

NATIONAL RECONNAISSANCE OFFICE

# Cost of Mission Assurance for Space Programs

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SUPRA ET ULTRA



# Outline

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- + Introduction
- + Cost of High-reliability Electronics Parts
- + Cost of Testing



## Some Background

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- 2008 → NRO defines “acquisition complexity” for commercial-like systems, focusing on communication satellites<sup>1</sup>
  
- 2009 → D/NRO requests wider comparison to include all DoD and NRO systems, focus on mission assurance impact
  
- 2010 → Aerospace Corp. “Value of MA” study<sup>2</sup> cites cost of mission assurance as 3-10% of program  
→ Numbers widely circulated among NRO, NASA, and DoD leadership at 2010 Mission Assurance Summit

<sup>1</sup> Alvarado, Wilmer, D. Barkmeyer and E. Burgess. Commercial-Like Acquisitions: Practices and Costs. *Journal of Cost Analysis and Parametrics*, Volume 3, Winter/Spring 2010.

<sup>2</sup> Yarbrough, Allyson. Considerations in Assessing the Value of Space Mission Assurance: A Joint Study. The Aerospace Corporation. 16 July 2010 (limited distribution).



# Goals and Challenges

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## Goals:

- Improve understanding of mission assurance costs within space systems engineering community
- Improve cost estimates

## Challenges:

- Cost data usually inconsistent with accepted definition of Mission Assurance
- MA is not “all-or-nothing” proposition, but no studies on marginal cost of MA
- Results of MA increases/decreases hared to measure



## Definitions for Better Cost Insight

### “Mission Assurance” Costs

- Ensuring that processes are documented, followed, updated
- **Definition endorsed at Mission Assurance Summits**
- Doesn't include cost of parts, testing, etc.

### Parts Costs

- Actual cost of parts required by MA
- Procurement, screening, destructive physical analysis, testing, engineering.
- Not included in “MA Costs” but driven by MA decisions

### Environmental Testing Costs

- Actual cost of test planning, conduct, and documentation at all assembly levels
- Not included in “MA Costs” but driven by MA decisions

We have compiled costs and requirements in each area for 15 govt. and commercial contracts



## Other Mission Assurance Costs

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- + Increased system cost to accommodate larger design margins (power, thermal, pointing)
- + Costs of extra hardware for redundancy
- + Costs of extra software for redundancy
- + Cost of customer oversight
- + Marginal costs of design, production, or testing to comply with standards in other areas

Batteries

Harness

Solar arrays

Mass properties

-- Ordnance

-- Pressure vessels

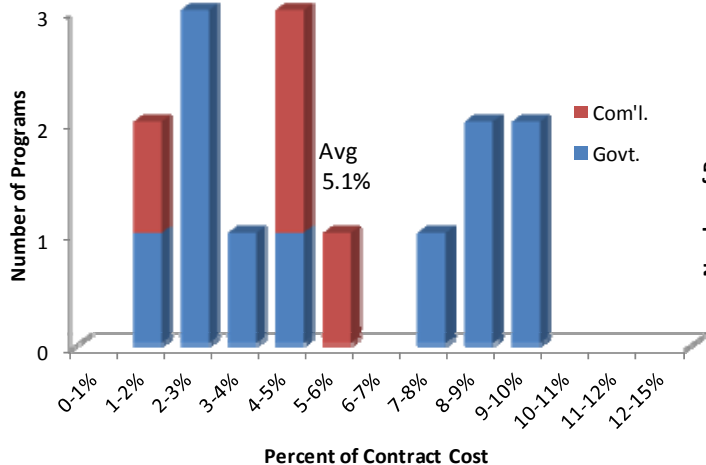
-- Cleanliness

-- EMI/EMC

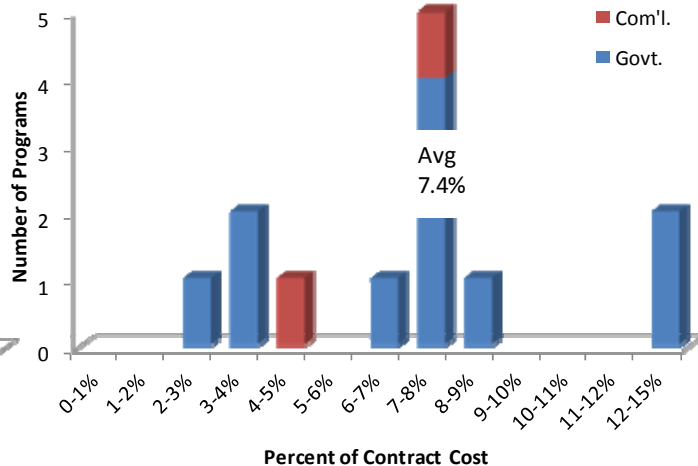


# Costs from 15 Contracts

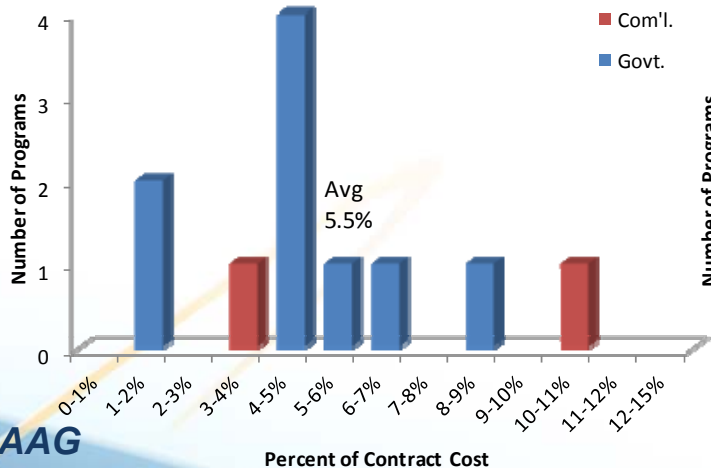
**Mission Assurance Costs**  
15 Contracts



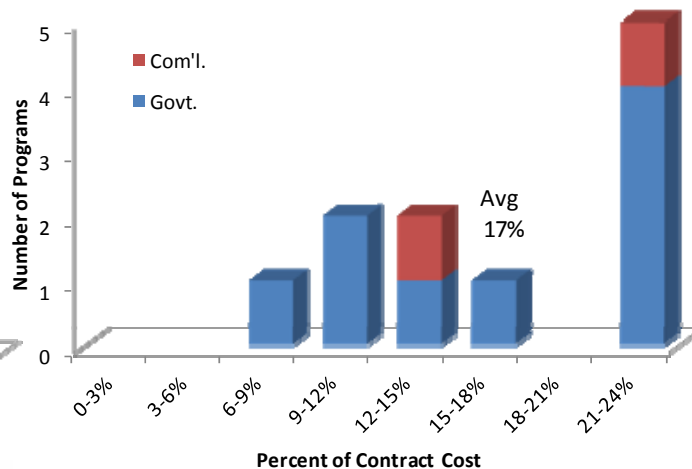
**Hi-Rel Parts Costs**  
13 Contracts



**Environmental Test Costs**  
11 Contracts Not Including Unit-Level Tests.



**Combined: MA+Parts+Testing**  
11 Contracts. Not Including Unit-Level Tests.









## Parts Cost Drivers (2 of 2)

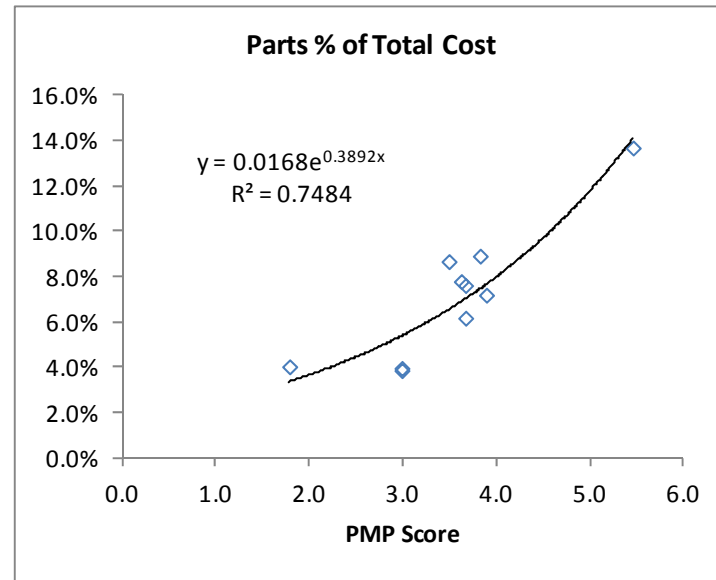
+ Example “PMP data sheet” for NRO baseline (continued):

Parts, Materials and Processes	RATING
<b>4. Destructive Physical Analysis</b> Percentage of part types requiring DPA Number of units per lot undergoing DPA DPA performed on mil-spec parts? Cost threshold beyond which DPA sample size reduced	TBD % 5 <input checked="" type="checkbox"/> none
<b>5. Parts Quality Assurance</b> Percentage of parts requiring upscreening Percentage of parts considered hi-rel Reuse of parts permitted? Time limit beyond which qualification by similarity not permitted Number of PARs & MARs PAR required for parts on Space Quality Baseline?	TBD% TBD% <input checked="" type="checkbox"/> none TBD <input checked="" type="checkbox"/>

+ Relative importance (costliness) of each section suggested by NRO subject matter experts yields a “PMP Score”



## Higher PMP Standards Drive Parts Costs



- + PMP score is a weighted average of PMP data-sheet responses
  - + Weights based on subject-matter expert guidance
  - + Actual costs from completed contracts
- + Many other factors affect parts costs, but relationship to PMP standards is clear



# Application for Estimating

## + *Parts cost model*

- + Use for analogy estimating – change in total program
- + Requires analogy and proposed PMP data sheets

**Cost Impact of Change to PMP Baseline**

Change in program cost	-0.5%	
Relative parts cost	0.88	
Estimated % of total cost	3.8%	3.4%
	Analogy	New
<b>Parts, Materials and Processes Score</b>	<b>2.12</b>	<b>1.8</b>
<b>PMP Control Program Scope (max score 0.5)</b>	<b>0.32</b>	<b>0.31</b>
Documented PMP control program?	1	1
Verify vendors/subs meet PMP requirements?	1	1
Addresses shelf life?	1	1
Addresses reuse?	0	1
Addresses derating?	1	1
Prime flows down derating requirements to vendors/subs?	1	1
Addresses freshness/revalidation process?	don't know	0
Addresses traceability and lot control?	1	1
New technology review board?	0	0
Prime flows down new tech review requirements to vendors/subs?	0	don't know
Corrosion/contamination prevention and control plan?	0	1

Result: Change in total space segment cost

Parts % based on regression of actuals from 10 contracts

Score based on 26 questions from PMP data sheets

Use both sets of data sheets to fill out matrix. "Don't know" responses are not included in score.





# Outline

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 + Cost of Testing



# MIL-STD-1540E: Qualification Tests

Table 6.3-1 Unit Qualification and Protoqualification Test Summary

Test	Reference Paragraph	Suggested Sequence	Electrical and Electronic	Antenna	MMA	Solar Array	Battery	Valve or Propulsion Component	Pressure Vessel or Component	Thruster	Thermal	Optical	Structural Components
Inspection <sup>(1)</sup>	4.6	1, 18	R	R	R	R	R	R	R	R	R	R	R
Specification Performance <sup>(1)</sup>	6.3.2	2, 17	R	R	R	R	R	R	R	R	R	R	ER
Leakage	6.3.3	3, 7, 12	ER	-	R	-	R	R	R	R	R	-	-
Shock	6.3.4	4	R	ER	ER	ER	R <sup>(6)</sup>	ER	ER	ER	ER	ER	ER
Vibration or Acoustic <sup>(2)</sup>	6.3.5	5	R	R	R	R	R	R	R	R	R	R	ER
Acceleration	6.3.6	6	ER	ER	ER	ER	ER	-	ER	-	-	ER	ER
Thermal Cycle	6.3.7	8	R	ER	ER	ER	R	ER	ER	ER	ER	ER	ER <sup>(3)</sup>
Thermal Vacuum <sup>(7)</sup>	6.3.8	9	R	R	R	R	R	R	R	R	R	R	-
Climatic	6.3.9	10	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER
Pressure	6.3.10	11	ER	-	ER	-	R	R	R	ER	ER <sup>(5)</sup>	-	-
EMC <sup>(4)</sup>	6.3.11	13	R	R	ER	ER	ER	ER	ER	ER	ER	ER	ER
Life	6.3.12	14	ER	ER	R	ER	R	R	ER	R	ER	ER	ER
Burst Pressure	6.3.13	15	-	-	ER	-	R	R	R	R	ER	-	-
Static Load	6.3.14	16	ER	ER	ER	ER	R	-	ER	-	-	-	R

R = Required  
ER = Evaluation required



# MIL-STD-1540E: Acceptance Tests

Table 6.3-2 Unit Acceptance Test Summary

Test	Reference Paragraph	Suggested Sequence	Electrical and Electronic	Antenna	MMA	Solar Array	Battery	Valve or Propulsion Component	Pressure Vessel or Component	Thruster	Thermal	Optical	Structural Components
Inspection <sup>(1)</sup>	4.6	1, 15	R	R	R	R	R	R	R	R	R	R	R
Wear-in	6.3.1	2	-	-	R	-	ER	R	-	R	-	-	-
Specification Performance <sup>(1)</sup>	6.3.2	3, 14	R	R	R	R	R	R	R	R	R	R	ER
Leakage	6.3.3	4, 7, 12	ER	ER	R	-	R	R	R	R	- <sup>(4)</sup>	-	-
Shock	6.3.4	5	ER	ER	ER	-	ER	ER	-	ER	-	ER	-
Vibration or Acoustic <sup>(2)</sup>	6.3.5 6.3.6	6	R	R	R	R	R <sup>(6)</sup>	R	ER	R	- <sup>(3)</sup>	R	ER
Thermal Cycle	6.3.8	8	R	ER	ER	ER	ER	ER	-	ER	ER	ER	-
Thermal Vacuum <sup>(7)</sup>	6.3.9	9	R	R	R	R	R <sup>(6)</sup>	R	ER	R	R	R	-
Proof Pressure	6.3.12	10	ER	-	ER	-	R	R	R	ER	- <sup>(4)</sup>	-	-
Proof Load	6.3.11	11	-	ER	ER	-	ER	ER	ER	ER	ER	ER	R <sup>(3)</sup>
EMC <sup>(5)</sup>	6.3.13	13	ER	ER	-	ER	ER	ER	-	-	-	-	-

R = Required  
ER = Evaluation required



# Cost Challenges ...

## + Satellite test programs vary:

- + Company-specific command media (commercial)
- + MIL-STD-1540E (usually tailored)
- + NASA/GSFC-STD-7000
- + Satellite heritage & complexity

Cost is one of many factors in selecting an approach

## + Technical differences may be clear, but cost impact is not

- + Measuring cost of each test not feasible (nor useful for predictive models)
- + Estimators need a metric to quantify testing rigor

Wanted:  
An independent variable

## + Options:

1. Count test types and equipment types
2. Assess rigor with Aerospace Corporation's Environmental Test Thoroughness Test Index (ETTI)<sup>4</sup>
  - + Addresses level of testing on each unit compared to MIL-STD
  - + Advanced ETTI under development now by NRO/SE

<sup>4</sup>Laube, R. B. The Environmental Test Thoroughness Index. Aerospace TOR-0086(6902-06)-2. 15 May 1986



# Counting Test by Equipment Type

Environmental test data sheet filled out for each program:

<b>UNIT-LEVEL QUAL/PROTOQUAL:</b>	Electrical & Electronic	Antenna	Mechanical	Solar Array	Battery	Valve or Prop. Component	Pressure Component	Thruster	Thermal	Optical	Structural Component	# of tests
Inspection												0
Spec. Performance												0
Leakage												0
Shock												0
Vibration												0
Acoustic												0
Acceleration												0
Sine Vibration												0
Thermal Vacuum												0
Thermal Cycle												0
Proof Pressure												0
EMC												0
Life												0
Burst												0
Burn-in												0
Static Load												0
Climatic												0

- One sheet for qualification testing
- One sheet for acceptance testing
- All tests are not equally difficult (costly)
  - ✓ Test-type weighting
- Some equipment is harder to test
  - ✓ Hardware-type weighting





## Weighting Factors Developed by NRO/Systems Engineering

Test	Test Weight	Rational
Leakage	0.3	High fidelity test of a short duration with expensive equipment
Shock	0.3	Test duration is short, yet the instrumentation and post test analysis is time consuming
Vibration	0.3	Test duration is short, yet the instrumentation and post test analysis is time consuming
Acoustic	<b>0.9</b>	Expensive equipment and instrumentation, # of personnel involved, and planning/modeling of test runs
Acceleration	0.3	Test duration is short, yet the instrumentation and post test analysis is time consuming
Sine Vibration	0.3	Test duration is short, yet the instrumentation and post test analysis is time consuming
Thermal Vacuum	<b>0.9</b>	Special test equipment and instrumentation required along with a large amount of time dedicated to this activity
Thermal Cycle	<b>0.9</b>	Special test equipment and instrumentation required along with a large amount of time dedicated to this activity
Proof Pressure	0.3	High fidelity test of a short duration with expensive equipment
Proof Load	0.1	Low technology and quick test to conduct
EMC	0.1	Test is non-time consuming with straight forward analysis
Life	<b>0.9</b>	Performing a series of spec. performance tests at extreme conditions
Burst	0.1	Low technology and quick test to conduct
Burn-in	0.1	Additional durations on thermal cycle test doesn't add much cost
Wear-In	0.1	Ambient test with no electronic functions verified
Static Load	0.1	Straightforward setup, no equipment functions tested
Climatic	<b>0.9</b>	Rarely performed because environments are controlled, but can be extensive



# Weighting Factors on Hardware Type

- + Same type of test costs more for complex equipment types
- + Tests on electronic equipment are more costly
- + Complex equipment has a higher cost .. A good weighting factor

Example: Weighting Factors based On Equipment Cost

Equipment Type	Relative Impact to Testing Costs
Electrical & Electronic	67.6%
Antenna	1.4%
Mechanical	4.7%
Solar Array	1.1%
Battery	0.7%
Valve or Prop. Component	0.6%
Pressure Component	0.0%
Thruster	0.7%
Thermal	0.7%
Optical	19.8%
Structural Component	2.5%

Every program has unique mix of equipment, unique weighting factors



## Example: Acceptance Score

UNIT-LEVEL ACCEPTANCE:	Electrical & Electronic	Antenna	Mechanical	Solar Array	Battery	Valve or Prop. Component	Pressure Component	Thruster	Thermal	Optical	Structural Component	Score by test type
	Inspection	-	-	-	-	-	-	-	-	-	-	-
Spec. Performance	-	-	-	-	-	-	-	-	-	-	-	0.00
Leakage	1.48	-	-	-	0.07	0.04	0.02	0.02	0.04	-	-	1.66
Shock	-	-	-	-	-	-	-	-	-	-	-	0.00
Vibration	1.48	0.53	0.34	-	0.07	0.04	-	0.02	0.04	-	-	2.52
Acoustic	-	1.59	-	-	-	-	-	-	-	-	-	1.59
Sine Vibration	-	0.53	-	-	-	-	-	-	-	-	-	0.53
Thermal Vacuum	4.45	-	1.02	-	-	-	-	0.07	0.11	-	-	5.65
Thermal Cycle	4.45	-	-	-	-	-	-	-	-	-	-	4.45
Wear-in	-	-	-	-	-	-	-	-	-	-	-	0.00
Proof Pressure	-	-	-	-	0.07	0.04	0.02	0.02	-	-	-	0.14
Proof Load	-	-	-	-	-	-	-	-	-	-	0.08	0.08
EMC	-	-	-	-	-	-	-	-	-	-	-	0.00
Burn-in	0.49	-	-	-	-	-	-	0.01	-	-	-	0.50
Score by Equipment Type	12.4	2.6	1.4	0.0	0.2	0.1	0.0	0.1	0.2	0.0	0.1	<b>17.12</b>

Overall score for acceptance program based on required tests



# Assessing the Cost Impact

## + Premise:

- + Parametric cost models account for several factors, but not testing
- + Units subject to more/less testing may tend to be above/below our models

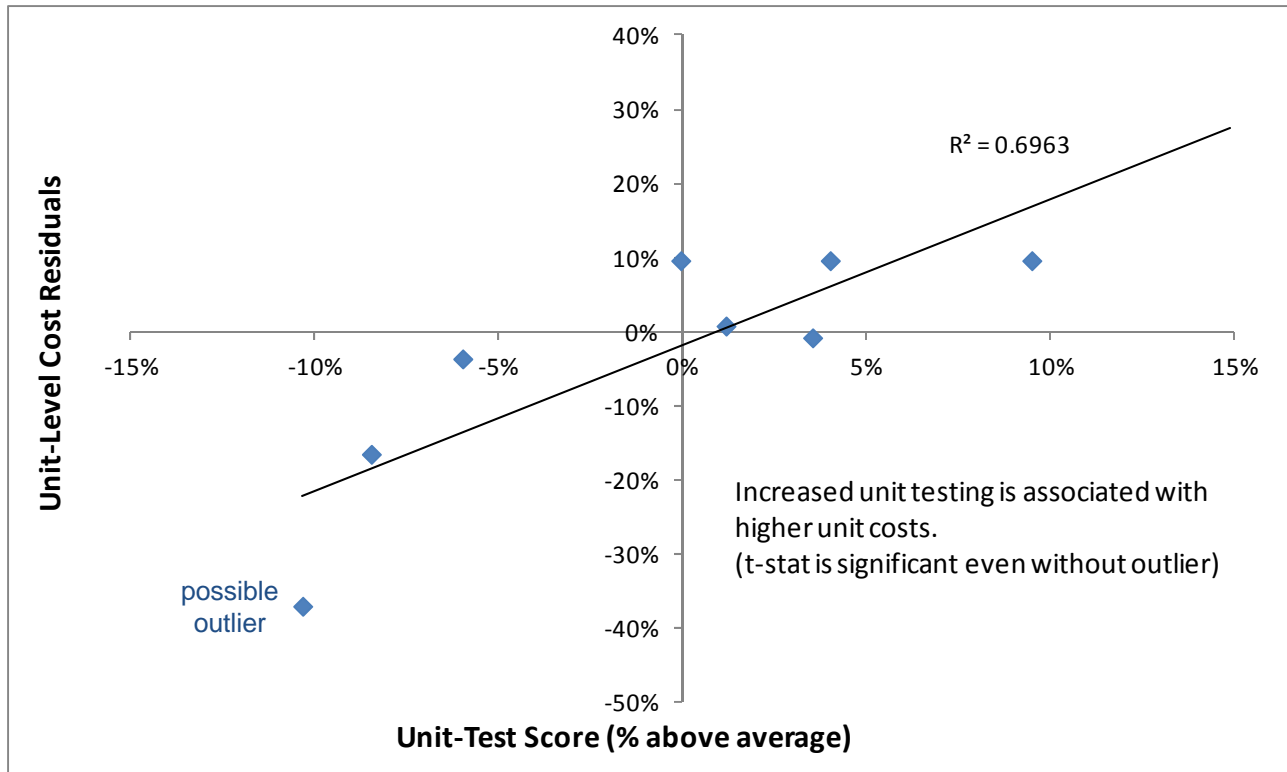
## + Database:

- + Unit-cost residuals from 2288 boxes
- + Percent above/below parametric models tabulated by program

Program	Average Percent Error	Count
A	-4%	< 100
B	-17%	>100
C	10%	< 100
D	1%	< 100
E	10%	>100
F	-1%	< 100
G	15%	>100
H	1%	>100
I	-1%	>100
All Data	0%	2288



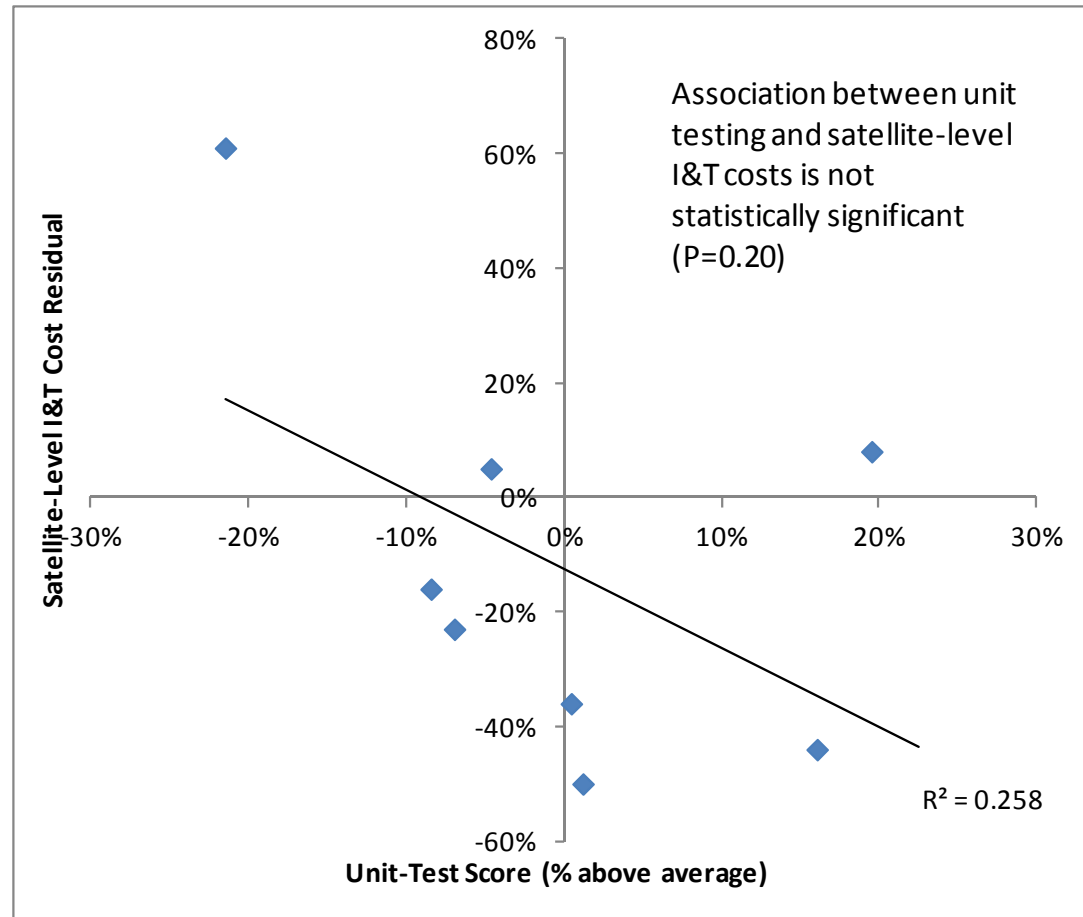
# Acceptance Test Score vs. Unit Cost Residual



Higher test score is associated with higher unit costs



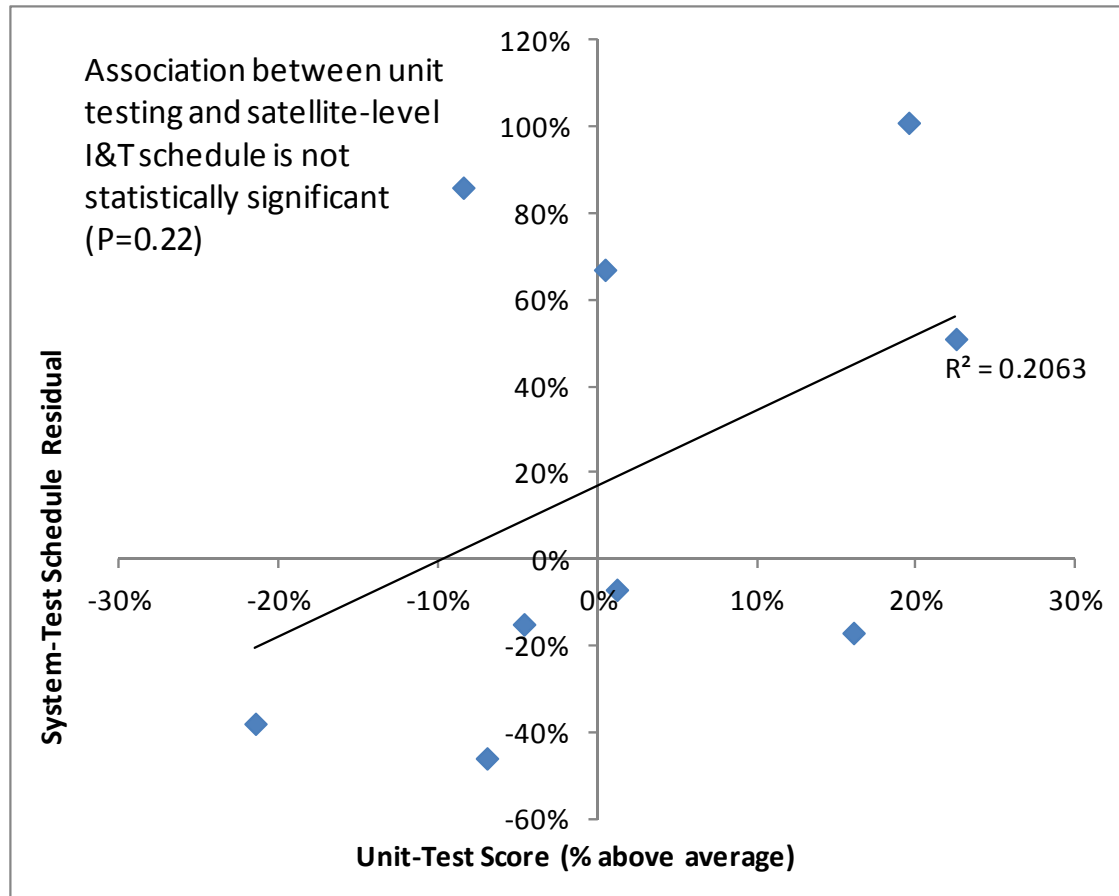
# Unit Testing vs. Satellite-Level I&T Cost



Assertion that more unit-level testing reduces satellite I&T cost cannot be confirmed with this method



# Unit Testing and Satellite Level I&T Schedule<sup>5</sup>



Assertion that more unit-level testing reduces satellite I&T schedule cannot be confirmed with this method

<sup>5</sup>Satellite-test schedule model from Burgess, E. Predicting System Test Schedules. Presented to Space System Cost Analysis Group, Santa Barbara, CA, July 2005.



# Cost Impact of Testing: Next Steps

- ✦ Replace simplistic counting method with Advanced ETTI
  - ✦ Current and historical programs being evaluated now by NRO/SE
  - ✦ More detailed
    - ✦ Every test on every box evaluated
    - ✦ Durations, temperatures, cycles, etc. compared to MIL-STD-1540E

Example: Unit Thermal Criteria		Mil Std 1540 E Compliant		
Parameter Evaluated for each unit	Weight	Qual	PQ	Acceptance
Thermal Cycles (deg C)	25	23 TC +4 TV (27 if no TV)	23 TC +4 TV (27 if no TV)	10 TC +4 TV (14 if no TV)
Temp Range or max environment $\pm$ margin	25	105C Range or $\pm$ 10 deg margin	95C Range or $\pm$ 5deg margin	85C Range
Thermal Vac for Vacuum sensitive electronic units	25	Min of 4 TV Cycles	Min of 4 TV Cycles	Min of 4 TV Cycles
Burn In	2	200 Hrs	200 Hrs	200 Hrs
... and so on (16 parameters evaluated for unit thermal)				

### Test Domain Weights

Test Level/ Domain	Thermal	Dynamic	EMI/EMC	Other
Unit	71	29	0	0
Vehicle	70	10	14	6

Unit and vehicle domains evaluated. Weights based on prior studies.





## Summary

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- + Mission assurance practices can affect costs in many areas
  
- + Cost models are developed in two key areas
  - + Hi-rel parts
  - + Environmental testing
  
- + Useful to assess cost impact of proposed changes
  - + Independent of contractor proposals



## Contact Information

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# Acronyms and Abbreviations

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- + ABPMPL As-Built Parts, Materials, and Processes List
- + CAAG Cost and Acquisition Analysis Group
- + D/NRO Director, NRO
- + DoD Department of Defense
- + ELDRS Enhanced Low Dose Radiation Susceptibility
- + EMC Electromagnetic Compatibility
- + ETTI Environmental Test Thoroughness Index
- + I&T Integration and Test
- + MA Mission Assurance
- + MAR Material Approval Request
- + MMA Moving Mechanical Assembly
- + NASA National Aeronautics and Space Administration
- + NRO National Reconnaissance Office
- + NRO/SE NRO Systems Engineering Directorate
- + PAR Part Approval Request
- + PMP Parts, Materials, and Processes
- + PMPCB PMP Control Board