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
Constellation Vehicle Approximate Size Comparison

Titan 4     Atlas 5    Space Shuttle

Saturn V
Ares I Elements

**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*

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

**Encapsulated Service Module (ESM) Panels**

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

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

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

Crew Module (JSC)
• Crew and cargo transport
• Under Prime contract

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

Service Module (GRC)
• Propulsion, electrical power, fluids storage
• 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

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

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

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

Vehicle 51.0.34
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
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
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
CxP T&V Mission & Vision

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

Identify Requirement Set

Write Verification Requirements

Develop Verification Strategy

Plan Verification Events

Plan and Conduct Readiness Reviews

Implement Verification Activities

Develop Verification Reports

Prepare Verification Closure Documentation

Review Verification Compliance
Avionics and Software Integrated Testing Approach

- CxP will use a 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
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)
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.
**Multi-Element Integrated Testing (MEIT)**

- **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

Development Flight Tests

Validation Flight Tests (Production Systems)

Ares I-X

Orion Project

Orion Prime

AA-1
Max q Abort

AA-2
Transonic Abort

AA-3
Tumble Abort

Ares I-Y
Orion 1
Orion 2
Orion 3
Orion 4

PA-1
PA-2

High Altitude Abort