MSFC-482

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Flight and Integrated Testing: Blazing the Trail for the Ares Launch Vehicles

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Abstract

It has been 30 years since the United States last designed and built a human-rated launch vehicle. NASA has marshaled unique resources from the government and private sectors that will carry the next generation of astronauts into space safer and more efficiently than ever and send them to the Moon to develop a permanent outpost. NASA's Flight and Integrated Test Office (FITO) at Marshall Space Flight Center has primary responsibility for developing and conducting critical ground and flight tests for the Ares I and Ares V launch vehicles. These tests will draw upon Saturn and the Space Shuttle experiences, which taught the value of using sound systems engineering practices, while also applying aerospace best practices such as "test as you fly" and other lessons learned. FITO will use a variety of methods to reduce the technical, schedule, and cost risks of flying humans safely aboard a launch vehicle.

FITO is divided into two principal operational areas: flight testing and integration and verification testing. The flight test team will conduct a progressive series of demonstration (ascent), verification (orbital), and mission flight tests of the Ares I and later Ares V launch vehicle. These flight tests will supplement the integration and verification team's ground tests, which will include vibration, avionics, and propulsion system testing.

The flight test group's first effort will be the Ares I-1 demonstration test, slated for April 2009. This test will demonstrate the ascent flight control system performance with dynamically similar hardware, determine roll control methods during flight, better characterize the stage separation environment experienced during future operational flights, test the parachute and recovery systems, validate ground operations, and gather critical data about the flight dynamics of the integrated launch vehicle stack,. The Ares I-1 test vehicle will incorporate a mix of flight and mockup hardware, reflecting a configuration similar in mass and weight to the operational vehicle. The vehicle's flight profile will closely approximate the flight conditions the Ares I will experience and will aid the timing of first stage burnout, first stage separation, and upper stage ignition. Ares I-1 is merely the first test in a flight manifest that includes two suborbital demonstrations, at least two orbital verification tests, and one automated mission flight. The flight test group will work with progressively more complex launch vehicles and tests, learning from experience as they progress toward crewed operations in 2014.

Ground testing was responsible for much of the Apollo-Saturn launch vehicles' success.[1] The integration and verification testing team, by conducting extensive ground testing of complete systems, can reduce risk to the vehicle prior to flight. For instance, one test the group will conduct is the ground vibration test, which will provide a pre-flight check to evaluate the vehicle's performance under launch-induced vibrations as well as the quality analytical models. Results from this test are analyzed to estimate a set of modal properties such as natural frequencies and mode shapes, and are then compared with the analytical model to determine the error and uncertainty of the model.[2]

Another important element of the Ares I-1 test flight is the avionics system. This system includes the flight avionics hardware, software, and ground command and control system. The avionics hardware for this flight is not required to be extensible to CLV; it is for test purposes. However, the guidance and control algorithm will be based on the one used for CLV. Testing of the GNC algorithms is a primary objective of the Ares I-1 flight. The avionics system will be a combination of avionics components from Evolved Expendable Launch Vehicles (EELVs) and heritage Space Shuttle systems. The Ares I-1 team will also employ a Systems Integration Laboratory (SIL) that tests the avionics on the ground and fully embraces the industry best practice of "test as you fly." The avionics system will employ the aircraft-qualified Development Flight Instrumentation (DFI) used for the Boeing 7E7 series and the U.S. Air Force Joint Strike Fighter (JSF) to collect, transmit, and store the data vital for a successful test flight.

Basing vehicle design refinements on flight and ground test information puts NASA one step closer to the full-up "test as you fly" scenarios and a fully operational fleet of launch vehicles.

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[1] Bilstein, Roger E. *Stages to Saturn.* Gainesville, FL: University of Florida Press, 2003, p. 183.
[2] "Uncertainty Models from Ground Vibration Testing." *NASATech.com.* 2 February 2006. http://www.nasatech.com/Briefs/Dec01/DRC0154.html.

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Abstract

It has been 30 years since the United States last designed and built a human-rated launch vehicle. The National Aeronautics and Space Administration (NASA) has marshaled unique resources from the government and private sectors that will carry the next generation of astronauts into space safer and more efficiently than ever and send them to the Moon to develop a permanent outpost. NASA's Flight and Integrated Test Office (FITO) located at Marshall Space Flight Center and the Ares I-X Mission Management Office have primary responsibility for developing and conducting critical ground and flight tests for the Ares I and Ares V launch vehicles. These tests will draw upon Saturn and the Space Shuttle experiences, which taught the value of using sound systems engineering practices, while also applying aerospace best practices such as "test as you fly" and other lessons learned. FITO will use a variety of methods to reduce the technical, schedule, and cost risks of flying humans safely aboard a launch vehicle.

Nomenclature

3D	=	Three Dimensional
ATVC	=	Ascent Thrust Vector Controller
CaLV	=	Cargo Launch Vehicle
CDR	=	Critical Design Review
CEV	=	Crew Exploration Vehicle
CLV	=	Crew Launch Vehicle
CM	=	Crew Module
COTS	=	Commercial Off The Shelf
CxP	=	Constellation Program
DCR	=	Design Certification Review
DFI	=	Developmental Flight Instrumentation
EDS	=	Earth Departure Stage
EELV	=	Evolved Expendable Launch Vehicle
EGSE	=	Electrical Ground Support Equipment
FITO	=	Flight and Integrated Test Office
FS	=	First Stage

FSB	=	Five Segment Booster
FTINU	=	Flight Test Inertial Navigation Unit
FTS	=	Flight Termination System
FTV	=	Flight Test Vehicle
GC-3	=	Ground Command, Control, and Communication
GN&C	=	Guidance, Navigation, and Control
GVT	=	Ground Vibration Test
ISS	=	International Space Station
IVDT	=	Integrated Vehicle Dynamic Test
IU	=	Instrumentation Unit
JSF	=	Joint Strike Fighter
KSC	=	Kennedy Space Center
LAS	=	Launch Abort System
LH_2	=	Liquid Hydrogen
LOX	=	Liquid Oxygen
MLP	=	Mobile Launch Platform
MMO	=	Mission Management Office
MSFC	=	Marshall Space Flight Center
MVAN	=	Multipurpose Van
NASA	=	National Aeronautics and Space Administration
OFI	=	Operational Flight Instrumentation
RCS	=	Reaction Control System
RoCS	=	Roll Control System
RRGU	=	Redundant Rate Gyro Unit
RSRB	=	Reusable Solid Rocket Booster
RSRM	=	Reusable Solid Rocket Motor
SDA	=	Shuttle-Derived Avionics
SIL	=	Systems Integration Laboratory
SM	=	Service Module
SRB	=	Solid Rocket Booster
TLI	=	Trans-Lunar Injection
TRR	=	Test Readiness Review
TS	=	Test Stand
TVC	=	Thrust Vector Control
US	=	Upper Stage
USE	=	Upper Stage Engine
USS	=	Upper Stage Simulator
VAB	=	Vehicle Assembly Building

I. Introduction: The Ares Launch Vehicles

The United States has committed to a new era of space exploration, beginning with a return to the Moon by the end of the next decade and human journeys to Mars and beyond in the decades that follow.[1] To execute these new missions, NASA will use lessons learned through the Apollo and Space Shuttle programs as well as technologies developed over 40 years of human spaceflight to build new launch vehicles. One of the lessons NASA has learned is to separate crew and cargo into two launch vehicles, resulting in the Ares I Crew Launch Vehicle (CLV) and the Ares V Cargo Launch Vehicle (CaLV)[2] (Figure 1).

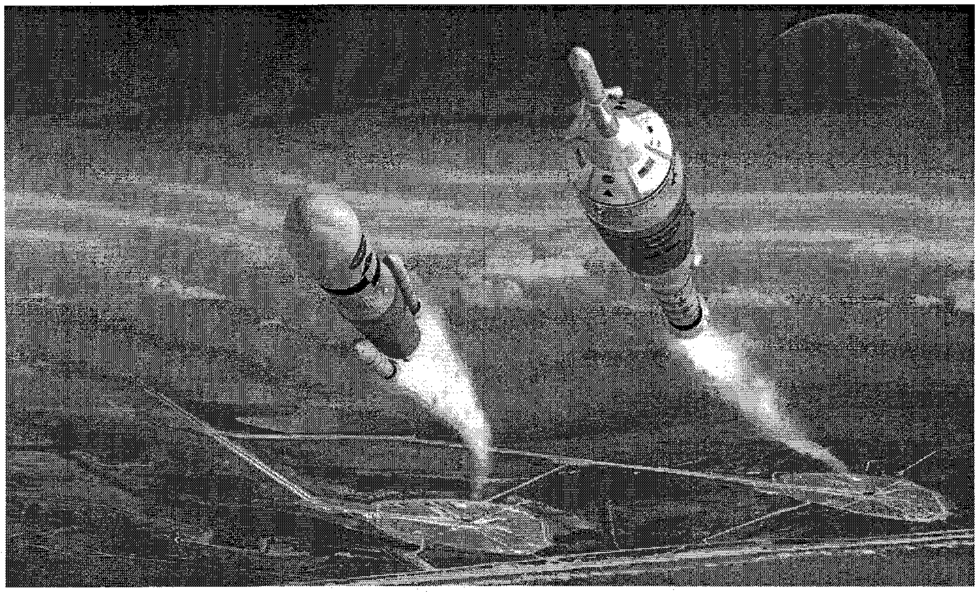

Figure 1. The Ares V Cargo Launch Vehicle (left) and Ares I Crew Launch Vehicle (right) will form the backbone of America's new era of space exploration. (NASA artist's concept)

Ares I serves as the crew launch vehicle for the crew module for lunar and Mars missions as well as a crew and cargo transfer vehicle for the International Space Station (ISS). Ares I will be designed and flown first to reduce the gap in human spaceflight capabilities between the retirement of the Space Shuttle and the first flight of the Orion Crew Exploration Vehicle (CEV) to ISS in 2015. This vehicle is powered by a Shuttle-derived, five-segment Solid Rocket Booster (SRB) first stage and a liquid-fueled, Saturn-derived J-2X engine for its upper stage. Ares I also includes a Launch Abort System (LAS), which covers the Orion Crew Module (CM) and moves it away from the rest of the vehicle quickly in the event of a malfunction that might endanger the crew. The LAS will provide a greater margin of safety than the Shuttle.

Ares V, which will begin full-scale development after the Shuttle's retirement, will be the largest launch vehicle ever built. With five commercial RS-68 engines (used on the Delta IV Evolved Expendable Launch Vehicle (EELV)) and two five-segment SRBs, the Ares V CaLV will generate 10.5 million pounds of thrust at liftoff. Ares V launches the Earth departure stage (EDS) into orbit, where it will await the launch and docking of an Orion CEV before providing a trans-lunar injection (TLI) burn (Figure 2).

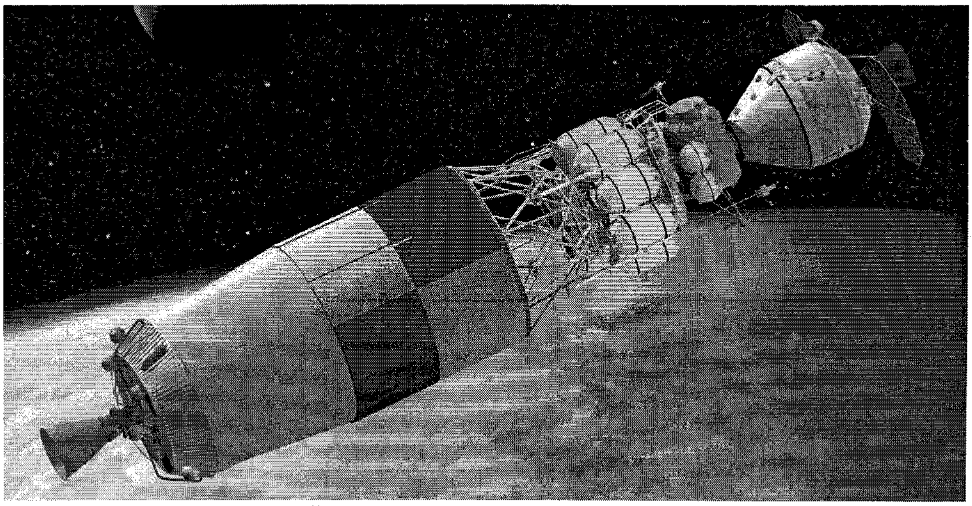

Figure 2. The Ares V Earth Departure Stage will transport the Lunar Surface Access Module and the Orion Crew Exploration Vehicle to lunar orbit (artist's concept).

While both of these vehicles will use hardware, equipment, and handling procedures developed for the Saturn and Shuttle programs, they are still new designs, and will require extensive testing before being declared "human-rated" and ready to fly crews to ISS or the Moon. The Exploration Launch Projects (ELP) Office at Marshall Space Flight Center (MSFC) has given the Flight and Integrated Test Office (FITO) the responsibility for managing ground and flight test operations for Ares I and Ares V. In May 2007, the Constellation Program (CxP), which is in charge of the overall missions to Moon, Mars, and beyond, stood up the Ares I-X Mission Management Office (MMO). This organization has the authority and responsibility for planning, organizing, and executing the first suborbital test of the Ares I launch vehicle in April 2009. Together, the FITO and Ares I-X MMO will conduct the necessary work to return America to the task of exploring the solar system.

II. Ares Testing Strategy and Testing Roles & Responsibilities

A. Testing Strategy

NASA has learned through experience that it can reduce operating costs through early, incremental, and thorough testing of its launch vehicles. This "test as you fly" strategy incorporates best practices from systems engineering as well as lessons learned. . To fly humans safely aboard a launch vehicle, requires a variety of methodologies to reduce the technical, schedule, and cost risks inherent in the complex business of space transportation.

Multiple demonstration and verification flight tests were conducted during the Saturn development effort to prove technology in its operating environment before relying upon it for human spaceflight. Less testing on the integrated Shuttle system did not reduce cost or schedule. NASA plans a progressive series of demonstration (ascent), verification (orbital), and mission flight tests to supplement ground research and high-altitude subsystem testing with real-world data, factoring the results of each test into the next one. In this way, sophisticated analytical models and tools, many of which were not available during Saturn and Shuttle, can be calibrated to increase confidence in their predictions. Despite the vast improvement in computing and predictive power of these tools, there is still no adequate substitute for anchoring the tools to real test data than flying actual hardware.

The first flight of Ares I, designated Ares I-X, will be a suborbital development flight test. Ares I-X gives NASA its first opportunity to gather critical data about the flight dynamics of the integrated launch vehicle stack, understand how to control its roll during flight, better characterize the severe stage separation environments that the upper stage engine will experience during future operational flights and demonstrate the first stage recovery system. NASA also will begin to modify the launch infrastructure and to fine-tune ground and mission operations, as the agency makes the transition from the Shuttle to the Ares/Orion system. The flight manifest includes two suborbital demonstrations, which will be supplemented by at least two orbital verification tests and one automated mission flight before crewed operations begin in 2015.

Ares I-X uses an innovative approach to gathering information prior to the Ares I Critical Design Review, which follows in late 2009. The Ares I-X Flight Test Vehicle (FTV) will incorporate a mix of flight and mockup hardware, reflecting a configuration similar in mass and weight to the operational vehicle. It will be powered by a four-segment reusable solid rocket booster (RSRB), which is currently in Shuttle inventory, and will be modified to include a fifth, spacer segment that makes it approximately the same size and weight as the five-segment RSRB, which will be available for the next flight test in 2012. The Ares I-X flight profile will closely approximate the flight conditions that the Ares I will experience through Mach 4.5, at an altitude of about 120,000 feet, through maximum dynamic pressure ("Max Q"), which is around 800 pounds per square foot. The flight also will aid the timing of first stage burnout, first stage separation, and upper stage ignition, which should occur around 130 seconds into flight. Basing vehicle design refinements on Ares I-X information puts NASA one step closer to the full-up "test as you fly" scenarios; each flight will be staged to affect future milestone reviews.

This particular mission makes maximum use of available inventory, while simulating the mass properties of hardware that will not be available until the Ares I-Y test flight in 2012. The Ares I-Y test, building upon experience gained during Ares I-X, is expected to have the following test objectives:

1. Demonstrate flight control algorithms with five-segment Solid Rocket Booster (SRB) and a high-fidelity Upper Stage Simulator.
2. Demonstrate first flight of five-segment SRB

3. Demonstrate a Launch Abort System (LAS) capable of high-altitude abort.
4. Measure and characterize launch and ascent environments for the five-segment SRB.
5. Demonstrate First Stage separation and recovery dynamics and performance.
6. Demonstrate first assembly processing from modified Kennedy Space Center facilities.

Orion 1, scheduled for early in 2013, will be the first flight with the Orion CEV but uncrewed. The other tests on the flight manifest will culminate with the first human crew being transported to ISS in 2015.

B. Roles & Responsibilities

The Ares I-X MMO was stood up to focus on the first flight of Ares, which includes vehicle design and fabrication; flight operations; ground operations like vehicle assembly, stacking, and launch preparations; ground/vehicle interfaces; and facilities conversion and development. FITO will continue making plans for the subsequent test flights, starting with the Ares I-Y test flight in 2012. This work will include determining future test requirements and establishing the infrastructure needed to make those tests possible; component-level testing; ground vibration testing (GVT); and integrated system testing. FITO is focused on ensuring that the Ares I vehicle, using data from the I-X, I-Y and Orion 1 test flights, is capable of human rating before the Orion 2 flight in late 2013.

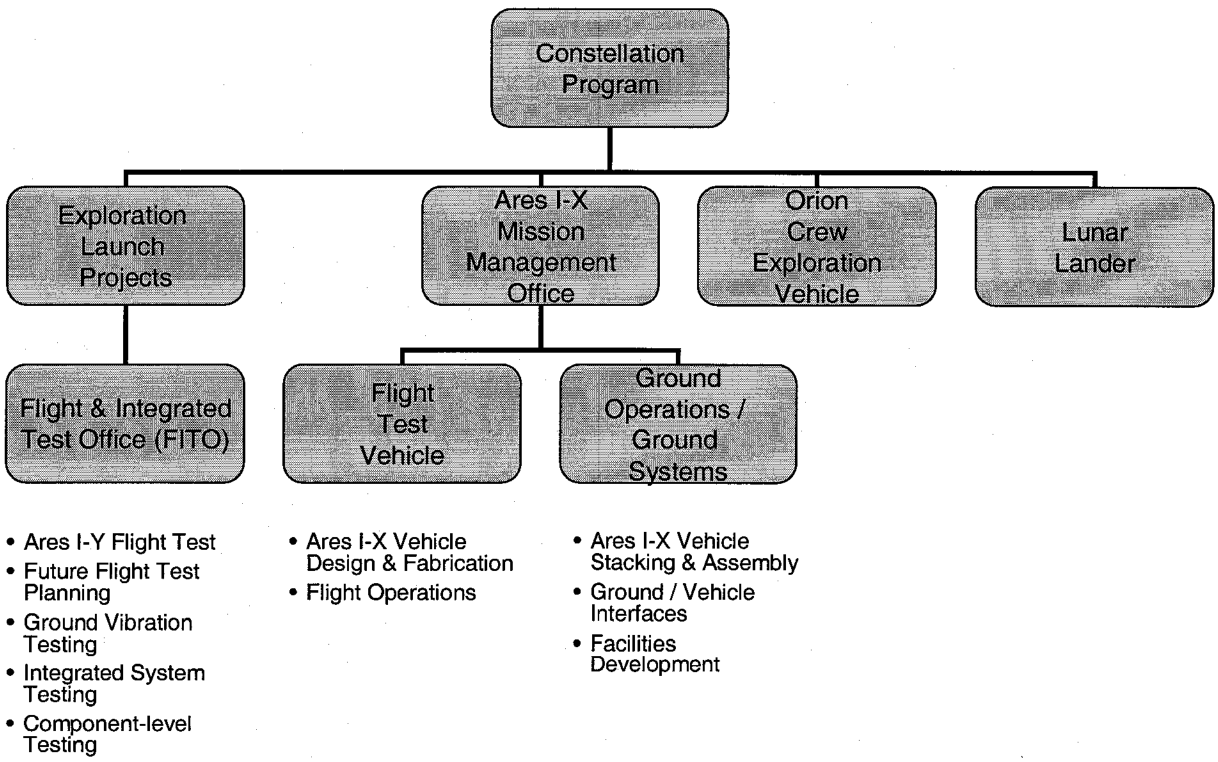

Figure 3. Ares vehicle testing organization and responsibilities.

III. Ground Vibration Testing

Engineers require detailed knowledge of the dynamic characteristics of the Ares I integrated vehicle at various critical points in its nominal, mission flight trajectory. To validate the structural design and guidance and control system design, MSFC will build and test an Ares I structural dynamics test article. The Ares I test article will be as flight-like as possible, although mass simulators and substitute element components will be used. Known loads will be applied as "inputs" and structural "output" responses measured to anchor a three-dimensional (3D) computer model of the test article. Loads will not be nearly as high as those during flight, but after these tests, the anchored computer model will allow MSFC personnel to extrapolate to higher structural load cases or off-nominal conditions. The computer model will reconcile any differences between the Ares I test article and the Ares I integrated flight vehicle.

A. Goals and Objectives

The purpose of structural dynamic testing is to provide test data to support the Ares I Design Certification Review (DCR), launch, flight, and ultimately human-rating of the launch vehicle system. The structural dynamic tests generate the data required to anchor and verify models used in the design of the integrated launch vehicle stack. The structural dynamic test program is also referred to as the Ground Vibration Test (GVT).

The goals of the GVT are to dynamically test a full scale Ares I test article integrated 5-segment first stage launch stack, an integrated Ares I Upper Stage, an integrated Crew Exploration Vehicle (CEV) (which consists of the Crew Module (CM), Service Module (SM), Instrumentation Unit (IU), Spacecraft Adapter, and Launch Ascent/Escape System (LAS)), and Upper Stage engine simulator at various key flight trajectory configurations.

The GVT objectives are to acquire the model validation data to anchor Ares I flight vehicle models. These Ares I test article configurations and GVT data will provide information about the forces applied at critical locations on the vehicle (such as actuator locations) and the response of flight sensors. In addition, GVT data will help determine the mode shapes, frequencies, and damping of the integrated launch stack both at ignition and first stage burn out and the second stage of flight. These parameters also are used to verify the finite element models used in loads analyses. These analyses verify the structural integrity of the Ares I vehicle during all phases of flight. The GVT will be conducted on Marshall Space Flight Center's historic Test Stand 4550, which also had a role in testing the Saturn V and Space Shuttle vehicles (Figure 4).

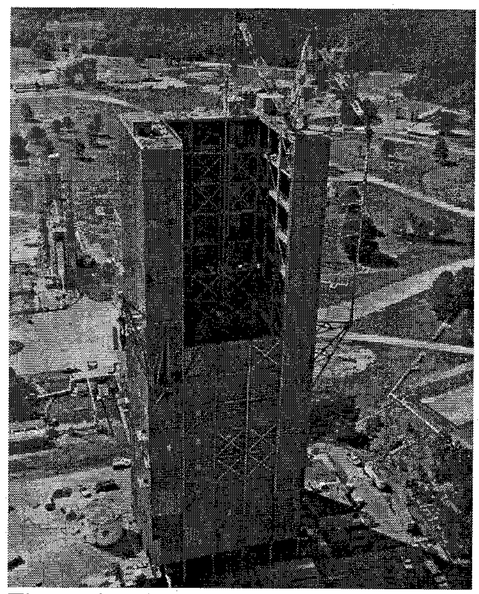

Figure 4. Dynamic Test Stand 4550 at Marshall Space Flight Center.

B. Dynamic Test Configuration

The Ares I Integrated Dynamic Test Vehicle is a dedicated test vehicle designed and built to flight specifications of the operational Ares I and Orion. The requirement for test article resemblance lies in the need to accurately reflect the correct dynamic characteristics of the flight vehicles. The Ares I /Orion is an integrated, stacked vehicle that consists of three primary elements: a solid-fuel Five Segment Booster (FSB), a liquid-fuel Upper Stage (US), and the Orion CEV.

The FSB comprises five Reusable Solid Rocket Motor (RSRM) propulsive segments whose design heritage relates to boosters flown in the Space Shuttle program (Figure 4). The FSB is developed by ATK and delivers 3,536,700 pounds of thrust in vacuum. The FSB provides the propulsion from liftoff through the launch ascent phase of flight. The FSB design includes an Aft Skirt, motor segments, forward skirt, forward skirt extension, and frustum. The FSB is designed to be reusable and is recovered after separation and splashdown in the Atlantic Ocean.

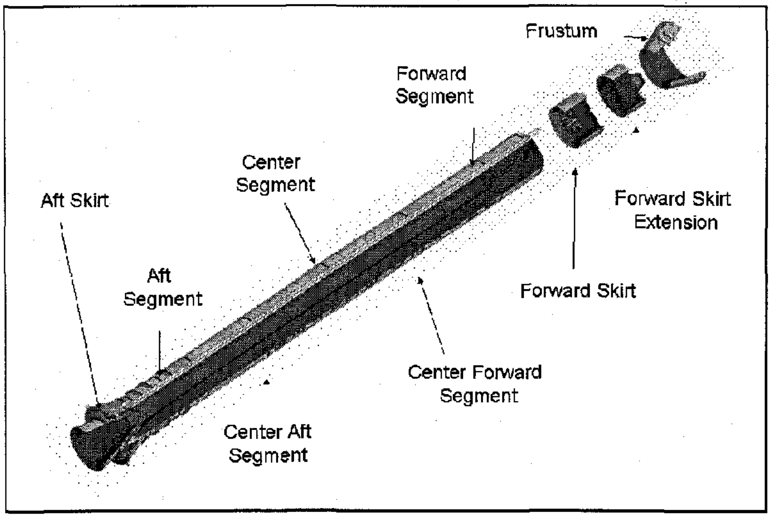

Figure 5. First Stage GVT hardware.

The IVDT consists of two full-stack GVTs and a potential series of 2nd Stage GVTs. One stack of five segments loaded with inert propellant will represent the FSB in the liftoff condition. A second stack of five empty segments will represent the FSB in the burned out condition prior to separation of the first stage.

The US (Figure 6) comprises an Interstage at the FSB/First Stage interface (not shown), a thrust structure, a J-2X Upper Stage Engine (USE), a liquid oxygen (LOX) tank, a liquid hydrogen (LH_2) tank, an Instrumentation Unit (IU), and an Orion Spacecraft Adapter. The US is developed by MSFC and weighs 325,348 lb when fully fueled.

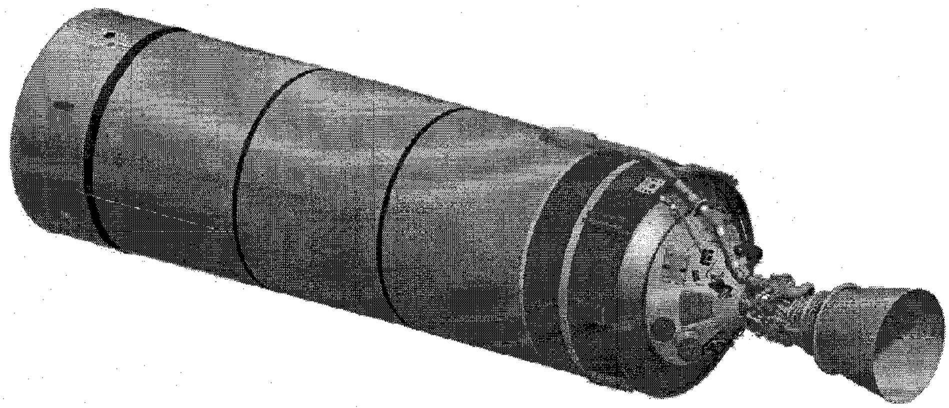

Figure 6. Ares I Upper Stage GVT hardware.

The Orion consists of a Service Module (SM), Spacecraft Adapter (SA), Crew Module (CM), and LAS. In order to account accurately for the effect of the Orion on the CLV flight vehicle, the hardware representing the Orion used for the IVDT must be dynamically similar to the flight configuration.

Test Article configurations refer to various test stack combinations associated with the flight trajectory profile (Figure 7). The current approved configurations are Ares I stacks. Vehicle configuration layouts for the IVDT (Full Stack GVT and 2nd Stage GVT) consist of six different test conditions occurring at three unique test positions in TS 4550 at MSFC. The term "test position" in the IVDT relates to a geographic location of the vehicle within Test Stand 4550.

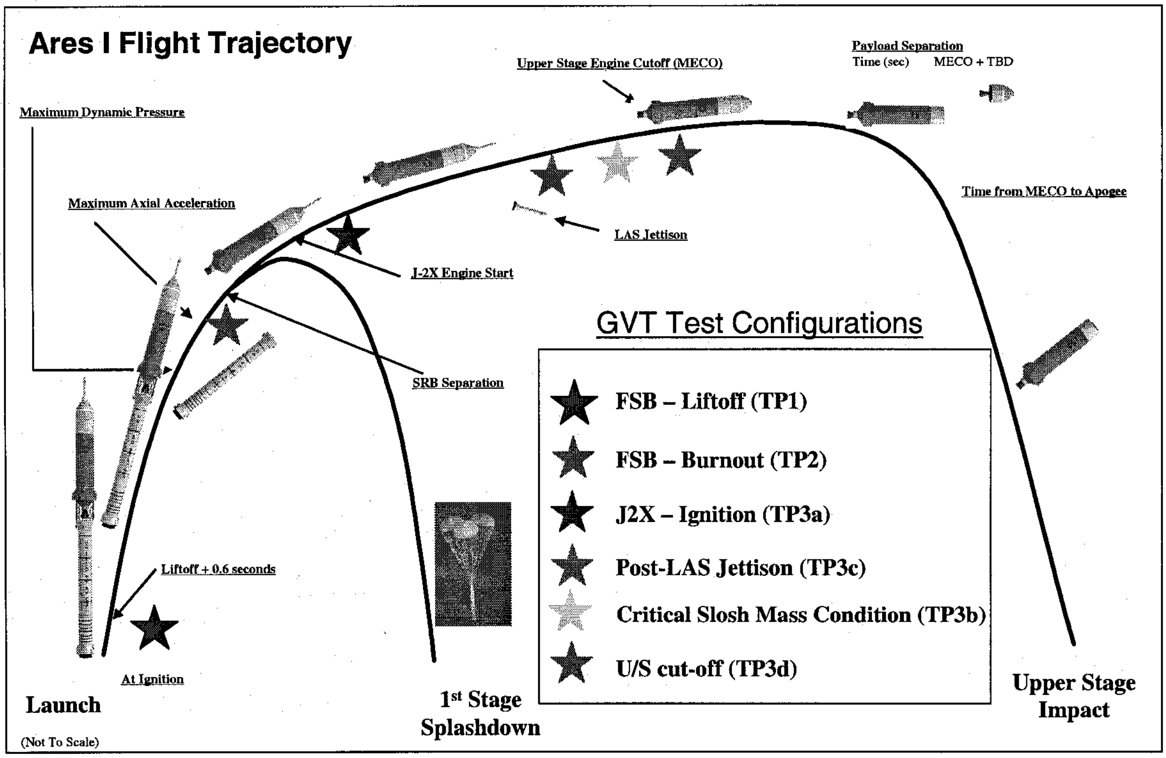

Figure 7. Ascent profile with key test points.

C. Success Criteria

Success criteria for GVT depend on specific test phases conducted in the IVDT, and will be reviewed in detail during the Test Readiness Review (TRR) for each test position.

For the modal survey test configurations, each configuration will be considered successful and complete when all target modes have been identified. Data from each configuration will be reviewed and judged to be valid before teardown and preparation for the next configuration begins. Should the measured target modes fail to meet goals, a test team consisting of representatives of the Engineering Directorate, the Test Laboratories, and FITO, as well as the elements will evaluate the data and recommend a course of action.

IV. Avionics Progress & Forward Work

The Ares I-X avionics hardware is already undergoing development and testing. This is possible because the avionics system will use a combination of avionics components from the Atlas V Evolved Expendable Launch Vehicle (EELV) and heritage Space Shuttle systems. The avionics system will employ the aircraft-qualified Development Flight Instrumentation (DFI) used for the Boeing 7E7 series and the U.S. Air Force Joint Strike Fighter (JSF) to collect, transmit, and store the data vital for a successful test flight.

The avionics hardware for this flight is not required to be extensible to Ares I; it is for test purposes. However, the guidance and control algorithm will be based on the one used for Ares I. Testing of the Guidance, Navigation, and Control (GN&C) algorithms is a primary objective of the Ares I-X flight test.

A. Ascent Thrust Vector Controller (ATVC)

While the hardware is mostly commercial-off-the-shelf, the avionics team is starting to map out the physical location and arrangement of the controller boxes as well as cabling within the FTV. The work receiving the most attention right now is the only new piece of hardware on the Ares I-X mission, the Ascent Thrust Vector Controller (ATVC) system. Because the FTV is using avionics from a liquid-fuel rocket, the system must be modified to control the solid-fuel SRB. The ATVC acts as the translation tool between these two systems (Figure 8).

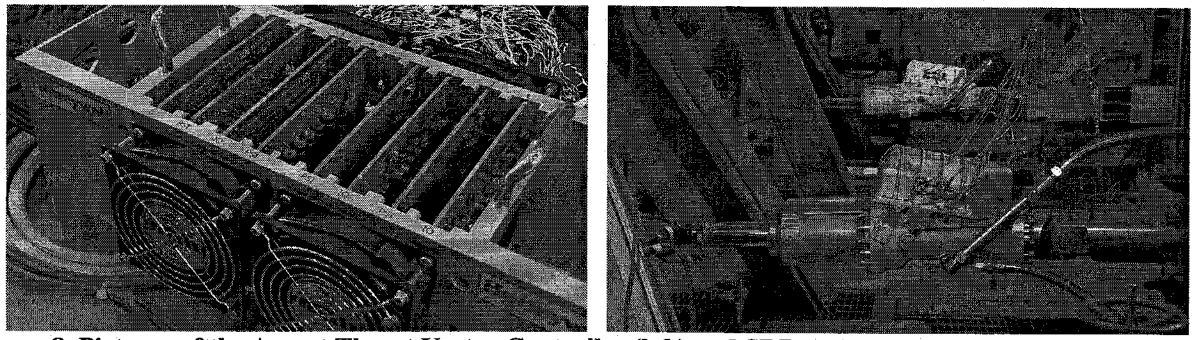

Figure 8. Pictures of the Ascent Thrust Vector Controller (left) and SRB rock and tilt actuators (right).

ATVC testing was completed successfully in Marshall Space Flight Center's Solid Rocket Booster actuator lab: in June. The testing went very well and demonstrated that the ATVC unit developed for the Ares I-X FTV provides all of the required functionality. In addition to the tests in the test plan, other tests were performed to characterize the end-to-end system gains and scaling factors for use in the flight control computer and for integrated vehicle testing in the Vehicle Assembly Building (VAB) at Kennedy Space Center (KSC).

Electrical tests with simulated actuator loads and sensors were conducted to verify the proper function of the prototype prior to connecting it to the SRB Thrust Vector Control (TVC) actuator. After electrical tests were completed, the ATVC prototype was interfaced with the TVC actuator using 160-foot-long cables, which is representative of what will be used on the FTV. The cabling configuration included a break-out-box with 10 feet of cabling between it and the ATVC prototype. A 150-foot length of cable completed the connection from the breakout box to the actuators. The test was conducted with two actuators to represent rock and tilt.

Many other tests were run to verify and refine the command scripts that would be used in performing many of the tests in the plan. The ATVC bypass function was tested to show that the ATVC properly bypasses a servo-valve whose delta pressure exceeds the threshold indicating a probable servo-valve failure. Additionally, the team characterized the ATVC system's end-to-end response to commands. Measurements were made to verify scaling and conversion factors, so the FTV flight computer will be able to generate the appropriate voltage command to the ATVC to get the desired nozzle position.

After electrical testing, the ATVC prototype was once again connected to the hydraulic actuators. The tests demonstrated the ATVC's ability to command the actuators appropriately, produce the proper equalization adjustment, and engage the servo-valve bypass.

The risk reduction testing was a great success in that it provided the opportunity to verify interfaces between the ATVC prototype and hydraulic actuators and discover any problems or incompatibilities. Two minor problems were found and corrected during the week of testing, validating Honeywell's rapid prototyping approach along with the rationale for conducting the risk reduction testing with flight-like hardware. The successful performance of the test plan after the problems were corrected will ensure that the ATVC flight units will not have interface issues when integrated in the FTV.

B. Trade Studies: Redundant Rate Gyro Unit (RRGU), Developmental Flight Instrumentation (DFI), and Flight Test Inertial Navigation Unit (FTINU)

In addition to testing new hardware, the Ares I-X avionics team must decide where to place its existing commercial-off-the-shelf (COTS) hardware and its related cabling within the FTV. Among the hardware that needs to be situated are the RRGU, DFI, and FTINU. The RRGU controls pitch and yaw to direct the flight path of the rocket; DFI is used primarily to provide data during the flight testing phases of the operational subsystems; the FTINU is a computer that determines the Ares I-X FTV's location and trajectory. A number of factors can impact the placement of these items, including vibration, heat, and aerodynamic environments. Trade studies are under way for placing RRGUs in the forward and/or aft ends of the Upper Stage Simulator (USS)

The FTV will fly a prescribed trajectory, simulating the Ares I ascent flight to obtain data that supports the flight test objectives. Ares I-X will not be commanded or controlled from the ground during flight, except for the

Flight Termination System (FTS), if required. The DFI will provide data to the operational Ares I program. The sensors are located on all elements of the flight test vehicle and have been specifically requested by the Ares I discipline leads. All data will be telemetered in real time as the primary method of data gathering. The data recorder, located on First Stage, will be recovered and used to fill in any drop-outs that occur during flight. This hardware, consisting of part new and part legacy Atlas hardware, will most likely be placed in the forward skirt of the First Stage. Because of bandwidth limitations, the team plans to equip the Ares I FTV with DFI, telemetry system(s), and a data recording system, which will be recovered with the First Stage after splashdown.

C. Ground Interfaces

The ground interfaces for the avionics have been established. The avionics team had a choice between using a Lockheed-Martin-provided multipurpose van (MVAN) or a customized Ground Command, Control, and Communication (GC3) unit, called a mini-GC3, embedded within the Mobile Launch Platform (MLP). The MVAN, which also services the Atlas program, is capable of commanding and monitoring avionics systems from the ground. However, location of the MVAN at the launch pad was a considerable challenge; the project also faced potential schedule conflicts with the Atlas program, reducing its availability and the team's ability to make quick changes. The recommendation to the MSFC Flight and Integrated Test Office (FITO) was to use the mini-GC3 unit, providing easier access to the ground-based avionics systems and enabling MLP modifications to occur parallel with Space Shuttle Operations.

D. Video Requirements

The avionics team has established the requirements for capturing, transmitting, and storing video imagery. Because the flight will study the dynamics of stage separation, the video cameras will provide an integral part of measuring the speed at which the USS separates from the First Stage and the J-2X nozzle clearance during separation. The current baseline mounts three digital cameras at 120° positions around the vehicle interior on the forward end of the Interstage, and focuses them on a series of highly reflective targets placed on the aft portion of the USS (Figure 8). Acceleration will be measured based on the rate the targets contract in the camera's field of view.

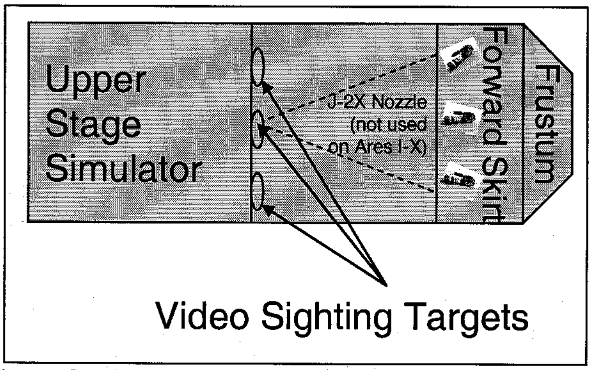

Figure 8. Video camera placement for the Ares I-X FTV.

E. The System Integration Laboratory (SIL)

The Ares I-X team also will employ a Systems Integration Laboratory (SIL) that tests the avionics on the ground and fully embraces the industry best practice of "test as you fly." The SIL, provided by Lockheed Martin at their Denver facility, will be a test platform for the Ares I-X integrated avionics system testing. Initial integration of the SRB Thrust Vector Controller (TVC) simulator is expected to be completed in July 2007. Final integration is scheduled for September 2007.

F. Avionics Critical Design Reviews (CDRs)

The CDR for the Shuttle-Derived Avionics (SDA) is currently scheduled for August 2007. The CDR for the avionics system, including the Atlas avionics systems and interface to the SDA, and is scheduled for September 2007. The software CDR for the Ares I-X avionics is scheduled for November 2007. This review will encompass the unmodified Atlas software as well as software modified for the Ares I-X.

Conclusion

NASA's Flight and Integrated Test Office will perform a wide variety of hardware testing for the Ares I in the next five years. Lessons learned from these tests will affect design and operational decisions made during the next uncrewed flight, Ares I-Y scheduled in 2012, and Orion 1, as well as Orion 2, the first crewed flight, both scheduled for 2013. The GVT and avionics testing are only two of many "test as you fly" efforts FITO and the Ares I-X MMO will complete to develop America's new human-rated launch vehicle. NASA will leverage lessons learned from the latest tests and simulations together with those learned from flying the Saturn and Shuttle heritage systems to ensure safer, more reliable launch vehicle's for the next generation of space explorers.

References

[1] National Aeronautics and Space Administration. *The Vision for Space Exploration.* February 2004.
[2] National Aeronautics and Space Administration. *NASA's Exploration Systems Architecture Study Final Report.* NASA-TM-2005-214062. November 2005, p. 21.

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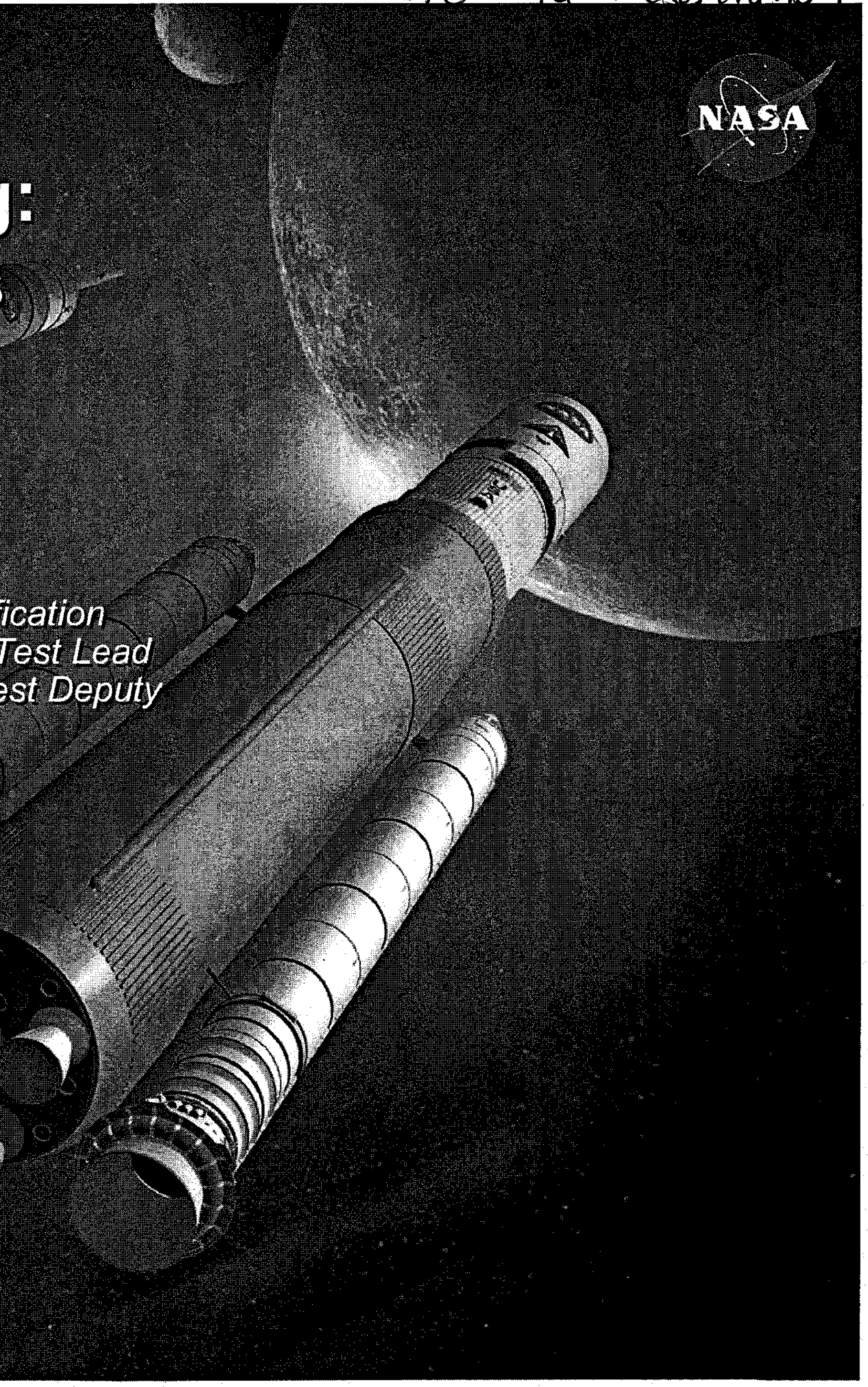

Flight and Integrated Testing: Blazing the Trail for the Ares Launch Vehicles

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AIAA Joint Propulsion Conference

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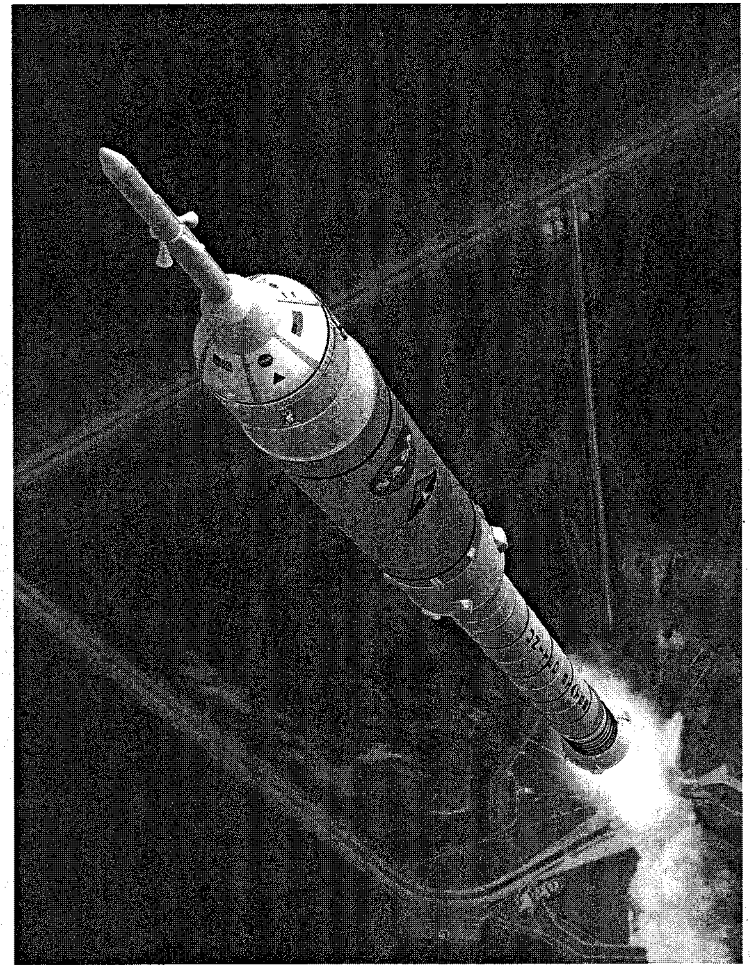
Agenda

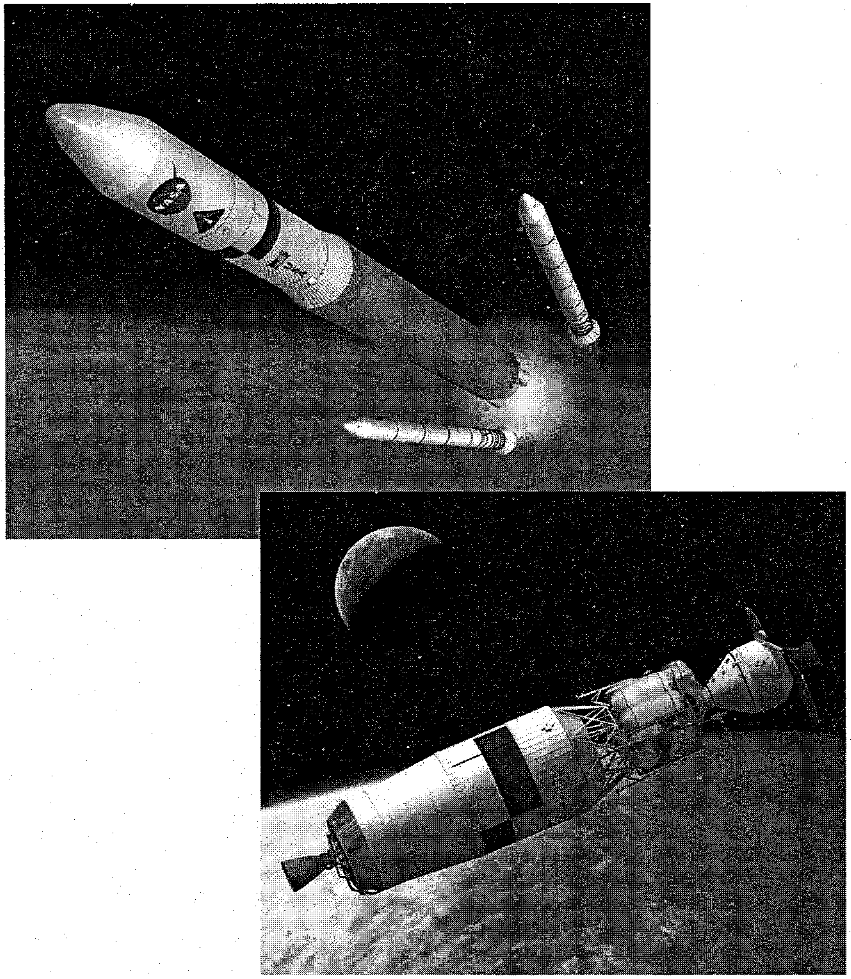
- Overview of the Ares Launch Vehicles
- Overview of the Testing Strategy and Roles & Responsibilities
- Ground Vibration Testing and Other Ground-Based Testing
- Avionics Overview, Current Developments, and Forward Work
- Questions

Overview of the Exploration Launch Projects Architecture



- ♦ **Ares I carries Crew Exploration Vehicle (CEV) to orbit to rendezvous with International Space Station or Ares V**
- ♦ **Ares I propulsion:**
  - First Stage: 5-segment Reusable Solid Rocket Booster (RSRB)
  - Upper Stage: J-2X

Exploration Launch Projects Architecture (cont'd)

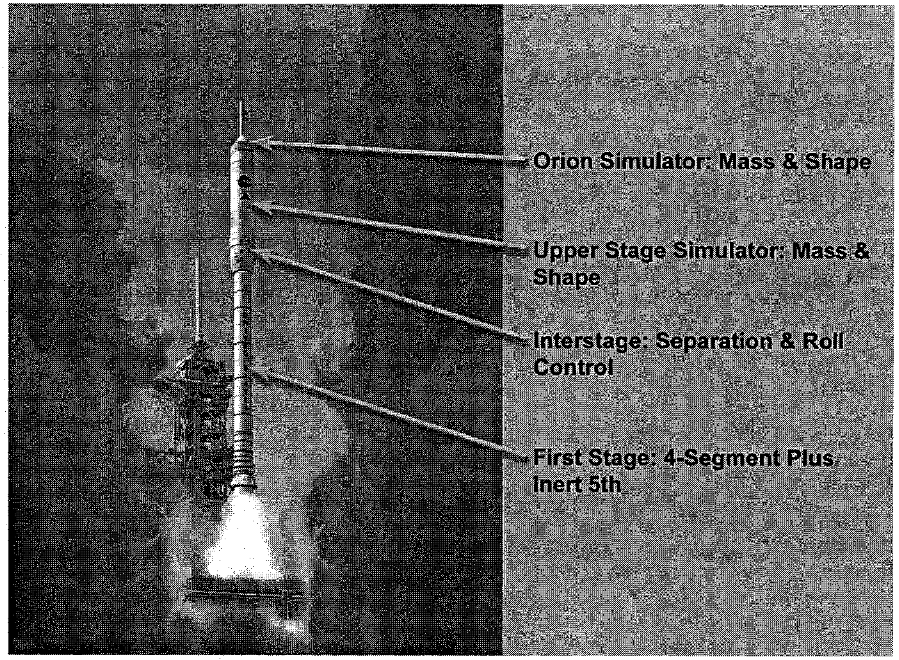


- **Ares V carries cargo to ISS or Lunar Lander and Earth Departure Stage to orbit**

- **Ares V Propulsion:**
  - Core Stage
    - 2 RSRBs
    - 5 RS-68
    - 33-foot (10 meter) diameter
  - Earth Departure Stage
    - J-2X for orbit circularization and Trans-lunar injection (TLI) burn

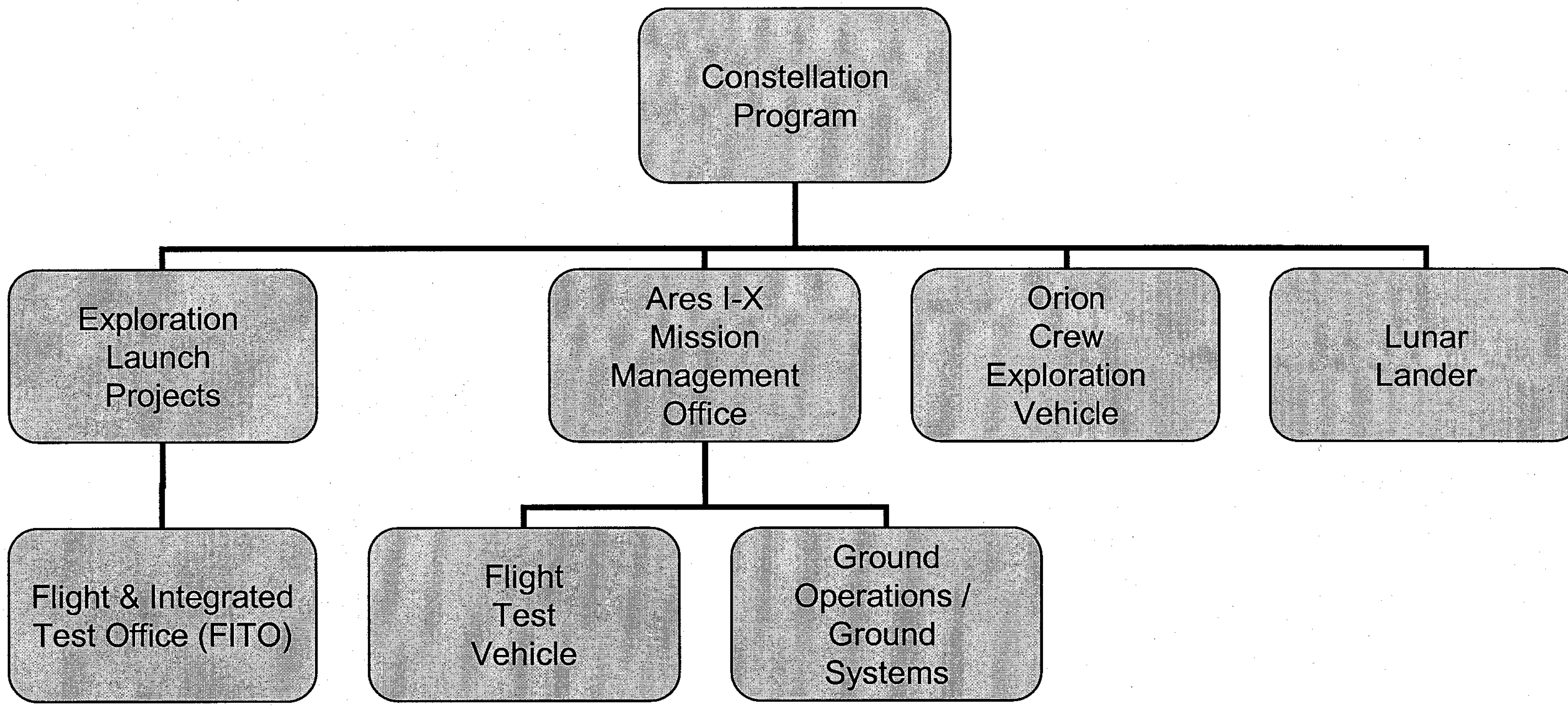
- **Common hardware and procedures with Ares I to reduce development and operations costs**

Overview of Ares I Test Flight Strategy



- **Progressive series of demonstration (ascent), verification (orbital), and mission flight tests**
- **Ground research and high-altitude subsystem testing incorporate real-world data from flight tests**
- **Ares I-X first suborbital ascent development flight test, scheduled for April 2009**
- **Flight test vehicle (FTV) uses mix of flight and mockup hardware**
- **Similar in mass, center of gravity, and length to final, operational system**
- **Flight profile approximates the flight conditions of Ares I**

Flight & Integrated Test Responsibilities

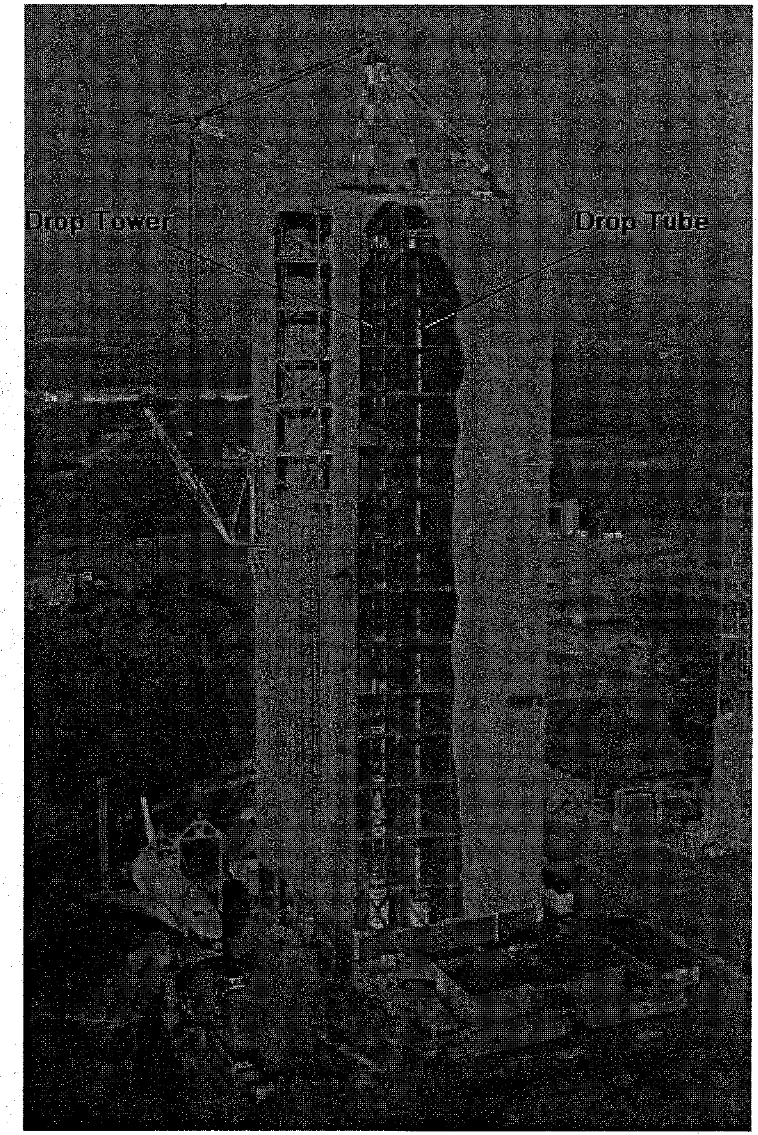


- Ares I-Y Flight Test
- Future Flight Test Planning
- Ground Vibration Testing
- Integrated System Testing
- Component-level Testing

- Ares I-X Vehicle Design & Fabrication
- Flight Operations

- Ares I-X Vehicle Stacking & Assembly
- Ground / Vehicle Interfaces
- Facilities Development

FITO Roles & Responsibilities

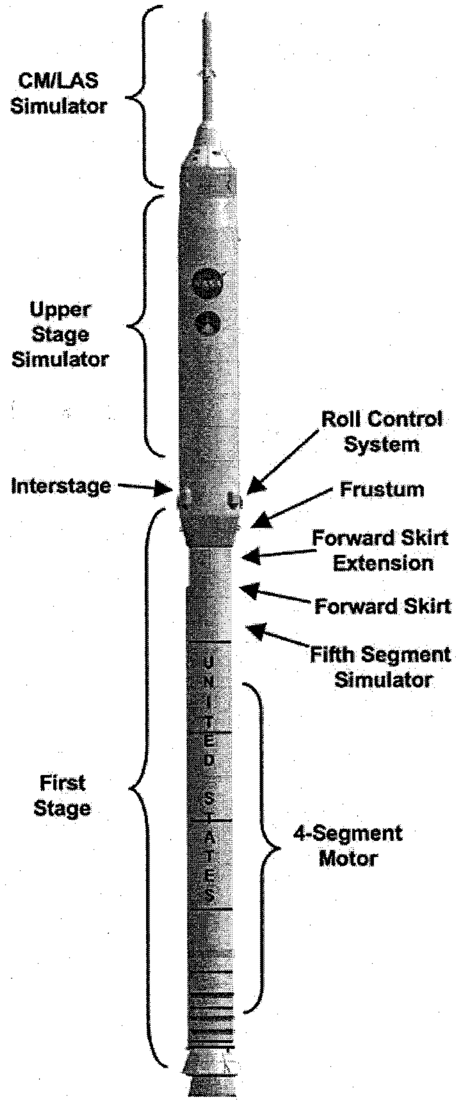


- Ares I-Y Flight Test
- Future Flight Test Planning
- Ground Vibration Testing
- Integrated System Testing
- Component-level Testing

Flight Test Objectives

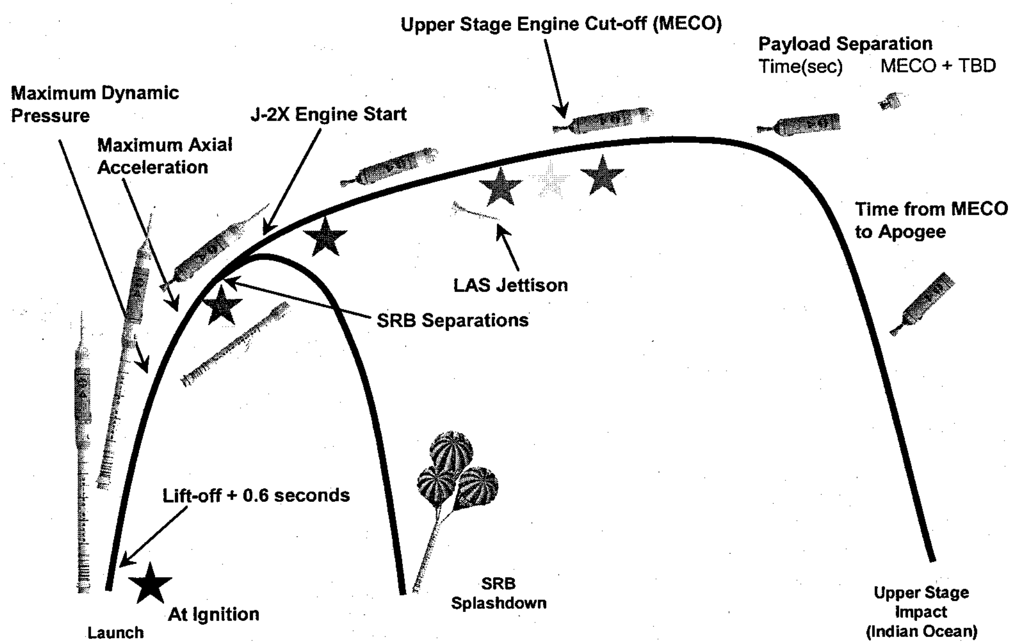
- **Ares I-X (April 2009)**
  - Demonstrate the ascent flight control system
  - Characterize and mitigating the roll torque due to first stage motor performance for a vehicle dynamically similar to the operational vehicle
  - Demonstrate nominal first and upper stage separation and clearances
  - Test the First Stage parachute recovery system and separation/entry dynamics
  - Validate assembly and processing flow, as well as launch and recovery operations
- **Ares I-Y (2012)**
  - Demonstrate flight control algorithms with five-segment Solid Rocket Booster (SRB) and a high-fidelity Upper Stage Simulator.
  - Demonstrate first flight of five-segment SRB
  - Demonstrate a Launch Abort System (LAS) capable of high-altitude abort.
  - Measure and characterize launch and ascent environments for the five-segment SRB.
  - Demonstrate First Stage separation and recovery dynamics and performance.
  - Demonstrate first assembly processing from modified Kennedy Space Center facilities.

Ground Vibration Testing



- **Goals and objectives**
  - Provide test data to support the Ares I Design Certification Review (DCR) and operations
  - Generate data to anchor and verify models used in design
  - Dynamically test full-scale Ares I test article in variety of configurations
  - Provide information about forces applied at critical locations on the vehicle
  - Determine the mode shapes, frequencies, and damping of the integrated launch stack
  - Verify the structural integrity of the Ares I vehicle during all phases of flight

GVT Configurations and Success Criteria

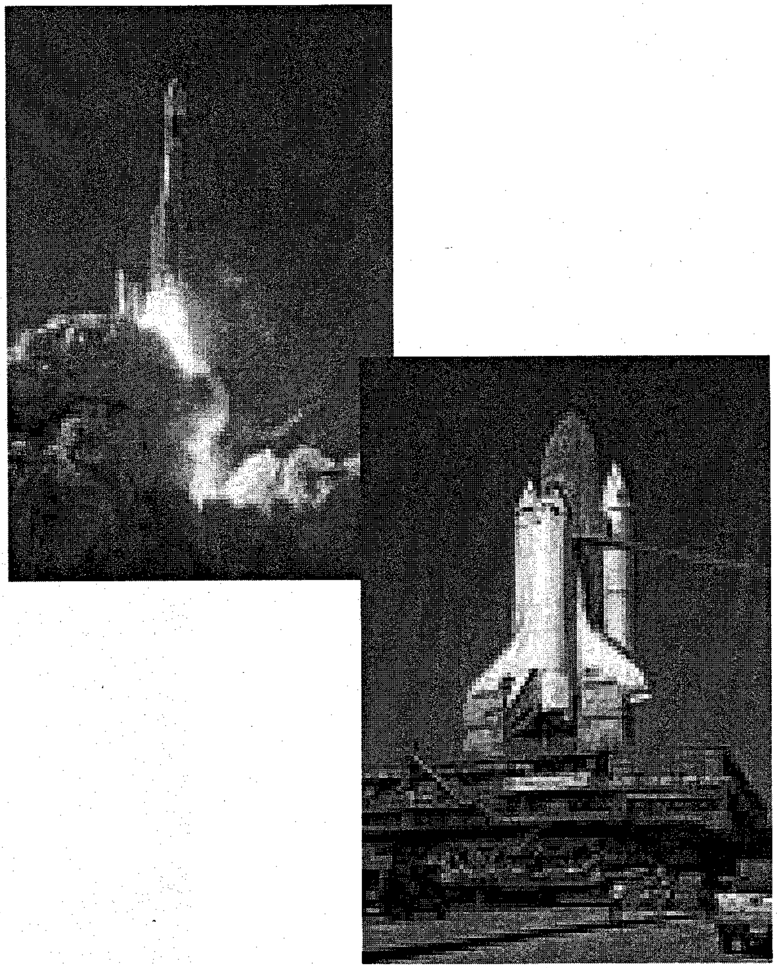


GVT Test Configurations

- ★ FSB - Lift-off (TP1)
- ★ FSB - Burnout (TP2)
- ★ J-2X - Ignition (TP3a)
- ★ Post-LAS Jettison (TP3c)
- ★ Critical Slosh Mass Condition (TP3b)
- ★ U/S Cut-off (TP3d)

- **Six test configurations**
  - First Stage liftoff
  - First Stage burnout
  - J-2X ignition
  - Post-LAS Jettison
  - Critical slosh mass condition
  - Upper Stage cutoff
- **Success Criteria**
  - All target modes are identified
  - Data from each configuration will be reviewed and judged to be valid before teardown and preparation for the next configuration begins
  - Should the measured target modes fail to meet goals, a test team will evaluate the data and recommend a course of action

Avionics – Overview



- **Combines components from Atlas, modified Space Shuttle systems, and new hardware**

- **Includes:**
  - Flight control systems
  - Ascent Thrust Vector Controller (ATVC)
  - Telemetry systems
  - Data recording—Development Flight Instrumentation (DFI) and Operational Flight Instrumentation (OFI)
  - Sensors
  - Power
  - Imaging / Video
  - Electrical Ground Support Equipment (EGSE)

Avionics Progress

- ♦ **Ascent Thrust Vector Controller (ATVC)**
- ♦ **Trade Studies**
  - Redundant Rate Gyro Unit (RRGU)
  - Developmental Flight Instrumentation (DFI)
  - Flight Test Inertial Navigation Unit (FTINU)
- ♦ **Ground Interfaces**
- ♦ **Video Requirements**
- ♦ **System Integration Laboratory (SIL)**
- ♦ **Avionics Critical Design Reviews (CDRs)**

Conclusion

- FITO will perform a wide variety of hardware testing for the Ares I in the next five years
- Lessons learned from testing will affect design and operational decisions made for Ares I-Y and beyond
- The GVT and avionics testing are two of many "test as you fly" efforts FITO and the Ares I-X MMO will complete to develop America's new human-rated launch vehicle
- NASA will leverage lessons learned from the latest tests and from flying the Saturn and Shuttle heritage systems to ensure safer, more reliable launch vehicle's for the next generation of space explorers

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