Improving Efficiency in Assembly, Integration, and Test

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Abstract

The Aerospace Corporate Chief Engineer's Office (CCEO) conducted an Assembly, Integration & Test (AI&T) Efficiency Study to gain insight and an understanding of why AI&T routinely suffers significant schedule delays related to inefficient operation. The study was undertaken as a result of customer concerns related to recent space vehicle AI&T activities that drove major schedule slips and cost increases on the program critical path. This effort was focused on studying Class A selected programs since 2000. Five areas of research were conducted, including: 1) defining what constitutes assembly, integration, and test for space vehicles; 2) a data analysis of space vehicle AI&T cycle time durations, 3) a comprehensive literature search on AI&T methods; 4) a benchmarking study of other industries to learn what innovative best practices companies use to become more efficient in their assembly and test operations; and 5) defining what drives AI&T efficiency /inefficiency.

Acknowledgments

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Introduction

Improving Efficiency in Assembly, Integration, and Test

Why We Test

- Demonstrate requirements have been meet
- Demonstrate flightworthiness by detecting and correcting anomalous behavior before flight
- Ensure survival of launch and operating environments
- Decrease mission risk
- Test Strategies
  - *Development (Proof of design concept + Development of manufacturing processes)*
  - *Qualification (Demonstrate 6σ design margins)*
  - *Protoqualification (Demonstrate 3σ design margins)*
  - *Acceptance (Demonstrate workmanship, functionality and performance)*
  - *Flightproof (Protoqualification levels + Acceptance durations for dynamics)*
- Common Test Objectives
  - *Design verification (Qualification and Protoqualification testing)*
  - *Margin demonstration*
  - *Workmanship screening*
  - *Performance to specification*
  - *Acceptance test validation*

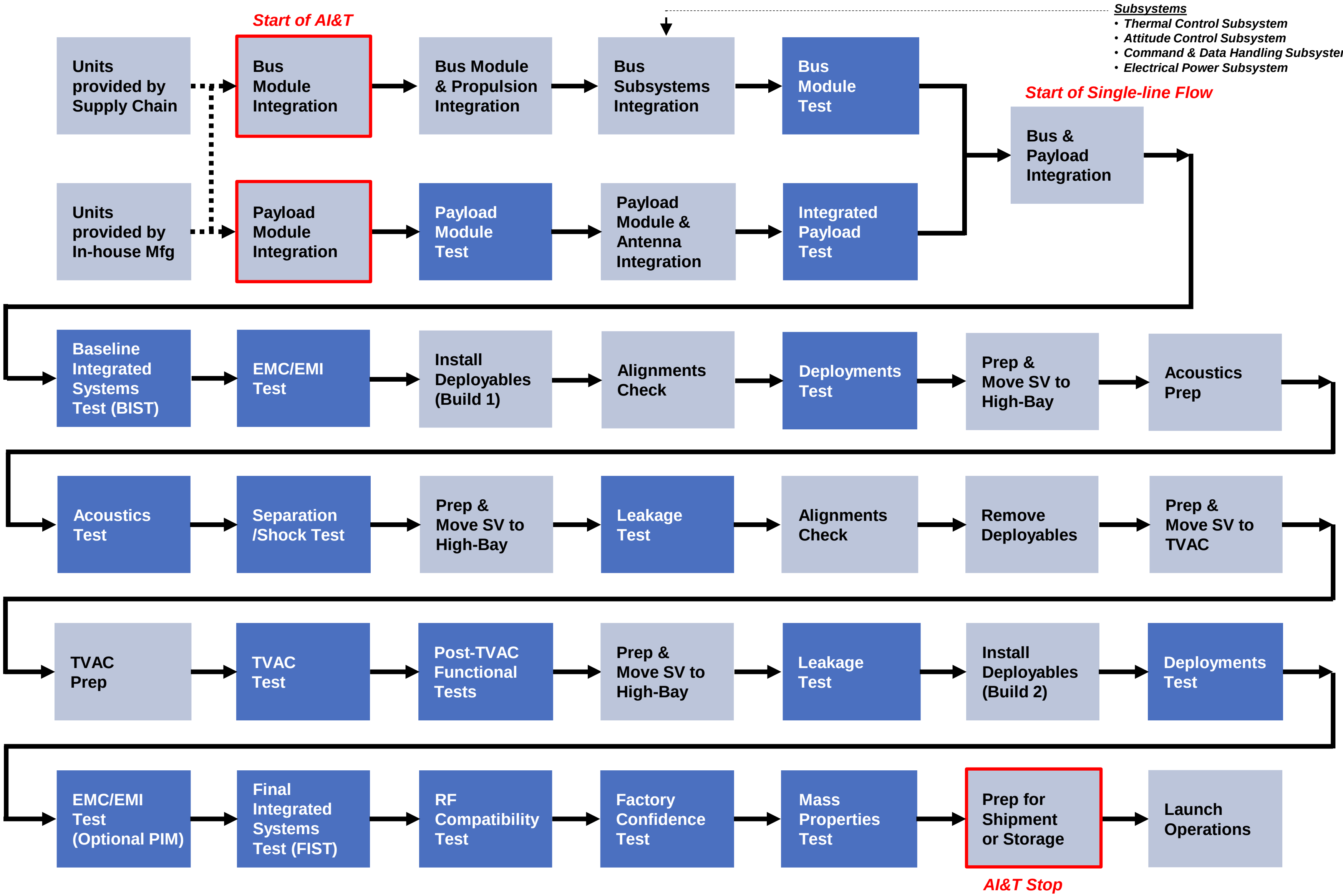
Effective testing is key to program and mission success

Key Terminology

- Definition of assembly, integration, and test (AI&T):
  - *Start of AI&T is when a completed bus structure and/or payload structure is assembled together, harnesses installed, and ready for unit integration*
  - *Conclusion of AI&T is shipment of the space vehicle to storage or to launch site*
- Efficiency: A measure of the ratio of actual hours worked compared to the total hours worked.
- Value Stream: All of the process steps, both value-added and non-value added, required to complete a product from beginning to end. Value stream mapping (VSM) is a Lean technique used to document, analyze and improve the flow of information or materials required to produce a product for a customer. VSM documents the current state and future state of a process after the process flow has been improved by eliminating the inherent waste in both non-value added and value-added steps.
- Waste: Any activity, task, or time element which does not add value to the product and creates inefficiency in the system. The 7 traditional wastes are: 1) defects; 2) excess inventory; 3) over-production; 4) waiting; 5) excessive motion; 6) transportation; and 7) over-processing.
- Value (from the customer's perspective): Performing a build or verification task one-time.

No consistent definition for the Start of AI&T; and no consistent definition of Value

Defining Assembly, Integration, and Test (AI&T)



EMI/EMC – Electromagnetic Compatibility/Interference PIM – Passive Intermodulation RF – Radio Frequency TVAC – Thermal Vacuum

Key Observations

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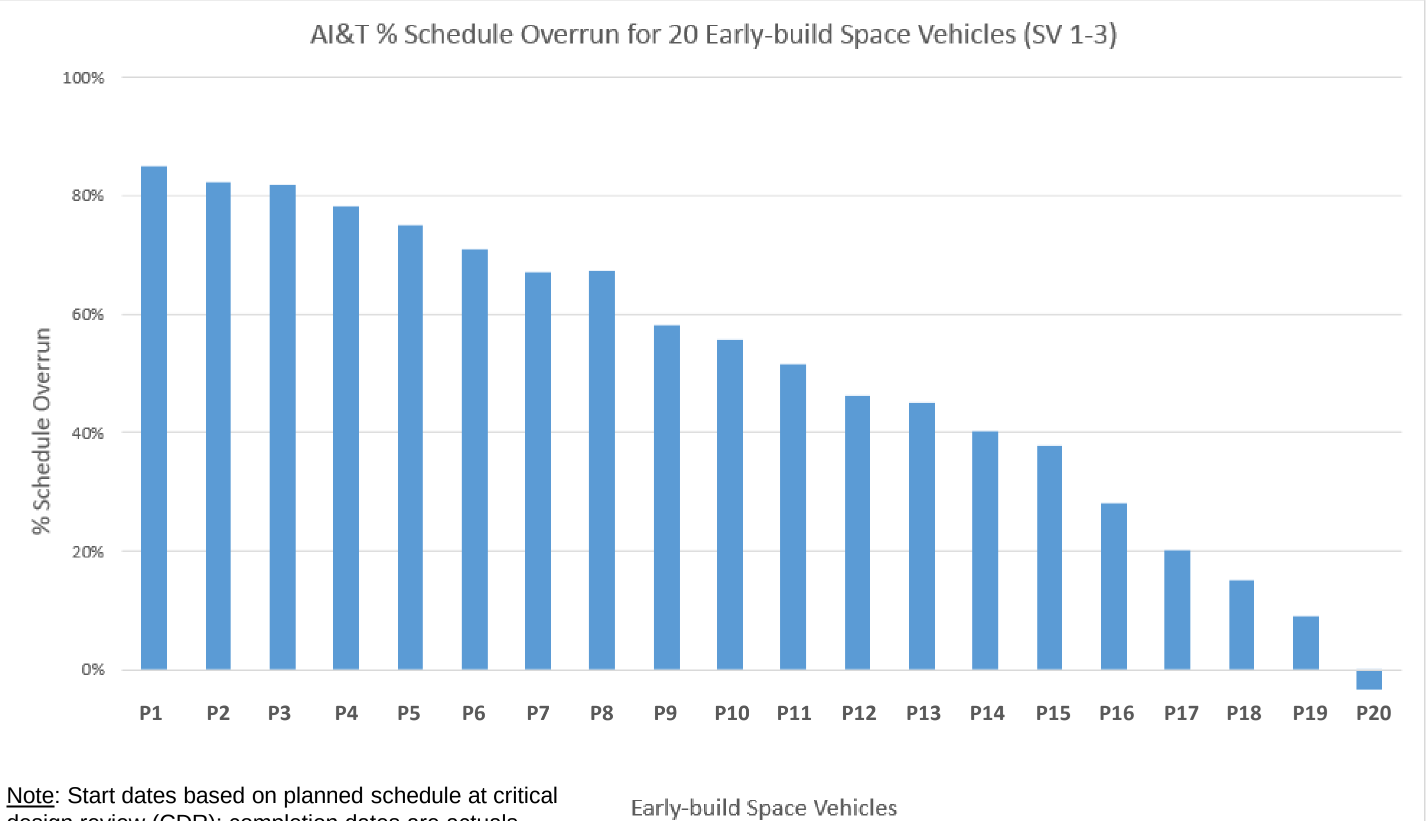
Program Schedule Analysis

- Perception exists that "AI&T is inefficient" and "AI&T is the major cause leading to cost overruns"



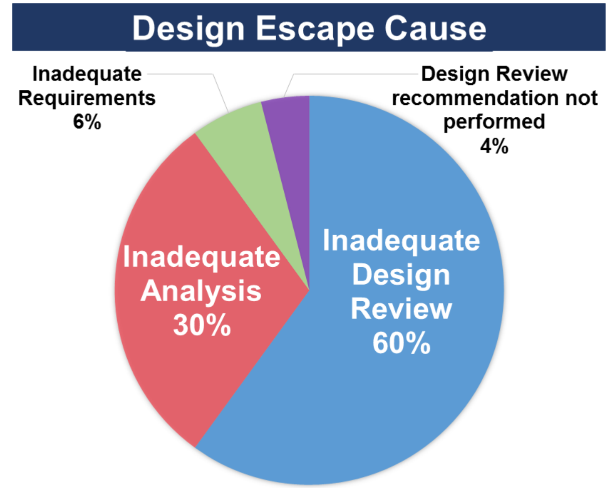
Note: Start dates based on planned schedule at critical design review (CDR); completion dates are actuals.

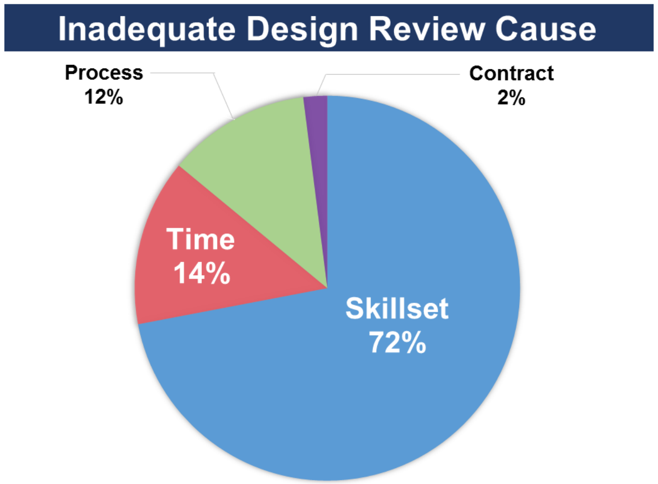
Source: AI&T Efficiency Study, TOR-2015-01412, 9 January 2017

Greater than 50% of the vehicles experienced more than 2X their planned AI&T duration

Contributors to Schedule Slips: Design

- Root cause of design escape varies
  - *Inadequate design review (60%)*
  - *Inadequate analysis (30%)*
- In 19 of 21 test cases that didn't have a fully-tested Engineering Model (EM), the designers indicated that issue would have been found had they utilized a fully-tested EM
  - *Provides the most robust validation method to flush-out inadequate analysis and packaging issues*
  - *A fully tested EM prior to CDR drives early discovery, demonstrates compliance while maturing the Design Review data products*
- Reviewer skillset implicated in cause of inadequate design reviews (72%)
  - *Not getting help; not the right persons; not raising issues*
  - *Mixed technology units require multi-discipline SMEs*
  - *Skillset of Government team should be supplemented with FFRDC oversight*

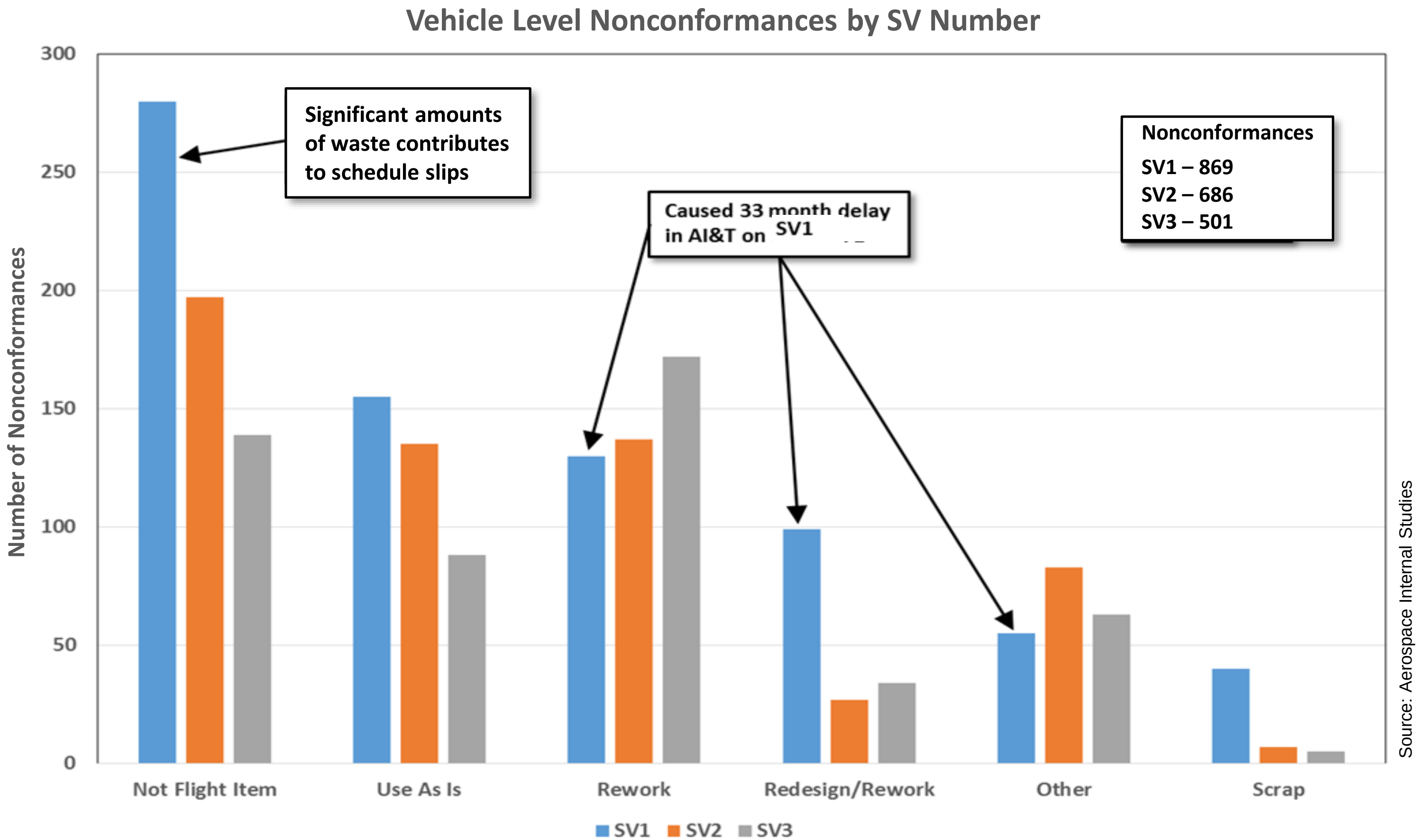




Source: Design Review Improvement Recommendations, TOR-2015-02545, 29 May 2015

Many design escapes are preventable with the right set of reviewers and having a robust design review process with incremental reviews

Contributors to Schedule Slips: Workmanship

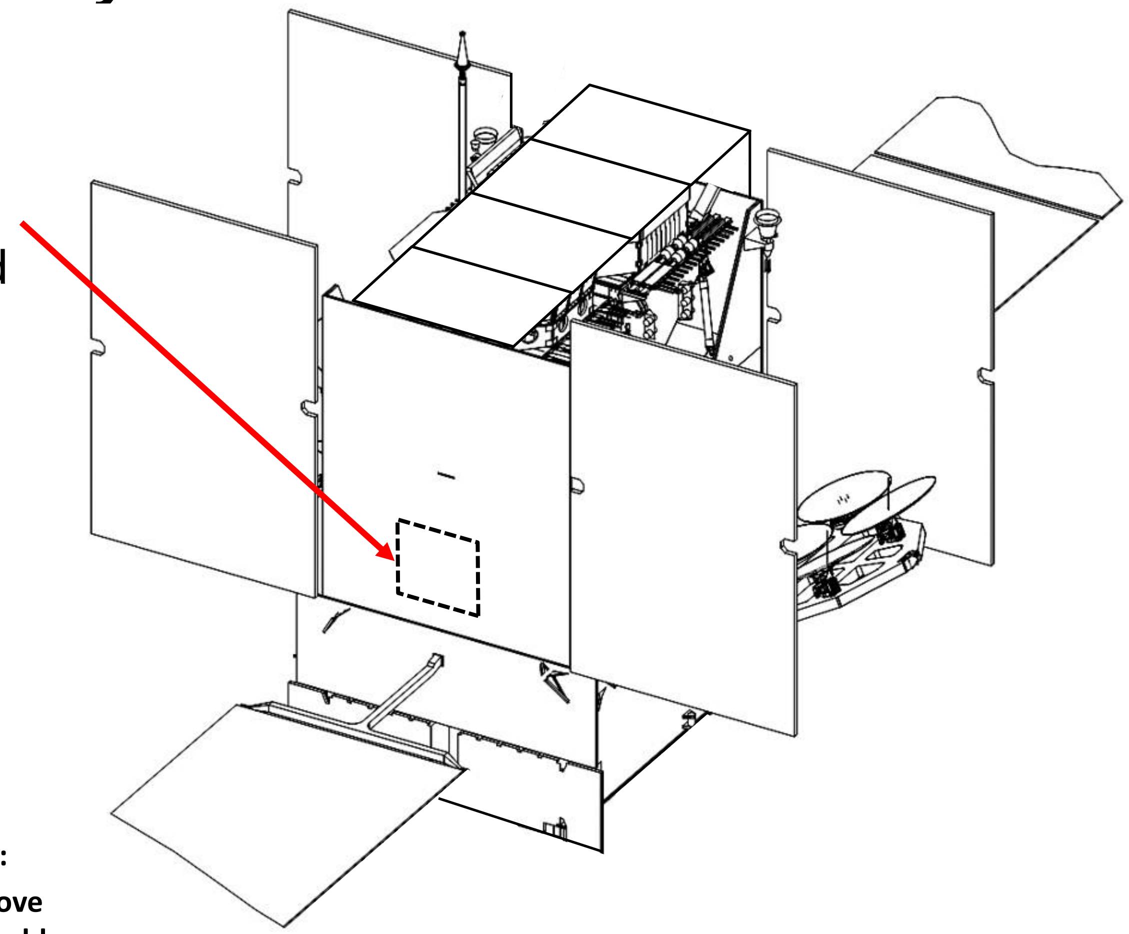


Anomalies during AI&T contributed to a 33-month schedule slip on SV1

Contributors to Schedule Slips: Space Vehicle Accessibility

- Failed components at space vehicle-level required access hole to be cut in load-bearing structural panel to remove and replace (R&R)
- This is what poor *Design for Accessibility* looks like – no way to access electronic components
- Space vehicle design created access constraint

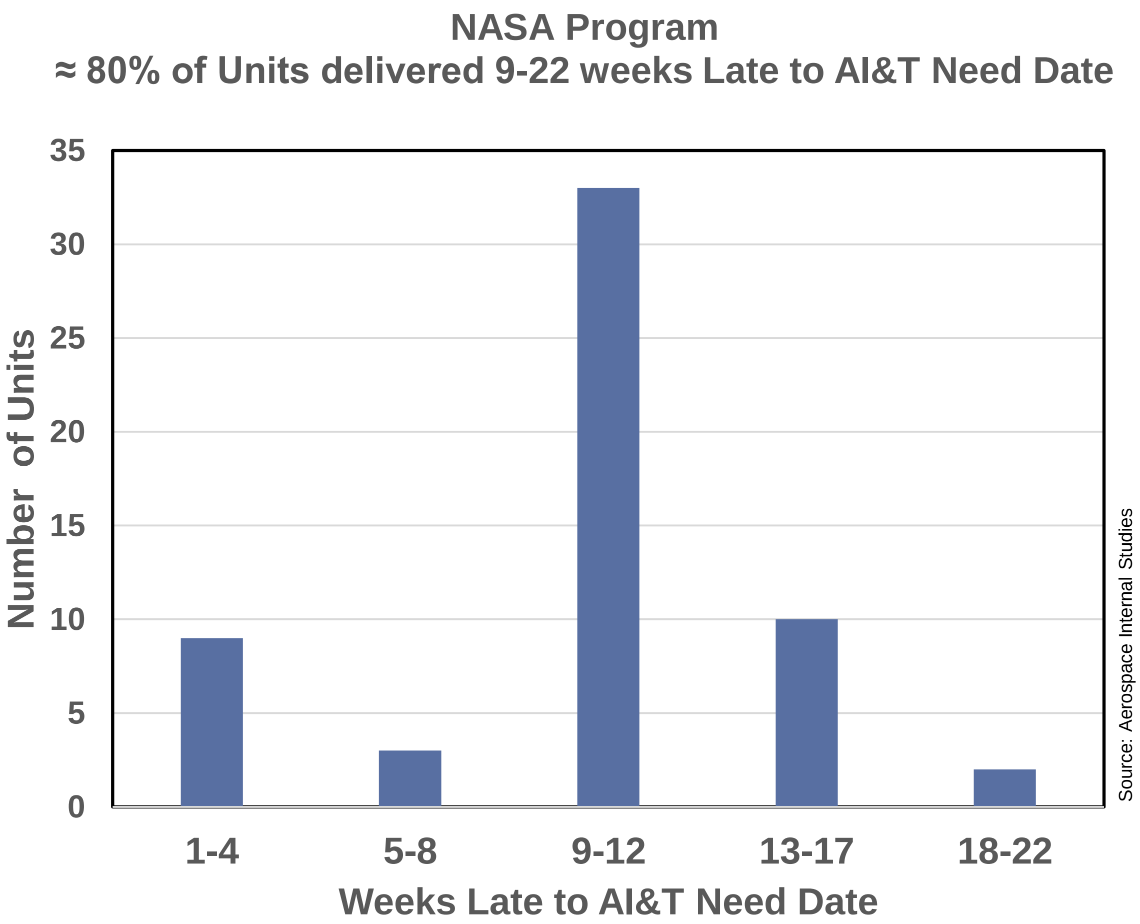
***Example of Design for Accessibility Requirement*:**
"The spacecraft shall be designed such that remove and replace of any unit does not require disassembly of the primary structure, removal of harnesses, or removal of other units."



Notional Space Vehicle
(Access hole depicted is representational not actual)

Poor space vehicle accessibility resulted in 6-month slip in AI&T

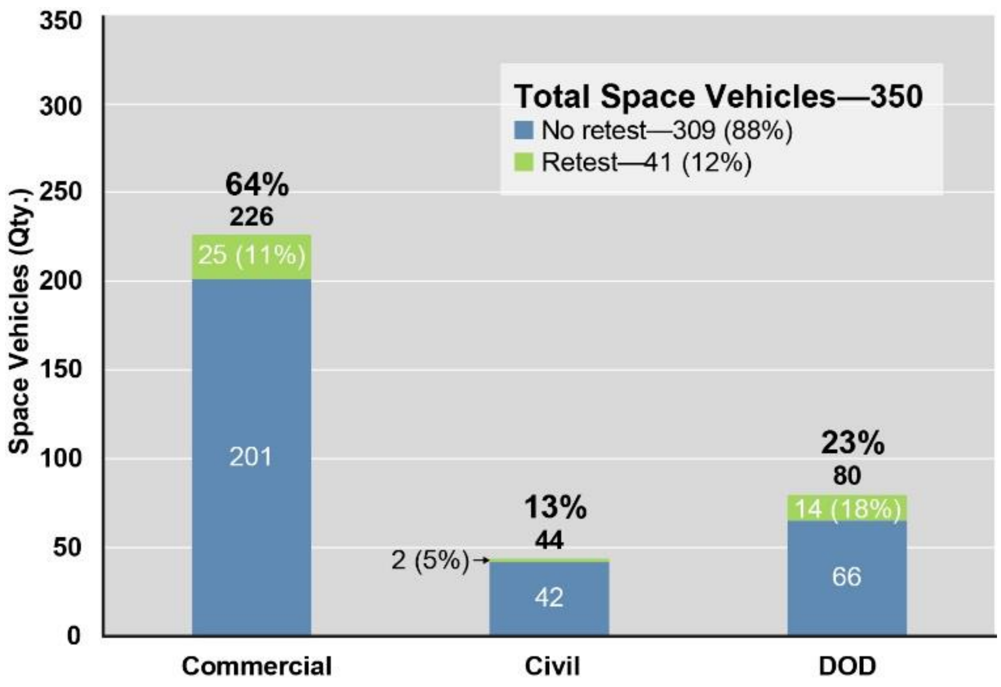
Contributors to Schedule Slips: Late Deliveries



Units delivered late to AI&T cause planned schedules to "go out the window"

Contributors to Schedule Slips: Late Cycle Escapes Detected in AI&T

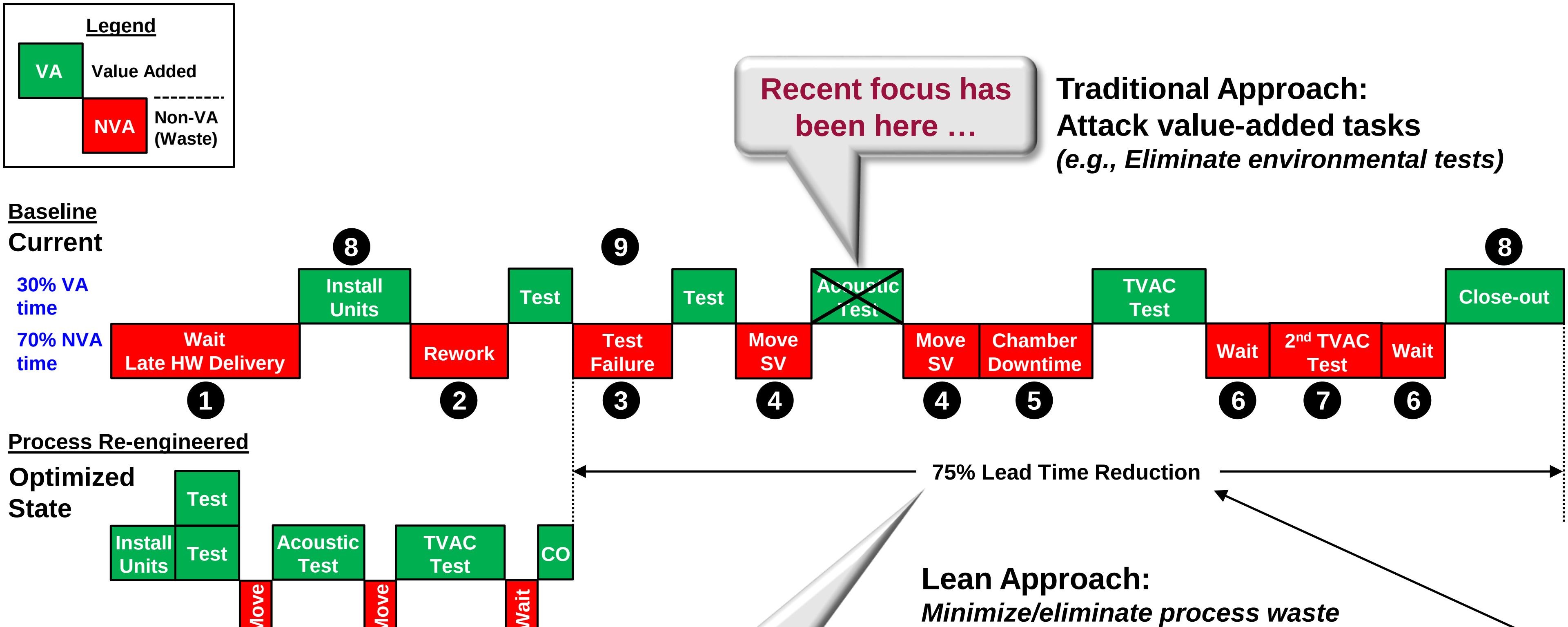
- Study of 350 space vehicles since 2000 showed 12% see thermal vacuum (TVAC) retest



Source: Mission Assurance Implications of Space Vehicle Thermal Vacuum Retest, TOR-2017-01693, 5 June 2017

Eliminating TVAC retests rests on stronger Unit design and screening

Embedded Waste in AI&T



Focus should be here!

Value Stream Analysis

1. Eliminate late hardware deliveries from in-house/external suppliers
2. Eliminate workmanship errors (rework) – fix quality to be repeatable
3. Eliminate design flaws (test failures) – increase test rigor
4. Minimize SV moves – collocate activities outside chamber/work cell
5. Eliminate chamber downtown-time – increase preventive maintenance
6. Minimize wait times
7. Eliminate TVAC retest (2nd TVAC)
8. Reduce installation and close-out steps durations
9. Perform tests in-parallel with other tests (whenever safely possible)

Lean Metrics

- % Reduction in Lead Time
- % VA time vs. NVA time
- Spaghetti Diagram (travel distances)
- Facility Space (square footage)

This is how you Lean …

Baseline – Current
⮤ **Process Improvement – Improved State**
⮤ **Process Re-engineering – Optimized State**
⮤ **Ideal State**

Key Observations and Key Recommendations

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Key Observations

- Six significant issues associated with schedule overruns during assembly, integration and test (AI&T) phase:
  1. *AI&T schedules at critical design review (CDR) are routinely unexecutable – flawed baseline schedule is used to measure later schedule performance*
  2. *Flight hardware design escapes detected in AI&T strongly drive schedule slips*
  3. *Flight hardware workmanship issues detected in AI&T strongly drive schedule slips*
  4. *Late delivery of flight hardware/software/GFE/GSE strongly drives AI&T schedule slips*
  5. *Thermal vacuum retest – 12% of studied vehicles see more than one TVAC test*
  6. *Significant amounts of waste exists (errors in procedures, test set-up/facility, test SW database errors, etc.)*

GFE – Government Furnished Equipment GSE – Ground Support Equipment TVAC – Thermal Vacuum

Key Recommendations

- Require schedules in the RFP response and at CDR account for AI&T inefficiencies to improve realism
- Strengthen design and review processes to minimize escapes into AI&T
  - *Require frequent incremental design reviews in addition to milestone reviews*
- Require “Design for Accessibility” as a key design requirement to reduce delays due to lack of space vehicle accessibility
- Fix design, workmanship, and software problems in manufacturing and in the supply chain (NOT in AI&T) to eliminate late deliveries
- Strengthen unit and lower level test programs to screen-out problems before delivery to AI&T to minimize impact of late cycle escapes
  - *Add board/slice thermal pre-conditioning*
  - *Use highly accelerated life testing (HALT) on new development units*
- Increase focus on the identification and elimination of waste – require value stream mapping and Lean metrics

RFP – Request for Proposal CDR – Critical Design Review

References

1. "*Design Review Improvement Recommendations*," TOR-2015-02545, The Aerospace Corporation, 29 May 2015.
2. "*Assembly, Integration, and Test (AI&T) Efficiency Study*," TOR-2016-01412 (Restricted access), The Aerospace Corporation, 9 January 2017.
3. "*Mission Assurance Implications of Space Vehicle TVAC Retest*," TOR-2017-01693, The Aerospace Corporation, 5 June 2017.

Biographies

Mr. Juranek has more than 32 years of experience working on Air Force, IC, MDA, NASA and commercial space programs. He is currently a Project Leader Sr. in the Corporate Chief Engineer's Office at The Aerospace Corporation. Prior to working at The Aerospace Corporation, Mr. Juranek worked as a Department Manager in Systems Engineering and as a Section Manager of Space Reliability Engineering at Raytheon Space & Airborne Systems. Additionally, he also spent part of his career at Boeing Satellite Systems (formerly Hughes Space and Communications) where he gained experience as both a production manager and an IPT Lead for xenon ion propulsion systems power supply manufacturing and test. During this time he also worked in Product Effectiveness, and spent time working with parent company General Motors/Delco Electronics to assist in bringing the Lean production philosophy to satellite manufacturing. Mr. Juranek started his aerospace career at Hughes Aircraft Radar Systems Group in 1985 working as a manufacturing engineering planner, and was a graduate of the Hughes Manufacturing Technology Rotation Program. Mr. Juranek holds a B.S. in Industrial Technology from Iowa State University, as well as a M.S. in Quality Assurance from California State University, Dominguez Hills.