Test & Verification Approach for the NASA Constellation Program

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Outline

- NASA’s Vision for Exploration
- Constellation Program Overview
- Constellation Vision for Test & Verification
- Test & Verification Implementation
The Vision for Space Exploration: Foundations for Exploration

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop & fly the Crew Exploration Vehicle no later than 2014
- Return to the Moon no later than 2020
- Extend human presence across the solar system & beyond
- Implement a sustained & affordable human & robotic program
- Promote international & commercial participation in Exploration

NASA Authorization Act of 2005

The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations.
Constellation Program Fleet of Vehicles

- Earth Departure Stage
- Orion Crew Exploration Vehicle
- Ares I Crew Launch Vehicle
- Ares V Cargo Launch Vehicle
- Altair Lunar Lander
Exploration Roadmap

- Lunar Robotic Missions
- Science Robotics Missions
- Research and Technology Development on ISS
- Commercial Crew/Cargo for ISS
- Space Shuttle Operations
- SSP Transition
- Ares I and Orion Development
- Operations Capability Development (EVA, Ground Operations, Mission Operations)
- Orion and Ares I Production and Operation
- Altair Lunar Lander Development
- Ares V & Earth Departure Stage
- Surface Systems Development
- Initial Orion (CEV) Capability
- Lunar Outpost Buildup
- SSP Transition Operations Capability Development (EVA, Ground Operations, Mission Operations)
Constellation Vehicle Approximate Size Comparison

 Titan 4  Atlas 5  Space Shuttle

 Ares I

 Ares V

 Saturn V
Ares I Elements

**Encapsulated Service Module (ESM) Panels**

**Instrument Unit**
- Primary Ares I control avionics system
- *NASA Design / Boeing Production*

**Stack Integration**
- 2M lb gross liftoff weight
- 325 ft in length
- *NASA-led*

**First Stage**
- Derived from current Shuttle RSRM/B
- Five segments/Polybutadiene Acrylonitrile (PBAN) propellant
- Recoverable
- New forward adapter
- Avionics upgrades
- *ATK Launch Systems*

**Upper Stage**
- 305k lb LOX/LH₂ stage
- 18 ft diameter
- Aluminum-Lithium (Al-Li) structures
- Instrument Unit and Interstage
- Reaction Control System (RCS) / roll control for first stage flight
- Primary Ares I control avionics system
- *NASA Design / Boeing Production*

**Upper Stage Engine**
- Saturn J-2 derived engine (J-2X)
- Expendable
- *Pratt and Whitney Rocketdyne*
Orion Elements

**Orion Crew Exploration vehicle (JSC)**
- *NASA Management and Integration*
- Prime contract Lockheed Martin: design, development, and production

**Launch Abort System (LaRC)**
- Emergency escape during launch
- Under Prime contract

**Service Module (GRC)**
- Propulsion, electrical power, fluids storage
- Under Prime contract

**Crew Module (JSC)**
- Crew and cargo transport
- Under Prime contract

**Spacecraft Adapter (GRC)**
- Structural transition to Ares launch vehicle
- Under Prime contract

**Test Abort Booster (DRC)**
- Procured through USAF contract
- In-house design
**Ares V Elements**

**Earth Departure Stage (EDS)**
- One Saturn-derived J–2X LOX/LH₂ engine (expendable)
- 33-ft diameter stage
- Aluminum-Lithium (Al-Li) tanks
- Composite structures
- Instrument unit and interstage
- Primary Ares V avionics system

**Stack Integration**
- 7.4M lb gross liftoff weight
- 360 ft in length

**First Stage**
- Two recoverable 5-segment PBAN-fueled boosters (derived from current Ares I first stage)

**Core Stage**
- Five Delta IV-derived RS–68 LOX/LH₂ engines (expendable)
- 33-ft diameter stage

**Payload Fairing**

**Altair Lunar Lander**

**EDS**

**J–2X**

**Loiter Skirt**

**Interstage**

**RS–68**
Lunar Lander

- Transports 4 crew to and from the surface
  - Seven days on the surface
  - Lunar outpost crew rotation
- Global access capability
- Anytime return to Earth
- Capability to land 20 metric tons of dedicated cargo
- Airlock for surface activities
- Descent stage:
  - Liquid oxygen / liquid hydrogen propulsion
- Ascent stage:
  - Storable Propellants
Map of Constellation content across NASA

**Ames**
- Lead Thermal Protection System ADP
- Aero-Aerothermal database
- Ares Abort simulations
- Software and GN&C support

**Glenn**
- Lead Service Module and Spacecraft Adapter integration
- Flight Test Article “Pathfinder” fabrication
- Ares I-1 upper stage simulator lead
- Ares power, TVC and sensors lead
- J-2X altitude/inspace testing
- SE&I Support

**Dryden**
- Lead Abort Flight Test Integration/Operations
- Abort Test Booster procurement
- Flight Test Article Development/Integration

**JPL**
- Thermal Protection System support

**Goddard**
- Communications Support

**Langley**
- Ares 1-X
- Lead Launch Abort System integration
- Lead landing system ADP
- Ares I-1 vehicle integration
- Ares aerodynamics lead
- SE&I Support

**Johnson**
- Home for Program
- Home for Projects: Orion, Mission Ops, EVA, Lunar Lander
- Lead Crew Module integration
- Orion Spacecraft Integration
- GFE projects management
- Flight Test Program

**Kennedy**
- Home for Ground Ops Project
- Ground processing
- Launch operations

**Marshall**
- Home for Ares Project
- Ares I and V development and integration lead
- LAS and SM SE&I Support

**Stennis**
- Rocket Propulsion Testing for Ares
CxP T&V Implementation

- Mission and Vision
- Organization
- Documentation
- Processes
- Integrated Testing
- Flight Testing
Challenges in CxP T&V Program

- **Attrition of workforce experienced in human spaceflight development**
  - Aging of existing human spaceflight programs as well as previous programs

- **Application of lessons learned**
  - Must ensure lessons learned are applicable to CxP

- **Developing integrated approach among multiple organizations**
  - Differing practices, documentation, vocabulary

- **New Information technology environment**
  - Requires shift in thinking from paper processes

- **Extensive use of heritage hardware envisioned for CxP**
  - Must be applied carefully when mission differs from original
T&V Strategic Emphasis and Key Tenets

♦ Reinvigorate T&V – thinking, experience, discipline, culture
  • T&V planners and practitioners get educated via OJT

♦ Incorporate lessons learned
  • Plan a project & THEN plan T&V is a current norm
    – This practice has piles of lessons written on it
  • Planning for T&V must MOVE LEFT
    – CONCURRENTLY with formulation of concepts and requirements
    – Enough work early enough
      • T&V effort INCLUDED in the plan, not added later

♦ Rules, standards, practices aimed/set for FAR more reliable exploration systems
  • Integrated T&V guiding policy, general requirements, standard practices, and cooperative implementation plans and processes
The primary mission of the CxP T&V function is to ensure the following objectives are accomplished through the life of the CxP:

- Verification that the Constellation Architecture satisfies the CARD and associated IRDs
- Verification that each ‘end item’ meets its specified requirements
- Verification that the ‘end items’ appropriately integrate with other end products and “systems”, as required (e.g., CEV integration with ISS)
- Validation that the Constellation Architecture satisfies its stakeholders’ needs

The vision of the CxP T&V function is that the following items be established, integrated, maintained, and be readily retrievable for all levels of the CxP Architecture throughout the life of the CxP:

- A formalized verification process that ensures CxP HW/SW complies with applicable design-to/performance/build-to specifications (e.g., CARD, SRD, ERD, IRDs/ICDs)
- A complete and readily accessible “materiel history” for all CxP ‘end items’
- A complete “certification baseline” that encompasses all CxP flight HW/SW
- Processes and tools to support the planning, execution, and assessment of effectiveness for verification activities performed throughout the mission integration lifecycles of each DRM
- A formalized validation process that confirms that CxP HW/SW and processes fulfill their intended capability, functionality, and performance
Test and Evaluation Organization

Constellation Test and Evaluation
Director, William Arceneaux (JSC)
Deputy Director, Tom Rathjen (JSC)

Cx Flight & Integration Testing
- Orion – ISS Campaign Test Strategy
- Mission Test Leads
- Multiple/Flight Element Integration Testing
- Shuttle/ISS Development Test Objectives
- Lunar Campaign Test Strategy

Cx Testing Facilities & Assets
- Propulsion TIG
- Wind Tunnel TIG
- Chambers TIG
- Structures TIG
- Environments TIG

Ares I-X Mission
Ares I-Y Mission
Orion 1, 2, & 3 Mission
Orion 4 & Subs Mission

CxAMP Operations
Test Integration Groups (TIGs)
Integration of Cx Program CofF Plans
CxP Requirements Flowdown

Level 0, NGO, OpsCon

Requirements Analysis

3.2 Cx Arch. Reqmts
3.3 Design Constr. Standards
3.4 External Interfaces
3.5 Physical Char.

3.7.X Systems

CARB

System n (3.7.n)

Decomp

Cx Program Controlled Architecture / Integrated System Level Reqts

Level 0/1

Decomp

3.2.X Allocated Requirements
3.3 Design Constr. Standards
3.4 External Interfaces
3.5 Physical Char.

3.7.XY

SRDs

Decomp

IRDs

ICDs

Level 2

Decomp

ERDs

Project Controlled

Level 3

Level 4 and Below Vendor or GFE Projects

18
CxP Model Based Systems Engineering Approach
CxP Verification Planning Documents

- Constellation Program Plan 70003
  - Constellation Architecture Requirements Document 70000
  - Environmental Qualification and Acceptance Testing Requirements (CEQATR) 70036
  - Systems Engineering Management Plan (SEMP) 70013
    - Master Integration and Verification Plan (MIVP) 70008
      - Integrated Test Plan 70084
      - Software Verification and Validation Plan 70086
      - Integrated Flight Test Strategy Document 70085
      - Ares I-1 Flight Test Plan 70127
Environmental Testing

- Developed CxP 70036 CxP Environmental Qualification and Acceptance Test Requirements
- Roughly equivalent to MIL-STD-1540, but many practices differ from DoD
- Utilizes Risk-based tailoring process
- Document addressed varying test practices within NASA community
- Resulted in formation of Environmental Testing Community of Practice (CoP)
Scope of CxP Verification

Policy laid out for -

- Qualification (specification compliance)
- Acceptance (N+1)
- Assembly and checkout
- Operations
- Validation
CxP Verification - General Process Flow

1. Identify Requirement Set
2. Write Verification Requirements
3. Develop Verification Strategy
4. Plan Verification Events
5. Plan and Conduct Readiness Reviews
6. Implement Verification Activities
7. Develop Verification Reports
8. Prepare Verification Closure Documentation
9. Review Verification Compliance
Avionics and Software Integrated Testing Approach

- CxP will use distributed approach for avionics and software integration and verification
- Utilizes high speed networks to leverage existing test facilities rather than developing a standalone integrated test facility
A-3 Test Stand

- Located at Stennis Space Center
- Will be used to test J-2X engine
- First large test stand built at the center since the 1960s
- 300-foot-tall, open-frame design will allow engineers to simulate conditions at different altitudes in order to test the J-2X's ability to function as a second stage engine for the Ares I and the Earth Departure Stage engine for the Ares V
- Test stand will generate approximately 4,620 pounds per second of steam to reduce the engine test cell pressure.
Space Power Facility

- Glenn Research Center Plumbrook Facility
- Will provide Orion Environmental Correlation Test (ECT) for the Ground Test Article (GTA) (vibro-acoustic) and Integrated Environmental Orion Qualification Testing in a “test as you fly” configuration.
  - Acoustic Vibration
  - Mechanical Vibration
  - Thermal-Vacuum
  - EMI/EMC
MEIT and FEIT

♦ The MEIT and FEIT tests will confirm that the work done by the Projects to verify the interfaces are complete and the elements are ready to fly and support in flight operations.

♦ Plans for these tests will be outlined in the Integrated Test Plan (ITP)
Flight Element Integrated Test (FEIT)

- FEIT - An FEIT is an integration test between new or significantly modified systems, elements, and modules being assembled into an integrated launch vehicle for the first time (e.g., CEV and CLV; LSAM, Earth Departure Stage (EDS), and CaLV) for the purposes of operational testing (i.e., typically not development testing) or crewed flight.
MEIT - An MEIT is an integration test between two or more flight systems which will be launched on separate launch vehicles and integrated together for the first time in space (e.g., CEV and ISS; CEV and LSAM/EDS).

MEIT 1 – Manned CEV-ISS-MS-C&T
MEIT 2 – (NOT PLANNED) unmanned CEV-ISS-MS-C&T
MEIT 3 – CEV-LSAM-MS-C&T
Flight Test Driving Principles

♦ Integrated flight test strategy encompasses development through operational validation

♦ Development tests inform design, models, adjustments

♦ Validation objectives:
  • Does the system ‘do what we want’?
  • Does the system ‘behave as expected’?
  • Do we understand how to operate the system?

♦ A mission’s objectives (test, ops) are linked to manifested capability set

♦ Testing continues after transition into mission service
Constellation’s Integrated Flight Test Strategy
Low Earth Orbit Servicing Capability

Ares I-X

Development Flight Tests

Orion Project

Orion Prime

AA-1 Max q Abort

PA-1

AA-2 Transonic Abort

PA-2

AA-3 Tumble Abort

Validation Flight Tests
(Production Systems)

Ares I-Y

Orion 1

Orion 2

Orion 3

Orion 4

High Altitude Abort