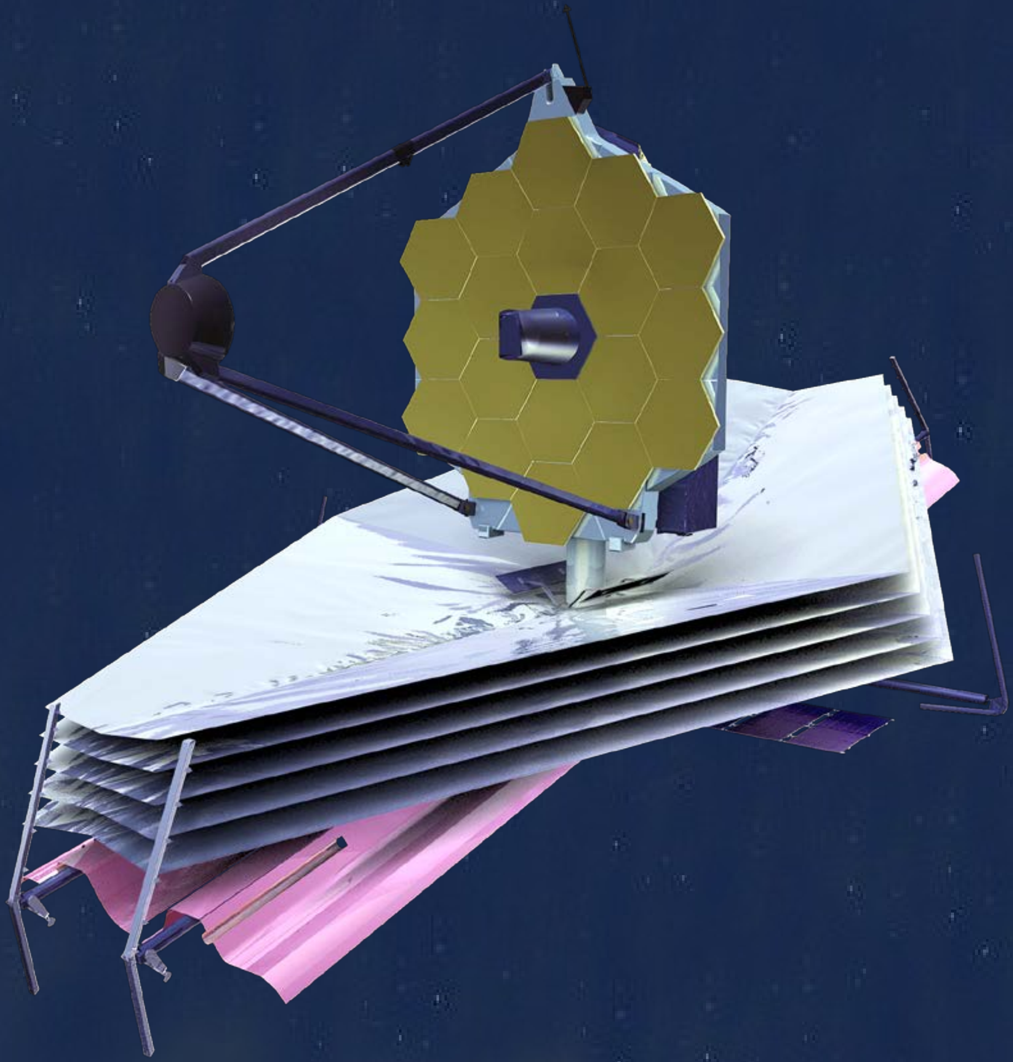
James Webb Space Telescope Optical Telescope Element Mirror Development History and Results



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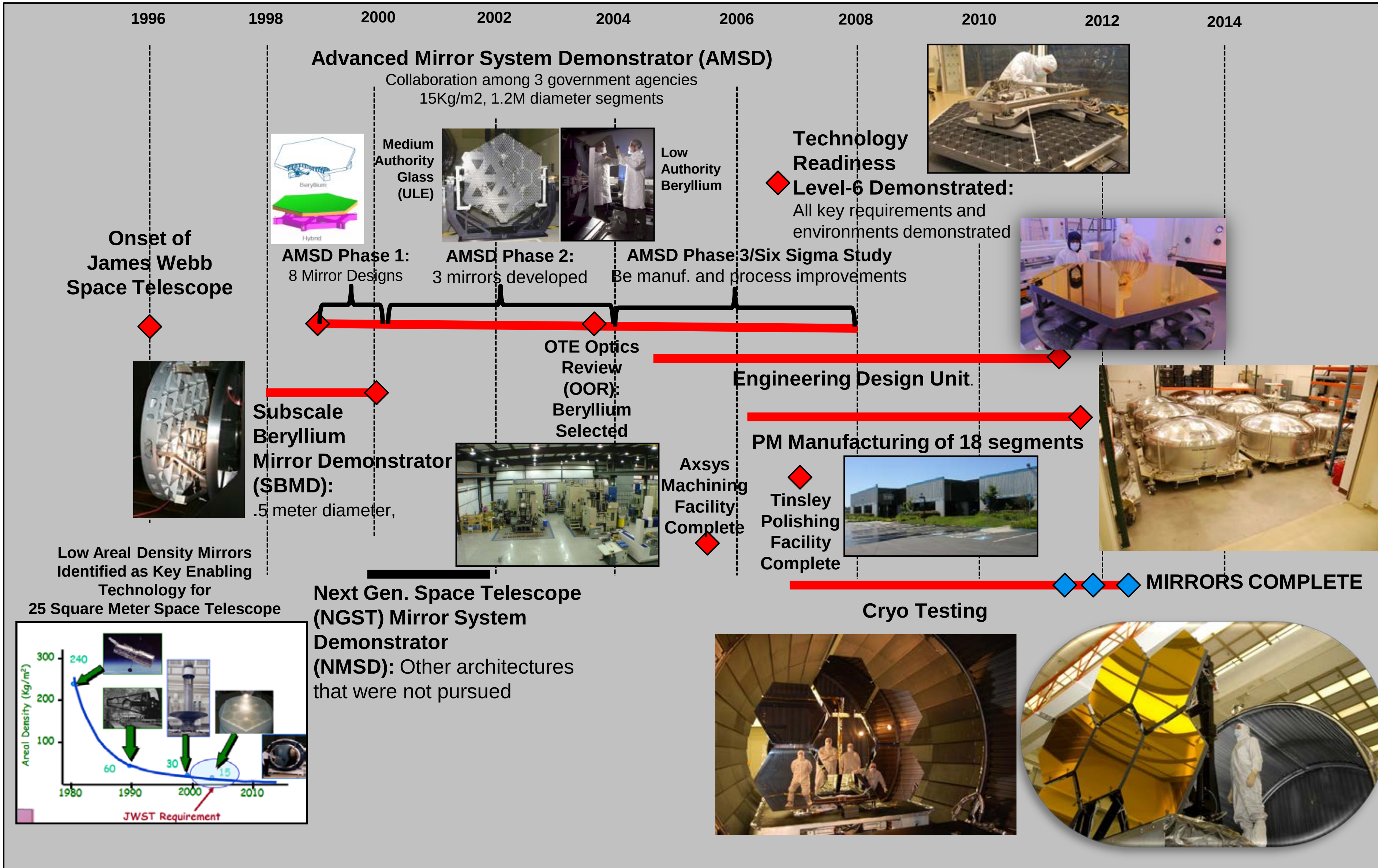
Outline

- Introduction
- As-executed roadmap
- Technology development
- Mirror Selection
- Mirror Process Flow
- As –run schedule
- Risk Management History
- Results

Mirror History



Mirror System Design Parameters Studied

Wide Variety of Mirror System Design Parameters Studied			
Item	SBMD (Ball)	NMSD	AMSD
Substrate Material	Be	Glass/Composite Hybrid (COI) Glass (UA)	Be (Ball) ULE (Kodak) SiO2 (Goodrich)
Reaction Structure	Be	Composite (both)	Composite (all)
Control Authority	Low (Focus Only)	Low (COI) High (UA)	Low (Ball) Medium (Kodak) High (Goodrich)
Mounting	Linear Flexure	Bipods (COI) 166 Hard (UA)	9 Bi-Flex (Ball) 16 Force (Kodak) 67 Bi/Ax-Flex (Goodrich)
Diameter	0.53 m	2 m (COI) 1.6 m (UA)	1.38 m (Ball) 1.4 m (Kodak) 1.3 m (Goodrich)
Areal Density	9.8 kg/m2 (mirror only)	13 kg/m2	15 kg/m2

Technology Development Specs

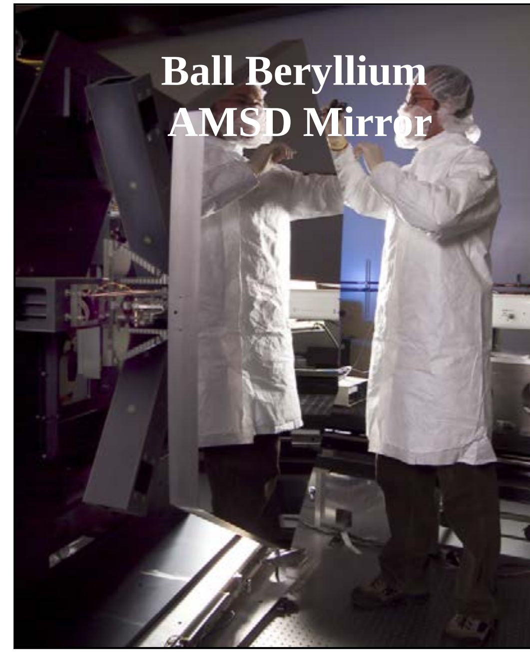
Mirror Technology Development Specifications				
Item	SBMD	NMSD	AMSD	Units
Form	Circle with Flat	Hex	Hex	
Prescription	Sphere	Sphere	Off-Axis Parabola	
Diameter	> 0.5	1.5 to 2.0	1.2 to 1.5	meter
Areal Density	<12	< 15	< 15	kg/m^2
Radius	20	15	10	meter
PV Figure	160	160	250	nm
RMS Figure	---	---	50	nm
PV Mid (1-10 cm^{-1})	63	63	---	nm
RMS Finish	3	2	4	nm
Stiffness (1st Mode)	---	---	150	HZ

Incremental TRL-6

Demonstrator	Technology	Validity to JWST
SBMD	Cryogenic Coating Cryo-Null Figuring	SBMD developed a low stress gold coating application that can be applied to any beryllium mirror. Coating of large mirrors (like JWST) is not material specific and has been developed on other flight programs.
AMSD Mirror	Figuring Cryogenic performance Actuation capability	All differences between the JWST PMSA and the AMSD mirror improves manufacturability, cryogenic performance, and provides more actuation degrees of freedom
AMSD Stress Coupons	Long term material stability	JWST PMSA's are manufactured using the exact processing developed on AMSD III to assure low residual surface stresses and low material creep.
JWST EDU & Flight Segment	Launch distortion Actuation Capability	JWST flight segment used to show technology readiness

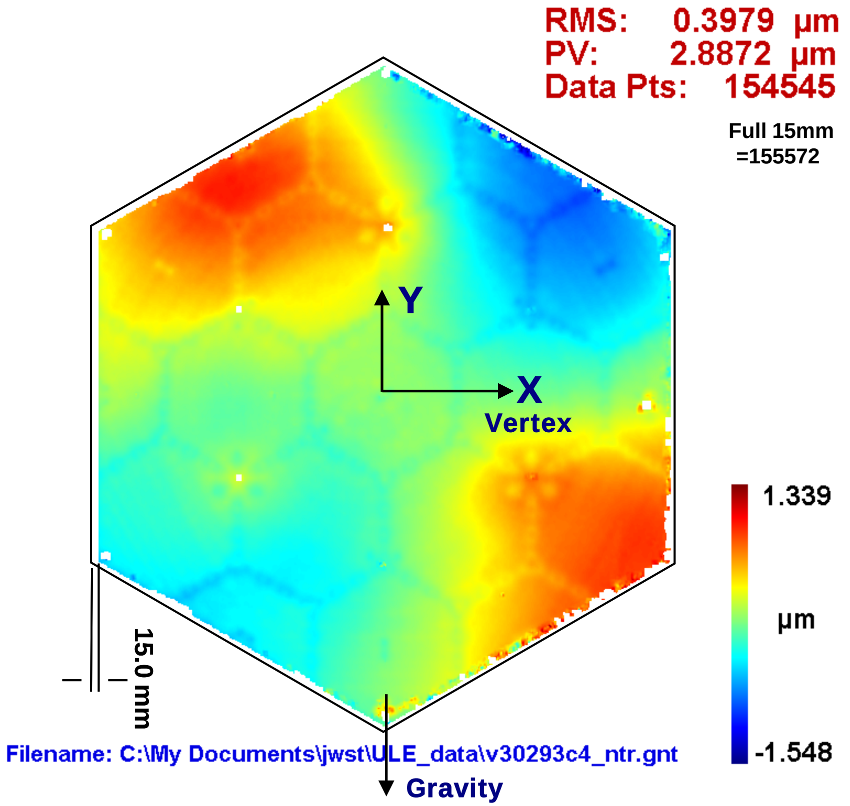
Advanced Mirror System Demonstrator (AMSD)

- NASA, DOD, NRO $50M partnership funded 3 lightweight mirror technologies shown on the right
- Ball beryllium mirror technology completed and baselined for JWST in 2003
  - Ball beryllium mirror demonstrated all key aspects of JWST technology except for demonstration of vibro-acoustics survival which will be demonstrated this June on the Engineering Design Unit mirror
- Mirror manufacturing of flight mirrors started in September 2003

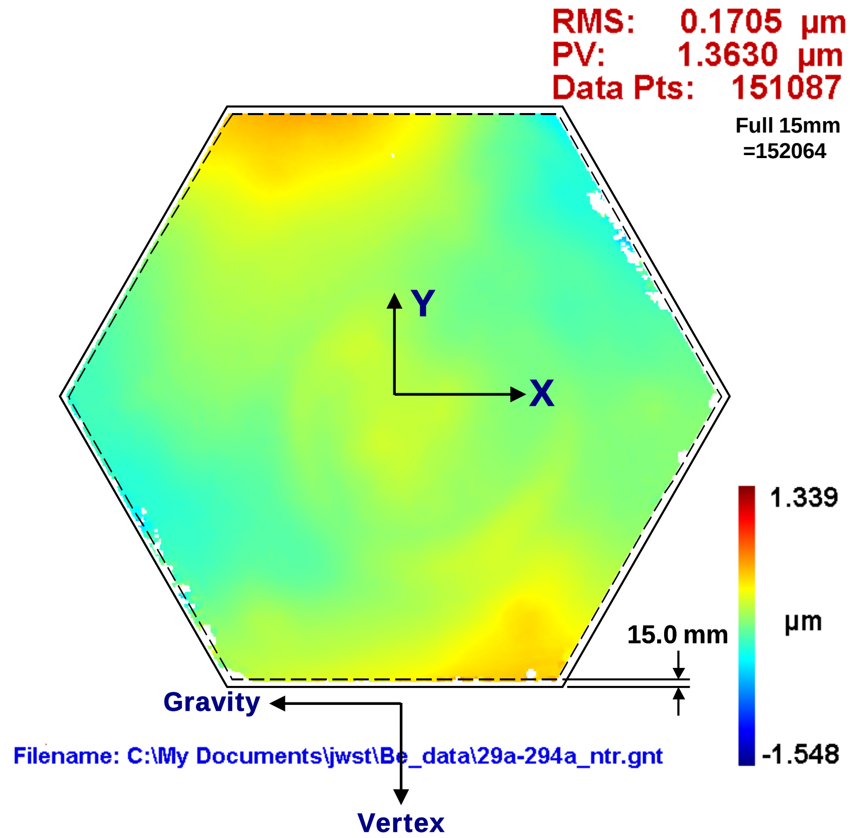


Mirror Technology Choices

~30 K minus Ambient



ULE

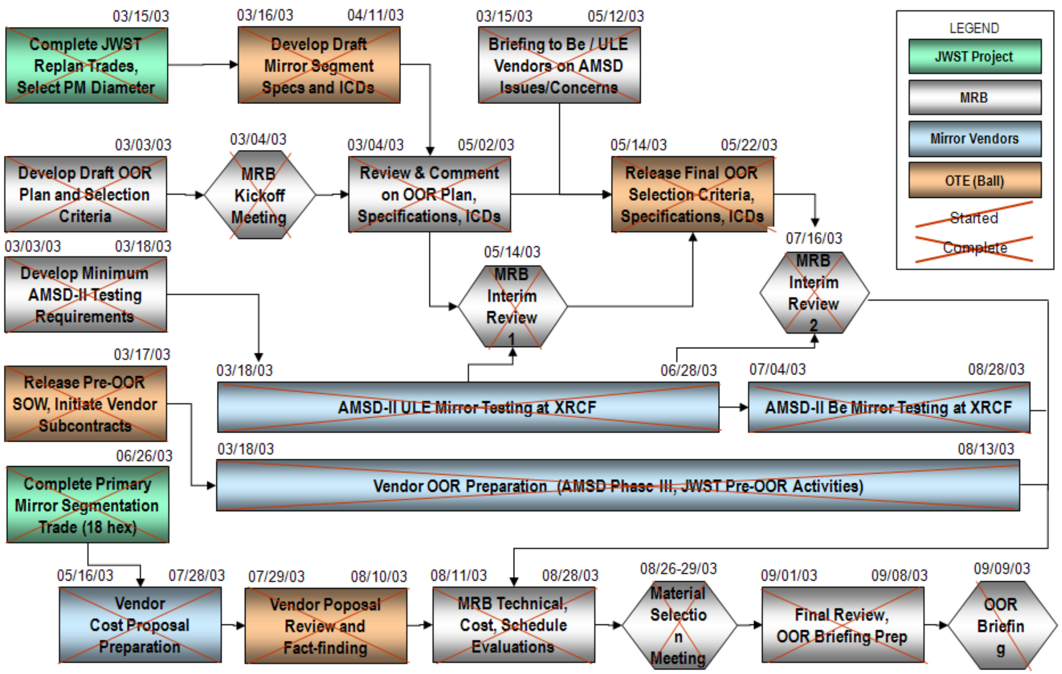


Be

Beryllium Mirror Had Superior Cryogenic Properties

Mirror Selection Process and Results

- Beryllium was rated as the highest performing, lowest technical risk solution
  - Material has superior cryo CTE and conductivity, only technical issue was managing surface stresses to achieve final convergences
  - Provided best potential science performance, had significant margins on thermal performance and stiffness/mass
  - Key concerns were schedule and staffing at Tinsley
  - Material and manufacturing cost deltas between ULE and Beryllium were small when compared to the potential schedule deltas



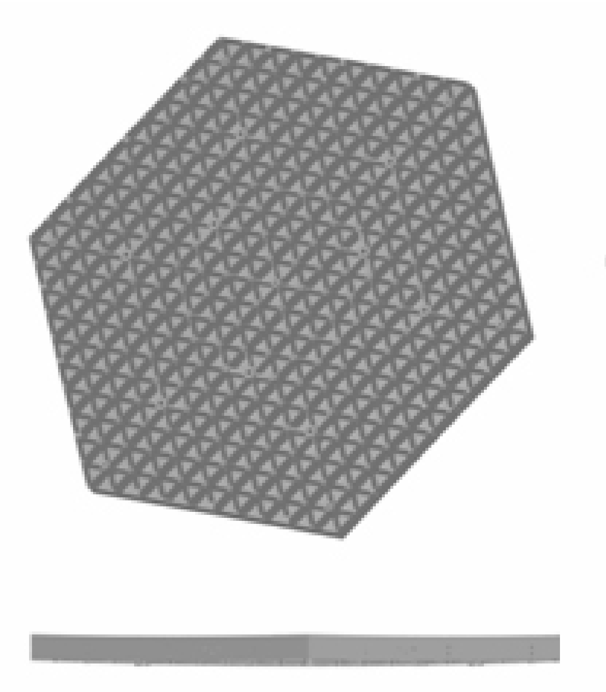
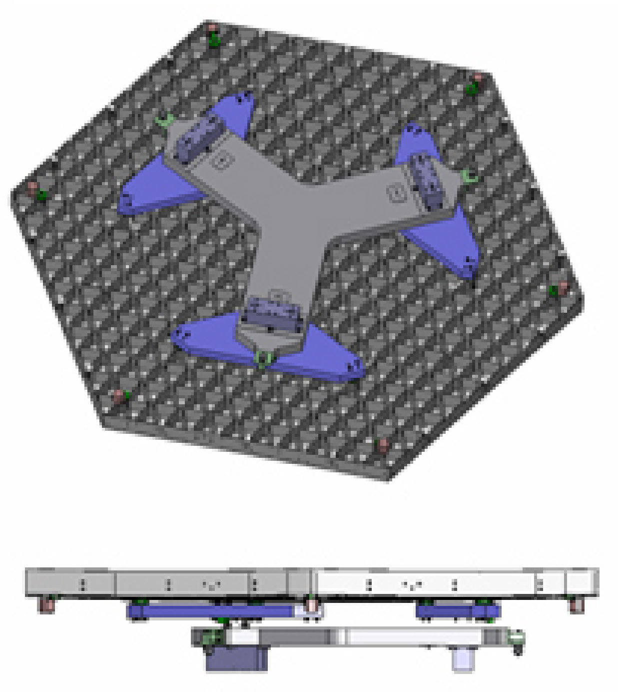
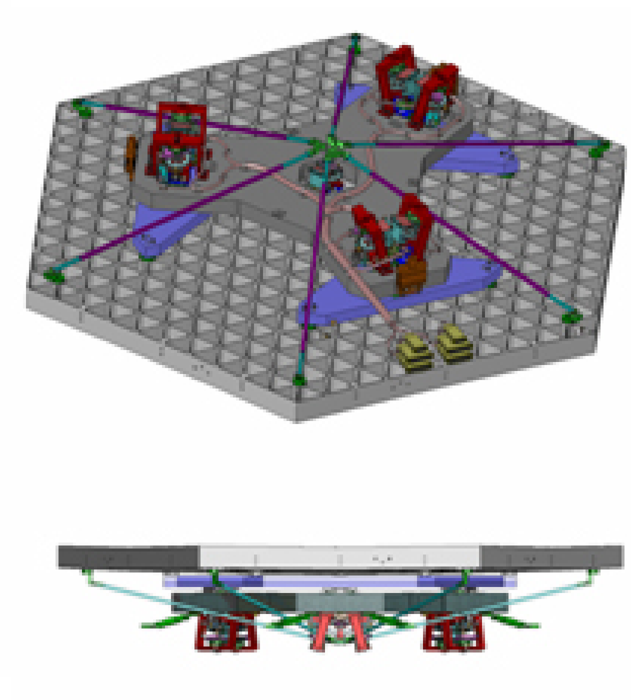
- **Mirror Recommendation Board (MRB)**

Lee Feinberg	GSFC, OTE Manager, MRB Co-Chair
Ritva Keski-Kuha	GSFC, OTE Deputy Manager
Mark Clampin	GSFC, JWST Observatory Scientist
Phil Stahl	MSFC, JWST Mirror Technology Lead
Kevin Russell	MSFC, AMSD Program Manager
Scott Texter	NGST, OTE Manager, MRB Co-Chair
Charlie Atkinson	NGST, OTE Deputy Manager
Gary Rosiak	NGST, Former NGST Phase 1 Program Manager
Beth Barinek	NGST, Ball Subcontract Technical Manager
Doug Neam	BATC, Vice President of Operations
Mark Bergeland	BATC, JWST Program Manager
Gary Matthews	EKC, Manager of Image Collection Systems

- **MRB Technical Consultants**

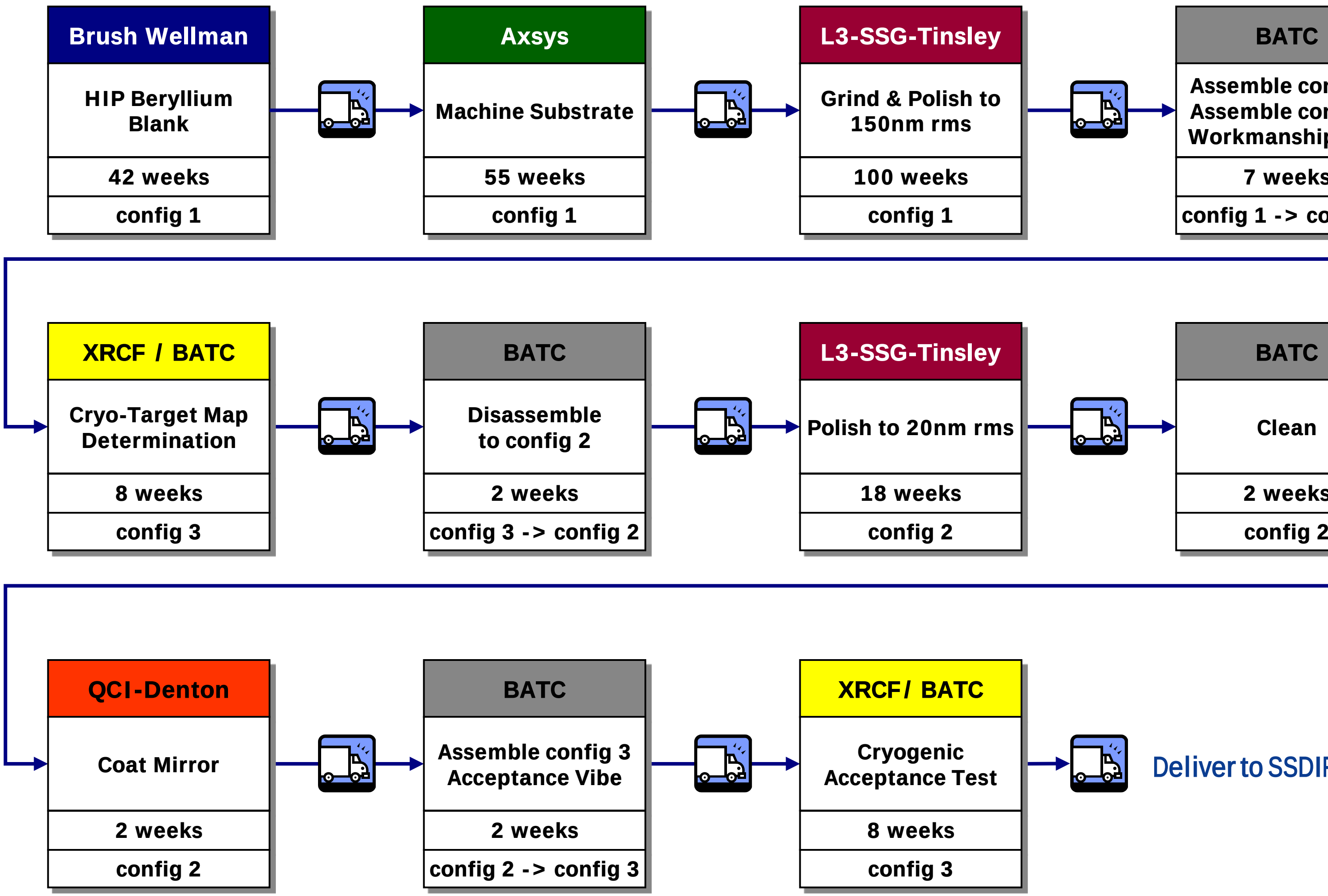
Lester Cohen	SAO, Chief Engineer
Matt Mountain	Gemini Director and JWST SWG Representative
John Hraba	MSFC
Gary Golnik	Schafer Corporation
Paul Lightsey	BATC, OTE Systems Engineer
James Hadaway	University of Alabama, Huntsville

Mirror Assembly Configurations

Configuration 1	Configuration 2	Configuration 3
		
Mirror Substrate Only	Mirror Substrate with Flexures, Whiffles and Surrogate Delta Frame	Fully Assembled PSMA with Hexapod Assembly and ROC Actuator

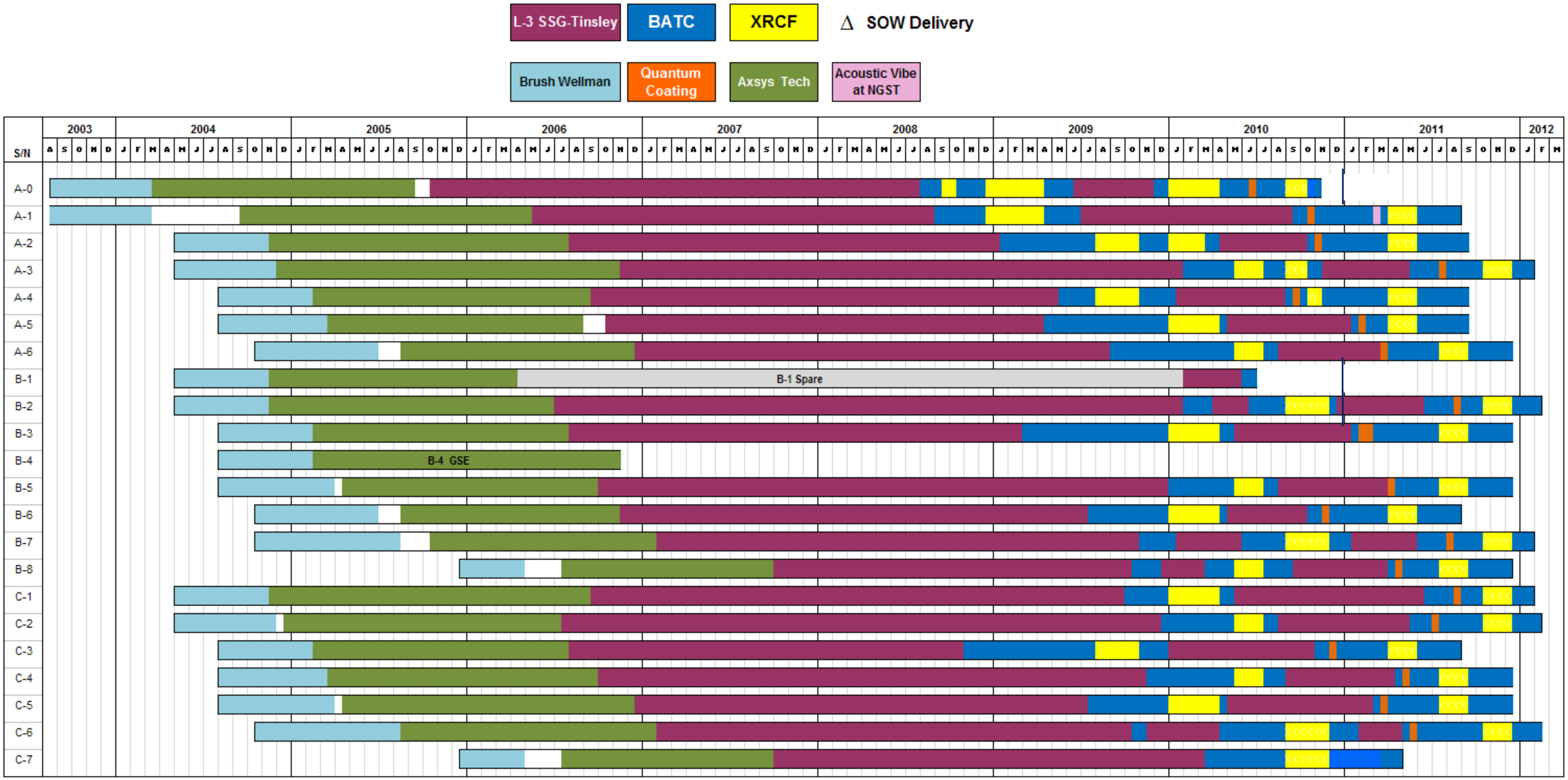
All JWST mirrors utilize similar support and actuation subsystems (PMSA, SMA, TM, FSM)

PMSA Processing Flow



Mirror production and testing involves a series of handoffs between several suppliers

Mirror Fabrication and Test Now Complete (As Run Schedule)

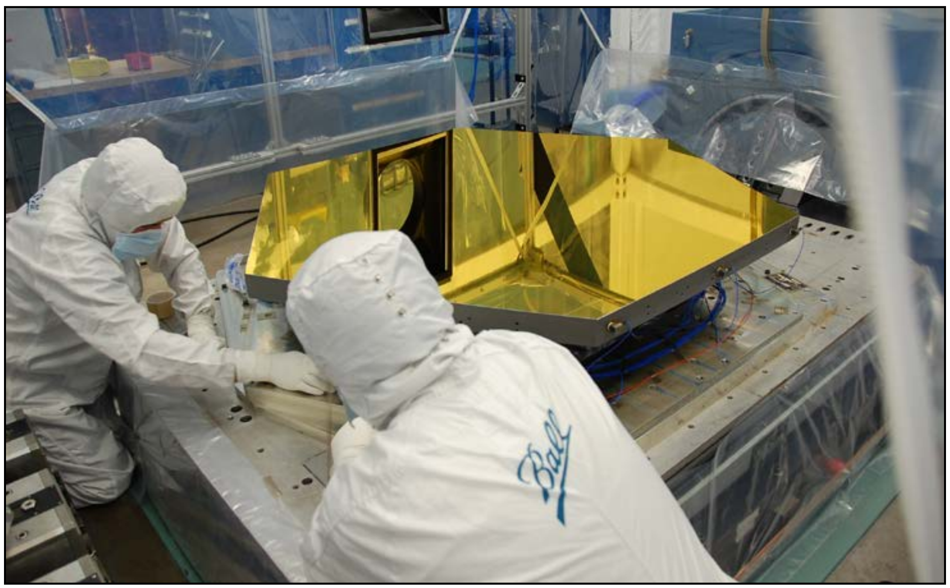


Sample of Mirror Risk Management History

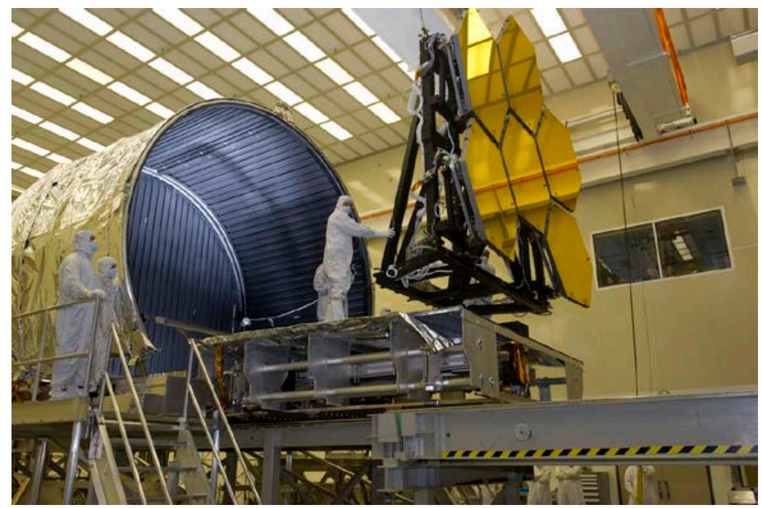
RISK Title	Likelihood	Impact	Exposure	Asignee	Dates	RISK	MITIGATION
Beryllium Mirror Optical Spec	Moderate	High	Moderate	Feinberg, Lee	Open 3/17/03 Closed 10/19/05	IF Lightweight mirrors do not meet optical spec at the segment level; THEN OTE will not meet level 2 image requirement at 2 microns	Completed fabrication of AMSD-2 mirrors 20 nm convergence task performed by Ball/Tinsley Additional AMSD-3 tasks and EDU
Beryllium mirror grinding/polishing stress characterization	Very Low	Low	Low	Feinberg, Lee	Open 4/4/03 Closed-Mitigated 3/1/11	IF the parameters that affect the residual stress created during grinding and polishing are not well understood; THEN the schedule for manufacturing the beryllium optics can easily exceed program requirements	Demonstrate Stress Controls on EDU and A1. Closed after second cryo test confirmed that cryo polishing successful.
Beryllium Mirror Performance	Low	Moderate	Low	Feinberg, Lee	Open-9/8/03 Closed-Mitigated 3/1/11	IF "Be" mirror do not converge to 20nm; THEN OTE will not meet final level 2 spec	Mitigated through additional AMSD-3 tasks and EDU, including 20nm demonstration (completing AMSD to 20nm's ambient)
PMSA Edges	Moderate	Very Low	Low	Feinberg, Lee	Open-1/23/04 Closed-Mitigated 3/1/11	IF the straylight effects of PMSA edges are not quantified and the edges processed to insure the straylight is within the acceptable limits ; THEN the level 2 encircled energy requirement may not be met and/or significant schedule slippages and cost overruns may occur.	Reviewed EDU, A1 edges, modelling of results. Metrology equipment added: Scanning Shack Hartman A1 edges met spec. EDU completed.

Environmental Testing

Acoustics

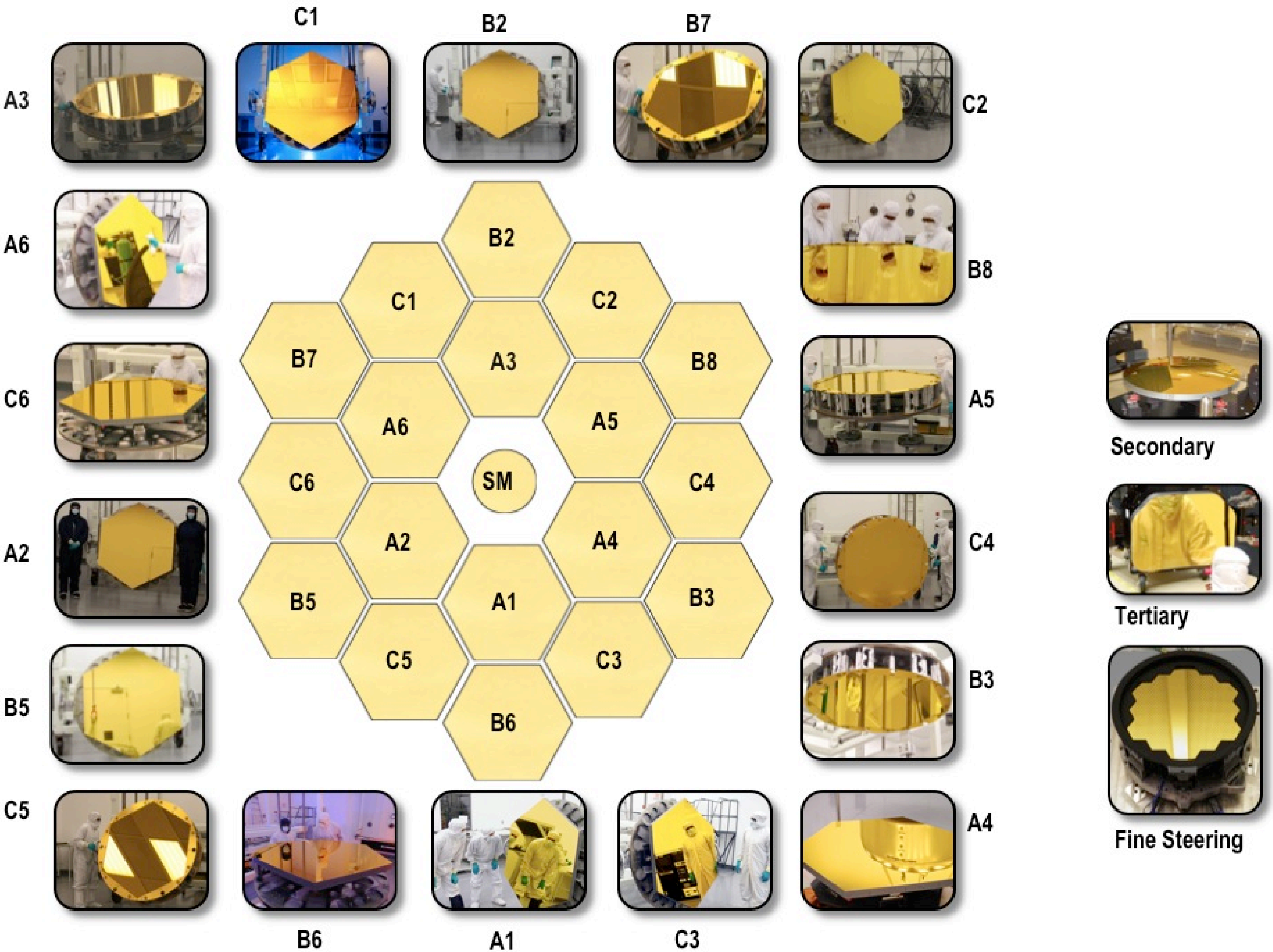


Vibe



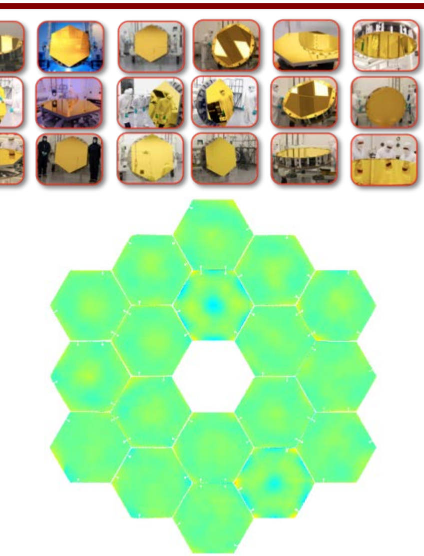
Cryo

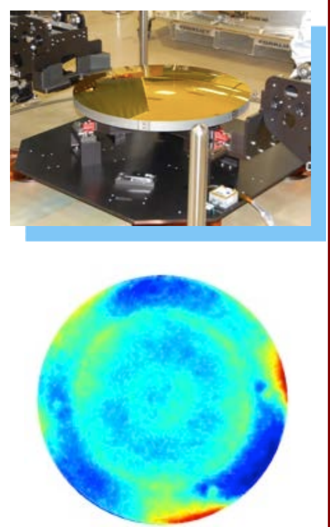
Mirror Results

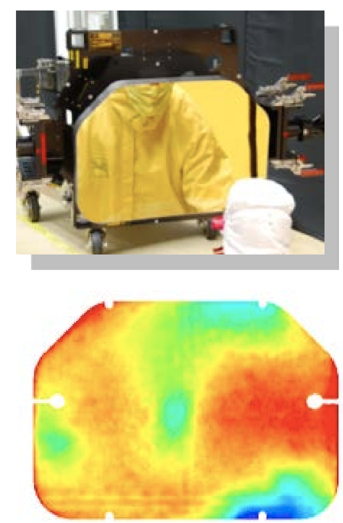


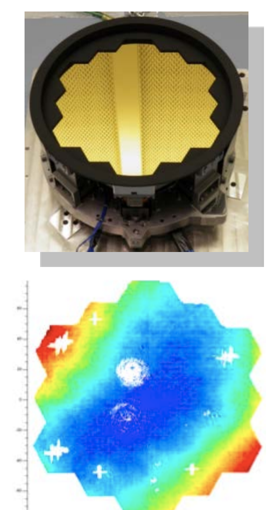
JWST Mirrors Completed in 2011

Mirror	Measured (nm rms SFE)	Uncertainty (nm rms SFE)	Total (nm rms SFE)	Req (nm rms SFE)	Margin (nm rms SFE)
Primary Mirror (18 mirror composite)	23.6	8.1	**25.0**	25.8	6.4
Secondary Mirror	14.7	13.2	**19.8**	23.5	12.7
Tertiary Mirror	18.1	9.5	**20.5**	23.2	10.9
Fine Steering Mirror	13.9	4.9	**14.7**	18.7	11.6


Primary Mirror


Secondary Mirror


Tertiary Mirror


Fine Steering Mirror

Mirror Results

	SFE total measured (nm rms)	hi freq measured (nm rms)	XRCF tot measured (nm rms)	XRCF hi measured (nm rms)	Tinsley sub aperture very hi measured (nm rms)	SFE metrology uncertainty tot (nm rms)	SFE metrology uncertainty hi (nm rms)
allocation	23.6	12.2					
max	44.2	12.5	44.0	11.7	5.8	8.2	2.3
min	16.5	8.1	15.7	7.1	2.9	8.0	2.3
rms	23.6	10.0	23.1	8.9	4.5	8.1	2.3
mean	22.4	9.9	21.9	8.8	4.4	8.1	2.3
std	7.5	1.4	7.6	1.4	0.9	0.1	0.0
cum							
A1	17.9	9.5	17.7	9.0	2.9	8.0	2.3
A2	22.2	11.2	21.9	10.7	3.4	8.0	2.3
A3	21.8	12.3	21.0	10.8	5.8	8.0	2.3
A4	17.1	8.2	16.8	7.5	3.2	8.0	2.3
A5	16.5	10.1	15.7	8.8	5.0	8.0	2.3
A6	44.2	12.5	44.0	11.7	4.5	8.0	2.3
B2	18.7	9.2	17.8	7.2	5.7	8.2	2.3
B3	18.7	9.1	18.2	8.1	4.2	8.2	2.3

	SFE total measured (nm rms)	hi freq measured (nm rms)	XRCF tot measured (nm rms)	XRCF hi measured (nm rms)	Tinsley sub aperture very hi measured (nm rms)	SFE metrology uncertainty tot (nm rms)	SFE metrology uncertainty hi (nm rms)
B5	18.4	9	18.0	8.1	3.9	8.2	2.3
B6	17.5	10.2	17.0	9.4	4.0	8.2	2.3
B7	22.6	8.9	22.2	7.8	4.3	8.2	2.3
B8	23.7	9.6	23.3	8.4	4.6	8.2	2.3
C1	22.1	9	21.5	7.4	5.1	8.2	2.3
C2	20.1	8.7	19.5	7.1	5.0	8.2	2.3
C3	18.1	8.1	17.8	7.4	3.2	8.2	2.3
C4	39.5	12.3	39.2	11.2	5.0	8.2	2.3
C5	20.5	10.2	20.1	9.3	4.2	8.2	2.3
C6	23.9	10	23.3	8.4	5.4	8.2	2.3

Surface Area Requirement: >1.4746 m2 per segment
Surface Area: 1.47533 m2 mean
Total PM Surface Area =26.55m2

See paper by Paul Lightsey for More details

The Team


Brush Wellman
James Webb Space Telescope
The "First Light" Machine
Ball
XRCF
OTE
Congratulations to the JWST Mirror Team
for successful program completion
June 15, 2011
Tinsley
C1
Metrology
QCI
Axsys Technologies

Summary

- In 8.5 years, 21 flight lightweighted, cryogenic beryllium mirrors were developed
- The original technology effort benefitted from a collaboration between NASA and other government agencies
- The development effort was led by Ball Aerospace with collaboration and input by NGAS, NASA and Academia
- The mirrors meet their top level specifications
- We overcame many technical challenges through aggressive risk management
- Our focus now is on finishing the rest of the telescope and performing system level testing