10. Test and Evaluation

10.1 Approach

Architecture Design, Development, Test, and Evaluation (DDT&E) schedule, costs, and risk are highly dependent on the integrated test and evaluation approach for each of the major elements. As a part of the Exploration Systems Architecture Study (ESAS), a top-level test and evaluation plan, including individual flight test objectives, was developed and is summarized in this section. The test and evaluation plan described here is derived from the Apollo Flight Test Program of the 1960s.

A more detailed test and evaluation plan will be based on detailed verification requirements and objectives documented in specifications and verification plans. In order to support schedule, cost, and risk assessments for the reference ESAS architecture, an integrated test and evaluation plan was developed to identify the number and type of major test articles (flight and ground) and the timing and objectives of each major flight test, including facilities and equipment required to support those tests. This initial plan is based on the Apollo Program and the ESAS Ground Rules and Assumptions (GR&As)—including the human-rating requirements from NASA Procedural Requirements (NPR) 8705.2A, Human-Rating Requirements for Space Systems.

10.2 Ground Rules and Assumptions

ESAS GR&As establish the initial set of key constraints to testing. Although all ESAS GR&As are considered, the specific ones listed below are particularly significant, as they deal with schedule and testing/qualification assumptions.

- The crew launch system shall facilitate crew survival using abort and escape. There will be three all-up tests of the Launch Abort System (LAS).
- Qualification of the Crew Launch Vehicle (CLV) requires three flight tests for human certification prior to crewed flight.
- Qualification of the Crew Exploration Vehicle (CEV) requires a minimum of one flight demonstrating full functionality prior to crewed flights.
- The first CEV human flight to the International Space Station (ISS) will occur in 2011.
- The CEV will support crew to ISS through ISS end-of-life (2016).
- Qualification of the Earth Departure Stage (EDS) for firing while mated to a crewed element requires a minimum of two flights to demonstrate functionality prior to crewed flight.
- Qualification of the Lunar Surface Access Module (LSAM) requires a minimum of one flight demonstrating full functionality prior to a lunar landing.
- Lunar mission rehearsal in-space with appropriate architecture elements and crew is required.
- There is a goal of performing the next human lunar landing by 2020—or as soon as practical.

The ESAS team also considered the guidance of NPR 8705.2A, Human-Rating Requirements for Space Systems. These requirements are identified in **Table 10-1**.

Table 10-1. Significant Human-Rating Requirements Pertaining to Test and Evaluation

1.6.7 Software Testing	"1.6.7.2—Flight software shall, at a minimum, be tested using a flight-equivalent avionics test-bed operating in a real-time, closed-loop test environment (Requirement 34357)."
1.6.8 Flight Testing	"1.6.8.1—In Volume III of the Human-Rating Plan, the Program Manager shall document the type and number of flight tests that will be performed across the mission profile under actual and simulated conditions to achieve human-rating certification (Requirement 34360)."
C.3 Applicability of Requirements	"C.3.1—Human-rating requirements are applicable to any system which transports or houses humans or interfaces with other systems which transport or house humans. Therefore, many uncrewed elements may also be subject to these requirements. For example, currently the expendable launch vehicle is not used in concert with a human-rated system, and so these requirements do not apply. However, if an expendable launch vehicle is used as part of a crewed launch system, human-rating requirements apply."
C.10 Crew and Passenger Survival	"C.10.3.4—Crew escape systems require extensive testing and analysis to verify the functional envelope and environment for system utilization, as well as detailed tests and assessments to ensure the system does not cause a fatality or permanent disability. Due to the dynamic and unpredictable nature warranting the use of crew escape systems, complete verification by integrated flight test is impossible. Crew escape systems may never be considered as a leg of redundancy."

10.3 Apollo as a Reference

The Apollo Program included the development of the Apollo spacecraft, the Saturn V Launch Vehicle (LV), and the Lunar Module (LM), as well as the development of test and launch facilities, launch and mission operations, and the tracking system. The Saturn V LV, Apollo spacecraft, and LM developments were examined to capture the testing approach of each. A summary of the Apollo test program is shown in **Figure 10-1**.

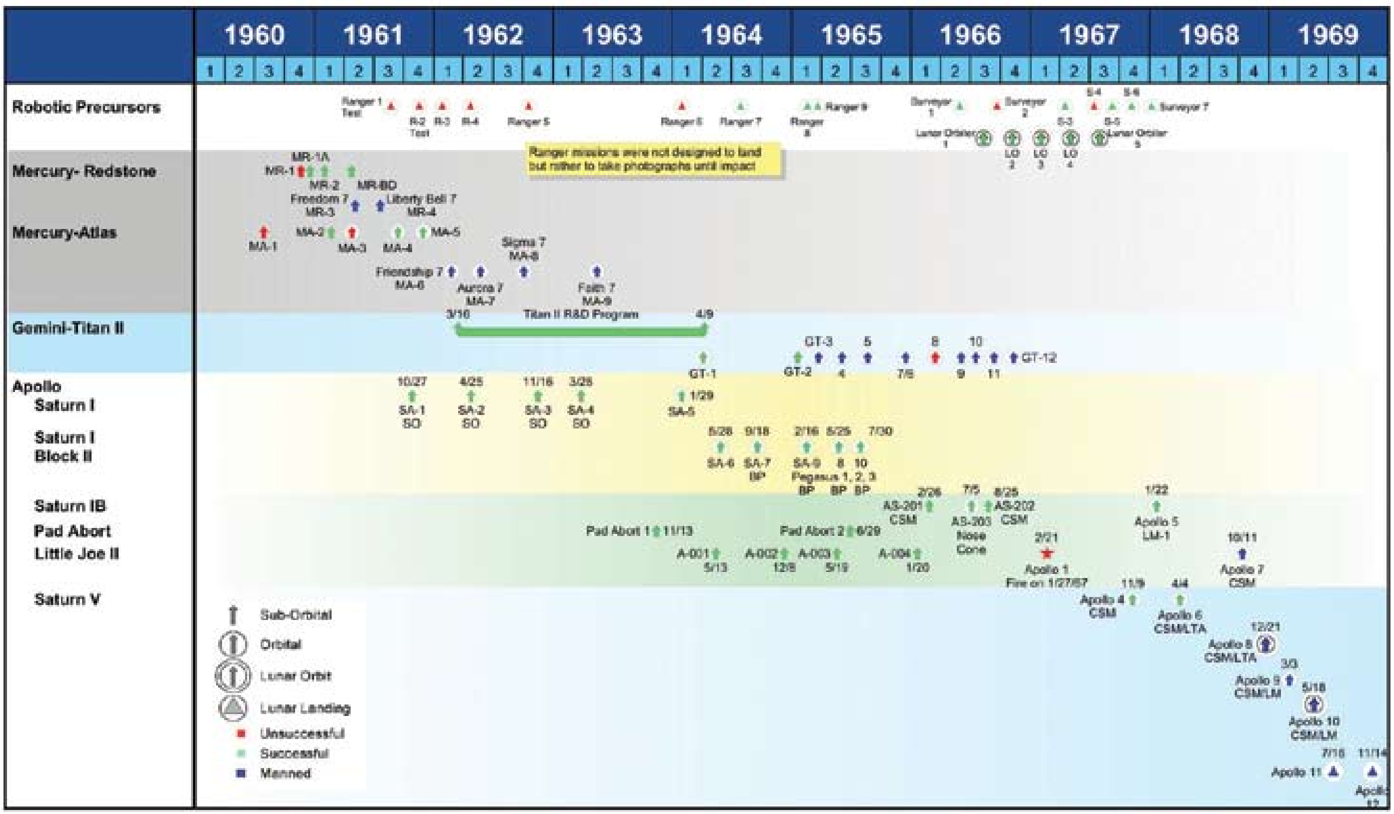

Figure 10-1. Apollo and Other Early NASA Milestones

The relationship between the ESAS test program and the Apollo test program is diagrammed in **Figure 10-2**.

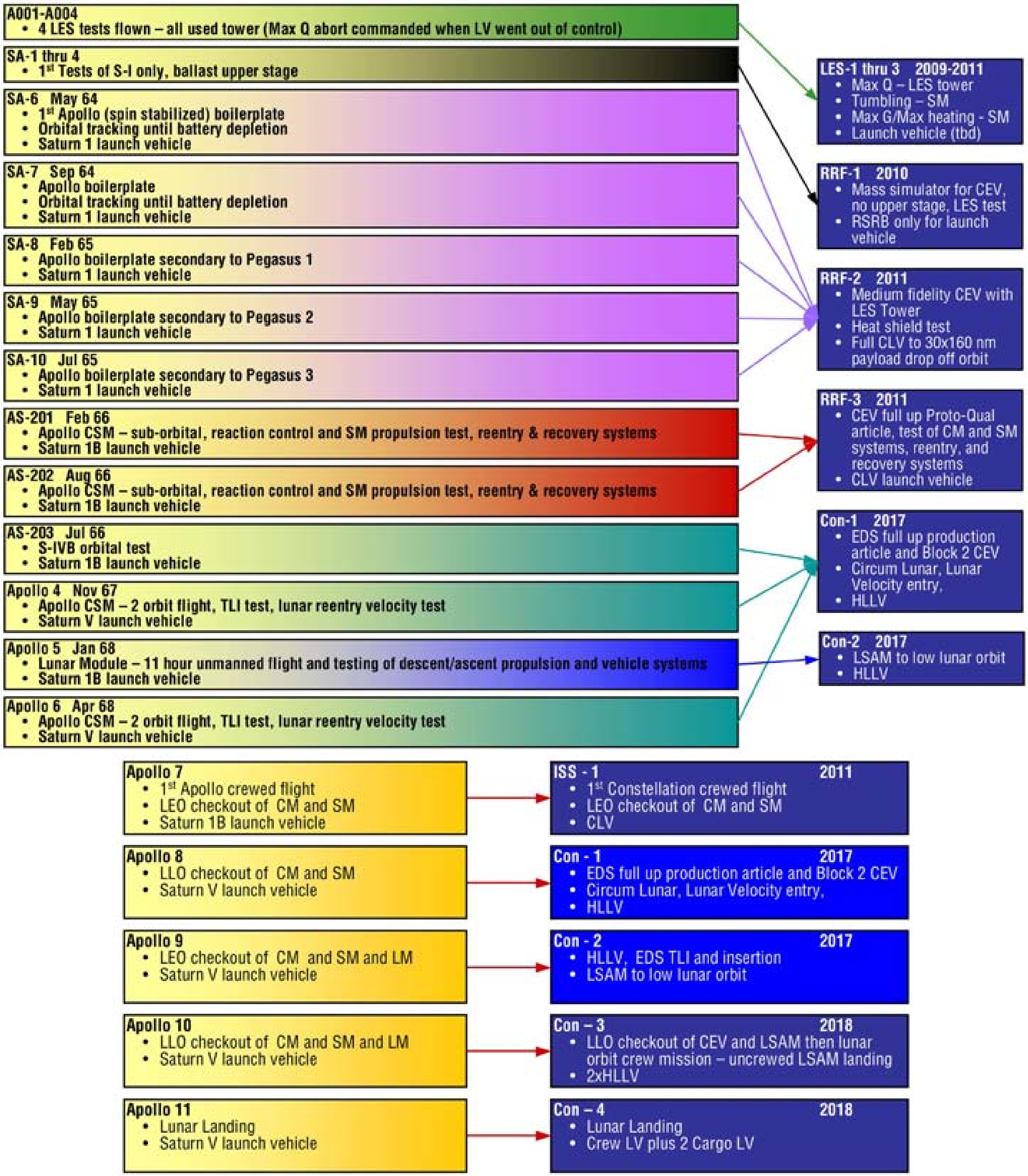

Figure 10-2. Apollo-Constellation Flight Tests Comparisons

10.4 ESAS Flight Test Program

Figure 10-3 reflects the summary flight test program based on the Shuttle-derived solution using a Solid Rocket Booster- (SRB-) derived booster for the CLV and a Space Shuttle Main Engine (SSME-) SRB-derived Cargo Launch Vehicle (CaLV) with Earth Orbit Rendezvous (EOR) and Lunar Orbit Rendezvous (LOR). Test descriptions for these flights with preliminary test objectives are provided in the remainder of this section.

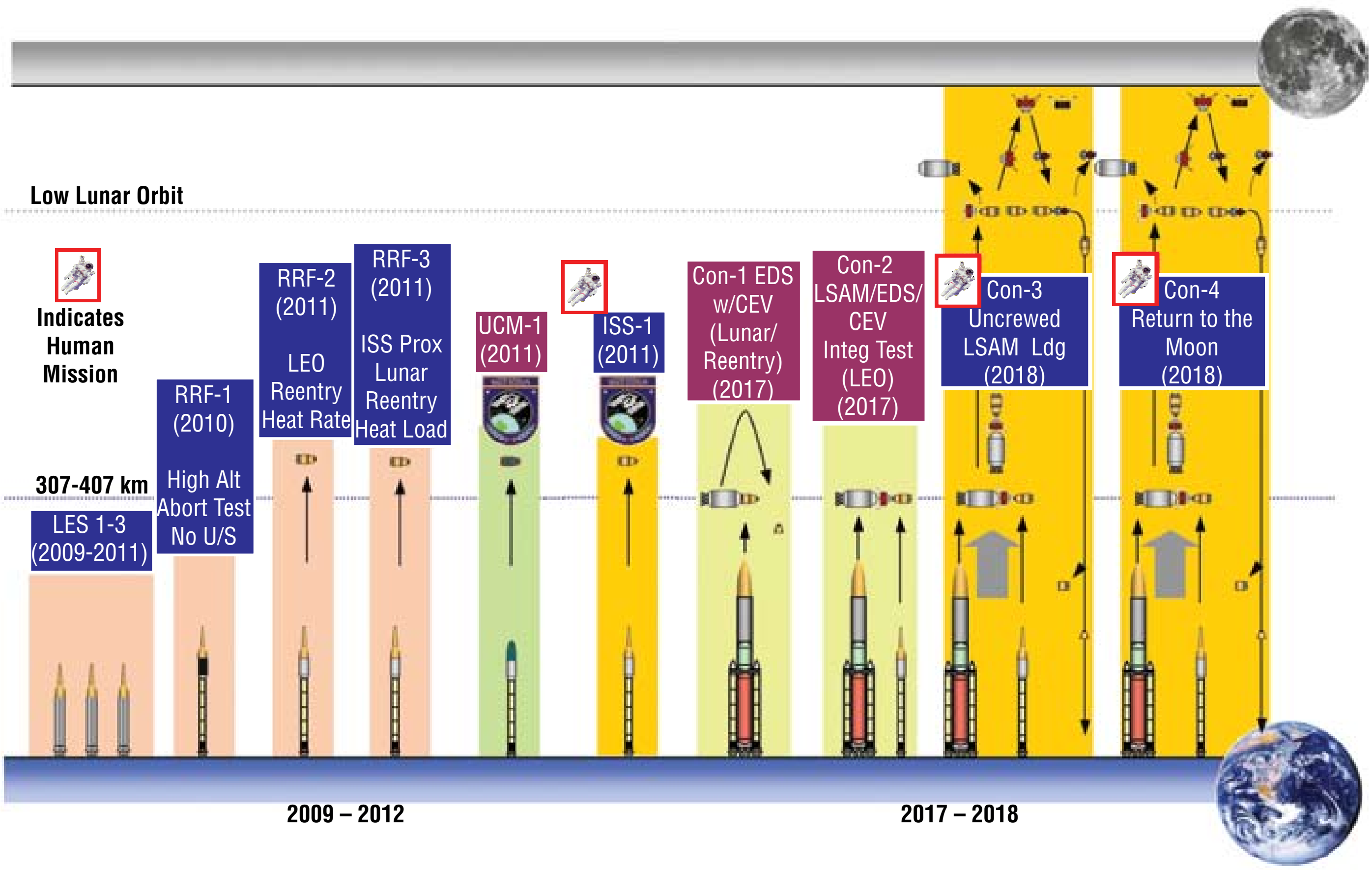

Figure 10-3. Flight Test Program Overview

10.4.1 Pad Abort - 1 (PA–1)

Space Vehicle: Crew Module (CM) Flight Test Article (FTA) (30-percent CM), surrogate Service Module (SM) interface.

Systems: Launch escape tower test article, Outer Mold Line (OML)/mass representative CM, power and communications system for telemetry, parachute system, landing impact attenuation system and recovery system, flight test instrumentation package.

Launch Vehicle: Not Applicable (N/A)—Ground structure to replicate conditions of test.

Objectives:

- Demonstrate satisfactory Launch Escape System (LES) performance in zero velocity, zero-tilt angle conditions.
- Demonstrate ability of LES to detect and initiate pad abort.
- Demonstrate CM/SM interface separation and pyrotechnics performance.

- Demonstrate LES control system capability to deliver CM to safe lateral distance and altitude location for worst-case pad explosion.
- Verify predictions on LES/CM integrated structural dynamics during launch pad abort and validate prediction models.
- Determine vibration and acoustic environment in the CM during low pad abort.
- Obtain data on thermal effects during boost of the launch escape motor plume impingement on the CM.
- Demonstrate LES tower jettison.
- Demonstrate operation of parachute system for low-altitude deployment.
- Demonstrate performance of impact attenuation system during pad abort.
- Demonstrate mission support facilities and operations needed for emergency crew recovery during launch abort.

Parameters: Zero altitude, zero velocity, zero angular rates.

Constraints:

- Early test that may not encompass mass of Block 2 CM.
- Start can be accelerated if chutes/landing are not part of these tests.
- Recovery system performance is critical since refurbishment and reuse of the CM article is planned.

10.4.2 Pad Abort - 2 (PA–2)

Space Vehicle: CM FTA (30-percent CM), surrogate SM interface.

Systems: Launch escape tower qualification unit, OML/mass representative CM, power and communications system for telemetry, parachute system, land-landing impact attenuation system and recovery system, flight test instrumentation package.

Launch Vehicle: N/A – Ground structure to replicate conditions of test.

Objectives:

- Demonstrate satisfactory LES performance in zero altitude, and dynamic angle change at (To Be Determined (TBD)) degrees per second.
- Verify capability of LES to detect and initiate pad abort.
- Verify CM/SM interface separation and pyrotechnics performance.
- Verify LES control system capability to deliver CM to a prescribed landing location that is a safe lateral distance and altitude location for worst-case pad explosion and does not endanger facilities or personnel.
- Verify vibration and acoustic environment predictions in the CM during low pad abort.
- Verify CM acceleration predictions during abort, chute deployment, and impact.
- Verify models on thermal effects during boost and during impingement of the launch escape motor plumes on the CM and the launch escape tower.
- Verify LES tower jettison system performance and safe disposal of tower.
- Verify operation of parachute system for low-altitude deployment.
- Demonstrate water landing.

- Demonstrate mission support facilities and operations needed for emergency crew recovery during launch abort with water impact.

Parameters: Zero altitude, zero velocity, angular rates TBD.

Constraints:

- Early test that may not encompass mass of Block 2 CM.
- It is assumed this test will be conducted at a location that permits a water landing—the test can meet all key objectives with a land landing as accomplished in PA–1.

10.4.3 Launch Escape System - 1 (LES–1) (Ascent Abort Test)

Vehicle: CM FTA (60-percent CM), surrogate SM interface.

Systems: Launch escape tower qualification unit, OML/mass representative CM, Command and Control (C&C) sufficient to initiate abort, power and communications system for telemetry, parachute system, land-landing impact attenuation system and recovery system, flight test instrumentation package.

Launch Vehicle: TBD LV.

Objectives:

- Demonstrate SM-executed (upper stage failures) abort modes at envelope conditions.
- Verify launch-escape power-on stability for abort in maximum dynamic pressure region (max q) with power-on tumbling (loss of control) conditions approximating emergency detection subsystem limits.
- Verify aerodynamic stability characteristics of escape configuration for ascent and abort conditions and collect data on dynamic pressure on CM during abort.
- Verify LES control system capability to recovery from tumbling condition.
- Verify launch escape tower/CM structural integrity during highly stressing abort condition.
- Demonstrate proper separation of CM from SM interface surrogate (reliability).
- Demonstrate capability of escape system to propel CM to predetermined distance from LV (reliability).
- Demonstrate launch escape tower separation following abort (reliability).
- Demonstrate satisfactory operation of parachute, landing system, and recovery systems (reliability).

Parameters: Altitude range—based on LV performance.

Constraints:

- Early test that may not encompass mass of Block 2 CM.
- CM is planned to be reused in subsequent ascent abort tests, so performance of parachutes and landing system is critical.

10.4.4 Launch Escape System - 2 (LES–2) (Ascent Abort Test)

Vehicle: CM FTA (60-percent CM), SM FTA.

Launch Vehicle: TBD LV.

Systems: Launch escape tower production unit, OML/mass representative CM with TPS with development unit heat shield, C&C sufficient to initiate abort, power and communications system for telemetry, CM parachute system, land-landing impact attenuation system and recovery system, flight test instrumentation package. SM equipped with development propulsion system and Reaction Control System (RCS) and associated avionics and structure.

Objectives:

- Verify satisfactory performance of the LES using an SM-initiated abort (after launch escape tower jettison) during max tumble (upper stage loss of flight control) at CEV flight mass.
- Verify separation and steering by SM and CM control system away from a tumbling upper stage to predetermined distance from the LV.
- Demonstrate SM propulsion system and RCS responsiveness to abort command, engine start, throttle up, and operation in a highly dynamic flight environment.
- Verify CM/SM structural integrity during abort from vehicle tumbling condition.
- Demonstrate normal launch escape tower separation under nominal ascent conditions abort (reliability).
- Demonstrate proper separation of CM from SM (reliability).
- Demonstrate CM passive stability following separation from SM and TPS performance under atmospheric heating.
- Demonstrate satisfactory operation of parachute, landing, and recovery systems (reliability).

Parameters: Altitude—desirable to replicate conditions early in upper stage burn.

Constraints:

- Early test may be inadequate for Block 2 CM mass and SM propulsion system performance.
- This test demands high-fidelity SM propulsion system and RCS.
- CM is planned to be reused in subsequent ascent abort tests, so performance of parachutes and landing system is critical.

10.4.5 Launch Escape System - 3 (LES–3) (Ascent Abort Test)

Vehicle: CM FTA (60-percent CM), SM FTA.

Launch Vehicle: LV.

Systems: Launch escape tower flight unit, OML/mass representative CM with development unit heat shield, C&C sufficient to initiate abort, power and communications system for telemetry, CM parachute system, land-landing impact attenuation system and recovery system, flight test instrumentation package. SM equipped with development propulsion system and RCS and associated avionics and structure.

Objectives:

- Verify satisfactory performance of the LES using an SM (or LES through analysis) initiated abort in lofted trajectory case leading to maximum gravity and Thermal Protection System (TPS) heating case.
- Verify separation and steering by SM/CM control system away from an upper stage and into a less-stressing reentry trajectory (maximum turning case).
- Demonstrate SM propulsion system and RCS responsiveness to abort command, engine start, throttle up, and operation (reliability).
- Demonstrate normal launch escape tower separation under nominal ascent conditions, including separation of the boost protective cover by the tower jettison motor and jettison of the forward heat shield by the thrusters (if these two structures are required) (reliability).
- Demonstrate proper separation of CM from SM (reliability).
- Verify CM passive stability following separation from SM and TPS performance under atmospheric heating.
- Demonstrate satisfactory operation of parachute and recovery systems (reliability).
- Demonstrate water landing and recovery force operations needed for emergency crew recovery during launch abort with water impact (deep water).

Parameters: Altitude—replicate conditions leading to max G and maximum heating case.

Constraints:

- Early test that may not encompass mass of Block 2 CM.
- This test demands high fidelity SM propulsion system and RCS.
- CM requires development unit heat shield (minimum).

10.4.6 Risk Reduction Flight - 1 (RRF–1) CLV Development Flight

Space Vehicle: CEV.

Systems: LES production, instrumented OML representative CEV test article with TPS and telemetry downlink capability.

Launch Vehicle: Four-segment Reusable Solid Rocket Booster (RSRB).

Systems: Flight article with a full first stage, simulated mass representative upper stage, flight instrumentation, parachute recovery system.

Objectives:

- Demonstrate CLV booster/first-stage subsystems and avionics performance.
- Demonstrate TVC and roll control performance in first-stage open-loop flight.
- Collect data to validate/anchor/update performance, acoustics, coupled loads, dynamics, and aerodynamic models for CLV and CEV.

- Demonstrate booster and upper stage separation.
- Demonstrate booster parachute systems and recovery.
- Demonstrate overall CLV first-stage performance.
- Obtain data on CEV environment during first-stage burn including dynamic pressure.
- Demonstrate ability of launcher anomaly detection system to identify failure of upper stage (dummy) to initiate abort with LES tower.
- Demonstrate LES performance following ascent on first stage in actual flight environment (reliability).
- Verify performance of RSRB water recovery system.
- Demonstrate mission support facilities and operations needed for launch, mission conduct, and water recovery of RSRB.

Parameters: Based on Stage 1 performance.

Constraints: First-stage test only.

10.4.7 RRF–2/CLV Certification Flight

Space Vehicle: CEV.

Systems: Production LES, ProtoQual 80-percent fidelity CM, 90-percent fidelity SM with telemetry downlink capability.

Launch Vehicle: Four-segment RSRB first-stage with single SSME upper stage.

Systems: Full-up integrated LV with launch abort detection system, SM adapter ring, final flight control system configuration, and full flight test instrumentation.

Objectives:

- Demonstrate upper stage propellant loading and management.
- Verify TVC and roll control performance in first stage.
- Demonstrate upper stage air start and flight control authority.
- Verify booster and upper stage separation dynamics.
- Verify predictions on full LV coupled loads and dynamics including the upper stage.
- Evaluate performance of emergency launch abort detection system.
- Verify performance of booster parachute and water recovery systems.
- Demonstrate all CLV subsystems and avionics performance in full function flight through staging and orbital insertion.
- Demonstrate nominal jettison of LAS tower (reliability).
- Validate performance predictions and models for SM.
- Demonstrate propulsion, maneuvering, navigation, and flight control functions of CEV.
- Demonstrate rendezvous with “virtual ISS” up to point of mating.
- Demonstrate simulated target acquisition for automated rendezvous and mating system checkout including collision avoidance function.
- Demonstrate power production and distribution subsystem performance.
- Demonstrate active thermal control functions.

- Demonstrate communication and remote commanding functions.
- Demonstrate SM deorbit, separation, and disposal.
- Demonstrate nominal-controlled OR failed-to-ballistic entry modes.
- Demonstrate land landing precision, touchdown systems, and recovery.

Parameters: Approximately 450 km (ISS-compatible) circular orbit, 51 deg. Mission duration is 24 hours (TBR).

Constraints: Assumes non-methane propulsion system for Block 1 SM.

10.4.8 RRF–3/CLV Certification Flight

Space Vehicle: ProtoQual Block 1 CEV (last preproduction CEV) with full SM.

Systems: Production launch escape tower system, all CM/SM systems including solar panels and deployment mechanisms, Automated Rendezvous and Docking (AR&D), propulsion (non-methane) flight test instrumentation package, CM reentry, and recovery systems.

Launch Vehicle: CLV (second full certification flight).

Systems: CLV production article with flight test instrumentation.

Objectives:

- Verify upper stage propellant loading and management.
- Validate crewed flight countdown procedures (CLV and CEV).
- Demonstrate Thrust Vector Control (TVC) and roll control performance in first stage (reliability).
- Verify upper stage air start and flight control authority.
- Demonstrate booster and upper stage separation dynamics (reliability).
- Verify performance of emergency launch abort detection system (monitoring mode).
- Demonstrate performance of booster parachute and water recovery systems (reliability).
- Verify all CLV subsystems and avionics performance in full function flight through staging and orbital insertion.
- Demonstrate nominal jettison of LAS tower (reliability).
- Verify propulsion, maneuvering, navigation and flight control functions of CEV.
- Verify relative navigation, targeting/display systems, and automated rendezvous and mating with ISS—assumes ISS outfitted with new adaptor.
- Verify capability of ISS crew to monitor, pilot, and abort rendezvous and mating.
- Verify quiescent (mated) operations with ISS, including interface functions and CEV subsystem performance (power, thermal, communication, etc.).
- Verify electromagnetic environments of CEV and ISS are compatible.
- Validate nominal and emergency ingress and activation procedures and functions.
- Verify crew accommodation (Environmental Control and Life Support (ECLS), etc.) functions.
- Demonstrate SM deorbit, separation, and disposal (reliability).
- Demonstrate performance for faster/steeper controlled entry. (Use residual SM propellant.)

- Demonstrate land-landing precision, touchdown systems, and recovery (reliability).
- Demonstrate operation of and recovery cycle for launch pad and support facilities (reliability).
- Demonstrate mission operations systems and procedures needed for launch and mission conduct (reliability).
- Demonstrate parachute and landing system performance and recovery force operations (confidence).
- Verify suitability of CM for refurbishment and reflight.

Parameters: Approximately 450 km (ISS-compatible) circular orbit, 51 deg. Mission duration is 24 hours (TBR).

Constraints: Assumes ISS outfitted with new adaptor otherwise limited to proximity operations.

10.4.9 Unpressurized Cargo Module - 1 (UCM–1)

Space Vehicle: UCM ProtoQual unit with CEV-derived SM.

Systems: All UCM/SM systems including power, avionics, AR&D (docking or berthing TBD), flight test instrumentation payload.

Launch Vehicle: CLV (can support certification of LV).

Systems: CLV production article with flight test instrumentation, qualification shroud.

Objectives:

- Verify predictions of LV coupled loads and vehicle dynamics with shroud.
- Verify and anchor aerodynamic models and wind-tunnel data for entire LV with shroud.
- Demonstrate jettison of shroud.
- Verify LV guidance subsystems performance with shroud.
- Verify CLV upper stage/UCM separation characteristics and parameters meet requirements.
- Verify operation and performance of all UCM avionics, rendezvous systems, and propulsion systems.
- Demonstrate AR&D system by conducting rendezvous and proximity operations with ISS (reliability).
- Verify electromagnetic environments of CEV and ISS are compatible.
- Verify ground processing and flight operations for UCM and UCM/CLV configurations.

Parameters: Approximately 450 km (ISS compatible) circular orbit, 51 deg. Mission duration is 24 hours (TBR).

Constraints:

- Only non-production UCM.
- Assumes ISS outfitted with new adaptor.
- Assumes substantial commonality with CEV systems.
- ESAS test and evaluation studies did not address qualification of shroud.

10.4.10 ISS–1 – Crewed Flight

Space Vehicle: Block 1 Production CM with SM and LES.

Systems: Production system, all CM/SM systems including AR&D, flight test instrumentation payload.

Launch Vehicle: CLV (fourth full-up flight)

Systems: CLV production article with flight test instrumentation.

Objectives:

- Verify CLV and CEV performance with human crew.
- Verify operation of all CEV subsystems with full human crew.
- Demonstrate rendezvous and docking with ISS.
- Demonstrate mission operations and full recovery force employment for human mission.

Parameters: Approximately 450 km (ISS-compatible) circular orbit, 51 deg. Mission duration is 24 hours (TBR).

Constraints: None.

Assumptions: No assessment of reuse of the CEV was made in this test and resulting flight program. Fundamental assumptions must be developed addressing:

- Whether ISS–1 delivers a crew that starts the 6-month on-orbit crew cycle;
- Whether the CEV for ISS–1 remains docked to ISS for 6 months to serve as a lifeboat; and
- The number of times a CEV is reused and the associated rationale for that assumption.

10.4.11 Constellation-1 – Uncrewed Mission (Low Earth Orbit (LEO))

Heavy-Lift Launch Vehicle - 1 (HLLV–1)/Earth Departure Stage - 1 (EDS–1)/CEV (Block 2)

Space Vehicles:

CEV

Systems: RRF–3 CM refurbished to Block 2 configuration with lunar mission avionics, subsystems and heat shield. Production LES and Block 2 SM with high Specific Impulse (Isp) propulsion system (assume methane) and other lunar mission subsystems.

EDS

Systems: Full EDS development flight test article and flight test instrumentation, restartable, with J–2 engine and avionics common with upper stages of CLV. Also includes all EDS autonomous operations avionics, telemetry systems, attitude control, extended flight power systems, and propellant management system for storing cryogenic propellants (Liquid Oxygen/Hydrogen (LOX/H2)) for multiple weeks.

Launch Vehicles:

HLLV (first certification flight for crewed operations)

Systems: HLLV development article (initial flight) with full flight test instrumentation. The configuration of the HLLV is based on Space Transportation System (STS-) derived elements including two five-segment RSRB boosters (common with the CLV) and five SSMEs on the base of an STS-derived LOX/H2 tank. Vehicle is an in-line configuration with the RSRBs attached to the main propellant tank and the payload carried atop it.

Objectives:

HLLV

- Verify propellant loading and management.
- Verify TVC and roll control performance of vehicle.
- Verify predictions on LV coupled loads and vehicle dynamics.
- Verify and anchor aerodynamic models and wind-tunnel data for entire LV.
- Demonstrate upper stage air start and flight control authority.
- Verify RSRB and core separation dynamics.
- Verify core and upper stage separation dynamics.
- Verify predictions on full LV coupled loads and dynamics including the upper stage.
- Demonstrate operation of and recovery cycle for launch pad and support facilities.
- Demonstrate mission operations needed for launch and mission conduct.

EDS

- Demonstrate structural integrity and verify loads and dynamic characteristics during propulsion system burns and validate mode models with solar power system deployed (if used).
- Demonstrate multiple restarts with CEV and validate control models by performing attitude control as integrated stack.
- Conduct burns after 14-day cold soak and verify propellant management and storage during extended on-orbit operations.
- Conduct burn to depletion to verify shutdown characteristics.
- Verify overall vehicle performance and thermal predictions and operation of all EDS subsystems including solar panel deployment and operation (if used) supporting certification for crewed use (Flight 1).
- Demonstrate flight operations needed for conduct of EDS mission.

CEV

- Verify performance of all Block 2 subsystems including autonomous operations modes and methane SM propulsion system.
- Collect data on ascent environment and dynamics with HLLV and during staging events.
- Verify integrity of EDS/CEV flight configuration during burns of EDS propulsion system.
- Collect data on environmient and dynamics during EDS burns including SM solar arrays.
- Validate CEV thermal models in stacked configuration and verify thermal compatibility.
- Verify electromagnetic environments of CEV and EDS are compatible.
- Verify CEV/EDS separation and associated interface terminations and dynamics.
- Verify CM heat shield performance during entry at lunar return velocity.
- Collect entry environmental data.
- Demonstrate mission operations during extended autonomous mission operations.

Parameters: 307- to 407-km circular orbit, 28.5 deg. Mission duration is 14 days minimum representing short lunar stay mission.

Constraints: Assume test program for Block 1 LES sufficient for Block 2 CEV.

Mission Profile:

- HLLV launch.
- HLLV jettisons spent RSRBs.
- HLLV shroud is jettisoned.
- HLLV delivers EDS/CEV to 30- x 160-nmi phasing orbit.
- HLLV upper stage and EDS/CEV separate.
- EDS performs burn(s) to circularize orbit (307–407 km).
- EDS conducts RCS burns while docked with CEV to verify controllability.
- CEV maintains attitude control during EDS burn to demonstrate controllability in contingency mode.
- EDS enters quiescent operations mode to demonstrate 2-week delay between Constellation element launches.
- EDS conducts burn to depletion to verify system performance predictions and put CEV on Earth-intersecting trajectory.
- CEV jettisons EDS and CEV conducts multiple Main Propulsion System (MPS) burns to verify Block 2 SM performance.
- CEV SM performs burn to depletion to accelerate the CM toward lunar return velocity (approximately 11 km).
- CEV conducts reentry at lunar return velocity for normal land recovery.

10.4.12 Constellation-2 – Uncrewed Mission (LEO)

HLLV/EDS/LSAM

CLV/CEV

Space Vehicles:

EDS

Systems: Full production article EDS with subset flight test instrumentation.

LSAM

Systems: Full LSAM ProtoQual FTA and full flight test instrumentation. Throttleable, CEV-derived methane engine, full set of vehicle systems to support crewed flight, propellant management system for storing cryogenic propellants (LOX/methane) for multiple weeks.

CEV

Systems: Full production Block 2 CEV with subset flight test instrumentation.

Launch Vehicles:

HLLV (second certification flight for crewed operations)

Systems: Production HLLV with subset of flight test instrumentation and new shroud.

CLV

Systems: Full production article with five-segment RSRB as tested on ISS resupply missions.

Objectives:

HLLV

- Demonstrate propellant loading and management (reliability).
- Demonstrate TVC and roll control performance of vehicle (reliability).
- Demonstrated performance and interaction of five SSME core engines and SSME/RSRB interaction during flight conditions (reliability).
- Demonstrate upper stage air start and flight control authority (reliability).
- Demonstrate RSRB and core separation dynamics (reliability).
- Demonstrate core and upper stage separation dynamics (reliability).
- Validate overall vehicle performance predictions and verify compatibility of HLLV, EDS, and LSAM.
- Demonstrate mission operations needed for launch and mission conduct.

CLV (five-segment)

- Demonstrate propellant loading and management of upper stage (reliability).
- Demonstrate TVC and roll control performance of vehicle (reliability).
- Demonstrate all staging events (reliability).
- Verify predictions on LV coupled loads and vehicle dynamics in shroud configuration with Block 2 CEV.
- Validate overall vehicle performance predictions and verify compatibility of five-segment CLV and Block 2 CEV.
- Demonstrate mission operations needed for launch and mission conduct.

EDS

- Demonstrate multiple restarts with LSAM and validate control models by performing attitude control as integrated stack with the CEV.
- Conduct burns after 14-day cold soak and verify propellant management and storage during extended on-orbit operations.
- Verify thermal predictions in EDS/LSAM/CEV configuration.
- Verify overall vehicle performance supporting certification for crewed use (Flight 2).

LSAM

- Verify performance of all subsystems (power, thermal, propulsion, avionics, Environmental Control and Life Support System (ECLSS)) including autonomous operations modes and methane propulsion system.
- Collect data on ascent environment and dynamics with HLLV and during staging events.
- Conduct LSAM RCS burns to verify LSAM/EDS configuration dynamics and controllability for AR&D with CEV and to validate LSAM control system models.
- Demonstrate LSAM navigation and control systems for conducting an AR&D with the CEV.
- Verify integrity of EDS/LSAM/CEV flight configuration during burns of EDS propulsion system.

- Collect data on environment and dynamics during EDS burns including LSAM solar arrays deployed.
- Conduct LSAM RCS burns to verify LSAM/CEV configuration dynamics and controllability and to validate LSAM control system models.
- Validate LSAM thermal models in stacked configuration with EDS and verify thermal compatibility.
- Verify electromagnetic environments of LSAM, CEV, and EDS are compatible.
- Verify LSAM–EDS separation and associated interface terminations and dynamics.
- Verify operation of descent stage jettison during propulsion system operation (fire-in-the-hole abort).
- Demonstrate LSAM controllability and operations after jettison of descent stage.
- Demonstrate mission operations during extended autonomous mission operations.

CEV Block 2

- Verify performance of all subsystems (power, thermal, propulsion, avionics, ECLSS) including autonomous operations modes and methane propulsion system.
- Collect data on ascent environment and dynamics with CLV and during staging events.
- Demonstrate CEV navigation and control systems for conducting an AR&D with the LSAM/EDS stack.
- Verify integrity of EDS/LSAM/CEV flight configuration during burns of EDS propulsion system.
- Conduct CEV RCS burns to verify LSAM/EDS/CEV configuration dynamics and controllability and to validate CEV control system models.
- Validate CEV thermal models in stacked configuration with LSAM and verify thermal compatibility.
- Verify LSAM/CEV separation and associated interface terminations and dynamics.
- Verify operation of MPS during burn to depletion.
- CEV conducts reentry at lunar return velocity for normal land recovery.
- Demonstrate mission operations during extended autonomous mission operations.

Parameters: 307- to 407-km circular orbit, 28.5 deg. Mission duration is 14 days minimum representing short lunar stay mission.

Constraints: None

Mission Profile:

- HLLV launch.
- HLLV jettisons spent RSRBs.
- HLLV jettisons shroud.
- HLLV delivers EDS/LSAM to 30- x 160-nmi phasing orbit.
- HLLV upper stage and EDS/LSAM separate.
- EDS performs burn(s) to circularize orbit (307–407 km).
- LSAM conducts RCS burns docked with EDS to verify integrity of configuration.

- EDS conducts RCS burns while docked with LSAM to verify controllability.
- LSAM maintains attitude control during EDS burn to demonstrate controllability in contingency mode.
- EDS enters quiescent operations mode to demonstrate 2-week delay between Constellation element launches.
- CLV launches with CEV.
- CLV staging followed by LES jettison.
- CLV delivers CEV to 30- x 160-nm phasing orbit.
- CEV conducts SM main propulsion burn to circularize.
- LSAM/EDS conduct active rendezvous and docking with CEV.
- CEV and LSAM/EDS undock and separate.
- CEV conducts active rendezvous and docking with LSAM/EDS.
- EDS conducts multiple burns to demonstrate control dynamics of integrated CEV/LSAM/EDS stack including with burns using LSAM and CEV RCS for control in a contingency operation. EDS changes orbit from circular to highly elliptical.
- EDS is jettisoned from LSAM/CEV stack and conducts burn to depletion supporting crewed certification and leading to destructive reentry.
- LSAM and CEV alternate control of vehicle to verify controllability during propulsion system burns.
- LSAM and CEV undock and the LSAM conducts simulated descent abort and transition to ascent system.
- CEV performs simulated autonomous maneuver to retrieve the LSAM; then the LSAM and CEV rendezvous and dock.
- LSAM conducts a burn to depletion of propulsion system to accelerate CEV for entry.
- CEV conducts SM burns to accelerate for lunar return entry velocity.
- LSAM conducts destructive reentry.
- CEV conducts reentry at lunar return velocity for normal land recovery.

10.4.13 Constellation-3 – Crewed Mission (Lunar Orbit)

HLLV/EDS/LSAM

CLV/CEV

Space Vehicles:

EDS

Systems: Full production EDS (launch with LSAM and orbit circularization achieves three flight certification for crewed operations).

LSAM

Systems: Full-production LSAM.

CEV

Systems: Full-production Block 2 CEV.

Launch Vehicles:

HLLV (launch with EDS/LSAM is third certification flight for crewed operations)

Systems: Full-production HLLV with shroud.

CLV (launch with CEV)

Systems: Full-production CLV.

Objectives:

- Verify and demonstrate performance of all lunar mission elements in LEO and lunar orbit.
- Demonstrate CEV and LSAM/EDS AR&D in LEO and lunar orbit (reliability).
- Verify CEV autonomous operation in lunar orbit.
- Verify LSAM operation in lunar orbit with full crew complement.
- Demonstrate and rehearse LSAM accessibility and systems performance by conducting EVA in lunar orbit.
- Demonstrate automated, uncrewed LSAM descent to lunar surface and landing.
- Verify LSAM systems operations on lunar surface.
- Demonstrate LSAM launch and ascent from lunar surface to AR&D with CEV.
- Demonstrate CEV AR&D with LSAM in lunar orbit in rescue mode.
- Assess LSAM survival unattended in lunar orbit.
- Verify mission operations plans and procedures for lunar landing mission.

Parameters:

- LEO: 307- to 407-km circular orbit, 28.5 deg.
- Lunar orbit: 100- x 500-km polar orbit with 0 deg inclination.
- Duration: 5-day lunar orbit mission. Total mission duration from first element launch to CEV landing is 25 days.

Constraints: None—all elements must operate as planned for lunar landing.

Mission Profile:

- EDS/LSAM launch on HLLV.
- CEV launches on CLV 14 days later.
- EDS/LSAM conduct AR&D with CEV.
- Crew fully checks out LSAM.
- EDS/LSAM/CEV performs Trans-Lunar Injection (TLI) burn.
- EDS conducts lunar orbit injection burn for LSAM/CEV and is jettisoned.
- LSAM and CEV rendezvous and dock.
- Full crew transfers to LSAM and completes vehicle checkout.
- Crew conducts EVA from LSAM to demonstrate vehicle ingress and egress and simulate lunar surface operations.
- Crew splits between CEV and LSAM; then the LSAM and CEV undock and conduct proximity operations while crew conducts complete checkout of LSAM.
- LSAM and CEV dock and full crew transfers to CEV.

- LSAM undocks and performs burn to initiate descent toward lunar surface.
- LSAM conducts lunar landing at Constellation 4 landing site and remains on surface for 2 days (TBR).
- LSAM jettisons descent stage and ascends to AR&D with CEV.
- Crew splits between LSAM and CEV and crew checks systems after descent and landing.
- LSAM and CEV undock and crew practices lunar orbit maneuvering in LSAM ascent stage.
- LSAM and CEV dock and crew returns to CEV.
- LSAM powered down for long-duration life testing in lunar orbit.
- CEV conducts Trans-Earth Injection (TEI) burn and direct entry recovery.

10.4.14 Constellation-4 – Crewed Mission (Lunar Landing)

HLLV/EDS/LSAM

CLV/CEV

Space Vehicles:

EDS

Systems: Full-production EDS.

LSAM

Systems: Full-production LSAM.

CEV

Systems: Full-production Block 2 CEV.

Launch Vehicles:

HLLV

Systems: Full-production HLLV with shroud.

CLV

Systems: Full production CLV.

Objectives: Return Americans to the Moon.

Parameters:

- LEO: 307- to 407-km circular orbit, 28.5 deg.
- Lunar orbit: 100- x 500-km polar orbit, 0 degrees inclination.
- Duration: 4-day lunar surface stay. Total mission duration from first element launch to CEV landing is 25 days (TBR).

Constraints: It is assumed on the first lunar landing with crew that the CEV will retain a subset of the normal crew complement.

Mission Profile:

- EDS/LSAM launch on HLLV.
- CEV launch on CLV 14 days later.
- EDS/LSAM conduct AR&D with CEV.
- Crew fully checks out LSAM.
- EDS/LSAM/CEV performs TLI burn.
- EDS conducts lunar orbit injection burn for LSAM/CEV and is jettisoned.
- Full crew transfers to LSAM and completes vehicle checkout.
- Crew splits between CEV and LSAM; then the LSAM and CEV undock and conduct proximity operations while crew conducts complete checkout of LSAM.
- LSAM performs burn to initiate descent toward lunar surface.
- LSAM conducts lunar landing and remains on surface for 4 days (TBR).
- LSAM jettisons descent stage and ascends to AR&D with CEV.
- LSAM and CEV dock and crew returns to CEV.
- LSAM powered down for long-duration life testing in lunar orbit.
- CEV conducts TEI burn and direct entry recovery.