Development of Environmental Qualification and Acceptance test Requirements for the Constellation Program and Comparison with MIL-STD-1540E

E. Strong
24th Aerospace Testing Symposium
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Outline

♦ Constellation Program Description
♦ Test & Verification challenges within Constellation Program
♦ Development of the CEQATR
♦ Comparison between CEQATR and MIL-STD 1540
Constellation Program Spacecraft

- Earth Departure Stage
- Ares V - Heavy Lift Launch Vehicle
- Orion - Crew Exploration Vehicle
- Ares I - Crew Launch Vehicle
- Altair - Lunar Lander
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*

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**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*

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**Upper Stage Engine**
- Saturn J-2 derived engine (J-2X)
- Expendable
- *Pratt and Whitney Rocketdyne*
Orion Crew Exploration Vehicle (JSC)

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

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

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

Service Module (GRC)
- Propulsion, electrical power, fluids storage
- Under Prime contract
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
NASA’s Past, Present, and Future Launch Vehicles

(Shown to scale)

<table>
<thead>
<tr>
<th>Rocket</th>
<th>Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo Saturn V</td>
<td>363</td>
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<tr>
<td>Space Shuttle</td>
<td>184</td>
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<tr>
<td>Ares I</td>
<td>328</td>
</tr>
<tr>
<td>Ares V</td>
<td>361</td>
</tr>
</tbody>
</table>
Launch Vehicle Size Comparison

Atlas V | Delta IV | Ares

Atlas | Delta

Source: Google Images
Relative size is approximate only
Diversity in Unmanned Systems

Source: Google Images
Diversity in Human Rated Systems
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/in-space 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**
- Lead Launch 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

**Langley**
- Lead Launch System integration
- Lead landing system ADP
- Ares I-1 vehicle integration
- Ares aerodynamics lead
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**Stennis**
- Rocket Propulsion Testing for Ares
Challenges

♦ Integrating multiple NASA centers, project offices, and contractors

♦ Aging of workforce and loss of expertise from previous programs

♦ Extended development cycles between major programs

♦ Practices from previous programs not always applicable for Constellation
Vision for CxP Environmental Testing

- Establish excellence agency-wide in verification discipline
- Capture latest industry/government/NASA best practices (learn from everyone)
- Recognize increased inherent risk of CxP lunar missions over LEO Shuttle/ISS (and even Apollo) missions
- Establish common terminology/understanding
- Provide training to establish minimum level of testing competence, convey CEQATR-specific expectations
- Establish consistent, program-wide, minimum standards, but allow risk-based tailoring
- **Selectively** incorporate lessons learned from previous and present programs in order to allow for more effective testing for CxP and future programs.
- Define testing early to avoid surprises at delivery
- Build and sustain the as-certified baseline and hardware test record.
Instead of CEQATR, why not use…

- MIL-STD-1540E  Test Requirements for Launch, Upper-Stage and Space Vehicles
- MSFC REQT-3019  Launch Vehicle Qualification Requirements
- SP-T-0023  Space Shuttle Specification Environmental Acceptance Testing
- SSP 41172  Space Station Program Qualification and Acceptance Environmental Test Requirements
- NASA STD 7001  Payload Vibroacoustic Test Criteria
- NASA STD 7002  Payload Test Requirements
- NASA STD 7003  Pyroshock Test Criteria
Differing Mission Profiles
Differing Configurations
Fitting within existing NASA documentation
Example Comparison Chart

<table>
<thead>
<tr>
<th>Specification Performance (1)</th>
<th>Electrical and Electronic</th>
<th>Antenna</th>
<th>Mechanism (Moving Mechanical Assy)</th>
<th>Solar Array</th>
<th>Battery</th>
<th>Valve or Propulsion</th>
<th>Pressure Vessel or Component</th>
<th>Fluid Equipment</th>
<th>Pressure Vessel (9)</th>
<th>Thruster</th>
<th>Thermal</th>
<th>Optical</th>
<th>Structural</th>
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<td>ER R R R R R R R R R R R</td>
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**Red** indicates unique CEQATR content  
**Blue** indicates unique 1540 content
## Differences in Scope

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<thead>
<tr>
<th>MIL-STD-1540</th>
<th>CxP CEQATR</th>
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<tr>
<td><strong>Inspection</strong></td>
<td>NA</td>
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<tr>
<td><strong>Specification Performance</strong></td>
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<tr>
<td><strong>Leakage</strong></td>
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<td><strong>Shock</strong></td>
<td>Shock</td>
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<td><strong>Vibration or Acoustic</strong></td>
<td>Random Vibration</td>
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<td>Acoustic Vibration</td>
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<td><strong>Thermal Cycle</strong></td>
<td>Sinusoidal Vibration</td>
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<td><strong>Thermal Vacuum</strong></td>
<td>Acceleration</td>
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<td><strong>NA</strong></td>
<td>Thermal Cycle</td>
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<td><strong>NA</strong></td>
<td>Thermal Vacuum</td>
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### Differences in Scope (cont.)

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<th>MIL-STD-1540</th>
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<tr>
<td>NA</td>
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<td>NA</td>
<td>Depressurization/Repressurization</td>
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<td>EMC</td>
<td>NA – Covered elsewhere</td>
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<tr>
<td>Life</td>
<td>Life</td>
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<td>Pressure</td>
<td>NA – Covered elsewhere</td>
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<td>Static Load</td>
<td>NA – Covered elsewhere</td>
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# Test requirements in other CxP documents

<table>
<thead>
<tr>
<th>Test</th>
<th>Governing CxP Document</th>
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<tbody>
<tr>
<td>Acoustic Noise</td>
<td>Human-Systems Integration Requirements</td>
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<td>EMC</td>
<td>Electromagnetic Environmental Effects (E3) Requirements</td>
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<td>Electromagnetic Environmental Effects (E3) Control Plan</td>
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<td>Ionizing Radiation</td>
<td>Ionizing Radiation Control Plan</td>
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<tr>
<td>Modal Survey, Pressure, Static Load</td>
<td>Structural Design and Verification Requirements</td>
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<td>Offgas, Outgas, Oxygen Compatibility</td>
<td>Standard Materials and Processes Requirements for Spacecraft</td>
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<td>Run-In</td>
<td>Design and Development Requirements for Mechanisms</td>
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<td>Ozone</td>
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<td>Electrical or Electronic Equipment</td>
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<td>Antenna</td>
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<td>Battery</td>
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<td>Thermal</td>
<td>Thermal Equipment</td>
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<td>Optical</td>
<td>Optical Equipment</td>
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<tr>
<td>Structural Components</td>
<td>NA – covered elsewhere</td>
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</table>
Environmental Test Requirement Definition Process

- Comparison of test approaches among participants
- Discussion of “best” requirements
- Comparison of historical test data and effectiveness of different approaches and parameters
- Discussion of technical factors driving different approaches/requirements
  - Eliminate “emotineering”
- Increased understanding among participants
- Follow-on negotiation of test requirements
- Establishment of Test & Verification Community of Practice
Environmental T&V CoP
Big Issues

♦ Unit acceptance vibration duration
♦ Shock testing for acceptance
♦ Margins/Maximum Predicted Environment
♦ Major Assembly Testing
  • Upper Stage
  • Space Vehicle
♦ Thermal Cycle Limits
♦ Qualification Random Vibration Approach
  • Two-phase CEQATR approach (QAVT/QVT) vs single enveloping test (baseline 1540 approach)
♦ Order of EMI in Test Sequence
  • First or last?
♦ Understanding of Tailoring
Why am I testing again?

Is the test effective in driving out latent defects?

- Are the proposed test levels sufficient to excite the hardware?
- Does my configuration have components that will be excited by the test?
CEQATR Tailoring Process

Constellation Environmental Qualification and Acceptance Testing Requirements (CEQATR)

Evaluate Article Under Test (AUT) Requirements

Tailor

Test Requirement Evaluation Report (TRER)

Compliant Requirements

AUT Test Verification Requirements

Risk Evaluation

Decision and documentation

CxP Program (Level 2)
- R Compliant
- R Tailored
- R Deleted

CxP Project (Level 3)
- Moderate & Low risk
- Low risk

CxP Sub-Project (Level 4 & below)
- Low risk

Low risk

Decision Package
- Added
- ER
- ER*
- Deleted
- Tailored
- Compliant

Approval level and change documents per risk

TRER

Engineering

TVD only

TRER &

TRER &

Decision Package
- High risk
- High risk
- High & Moderate risk
- High risk
- High risk

TRER & Deviation

Low risk

Moderate Risk

Moderate & Low risk

Low risk

Risk Evaluation

High risk

High risk

High & Moderate risk

High risk

High risk

TRER & Deviation

Low risk

Moderate Risk

Moderate & Low risk

Low risk

TRER & Deviation

Low risk

Moderate Risk

Moderate & Low risk

Low risk

TRER & Deviation

Low risk

Moderate Risk

Moderate & Low risk

Low risk

TRER & Deviation

Low risk

Moderate Risk

Moderate & Low risk

Low risk

TRER &
Current Status

♦ Revision A Baselined
♦ Revision B in Work
  • Environmental tests, including humidity
  • Clarification
  • Low Frequency Vibration
  • Biased Tolerances for Vibration/Acoustic
  • Thermal Uncertainty/MPE
Questions?