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Update to NRO CAAG Space System Test Schedule Estimating Model

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Objective

- NRO CAAG system test schedule model was last updated in 2007
  - Based on NRO and Air Force programs
  - Few programs with ATP after 2000
- Update nearly doubles size of dataset
  - Includes government civil programs
  - Includes more modern programs

Space System Test Scope

- From beginning of system test…
  - Point in time when electrical power is applied to an integrated satellite consisting of bus and payload components.
  - Exceptions are made for certain appendages such as antennas and solar arrays, and for secondary payloads.
- …To launch availability
  - Actual launch date less storage time that occurred during or after system test
- Consistent with Aerospace Corporation studies
  - Tosney & Quintero, 1995
  - Arnheim, 2004

Updating the 2007 System Test Schedule Model

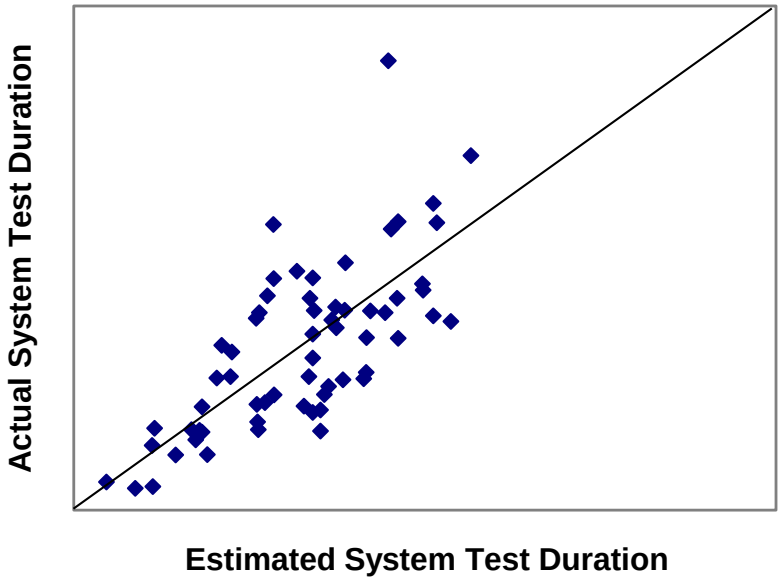
2007 System Test Schedule Model

Time from System Test Start to First Launch Availability (months)

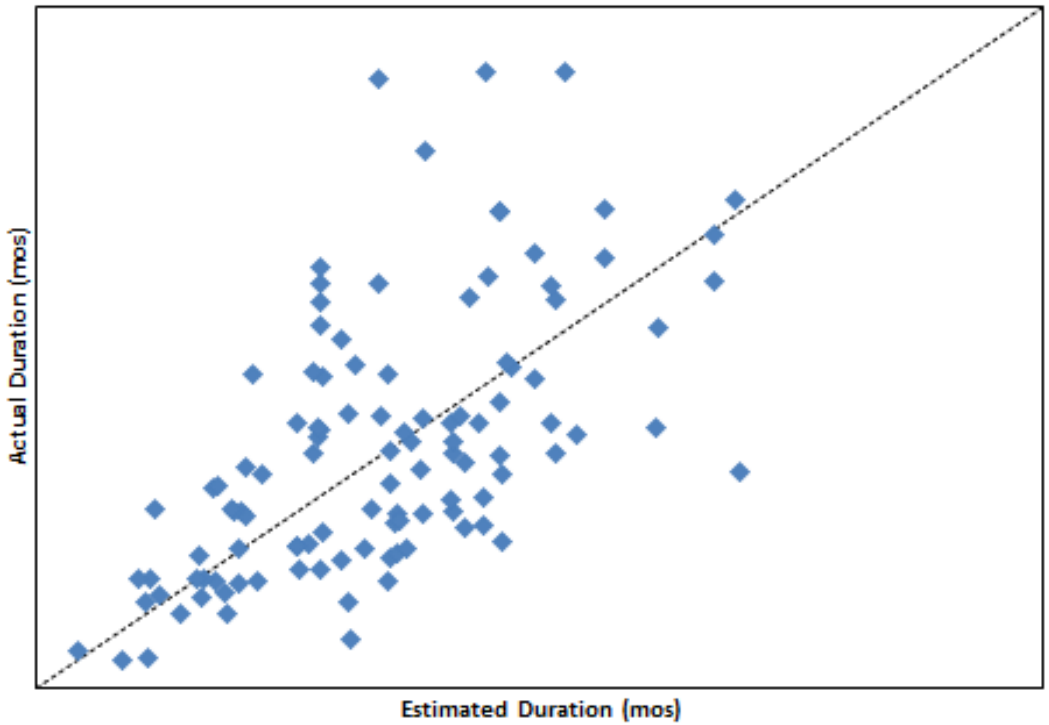
$$= -5.5 + 0.44\,[\text{Dry Weight (lbs)}]^{.24}\,[\text{Design Life (mos)}]^{.427}\,(0.75^{[\text{COMM}]}) + 7.8\,[\#\text{ mission types}]$$

COMM – Satellite primary mission is communications
Mission Types – count of the number of categories of payload from this list: Communications, Signals Intelligence, Optical, Active Sensing, Other Scientific

- Previous model was developed in 2007
  - Based on 61 NRO and AF programs
  - No civil programs
  - SPE: 37%
  - R^2: 0.52
- Update adds 49 new datapoints
  - 28 NRO and AF
  - 21 government civil
  - 21 awarded since year 2000



Performance of 2007 SER Against New Dataset



DOF	104
SPE	49%
R^2	0.35
Bias	7%

- 2007 Model performance degrades when considering new data
- Tends to underestimate longer programs
- Non-military programs appear in family with military/intelligence programs

Potential Schedule Drivers

Candidate Continuous Drivers	Population %
Design Life	100%
Dry Wt.	100%
BOL Power	84%
Number of Types of Missions (1-5)	100%
Number of Distinct Mission Payloads	99%
Wet Mass	19%
Max Data Rate	20%
On Board Data Storage Capacity	2%
Number of Band Regimes	23%
1/Pointing Accuracy	46%
Total Battery Capacity	10%
Bus Nominal Voltage	5%
Prop Wt	54%
Solar Array Area	14%
RCS No. of Thrusters	17%
RCS Isp	6%
Total Thrust	6%
Instrument Weight	77%
Instrument Mass Fraction	74%
No. of Distinct Instrument Types	75%
Bus New Design Factor	16%
Instruments New Design Factor	16%
No. Customers	76%
No. Organizations	71%

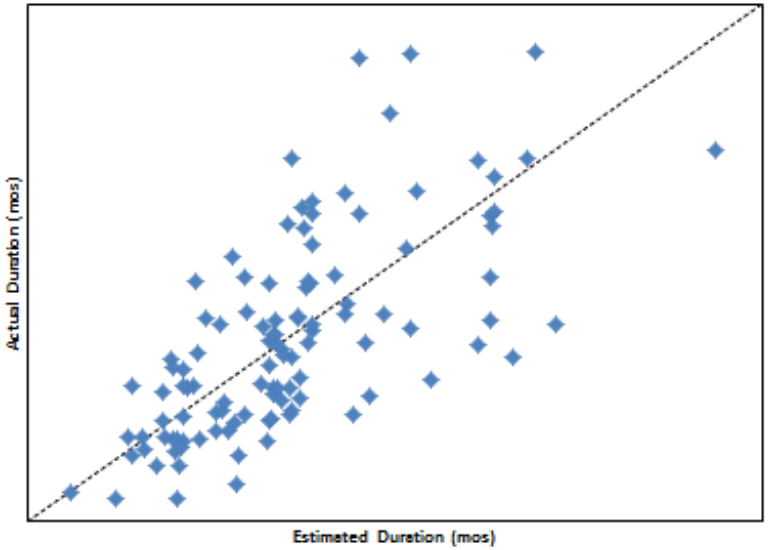
Candidate Binary Drivers	Population %
Joint or Foreign-Led Spacecraft	99%
Demo	100%
Block Change/New Program	100%
Incumbent Contractor	100%
New program	100%
Option on Prior Contract	99%
Remote Sensor	99%
Optical Payload	100%
Storage Period	100%
COMSAT	100%
GFE PL	78%
Class A/B or Class-C/D	93%
Qual Unit	35%
LEO Orbit	100%
HEO/MEO Orbit	100%
GEO Orbit	100%
Interplanetary	100%
Complex Deployment	15%
High Gain Antenna	1%
Active Thermal Control	74%
Cryogenic Control	74%
3-Axis Stabilization	69%
Ni-H or Li Battery	16%
Deployed Solar Array	83%
Traditional RCS	18%

- 49 potential drivers collected
  - Data collection focused on populating strong drivers
  - Expected weaker drivers have missing data
- Developed candidate SERs with fully-populated drivers
- Employed regression imputation with some restrictions
  - Fully-populated (green) drivers must account for 75% or more of the score (total variation possible in estimates)
  - Very sparse (red) drivers do not contribute to the score
  - Consistent with best results of CAAG tests of imputation methods
- Drivers with missing data that appeared strong
  - Pointing Accuracy
  - GFE Payload
  - Payload Mass Fraction

- Final result – relationship driven by only fully-populated drivers!
- Led back to traditional analysis with the chosen combination

Updated System Test SER – Recommended Model

$$[\text{Duration (mos)}] = 1.80 * [\text{Design Life (mos)}]^{0.19} * [\text{Dry Weight (lbs)}]^{0.16} * 1.34^{[\text{Mission Types}]} * 1.40^{[\text{Storage Period}]} * 0.89^{[\text{Comsat}]}$$



DOF	104
SPE	40%
R^2	0.46
Bias	0%

- Solved using LOLS
- Civil data appears in-family
- Similar drivers to 2007 model
  - New driver, whether vehicle had a storage period, is strong
  - Storage could be responsible for longer schedules in multiple ways

Could Storage *Really* Extend Test Schedule by 40%?

- Test schedule data does not include time in storage, but includes test time before and after storage period
- Storage generally happens for one of two reasons

Reasons	Consequences
• Planned (e.g. ground sparing, launch-on-need) • Unplanned (e.g. late payload delivery, LV failure investigation)	• Re-work • Re-test • Additional prep time • Slower pace of test operations • Interruption of test facility flow • As much as ~1 year of additional time in test

Significant re-test effort can be required post-storage

Aerospace Findings*

- Disturbing the Vehicle While in Storage is a Major Source of Failures/Anomalies
- Low Humidity (RH<50%) Inhibits Degrading Processes, But ESD Control Precaution Must Be Taken
- Nitrogen Purge Inhibits Degrading Processes
- Removal of Batteries, Reaction Wheels, Gyros is Application Dependent
  - Benefit of Controlling their Environment Independent of Vehicle Needs to Be Balanced Against the Need to Not Disturb the Vehicle
- Thermal Vacuum Testing Has Proven to Be Most Perceptive Post-Storage Test
  - Benefits Need to Be Weighted Against the Risks Associated With Disturbing the Vehicle
  - Thermal Cycling (at Ambient Pressure) May Be Adequate in Many Cases
- Storage Periods Greater Than 3 Years Leaves Significant Likelihood of Remaining Failures Upon Recall From Storage

*Sources:
Elias, J.D., “General Satellite Storage and Post-Storage Testing Requirements”, ATM 90(5436-03)-1, The Aerospace Corporation, 18 April 1990
Laube, R.B., “Testing of Satellites After Storage, ATM-87(2902-06)-1, The Aerospace Corporation, 20 November 1986.
Hamburg, O., “Satellite Storage Test Requirements”, Aerospace ATM 91(6904-40)-1, 17 December 1990
GE Astro-Space Division, “Defense Satellite Communication Systems Phase 3 Program – Final Report on the Effects of Extended Storage”, CDRL No. 043A17, 1988.
Slaughter, R.G., “DSCS III TWTA Storage Concerns B8/B9 (and other) Satellites IRR Team Review” (briefing), The Aerospace Corporation, August 1988.

Storage Related Risk

- Failures Caused By Vehicle Handling
  - For >3 Years- More Vehicle Handling Likely Due to Uncovering of Part Issues
  - Include Electrical Breaks Within Assemblies and Interfaces, TWTA Degradation (If Direct Handling)
- Poor Storage Environment Conditions Caused By High Relative Humidity Levels
  - Degradation of Electronic Piece Parts, Pyrotechnic Devices- Caused By High Level of Relative Humidity
  - Capacity Loss of NiH Batteries- If Not Kept in Cold Storage
- Failures Most Likely Be Exposed By Thermal Cycling/Vacuum
  - Thermal Testing More Perceptive Than Ambient Test
  - Per Aerospace Study- Lack of SV Thermal Testing For Storage > 3 Years Leaves High Risk of Undetected Failures
- Planned storage periods for many vehicles can greatly exceed 3 years
  - Requires re-test due to duration alone

Sources:
Elias, J.D., “General Satellite Storage and Post-Storage Testing Requirements”, ATM 90(5436-03)-1, The Aerospace Corporation, 18 April 1990
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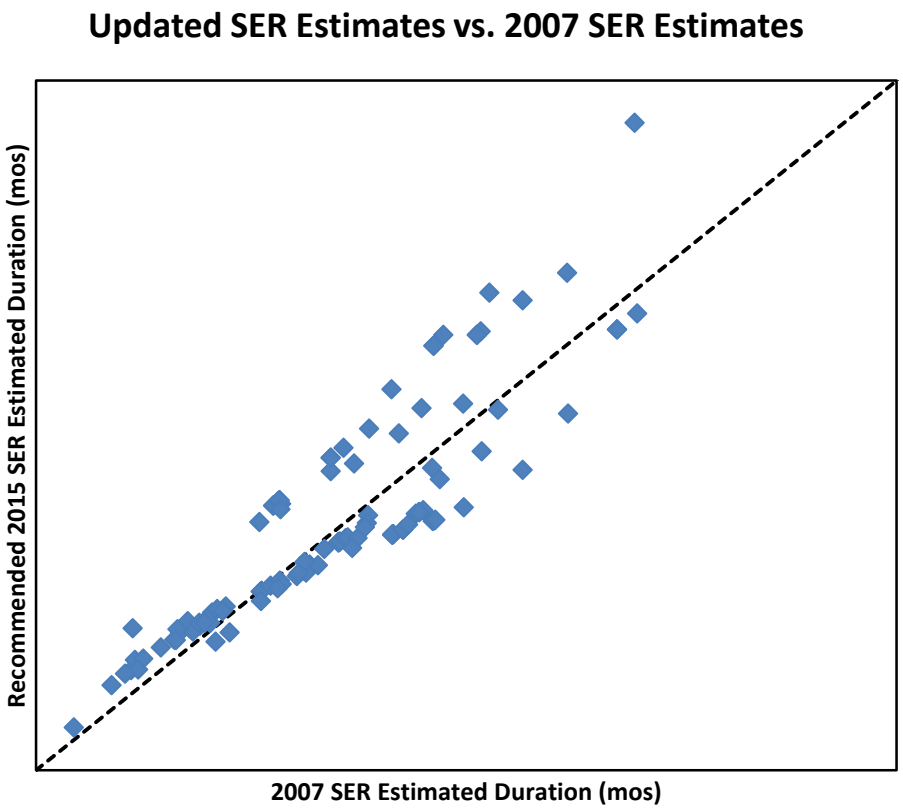
Recommended SER vs. 2007 SER



- Estimates for some programs may change by up to ~10 months, but not consistently shorter or longer than previous estimates
- New programs are estimated consistently between the two models

Summary

- Recommended SER for System Test Schedule:

$$\textbf{[Duration (mos)]} = 1.80 * \textbf{[Design Life (mos)]}^{0.19} * \textbf{[Dry Weight (lbs)]}^{0.16} * 1.34^{\textbf{[Mission Types]}} * 1.40^{\textbf{[Storage Period]}} * 0.89^{\textbf{[Comsat]}}$$

COMM – Satellite primary mission is communications
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- Recommended SER improves upon 2007 SER by incorporating 49 new datapoints
  - 61 → 110 programs
  - Includes non-military/intelligence programs for the first time
- Recommended SER produces estimates in line with 2007 SER
- More data collection could lead to further improvements

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