

Development Status of the J-2X

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In June 2006, the NASA Marshall Space Flight Center (MSFC) and Pratt & Whitney Rocketdyne began development of an engine for use on the Ares I crew launch vehicle and the Ares V cargo launch vehicle, shown in Figure 1. The development program will be completed in December 2012 at the end of a Design Certification Review and after certification testing of two flight configuration engines. A team of over 600 people within NASA and Pratt & Whitney Rocketdyne are currently working to prepare for the fall 2008 Critical Design Review (CDR), along with supporting an extensive risk mitigation test program.



Figure 1. Ares V Cargo Launch Vehicle and Ares I Crew Launch Vehicle

I. The Mission of the J-2X Engine

The J-2X will power the Ares I upper stage and the Ares V earth departure stage (EDS). The initial use will be in the Ares I, used to launch the Orion crew exploration vehicle. In this application, it will power the upper stage after being sent aloft on a Space Shuttle-derived, 5-segment solid rocket booster first stage. In this mission, the engine will ignite at altitude and provide the necessary acceleration force to allow the Orion to achieve orbital velocity. The Ares I upper stage, along with the J-2X, will then be expended.

On the Ares V, first stage propulsion is provided by five RS-68B engines and two 5-segment boosters similar to the Ares I configuration. In the Ares V mission, the J-2X is first started to power the EDS and its payload, the Altair lunar lander, into earth orbit, then shut-down and get prepared for its next start. The EDS/Altair will remain in a parking orbit, awaiting rendezvous and docking with Orion. Once the two spacecraft are mated, the J-2X will be restarted to achieve

earth departure velocity. After powering the Orion and Altair, the EDS will be expended.

By using the J-2X Engine in both applications, a significant infrastructure cost savings is realized. Only one engine development is required, and the sustaining engineering and flight support infrastructures can be combined. There is also flexibility for changing the production and flight manifest because a single production line can support both missions with minimal differences between each engine configuration kit.

II. Engine Description

The J-2X is based on the successful J-2 family of engines which powered the Saturn V upper stages and had been the basis for the J-2S and X-33 aerospike engines. The J-2 family of engines has undergone a number of modifications in its history. The original J-2 engine evolved to a 230,000-pound thrust engine for its use on the Saturn V moon rocket. The J-2S, a simplified version of the basic J-2, achieved 265,000 pounds of thrust and demonstrated the tap-off drive cycle. This engine achieved an 11-second improvement in specific impulse over that basic J-2. In the mid-1990s, production of J-2 components was restarted to support the X-33 linear aerospike engine. This demonstrated the ability for the J-2 hardware to undergo significant modification for new applications. Figure 2 shows these three variants of the J-2 engine system during ground testing.

The increased performance needs of the Ares vehicle architecture requires that the J-2X further improves engine performance by providing 294,000 pounds of thrust while delivering 448 seconds of specific impulse. Like the basic J-2 and Linear Aerospike, the J-2X uses a conventional gas generator power cycle. To provide the unprecedented levels of performance for a gas generator cycle engine, the J-2X is increasing nozzle expansion ratio through the use of a film cooled nozzle extension, as well as increasing the element density of the main injector. Additional thrust is provided through increasing chamber pressure over the J-2 and J-2S configurations.

Other improvements in the engine incorporate a number of flight-proven technologies such as a copper-cooled main combustion chamber for added cooling margin with the increased chamber pressure, evolved turbopumps to incorporate margin enhancements proven in the RS-68 engine, and a modern control suite of redundant digital controls and sector ball valves. Retained from the original design are the proven, brazed regenerative nozzle, scissor inlet ducts, and gimbal bearings. In each case, existing

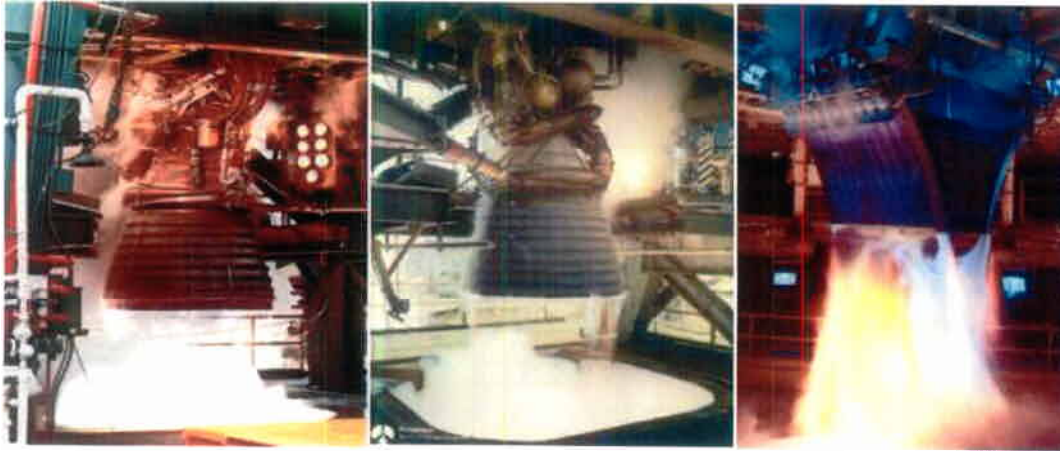


Figure 2. The J-2, J-2S, and J-2 derived X-33 Aerospike Engine Systems

vendors and fabrication capability exists to support a long product life cycle. The J-2X engine configuration is shown in Figure 3 along with the Delta IV and Ares V booster engine, the RS-68, for size comparison.



Figure 3. The J-2X engine shown in size comparison with the RS-68 booster engine

III. Development Program

The current flight manifest for the Ares I vehicle requires that the J-2X engine be developed very quickly compared to other manned flight engines of this class. In order to meet this aggressive schedule, the development effort must be highly integrated and take every practical opportunity to mitigate risk as early as possible, through both the design and test phase. To accomplish this, several design “best practices” from the RS-68 development program will be used in combination with as much early component testing as possible to inform the design.

There will be a significant effort to design, analyze, and verify that the design will be adequate for the mission needs. Design will be performed using a linked, parametric computer-aided design using Pro-Engineer for modeling. These models are then electronically linked to a suite of analytical tools, assuring that the as-designed configuration is the same as the as-analyzed form. This design definition is then graduated for use in computer-aided manufacturing to provide additional assurance that the as-built configuration meets design intent. The engine design being used to prepare for the critical design review is shown in Figure 4.



Figure 4. J-2X Engine Mode

Figure 5 shows the development program’s top-level schedule. This schedule also shows flights supported by the development program. A mass simulator will be provided for Ares 1-Y late in 2012, as well as a fully functional engine to support the Ares 1 test flight in 2013.

During the design process, there will be a series of significant risk mitigation tests to provide early recognition of potential design risks and to provide more schedule margin by addressing risks early in the development process. Testing has already been completed on subscale injectors, a full-size gas generator, as well as a powerpack using heritage J-2/J-2S/X-33 hardware. Figure 6 shows the subscale main injector test article used to anchor injector performance predictions.

Figure 7 shows the full-scale workhorse gas generator installed in the test stand at NASA MSFC which is currently being tested to fully characterize gas generator performance and functionality. Additional risk mitigation component testing will be conducted to inform the evolved design of the turbomachinery’s bearings, dynamic seals, and inducers.

Powerpack 1 testing using heritage hardware was initiated in December 2007 and is ongoing at NASA’s Stennis Space Center A-1 test stand. Figure 8 shows the powerpack being installed in the test stand.

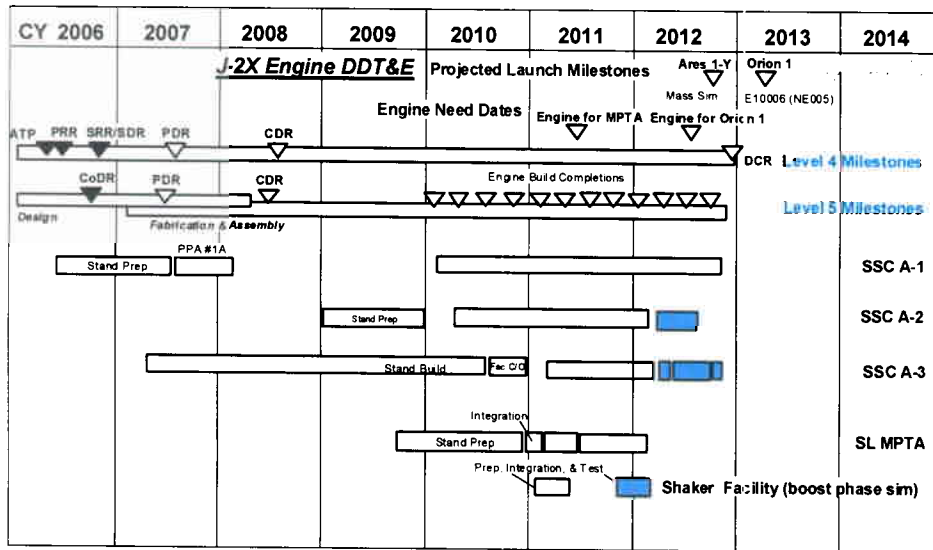


Figure 5. J-2X engine development schedule



Figure 6. Subca NASA MSFC le main injector testing at



Figure 7. Full-scale workhorse gas generator in test stand at NASA MSFC



Figure 8. Installation of the heritage hardware powerpack in Test Stand A-1 at NASA SSC

The test article consists of two existing turbopumps configured for the X-33 linear aerospike engine and a modified J-2 gas generator. This test series is designed to provide additional information on turbomachinery characteristics, particularly in areas where additional characterization of performance margins is of interest to analysts. This test series is scheduled for completion in May 2008. Figure 9 shows the powerpack at full power during a March 2008 test.

Component-level testing will progress to engine-level testing in 2010, following a second powerpack test series

using J-2X configuration turbomachinery and gas generator. This highly parallel development and certification testing will be accomplished by taking full advantage of the test stand capabilities offered by the Stennis test stand complex. Testing will be conducted at both sea level, as well as simulated altitude. The program will use seven development engines, leading to the testing of two certification engines. The test program is planned to perform over 200 engine hot-fire tests to fully investigate the engine's operation and to certify the design ready for human flight.

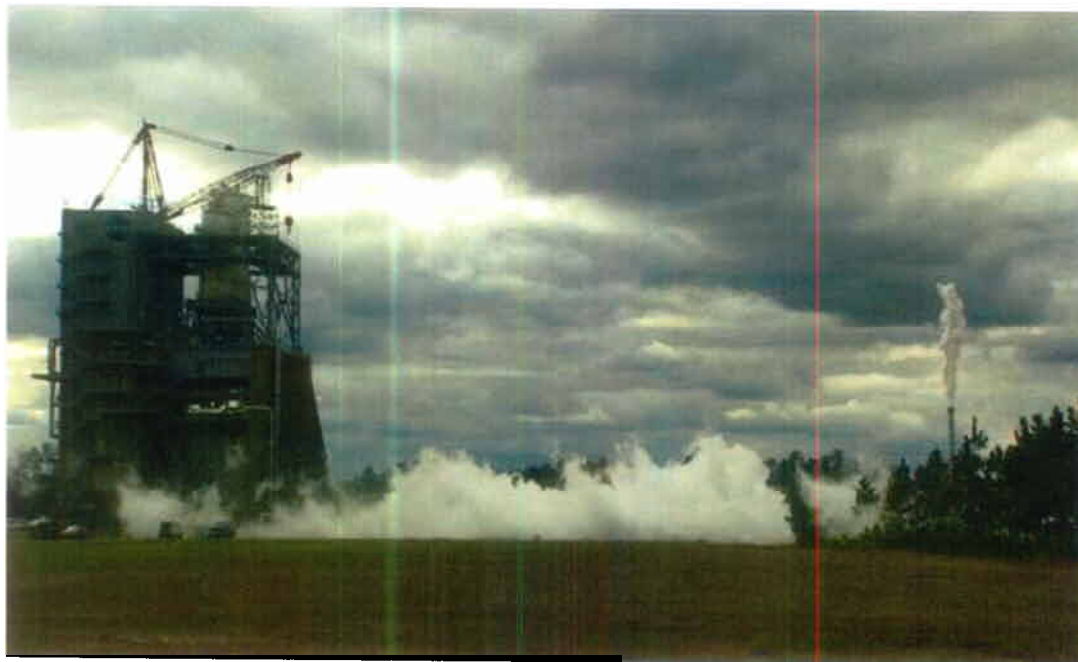


Figure 9. Heritage hardware powerpack testing at Test Stand A-1

IV. Facilities

There are a number of facilities required to support the thorough test program for component testing and engine full-scale testing. Component testing has been initiated at several of MSFC's facilities, including subscale injector, gas generator, and inducer water flow tests. Still to come will be additional inducer water flow testing, seal testing, turbine airflow tests, and workhorse, full-scale gas generator tests. The use of these existing facilities has given the program the ability to gather early environmental characterization to support engine design and analysis.

The location for all powerpack and engine test will be Stennis Space Center. The J-2X team already is testing a heritage hardware powerpack in test stand A-1. This test stand will also be home to Powerpack 2 testing in 2010, followed by complete engine level testing in the J-2X's sea level configuration not using the nozzle extension.

Test Stand A-2, currently used by the Space Shuttle Program for the Space Shuttle Main Engine, will be turned over to the J-2X program in 2009 and will be the site of the first engine-level test in early 2010. This test stand has a self-pumping altitude simulation diffuser that will enable

testing with a shortened nozzle extension to gain information on the nozzle-to-nozzle extension joint and to anchor the modeling on film cooling effectiveness on the forward end of the nozzle extension.

The latest addition to the NASA SSC A-complex is test stand A-3, which is being built to support the critical altitude test requirements of the J-2X program. An artist's concept of the completed test stand is shown in Figure 10.

It will be completed in late 2010, and testing will commence in 2011. This test stand will provide full altitude simulation through an actively pumped diffuser with an enclosure large enough to permit engine gimbal testing. The facility will be capable of performing full-duration tests to simulate entire mission duty cycles. Upon completion of the development program, the A-3 test stand will be used to acceptance test engines for the production program. Risk mitigation testing for the development of the actively pumped diffuser is taking place at SSC with a subscale diffuser, which will inform the design and performance characteristics of the A-3 altitude facility diffuser. A recent photograph of the A-3 construction site is shown in Figure 11 and subscale diffuser testing is shown in Figure 12.



Figure 10. A-3 altitude simulating test stand for J-2X



Figure 11. Test stand A-3 under construction at NASA Stennis Space Center

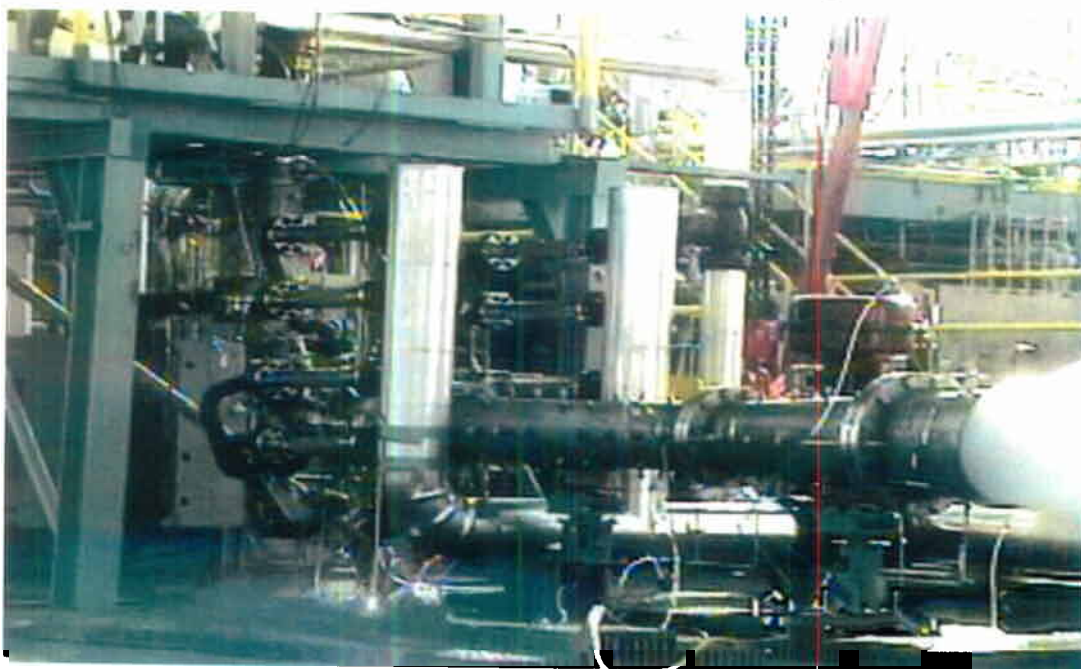


Figure 12 – A-3 Subscale diffuser risk mitigation testing at Stennis Space Center

V. Summary

The J-2X development program continues to make progress towards a December 2012 Design Certification Review. The program has completed its Preliminary Design Review in the summer of 2007 and is heading for a Critical Design Review in September 2008, with component CDRs beginning in 2008.

Component testing on injectors, igniters, and turbomachinery components has been completed. Continued component testing on other parts will occur

through 2010. Powerpack 1, using heritage hardware, has begun testing to provide early environmental data and will be followed with a J-2X configuration powerpack in 2010.

Engine testing will commence in 2010 at NASA's Stennis Space Center on three test stands including the new altitude simulation facility. The program will test 7 development engines along with two certification engines. One of the development engines will be provided for stage testing and another development engine will be supplied for a development flight test, which will take place in 2013.

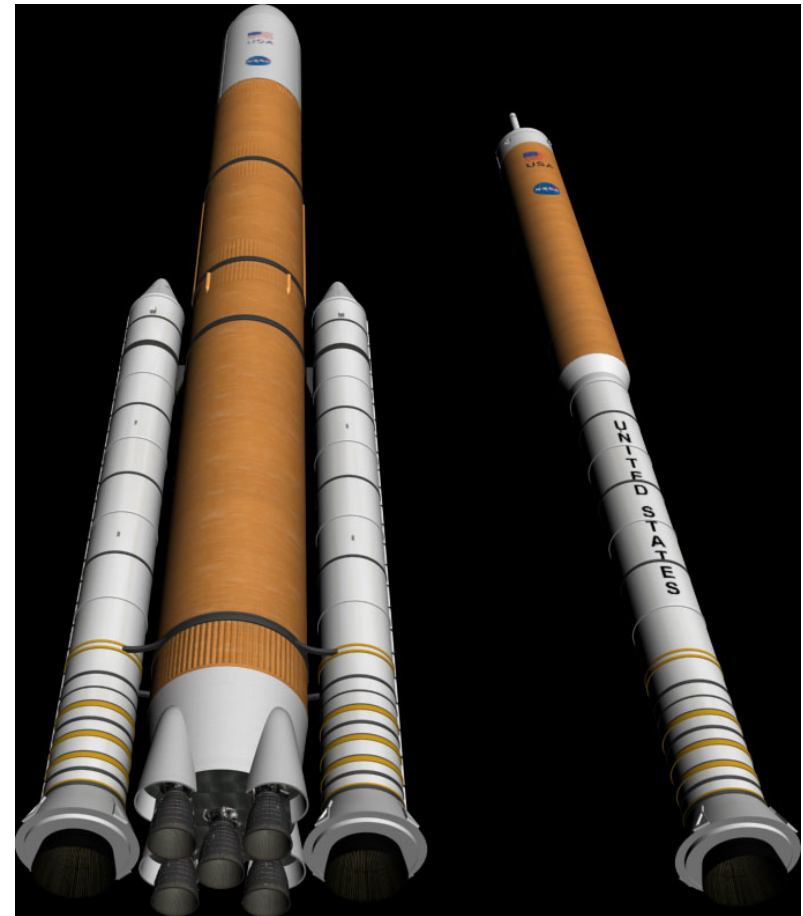


Development Status of the J-2X

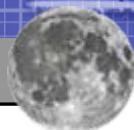
Mike Kynard & John Vilja
May 2007

Ares Family of Launch Vehicles

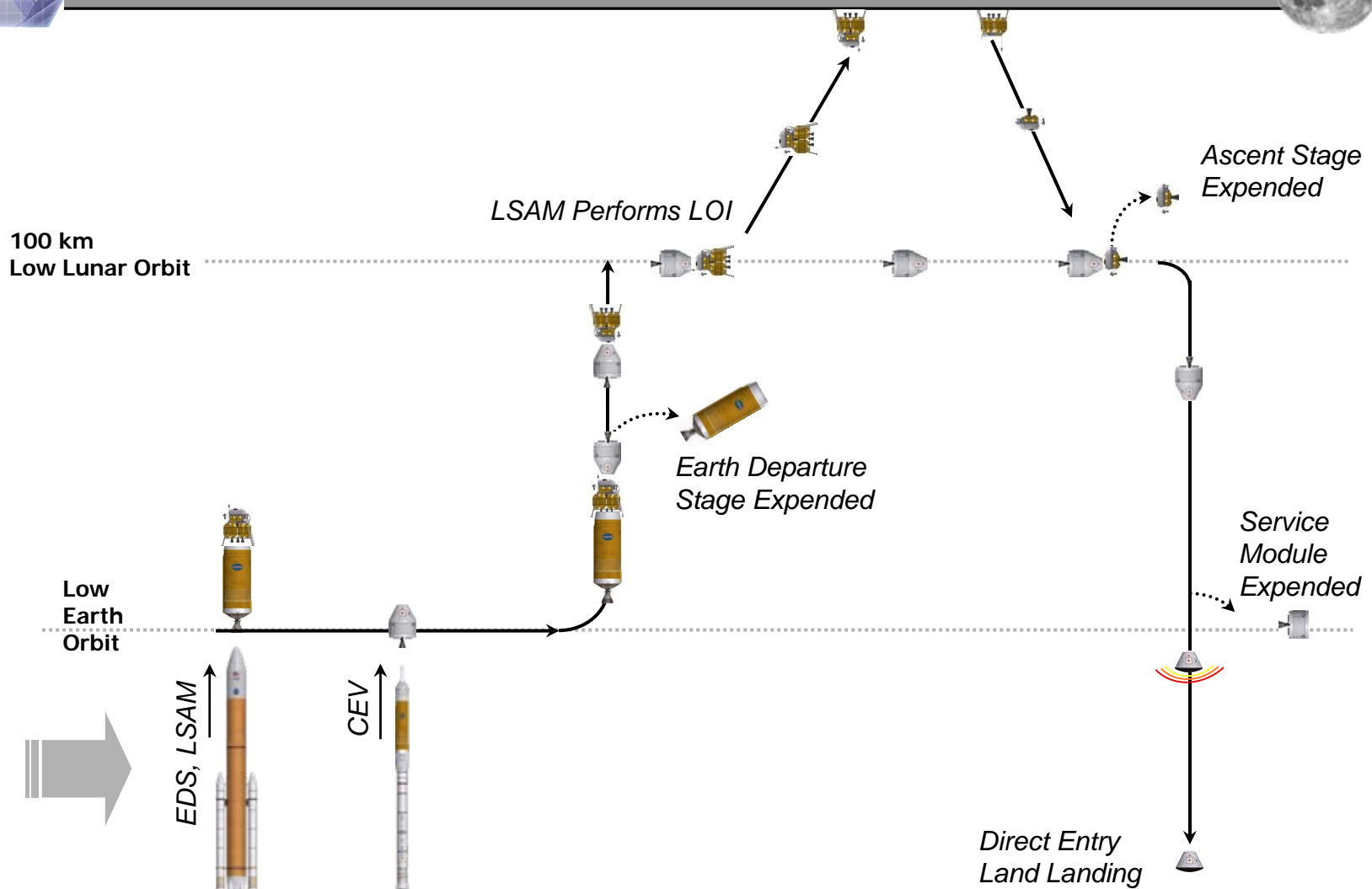
- **Ares I**
 - “Crew Launch Vehicle”
 - Solid 1st stage
 - O₂/H₂ second stage
- **Ares V**
 - “Cargo Launch Vehicle”
 - O₂/H₂ 1st stage
 - Solid Boosters
 - O₂/H₂ second stage / Earth departure stage



"1.5 Launch" Earth Orbit / Lunar Orbit Rendezvous



MOON



Vehicles Not to Scale



EARTH

J-2 Engine Lineage

J-2X: Adding a new member to the family



J-2 Engine Hot Fire



1960-1970

1965-1971

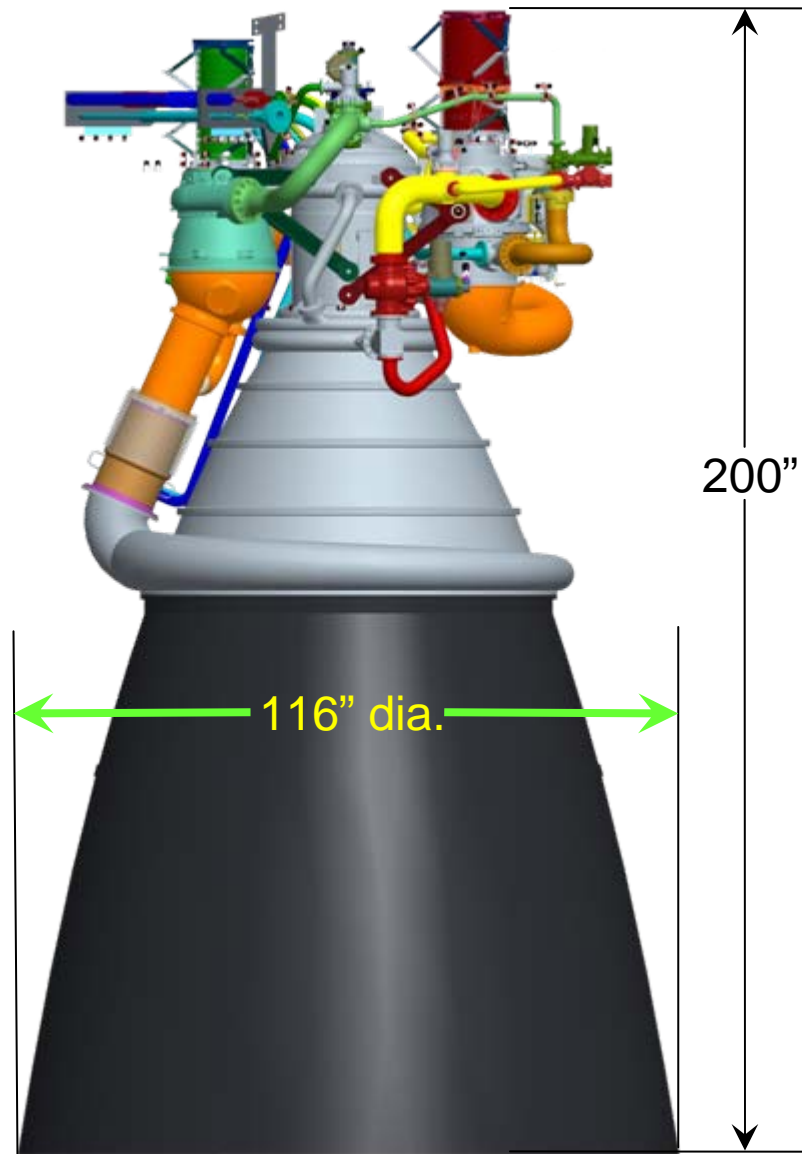
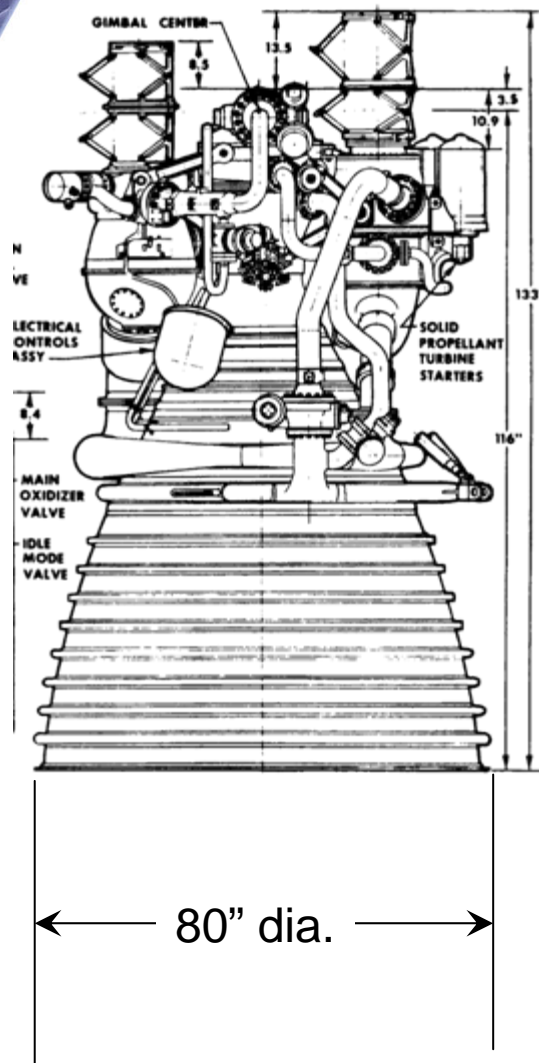
1996-2001

2006-

Configuration	J-2	J-2S	X-33	J-2X
Thrust	230 klb	265 klb	261 klb	294 klb
Isp	425 sec	436 sec	419 sec	448 sec
Mass	3,492 lb	3,800 lb	7,500 lb	5,450 lb
Length	116 in	116 in	79 in	185 in

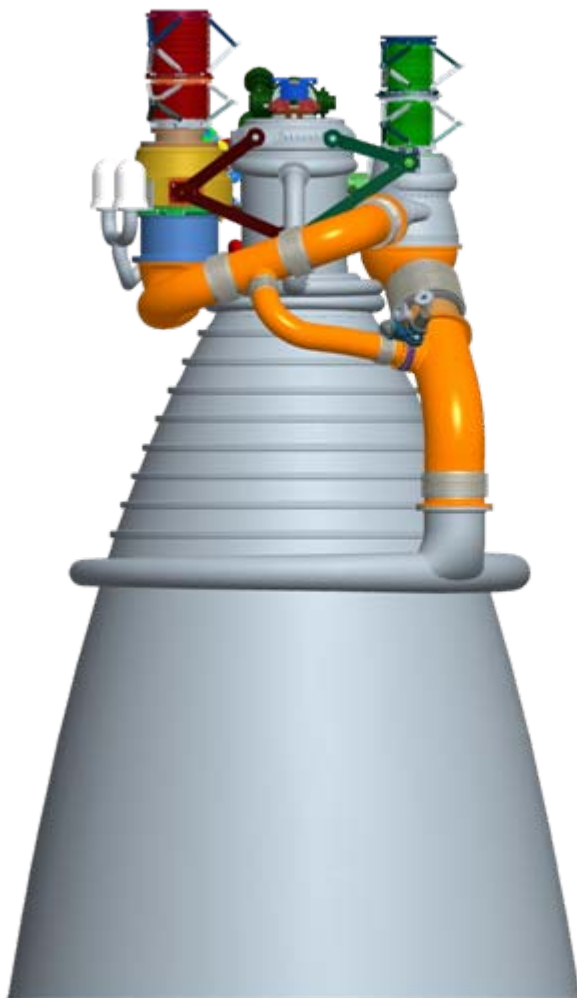
Requirements

J-2X vs J-2S & J-2 Size Comparison

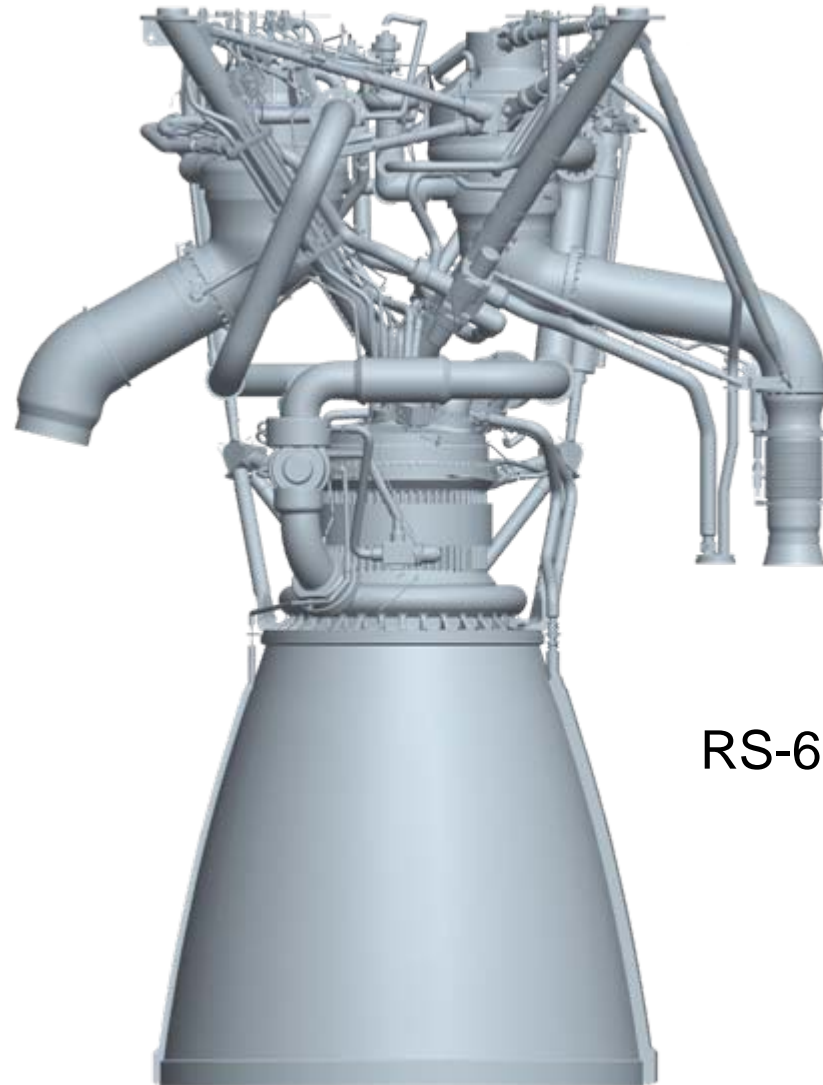


J-2X & RS-68 Size Comparison

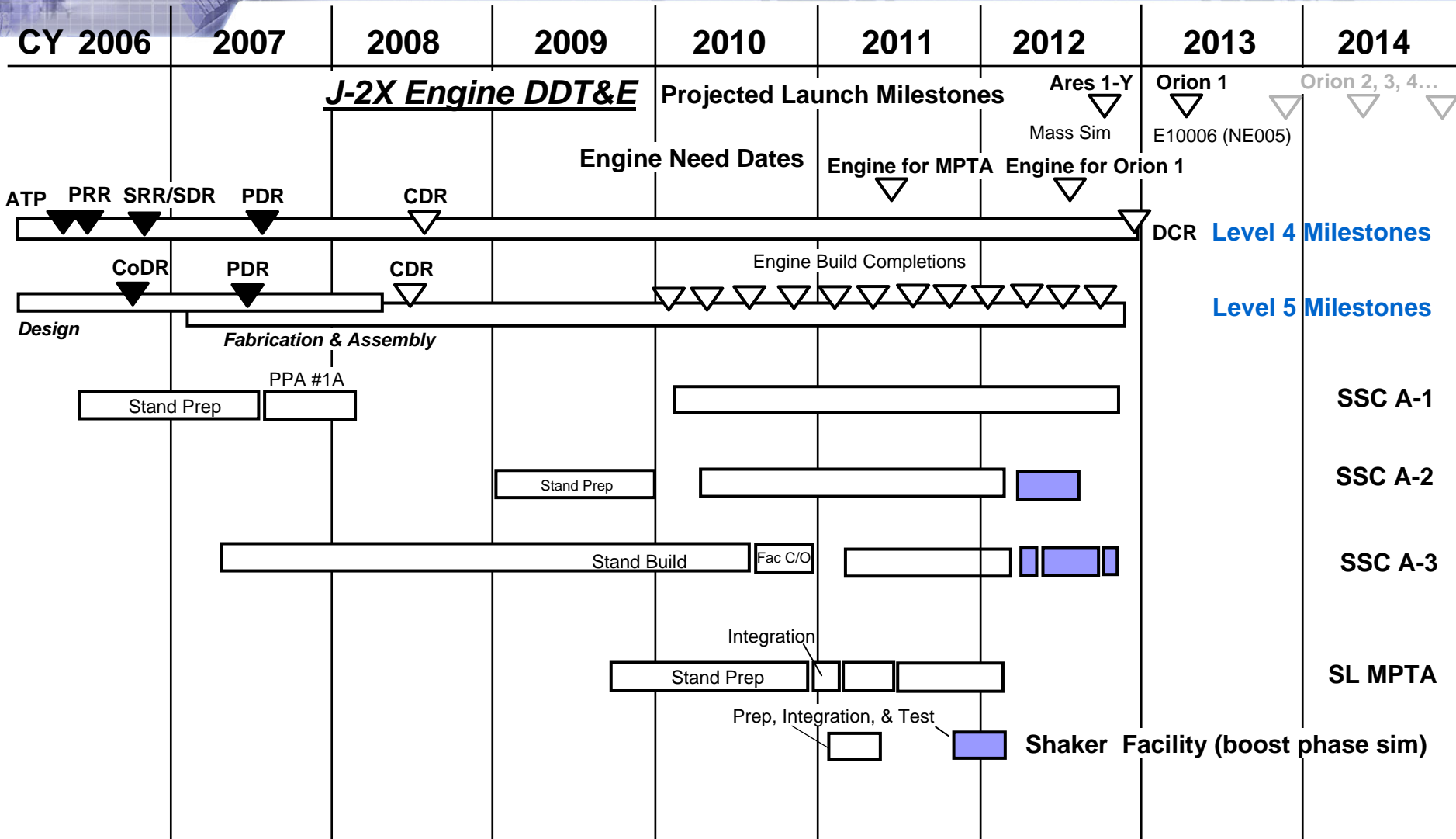
J-2X



RS-68



J-2X System Development Plan



Component Testing ongoing



Workhorse GG at MSFC



Subscale Main Injector Test

Powerpack Testing Ongoing



J-2X Test Stands



SSC A-1



SSC A-3

SSC A-2



J-2 Legacy Expertise Support



J-2X Powers the Vision for Space Exploration



Pratt & Whitney
A United Technologies Company

- **PWR on contract for \$1.2B DDT&E effort**
- **Accelerated schedule - early testing / fab critical**
- **Rely on heritage & flight proven technology**
- **Production contract expected in 2010**
- **J-2X success critical to Exploration sustainability**

Low risk propulsion for Exploration