NASA Exploration Launch Projects Systems Engineering Approach for Astronaut Missions to the Moon, Mars, and Beyond

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The U.S. Vision for Space Exploration directs NASA to design and develop a new generation of safe, reliable, and cost-effective transportation systems to fulfill the Nation's strategic goals and objectives. These launch vehicles will provide the capability for astronauts to conduct scientific exploration that yields new knowledge from the unique vantage point of space. American leadership in opening new frontiers will improve the quality of life on Earth for generations to come.

The Exploration Launch Projects office is responsible for delivering the Crew Launch Vehicle (CLV) that will loft the Crew Exploration Vehicle (CEV) into low-Earth orbit (LEO) early next decade, and for the heavy lift Cargo Launch Vehicle (CaLV) that will deliver the Lunar Surface Access Module (LSAM) to LEO for astronaut return trips to the Moon by 2020 in preparation for the eventual first human footprint on Mars. Crew travel to the International Space Station will be made available as soon possible after the Space Shuttle retires in 2010. Figure 1 shows the CLV/CEV system concept on the launch pad. Figure 2 shows the CaLV concept on its way to Earth orbit.

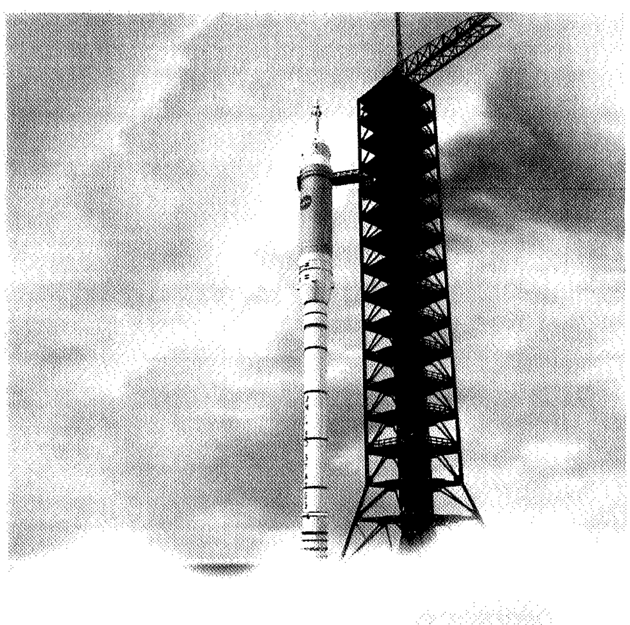


Figure 1. The CLV will loft the CEV into LEO.

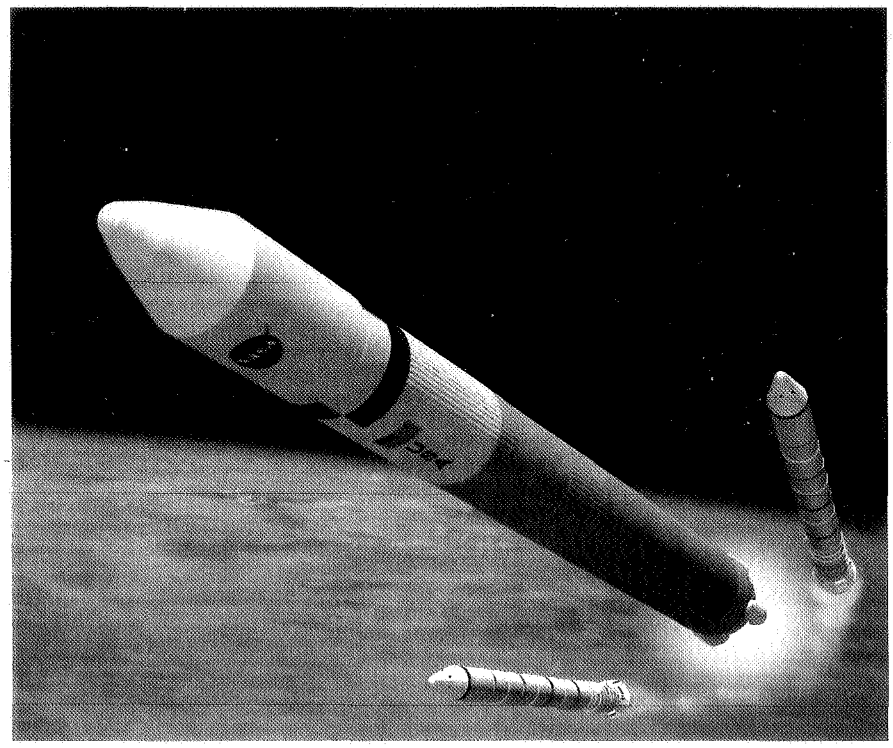


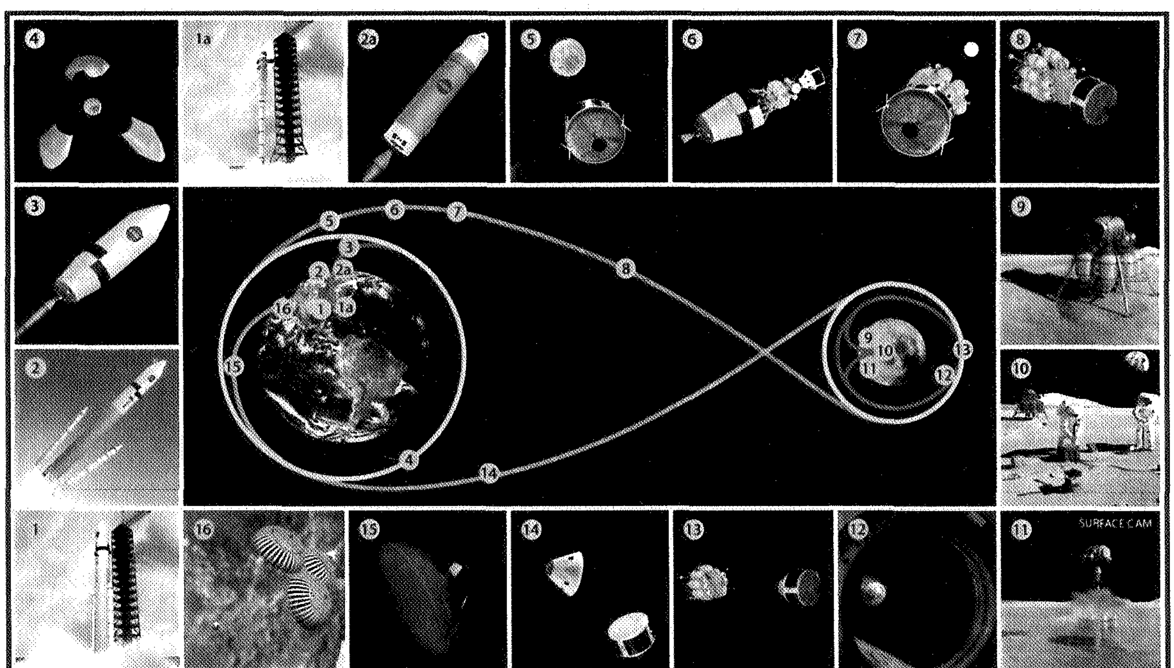
Figure 2. The CaLV will carry up to 125 metric tons to LEO.

The Exploration Launch Projects' formulation phase began in September 2005, using vehicle configuration options recommended by the Exploration Systems Architecture Study (ESAS) as points of departure for trade studies leading to the optimum vehicle designs to be developed in the implementation phase. As a result of this systems engineering approach, in January 2006, the Agency streamlined its CLV design, development, test, and evaluation (DDT&E) hardware plan so that the CLV first stage and upper stage engine are fully extensible to the CaLV core stage and Earth Departure Stage (EDS) propulsion elements, saving billions of dollars in nonrecurring investment and reducing the logistics footprint through common manufacturing, and processing facilities, with resultant reductions in recurring operations costs.

Furthermore, in May 2006, the ESAS-recommended CaLV configuration was updated to reflect the findings of business planning and engineering analyses conducted in spring 2006. As a result, the re-baselined CaLV configuration saves DDT&E costs by a potential interagency partnership for main engines upgrades and reduces life-cycle costs by changing from a modified Space Shuttle Main Engine (RS-25) to a commercially available, expendable one. Specifically, using the liquid oxygen/liquid hydrogen (LOX/LH2) RS-68 engine, which was developed as part of the U.S. Air Force's Evolved Expendable Launch Vehicle (EELV) Program and is currently flown on the Delta IV, gives NASA an opportunity to partner with another Government agency for safety, reliability, and performance upgrades to this currently available engine. By contrast, the RS-25 was estimated to be twice as expensive after modifications for expendability, and was rated highly complex compared to the relatively simple, low-cost RS-68.

The Exploration Launch Projects' hardware development plan reduces technical and management risks by building on proven flight hardware from the Saturn, Space Shuttle, and EELV Programs, and by applying lessons learned to bolster systems engineering practices. The current CLV in-line configuration consists of a single Shuttle derived 5-segment RSRB first stage and a new upper stage design powered by a LOX/LH2 J-2X engine, which is an evolution of the J-2 that powered the Saturn V upper stages. The CLV will loft the 25 metric ton (55,000 lb) CEV into LEO early next decade. This system is estimated to be 10 times safer than the Shuttle due to its in-line configuration that places the crew above the rocket and the CEV launch abort system that can rapidly move the crew away in case of an emergency. Apollo, Shuttle, and EELV experts are integrally involved in developing both the CLV and CaLV systems.

The current CaLV configuration has a core stage propulsion system comprised of: (1) two 5-segment RSRBs and a core stage, which is sized similar to the Saturn V's 33-foot tank diameter, that delivers LOX/LH2 to a cluster of five aft-mounted RS-68 engines, and (2) an EDS upper stage powered by a LOX/LH2 J-2X engine, with a payload shroud that opens during ascent to release the LSAM. An interstage provides structural connection between the core stage and the EDS. This CaLV configuration can deliver 137 metric tons (300,000 lb) to a 30-by-160-nautical mile orbit inclined at 28.5 degrees, or 55 metric tons (120,000 lb) to trans-lunar orbit. The lunar mission scenario begins with the CLV placing the CEV into LEO where it will rendezvous with the LSAM that has been delivered by the CaLV (see Figure 3).



1. Cargo Launch Vehicle (CaLV) liftoff.
2. Solid Rocket Booster (SRB) separation.
3. Earth Departure Stage (EDS) fires for Earth orbit insertion.
4. Payload shroud separates to expose Lunar Surface Access Module (LSAM).
1a. Crew Launch Vehicle (CLV) liftoff.
2a. Upperstage fires for Earth orbit insertion.
5. Crew Exploration Vehicle (CEV) docks with LSAM and EDS.
6. EDS fires for lunar destination.
7. CEV and LSAM undock from EDS.
8. LSAM fires for lunar orbit insertion.
9. LSAM lands on lunar surface.
10. Conducting activities on the lunar surface.
11. LSAM ascent stage liftoff viewed from surface camera.
12. LSAM ascent stage prepares to dock with CEV.
13. LSAM ascent stage and CEV separate.
14. Capsule separates from service module.
15. Capsule reenters Earth's atmosphere.
16. Chutes open for landing and recovery in the Western U.S.

Figure 3. Lunar mission scenario.

CLV and CaLV integration involves processing the vehicle subsystems into respective stages and mating the vehicle stacks. It also includes incorporating various payloads — including the CEV with the CLV and the LSAM with the CaLV — and interfacing with a number of logistical applications — from manufacturing and processing, to shipping, testing, and launching. Figure 4 provides expanded views of each vehicle, showing the major subsystems and payloads that will be incorporated into these space transportation systems. The CLV first stage boundary starts at the launch pad interface and ends at the separation plane between the forward frustum and the interstage barrel section that mates it to the upper stage, which interfaces to the CEV with its integrated Launch Abort System (LAS) by a spacecraft adapter. Atop the CaLV central booster is an interstage cylinder and a newly designed forward adapter that mates the first stage with the EDS; the LSAM interfaces with the EDS, which connects on orbit to the CEV before the EDS engine fires to achieve escape velocity and begin the journey to the Moon.

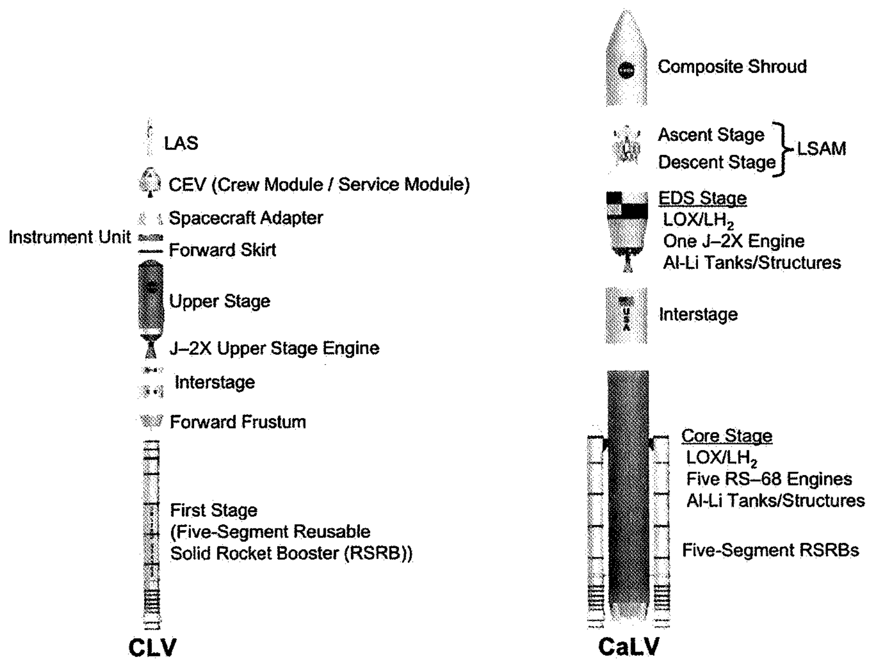


Figure 4. Expanded views of the CLV and CaLV systems.

The Exploration Launch Projects office implements stringent systems engineering standards to improve accuracy and reduce rework. A robust vehicle integration element facilitates communication via embedded touch-points throughout the various hardware offices, as well as through on-site resident staff members located at geographically dispersed business units, including contractor facilities. Following a rigorous configuration management process improves clarity across the various Government and contractor work in progress. As is shown in Figure 5, the Exploration Systems Mission Directorate (ESMD) Implementation Plan flows into the Constellation Architecture Requirement Document, which informs the CLV and CaLV System Requirements Documents. At lower levels, each launch vehicle system is governed by an Interface Requirements Document, which details the various linkage points (for example, power, command and control, communications, and mechanical interfaces), and by an operations concept, which covers the multitude of aspects that go into integrating the vehicle subsystems, stacks, and payloads. Furthermore, a series of flight demonstrations — from simulators to high-fidelity vehicles — will provide the opportunity to validate modeling and simulation, test mission scenarios, and further influence integration decisions. These and other risk mitigation strategies are being employed to improve overall integration and increase the likelihood of mission success. This paper addresses the integration process, and key integration issues and methodologies for resolution.

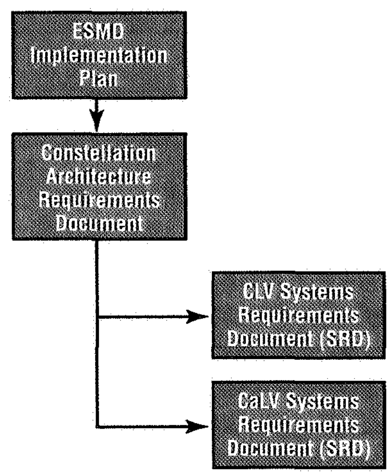


Figure 5. High-level requirements flow down to system requirements to reduce programmatic and technical risk.