

Objectives and Progress on Integrated Vehicle Ground Vibration Testing for the Ares Launch Vehicles

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Abstract

Introduction

As NASA begins design and development of the Ares launch vehicles to replace the Space Shuttle and explore beyond low Earth orbit, Integrated Vehicle Ground Vibration Testing (IVGVT) will be a vital component of ensuring that those vehicles can perform the missions assigned to them. A ground vibration test (GVT) is intended to measure by test the fundamental dynamic characteristics of launch vehicles during various phases of flight. During the series of tests, properties such as natural frequencies, mode shapes, and transfer functions are measured directly. This data is then used to calibrate loads and control systems analysis models for verifying analyses of the launch vehicle. The Ares Flight & Integrated Test Office (FITO) will be conducting IVGVT for the Ares I crew launch vehicle at Marshall Space Flight Center (MSFC) from 2011 to 2012 using the venerable Test Stand (TS) 4550, which supported similar tests for the Saturn V and Space Shuttle vehicle stacks (Figure 1).

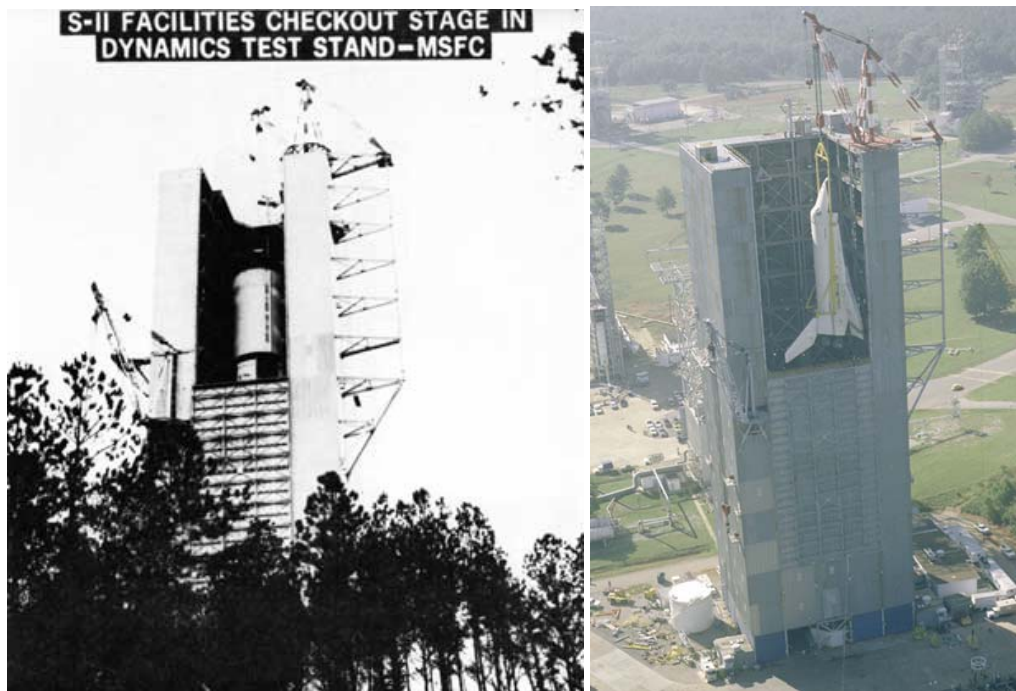


Figure 1. MSFC's Test Stand 4550 is about to reprise its role as a primary test site for America's human space exploration vehicles

Overview of the Ares Vehicles

The Ares I crew launch vehicle will lift the Orion crew module to low Earth orbit. Ares I has an in-line, two-stage configuration. The first stage is a five-segment solid rocket booster (SRB) based on the heritage Space Shuttle SRB design, and, like the Shuttle SRBs, is designed to be reusable. The Upper Stage is powered by the J-2X engine, which is derived from the Saturn second-stage J-2 engine and incorporates technologies from other engines. The Orion Crew Module (CM) sits on top of the second stage.

Ares I is approximately 325 feet tall, weighs 2 million pounds at launch and is capable of lifting 56,500 pounds into low Earth orbit (LEO). Ares I has two missions: carrying up to six crew (or cargo) to the International Space Station or carry four astronauts to LEO for rendezvous with Ares V for missions to the Moon.

The Ares V cargo launch vehicle will be a heavy-lift vehicle designed to launch the Altair lunar lander and cargo to LEO to rendezvous with the Orion CM. The core stage will be powered by five RS-68 LOX/LH₂ engines. Two five-segment SRBs, like the first stage of Ares I will also provide launch power. The second stage, or Earth departure stage (EDS), will be powered by a single J-2X engine, the same used for the Ares I second stage. Ares V will be 360 feet tall, weigh 7.4 million pounds at launch and will be capable of lifting about 316,000 pounds into LEO and 140,200 pounds to lunar orbit. (Figure 2).

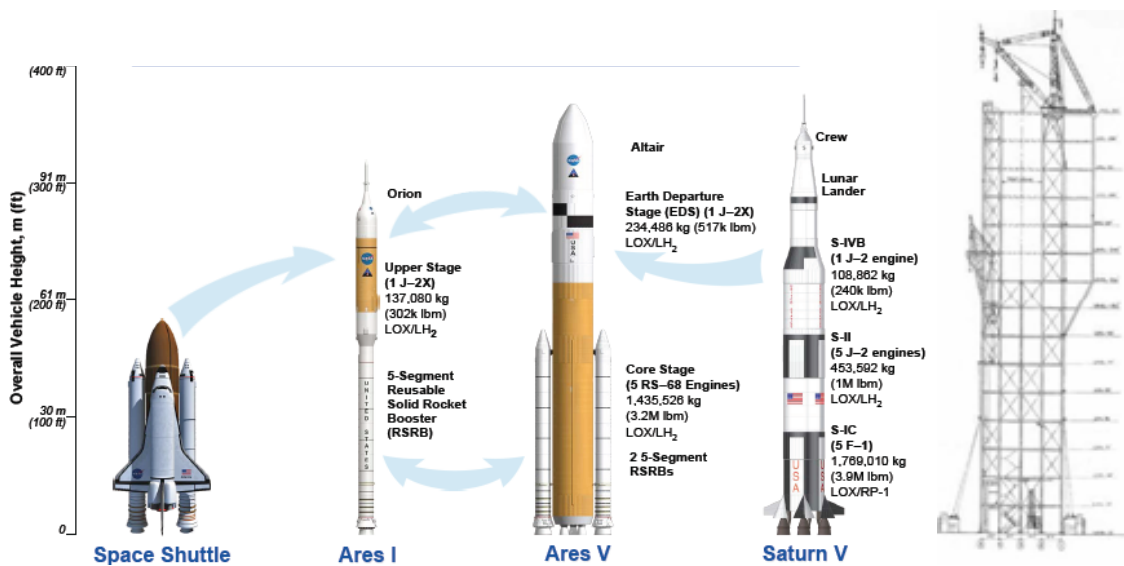


Figure 2. Launch Vehicle Size Comparison

Testing Overview

Most launch and space vehicles, as well as aircraft, undergo dynamic testing, also known as modal testing or GVT. Such testing is conducted to validate pre-test finite element models (FEMs) for use in verification loads analysis. The testing also determines test confirmed natural frequencies, mode shapes and damping for the vehicle under test. This data supports controls analysis by providing this test data to reduce uncertainty in models. Subsystem objectives are also obtained during dynamic testing such as verification of minimum subsystem frequency requirements and to confirm flex effects between control sensors and thrust locations.

Without test calibrated models, the model uncertainty factor (MUF) used in verification loads analysis is not updated and remains at earlier design phase levels. This can translate into increased vehicle mass if margins are insufficient. Poorly understood vehicle modes can also cause vehicle instability due to

incorrect modeling and boundary conditions. If model uncertainties are too large, GN&C stability requirements cannot be met to meet the Orion Design Certification Review (DCR).

Hydraulic shakers will be used to excite the vehicle at various locations that will be determined by pre-test analysis. It is anticipated that the majority of shaker locations will be near the base of the vehicle. Both random and sinusoidal excitation will be used during the IVGVT.

Instrumentation will consist primarily of accelerometers. At this time in test planning and analysis, it is not known if strain gauges will be used, nor has the requirements development process identified quantity or location for vehicle instrumentation. The phase II requirements development will produce a preliminary instrumentation plan in the summer of 2008.

Plans to perform the Integrated Vehicle GVT (IVGVT) for Ares I began in early 2006. The models correlated from IVGVT test data will support the Ares I Design Certification Review (DCR) in July 2013. The DCR supports the first crewed launch of the Ares I/Orion vehicle planned for September 2013 as part of human rating the vehicle.

Phase I of test requirements development for the IVGVT was completed in January 2008. This phase consisted mostly of beam model development and exploration of frequency ranges of interest. Phase II is currently underway and will be completed prior to the Ares I Preliminary Design Review (PDR) schedule for late summer 2008. The test requirements support development of the IVGVT Test Plan as well as the Special Test Equipment (STE) development and design and facilities modifications. A draft test plan will be submitted for review at the Ares I PDR. STE design is nearing completion of the preliminary phase in late spring 2008.

Modifications to MSFC Dynamics Test Stand 4550

It has been nearly 30 years since the Space Shuttle Mated Vehicle Ground Vibration Test (MVGVT) in TS 4550. Because of this long period of disuse, TS 4550 is being repaired and modified for reactivation to conduct the Ares I IVGVT (Figure 3).



Figure 3. The roof panels were removed and the main door was lowered (opened) on Test Stand 4550 for the first time in 29 years this past April.

The 200-ton derrick crane on top of the test stand has undergone significant refurbishment, including installation of a new motor. In March 2008, the crane was used to remove the roof panels and lower the

door for the first time since the MVGVT. Currently the Shuttle-era platforms are being removed through a demolition effort. They will be replaced with mast climbers (Figure 4) that provide ready access to the test articles at various levels and can be moved easily to support different test positions within the test stand. Two new cranes are being procured, a jack/gantry crane system and a 100-ton mobile crane, which will be used to aid in moving test articles both at the test stand and at the Redstone Arsenal railhead where first stage segments will be received.

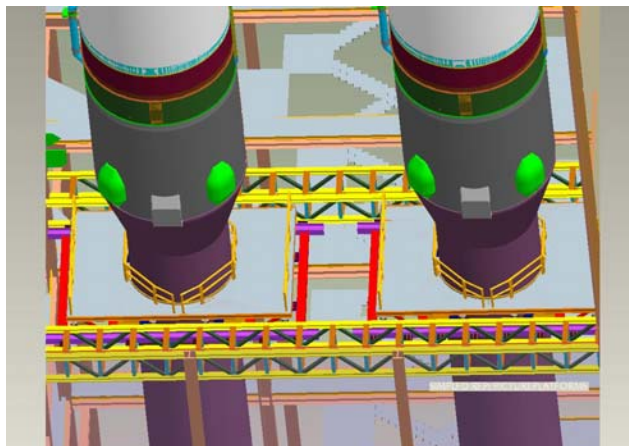


Figure 4. Mast Climber Concept for TS 4550

The approved design upgrades for TS 4550 include a new electrical system spanning the full height of the test stand and additional improved safety features. Work on these modifications will begin in the summer of 2008 and is scheduled to complete in the summer of 2009.

The Hydraulic Support Systems (HDSs) that were used for Saturn and Shuttle (Figure 5) are being disassembled and evaluated for use during IVGVT. Progress to date indicates that the 45-year-old HDSs can be refurbished in support of the Ares I IVGT. In parallel with the HDS evaluation, an alternate concept of a pneumatic system is being explored. A decision on which suspension system to use for IVGVT will be made in late summer 2008.

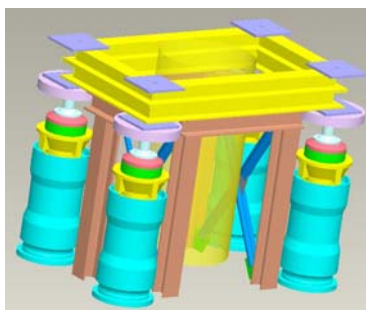


Figure 5. HDS Concept with New Attach Frame

Testing Configurations and Objectives

The current plan is for the Ares I IVGVT to test six configurations in three unique test positions in TS 4550. Test position 1 consists of the full launch stack at lift-off (using inert first stage segments). Test position 2 consists of the full launch stack at first stage burn-out (using empty first stage segments). Test position 3 consists of the Upper Stage and Orion crew module. Four test configurations will be tested. These are J-2X ignition, post Launch Abort System (LAS) jettison, critical slosh mass, and J-2X burn-out. Transfer function measurements will be made during all test configurations (Figure 6).

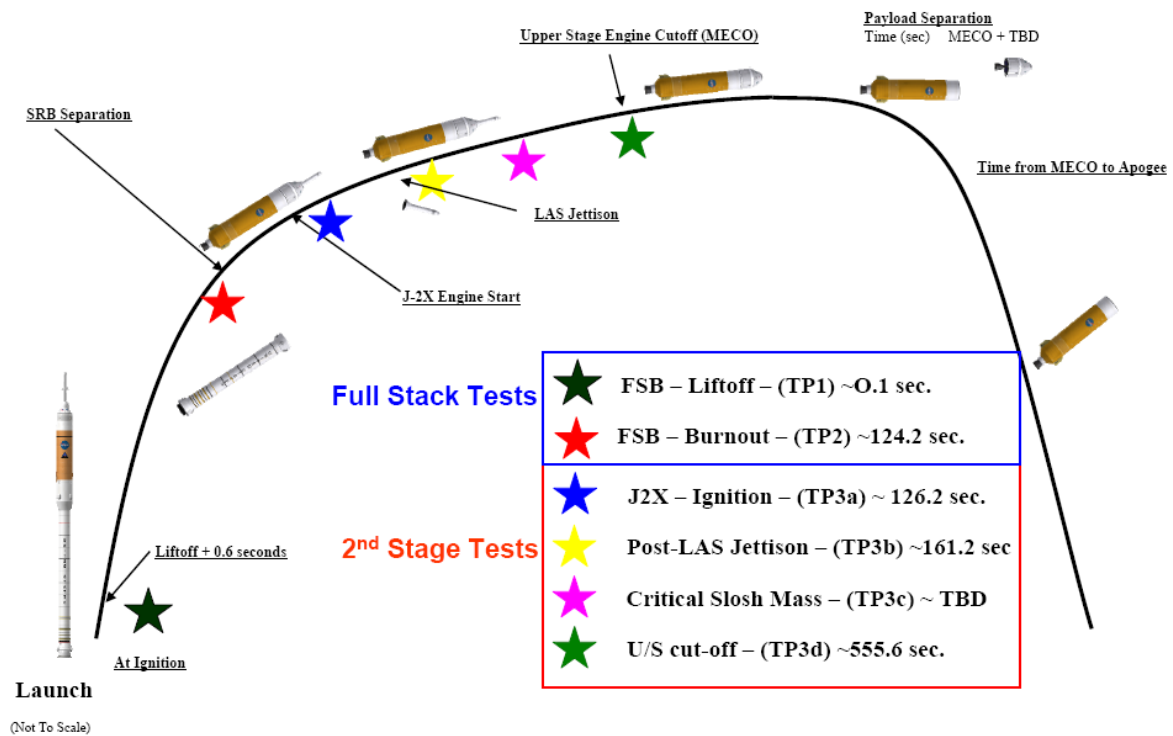


Figure 6. Ares I IVGVT Test Configurations

The Ares IVGVT will be conducted from mid-2011 to mid-2012. It is intended to measure by test the fundamental dynamic characteristics of Ares I during various phases of operation and flight. The final measured results of the IVGVT are clearly dependent on the vehicle hardware used during the test. A fundamental philosophy of structural dynamic testing is to have as few differences between the test article and the flight article as possible. For accurate testing and model correlation, both the test and flight configurations must be known and differences understood fully, which is sometimes referred to as “test what you fly, fly what you test.” To accurately represent the properties of the Ares I flight vehicles, the Ares I IVGVT will be conducted on a test article built to flight-equivalent specifications. Mass simulators of components may be used for flight-quality components that are not available in the scheduled test timeframe, provided there is sufficient technical rationale to do so.¹

Test objectives pertaining to flight control objectives are to obtain:

- 1) Natural vehicle mode shapes, frequencies, generalized mass and damping characteristics which are used in the stability equations, and
- 2) Amplitude and phase response of the elastic vehicle from thruster locations to all flight control sensor locations.²

Structural dynamic test objectives are to obtain:

- 1) Mode shapes, frequencies and damping to be used as the reference for test calibrated CLV configuration models that form the basis of final verification loads and GN&C controls analysis, and
- 2) Experimental non-linear characteristics of vehicle configurations by exciting the test specimen at different force levels.³

Ares V planning and early design is in work at this time, but at a very low level of effort as the Constellation program focus at this time is on Ares I/Orion development and launch. However, initial planning for the Ares V IVGVT has been ongoing. This consists primarily of facility studies and a preliminary schedule for long-range budget planning purposes. Ares V efforts are expected to increase in fiscal year 2010.

Conclusion

In the next three years, FITO will complete its refurbishing of TS 4550, designing the test and data collection equipment, and finalizing the configurations of the test articles to be used in the IVGVT. These activities will be concurrent with Ares I vehicle development and pose a variety of challenges. However, with NASA's dynamic testing capabilities reestablished, the FITO team will be well positioned to perform similar work on Ares V, the largest exploration launch vehicle NASA has ever built. These testing efforts continue NASA's 50-year commitment to using continual testing and data analysis to develop safer, more reliable launch vehicles.

¹ Archiable, George W., "Ares I Integrated Vehicle Ground Vibration Test Plan," unreleased draft version (February 2008).

² Ibid.

³ Ibid.