structure. With these improvements in construction, the 150-foot diameter quarter-spherical main parachute of Ares will provide the equivalent drag of a 157-foot diameter conical parachute. A side-by-side comparison of the two construction techniques is depicted in Figure 7.

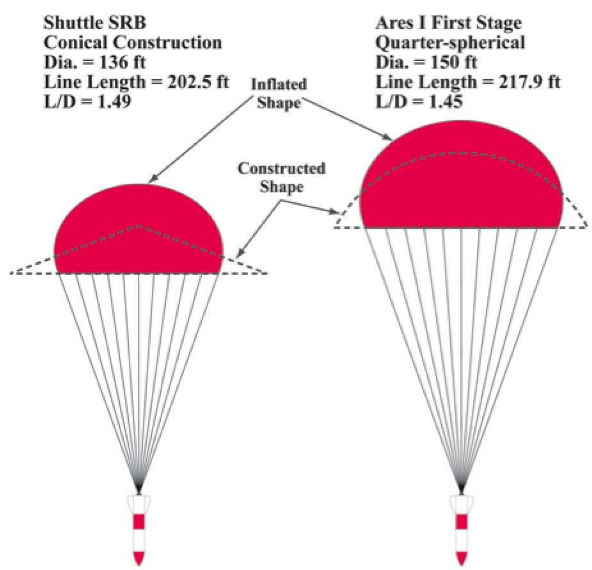

Figure 7. Shuttle SRB and Ares I First Stage parachute construction features.

Similar to the SRB parachute design, the horizontal ribbons of all of the Ares I First Stage parachutes use single ply nylon of various widths and strengths, depending on their location in the canopy. Nylon ribbons in large parachutes are susceptible to abrasion and friction burning, especially with the addition of the Kevlar radials. This is inherent with the high bag strip velocities seen in the Ares reentry environment, especially when the parachutes are being deployed from large structures that may be tilted during deployment and are not perfectly aligned with the direction of the deployment force.

Repairable abrasion and minor ribbon tears have occurred on most SRB missions. Occasionally, due to extreme events, a long continuous tear will occur in consecutive ribbons within a single gore. The SRB program, on a few occasions, has experienced tears that have propagated through the entire length of a gore causing a complete parachute failure. Consequently, the SRB program has modified their main parachutes by installing additional stronger nylon ripstop ribbons as an overlay onto various existing horizontal ribbons. The ripstop strength and spacing was determined by analysis. Ripstop is a backup, fail safe system designed to stop tears that propagate through a gore by being stronger than their adjacent ribbons. Ares I First Stage has incorporated the extra strength ripstop ribbons into the initial design of the parachutes by replacing the standard ribbon with the ripstop ribbon at designated locations. Examples of SRB parachute tears contained by ripstop are shown in Figure 8.

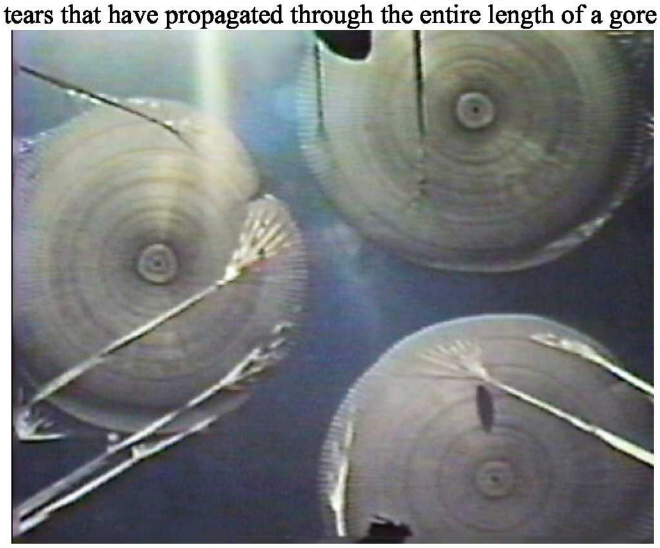

Figure 8. This is an example of SRB parachute tears that have been contained using ripstop ribbons.

The parachute vent forms the structural apex of the canopy where the radial loads converge. The Shuttle SRB program constructed the vent using a vent band and vent lines that cross from one side of the vent band to the opposite. Another SRB upgrade came with the realization that parachute damage can be induced by vent dynamics. The vent lines on large parachutes constitute a very large mass of material. If the deploying parachute is tilted from the deployment force, line sail can induce a whiplash effect in the suspension lines and canopy as they are being payed out of the bag. As the whiplash propagates through the parachute to the vent area, this large mass at the end of the whip will fold over onto the upper portion of the canopy striking it with a large force. This impact force compounded with subsequent friction burning can cause serious ribbon damage and tears, and has led to parachute failures on Shuttle SRBs. The vent areas of the Ares I First Stage parachutes are designed using vent hoops fabricated with multiple plies of Kevlar cord. Two vent hoops per parachute allow for a more orderly attachment to the radial end loops as alternating radial end loops are attached to a vent hoop. The vent hoops eliminate the large mass of vent lines at the apex of the parachute. It is anticipated that the vent hoop design will solve most of the vent dynamics issues experienced with the vent lines of the SRB. The vent area designs are shown side-by-side for comparison in Figure 9.

Figure 9. SRB main chute vent area design (left).
Ares I main chute vent area design (right).

IV. Design Status

As previously stated, the Ares I First Stage DSS parachutes will be a design evolution of Shuttle's heritage SRB system. The key driving requirements established for the parachute's design are the maximum Q at aeroshell separation, maximum water impact velocity, and the upper limit on the main parachute size. The Ares I First Stage pilot parachute is a modernized version of the respective SRB pilot. It has increased porosity to decrease the opening shock and reduce loads, the more aerodynamically efficient canopy profile, Kevlar axial load-bearing components, vent hoop, and continuous ribbon construction. The Kevlar radials increase its load carrying capability while reducing weight. A side-by-side photographic comparison of the pilot parachutes is shown in Figure 10. Table 1 follows to provide a physical comparison of the Shuttle SRB and Ares pilot parachutes.

Figure 10. Shuttle SRB pilot parachute (left).
Ares I pilot parachute (right).

Table 1. Parachute Overview:
The Ares I and the Shuttle SRB Pilot Parachutes.

Ares I Pilot Parachute Overview and Comparison to the Shuttle SRB Pilot		
Parameter	**SRB Pilot Chute**	**Ares I Pilot Chute**
Canopy Profile	20^{o} Conical	Quarter-Spherical
Construction	Cut Gore	Continuous Ribbon
Number of Gores	16	16
Nominal Diameter	11.5 feet	11.5 feet
Geometric Porosity	16%	19.3%
Drag Area	62 $feet^2$ (Reefed to 90%)	59 $feet^2$ (Reefed to 92%)
Pack Weight	41 lb_m	37 lb_m

The Ares I First Stage drogue parachute is a larger version of the SRB drogue. It has increased porosity, the more aerodynamically efficient quarter-spherical canopy profile, Kevlar axial load-bearing components, vent hoops, continuous ribbon construction, and ten ripstop ribbons strategically placed in the canopy. Comparisons of the drogue parachutes are presented in Table 2.

Table 2. Parachute Overview:
The Ares I and the Shuttle SRB Drogue Parachutes.

Ares I Drogue Parachute Overview Comparison to the SRB Drogue		
Parameter	**SRB Drogue Chute**	**Ares I Drogue Chute**
Canopy Profile	20^{o} Conical	Quarter-Spherical
Construction	Cut Gore	Continuous Ribbon
Number of Gores	60	72
Nominal Diameter	54 feet	68 feet
Geometric Porosity	16.0%	19.7%
Drag Area	1490 $feet^2$	2180 $feet^2$
Number Reefed Stages	2	3
Packed Weight	1225 pounds	1250 pounds

The three Ares I First Stage main parachutes are a larger version of the SRB main parachutes. With the intent to increase drag and provide more positive and consistent parachute inflation, the initial design started out with a reduced porosity from that of the SRB. The first two drop tests demonstrated that the main parachutes produced considerably more drag than was predicted and they exhibited some chute instability under full canopy as well. As a result of these early tests, the porosity of the mains is being increased to be more consistent with that of the SRB. The mains also incorporate the more aerodynamically efficient quarter-spherical canopy profile, Kevlar axial load-bearing components, vent hoops, continuous ribbon construction, and fifteen ripstop ribbons strategically placed in the canopy. Comparisons of the main parachutes are shown in Table 3. A main parachute in fabrication is shown in Figure 11.

Table 3. Parachute Overview:
The Ares I and the Shuttle SRB Main Parachutes.

Ares I Main Chute Overview Comparison to SRB Main Chute		
Parameter	**SRB Main Chute**	**Ares I Main Chute**
Canopy Profile	20^{O} Conical	Quarter-Spherical
Construction	Cut Gore	Continuous Ribbon
Number of Gores	160	160
Nominal Diameter	136 feet	150 feet
Geometric Porosity	15.4%	15.0%
Drag Area	8550 $feet^2$	11,800 $feet^2$
Number Reefed Stages	2	2
Parachute Pack Weight	2170 $pounds_m$	2080 $pounds_m$

Figure 11. Ares I main parachute fabrication.

V. Test Program

A drop test matrix was developed early in the program to identify the type of tests, test objectives, test conditions, and number of tests for each of the parachutes. The test matrix was divided into two categories, the first for establishing the basic performance characteristics of the parachutes, and the second as design load certification tests. The purpose of the basic performance tests is to measure the drag area at full open as well as at various reefing positions, and to measure the peak inflation loads. This data is used to establish the optimal reefing stages for load balancing and performance enhancement for the flight parachutes. The design load tests will consist of two tests for each parachute. One test will be conducted at the parachute's design load and the second test will be conducted at a 15% to 20% over design load to verify margin of safety. The performance and design load tests of the main parachute will be conducted using a single main parachute. At least one and possibly two main cluster tests will measure the total drag, and observe the inflation and stability characteristics of the large mains in a cluster configuration.

At publication, all of the basic performance tests have been completed for the pilot, drogue, and single main. One cluster test has been completed as well. Accurate design analysis of the redesigned Ares I parachutes has resulted in drop tests to date yielding results very close to predictions. The pilot chute is well characterized and will be built as designed and tested. The first drogue test experienced some line sail and corresponding minor upper canopy damage. As a result, three additional ripstops have been added to the upper and middle canopy. Additional line ties and stronger line ties were also added in the line compartment of the drogue bag. Additionally, a few other minor modifications were made to provide better control of the parachute deployment. The modifications to the packing procedures combined with the addition of a pilot chute to deploy the drogue eliminated the line sail and subsequent canopy damage during the second drogue test. Otherwise, the drogue performance characteristics were all close to predictions. The main parachutes, with their lower porosity, exhibited a higher drag and higher subsequent inflation loads than predicted. As previously noted, the porosity has been increased to that of the SRB mains to keep loads more in line with the design. All other test results indicate that the main design will meet its requirements. Scenes from some of the drop tests are shown in Figure 11.

Figure 11. Parachute drop testing.

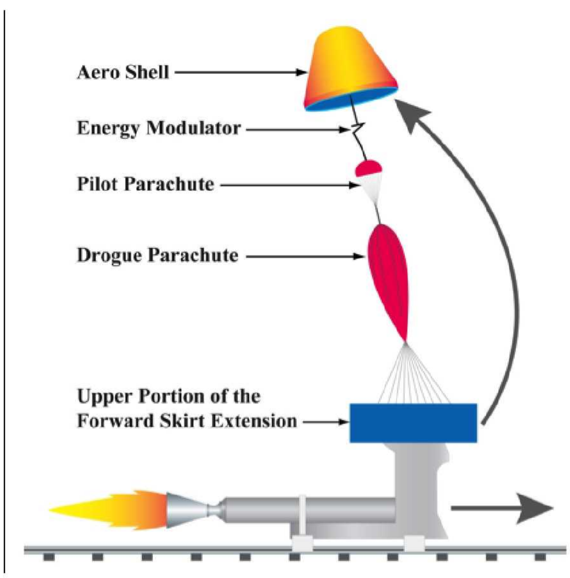

Figure 13. Rocket sled tests will be used to characterize ejection and deployment.

Two rocket sled tests will be conducted to characterize ejection of the aeroshell and deployment of the pilot and drogue under high Q conditions to compare with the analysis. A schematic of the rocket sled tests is shown in Figure 12.

In mid to late 2009, the Ares I program will launch the Ares I-X, a development flight test vehicle. The Ares I-X will have a 4-segment Shuttle SRB motor with a dummy fifth segment as the First Stage, and a dummy Upper Stage integrated with the Orion crew capsule and launch abort system. The outer mold line of the Ares I-X vehicle will closely match that of the Ares I. The primary objectives of this mission are to demonstrate dynamic control of the Ares I vehicle through launch and ascent, to perform separation and staging of the First Stage from the Upper Stage, to characterize the magnitude of the integrated vehicle roll torque throughout the flight, to record the reentry vehicle dynamics, and to demonstrate parachute performance with successful recovery of the First Stage. New Ares I First Stage parachutes had to be ready early in the development program for the recovery of the Ares I-X First Stage. This produced a significant challenge and led to early design decisions in an accelerated development and test program.

The Ares I-X reentry trajectory and loads environment, and the pilot and drogue deployment Q will be close to the SRB environment, which will be considerably lower than that of the Ares I First Stage. This provides extra margins on the parachutes and provides the confidence to fly them before conducting the design and over load drop tests. The benefits of the Ares I-X mission far out weigh the risks involved in flying development parachutes, as this is a unique opportunity to conduct a complete integrated flight test of the entire system through the full range of operation. A few of the major benefits of this test flight are to measure the trajectory response of the high altitude tumble during reentry; observe aeroshell and parachute deployment dynamics with an airborne optical system; measure parachute loads, drag areas, and water impact velocity; and assess the performance of the entire system under full load. The DSS was at a Preliminary Design Review (PDR) maturity level when fabrication of the parachutes for Ares I-X had to begin.

VI. Conclusion

At the time of publication, the Ares I-X mission is awaiting launch. The Ares I First Stage development is less than one year beyond completion of its PDR with about two years remaining until Critical Design Review (CDR). The DSS development will continue with a strong emphasis on completing the test program to validate the design. Over the next two years, the DSS will continue to respond to the ongoing vehicle changes that may have an affect on the reentry environment and DSS performance such as: booster mass, ascent trajectory and separation staging conditions, motor performance, aerodynamic uncertainties, tumble motor performance, and changes to the vehicle center of gravity and center of pressure locations.

National Aeronautics and Space Administration

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20th AIAA Aerodynamic Decelerator Systems Technology Conference

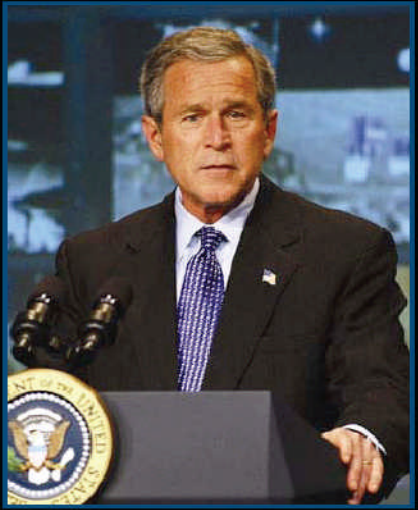
Ron King, Ares Deceleration Subsystem Manager

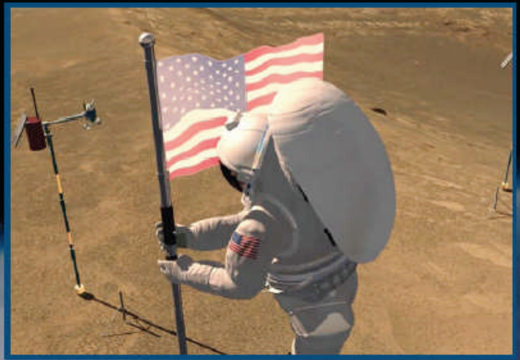
May 7, 2009

Ares Program Overview

A Bold Vision for Space Exploration, Authorized by Congress

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration





NASA Authorization Act of 2005

The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations.

Ares Program Overview

QuickTime™ and a
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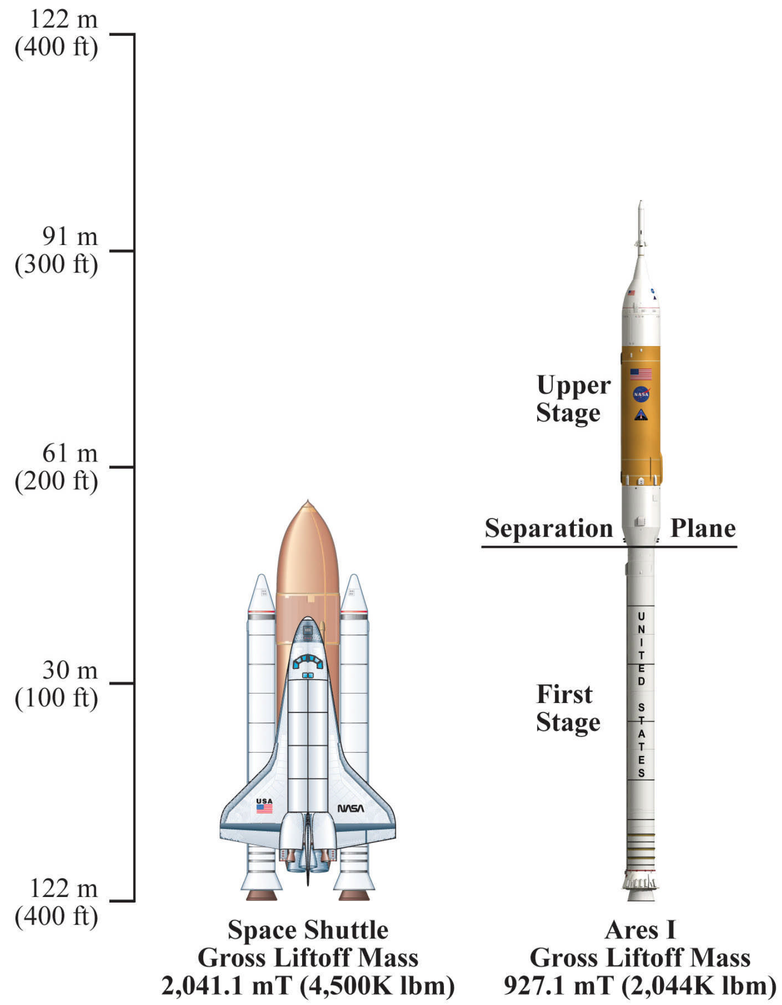
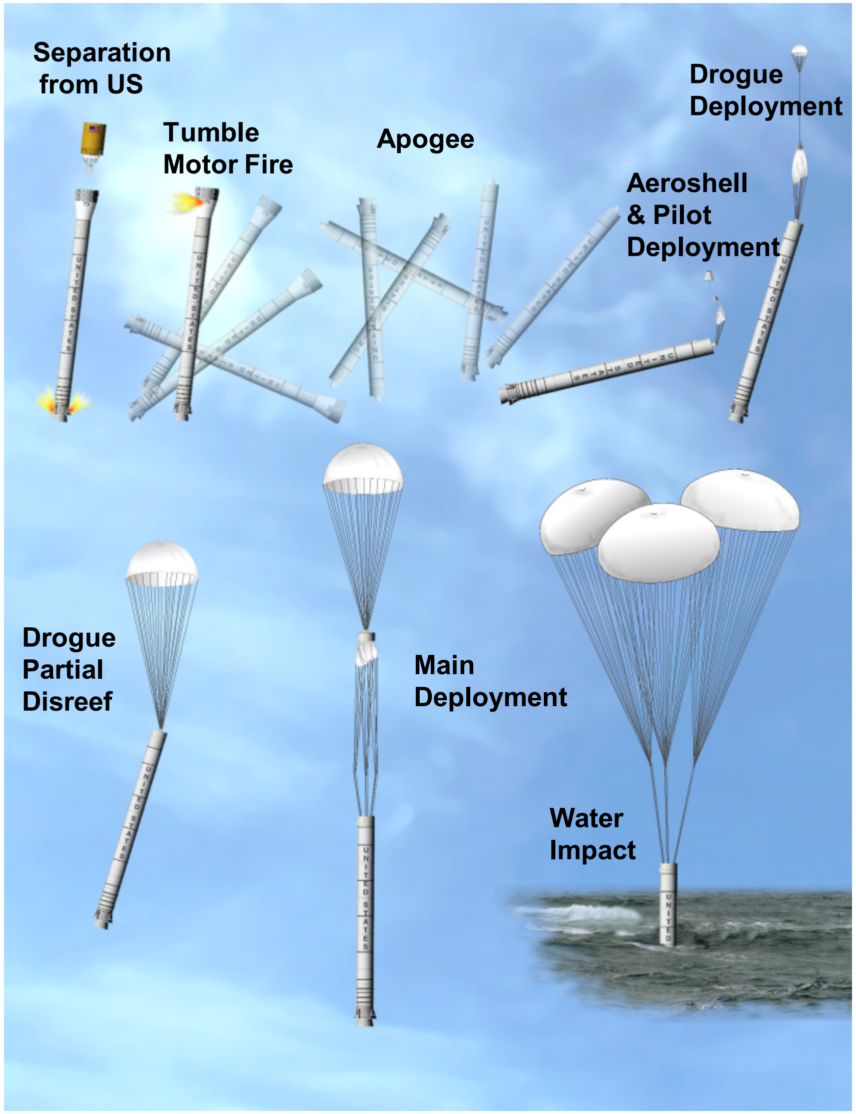
Ares I - Shuttle Vehicle Comparison

- Ares I First Stage is a 12-foot diameter, 5-segment reusable solid rocket motor (SRB heritage)
- The Shuttle SRB is a 4-segment reusable solid rocket motor
- Ares I separates from the Upper Stage at approximately 130 sec. and 190,000 ft.
- Ares I is heavier & faster than SRB
- Ares I weighs approximately 210,000 lbs. with a reentry velocity approaching Mach 6



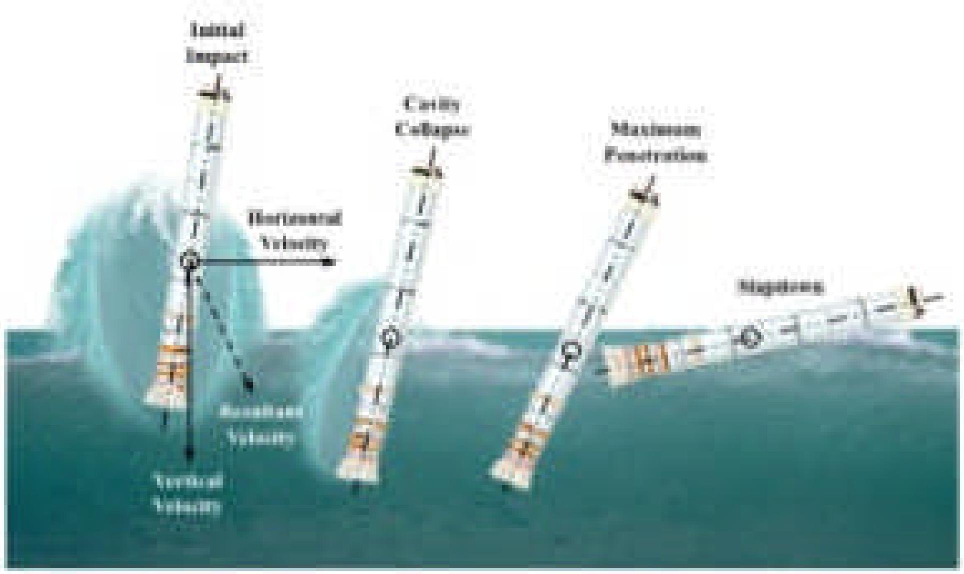
Reentry & Deployment Sequence

- The Ares I deployment sequence is similar to SRB with the addition of tumble motors
- Aeroshell ejection is triggered by a pre-set barometric altitude switch assembly
- Aeroshell deploys the pilot
- Pilot deploys the drogue
- Drogue slows and stabilizes the booster in a tail-down attitude
- 3 mains achieve the desired terminal velocity for water impact



Basis for Design

- **Program requirement:** The booster must be recoverable with no more hardware attrition than the Shuttle SRB.
- Establish maximum water impact velocity to meet attrition requirement
  - Main parachutes must be large enough to achieve required water impact velocity, but not too large to introduce deployment & inflation risks
  - SRB history uncertain on exact relationship of damage to reentry conditions, but cavity collapse is influenced more by kinetic energy than velocity
  - ***Velocity was derived by maintaining an equivalent kinetic energy as SRB***
  - The derived velocity from this approach produces 150 ft. main parachutes

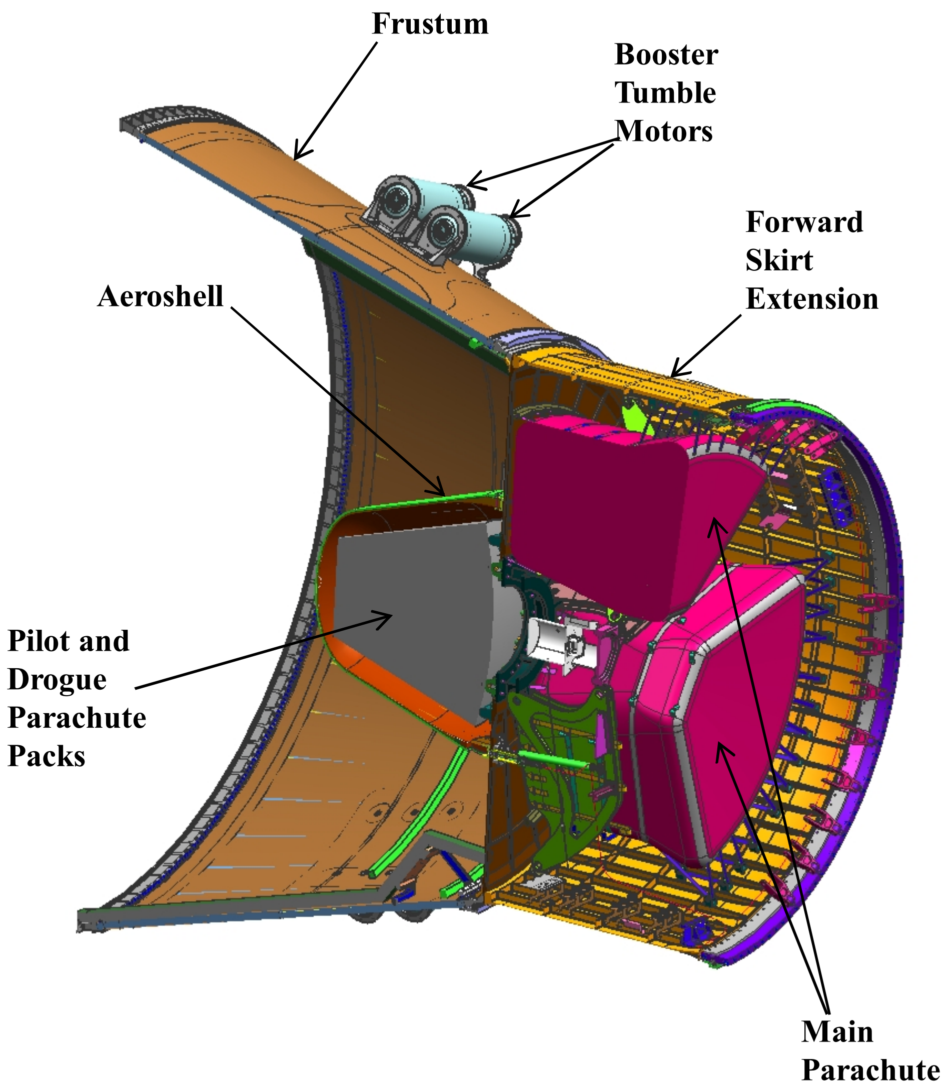


Primary water impact loading events

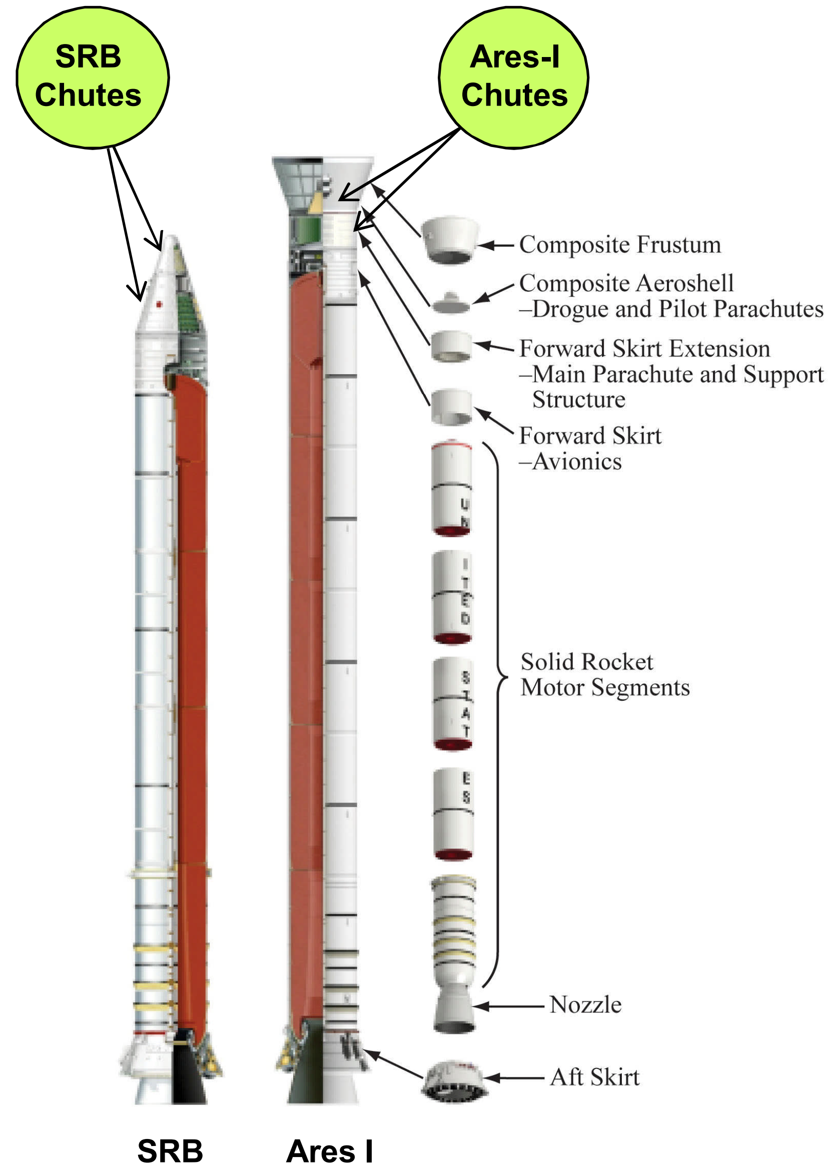
Basis for Design (cont.)

- A parachute deployment analysis using an analytical model determined the maximum allowable 95th percentile dynamic pressure (Q) at aeroshell ejection
  - Designing for 100% of all possible trajectories was not considered
    - Too expensive and technically challenging
- Max Q is the structural design requirement for the parachutes and supporting attach structures
- Additional aerodynamic drag required to achieve this max Q
  - SRB experiences natural aerodynamic drag prior to parachute deployment
  - Ares I reentry velocity is still too high prior to parachute deployment
- High altitude trade study selected the ***"Induced Pitch Tumble"*** option
- Tumble motors fire soon after separation from Upper Stage
  - Increased pitch rate adds drag to the booster by delaying its trim point
  - Forces booster to spend more time in near broad site angle of attack

Decelerator Subsystem Hardware



Ares I Forward Assembly



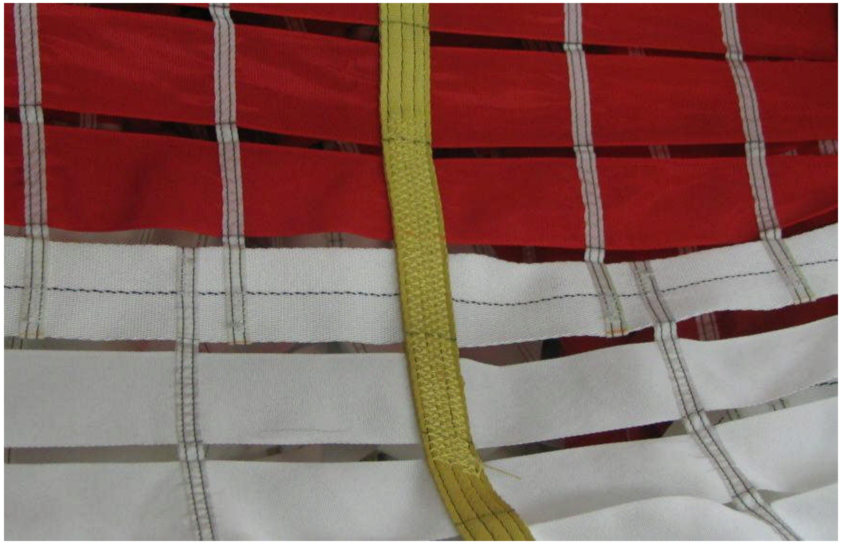
Material Design Changes

- Vehicle performance requirement
  - Chute packs cannot exceed pack weight or volume of SRB packs
- Design challenge
  - Larger & stronger chutes within same weight & volume
- Use stronger and lighter materials
  - SRB used all nylon based on 1970's technology
- Ares I using Kevlar for all structural axial load-bearing members
  - Radials, suspension lines, reefing lines, skirt band, vent hoops
  - Kevlar has a higher strength to weight ratio than nylon
  - Ares ribbons remain nylon
- Ares I incorporates nylon ripstop ribbons in design
  - Ripstop is a backup system to stop propagation of ribbon tears in a gore
  - Ripstop ribbons are stronger than the adjacent ribbons
  - Ripstop strength and location determined by analysis

Construction Design Changes

- SRB chutes were all constructed with a cut gore design
- Ares I chutes are constructed with continuous ribbon design
- Continuous ribbon reduces overall chute weight by about 8%
  - Avoids ribbon overlap where gores are sewn together
- Continuous ribbon increases parachute strength
  - Horizontal ribbons pass through radials without joints

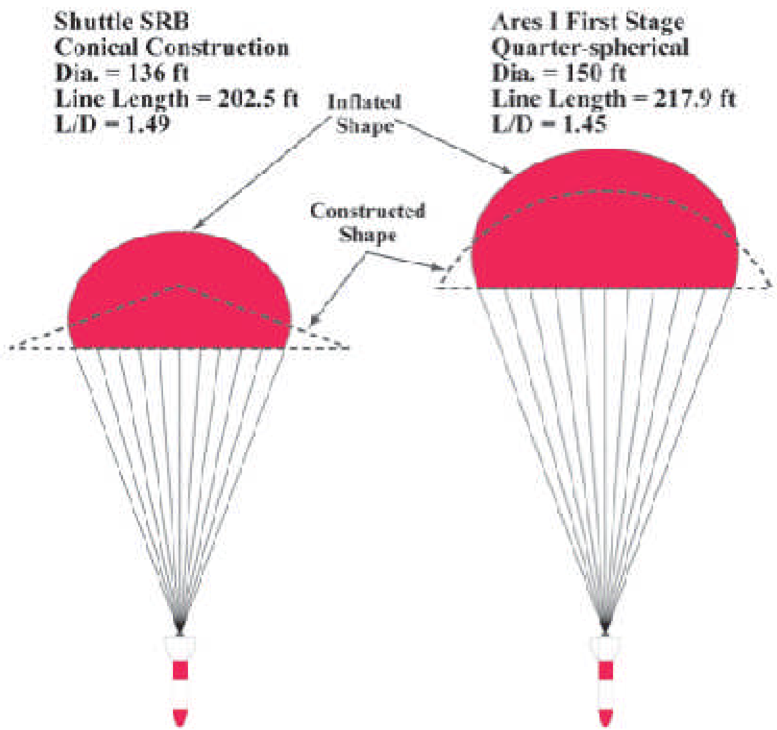
SRB Cut Gore



Ares I Cont. Ribbon

Construction Design Changes (cont.)

- SRB chutes uses 20-degree conical construction
- Ares I chutes use quarter-spherical construction
- Quarter-spherical canopy produces a closer match to its inflated shape
  - Provides more drag performance for a given diameter
  - Creates a uniform distribution of stresses in the canopy structure
  - The Ares 150 ft. quarter spherical chute provides the equivalent drag of a 157 ft. conical chute



Vent Hoop Design Changes

- SRB used a vent band & vent lines crossing over the vent band
  - Vent dynamics of large mass can induce canopy damage during deployment
  - Attributed to parachute failures on Shuttle SRB
- Ares I uses two vent hoops with multiple plies of Kevlar cord
  - Alternating radial end loops terminate at the vent hoops
  - Eliminates large mass of vent lines at chute apex

QuickTime™ and a
decompressor
are needed to see this picture.

SRB 136 ft. Main Chute Vent Band

Ares 150 ft. Main Chute Vent Cap

Ares-SRB Parachute Comparison

Parameter	SRB Pilot Chute	Ares I Pilot Chute
Canopy Profile	20^o Conical	Quarter-Spherical
Construction	Cut Gore	Continuous Ribbon
Number of Gores	16	16
Nominal Diameter	11.5 feet	11.5 feet
Geometric Porosity	16%	19.3%
Drag Area	62 $feet^2$ (Reefed to 90%)	59 $feet^2$ (Reefed to 92%)
Pack Weight	41 lb_m	37 lb_m

Ares I to SRB Pilot Chute Comparison

Parameter	SRB Drogue Chute	Ares I Drogue Chute
Canopy Profile	20^o Conical	Quarter-Spherical
Construction	Cut Gore	Continuous Ribbon
Number of Gores	60	72
Nominal Diameter	54 feet	68 feet
Geometric Porosity	16.0%	19.7%
Drag Area	1490 $feet^2$	2180 $feet^2$
Number Reefed Stages	2	3
Packed Weight	1225 pounds	1250 pounds

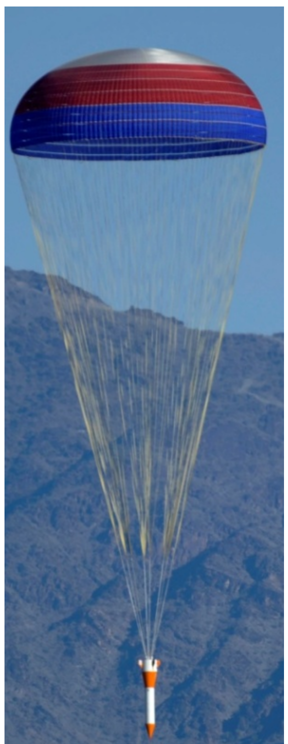
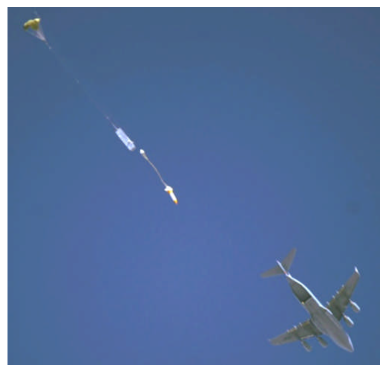
Ares I to SRB Drogue Chute Comparison

Parameter	SRB Main Chute	Ares I Main Chute
Canopy Profile	20^O Conical	Quarter-Spherical
Construction	Cut Gore	Continuous Ribbon
Number of Gores	160	160
Nominal Diameter	136 feet	150 feet
Geometric Porosity	15.4%	15.0%
Drag Area	8550 $feet^2$	11,800 $feet^2$
Number Reefed Stages	2	2
Parachute Pack Weight	2170 $pounds_m$	2080 $pounds_m$

Ares I to SRB Main Chute Comparison

Drop Test Program

- Two basic design tests for each parachute have been conducted
- Design Load & Overload tests will be conducted for each parachute
- Test data to date has been very close to predictions
  - Minor changes to porosity, packing procedures, ripstop locations


Ares I-X

- Ares will launch Ares I-X, development flight test vehicle, in late 2009
  - 4-segment SRB motor with a dummy fifth segment & Upper Stage
- Drove early design decisions, accelerated development & test program
  - Reentry & chute deployment environments will be close to Shuttle SRB
  - Provides margins and confidence to fly chutes before design/overload tests
  - Benefits of Ares I-X flight out weigh risks of flying developmental chutes
- Major benefits of this mission
  - Opportunity for fully integrated flight test of entire system
  - Measure reentry trajectory response of high altitude tumble motors
  - Observe aeroshell and chute deployment dynamics
  - Measure chute loads, drag area, water impact velocity
  - Assess system performance under full load

Conclusion

- Program is approximately two years from Critical Design Review
- Deceleration system will continue to assess vehicle changes that may affect reentry environments as development & testing continues
  - Booster mass growth, motor performance, tumble motor performance
  - Ascent trajectory and separation staging conditions
  - Refinement of aerodynamic uncertainties
  - Negative shifts in center of gravity and center of pressure

Ares I Main Parachute in fabrication

Questions

QuickTime™ and a
decompressor
are needed to see this picture.

JDTV on the Ground Following DDT-2