MCR an spa company

Applying System Readiness Levels to Cost Estimates – A Case Study

May 17 - 19, 2022

Patrick Malone

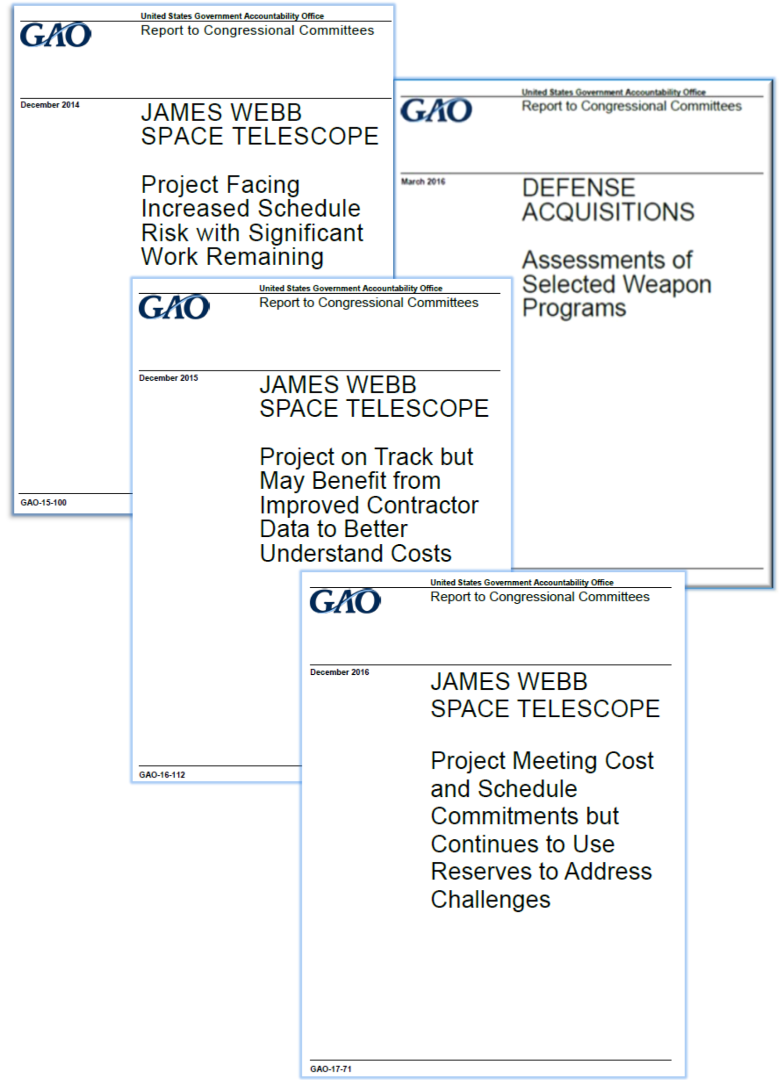
Professional Development & Training Workshop
May 17-19, 2022 ICEAA Pittsburgh, PA

Originally presented at the IEEE Aerospace Conference March 2018

IEEE AEROSPACE CONFERENCE
YELLOWSTONE CONFERENCE CENTER, BIG SKY, MONTANA.
MAR 3 – MAR 10, 2018

Topics

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- Cost and Time to Mature
- Integrated Framework
- Application Example
- Conclusions and Future Study


GAO
United States Government Accountability Office
Report to Congressional Committees
December 2014
JAMES WEBB SPACE TELESCOPE
Project Facing Increased Schedule Risk with Significant Work Remaining
GAO-15-100

GAO
United States Government Accountability Office
Report to Congressional Committees
March 2016
DEFENSE ACQUISITIONS
Assessments of Selected Weapon Programs

GAO
United States Government Accountability Office
Report to Congressional Committees
December 2015
JAMES WEBB SPACE TELESCOPE
Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs
GAO-16-112

GAO
United States Government Accountability Office
Report to Congressional Committees
December 2016
JAMES WEBB SPACE TELESCOPE
Project Meeting Cost and Schedule Commitments but Continues to Use Reserves to Address Challenges
GAO-17-71

Agenda

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- Cost and Time to Mature
- Integrated Framework
- Application Example
- Conclusions and Future Study

Applying System Readiness Levels to Cost Estimates - A Case Study

Patrick K. Malone
MCR, LLC
550 Continental Suite 185
El Segundo, CA 90245
310-640-0005
pmalone@mcri.com

Abstract— Accurately estimating cost, schedules and expected technical performance of large complex systems and systems of systems (SoS) pre-development is difficult. As programs mature and begin execution, they often plague of cost growth and schedule delays due to unexpected deviations from initial assumptions or complexity. For example, Government Accountability Office's (GAOs) 2016 review of selected weapons systems found that twelve of the 43 programs in the report had cost growth from 4% to 45% as well as schedule delays averaging thirty months. Similarly, the James Webb Space Telescope (JWST) has had multiple over runs from inception.[1,2] As the program continued cost growth and schedule delays due in part to technical maturity and complexity were apparent resulting in a 2011 re-baseline. The launch, now planned for 2018, has jeopardized the science community's ability to collect timely and relevant deep space scientific data requiring the Hubble Space Telescope (HST) to perform significantly beyond its already extended design life. Using System Readiness Levels (SRLs), an emerging technique, in concert with heuristic cost and schedule analysis may provide enhanced capabilities for pre-development cost estimates and schedule completions within the acquisition lifecycle. Up to now, theoretical and analytical approaches are in the literature. This paper investigates actual program cost and schedule history through program development, then comparing it to SRL forecasting techniques to demonstrate its validity. The resulting approach will support future estimating accuracy through higher fidelity information for early decision-making. We research and collect actual program development cost, schedule and technical history for Major Defense Acquisition Programs (MDAPS) and NASA flagship programs; then compare the actual growth metrics to the SRL forecasts. This empirical cross-referencing applied to the SRL framework can support more realistic cost and schedule forecasting early in program development. Evaluation of the data to support a null hypothesis demonstrating a statistically significant approach can provide significant cost and schedule estimating process improvement; with a goal of implementing a validated process early into forecast models. The method can isolate specific areas for Technology Maturity and Risk Reduction (TMRR) focus and actions for specific sub-systems within the system or SoS pre-milestone B for DoD and Phase B for NASA. Moreover, cost and schedule realism, and credibility at the start of "Program of Record" with high confidence realized. The data analyses will provide demonstrated confidence using these methods. A follow up example to demonstrate the method will be shown. Future research will include the addition of more program data points to enhance the robustness of the method, and model enhancements to define cost and schedule drivers within the systems and SoSs.

TABLE OF CONTENTS

1. INTRODUCTION

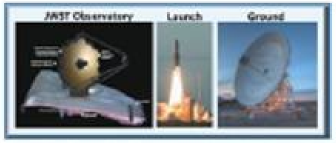


Figure 1 - Complex Systems such as JWST can incur significant cost growth and schedule delays if System Readiness Level is lower than forecast.

Accurately estimating cost, schedules and expected technical performance of large complex systems and systems of systems (SoS) pre-development is difficult. As programs mature and begin execution, they have cost growth schedule delays and requirements changes due to unexpected deviations from initial assumptions or complexity. Many Government organizations recognize this and plan for incremental development to mature these complex systems. Unfortunately, this adversely affects programs due to other factors such as funding and reprogramming. For example, in 2003, the Air Force originally planned to field the enhanced F-22A capabilities in three development increments for completion in 2010.

978-1-5386-2014-4/18/$31.00 ©2018 IEEE 1

Introduction

- GAO 2016 review of Selected Defense Systems reveals
  - **53%** of programs had cost growth, median of **42% growth***
  - Schedule delays averaged **30 months** (2.5 yrs) or more to IOC
  - Lack of knowledge at Milestone B impacts program performance
- NASA Single-Project Program Addressed
  - 10 fold cost growth, 15 year delay
- Acquisition requirements
  - DoD
    - Should Cost and Affordability Goals required at Milestone A
    - Knowledge Assessment throughout the lifecycle
  - NASA
    - Requirements defined
    - Knowledge Assessment similar to DoD guidelines
- **Problem**
  - Developing an objective assessment
  - Over confidence in maturity assessment
  - Optimistic estimates of cost and time to mature before Milestone B
  - Lack of a repeatable process

*** 7 of the top 10 programs reviewed for the 2016 report**

Top 10 DoD Programs Reviewed

Item	Program	Years since first full estimate	Total acquisition cost (FY 2016, $B)	Total acquisition cost growth since initial estimates	Growth Percent
1	F-35 Joint Strike Fighter	14	$ 340	$ 111	33%
2	DDG 51 Arleigh Burke Class Guided Missile Destroyer	33	$ 115	$ 99	86%
3	SSN 774 Virginia Class Submarine	21	$ 91	$ 26	29%
4	V-22 Osprey Joint Services Advanced Vertical Lift Aircraft	33	$ 62	$ 19	31%
5	Evolved Expendable Launch Vehicle	19	$ 61	$ 42	69%
6	Trident II Missile	38	$ 58	$ 2	3%
7	KC-46 Tanker Modernization Program	4.9	$ 44	$ (4)	-9%
8	Gerald R. Ford Class Nuclear Aircraft Carrier	11.7	$ 36	$ (2)	-6%
9	P-8A Poseidon Multi-Mission Maritime Aircraft	15.8	$ 33	$ 0	0%
10	UH-60M Black Hawk Helicopter	14.7	$ 26	$ 12	46%

Source: GAO-16-0329SP – Assessments of Major Weapons Programs

Many MDAPs continue to experience cost and schedule growth

Background

- Programs begin with limited information
  - Technical maturity may be lacking
  - Cost and schedules are often optimistic
- Less detailed knowledge leads to
  - Unexpected capability gaps
  - Cost and schedule growth
  - Nunn-McCurdy breaches

Source: U.S. Air Force

GPS III

Procurement Cost Growth	14.3%
Program Unit Cost Growth	16.3%

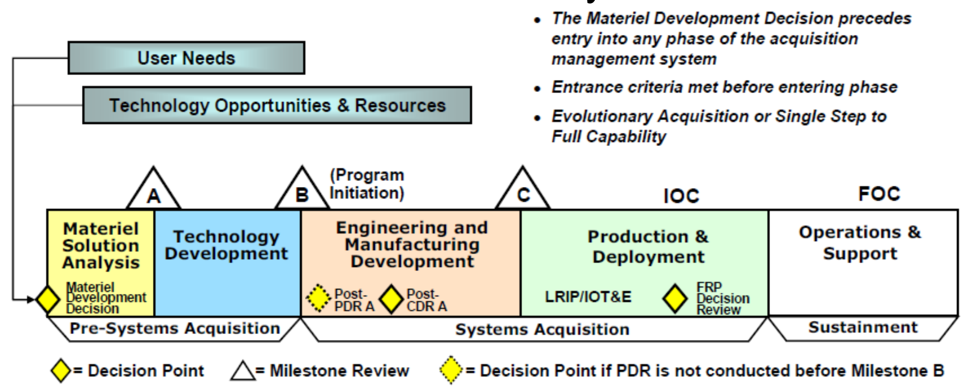
	Significant Breach	Critical Breach
Current Baseline Estimate	≥ 15%	≥ 25%
Original Baseline Estimate	≥ 30%	≥ 50%
Source: 10 U.S.C. § 2433.		

Growth in Procurement Acquisition Cost or Procurement Unit Cost Thresholds require a report to congress

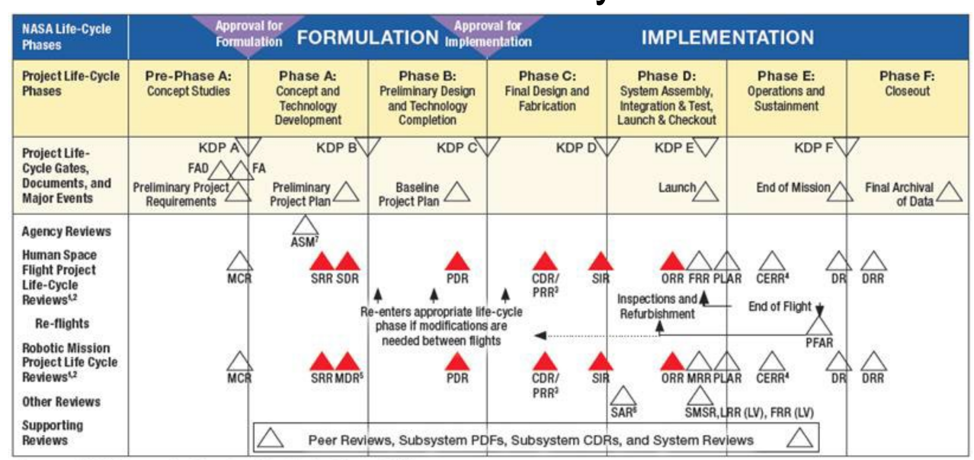
Agenda

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- Cost and Time to Mature
- Integrated Framework
- Application Example
- Conclusions and Future Study

DoD 5000 Lifecycle

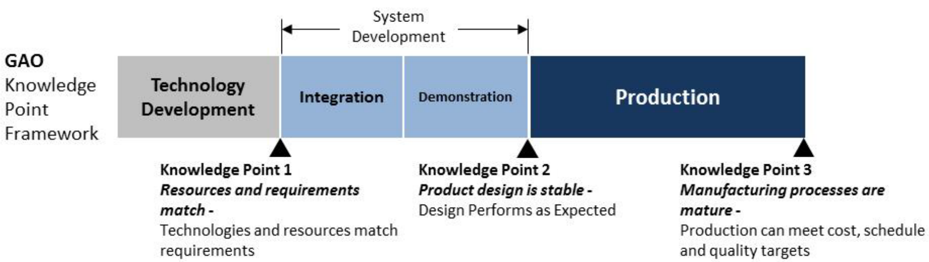


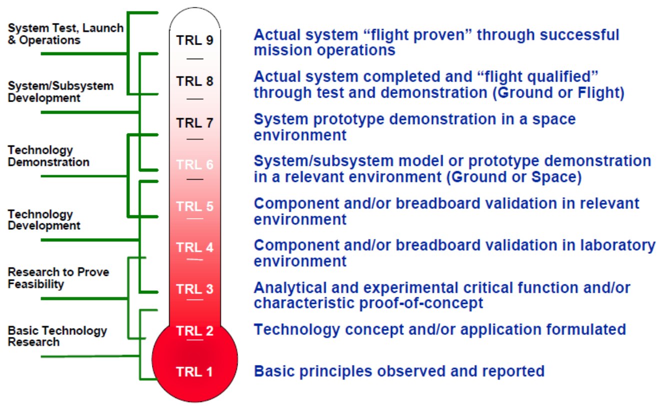
NASA Lifecycle



Source: NASA System Engineering Handbook, Figure 3.0-1

Tools and Techniques





SRL = IRL X TRL

$$\begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} IRL_{11} & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_{22} & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_{33} \end{pmatrix} \times \begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix}$$

$$\text{Composite SRL} = 1/n(SRL_1/n + SRL_2/n + SRL_3/n)$$

- GAO Knowledge point Framework reduces risk
- Technology Readiness Levels serve as a guide
- System Readiness Levels
  - TRL & Integrations add fidelity
- Metrics to Support
  - Cost
  - Schedule
  - Technical Performance

Knowledge Points and SRLs support robust cost and schedule forecasting

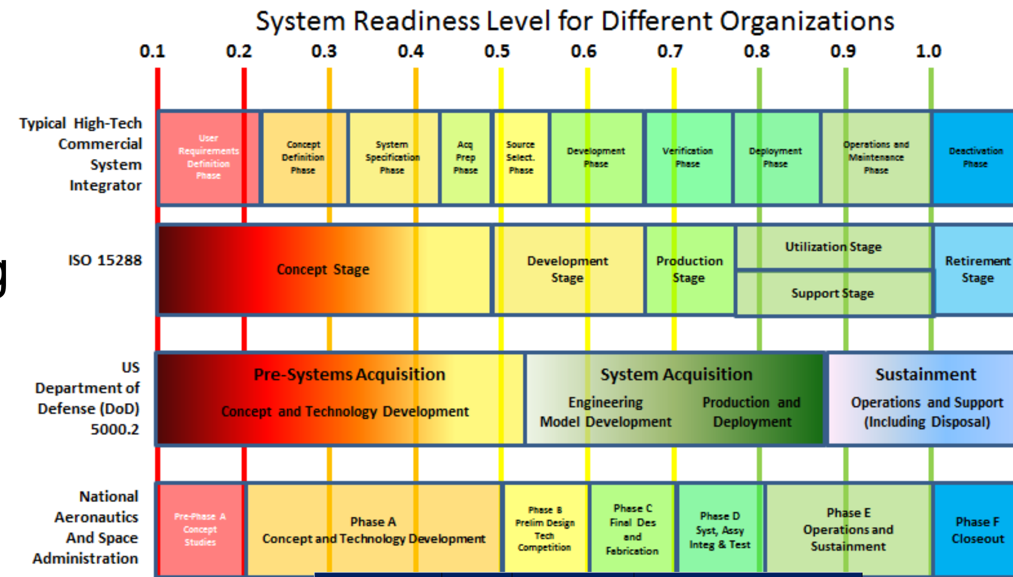
Tools and Techniques (cont.)

- Cross Referencing tools and techniques by program lifecycle guides analysis
  - Program Formulation
  - Development
  - Flight
  - Operations
- Lack of knowledge can impact performance metrics

TRL/ IRL	TRL/IRL Normalized to SRL	SRL	GAO Knowledge Point	Acquisition Milestones
	0.9	0.1		
1	1			Material Decision
2	2			**Milestone A Alternatives**
	3			SRR
	3.5	0.39		
3	3.6	0.4		
4	4			SFR
	5			**PDR Milestone B**
	5.3	0.59	**KP 1**	
5	5.4	0.6		
6	6			CDR
	7			TRR
	7.1	0.79	**KP 2**	**Milestone C**
7	7.2	0.8		
	8	0.89	**KP 3**	IOC
8	8.1	0.9		
9	9	1		FOC

Agenda

- Introduction
- Tools and Techniques
- **Implementing and Forecasting SRLs**
- Cost and Time to Mature
- Integrated Framework
- Application Example
- Conclusions and Future Study



TRL Normalized	SRL	Acquisition Phase	Definitions
0.9	3.5	0.10 - 0.39	Concept Development	Refine initial concept; develop system/technology strategy.
3.6	5.3	0.40 - 0.59	Technology Development	Reduce technology risks and determine appropriate set of technologies to integrate into a full system.
5.4	7.1	0.60 - 0.79	Engineering Model Development (formerly SDD)	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
7.2	8.0	0.80 - 0.89	Production	Achieve operational capability that satisfies mission needs.
8.1	9.0	0.90 - 1.00	Operations and Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total lifecycle.

System Readiness Levels - Method

- SRL: f(TRL, IRL)

SRL = IRL X TRL

$$\begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} IRL_{11} & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_{22} & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_{33} \end{pmatrix} X \begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix}$$

$$\text{Composite SRL} = 1/n(SRL_1/n + SRL_2/n + SRL_3/n)$$

$$= 1/n^2(SRL_1 + SRL_2 + SRL_3)$$

SRL approach highlights strengths and weaknesses in trade space

SRL –TRL and IRL Definitions

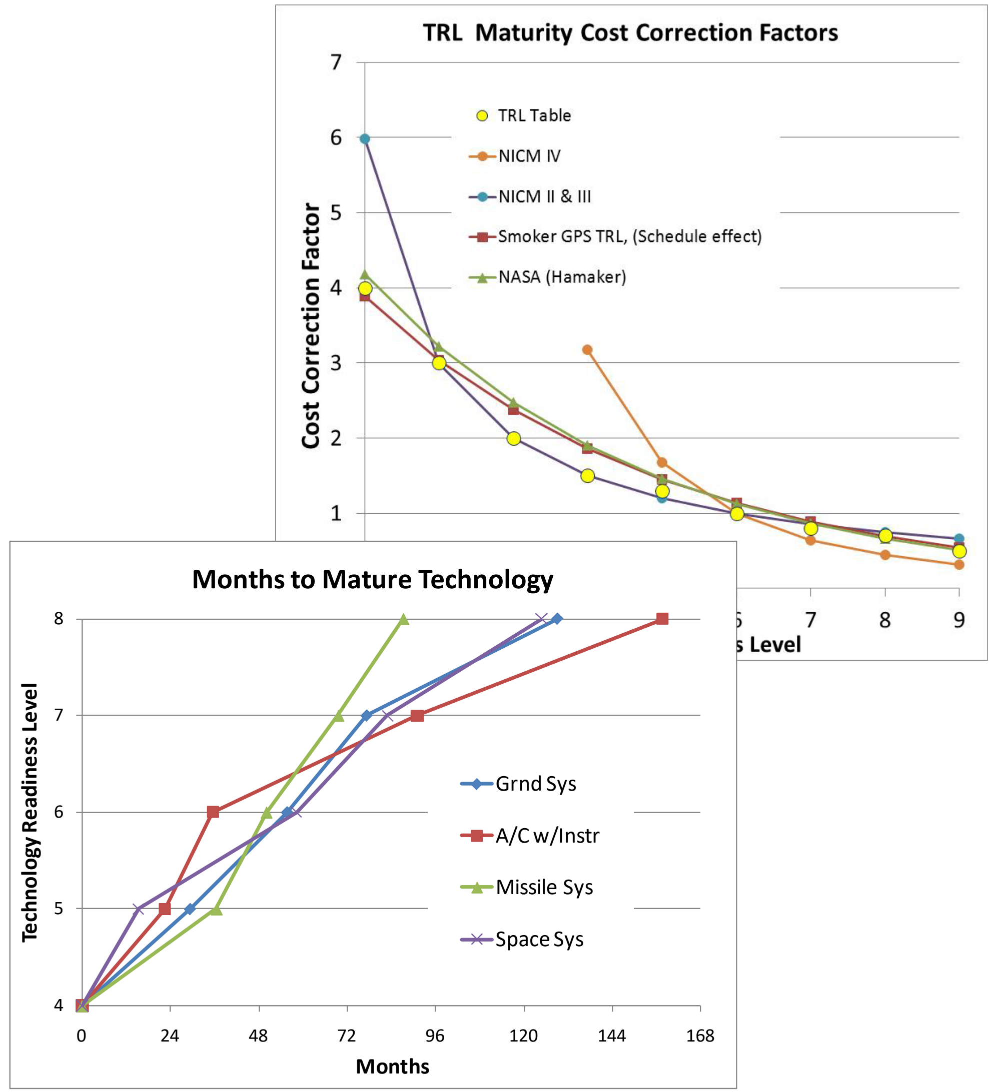
TRL/ IRL	TRL Definition	IRL Definition
1	Basic principles observed and reported	An **Interface** between technologies has been identified with sufficient detail to allow characterization of a relationship
2	Technology concept and/or application formulated	There is some level of specificity to characterize the **Interaction** (i.e. ability to influence) between technologies through their interface.
3	Analytical and experimental critical function and/or characteristic proof of concept	There is **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
4	Component and/or breadboard validation in a laboratory environment	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.
5	Component and/or breadboard validation in a relevant environment	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.
6	System/subsystem model or prototype demonstration in a relevant environment	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.
7	System prototype demonstration in an operational environment	The integration of technologies has been **Verified and Validated** and an acquisition/insertion decision can be made.
8	Actual system completed and qualified through test and demonstration	Actual integration completed and **Mission Qualified** through test and demonstration, in the system environment
9	Actual system proven through successful mission operations.	Integration is **Mission Proven** through successful mission operations.

SRL Maturity Compare and Contrast

TRL Normalized		SRL	Acquisition Phase	Definitions
0.9	3.5	0.10 - 0.39	Concept Development	Refine initial concept; develop system/technology strategy.
3.6	5.3	0.40 - 0.59	Technology Development	Reduce technology risks and determine appropriate set of technologies to integrate into a full system.
5.4	7.1	0.60 - 0.79	Engineering Model Development (formerly SDD)	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
7.2	8.0	0.80 - 0.89	Production	Achieve operational capability that satisfies mission needs.
8.1	9.0	0.90 - 1.00	Operations and Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total lifecycle.

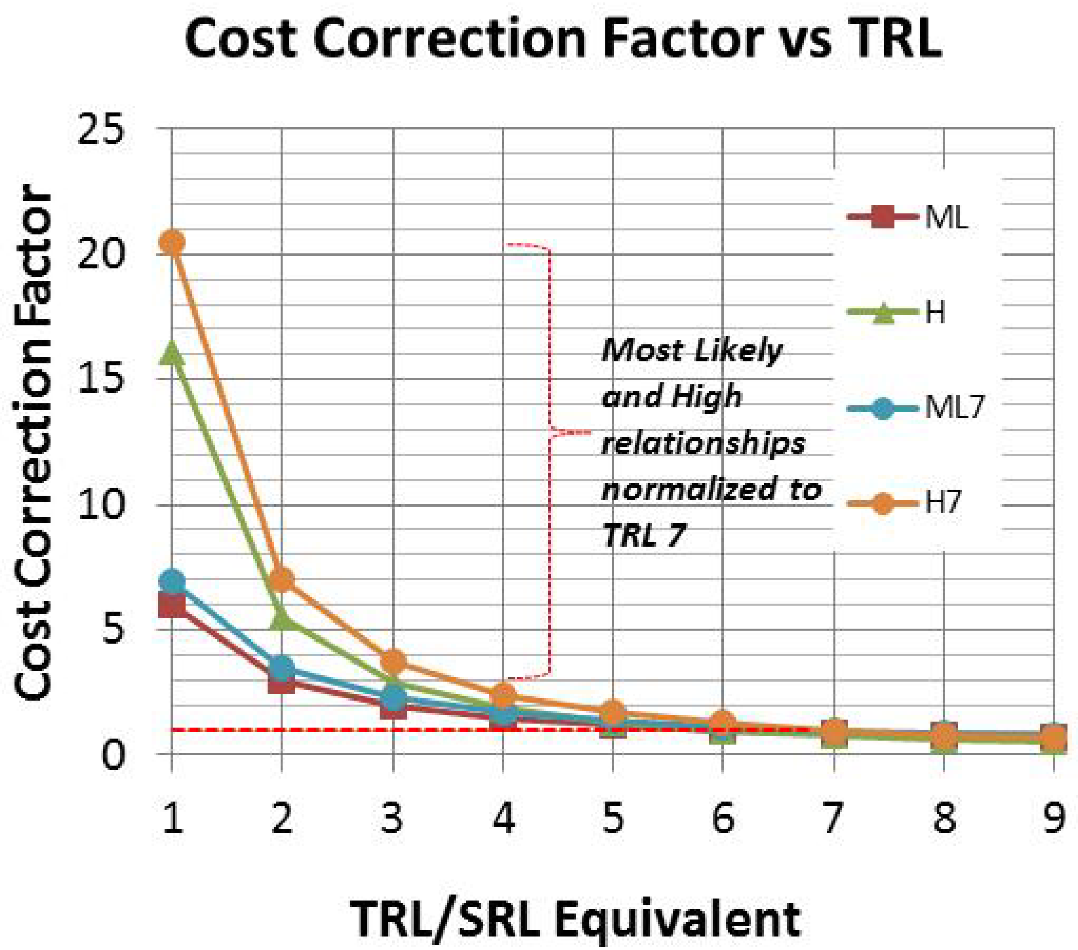
Agenda

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- **Cost and Time to Mature**
- Integrated Framework
- Application Example
- Conclusions and Future Study

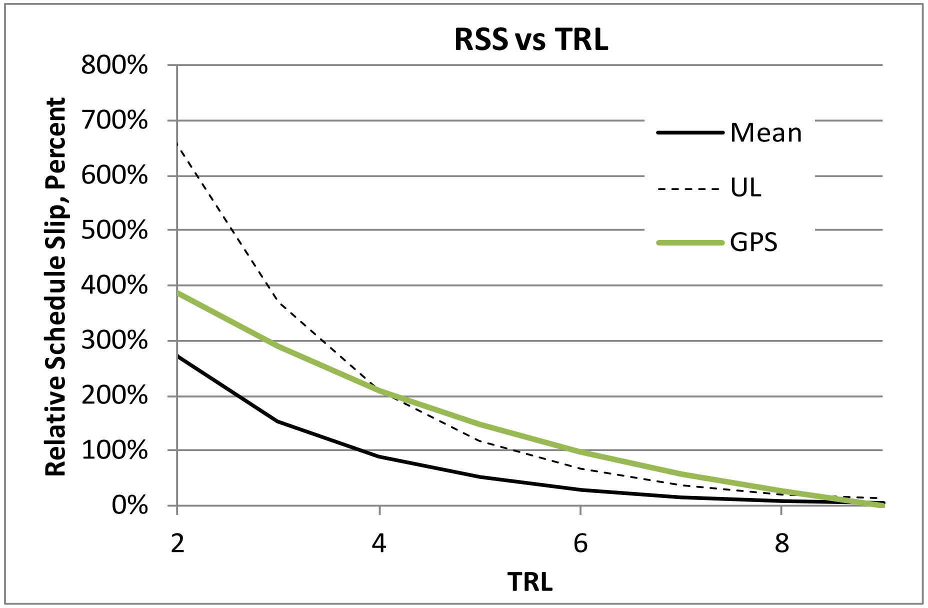


Cost to Mature

- Cost Correction Factor for our Case Study is normalized to TRL7
- Used as a basis for the analysis



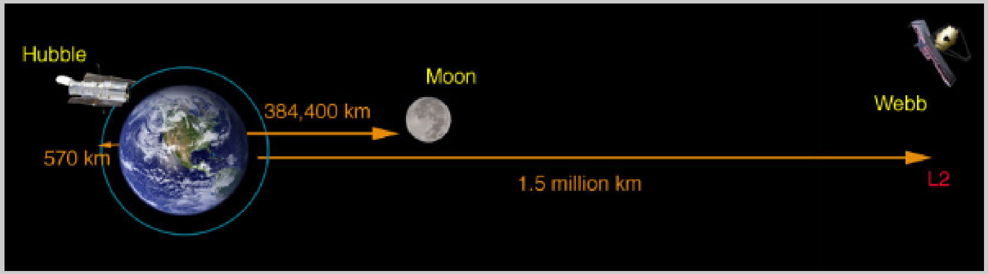
Time to Mature



- Work done by Dubos et al provide a range of time to mature
- Analysis of SAR data (Smoker) falls between the mean and upper limits
- Supports uncertainty boundary's
- Integrated with our analysis

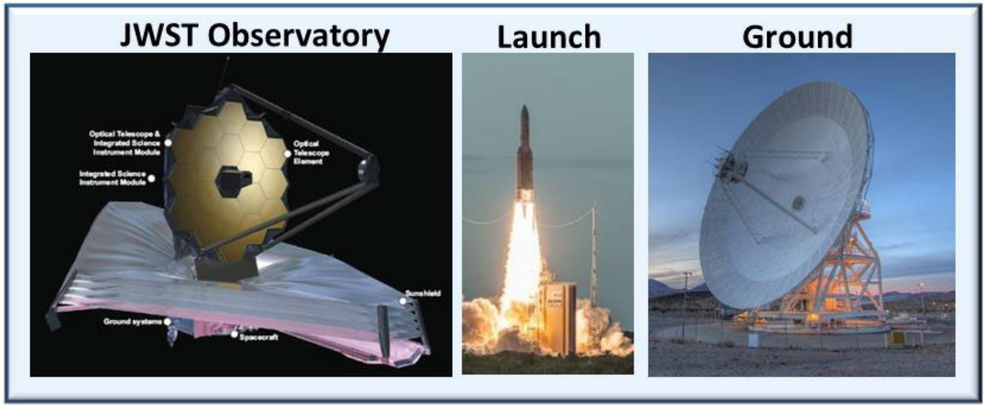
Agenda

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- Cost and Time to Mature
- Integrated Framework
- Application Example
- Conclusions and Future Study

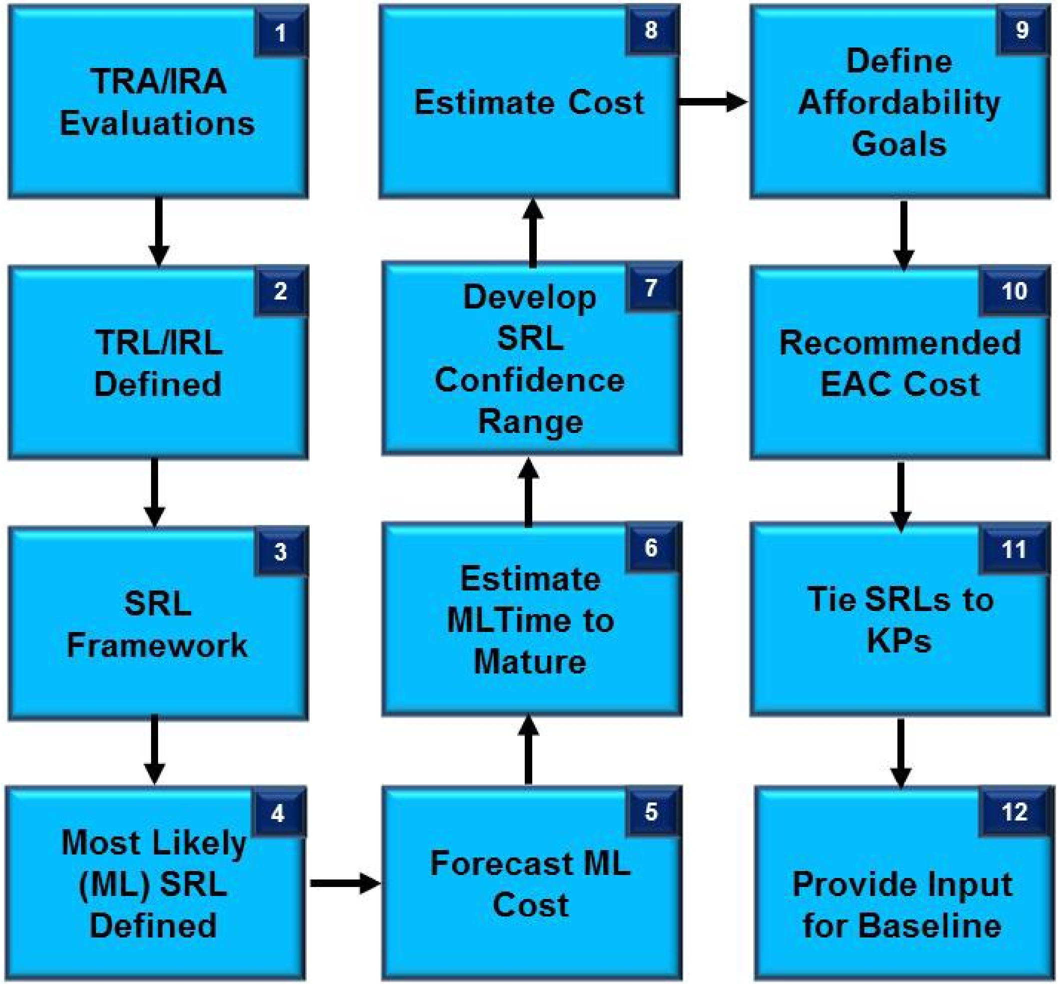


Webb will orbit the sun 1.5 million kilometers (1 million miles) away from the Earth at what is called the second Lagrange point or L2. (Note that these graphics are not to scale.)

Source: https://jwst.nasa.gov/orbit.html



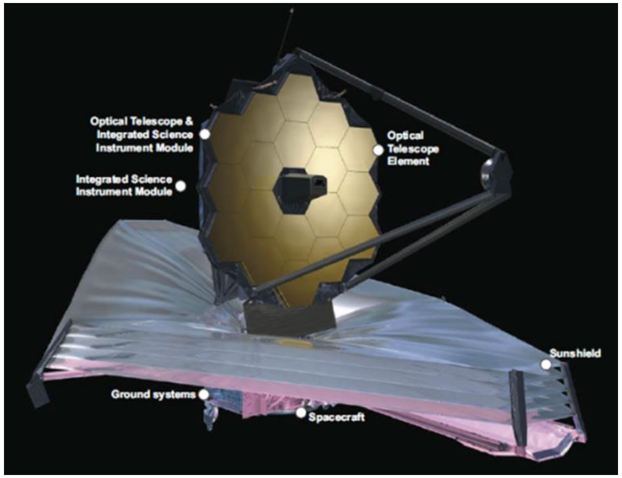
Integrated Framework



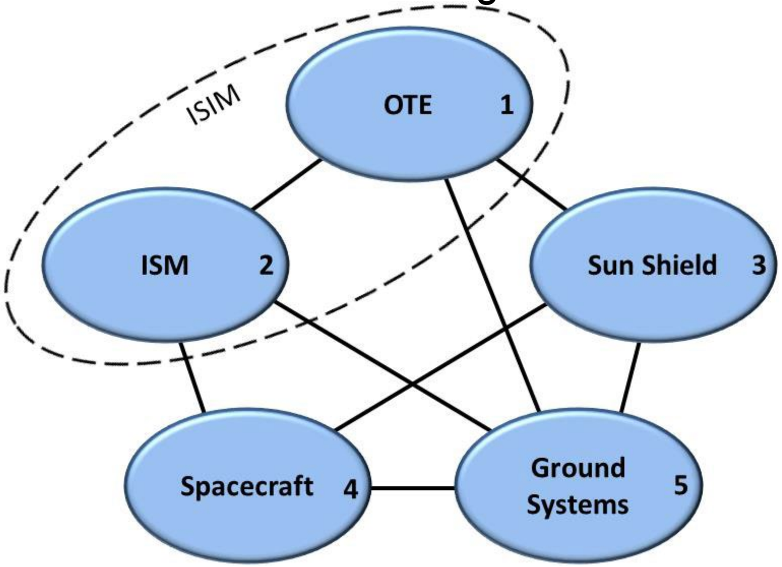
- 12 Step process
  - 1 – 2 TRA/IRA, TRL/IRL
  - 3- 4 SRL Framework
  - 5 – 6 Cost/Schedule
  - 7 – Confidence
  - 8 – 9 Cost/ Aforability
  - 10 -12 Recommendations

Agenda

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- Cost and Time to Mature
- Integrated Framework
- **Application Example (Case Study)**
- Conclusions and Future Study



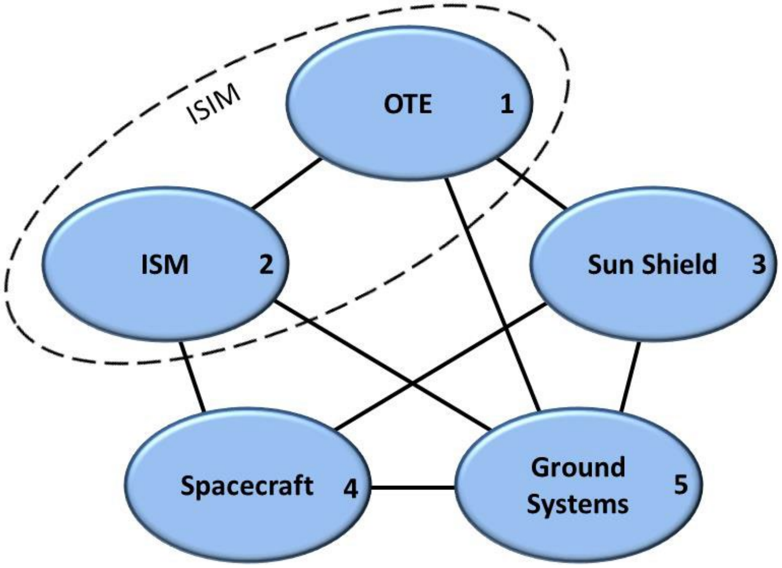
SRL Block Diagram



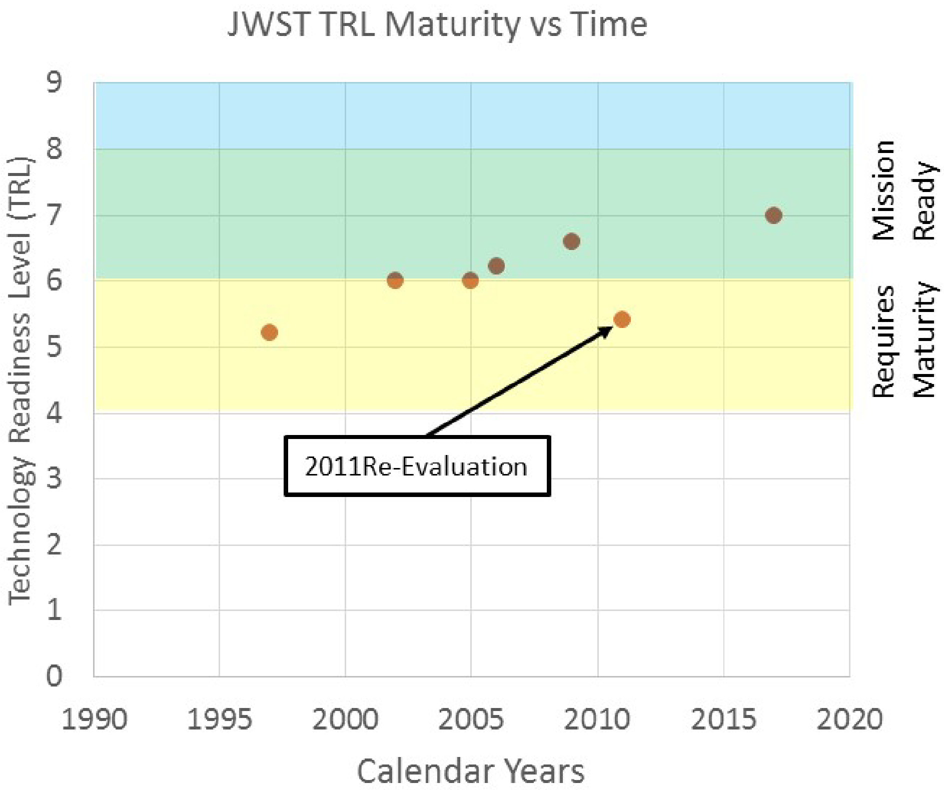
Case Study Framework

- System Comprised of:
  - Integrated Science Instrument Module
    - Optical Telescope Element
    - Integrated Science Module
  - Sun Shield
  - Spacecraft
  - Ground Systems
- Technology and integration linkages

System	Technology	TRL	Integrating Technologies	IRL
OTE	1	3	1,2;1,3; 1,4	3,1,2
ISM	2	3	1,2;2,4;2,5	3,4,3
Sun Shield	3	2	1,3;3,4;3,5	1,1,1
Spacecraft	4	4	2,4;3,4;4,5	4,1,1
Grnd Sys	5	4	1,5;2,5;3,5;4,5	2,3,1,4



Case Study Initial Conditions (TRL method)



- TRL assessment early in program showed
  - Some Maturity needed
  - Continued development
- TRL Assessment mid-program
  - Showed progress
  - Re-eval less progress

Case Study SRL Method (Initial)

- SRL framework initial assessment
  - TRL Equivalent
  - 1.3
- Additional Requirements
- Less demonstrated maturity
- Enhance development program

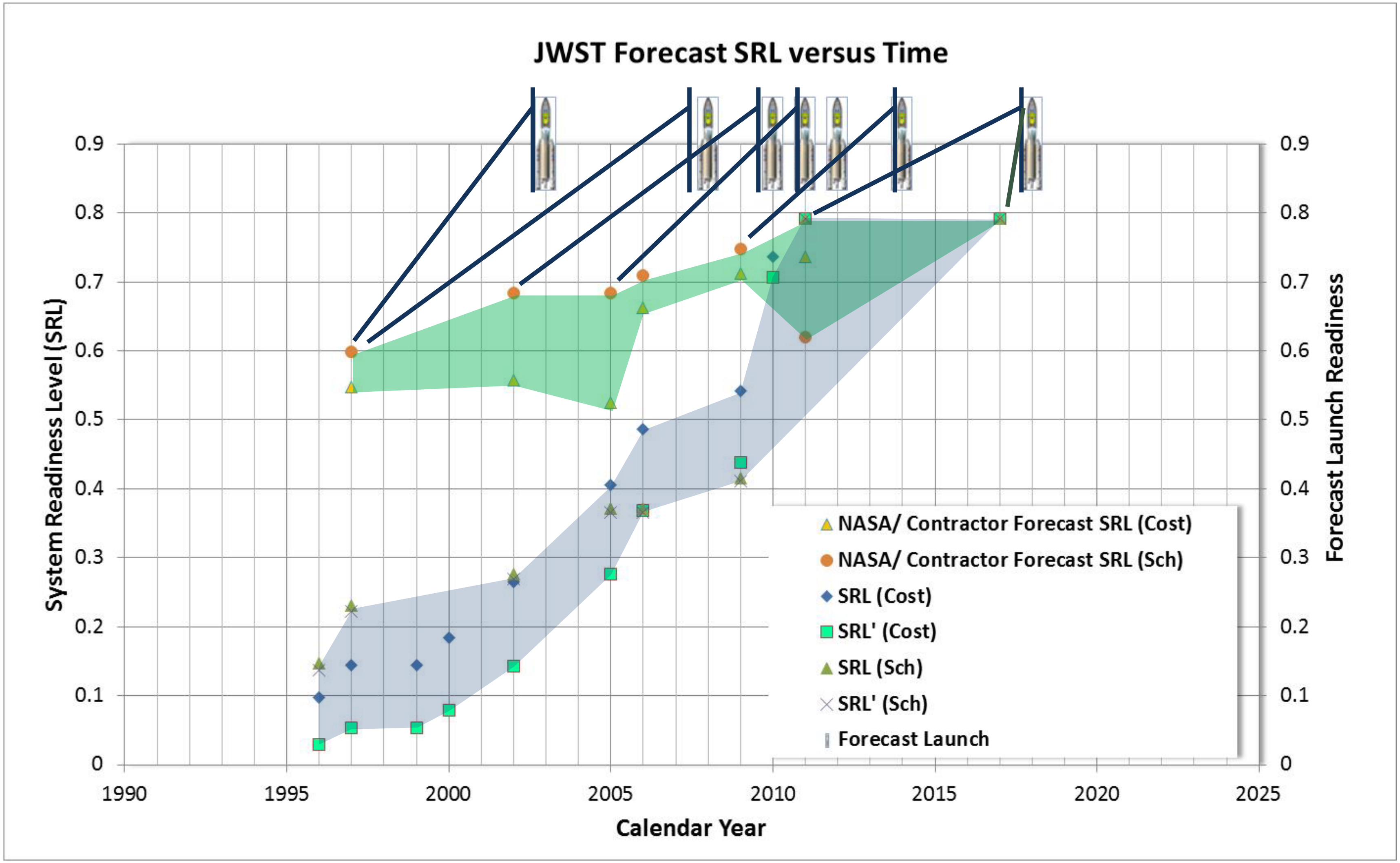
1997	Initial Assessment			IRL					
	Technology	TRL		1	2	3	4	5	
OTE	1	3	1	9	3	1	0	2	
ISM	2	3	2	3	9	0	4	2	
Sun Shield	3	2	3	1	0	9	1	1	
Spacecraft	4	4	4	0	4	1	9	4	
Grnd Sys	5	4	5	2	2	1	4	9	
	Average	3.2							
	Normalized								
	Technology			1	2	3	4	5	
OTE	1	0.33	1	1.00	0.33	0.11	-	0.22	
ISM	2	0.33	2	0.33	1.00	-	0.44	0.22	
Sun Shield	3	0.22	3	0.11	-	1.00	0.11	0.11	
Spacecraft	4	0.44	4	-	0.44	0.11	1.00	0.44	
Grnd Sys	5	0.44	5	0.22	0.22	0.11	0.44	1.00	
			No. of Interactions	4	4	4	4	5	21
			Matrix Det.	0.57	0.74	0.36	0.81	0.81	3.30
			SRL Avg	0.1420	0.1852	0.0895	0.2037	0.1630	**0.16**
			TRL Equivalent						1.33

Case Study SRL Method (Near Final)

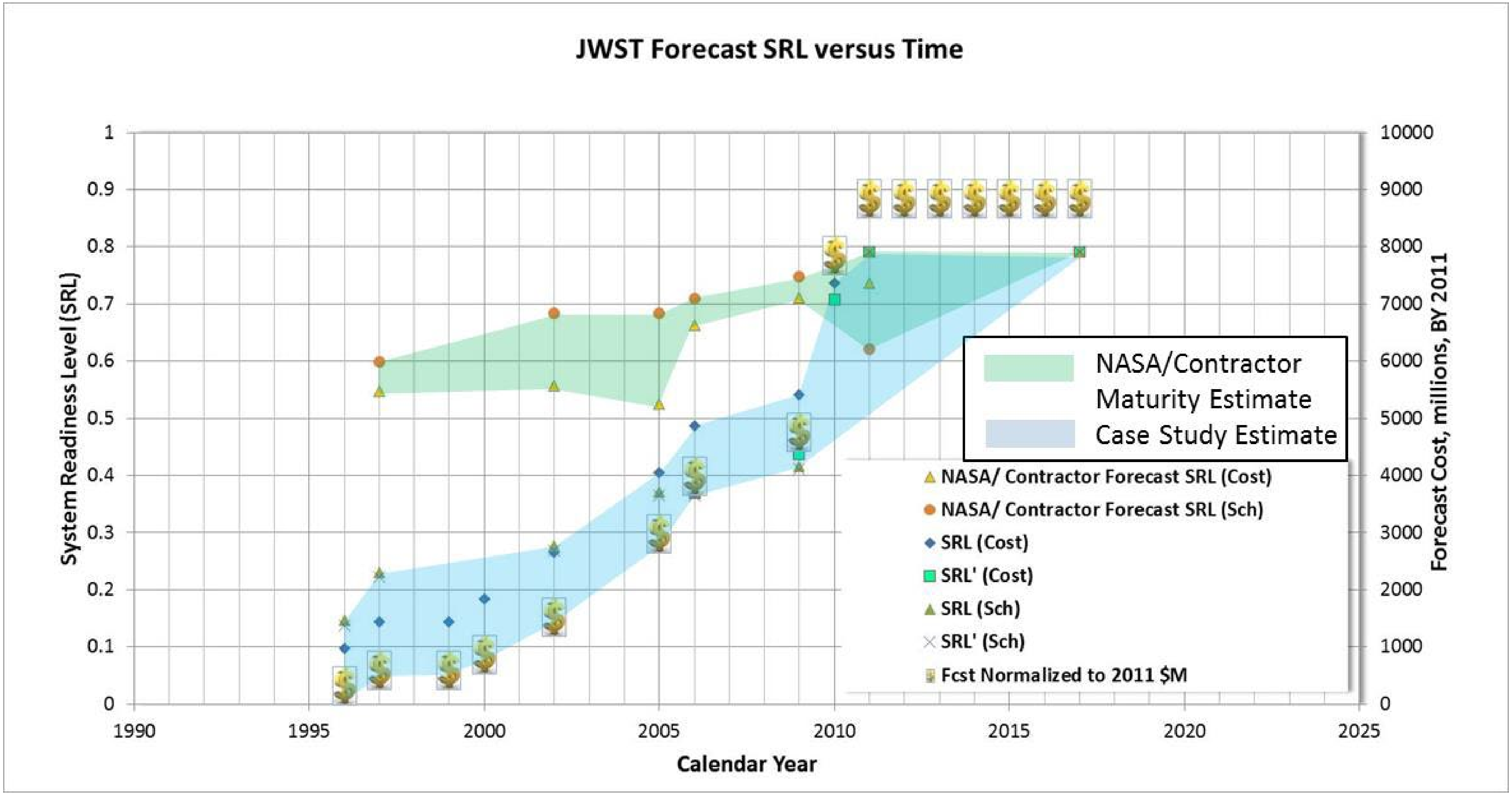
- SRL framework near final assessment (2017)
  - TRL Equivalent
  - 6.7
- Following 2011 re-evaluation
- Enhanced development
- Limited budget

2017	Updated Assessment			IRL					
	Technology	TRL		1	2	3	4	5	
OTE	1	7	1	9	8	6	0	7	
ISM	2	8	2	8	9	0	8	8	
Sun Shield	3	7	3	6	0	9	6	7	
Spacecraft	4	9	4	0	8	6	9	8	
Grnd Sys	5	9	5	7	8	7	8	9	
	Average	8							
	Normalized								
	Technology			1	2	3	4	5	
OTE	1	0.78	1	1.00	0.89	0.67	-	0.78	
ISM	2	0.89	2	0.89	1.00	-	0.89	0.89	
Sun Shield	3	0.78	3	0.67	-	1.00	0.67	0.78	
Spacecraft	4	1.00	4	-	0.89	0.67	1.00	0.89	
Grnd Sys	5	1.00	5	0.78	0.89	0.78	0.89	1.00	
	No. of Interactions			4	4	4	4	5	21
		Matrix Det.		2.86	3.36	2.74	3.20	3.89	16.05
		SRL Avg		0.7160	0.8395	0.6852	0.7994	0.7778	**0.76**
		TRL Equivalent							6.70

Case Study – Historical Survey

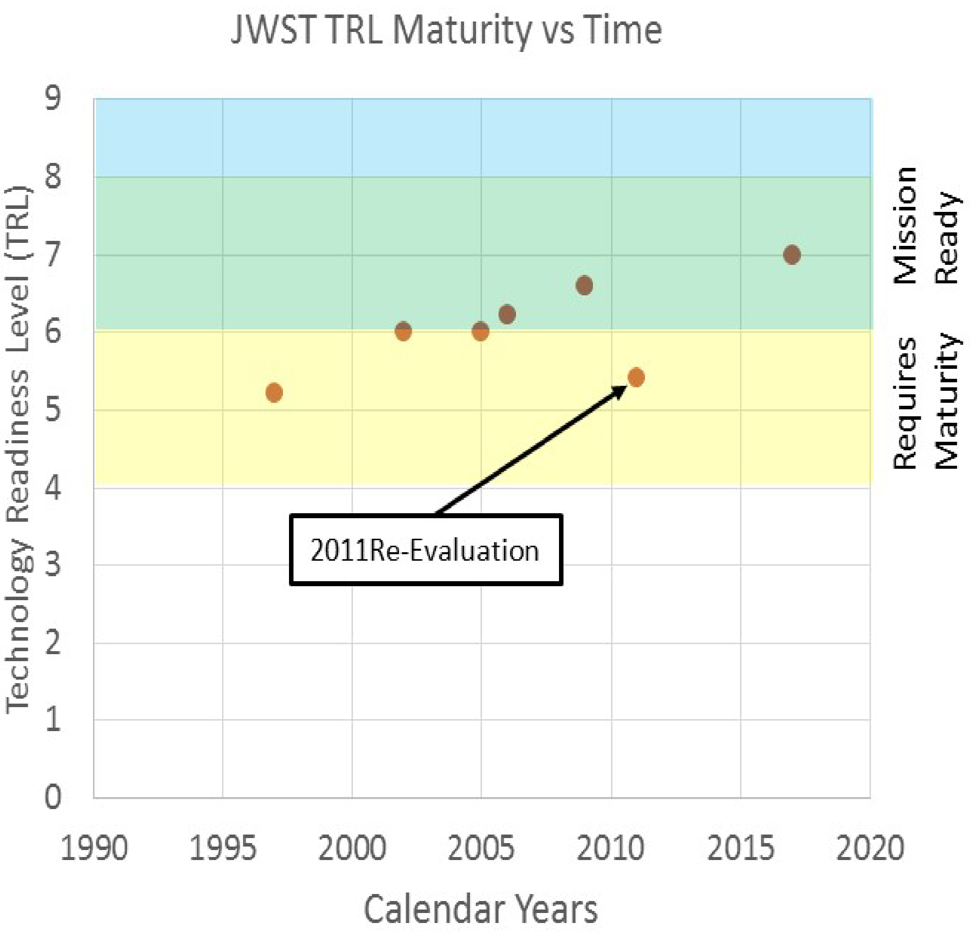


Case Study – Cost and Schedule

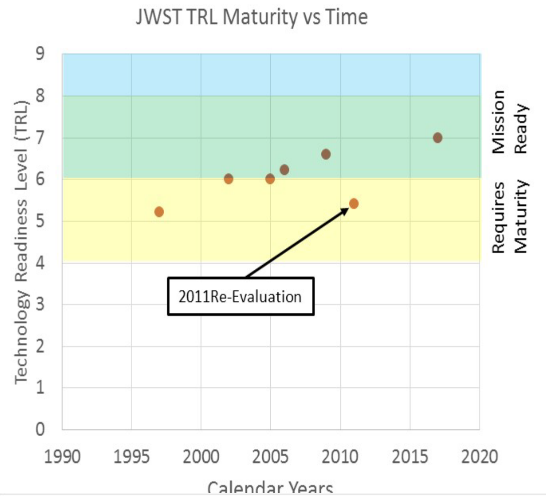


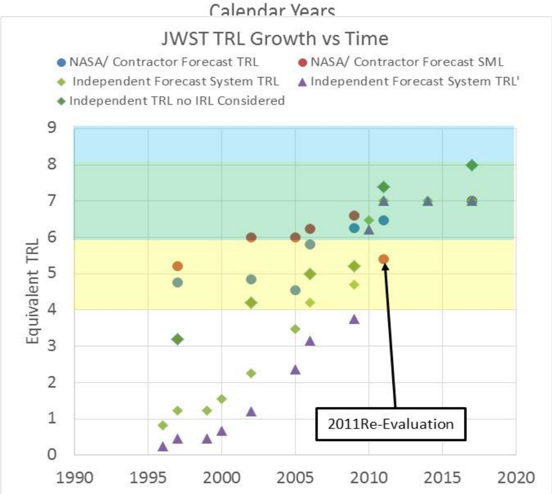
Agenda

- Introduction
- Tools and Techniques
- Implementing and Forecasting SRLs
- Cost and Time to Mature
- Integrated Framework
- Application Example
- Conclusions and Future Study



Conclusions





- TRL alone may not provide the clearest maturity snapshot of a complex system
- SRL approach can highlight lower maturity areas including interfaces
- A knowledge based framework supports realistic cost and schedule forecasting
- Future program can benefit from early multi-tiered maturity growth

SRL Method is consistent with 2011 maturity evaluation

Future Study

- Additional cases to support further validation of the method
- Review of lessons learned and application within the GAO knowledge point framework

	Maturity		Cost/CCF		Dubos et al		Smoker		
			ML	High	ML	High	Low	ML	High
	SRL	TRL (equ)	CCFml	CCFh	Schedule		Schedule		
Initial SRL	0.16	1.33	5.26	13.21	3.95	9.61			
Desired SRL	0.76	6.70	1.05	1.07	0.19	0.45			
Delta Increase in Funding			5.50	14.14					
Delta Increase in Schedule					375%	916%			
Cost $B (BY2011)	$0.59		$ 3.8	**$ 8.9**					
Schedule Months	132				495.1	1,341.7	277.3	522.6	1,430.3
Years	11				41.3	111.8	**23.1**	43.5	119.2

References

- GAO-17-71"JWST Project Meeting Cost and Schedule Commitments but Continues to Use Reserves to Address Challenges", 2017
- GAO-16-112, "JWST Project on Track but may Benefit from Improved Contractor Data to Better Understand Costs", 2016
- GAO-08-467SP Assessments of Major Weapon Programs, F22A, pg 85.
- NM 7120-81 (also NPR 7120.5D) NASA Space Flight Programs & Project Management Requirements, 2.1 "Programs and Projects"
- USC 10, 2433 Unit Cost Report.
- Sauser, B., Verma, D., Ramirez-Marquez, J., and Grove, R., "From TRL to SRL: The Concept of Systems Readiness Levels", Conference on Systems Engineering Research, 2006.
- Sauser, B., Ramirez-Marquez, J., "System (of Systems) Acquisition Maturity Models and Management Tools", Stevens Institute of Technology School of Systems and Enterprise, 2009.
- Malone, P.K., "Enhancing Weapon System Initial Cost Estimate Credibility with Advanced Tools", IEEE Aerospace Conference, Big Sky, MT, 2017
- Sadin, S. - Wikipedia credits NASA's Stan Sadin, NASA HQ with inventing the original (7 level) TRL scale in 1974
- Mankins, J., "Research & Development Degree of Difficulty" Advanced Projects Office of Space Flight NASA Headquarters, 1998.
- Bilbro, J. "Systematic Assessment of the Program/Project Impacts of Technological Advancement and Insertion", George C. Marshall Space Flight Center, 2006.
- Valerdi, R. and Boehm, B., "COSYSMO: A Systems Engineering Cost Model", USC Center Systems and Software Engineering, 2010.
- Nolte, W. Technology Readiness Calculator, http://www.dtic.mil/ndia/2003systems/nolte2.pdf.
- Buede, D. "The Engineering Design of Systems", John Wiley & Sons, New York, 2000.
- Malone, Smoker, Apgar, and Wolfarth, "The Application of TRL Metrics to Existing Cost Prediction Models", IEEE Aerospace Conference, Big Sky, MT, 2011.
- Smoker, R. and Smith, S. "System Cost Growth Associated with Technology-Readiness Level" published in the Journal of Parametrics, Volume XXV, Issue No. 1, Spring 2007, pg. 8.
- Peisen, J.; Schulz, L.; Golaszewski, S.; Ballard, D.; and Smith, J. – "CASE STUDIES: TIME REQUIRED TO MATURE AERONAUTIC TECHNOLOGIES TO OPERATIONAL READINESS" 1999; www.aeronautics.nasa.gov/docs/study/221/finalrpt.pdf.
- Dubos, G, Saleh, J. and Braun, R.; "Technology Readiness Level, Schedule Risk, and Slippage in Spacecraft Design", Journal of Spacecraft and Rockets, Vol 45, No 4, July – August 2008.
- Lee, T., and Thomas, L. D., "Cost Growth Models for NASA's Programs," Journal of Probability and Statistical Science, Vol. 1, No. 2, Aug. 2003, pp. 265–279.
- Browning, T. R., "Sources of Schedule Risk in Complex System Development," Systems Engineering, Vol. 2, No. 3, 1999, pp. 129–142.
- GAO-13-4 James Webb Space Telescope - Actions Needed to Improve Cost Estimate and Oversight of Test and Integration, 2013.
- JWST Design, http://www.stsci.edu/jwst/overview

TRL/ IRL	TRL/IRL Normalized to SRL	TRL Definition	IRL Definition	DOD Program Lifecycle Phase	SRL Definition	SRL	GAO Knowledge Point	Acquisition Milestones
	0.9					0.1		
1	1	**Basic** principles observed and reported	An **Interface** between technologies has been identified with sufficient detail to allow characterization of a relationship					Material Decision
2	2	Technology concept and/or application **formulated**	There is some level of specificity to characterize the **Interaction** (i.e. ability to influence) between technologies through their interface.	Concept Development	Refine initial concept; develop system/technology strategy.			**Milestone A Alternatives**
3	3	Analytical and experimental critical function and/or characteristic **proof of concept**	There is **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.					SRR
	3.5					0.39		
	3.6					0.4		
4	4	Component and/or breadboard validation in a **laboratory environment**	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.					SFR
5	5	Component and/or **breadboard** validation in a **relevant environment**	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.	Technology Development	Reduce technology risks and determine appropriate set of technologies to integrate into a full system.			**PDR Milestone B**
	5.3					0.59	**KP 1**	
	5.4					0.6		
6	6	System/subsystem model or **prototype** demonstration in a **relevant environment**	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.	Engineering Manufacturing Development	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.			CDR
7	7	System **prototype** demonstration in an **operational environment**	The integration of technologies has been **Verified and Validated** and an acquisition/insertion decision can be made.					TRR
	7.1					0.79	**KP 2**	**Milestone C**
	7.2					0.8		
8	8	Actual **system** completed and **qualified through test and demonstration**	Actual integration completed and **Mission Qualified** through test and demonstration, in the system environment	Production and Deployment	Achieve operational capability that satisfies mission needs.	0.89	**KP 3**	IOC
	8.1					0.9		
9	9	Actual **system proven** through successful mission operations.	Integration is **Mission Proven** through successful mission operations.	Operations and Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total lifecycle.	1		FOC

JWST Historical Summary

Year	Calendar Year	Activity	Estimate Cost $M	BY	Fcst Normalized to 2011 $M	Mirror Size Diameter Meters	Forecast Years to Launch	Planned Launch Date	Program Phase	Orbit
1	1989	Concept Studies				4			Pre-A	
2	1990					4			Pre-A	
3	1991					4			Pre-A	
4	1992					4			Pre-A	
5	1993					4			Pre-A	
6	1994	Program Hi-Z				4			Pre-A	1-3AU
7	1995					4			Pre-A	
8	1996		$ 500.0	1996	$ 322.97	8	7	2003	Pre-A	L2, 3AU
9	1997	NGST	$ 900.0	1997	$ 589.35	8	11	2008	Pre-A	L2
10	1998	NGST				8			Pre-A	L2
11	1999	NGST	$ 900.0	1997	$ 589.35	8	9	2008	A	L2
12	2000	NGST	$ 1,200.0	2000	$ 859.05	8	8	2008	A	L2
13	2001	NGST				8			A	L2
14	2002	Re-named JWST, Responsibilities transferred to TRW	$ 2,000.0	2002	$ 1,524.97	6.1	8	2010	B	L2
15	2003					6.5			B	L2
16	2004					6.5	7	2011	B	L2
17	2005	2 - 3.5B change in cost not fully explained	$ 3,500.0	2005	$ 2,979.47	6.5	8	2013	B	L2
18	2006	System Design Review Completed	$ 4,500.0	2006	$ 3,990.57	6.5	7	2013	B	L2
19	2007					6.5			C/D	L2
20	2008					6.5			C/D	L2
21	2009		$ 4,964.0	2009	$ 4,754.64	6.5	5	2014	C/D	L2
22	2010		$ 8,000.0	2010	$ 7,840.18	6.5			C/D	L2
23	2011	Congress Capped program at $8B, with a rebaseline of $8.835B	$ 8,835.0	2011	$ 8,835.00	6.5	7	2018	C/D	L2
24	2012				$ 8,835.00	6.5			C/D	L2
25	2013				$ 8,835.00	6.5			C/D	L2
26	2014				$ 8,835.00	6.5	4	2018	C/D	L2
27	2015				$ 8,835.00	6.5			C/D	L2
28	2016	Integration and Test, 22 deployment events, more than typical			$ 8,835.00	6.5			C/D	L2
29	2017	Integration and Test, total of 5 integration events, 3 not started. OTE and ISIM Integration took longer than planned.	$ 8,835.0	2011	$ 8,835.00	6.5	1	2018	C/D	L2
30	2018	Planned Launch								
31	2019									
32	2020									

Questions

MCR

CRITICAL THINKING.
SOLUTIONS DELIVERED.

INTEGRATED PROGRAM MANAGEMENT

Defense | Energy | Information Management | National Security | Space | Transportation