

CONSTELLATION'S FIRST TEST FLIGHT: ARES I-X

S.R. Davis and B.R. Askins

NASA Marshall Space Flight Center/Ares I-X Mission Management Office
Huntsville, AL

ABSTRACT

On October 28, 2009, NASA launched Ares I-X, the first flight test of the Constellation Program that will send human beings to the Moon and beyond. This successful test is the culmination of a three-and-a-half-year, multi-center effort to design, build, and fly the first demonstration vehicle of the Ares I crew launch vehicle, the successor vehicle to the Space Shuttle. The suborbital mission was designed to evaluate the atmospheric flight characteristics of a vehicle dynamically similar to Ares I; perform a first stage separation and evaluate its effects; characterize and control roll torque; stack, fly, and recover a solid-motor first stage testing the Ares I parachutes; characterize ground, flight, and reentry environments; and develop and execute new ground hardware and procedures. Built from existing flight and new simulator hardware, Ares I-X integrated a Shuttle-heritage four-segment solid rocket booster for first stage propulsion, a spacer segment to simulate a five-segment booster, Peacekeeper axial engines for roll control, and Atlas V avionics, as well as simulators for the upper stage, crew module, and launch abort system. The mission leveraged existing logistical and ground support equipment while also developing new ones to accommodate the first in-line rocket for flying astronauts since the Saturn IB last flew from Kennedy Space Center (KSC) in 1975.

This paper will describe the development and integration of the various vehicle and ground elements, from conception to stacking in KSC's Vehicle Assembly Building; hardware performance prior to, during, and after the launch; and preliminary lessons and data gathered from the flight. While the Constellation Program is currently under review, Ares I-X has and will continue to provide vital lessons for NASA personnel in taking a vehicle concept from design to flight.

INTRODUCTION

Since 2005, NASA's Constellation Program has been designing, building, and testing the next generation of launch and space vehicles to carry humans beyond low-Earth orbit (LEO), including the Ares I crew launch vehicle and Ares V cargo launch vehicle. Ares I and Ares V are being managed by the Ares Projects out of NASA's Marshall Space Flight Center (MSFC) in Huntsville, AL.

Ares I is designed to carry up to four astronauts to the International Space Station (ISS). It also can be launched in tandem with the Ares V cargo launch vehicle to perform a variety of missions beyond LEO. The Ares I-X development flight test was conceived in 2006 to acquire early engineering, operations, and environment data during liftoff, ascent, and first stage recovery for Ares I. The flight test data from Ares I-X will be used to improve the Ares I design before its critical design review in 2011—the final review before manufacturing of the flight vehicle begins.

I. VEHICLE ELEMENTS & MISSION OBJECTIVES



Figure 1. Ares I-X performs a “fly-away” maneuver just after liftoff from Kennedy Space Center’s Launch Complex 39B.

The Ares I-X flight test vehicle (FTV, Figure 1) was not designed to be a full-up space launch vehicle, but rather a development test article for evaluating how the rocket performs from liftoff through first stage separation and recovery of the first stage. The rocket consisted of a four-segment solid rocket booster (SRB) from the Space Shuttle inventory with a spacer segment to simulate a five-segment SRBs outer mold line with new forward structures, an active roll control system (RoCS), Atlas V avionics, and outer mold line simulators for the upper stage, Orion crew module, and launch abort system.

The flight and ground elements were developed, built, and integrated at multiple NASA centers, with the first stage managed at MSFC in Alabama and fabricated at ATK in Utah; the avionics systems managed by MSFC and built and tested by a combined Jacobs Engineering/Lockheed Martin team in Alabama and Colorado; the roll control system managed at MSFC and reconfigured for Ares I-X at Teledyne Brown Engineering in Huntsville, AL; the upper stage simulator built in-house at Glenn Research Center (GRC) in Ohio; the crew module/launch abort system (CM/LAS) simulator built in-house and systems engineering and integration (SE&I) function performed at Langley Research Center (LaRC) in Virginia; and the ground systems and ground operations performed at Kennedy Space Center (KSC) in Florida.

This part-active, part-simulator vehicle was designed to achieve—and met—all of the following primary objectives:

- Demonstrate control of a dynamically similar, integrated Ares I/Orion, using Ares I relevant ascent control algorithms
- Perform an in-flight separation/staging event between a Ares I-similar first stage and a representative upper stage
- Demonstrate assembly and recovery of a new Ares I-like first stage element at KSC
- Demonstrate first stage separation sequencing, and quantify first stage atmospheric entry dynamics, and parachute performance
- Characterize magnitude of integrated vehicle roll torque throughout first stage flight

II. OPERATIONAL LESSONS LEARNED

Operational lessons from Ares I-X will be especially important for NASA as the agency retires the Space Shuttle and transitions to the Constellation Program, which is designed to explore beyond LEO, but also be less labor-intensive during stacking and pad operations than Shuttle. The Ares I-X mission had a “lean” team, comprising approximately 700 civil servant employees over the life of the project compared to the thousands involved in Shuttle and Apollo missions. While missions to and beyond low-Earth orbit obviously will require additional personnel, this lean approach will serve as a model for future Constellation missions. The effort to

design, build, transport, assemble, and launch Ares I-X provides an opportunity for a new generation of engineers and operations staff to work while learning with a new launch vehicle.

Logistics and Infrastructure

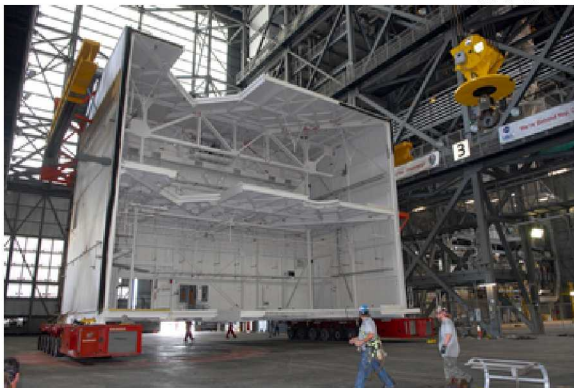
Several special logistics arrangements had to be made to transport all of the vehicle elements to KSC. Additionally, vehicle stacking and launch infrastructure had to be modified at KSC's Vehicle Assembly Building (VAB) and Launch Complex (LC) 39B to accommodate this new rocket.

Because the Ares I-X flight test vehicle (FTV) was built at multiple sites across the nation, it required multiple means of transportation to reach KSC. The first stage motor segments traveled from the ATK plant in Utah to Florida by rail, using methods and equipment already set up to support the Space Shuttle. The new forward structures arrived from an ATK subcontractor via truck from Indiana. The CM/LAS simulator was flown to KSC on a U.S. Air Force C-5 cargo transport.

The upper stage simulator (USS) required the most complex transportation logistics, as Glenn Research Center (GRC) in Ohio traditionally has not been part of NASA's launch vehicle infrastructure (Figure 2). The USS had to be broken up into 11 cylindrical sections known as "tuna cans" no taller than 9.5 feet (2.9 meters) to ensure that they could fit under bridges when transported by truck via interstate highways and under bridges when transported by commercial barge on the Ohio and Mississippi Rivers. The USS segments also included interior platforms and ladders to give ground operations staff access to interior sections to the top of Ares I-X above the height of the Shuttle-era fixed service structure (FSS) at Launch Complex 39B.



Figure 2. Transport sequence for the Ares I-X Upper Stage Simulator: tractor-trailer to the Ohio River, barge transport on the Delta Mariner to KSC, tractor-trailer from port into the VAB.



In the VAB, several platforms and other structures designed for the Space Shuttle's configuration had to be removed to accommodate the much taller, in-line design of Ares I-X, while other platforms and environmental control systems had to be installed to meet flight test needs (Figure 3).

Vehicle preparation activities resulted in lessons learned for ground operations personnel, including hardware deliveries, cable routing, transferred work and hardware custodial paperwork.



Figure 3. Platform C was removed from the VAB's High Bay 3 (top) and other platforms were added (bottom) to give ground operations staff access to the Ares I-X interstage segment.

Ares I-X also proved to be a resource challenge, as individuals and ground service equipment (GSE) supporting the mission also were required for Shuttle or Atlas V operations at LC 40/41 at Cape Canaveral Air Force Station. Conflicts over resources will continue to be a challenge for the agency in the next few years, especially if Ares flight tests continue while the Space Shuttle Program is extended.



Figure 4. Gaseous oxygen arm being removed (left) and artist's concept (right) depicting hardware added to LC 39B for Ares I-X.

At LC 39B, several Shuttle-specific access arms were removed (e.g. the gaseous oxygen "cap" usually attached to the top of the external tank) and others were added (the vehicle stabilization system, environmental control system, and access bridge for the first stage avionics module) to accommodate the Ares I-X FTV (Figure 4). However, this work was delayed by resource conflicts, including a launch-on-need backup Shuttle mission for the Hubble Space Telescope servicing flight in August 2009.



Figure 5. The GC3 rack installed in the Mobile Launcher Platform also is used to control Atlas V.

Ground command, control, and communication (GC3) hardware was incorporated into the Mobile Launcher Platform (MLP). The primary function of the GC3 unit, an Atlas V system provided by Lockheed Martin, was to provide control and data interfaces between the FTV and ground operations during countdown operations.



Figure 6. The VAB Launch Control Center's Firing Room 1, before (top) and after (bottom) refurbishment for Ares I-X.

Perhaps the most dramatic change made to KSC's launch infrastructure was made to the VAB Launch Control Center's Firing Room 1. Originally used to launch the first Space Shuttle mission, Firing Room 1 received a complete refurbishment of its wiring, computer, console, and interior fixtures. The entire room was not needed, given the limited scope of Ares I-X, but once flight testing is completed, the room will be remade to support full Constellation Program missions to the International Space Station, the Moon, and beyond.



Figure 7. The single lightning mast atop the fixed service structure (FSS) at LC 39B (top) was replaced by a trio of towers (bottom).

The lightning protection system at LC 39B was replaced by a trio of 600-foot-tall towers connected by a catenary wire to account for the much greater height of the vehicle (Figure 7). These towers will be kept in place when the rest of the LC 39B service structure is dismantled to make way for purpose-built structures needed for the Constellation Program.

Like Shuttle, Ares I-X was stacked on a MLP and rolled out to the pad on an Apollo-era crawler-transporter. Ares I-X was held in place by the four hold-down posts attached to the first stage aft skirt during rollout, and a new vehicle stabilization system (VSS) added to the vertical service structure held onto the vehicle keeping it from swaying on the pad prior to launch. Both systems proved more than sturdy enough to keep the vehicle vertical. Wind-induced oscillations,

even during winds up to 25 knots, did not exceed three inches over the entire length of the 327-foot rocket. The VSS itself, comprising commercial hydraulic struts, was a low-cost design choice made late in the project that proved as effective as a proposed support tower built atop the MLP. The use of commercial hardware saved the agency millions of dollars.

Vehicle Stacking and Launch

The stacking of Ares I-X went very smoothly, demonstrating the conscientious efforts by the Ares I-X team to keep the vehicle's design and hardware fabrication integrated across multiple NASA centers. The vehicle segments, but also particularly the avionics hardware, fit and functioned together with minimal rework. Problems were solved by a dedicated trouble-shooting team established on-site at the VAB, with a separate team established to address issues with the over 700 sensors comprising the developmental flight instrumentation (DFI).

One of the most surprising lessons learned during Ares I-X was the launch constraint imposed by triboelectrification, a static-generating condition created by flying through moisture-laden clouds that can interfere with radio signals to and from the vehicle. Triboelectrification can be mitigated most easily by encasing electronics in "Faraday cage" structures that insulate electronics from exterior sources of static and by covering the vehicle in non-static-producing paint. Late in the mission planning, there was some question about whether Ares I-X had paint which was not consistent with triboelectrification requirements on some of its exterior surfaces. Because the mitigation analysis was still in work as the launch day approached, the four-hour scheduled launch windows in October were constrained by the need for nearly cloud-free skies. Ares I-X finally launched on the second day's attempt after multiple windows failed to meet triboelectrification requirements. Future Ares vehicles will address this issue earlier in the requirements process.

Additional challenges to launch were created by difficulties removing a five-hole probe sensor cover prior to launch, commercial shipping entering the launch range, and the need to recheck the avionics systems after a thunderstorm that produced lightning strikes near the vehicle the night after the first day's launch window.

III. ORGANIZATIONAL LESSONS LEARNED

Lessons learned from Ares I-X will be shared with the Ares Projects through written and verbal reports, video bites, team meeting with CxP teams and through integration of mission team members into the Project workforce.

As noted earlier, the flight and ground elements were developed, built, and integrated at multiple NASA centers, making for a complex technical and management environment. Because of this complexity and the likelihood that it will continue, Ares I-X was observed closely as a potential management model for future human spaceflight projects.

Originally multiple organizations were charged with responsibility for executing Ares I-X, including the Ares Projects Flight and Integrated Test Office (FITO) at MSFC, SE&I at LaRC, and Ground Operations at KSC. The Ares I-X Mission Management Office (MMO) at JSC was established by the Constellation Program as a separate organization uniting these diverse entities to reduce red tape, overlapping/conflicting lines of authority, and numbers of review boards required to approve engineering changes. With the MMO established, mission goals, roles, and responsibilities were more clearly defined and progress became more rapid.

Over the course of test development, the MMO identified the following lessons learned as affecting mission success:

Establish Clear Mission Objectives

In the case of Ares I-X, these objectives supported early definition of the flight and ground hardware configurations; helped define the organizational structure; supported a more rapid development timeline; and reduced continual assessment of mission objectives and requirements. As a result of establishing our mission objectives early and not allowing them to evolve or "creep," the team was able to stay on task and, for the most part, stay on schedule.

Employ a Small and “Flat” Team Organization

The smaller, leaner, and “flatter” (compared to the Shuttle or parent Ares) organization minimized decision times, encouraged communication among the various players, and enhanced a “sense of team.” A small team provided almost a “skunk works”-like approach, where the MMO was able to pull talented people and dedicated people from across the agency. One thing that could have been done earlier and better was to co-locate key personnel in one location, but that option was not feasible. Instead, the team communicated daily via teleconferences, email, and in-person meetings. However, there were times when the smaller staff resulted in work overloading on particular individuals. The end result was that the small, flat team worked well for Ares I-X, but it might not work in other situations. Efforts will need to be made in the future to ensure that similar “lean” teams have contingency plans and backup resources to call upon to reduce workload on key personnel.

Loads and Environments Development

The estimated aerodynamic, thermal, acoustic, and other loads and environments affecting the FTV were analyzed right up to the end, as the computer models for the flight environments and the vehicle flying through them evolved. The models evolved as the team learned to refine which elements of their models were too conservative or not conservative enough. These loads analysis cycles caused a strain on the team and additional time pressure as the launch date approached. In the future, flight test teams should learn to expect loads and environments changes and plan accordingly.

Establish Clear Development Flight Instrumentation (DFI) Requirements

When the engineers and scientists were originally asked what DFI sensors they needed or wanted on the FTV for an effective test, the total requested resulted in a list of over 5,000 sensors. Additionally, more time was spent discussing potential sensor removal (or better stated as “not installation”) than the actual time installing the sensors. As a result of these situations, it became clear that working from the top down based on flight test objectives leads to a more appropriate sensor suite. The MMO leadership team came to realize that proposing a reduction to an approved sensor suite will most likely result in a lengthy discussion (controversy). The best way to handle issues of this sort is to establish a separate DFI Control Board.

It Takes a Lot of Effort to Change Very Strong Institutional and Programmatic Ways of Doing Business

While NASA is assumed by the public to be a single entity spread across multiple Centers, the fact remains that each of these Centers has its own special history, institutional culture, and set of practices that affect how business is done. For example, technical and procedural terminology is different between centers, and there are variations in practices and procedures for verification, integrated testing, engineering file formats, and review processes, which can impact the program. These inter-Center differences mean that future mission teams will need to establish review processes early to eliminate conflicting or overlapping engineering reviews. Another lesson learned while developing the avionics for Ares I-X was that contractor processes are different from, and in some cases more applicable to, the project at hand.

Establish an Engineering Development Fixture (EDF) for CAD 3-D Models

Early in the formation of the Ares I-X MMO, the team established a digital EDF that supported fit checks of interfaces and configuration changes/updates; enabled the team to move through the design process quickly while communicating at the design level between IPTs; and supported the engineering and independent review process used in detailed communication of the design. By establishing the requirement for an EDF early in the design process, the team was able to identify interferences early that saved schedule, cost, and rework. A CAD model delivery schedule and format specifications should have been established as contractual requirements early in the flight test planning. One thing the Ares I-X team did not do was establish fixed standards for submitting engineering models. As a result, a great deal of time was spent converting file formats, which slowed our use of the EDF.

IV. PRIMARY OBJECTIVES AND FLIGHT DATA

Ares I-X was a test flight that was designed to meet a set of objectives to supply data to the Constellation Program. Ares I-X met all of its primary and secondary objectives, which are listed below, along with a brief description of the extent to which each objective was met:

Primary Objectives

P1: Demonstrate control of a vehicle dynamically similar to the Ares I/Orion vehicle using Ares I relevant flight control algorithms. – Was successfully met based on the GNC data from the flight.

P2: Perform a nominal in-flight separation/staging event between an Ares I-similar first stage and a representative upper stage. – Was successfully met based on all data. The inert USS experienced aerodynamic instability after separation, causing what looked like a non-nominal trajectory on video, but there was no recontact after separation.

P3: Demonstrate assembly and recovery of a new Ares I-like first stage element at KSC. The Ares I-X team very successfully demonstrated assembly in the VAB and recovery of the first stage by the Shuttle recovery ships.

P4: Demonstrate first stage separation sequencing, and quantify first stage atmospheric entry dynamics, and parachute performance. – The first stage was recovered successfully; however, one main parachute failed and one was damaged, while the remaining main parachute's performance is being characterized to influence the design of the new system.

P5: Characterize magnitude of integrated vehicle roll torque throughout the first stage of flight. – Roll torque was successfully measured with very little roll torque detected out of the motor or the aerodynamic loading measured by the rocket's GN&C system.

Secondary Objectives

S1: Quantify the effectiveness of the first stage separation motors. – This objective was met based on flight data reviewed from first stage.

S2: Characterize induced environments and loads on the FTV during ascent flight phases. – This was met based on the data collected in flight, with loads, aerodynamics, vibroacoustics, and thermal environments feeding back into the models' predictions.

S3: Demonstrate a procedure to determine the vehicle's pre-launch geodetic orientation vector for initialization of the flight control system. – This objective was met and developed by the Ares I-X Avionics IPT.

S4: Objective deleted.

S5: Characterize induced loads on the launch vehicle on the launch pad. – This information was through data collected on loads, vibroacoustics, and thermal environments in flight.

S6: Assess potential Ares I access locations in the VAB and on the pad. – Vehicle access locations were assessed and the objective was met, but the access for the Ares I-X ended up being too different from the Ares I design.

S7: Validate first stage electrical umbilical performance. – The first stage's umbilical performance was assessed and the objective was met, but the umbilical for the test flight became a design customized for Ares I-X only.

Ares I-X was a very successful flight test for NASA and the nation's space program.

CONCLUSION

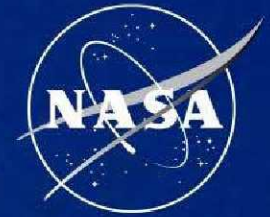
Ares I-X has provided NASA personnel with first-hand knowledge of how to develop, build, launch, and absorb the lessons from a new launch vehicle. This valuable experience will continue to provide dividends as the agency develops Ares I or any rocket to succeed the Space Shuttle. Hardware and formal processes can be transferred from one generation of engineers and

operations personnel relatively easily. The more flight tests NASA personnel are able to perform in the coming years, the better prepared they will be to handle future challenges and emergencies when human beings once again explore beyond low-Earth orbit.

ONGOING AND FUTURE WORK

Ares I-X is still developing the final reports that turn the data findings over to the mainline Ares Projects. The team is working with the preliminary data now; they will then take the final data and generate final correlation back to the Ares I flight vehicle models to see how their models and predictions are performing. This is a large, complex task, which is scheduled to be complete by October 1, 2010. The data and understanding gained from Ares I-X will go a long way with helping NASA understand any vehicle that is developed in the future.

Mission Management Office (MMO)



Ares I-X Constellation's First Test Flight: Ares I-X

S.R. Davis, **Deputy Mission Manager**

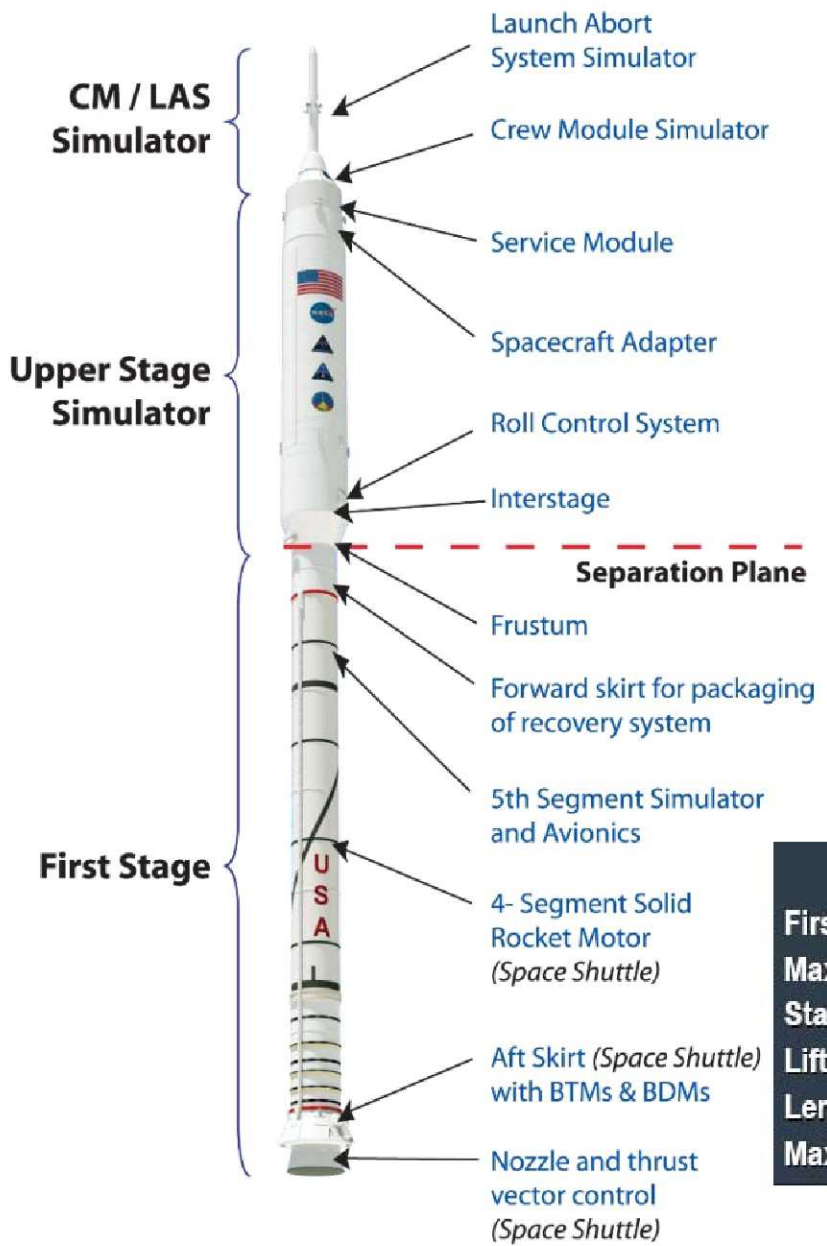
B.R. Askins, Project Integration Manager



- ◆ **Vehicle Elements & Mission Objectives**
- ◆ **Operational Lessons Learned**
 - Logistics and Infrastructure
 - Vehicle Stacking and Launch
- ◆ **Organizational Lessons Learned**
- ◆ **Mission Objectives and Results**
- ◆ **Conclusion**



Vehicle Overview



◆ Combined proven space flight and simulation hardware

• Active Systems included:

- Four-segment solid rocket booster
- Atlas V-based avionics
- Roll control system
- Parachutes deceleration system
- Booster deceleration and tumble motors
- Developmental flight instrumentation

• Simulator hardware

- Upper stage
- Orion crew module
- Launch abort system
- Fifth segment of booster

	Ares I-X	Ares I
First Stage Max. Thrust (vacuum):	14.1M N (3.13M lbf)	15.8M N (3.5M lbf)
Max. Speed:	Mach 4.7	Mach 5.84
Staging Altitude:	39,624 m (130,000 ft)	57,453 m (188,493 ft)
Liftoff Weight:	834k kg (1.8M lbm)	927k kg (2.0M lbm)
Length:	99.1 m (327 ft)	99 m (325 ft)
Max. Acceleration:	2.46 g	3.79 g



Ares I-X Development Flight Test



P2) Perform in-flight separation/staging event at 124 sec ~ 130,000 feet

Vehicle Height:	327 feet
Weight at Ignition:	1.8 M-lbm
Max. Acceleration:	2.5 g's
Max. Speed:	Mach 4.7

P4) Demonstrate FS entry dynamics and sequencing of events (parachute deployment, etc.)

P5) Characterize integrated vehicle roll torque

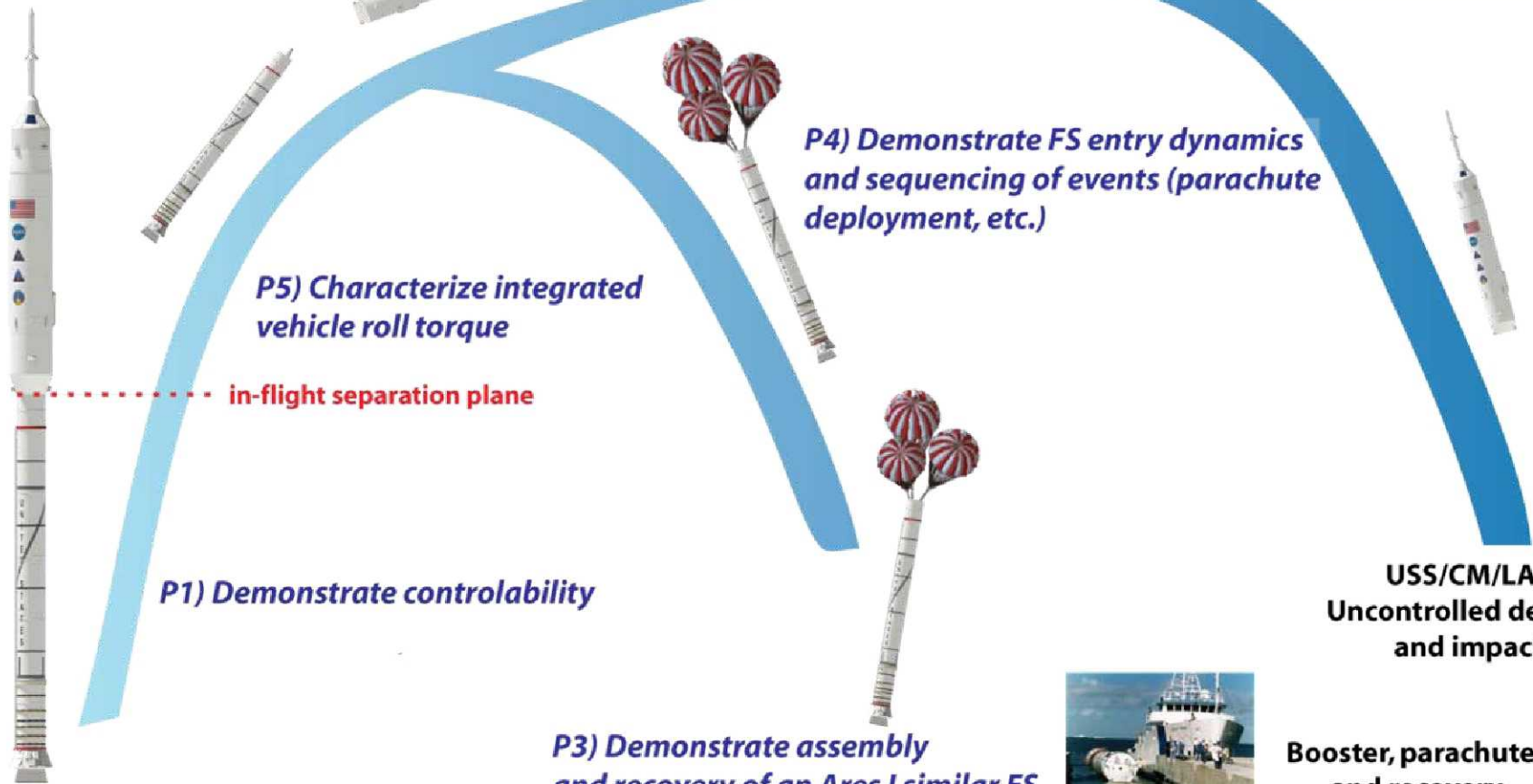
in-flight separation plane

P1) Demonstrate controlability

P3) Demonstrate assembly and recovery of an Ares I similar FS

**USS/CM/LAS
Uncontrolled descent and impact**

Booster, parachutes and recovery





Achieved ALL Primary objectives:

Demonstrated control of a dynamically similar, integrated Ares I/Orion, using Ares I relevant ascent control algorithms

Performed an in-flight separation/staging event between a Ares I-similar First Stage and a representative Upper Stage

Demonstrated assembly and recovery of a new Ares I-like First Stage element at KSC

Demonstrated First Stage separation sequencing, and quantified First Stage atmospheric entry dynamics, and parachute performance

Characterized magnitude of integrated vehicle roll torque throughout First Stage flight

- ◆ **Transportation of vehicle elements**
- ◆ **Launch infrastructure modifications:**
 - KSC Vehicle Assembly Building
 - Launch Complex 39B
- ◆ **Resource challenges**





Operational Lessons Learned – Logistics and Infrastructure (2 of 2)

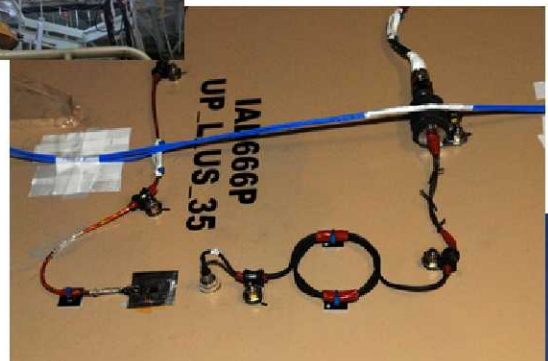


- ◆ **Mobile Launcher Platform**
- ◆ **Launch Control Center Firing Room**
- ◆ **Lightning Protection System**



Operational Lessons Learned – Vehicle Stacking and Launch

- ◆ Vehicle stacking
- ◆ Developmental Flight Instrumentation (DFI)
- ◆ Triboelectrification





Liftoff of Ares I-X!





Organizational Lessons Learned



- ◆ **Establish clear mission objectives**
- ◆ **Employ a small and “flat” team organization**
- ◆ **Expect loads and environments to evolve**
- ◆ **Establish clear DFI requirements**
- ◆ **It takes a lot of effort to change very strong institutional and programmatic ways of doing business**
- ◆ **Establish an engineering development fixture (EDF) for CAD 3-D models**



Primary Objectives & Results



Objective	Result
P1: Demonstrate control of a vehicle dynamically similar to the Ares I/Orion vehicle using Ares I relevant flight control algorithms.	Objective met.
P2: Perform a nominal in-flight separation/staging event between an Ares I-similar first stage and a representative upper stage.	Objective met. Inert USS experienced aerodynamic instability after separation, but no recontact after separation.
P3: Demonstrate assembly and recovery of a new Ares I-like first stage element at KSC.	Objective met.
P4: Demonstrate first stage separation sequencing, and quantify first stage atmospheric entry dynamics, and parachute performance.	Objective met.
P5: Characterize magnitude of integrated vehicle roll torque throughout the first stage of flight.	Objective met.



Secondary Objectives & Results



Objective	Result
S1: Quantify the effectiveness of the first stage separation motors.	Objective met.
S2: Characterize induced environments and loads on the FTV during ascent flight phases.	Objective met.
S3: Demonstrate a procedure to determine the vehicle's pre-launch geodetic orientation vector for initialization of the flight control system.	Objective met.
S4:	Objective deleted early in development.
S5: Characterize induced loads on the launch vehicle on the launch pad.	Objective met.
S6: Assess potential Ares I access locations in the VAB and on the pad.	Objective met, but access for Ares I-X ended up being different from the Ares I design.
S7: Validate first stage electrical umbilical performance.	Objective met, but umbilical for test flight became customized for Ares I-X only.

- ◆ **Ares I-X has provided NASA personnel with first-hand knowledge of how to develop, build, and fly a new launch vehicle**
- ◆ **This valuable experience will provide dividends as the agency works with new launch vehicles**
- ◆ **Hardware and processes can be transferred from one generation of engineers and operations personnel to the next**
- ◆ **The more flight tests NASA personnel are able to perform, the better prepared they will be to handle future challenges and emergencies**





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