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DEVELOPMENT OF THE J-2X ENGINE FOR THE ARES I CREW LAUNCH VEHICLE AND THE ARES V CARGO LAUNCH VEHICLE: BUILDING ON THE APOLLO PROGRAM FOR LUNAR RETURN MISSIONS

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ABSTRACT

The United States (U.S.) Vision for Space Exploration has directed NASA to develop two new launch vehicles for sending humans to the Moon, Mars, and beyond. In January 2006, NASA streamlined its hardware development approach for replacing the Space Shuttle after it is retired in 2010. Benefits of this approach include reduced programmatic and technical risks and the potential to return to the Moon by 2020 by developing the Ares I Crew Launch Vehicle (CLV) propulsion elements now, with full extensibility to future Ares V Cargo Launch Vehicle (CaLV) lunar systems. The Constellation Program selected the Pratt & Whitney Rocketdyne J-2X engine to power the Ares I Upper Stage Element and the Ares V Earth Departure Stage (EDS). This decision was reached during the Exploration Systems Architecture Study and confirmed after the Exploration Launch Projects Office performed a variety of risk analyses, commonality assessments, and trade studies. This paper narrates the evolution of that decision; describes the performance capabilities expected of the J-2X design, including potential commonality challenges and opportunities between the Ares I and Ares V launch vehicles; and provides a current status of J-2X design, development, and hardware testing activities. This paper also explains how the J-2X engine effort mitigates risk by testing existing engine hardware and designs; building on the Apollo Program (1961 to 1975), the Space Shuttle Program (1972 to 2010); and consulting with Apollo-era experts to derive other lessons lived to deliver a human-rated engine that is on an aggressive development schedule, with its first demonstration flight in 2012.

INTRODUCTION

The U.S. Vision for Space Exploration requires safe and highly reliable launch vehicles to send astronauts to the Moon, Mars, and beyond.[1] The Ares I, slated to fly in the 2014 timeframe, and the Ares V, due to fly by 2020 (Figure 1), are being designed to provide safe, reliable, sustainable space transportation systems built on a foundation of legacy knowledge and heritage hardware. Together, these systems will replace the Space Shuttle, which will be retired by 2010.

The lunar mission begins by launching the Ares V, whose Earth Departure Stage transports the Lunar Surface Access Module (LSAM) into space. The EDS will ignite at altitude to put it and its payload into a stable orbit. The Ares I will then launch with astronauts aboard the Orion Crew Exploration Vehicle (CEV) to rendezvous with the EDS/LSAM in Earth orbit. NASA's Constellation Program manages the launch vehicles, stages, crew, and lunar lander spacecraft.

The Ares I, shown in Figure 2, is a 2-stage vehicle that will launch the Orion into Earth orbit for missions to the International Space Station or to rendezvous with the Ares V for missions to the Moon, Mars, or other destinations. The Launch Abort System (LAS) atop the Orion capsule can safely rocket the capsule and crew away from the launch vehicle in case of an emergency, an escape feature not found on the current Space Shuttle fleet.

Figure 1. Artist's concept of the Ares V, left, and Ares I in flight.

The Ares I first stage is a single 5-segment Reusable Solid Rocket Booster (RSRB), which is derived from existing Space Shuttle hardware and uses polybutadiene acrylonitrile (PBAN) propellant. The Ares I Upper Stage is powered by the J-2X engine, a liquid oxygen/liquid hydrogen (LOX/LH2) engine based on the J-2 engine used in the S-II and S-IVB upper stage propulsion systems found on NASA's Apollo Program Saturn V.

The Ares V baseline configuration for lunar missions, also shown in Figure 2, consists of two Shuttle-derived 5-segment RSRBs, similar to the Ares I first stage, along with a 33-foot diameter Core Stage delivering liquid oxygen and liquid hydrogen to a cluster of five RS-68 engines. Atop the Core Stage is the EDS, which is powered by a J-2X engine, the same as the Ares I Upper Stage's engine. The EDS engine will ignite at altitude to put the vehicle in a stable orbit. Once the EDS reaches orbit and docks with the Orion, the J-2X engine will re-ignite to begin trans-lunar injection (TLI) to reach lunar orbit. The engine hardware commonality is expected to reduce development and operations costs.

RESULTS AND DISCUSSION

MANAGEMENT APPROACH TO REDUCE DESIGN RISK

Propulsion systems historically represent the most technologically challenging area of any space vehicle development because of the high operating pressures, temperatures, and other performance requirements. NASA's risk reduction strategy for design, development, test, and evaluation of the J-2X engine is to build upon heritage hardware and apply valuable experience gained from past development efforts. For example, a key element of this engine, the turbomachinery, was successfully recreated and re-developed during the X-33 Program. Understanding the results of that testing is informing the development cycle of the current design. In addition, NASA and its industry partner, Pratt & Whitney Rocketdyne, which built the original J-2, have tapped into their extensive databases and are applying lessons conveyed firsthand by Apollo-era veterans of America's first series of Moon missions in the 1960s and 1970s.

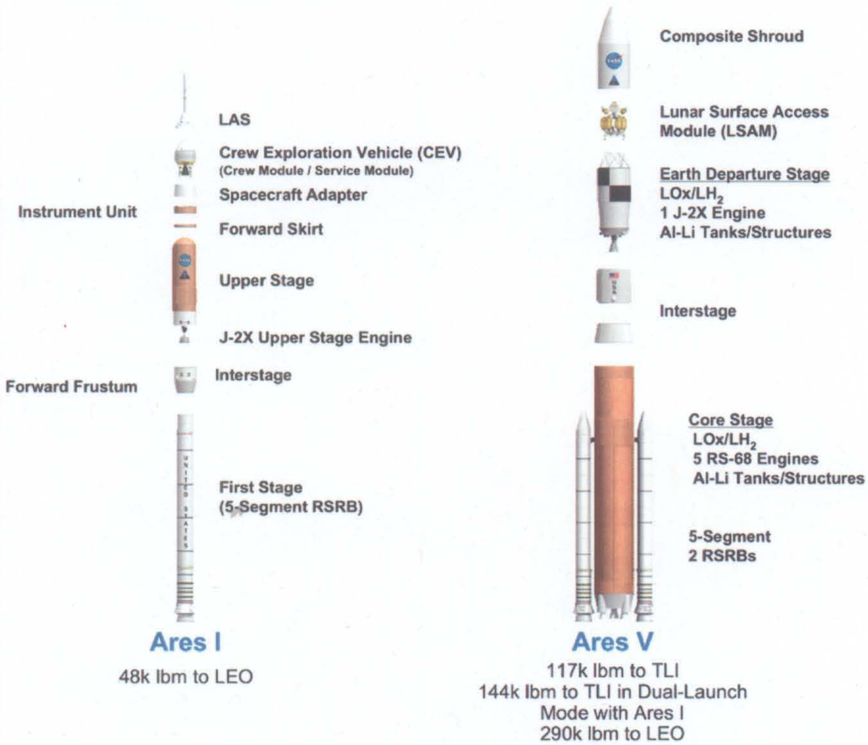

Figure 2. Expanded view of the Ares I and Ares V.

. NASA's development approach for the J-2X engine includes:

- Early requirements definition and management.
- Incorporating lessons learned from the J-2 heritage programs.
- Initiating long-lead procurement items before the Preliminary Design Review.
- Incorporating design features for anticipated Earth Departure Stage requirements.
- Identifying facilities for sea-level and altitude testing.
- Starting ground support equipment and logistics planning at an early stage.

Other risk reduction strategies include using a proven gas-generator cycle engine with recent development activity; using heritage-based turbomachinery; applying, where feasible, current and recent advances in main combustion chamber technology; updating materials where feasible; and performing rigorous development, qualification, and certification testing of the engine system, with a philosophy of "test what you fly, and fly what you test." These and other active risk management strategies are in place to deliver the J-2X engine for low-Earth orbit and lunar return missions.

EVOLUTION OF THE J-2X DESIGN DECISION

The original Exploration Systems Architecture Study was conducted between May and September 2005, followed by a final report in November 2005. The ESAS was charged with recommending and assessing viable launch system architectures to support exploration of the Moon and Mars, as well as access to the International Space Station.[2]

The Exploration Launch Projects (ELP) Office was created in October 2005 to manage the Ares I and Ares V developments. It assigned the J-2X Upper Stage Engine Element team to provide a propulsion system for both the Ares I Upper Stage and Ares V Earth Departure Stage. Three alternatives for the Ares I Upper Stage were considered during the ESAS: a single expendable version of the Space Shuttle Main Engine (SSME), a pair of J-2S engines—derivatives of the J-2 engine flown on the Saturn V launch vehicle's S-II and S-IVB stages—or a cluster of four new expander engines. The ESAS recommended the SSME (RS-25)—redesigned to be expendable —for its long performance history and proposed commonality with the Ares V, which was going to use the SSME on its Core Stage.[3] The EDS would use two J-2S engines.

After the Exploration Systems Architecture Study, follow-on systems engineering studies concluded that two J -2S engines imposed a weight penalty on the EDS without a comparable improvement in performance. The second engine was dropped from the design as a result. The Exploration Launch Projects Office conducted a subsequent study in January 2006 to further evaluate the J-2 engine and its derivatives. The RS-68 was chosen over the SSME as the main engine for the Ares V Core Stage following this extensive bottom-up review to dramatically reduce development and operational costs.

HISTORY OF THE J-2 ENGINE

The original J-2 engine was developed in the early 1960s for the Saturn IB and Saturn V vehicles. The liquid hydrogen engine, developed by Rocketdyne, was designed for high reliability, efficient packaging of components, and restart capability in flight.

Rocketdyne also developed a simplified version of the J-2, called the J-2S. The J-2S was also a liquid hydrogen engine with increased thrust and specific impulse, improved component accessibility, and the same vehicle interface as the J-2. The J-2S was a totally different engine from the J-2, in that it featured a unique tap-off cycle, where combustion products are tapped off the main combustion chamber to drive the turbines, eliminating the need for a gas generator. While the tap-off cycle engine had its benefits, it also had design problems and was never flown. The engine study team was concerned because the J-2S was a new design with a low technology readiness level. Additionally, it was untested in flight and lacked complete drawings and documentation. In the end, the J-2S was not recommended as a viable option for the current development program.

Two additional variations of the J-2S design—the J-2Sd and J-2+—also were considered as options for the engine study. The J-2Sd is a derived J-2S engine concept based on the J-2S tap-off cycle and existing J-2S Mk 29 fuel and oxidizer pumps. The J-2Sd engine design ultimately was not chosen for near-term development because its state-of-the-art thrust chamber assembly would have created schedule delays due to its low technology readiness levels. Also, the engine would have been heavier than the original tube wall design.

The powerpack of the J-2+ engine was used as part of the aerospike propulsion system designed for the X-33 Program and used existing Mk 29 pumps and a new state-of-the-art injector, chamber, and nozzle, but it had the same potential schedule problems as the J-2Sd.

Given the aforementioned limitations of other J-2 variants, the team selected the J-2X, an advanced derivative of the J-2, as the engine for both the Upper Stage and the Earth Departure Stage. This decision means that investments made in the Ares I upper stage engine are directly applicable to the Ares V. The main requirements and their design impacts are shown in Figure 3.

The goal to use heritage-based hardware and legacy knowledge to supply a common engine was intended to:

- Improve the J-2 engine's performance.
- Reduce the number of new engines to be developed.
- Take advantage of institutional NASA and industry knowledge regarding the J-2.
- Simplify recurring operations.
- Leverage a higher technology readiness level than was available for the SSME.

• Reduce recurring and nonrecurring costs through fleet commonality.[4]

The J-2 engine also had an advantage in that it was a human-rated engine capable of restarting in flight, something the SSME was not designed to do.[5] Finally, the modifications needed to develop the J-2X were much less expensive and less risk-intensive than trying to modify the highly complex SSME for in-flight restart.

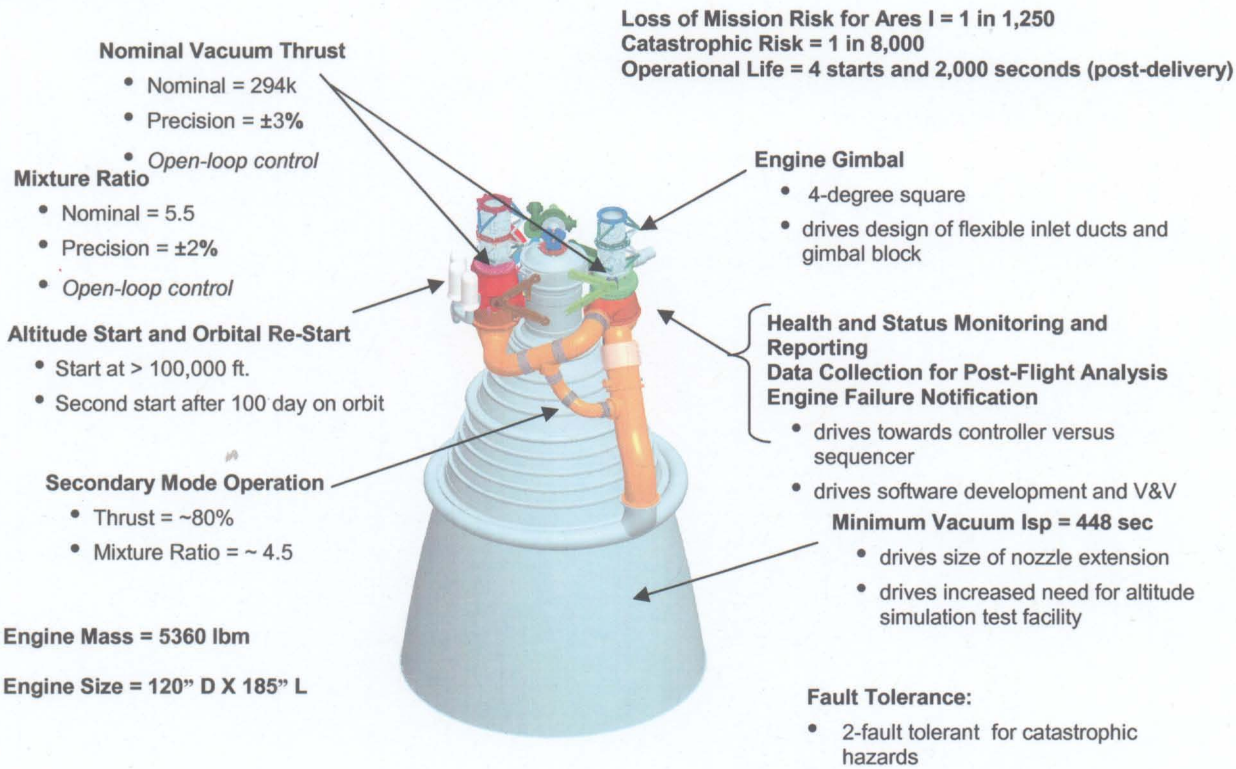

Figure 3. J-2X Key Requirements.

COMMONALITY CHALLENGES

Commonality is one of the goals of the Constellation Program. A Commonality Assessment in May 2006 brought together a multi-disciplined panel of aerospace experts to assess potential commonalities between Ares I and Ares V and the challenges. The panel concluded that the J-2X interfaces to the stage and main propulsion system should be the same for both vehicles. Installation processes could be made common also, along with avionics and software from the RS-68 on the Ares V and common avionics and sensor components shared by the Ares I and Ares V. It was also believed that one certification program could cover the J-2X for both the Ares I and Ares V. However, the different performance requirements and operating environments for the two vehicles result in different engine specifications. Given the number of potential differences, a single certification may not be possible. The near-term need for Ares I is driving development, while Ares V requirements remain in flux.

Two key differences between the J-2X applications for Ares I and Ares V both result from the lunar mission scenario. The Ares I requires only one J-2X start at altitude. For the Ares V mission, the J-2X would be required to ignite first at altitude and burn for about 8 minutes to put the EDS and LSAM in a stable orbit. Following rendezvous with the Orion (Figure 4), it must re-start for about 5 minutes to escape Earth's gravity and transfer to lunar orbit.

The current Constellation Architecture Requirements Document requires a loiter capability between start and re-start of up to 95 days. Early engineering studies deemed this window necessary because the departure stage and lunar lander are launched separately from the Orion. This loiter time took into account launch window availability, technical or weather delays, and other events that might delay the Orion's rendezvous. However, this extended loiter period posed serious impacts to the Earth Departure Stage and J-2X in multiple areas.[6] Among those are on-orbit propellant management, micrometeoroid protection, cryocoolers for on-orbit propellant management, additional flight instrumentation, and propellant tank pressurization. The baseline engine would require additional igniters to initiate the second start. In addition, the engine would require active avionics and power during conditioning and terminal count for the second burn. The ELP Office is gathering data on the potential impacts of the different operating requirements, with consideration toward reducing the duration of the loiter requirement.

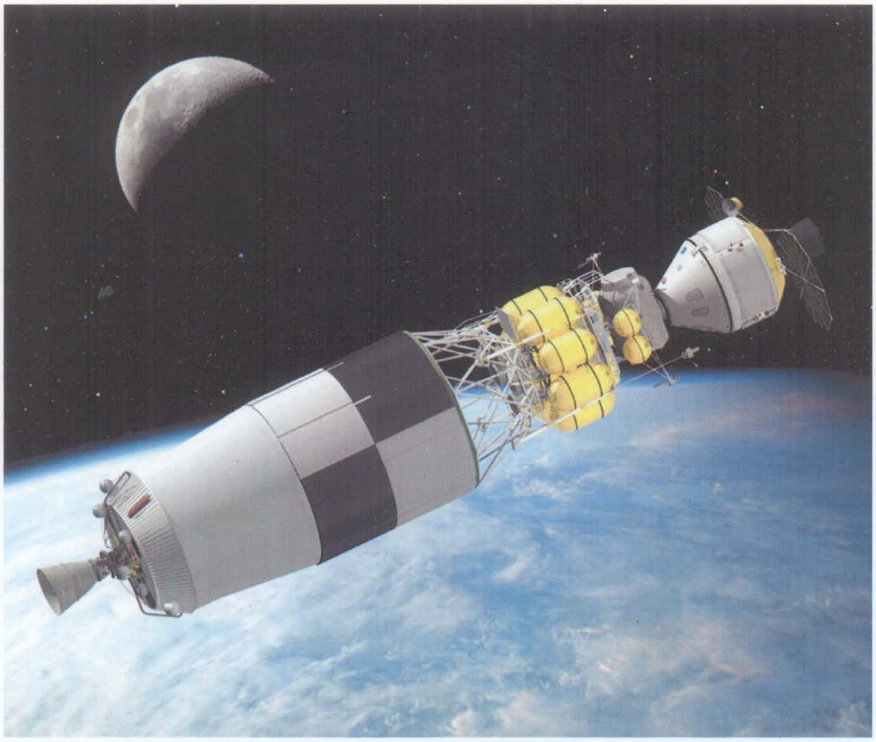

Figure 4. Ares V EDS/LSAM/Orion artist's concept.

ACCOMPLISHMENTS TO DATE

Due to its heritage head start, the J-2X government/industry team made significant progress in 2006 and early 2007, leading programmatically and technically in many ways the development efforts of other Constellation projects and elements. Several major milestones along the path from Preliminary Requirements Review in 2006 to Preliminary Design Review later this year are summarized below.

The Upper Stage Element Office was created in early 2006 to develop the J-2X, drawing on experts in engine development from across NASA and its contractor partners, as well as consultants with direct experience with the Apollo Saturn program.

One of the first things the Element Office did was reach back within the NASA and Pratt & Whitney Rocketdyne organizations to consult with individuals who had worked on the original J-2 engine. The Element Office formally chartered an independent team to provide assessments, ensure that the Engine office applied lessons learned, and verify that the team was "doing the right things."

A J-2X "grey-beard" team (consisting of Apollo-era J-2 engineers) met to discuss historical problems with the engine and suggest possible design approaches for future engines. This independent team reported results based on previous data and participated in the J-2X Engine Preliminary Requirements Review (PRR).

The grey-beard team also contributed to NASA's risk reduction efforts by drawing upon their "lessons lived" during the Apollo era. Their inputs addressed a wide range of issues, including testing procedures, hardware evaluations, engineering fixes and problem-solving approaches, developmental lessons learned from the Space Shuttle Main Engine and Evolved Expendable Launch Vehicle programs, and potential design improvements for the J-2X.

Following the grey-beard discussions, the J-2X team developed a procurement strategy for the engine, as well as a draft statement of work. Based on the acquisition study, a bottom-up review was performed for the J-2X, which included: the engine's design and development approach; integrated master schedule with critical path assessments for immediate implementation; and project resource requirements (including labor, facilities, and budget). From these actions, the J-2X team was able to publish a synopsis of the engine to be developed, all within 4 months of engine selection.

Between April and June 2006, the J-2X Office created the planning and design documents necessary to establish the budget, develop Data Requirements Documents and complete the Statement of Work. The Element also began making preliminary design decisions, such as the gas generator operating cycle, minimal changes to turbomachinery, and parallel pursuit of a "de-rated" 274,000-pound thrust variant capable of supporting initial Earth orbital missions in the event the 294,000-pound thrust level needed for lunar missions encountered delays.

During May 2006, the J-2X team developed Facility Requirement Documents to support the development of test facilities required testing for the development, qualification, certification, and acceptance testing for the J-2X engine.

In June 2006, Exploration Launch Projects engineers on the Upper Stage Engine Board completed a Preliminary Requirements Review, determining that the engine requirements were mature enough to begin developing subsystem and component requirements and begin engine conceptual design in preparation for a SRR/SDR in fall 2006 that would verify the engine requirements satisfy the launch vehicle needs.

From spring to fall 2006, the J-2X team identified all of the existing J-2 hardware from the Apollo program and the X-33 aerospike engine program and designated it for transfer to the J-2X program. The X-33 turbomachinery was removed from the X-33 power pack, which was located at Stennis Space Center and transferred to the J-2X effort (Figure 5). Additional X-33 hardware was located at Marshall Center. The hardware was shipped to the contractor for tear-down and inspection.

Figure 5. X-33 aerospike engine turbomachinery removal at Stennis Space Center.

In June 2006, Marshall engineers completed testing of the J-2X Augmented Spark Igniter, which will ignite the hydrogen and oxygen propellant elements in the combustion chamber. During the igniter tests, engineers integrated the igniter assembly—spark plugs, propellant injectors, and ignition torch—and fired it in a vacuum chamber to simulate conditions the Ares I upper stage will experience during its high-altitude start.

Also in June 2006, Marshall personnel completed hot-fire testing of a subscale main injector, which injects and mixes liquid hydrogen and liquid oxygen in the main combustion chamber, where they are ignited to produce thrust (Figure 6). The subscale injector contained 40 individual propellant flow elements. Approximately 50 hot-fire tests were completed.

Figure 6. Subscale main injector test.

Subscale injector testing resumed in July 2006 on a 58-element injector, which is the J-2X baseline element density, at the same conditions used for the previously tested 40-element injector. The J-2X Combustion Devices Integrated Product Team went to 100% power level on the planned injector design. The resulting data were applied toward the design and manufacture of a full-scale injector design for testing in 2007.[7]

On Nov. 9, 2006, a ceremony at Stennis Space Center in Mississippi formally marked the handover of the A-1 test stand from the Space Shuttle Program to the Constellation Program. The stand, once used for testing Saturn V stages and Space Shuttle Main Engines, is undergoing refurbishment in 2007 to support J-2X testing. Also at Stennis in late 2006, machining of heritage J-2 engine hardware began in preparation for J-2X Power Pack testing in 2007 (Figure 7).

Testing of the J-2 heritage valves was also conducted in October and November 2006 at the Marshall Center. Initial checkout of valve position indicators was followed by proof testing of the Main Fuel Valve (MFV), Main Oxidizer Valve (MOV), and Oxidizer Turbine Bypass Valve (OTBV). Ambient and cryogenic leak checks and cycle testing of the MOV were performed, along with ambient leak checks, cycle testing of the MFV, cryogenic leak checks and cycle testing of the MFV, OTBV leak checks and cycle testing.

In December 2006, the Engine Element successfully completed a combined System Requirements Review/System Definition Review. Encompassing requirements, conceptual design and planning to meet J-2X-related aspects of the exploration mission, this review established that the J-2X has a solid foundation of technical requirements and a resulting engine system conceptual design on which to base further design and development.

Also in November 2006, NASA completed a System Requirements Review of the Constellation Program, first review of all systems for the Orion spacecraft and the Ares I and Ares V rockets, including the J-2X.[8] It was the first system requirements review NASA has completed for a human spacecraft system since a review of the space shuttle's development held in October 1972. The Constellation Program system requirements were the product of 12 months of work by a NASA-wide team.

Figure 7. Heritage J-2 undergoes power pack preparations.

The system requirements review is one in a series of reviews that will occur before NASA and its contractors build the Orion capsule, the Ares launch vehicles, and establish ground and mission operations. The review guidelines narrow the scope and add detail to the system design. Project level reviews were slated for 2007. Once the project-level reviews are complete, the Constellation Program will hold another full review to reconcile the baseline from this first review with any updates from the project reviews. A lunar architecture systems review of equipment associated with surface exploration and science activities on the moon is expected in the spring of 2009.

J-2X ENGINE SRR/SDR CHANGES AND THE PATH FORWARD

The J-2X Element conducted a combined SRR/SDR in October and November 2006. As a result of analyses and testing during 2006, the J-2X engine that emerged from the SRR/SDR essentially represented a more complete block change than initially baselined as the Element headed toward component-level Preliminary Design Reviews in June 2007 for J-2X contractor Pratt & Whitney Rocketdyne and July/August for the Element.

A single engine development cycle remains the goal for fulfilling the upper stage requirements of both Ares I and Ares V. Overall project risk will be achieved by leveraging J-2, J-2S, and RS-68 experience, designs, and hardware to the extent feasible, as well as the more recent XRS-2200 development experience. The design heritage of the post SRR/SDR configuration is shown in Figure 8.

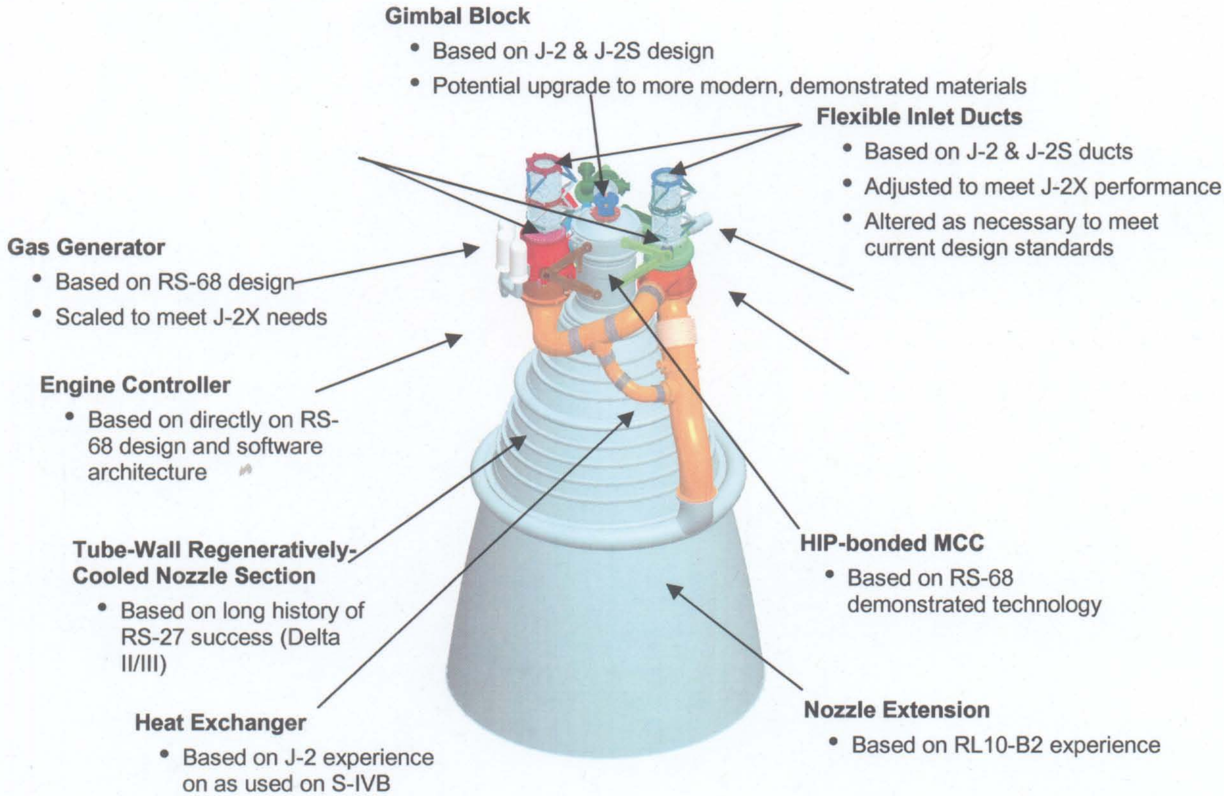

Figure 8. Heritage of J-2X components.

Approaching SRR/SDR, the Element was still carrying 274,000-pound thrust and 294,000-pound thrust options, the former for Earth orbital and International Space Station missions and the later for the lunar mission requirement. The Element subsequently gained sufficient confidence to eliminate the 274K option.

In its latest configuration, the J-2X will use RS-68 flight type Main Injector, Gas Generator and Main Combustion Chamber with Augmented Spark Injector, all scaled to the smaller J-2X. Dropped from the design was an option for a J-2 heritage gas generator. A Channel Wall Nozzle design was dropped in favor of a Tube Wall regeneratively cooled nozzle.

However, the case for several design and program decisions remained open following SRR/SDR, and the Element added a Resynchronization Review in March 2007 to resolve the final details before proceeding to Preliminary Design Review.

Trades between metal and carbon composite nozzle extensions continued past SRR/SDR. It was rated the element's top risk going into 2007. Following the review, engineers decided that the metal options studied lacked sufficient temperature margin and opted to go forward with composite materials to the Resynchronization Review. Composites were found to have higher development costs but significantly higher margin required for the J-2X mission.

The effectiveness of Turbine Exhaust Gas cooling for the nozzle was not well characterized at SRR/SDR. Engineers subsequently added a Turbine Exhaust Gas Manifold to the design that will provide cooling, as well as extra Specific Impulse.

The design details of the gas generator (GG) were not finalized at SRR/SDR. Unlike a main injector, driven by performance and stability, the gas generator injector is driven by stability and temperature uniformity, which can affect downstream components. Plans were added for a "workhorse" GG in fall 2007 to test 43- and 61-element injectors to establish final density and the total number of elements on the full-scale injector. The workhorse GG will include a turbine simulator – including ducting and orifice representative of the actual turbine back pressure – in an effort to understand turbine temperatures and resulting turbine blade durability.

In addition to dropping the parallel 274,000-pound thrust version and adopting the 294,000-pound assured design, turbomachinery engineers adopted the necessary changes to the Mk-29 pumps to meet "best practices" design requirements. Two additional turbomachinery spare sets and spares were added to the development project. Both the Fuel and Oxidizer Turbo Pumps were still undergoing rotordynamic trades, and a fracture control assessment left open material selections. Several turbopump material and design changes were selected for improved strength, load reduction, rotor stability enhancement, improved fault tolerance, and ease of assembly and disassembly.

Despite its greater complexity, helium spin start for start and re-start was selected over solid propellant gas generators due to the potential for debris generation by the later. Engineers retained the J-2 heritage 8-inch scissors ducts.

The Element retained the baselined dual channel Engine Controller Unit, open loop control mode, and pneumatic valve actuation. However, as a result of heritage valve testing in 2006, the goal of using heritage butterfly valves for the Main Fuel, Main Oxidizer, and Oxidizer Turbopump Bypass Valves was dropped in favor of sector ball valves, where there was greater recent experience and potential for better control authority.

ENGINE TEST PLANS AND TEST FACILITIES DECISIONS

Engine component test plans call for 3 powerpacks (turbomachinery, gas generator, and inlet ducts), which will undergo 40 starts and 12,000 seconds of operation. The first power pack test series is scheduled to begin in fall 2007. Objectives of this early J-2X powerpack series of tests include preparation and testing of the facility, obtaining inducer flow environments (with high-frequency pressures), obtaining pump performance (with better temperature and pressure data), and possibly testing the helium heat exchanger performance. The turbomachinery development program also includes water flow testing of existing pump inlets, a turbine air flow test, and water flow tests of the inducers. Dropped from the test program for cost/benefit reasons were a Thrust Chamber Assembly test series and a full scale Main Injector test series. Both subsystems will undergo their first tests on Engine 1.

A key decision to assure the availability of test assets included re-baselining altitude testing from Glenn Research Center's Plum Brook Station to a new test stand planned for Stennis Space Center. The decision followed an internal review of technical, cost and schedule issues associated with altitude testing at Plum Brook versus Arnold Engineering Center or Stennis. The proposed A-X test stand at Stennis would be capable of 550 seconds run time, 5 degrees thrust vector control, 0.4 psi maximum test cell pressure. It would be ready to support testing by September 2010. All potential test sites required extensive modifications. Plum Brook was judged the highest technical risk, with AEDC judged the lowest. However, Stennis offered greater flexibility for block upgrades, anomaly resolution/maturity testing, acceptance testing. Preliminary engine system test plans are outlined in Table 1.

Table 1. J-2X Engine Hot Fire Test Summary.

		Starts on Engine			Starts on Stage	
		Stennis	Stennis AX	Total	Ground Test	Flight Test
Development	E10001	25		25		
	E10003	25		25		
	E10004	11	20	31		
	E10005	30		30		
	Total	**91**	**20**	**111**		
Certification	E20001	6	19	25		
	E20002	19		19		
	Total	**25**	**19**	**44**		
Main Propulsion Test Article	E10002	6		6	11	
Test Flight	E10006	4		4	2	1
Subtotal		126	39	165		
10% Repeat Tests		13	4	17		
Total		**139**	**43**	**182**		

While the J-2X Upper Stage Engine team has made much progress, there is still much to be done to be ready the engine for its first flight in 2013. Future milestones appear in Table 2 below. Current planning supports Preliminary Design Review in 2007 and Critical Design Review in 2008. The PDR will provide completed design specifications, identification, and acquisition of long-lead items, manufacturing plans, and life cycle cost estimates. At CDR, the design will be 90 percent complete. CDR will disclose the complete system in full detail, determine that technical problems and design anomalies have been resolved, and ensure that the design is mature enough to begin manufacturing, integration and verification of mission hardware and software.

Table 2. J-2X engine major milestones.

Date	Event
March 2007	J-2X Resynchronization Review
June 2007	J-2X Preliminary Design Review, Pratt & Whitney Rocketdyne
August 2007	Preliminary Design Review, NASA
August 2007	Work Horse Gas Generator testing begins, MSFC
November 2007	J-2X Power Pack IA testing begins, SSC Test Stand A-1
August 2008	Critical Design Review
May 2010	First J-2X Engine Systems Test
March 2011	Main Propulsion Test Article testing begins
November 2011	Design Certification Review
September 2013	Orion 3 mission, first J-2X flight
2014 timeframe	Orion 4 mission, first production J-2X flight
2014 timeframe	Orion 5 mission, second production J-2X flight, first human flight

As part of a flight test strategy to assure that Ares I is ready for human crews, Ares I-X will fly in June 2009 with a mass simulator while the new engine fleet undergoes development and certification testing. Development Engine 1006 will debut the J-2X capabilities in 2013 with the uncrewed flight of Orion 3. Production Engine 3001 will fly on the uncrewed Orion 4 flight in the 2013 timeframe, followed in 2014 by Production Engine 3002 that will carry the first crew on Orion 5.

SUMMARY AND CONCLUSIONS

NASA's Exploration Launch Projects Office is dedicated to designing the Ares I and Ares V launch vehicle systems for safety, simplicity, robust operability, and streamlined supportability to reduce operations costs, allowing NASA's resources to be focused more fully on space exploration instead of routine operations. The Exploration Launch Projects Office will continue to reduce risks by drawing upon lessons learned in the past and applying modern engineering tools and processes. Hardware commonality between the two launch vehicles—as exemplified by the J-2X Upper Stage Engine element—will reduce the fleet's logistics footprint, as well as nonrecurring and fixed operations costs. The J-2X team will continue to emphasize a "test as you fly, fly what you test" development philosophy as it begins validating and verifying critical engine hardware. This team-based, test-based engineering strategy will help sustain long-term space exploration, expanding humanity's reach to the Moon, Mars, and beyond.

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