JWST Project Status for the Space Studies Board (SSB)

June 13, 2006

Phil Sabelhaus

JWST Project Manager

Topics

- JWST Introduction & Status
- Recent Technical Progress
- Results of Rebaselining
- JWST Technology
- Plan Forward
- Answers to SSB Questions
- Summary

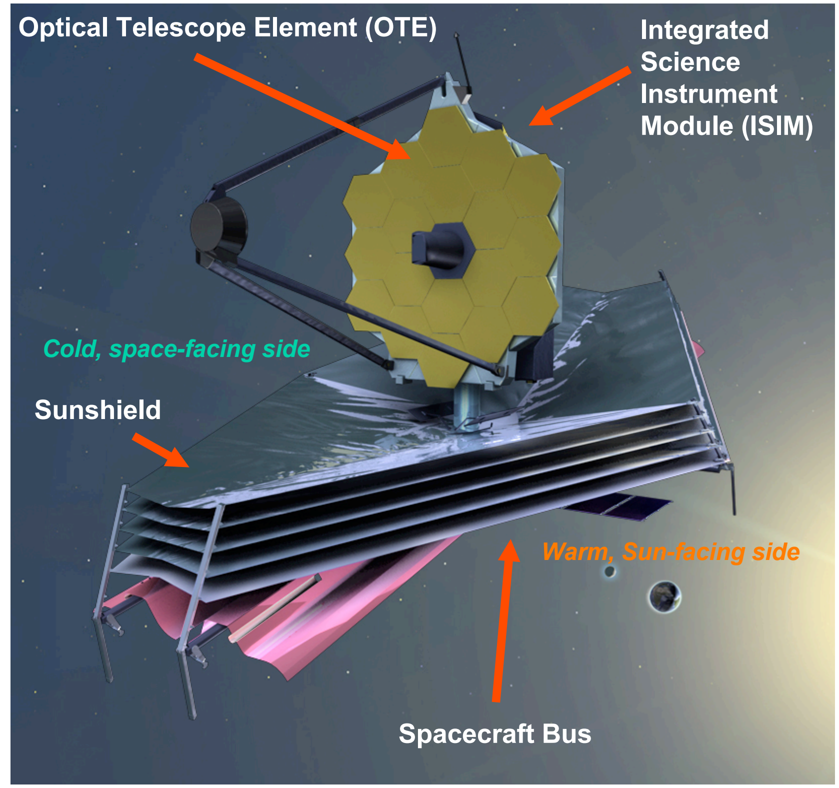
James Webb Space Telescope (JWST)

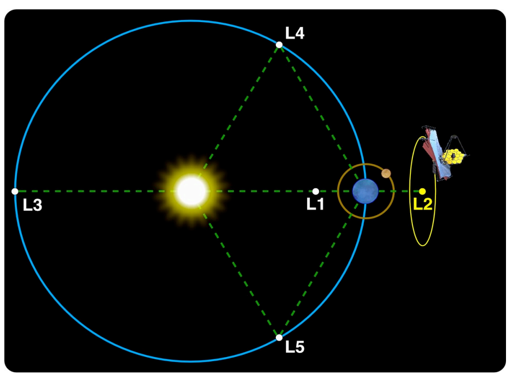
Mission Objective

- Study the origin and evolution of galaxies, stars and planetary systems
  - *Optimized for infrared observations (0.6 – 28 μm)*

Organization

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Space Technology
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA
- Operations: Space Telescope Science Institute (STScI)



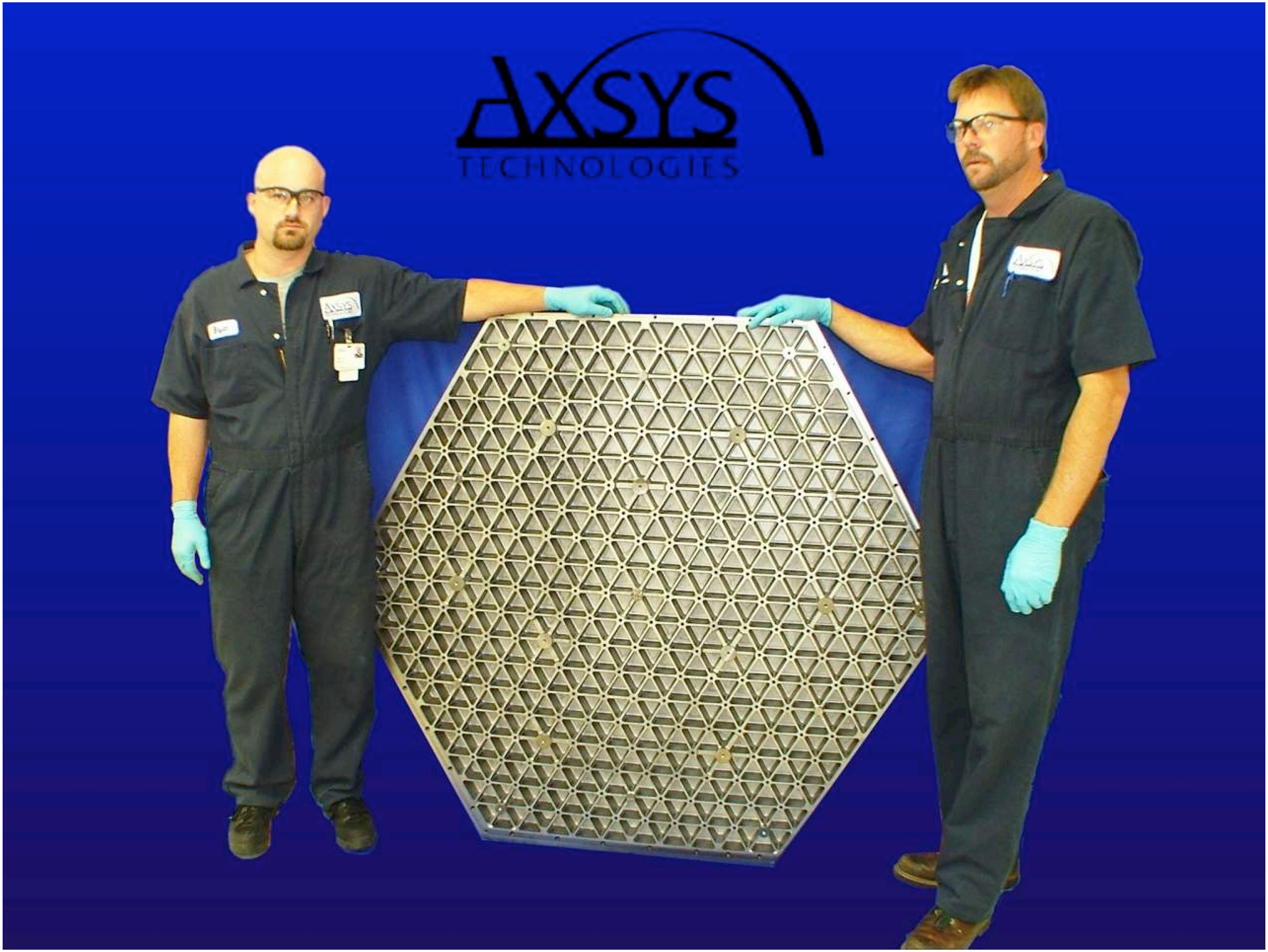


Description

- Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch NET June 2013 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov

JWST Full Scale Model at the GSFC

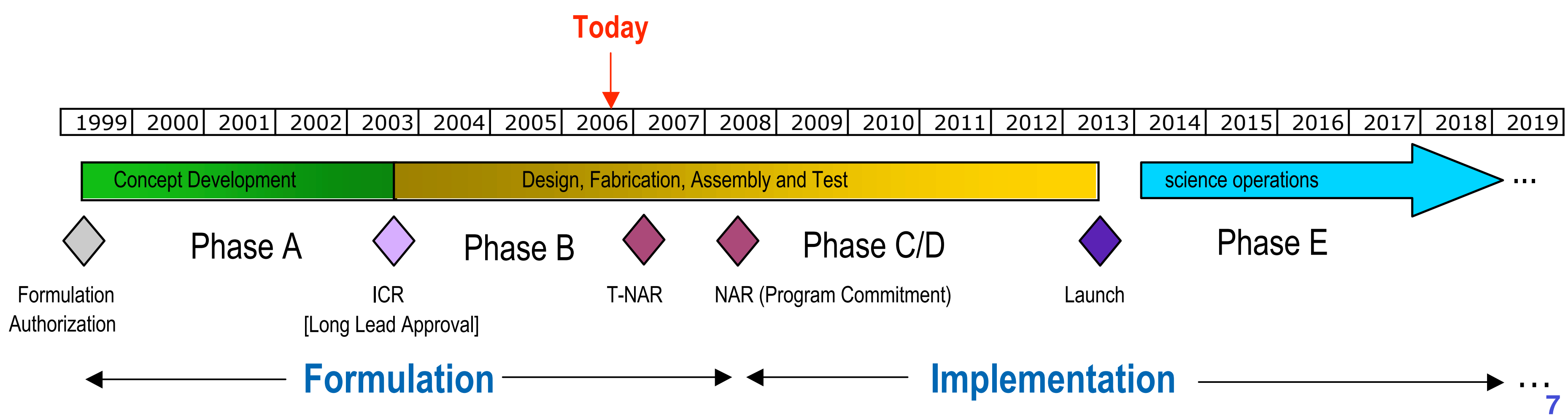

AXSYS
TECHNOLOGIES

JWST Overview Schedule

JWST Financial Fast Facts

- Current Status as of April 06 (RY$):
  - Remaining cost to 2013 launch: ~$2.5B
    - Sunk cost through end of FY06: $1.0B
      - Includes $230M early technology development investment
- Operations (RY$):
  - Direct support to university and other institution users: ~$25M/yr
    - Ten year operations and data analysis: $890M

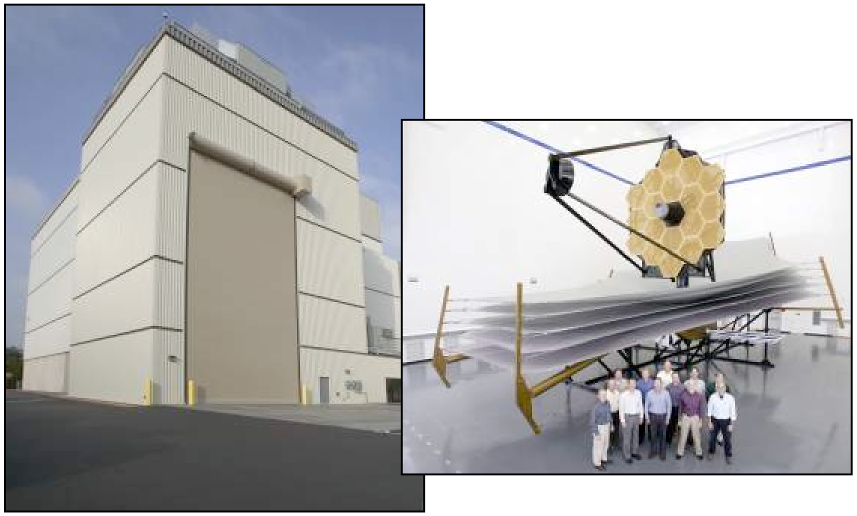
Mission Comparison ($B)			
	HST	Chandra	JWST (Projected)
Phase A-D	4.1 (FY06)	3.4 (FY06)	3.3 (FY06)
Lifecycle	7.5 (RY)	3.1 (RY)	4.5 (RY)



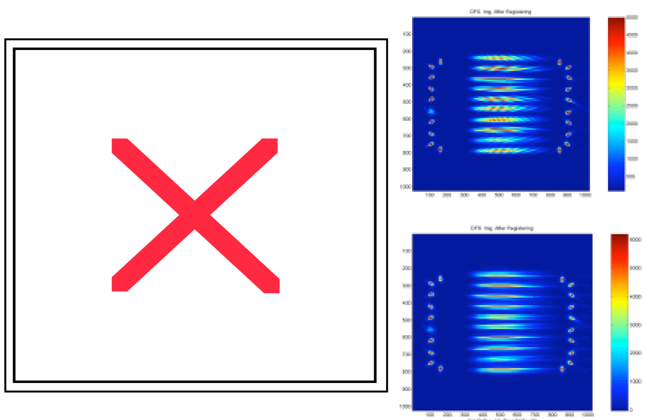
JWST Status

- Rebaselining activities are complete
  - Results presented to the Agency Program Management Council (PMC) on April 13th
- Approval to use the European Space Agency (ESA) provided Ariane 5 launch vehicle was received in December 2005 (including approval of the Technical Assistance Agreement between Northrop Grumman and Arianespace
  - Initial interface definition meeting with Northrop and Arianespace held in May 2006
- Continuing to make excellent progress towards the June 2013 Launch Readiness Date (LRD)
  - Successful System Definition Review (SDR) in January 2006
  - Flight Primary Mirror (PM) production is on schedule; all 18 flight primary mirrors have started or completed the machining process; the first two were completed last month; the rest will be completed by the end of 2006
    - PM Engineering Development Unit (EDU) is being polished at Tinsley
  - Instrument Critical Design Reviews (CDRs) start this year
    - NIRCam CDR was held at the end of May
  - All mission critical technologies are on schedule to be demonstrated in a space like environment by the end of 2006

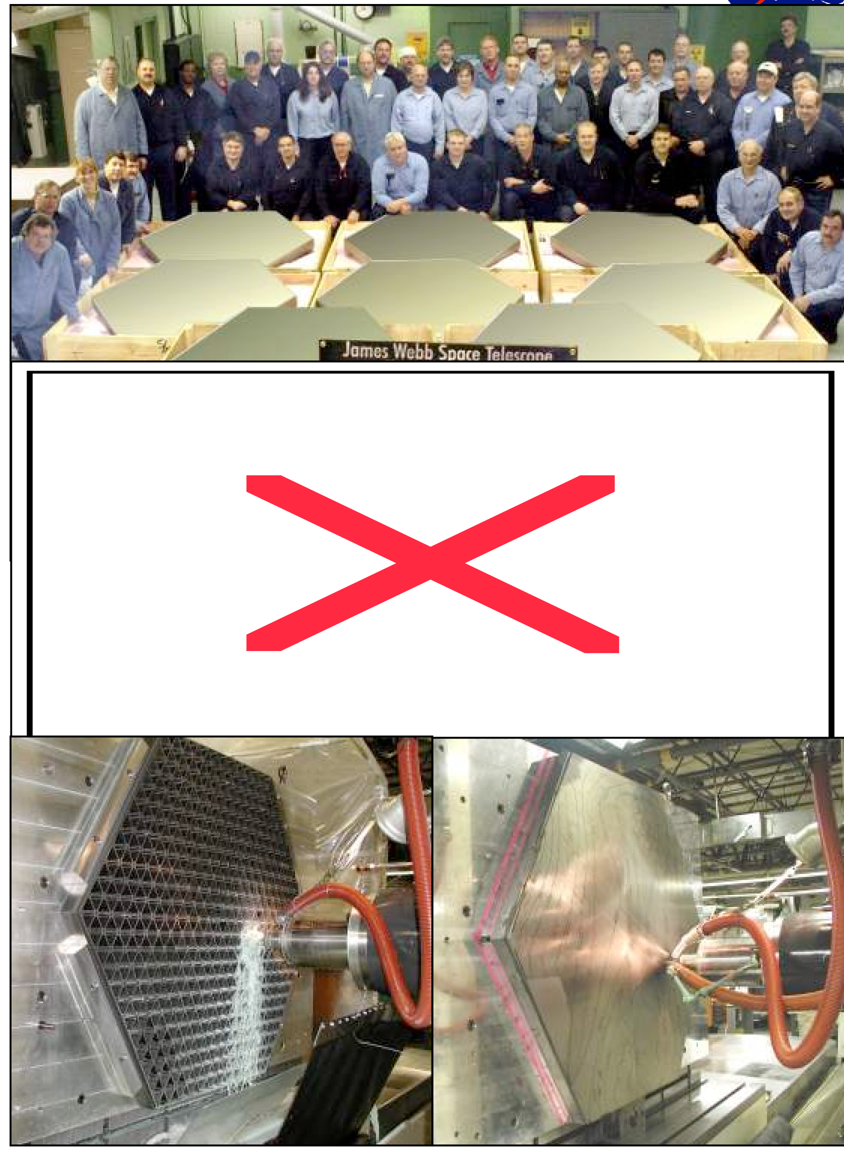
Recent Progress – *"JWST is under Construction"*



Completed new 10,500 sq. ft. Class 10K high bay for Observatory integration and test

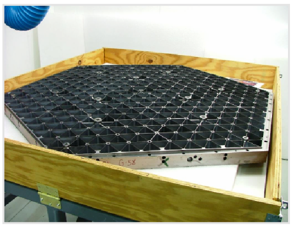


Conducted successful experiment at Keck Observatory to prove wavefront sensing coarse phasing approach



Completed manufacturing of all flight beryllium mirror blanks with 17 of 18 flight mirrors in precision machining

Flight Primary Mirror Segments in Machining at Axsys



COMPLETE!!
PMSA #1 (EDU-A / A1)

PMSA #2 (6 / B2)

PMSA #3 (4 / C1)

PMSA #4 (5 / A2)

COMPLETE!!
PMSA #5 (3 / B1)

PMSA #6 (7 / C2)

PMSA #7 (13 / A4)

PMSA #8 (11 / B3)

PMSA #9 (12 / C3)

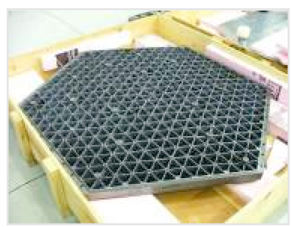
PMSA #10 (16 / A5)

PMSA #11 (17 / B5)

PMSA #12 (15 / C4)

PMSA #13 (8 / A3)

PMSA #14 (20 / B6)



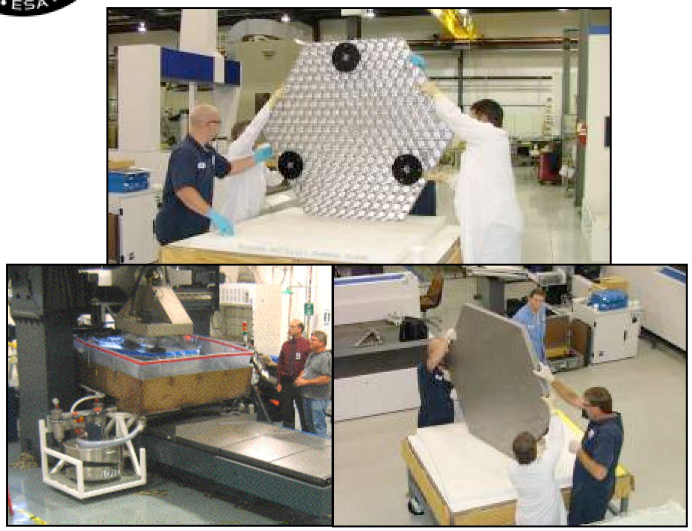
PMSA #15 (18 / C5)

PMSA #16 (19 / A6)

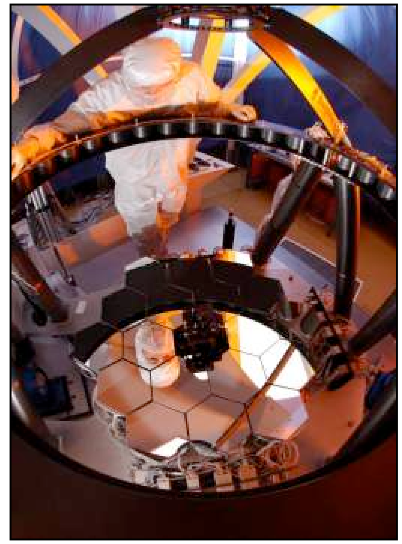
PMSA #17 (22 / B7)

PMSA #18 (21 / C6)

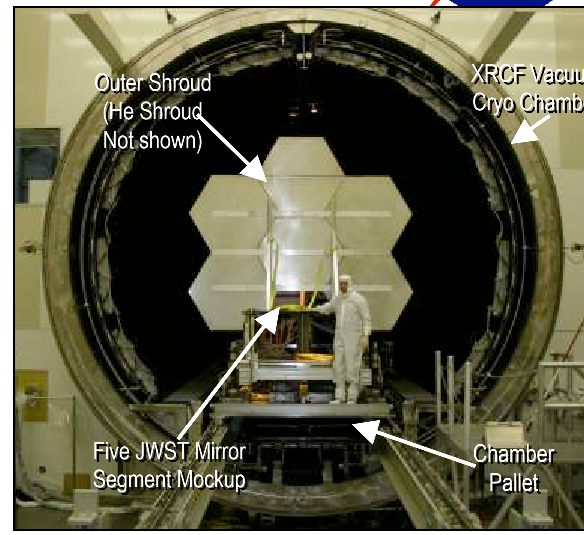
Recent Progress (continued)



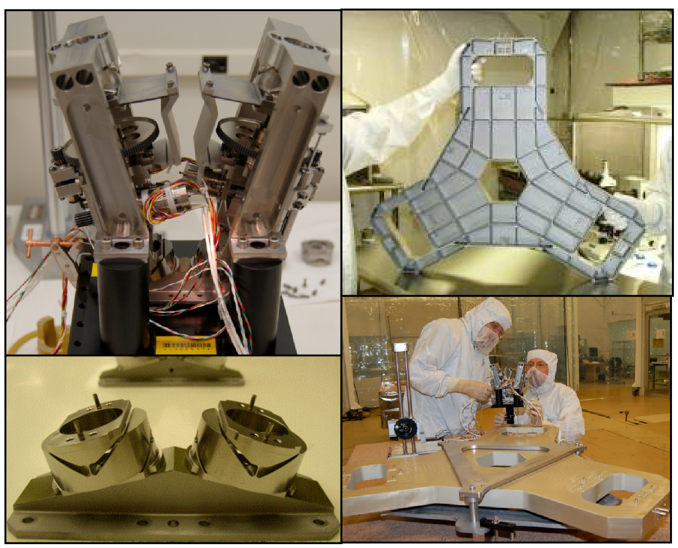
Engineering Model mirror completed precision machining and undergoing grinding



Completed 1/6th scale Test Bed Telescope integration and initial alignment to prove wavefront sensing and control algorithms



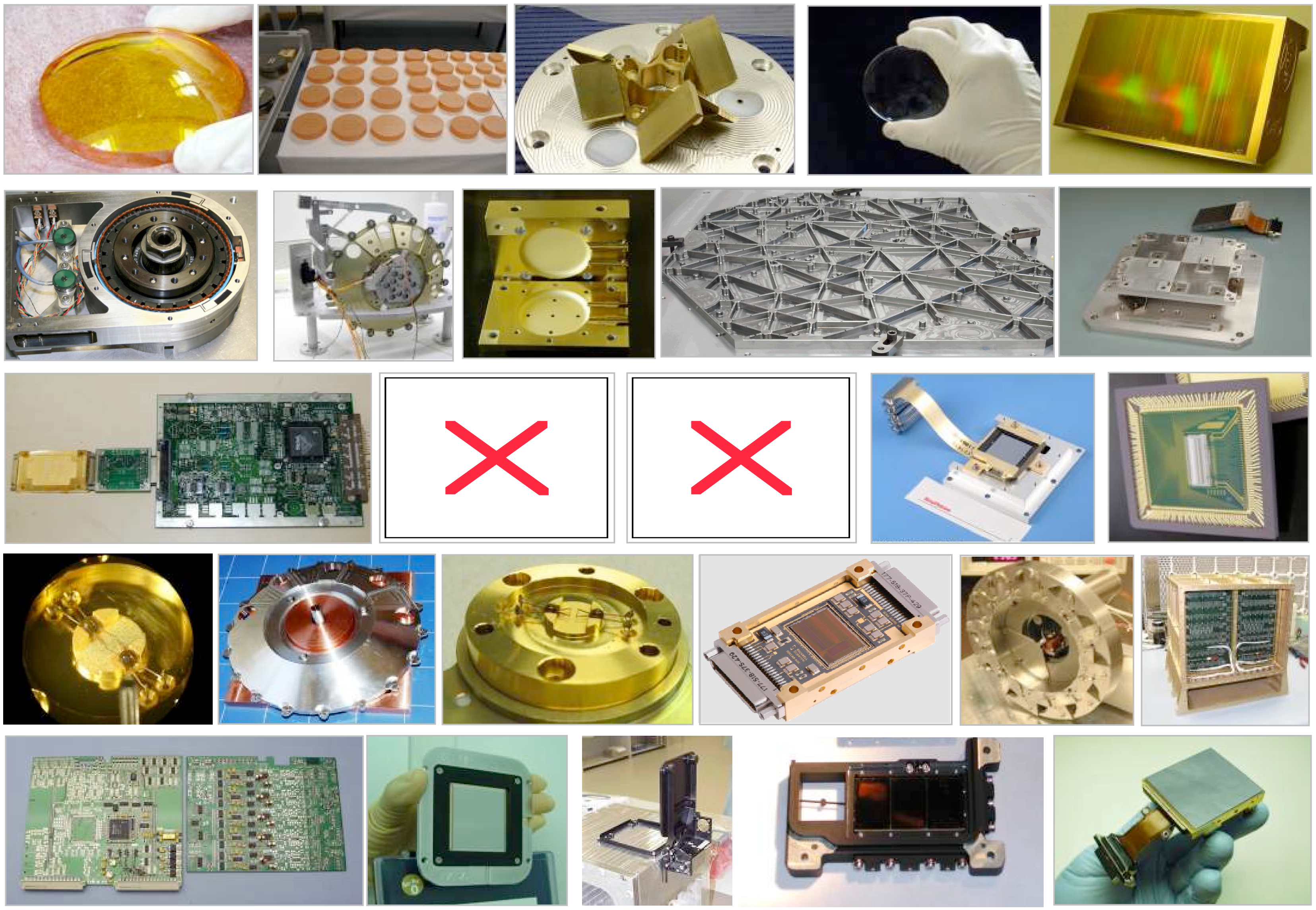
MSFC X-Ray Calibration Facility being readied to test mirrors at cryogenic temperatures



EM mirror support structure and actuators are complete

Completed fabrication of parts for cryogenic Backplane Stability Test Article and GSFC proved innovative metrology concept

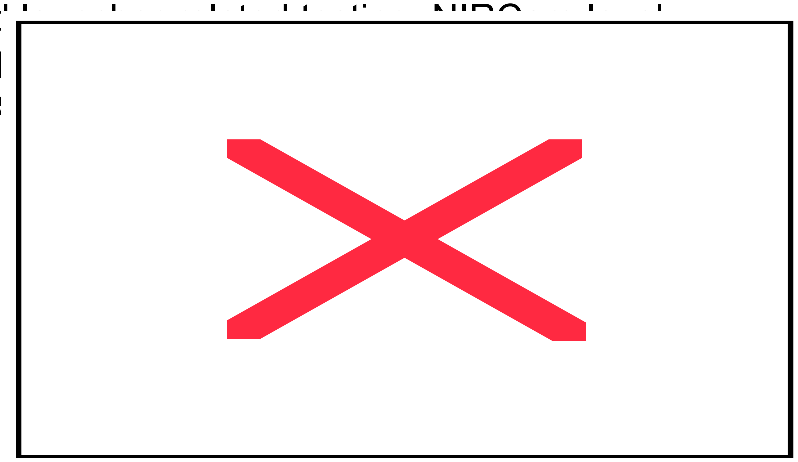
Instrument Hardware in Production



Cost Growth and Rebaselining Results

JWST Cost Growth History

- Over the course of the formulation phase, the Project's estimate for completion of JWST has increased
  - Growth driven by both external and internal factors
- Net life cycle cost growth from $3.5B to $4.5B in RY$'s since 2004 baseline
  - 30% growth ($1B)
- Majority of this increase due to external factors
  - 15% ($530M) due to 22 month launch delay:
    - Delay in approval for Ariane 5 launch vehicle
    - Fiscal year funding limitations through 2007
  - 4% ($125M) due to added contingency budget reserves
- Balance of growth due to project internal changes
  - 11% ($386M) due to changes in requirements and growth in implementation
    - Cost increases in getting major suppliers under contract
    - Architecture changes: cryocooler, ASIC control of detectors, dedicated ISIM electronics compartment, added pupil imaging lens, etc
    - I&T reevaluation: test facility changes, added wavefront sensing testing, cryogenic telesco
    - Cost growth in instruments: detectors, micros
- Remaining cost to 2013 launch: ~$2.5B

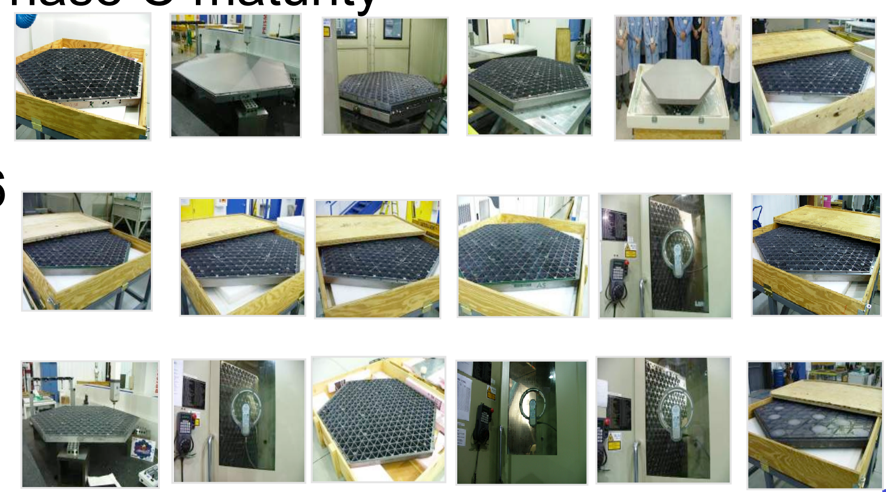


Changes resulting from Rebaselining

- Completed Project Rebaselining within the parameters established last September
  - Estimated Development Cost to Launch last September was $2.8B and is still $2.8B ($2.5B month end May 2006)
  - LRD was June 2013 and is still June 2013
  - Funded schedule reserve was 8 Months and is still 8 months
  - Non Advocate Review (NAR) was January 2007 and is now the Spring 2008
    - Still plan to complete technology demonstrations by January 2007 at the Technology NAR
    - Moved to coincide with the Mission Preliminary Design Review (PDR)
  - PDR was March 2008 and is still March 2008
  - Contingency on cost to launch through liens was 18% is 18%

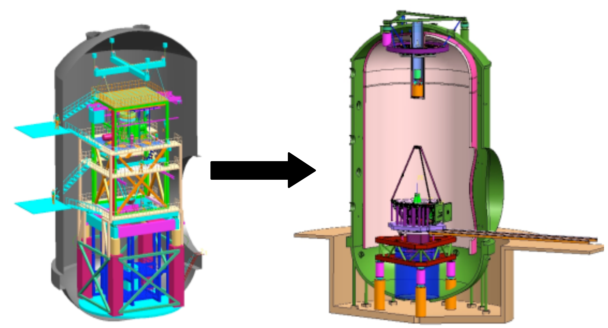
JWST Cost Stability Achieved

- Factors that influenced past growth are now resolved or mitigated
  - Use of Ariane launch vehicle has been approved
  - All major suppliers are under contract
  - Test facilities have been selected
  - Architecture definition is complete
    - Interface requirements are defined
  - Scope of work defined and documented for all elements
  - All mission enabling technologies will be demonstrated in 2006
    - Technology development risk retired six years before launch
- Key elements are mature, in or approaching Phase C (critical design)
  - 55% of Observatory mass is at Phase C maturity
  - All Instruments in Phase C
  - Telescope subsystems begin critical design (Phase C) in 2006
  - Long-lead Flight hardware is in production



JWST Cost Stability (Continued)

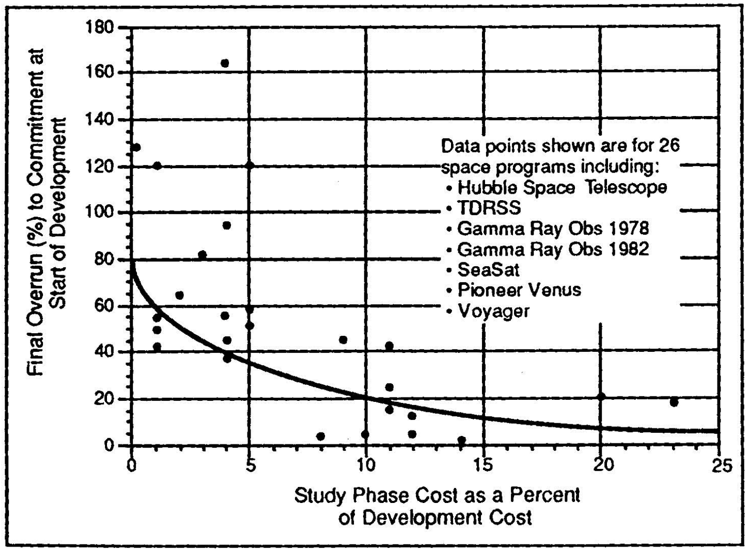
- Project decisions have lowered overall technical/schedule/cost risk
  - Architecture and interfaces simplified via trade studies
    - Standard Launch Vehicle Adapter
    - Dedicated ISIM Electronics Compartment
    - Cryo ASIC for detector data A/D conversion
  - Test program more robust
    - "Cup Up" Telescope Integration and Test
    - Cryo Telescope Simulator for ISIM-level testing
    - Added Wavefront Sensing Testing at NIRCam-level
    - JSC facility selected for OTE testing
  - Science Assessment Team requirement relaxations implemented



- Schedules are baselined & have adequate contingency
- JWST government and contractor team have relevant experience
  - Key players in the development of HST, Chandra, and Spitzer
  - Extensive experience in space flight deployable systems
- Project estimate validated by NASA HQ independent review team
  - SRT Independent Cost Estimate (ICE) using Price H was within 5% of the project's estimate
  - EAC has been stable for a year; no change as a result of independent review

JWST Following Low Cost Risk Strategy

- Studies have shown that the risk of overrun at completion declines with the increase in investment in Phase A/B
  - An analysis of 26 missions showed that the risk of cost growth was less than 5% when more than 25% of development cost was spent during the study phase

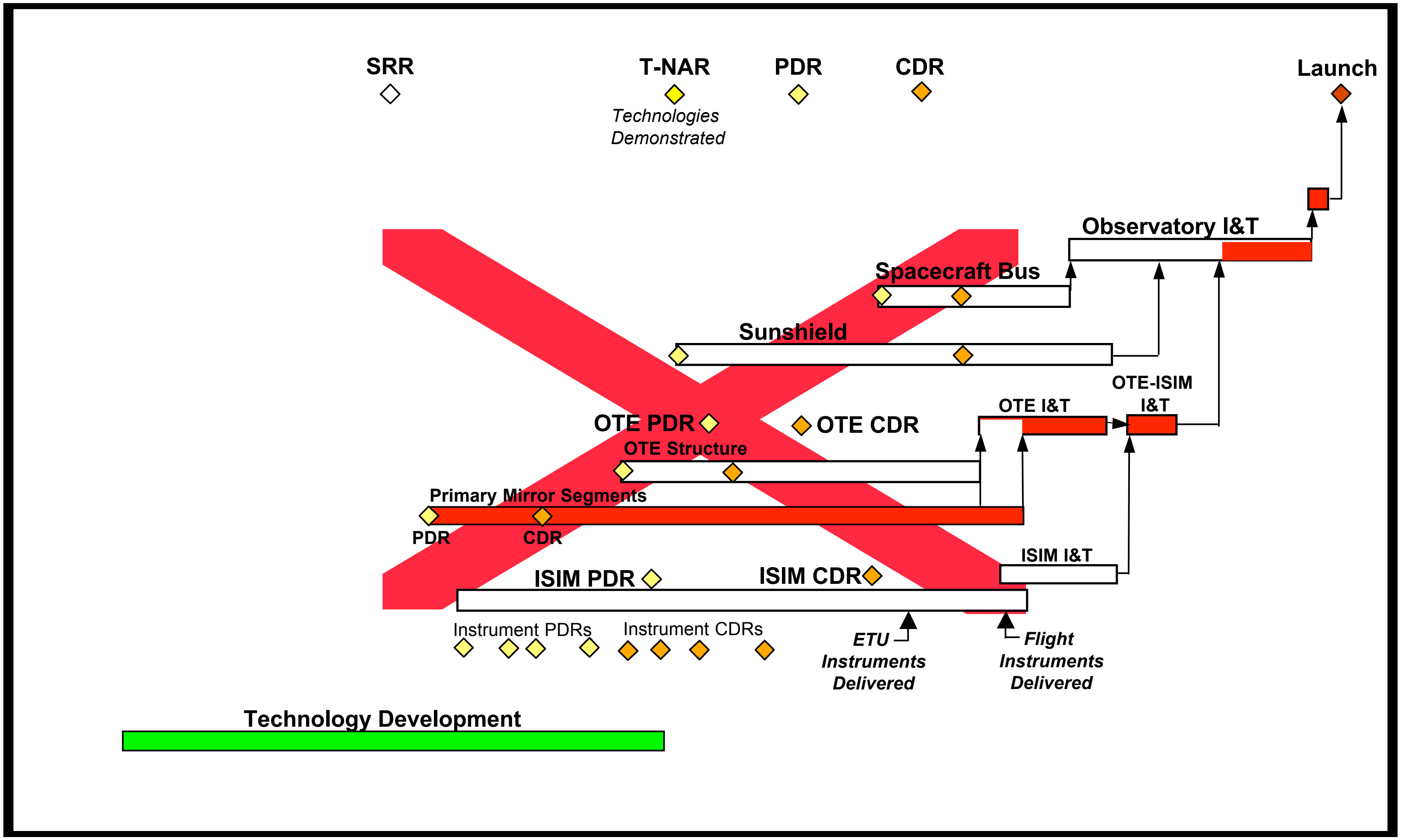


NASA Engr Mgmt Council Report 1992

- JWST will spend 49% of its total cost by the end of Phase B in March 2008
  - Unprecedented for a NASA project of this size
- Expenditures through FY 2006 will be 32% of total development cost
  - Already a significant indicator of total cost stability
- Early spending in technologies and architecture definition lower overall risk

Major Milestones vs Cost Profile

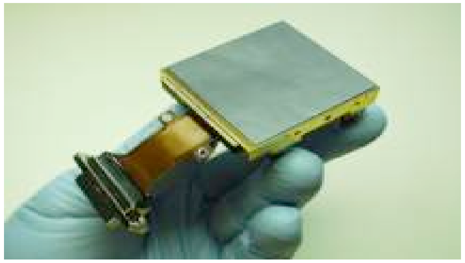
- JWST rapidly approaching its spending peak



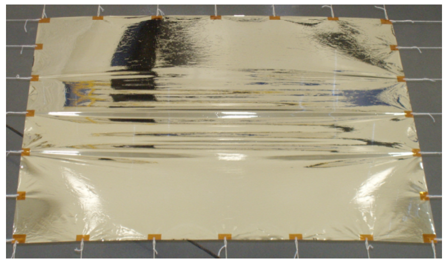
JWST Technology

Technologies Demonstrated in 2006

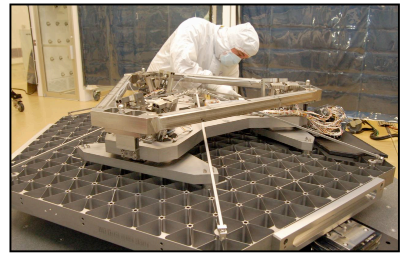
(All our mission critical technologies)



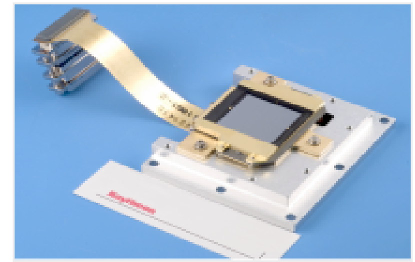
Near Infrared Detectors √
April 2006



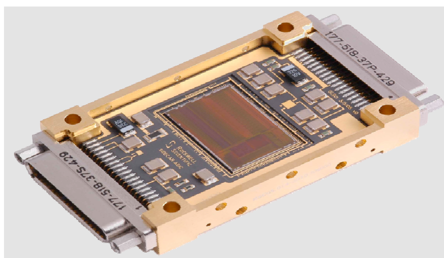
Sunshield Material √
April 2006



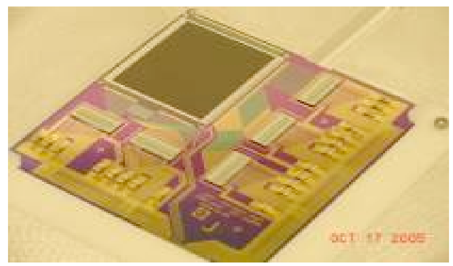
Primary Mirror Segment Assembly
June 2006



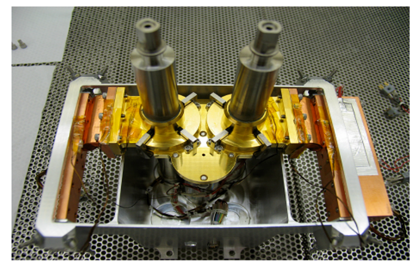
Mid Infrared Detectors
July 2006



Cryo ASICs
August 2006

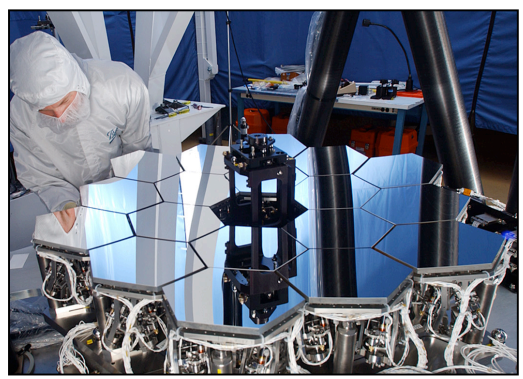


Microshutter Arrays
August 2006

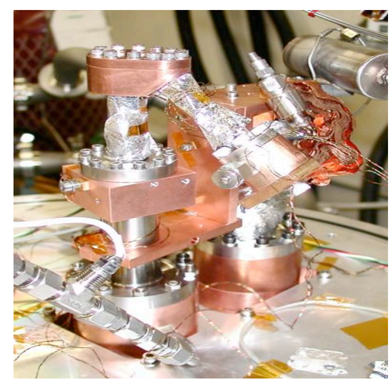


Heat Switches
September 2006

Large Precision Cryogenic Structure
November 2006



Wavefront Sensing & Control
November 2006



Cryocooler
December 2006

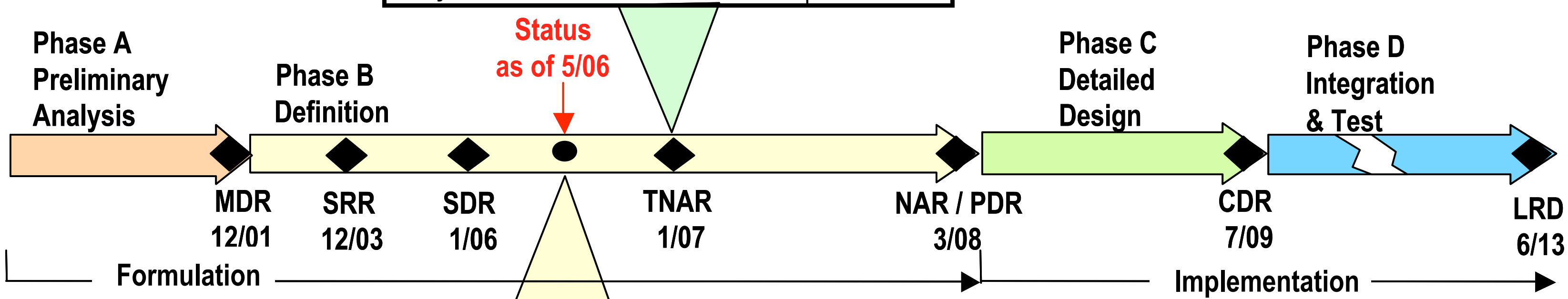
Observatory Oversight

- JWST key technology areas have rigorous oversight from Product Integrity Teams (PIT) with extensive large optics and flight experience e.g. OTE PIT
  - James Wyant, University of Arizona, Co-chair
  - Duncan Moore, University of Rochester, Co-chair
  - Bob Gehrz, University of Minnesota
  - Bob Shannon, University of Arizona
  - John Mangus, Private/Ex-GSFC
  - Robert Laskin, JPL
  - Roy Frieden, University of Arizona
  - Jim Burge, University of Arizona
  - Mark Kahan, ORA
  - Jim Fienup (University of Rochester)
  - Gary Chanan, UCI
  - George hartig (STScI)
  - John Hayes, 4D Technologies
  - Mike Krim, Private/Ex-Goodrich
  - Greg Forbes, QED
  - Matt Mountain, Gemini Observatory
  - Larry Step, Gemini Observatory
- Wavefront Sensing and Control PIT
- Deployment Review Team
- Sunshield PIT

Plan Forward

Design Plan

Technology Development Hardware	TRL-6 Status
NIR Infrared Detectors	Complete
Sunshield Materials	Complete
Light Weight Cryogenic Mirrors	Jun-06
Mid Infrared Detectors	Jul -06
Microshutter Arrays	Aug-06
Cryogenic Detector Readout ASICs	Aug-06
Cryogenic Heat Switches	Sep-06
Large Precision Cryogenic Structure	Nov-06
Wavefront Sensing and Control	Nov-06
Cryocooler	Dec-06

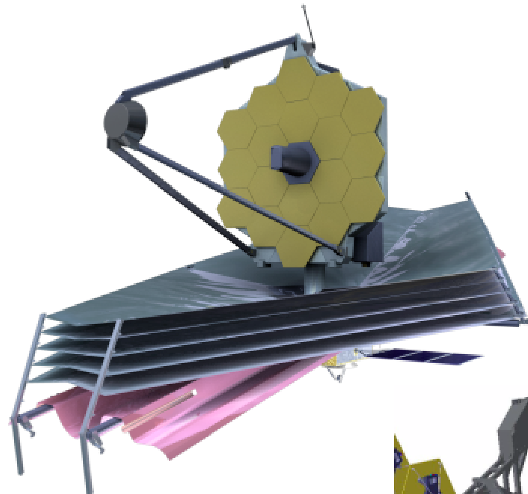


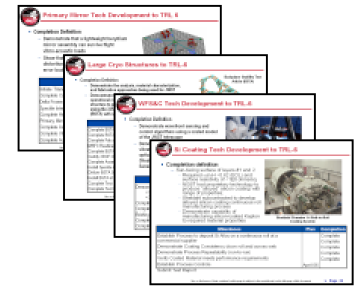
System Components	SRR	PDR	CDR
System	Dec-03	Mar-08	Jul-09
Observatory	Dec-03	Mar-08	Jul-09
Optical Telescope Element (OTE)	Mar-03	Apr-07	Apr-08
Primary Mirror Segments	Jan-04	Jul-04	Sep-05
Backplane Assembly	Aug-04	Jun-06	Apr-07
Integrated Science Instrument Module (ISIM)	Mar-04	Oct-06	Dec-08
Near-Infrared Camera (NIRCam)	Nov-03	Oct-04	May-06
Near-Infrared Spectrograph (NIRSpec)	Oct-04	Dec-05	Jan-08
MIRI Optics Systems	Mar-04	Dec-04	Oct-06
MIRI Cooling System	Feb-07	May-07	Mar-08
Fine Guidance Sensor (FGS)	Apr-04	May-05	Nov-06
Tunable Filter (TF)	Apr-04	May-05	Mar-07
ISIM Flight Software (FSW)	May-04	Feb-06	Mar-07
Spacecraft Bus	Oct-04	Sep-08	Sep-09
Sunshield	Oct-04	Jan-07	Sep-09
Observatory FSW	May-05	Sep-07	Oct-08
Ground Segment	Oct-04	Dec-08	Dec-09

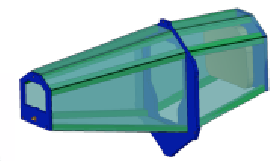
Pending
Completed

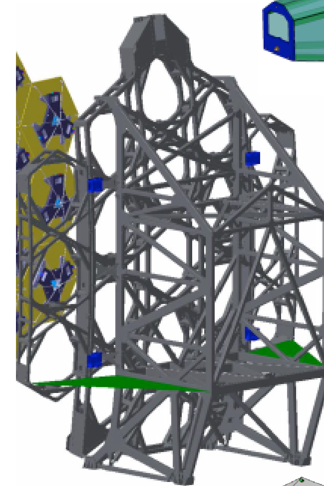
Major Efforts in FY07

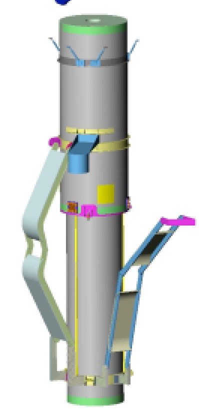
- Technology NAR
- Observatory Definition Review
- ISIM PDR
- FGS CDR
- Optical Telescope Element PDR
- Backplane CDR and start of flight manufacturing
- Deployed Tower Subsystem PDR
- Primary mirror fine grinding, and secondary mirror precision machining
- Sunshield PDR, folding model test and membrane fabrication
- Optical simulator design and fabrication
- Aft Optics Subsystem (AOS) CDR, fabrication and test

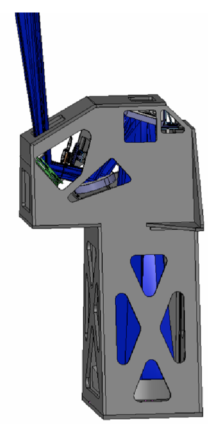


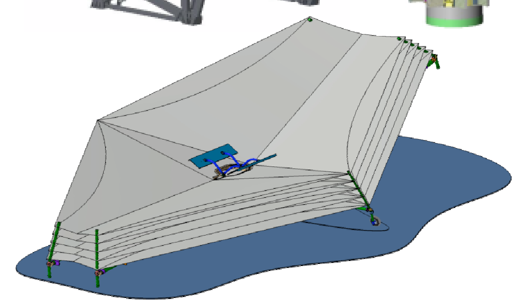










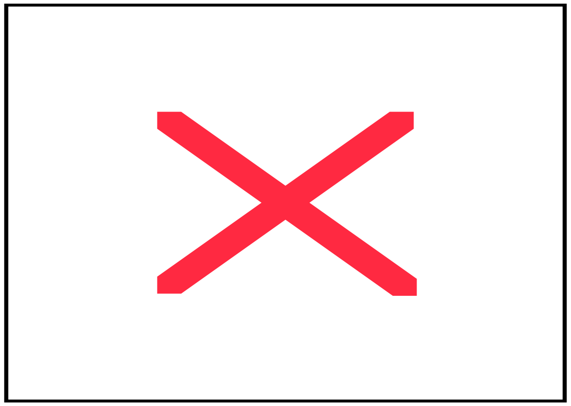


Use of Pathfinder Hardware

- A complement of Pathfinders, Test Beds and Engineering Test Units (ETUs) is integrated into the verification / I&T program to (ala Chandra):
  - Provide early and / or pre-emptive insight into opto-mechanical and thermal parameters
    - Early validation of critical analytical models
  - Provide dress rehearsals of the setups for the system tests
  - Some of the pathfinders and ETUs double as critical Ground Support Equipment for system tests
    - NIRCam and FGS ETUs are used for OTE tests
    - OTE Engineering Model (EM) used for Spacecraft Structural tests
  - Pathfinder / ETU components can be used as flight hardware surrogates for I&T work arounds, if needed
- Major Pathfinders / ETUs include:
  - OTE Pathfinder
  - Sunshield Evolutionary Pathfinder
  - Primary Mirror Engineering Development Unit
  - Backplane Stability Test Article
  - Sub-scale Observatory Thermal Test Model
  - ETU ISIM which includes ETU ISIM structure, NIRCam, FGS
  - Test-Bed Telescope

CCOS Grinding Progress on EDU

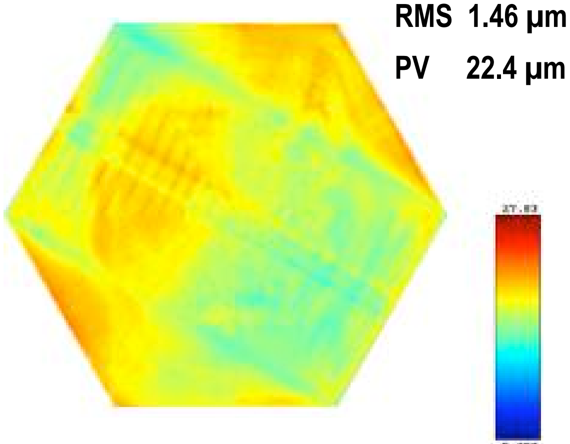
PRE CCOS PROCESSING FIGURE
1/10/2006

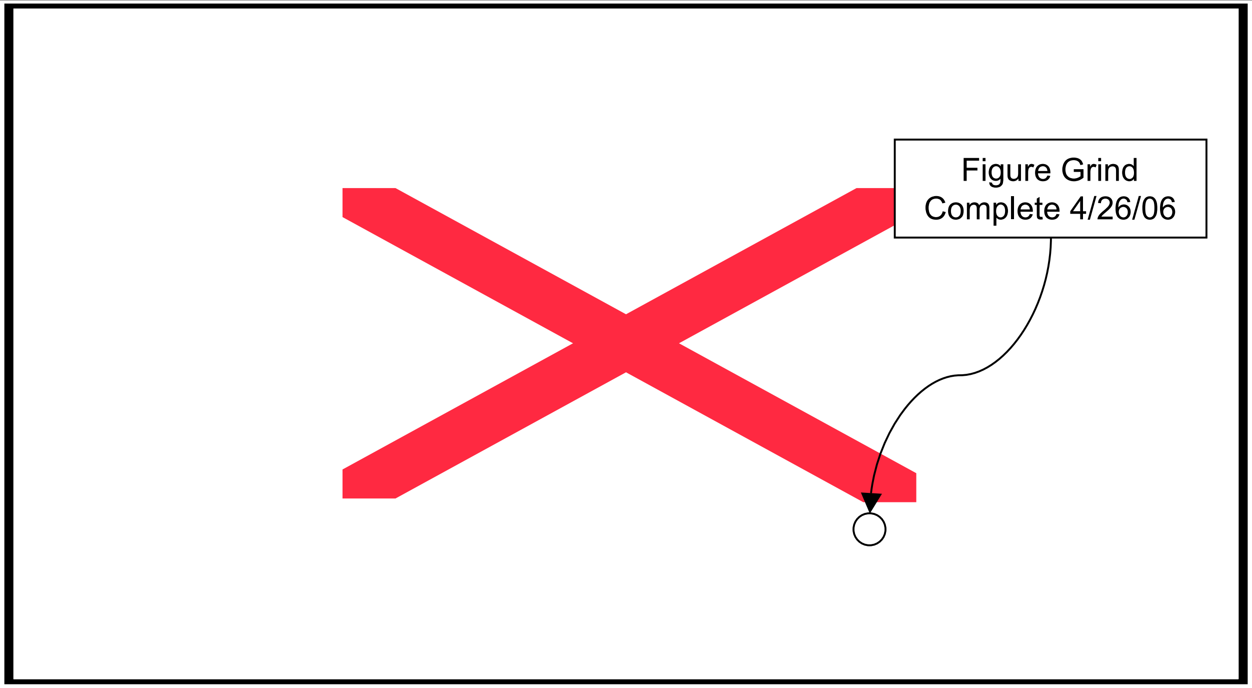


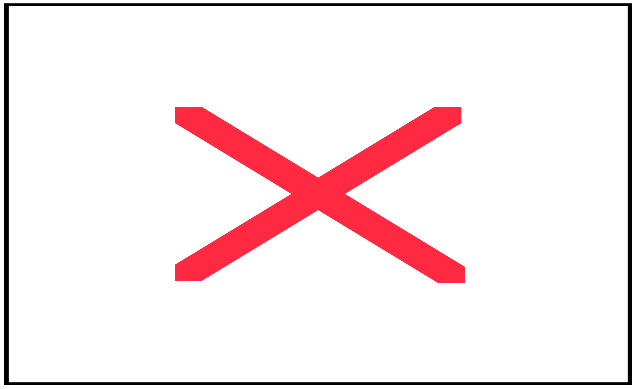
POST 15th GRIND ITERATION FIGURE
4/21/2006

RMS 1.46 µm

PV 22.4 µm





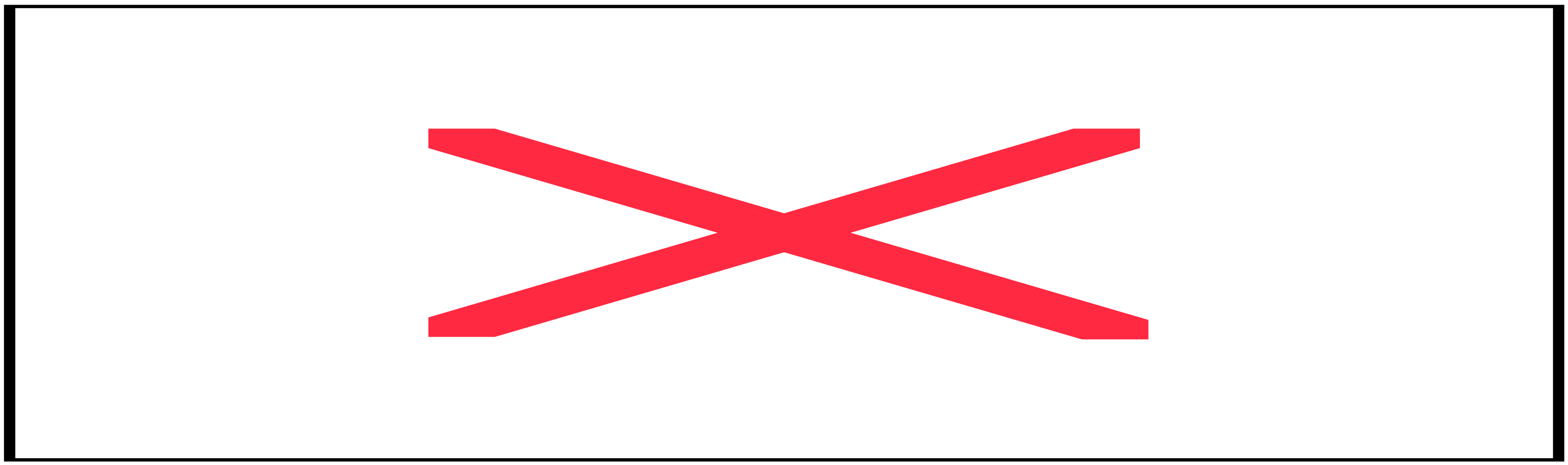


- Figure Grinding Operation converged faster than schedule baseline.
- Bending from stress flattened out during Even Slice Grinding just as predicted from Experiments after 0.0006” evenly removed.
- Segment B1 will start out the grinding process >2.5x BETTER than the EDU

Answers to SSB Questions

JWST Reserves/FCA Impacts

- **Schedule Reserve**: 8 months of funded (included in the budget) through launch
- **Budget Reserve:** 19% set aside as unencumbered dollar reserves through launch
- **Technical Reserves:**



Impact of Full Cost Accounting (FCA): NASA implemented FCA in the FY2005 budget. This increased the project's total cost by ~13%

JWST Primary Concerns/Mitigations

TECHNICAL

•**Backplane stability at cryogenic temperatures**

- Cryogenic test of Backplane Stability Test Article (BSTA--represents one sixth of the total backplane structure) will validate the models and analytical approach being used to predict stability of the complete flight backplane structure and help validate backplane design

• **System optical testing**

- Multiple, independent modeling techniques being applied to series of cases to show that optical testing approach will work and that the overall optical requirements will be met
- Periodic reviews by independent panel of optical experts [JWST Optical Product Integrity Team (PIT)] adds rigor and ensures realistic planning

•**System-level cryogenic testing**

- Incremental, recursive approach (model>integrate>test>analyze/validate/verify) similar to Chandra and Spitzer; applied to pathfinder and engineering test unit (ETU) hardware before flight hardware
  - Validates and verifies procedures without risking flight hardware
  - Finds problems off of critical path, allows time for fixes without moving launch
- Healthy funding reserves and funded, unallocated schedule slack in the cryogenic testing years provides flexibility to address unknown-unknowns, adds confidence to schedule

JWST Primary Concerns/Mitigations

PROGRAMMATIC

- **Budget Uncertainty**
  - Project rebaseline produced detailed plan & schedule for a June 2013 launch readiness date within NASA Headquarters Science Mission Directorate (SMD) provided budget profile
  - SMD Chartered Special Review Team (SRT) found budget contingency levels to be low in the early years compared with current standards
  - Project has proposed to SMD rephasing of budget contingency from later to earlier years (The total budget value for contingency is unchanged)
  - SMD work with NASA Advisory Council Astrophysics subcommittee to consider programmatic mix for FY08 budget preparation
  - Need budget stability to execute the plan

- **NASA technical insight into the launch readiness of the Ariane 5 launch vehicle**
  - Inclusion of language in ESA/NASA Joint Project Implementation Plan (JPIP) ensures NASA participation in all of the major launch vehicle reviews

- **Impact of U.S. ITAR laws on communications [risk to systems engineering, mission success]**
  - CSA: FGS related work:
    - FGS prime contractor COM DEV has received State Dept approval to share ITAR data
    - CSA proposal has potential to remove the barriers without compromising the laws of either the U.S. or Canada
  - ESA: NIRSpec, MIRI, Ariane related work:
    - No issues; diligence continues

JWST's System PDR

- The SSB forwarded the following question:
  - By traditional criteria, JWST appears to be in Phase C/D already. Why do you consider it to still be in Phase B?

- A linear sequence of mission phases is used by NASA as part of their formal process of confirming that programs are sufficiently mature to warrant authority to proceed to successive phases; an overlap of activities among the phases is not unusual
- A successful mission-level PDR is among the standard NASA criteria for agency approval to enter Phase C
  - However, the agency can and does approve Phase C/D long-lead starts in Phase B, such as the JWST mirrors and detectors
- GSFC/NASA standards for a successful mission-level PDR tend to drive programs to complete lower-level PDRs prior to the mission PDR
- While many parts of JWST are past PDR,and some are past CDR, others will not reach PDR until 2008
  - From a budgetary perspective, it is most efficient to conduct the program this way in order to manage early-year spending and to control marching army costs; efforts are not started until they are needed
- The JWST System PDR has therefore been set for March 2008 to maximize the data available for a successful review of the entire system

Ariane 5 Approval Delay

- The overall delay in the JWST launch readiness date is 22 months and an estimated cost increase of $530M
  - Twelve months were attributed to the change in launch vehicle from an Atlas to the Ariane 5
  - The other 10 months resulted from NASA budget profile limitations in FY06 and FY07 as well as budget cuts in previous years
- History:
  - In June 2004, NGST notified NASA that if a Technology Assistance Agreement (TAA) was not in place by November 2004, they would be unable to hold the August 2011 launch date
  - Due to the delayed Government interagency coordination process, the TAA was not approved until December 2005, 13 months later than needed
  - The selection of the launch vehicle directly affected items on the program critical path, particularly the spacecraft structure
    - Fundamental differences exist between the launchers
    - The Atlas optimally accepts a four point mounting system while for Ariane, it is a circular system. Ariane has unique placement of internal membranes protecting launcher avionics that results in very different keep out regions than the Atlas. You can't proceed into preliminary and then detailed design with such large uncertainties
  - We were able to shave 3 months off the integration flow and therefore reduce the TAA delay to 10 months
    - However, Ariane requires additional testing that is not part of the Atlas flow, adding back two months for a total 12 month impact associated with the launch vehicle selection
- So, the delayed decision on the use of the Ariane cost 10 months and the extra Ariane testing added 2 months; So, the total due to change in the launch vehicle is 12 months and ~$290M. So, where'd the money go?
  - Basically, marching army costs used to best advantage of the project

Lessons Learned

- **JWST is currently leveraging lessons learned from other comparable space observatories; in particular HST, Spitzer, and Chandra:**
  - Aggressively pursuing the overarching lesson to invest in technology early
    - Demonstrate critical enabling technologies early. Do not wait until later development phases to invent things critical to your mission
  - Significant early investment in architecture definition and design

- **Specific Lessons Learned from Spitzer:**
  - Account for distortion of optical Ground Support Equipment (GSE) during cryogenic testing
  - Do not under estimate the complexity of cryogenic thermal balance testing, and do not over estimate its accuracy
    - Use the correct blend of analysis and test to verify thermal performance and workmanship
  - Develop test plans with people capable of analyzing the data and empowered to make decisions present during the test
  - Start the development of flight software early
  - Use ASICs where possible to reduce electrical noise risk
  - To minimize hazards to hardware, do the minimum number of cryo cycles, and use pathfinder equipment for rehearsals

Lessons Learned - Continued

- **Specific Lessons Learned from HST:**
  - Formulate a verification program with multiple cross-checks
    - Do not rely on the results of a single test or analysis as the basis for critical requirements verification
  - Incorporate a Fine Steering Mirror to aid in the control of the observatory Line of Sight
  - Use the Flight Ground System (Eclipse) and operational scripts for Instrument and Observatory I&T
- **Specific Lessons Learned from Chandra:**
  - Incorporate pathfinders into the test program as dress rehearsals for critical tests
  - Get large optics tests done early
- **In addition, JWST team members have been key players in the development of these 3 NASA great observatories**
  - The GSFC government team has HST and Spitzer experience
  - NGST was the prime contractor on Chandra - with the same subs Ball, ITT
  - Ball was a major player in HST and Spitzer
  - U of Arizona has HST and Spitzer instrument team experience
  - The STScI was the Science Operations Center for HST

Lessons Learned - Continued

- **Lessons Learned on JWST so far:**
  - Getting approval to use foreign launch vehicle will take longer than you ever thought
    - Took over 2 _ years from official ESA offer to final U.S. government approval
  - ITAR has emerged as a huge hassle and the State Dept continues to get more conservative in the interpretation of rules
    - An international contribution is not worth the overhead unless it’s value is a significant fraction of the total budget
  - Only accept international contributions where the interfaces can be clearly defined
    - Have partners provide a whole instrument, not fractions of an instrument
  - Identify your enabling technologies early and buy down as much risk as possible in Pre-Phase A
  - Don't let your contractor select the test facility if you have to pay for it
    - NGST seriously underestimated the cost and risk of upgrading the Plum Brook facility for cryo testing

Plan for Further Cost Increases

- The SSB forwarded the following question:
  – If you believe that the program is past the point where descoping is possible, what is the likely course of action if further cost increases are encountered?

- The real question is does the project have an adequate plan and reserves to handle this cost growth and why do you think it is adequate?
  – Yes, the project has a good plan. It consists of 8 months of funded schedule slack, an overall budget contingency of 19% (that is above the funded schedule slack) and hardware path finders to support schedule work around that may present themselves during the flight builds
  – Large cost growths usually present themselves from poorly defined requirements at the time of contract awards – case in point is the late launch vehicle selection after spacecraft contract was in place. For JWST, the launch vehicle was the last top level requirement uncertainty. All other top level requirements are, and have been, in place and reviewed numerous times (MDR 12/01, SRR 4/04, SDR 1/06). Further, **all key** components of the mission are under contract and a majority of the them have completed their PDRs or are within a couple of months of it. There are even some, like the instruments that have had or are quickly approaching CDRs
  – So, cost growth from requirements should be minimal at this stage but cost growth from problems in development and testing are real and to be expected. These growths usually present themselves in the form of schedule slips to accommodate problem investigations and resolution. As mentioned earlier, there is funded schedule reserve. Also, the profile of the project cost contingency is back loaded so that most of it resides during the I&T portion of the program where we expect to see most of these difficulties

Summary

SSB Questions Cross Reference

1	a) What is the JWST funding profile? b) Is there a management reserve? c) What is the current burn rate? d) How likely is it that the JWST spending profile will follow the current plan and allow a wedge of funding for new projects to open up in 2009, as currently projected?	Phil Sabelhaus
2	What has been the effect on JWST of the move to full cost accounting?	Phil Sabelhaus
3	a) What descoping options are available at this point in the program? b) If you believe that the program is past the point where descoping is possible, what is the likely course of action if further cost increases are encountered?	Eric Smith Phil Sabelhaus
4	(a) What are your three greatest technical and three greatest programmatic concerns? (b) What is the risk mitigation strategy for each of them?	Phil Sabelhaus
5	By traditional criteria, JWST appears to be in Phase C/D already. a) Why do you consider it to still be in Phase B? You attribute about $500 million of the cost increase to delays in obtaining approval for the use of Ariane V to launch JWST. b) If the program is only in Phase B, why was selection of a launch vehicle so crucial? Where did that money go?	Phil Sabelhaus
6	a) What "lessons learned" from previous programs that encountered difficulties are being applied to the JWST program? b) Have any new lessons been learned from JSWT so far? For example, what changes in program execution would you suggest to improve cost control for future missions of this complexity?	Phil Sabelhaus

Summary

- JWST identified a 30% net cost growth from $3.5B to $4.5B over a 2 year period
  - Majority of growth due to 22 month launch delay and added contingency
    - Delay due to lack of approval for Ariane 5 and budget cuts through 2007
  - Balance of growth due to changes in requirements & growth in implementation
- Factors that caused growth are now eliminated or reduced
  - Launch vehicle selected; all major suppliers are under contract
  - Observatory architecture is defined and requirements are stable
  - Key decisions have lowered overall project risk
    - Architecture and interfaces simplified
    - Test program more robust
- Project estimate to complete has withstood rigorous external review
- JWST is making excellent progress
- Project plan is prudent and sound
  - Mission critical technologies are on schedule to be demonstrated by the end of 2006
    - More than 6 years before launch
  - High-complexity and long-lead hardware items being developed and built early
    - ISIM and Telescope subsystems reach PDR in 2006
    - Instruments start CDR's this year
  - Extensive use of pathfinder and engineering test unit hardware in I&T program
  - Formal, rigorous scientific oversight of development
  - Multiple risk mitigation strategies are aggressively being pursued

Back Up

Special Review Team Findings

Technical

- Canadian Space Agency FGS ITAR Issue - Resolved
- Flight Back Plane Performance Verification - Accepted
- Mirror Segment Spares - Accepted
- ISIM Structure Issue - Accepted
- “Test As You Fly” Exceptions – Accepted

Programmatic

- Low early year contingency – Being worked with NASA HQ SMD

Early Year Contingency

- SRT issue: *Low early year contingency*

- GSFC Response:
  - Agree that the early year contingency is less than desirable
    - This was known at the start of the replan
    - But the contingency levels consistent with Chandra
  - Proposed a modest rephasing of contingency from FY11-12 to FY08-09 as part of our POP submittal to address this issue
    - No increase in our estimate at complete, i.e. total project cost will remain the same
  - Many factors make the current early year contingency levels acceptable
    - Risk reduction activities
    - Chandra benchmarking
    - Additional "knobs to turn"
      - Modulate carry out funding
      - Contractors can use risk funds
      - Etc

Chandra is an Appropriate Benchmark

- Chandra and JWST are both large, flagship programs for NASA
- Comparable program cost
  - Chandra at $3.4B (through launch in $FY06), JWST at $3.3B (through launch)
- Comparable responsibilities for NASA and Contractor teams
  - Both JWST and Chandra civil servant workforce is 15% of effort
- Same Contractor team (in fact, many of the same critical personnel)
- Comparable pathfinder risk reduction program for critical path activities
  - Chandra: TMA and VETA–I/II
  - JWST: AMSD, Primary Mirror Segment EDU and OTE Pathfinder
- Comparable Spacecraft Bus complexity
- Comparable Full Observatory I&T (less thermal vacuum test)
- Sizable facility construction for both programs
- Chandra had higher cost and schedule risks earlier in the program
  - Chandra risks were greater than JWST in the early manufacturing phase and were less than JWST in the later I&T phase
  - JWST mirror manufacturing relies on more standard processing and metrology than Chandra
  - JWST demonstrations are much more mature
    - AMSD and EDU vs. TMA and H1/P1
  - JWST I&T is more complex than Chandra due to the cryogenic nature of the large scale testing and the deployment verifications

Chandra Scenario

- In 1994 Agency PMC, unencumbered contingency was the key programmatic issue
- Independent review team argued for at least 20% contingency on top of total project scope plus identified liens and threats
- Like JWST, counter-argument was that thorough identification of budget threats was actually an indicator of lower risk
- Outcome: Chandra worked to program plan (below) and made expected progress toward launch through all 3 early years with low contingency (PDR 11/94, CDR 2/96)

Note: FY94 contingency for half year. Effective annual contingency was 5.8%.

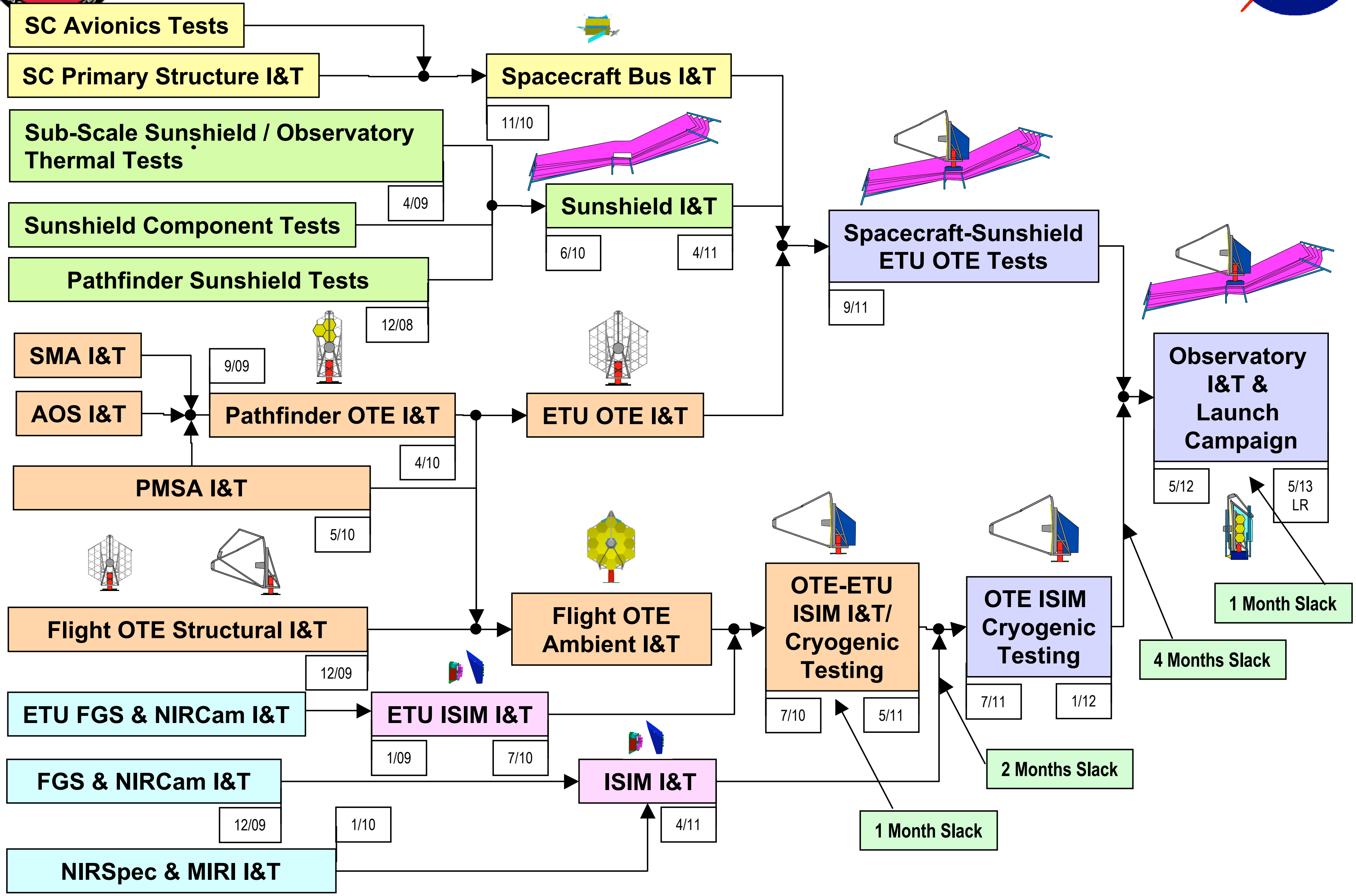
Technical Impact of LV Selection

- The SSB Forwarded the following question:
  - If the program is only in Phase B, why was selection of a launch vehicle so crucial?
- Fundamental differences exist between the launchers under consideration for the JWST mission. These differences include:
  - Orbital injection scenarios and trajectories
  - Orbital injection dispersions
  - Launcher environments and loads
  - Launcher-to-Observatory mechanical interfaces
  - I&T flows and required testing
- The selection of the LV had critical implications for fundamental system design considerations, such as resource allocations and interface definitions Most important of these are:
  - The dry mass of the observatory
  - The propellant needed to correct LV dispersions
  - The mission planning and basic orbit design to avoid eclipses and minimize stray-light from the Earth and Moon
  - The LV-to-Observatory I/F (A 4 point mount as on Atlas or a ring as on Ariane)
  - Acoustic Loads (which have important impacts of the mirror design)
- The resolution of these are required for the completion of the Phase B portion of the program

Hardware Production Plan

- Start long-lead-time hardware early
  - Telescope mirrors
  - Detectors
  - Microshutters
- Prioritize development of high complexity items to buy down risk
  - Telescope structure
  - Instruments
  - Sunshield
- Produce breadboard components in preliminary design phase to verify key performance parameters and manufacturing techniques
  - Telescope and instrument mechanisms
  - Instrument mirrors, filters, and lenses
  - Structure subassemblies and joints
  - Electronics
- Produce engineering test unit and/or pathfinder hardware prior to flight hardware production
  - Telescope
  - Instruments
  - Sunshield

JWST Integration & Test Plan

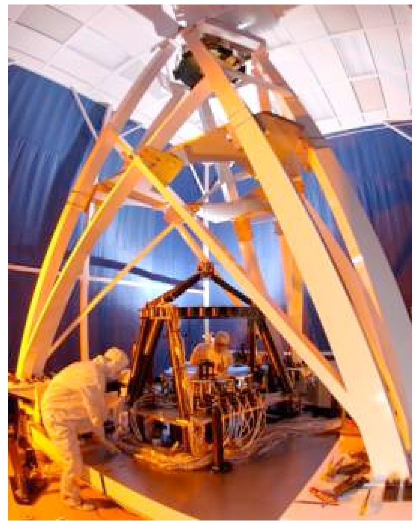


Verification Facilities Exist

Johnson Space Flight Center Chamber A
- Primary optical test facility for OTE+ISIM cryogenic thermal/optical testing.
- Final optical performance and WFS&C test conducted here.

Rambo (BATC)
Primary optical test facility for cryogenic testing of SMA and AOS

Test Bed Telescope (BATC)
Primary facility for development and testing of the WFS&C Algorithms



Space Environment Simulator (GSFC)
Primary optical test facility for cryogenic testing of ISIM

X-Ray Calibration Facility (MSFC)
Primary optical test facility for cryogenic testing of PMSAs and BSTA

JWST has Multiple Strategies to Manage Risk

- JWST has an active risk management process
  - Used to identify risks and develop mitigation plans
  - Programs to retire technical/programmatic risks are included in budget
    - Eg: OTE pathfinder, Sunshield pathfinder, Instrument component pathfinders
- JWST has a comprehensive Engineering Test Unit program
  - Includes pathfinder instruments, ISIM & OTE structures, thermal system
  - Pathfinder testing at Instrument-, ISIM-, and OTE/ISIM-levels of assembly
- Early investment in mission-enabling technologies
  - Technology risks will be retired six years before launch
- Critical spare components included in budget
  - Mirrors, detectors, cryocooler, microshutter, electronics
- Explicit margin is carried on science performance parameters
  - Sensitivity, wavefront error, pointing accuracy
  - Margins will be used to accept lower performance, avoiding cost growth
- Explicit margin is carried in resource budgets (mass, power, etc)
  - Will be used to solve design and manufacturing problems
- Funded schedule contingency of one month per year
- Overall cost contingency
  - Although contingency through 2009 is low, overall contingency is reasonable

Risk Management - Continued

- Fully centralized Project Management and System Engineering
  - GSFC manages all instrument teams, international team members, and operations center
  - NGST, as Prime, has all sub-contractors under contract
  - GSFC and NGST has good working relationship with representative science community
- *SRT concurs:*
  - *Scientific performance meets the expectations of the science community.*
  - *Technical content is complete and sound, GSFC and Contractor teams are effective*

- Rigorous oversight of science-engineering trades by experienced representatives:

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