U.S. House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Space

Searching for the Origins of the Universe: An Update on the Progress of the James Webb Space Telescope

CHARTER

Tuesday, March 24, 2015
10:00 a.m. – 11:30 a.m.
2318 Rayburn House Office Building

Purpose

On March 24, 2015, the Science, Space, and Technology Subcommittee on Space will hold a hearing titled *Searching for the Origins of the Universe: An Update on the Progress of the James Webb Space Telescope*. The hearing will cover the development history of the James Webb Space Telescope (JWST) and NASA's progress to-date since the program was last re-baselined in 2011. Witnesses will testify on the technical challenges associated with completing the JWST by the target launch date of October 2018, at a life-cycle cost no greater than $8.85 billion.

Witnesses

- **Dr. John Grunsfeld,** Associate Administrator, Science Mission Directorate, NASA
- **Ms. Cristina Chaplain,** Director of Acquisition and Sourcing Management, U.S. Government Accountability Office (GAO)
- **Mr. Jeffrey Grant,** Vice-President & General Manager, Space Systems, Northop Grumman Corporation
- **Dr. John C. Mather,** Senior Project Scientist, James Webb Space Telescope, Goddard Space Flight Center (GSFC), NASA

Background

In 2001, the James Webb Space Telescope (then called the Next Generation Space Telescope) was ranked as the highest priority large space mission in astronomy by the National Academies of Science in their decadal survey *Astronomy and Astrophysics in the New Millennium*.[1] Originally estimated by the decadal committee to cost $1 billion and to launch in 2007, JWST was touted as the next Great Observatory. Its 18 mirrors will provide a collecting area for light

[1] http://www.nap.edu/catalog/9839/astronomy-and-astrophysics-in-the-new-millennium

that is seven times larger than that of the Hubble Space Telescope, and a camera that will capture larger fields of view than Hubble.[2]

The main technical features of JWST include a 6.5 meter diameter mirror optimized for observations in the infrared using four specialized scientific instruments (detailed below). JWST is set to orbit nearly one million miles from Earth in the Earth-Sun Lagrange (L2) point.[3] These technical capabilities are expected to produce unparalleled scientific discovery, glimpsing back to the origins of the galaxies, providing insights into the early formation of stars and planets, and characterizing exoplanets.

After scrutiny arising from years of program cost and schedule overruns, NASA developed a revised plan for JWST development back in 2011 for its completion and launch by October 2018. The current projected life-cycle costs now total just over $8.8 billion. Through appropriations language, Congress also directed a cost cap on spending for JWST, and required GAO to provide to Congress each year an audit of the program.[4]

Program Timeline

- **June 1997** – *The Next Generation Space Telescope: Visiting a Time When Galaxies Were Young* report utilized initial feasibility studies to present a technological roadmap for the development of the next generation space telescope (NGST) in the next decade at a cost of $500 million and launch date of 2007.
- **2001** – Telescope identified by the National Academy of Sciences (NAS) as top-priority in Decadal Survey, *Astronomy and Astrophysics in the New Millennium*; estimated cost $1 billion.
- **Summer 2002** – NASA Mission Definition Review completed and project moved out of Phase A (feasibility studies) into Phase B (definition studies); the cost was estimated to be $2.5 billion with a launch date of 2010; Northrop Grumman was awarded the prime contract.
- **March 2005** – NASA identified further cost growth, increasing the life-cycle cost estimate to $4.5 billion and a schedule slip of two years.
- **April 2006** – Independent review teams concluded that JWST's scientific performance and technical content were sound, with concerns centered on a realistic cost estimate.
- **July 2008** – Program confirmation review placed the baseline life-cycle cost at $5 billion with a launch date of June 2014.
- **June 2010** –Based on concerns expressed by Congress, NASA commissioned an Independent Comprehensive Review Panel (ICRP), led by Dr. John Casani of NASA Jet Propulsion Laboratory.
- **October 2010** – ICRP report delivered to NASA and to Congress; NASA notified Congress that JWST's costs had grown and the schedule would be delayed, triggering a 'Breach Report' (more below).

[2] http://jwst.nasa.gov/comparison_about.html

[3] http://jwst.nasa.gov/orbit.html - The Lagrange 2 point is a semi-stable elliptical orbit around the Earth and beyond the Moon.

[4] See Appendix A and http://www.gpo.gov/fdsys/pkg/BILLS-112hr2112enr/pdf/BILLS-112hr2112enr.pdf

- **September 2011** – JWST re-plan approved with new baseline of $8.8 billion total life cycle cost with launch readiness date of October 2018.
- **2012-2013 –** Integration of scientific instruments.
- **2014 –** Integration and testing at Goddard Space Flight Center (GSFC), and manufacturing of the spacecraft.
- **2015 –** Integration and testing continues. The mirror segments, secondary mirror, and optics will be assembled into the telescope. The pathfinder backplane was transferred to Johnson Space Center (JSC) from GSFC in January, and preparations are being made to transfer JWST to JSC for further integration testing.
- **2016 –** The three main components (instruments, telescope, and spacecraft) of the observatory will be assembled.
- **2017 –** The completed observatory will be tested as a single unit.
- **2018 –** The observatory will be further tested and prepared for launch on Ariane V rocket from Kourou, French Guiana.

Program Design Elements & Status

Sunshield

A critical element of the telescope's design is a giant tennis-court sized sunshield that will block the mirrors and science instruments from light from the Sun, Moon, and Earth as well as prevent radiation from the telescope's own heat-producing equipment. The sunshield will consist of five layers – none touching the other – of a heat-resistant material called silicon-coated Kapton. Each layer will be no thicker than half of a human hair.

In order to ensure a successful sunshield design and deployment, the sunshield underwent extensive testing. A template membrane was constructed and tested to validate that its shape holds under tension and to verify the folding/packing concept works on a full-scale mockup. Additionally, a one-third scale model was constructed to test deployment and undergo thermal testing in a cryogenic chamber. Currently, the third of five layers to be launched with the completed telescope is being fabricated, and the fourth and fifth layers are proceeding with fabrication on schedule.

Mirrors

The purpose of the mirrors is to collect the light and channel it to the instruments. Because JWST is designed to detect the faintest of infrared light, billions of light years away, the mirrors must be precisely engineered. If someone held up a lighted match in New York City, the mirrors will be calibrated to such a degree of sensitivity that the match's light could be visible in Los Angeles. JWST's primary mirror is made up of 18 individual hexagonal segments that fold up inside the launch vehicle's fairing; once deployed the mirrors will function as a single 6.5 meter (21.3 feet) diameter mirror – the largest ever to be deployed in space. All 18 mirrors have been manufactured, polished, and coated and all are ready for final assembly.

Scientific Instruments

The Integrated Science Instrument Module (ISIM) contains four science instruments and a guide camera. The ISIM and science instruments are 90 percent complete and are undergoing integration at NASA Goddard Space Flight Center (GSFC); however, the Mid-Infrared

Instrument (MIRI) cryocooler compressor assembly is still experiencing problems. It has now moved onto the critical path for the launch schedule, and it could mean a significant use of schedule and cost reserves if problems are not solved.

- Mid-Infrared Instrument (MIRI) – provided by the European Consortium with the European Space Agency (ESA) and by NASA Jet Propulsion Laboratory (JPL). MIRI has both a camera and a spectrograph that sees light in the mid-infrared allowing it to see newly forming stars as well as faintly visible comets and objects in the Kuiper Belt in our solar system. MIRI's camera will provide visible light imaging similar to those the public has come to expect from Hubble. The spectrograph can provide new physical details never before seen of the objects it will observe.
- Near-Infrared Camera (NIRCam) – provided by the University of Arizona, NIRCam is Webb's primary imager to detect light from some of the earliest stars and galaxies in the universe. NIRCam is equipped with coronagraphs that will allow astronomers to take pictures of very faint objects around a central bright object, like solar systems. NIRCam's coronagraphs work by blocking a brighter object's light, making it possible to view the dimmer object nearby - just like shielding the sun from your eyes with an upraised hand can allow you to focus on the view in front of you. With the coronagraphs, astronomers hope to determine the characteristics of planets orbiting nearby stars.
- Near-Infrared Spectrograph (NIRSpec) – provided by the European Space Agency (ESA), with components provided by NASA GSFC. Used to disperse light from an object into a spectrum by which physical properties such as temperature, mass, and chemical composition can be determined.
- Fine Guidance Sensor Tunable Filter Imager (FGS-TFI) – provided by the Canadian Space Agency. The Fine Guidance Sensor allows the telescope to point precisely while the Tunable Filter will be able to select and focus on extremely specific wavelengths of light. Most cameras can only see a certain wavelength, but FGS-TFI will be able to pick from a range. The FGS-TFI will be used to study just-forming planetary systems and dust disks that could become planets, the internal dynamics of galaxies, and the characteristics of elements and molecules in clouds of stellar gas.[5]

Spacecraft Bus

The spacecraft bus houses the electronics, attitude and thermal control, communications and propulsion systems. These systems are considered relatively standard given that all space telescopes and satellites require similar systems. As of the first quarter of 2015, JWST's spacecraft bus is more than 70 percent completed, but is experiencing a cost overrun. The overrun is being funded with program cost reserves.[6]

Assembly and Testing

A majority of the hardware for JWST has been constructed. Unlike the Hubble Space Telescope, the Webb Space Telescope does not have the capability to be serviced and upgraded. The majority of the cost and time remaining to complete JWST will be in assembly and testing. Along the way, components must be tested to make sure they function individually, as a group,

[5] http://www.jwst.nasa.gov
[6] JWST quarterly briefing to House Authorization Staff, NASA, February 24, 2015, p. 26

and as the complete telescope. In addition, hardware such as platforms and machinery must be specifically made to accommodate construction of the huge telescope.

GSFC is in charge of assembling each of the science instruments into a larger unit, which will be subjected to both temperature and vibration testing. The mirrors will be mounted to their support structure and tested. The testing ensures that JWST can withstand the stress of launch and the extreme conditions of the telescope's orbit nearly 1 million miles from Earth while operating at temperatures approaching -400 degrees Fahrenheit in order to detect the infrared spectrum from faint, distant objects in the universe,

Following assembly, JSC will then test the spacecraft in a large 120-foot-tall vacuum chamber (Chamber A) originally used for the Apollo program. The chamber has been modified to ensure testing at the proper cryogenic temperatures. Once that test is complete, the sunshield and spacecraft bus will be added to the package and tested yet again before being readied for launch.[7]

JWST Influence on Astronomy and Astrophysics Decadal Survey Priorities

Despite changes to the JWST program following the 2001 decadal – including revised cost and schedule baselines, as well as de-scoping the segmented mirrors from an 8 meter to a 6.5 meter diameter – JWST was supposedly still on track (based on the revised cost and schedule) when it was time again for the National Academies to conduct the next decadal survey. Given assurances by NASA, the survey committee had little evidence to believe otherwise. Yet, even as doubts emerged, the committee presented its recommendations assuming JWST would be launched no later than the middle of the decade. *New Worlds, New Horizons in Astronomy and Astrophysics* (2010) therefore moved forward under the assumption that JWST would be completed as planned and recommended pursuit of the next top-priority mission, the Wide-Field Infrared Telescope (WFIRST). WFIRST would conduct exoplanet and dark energy research. It is uncertain when WFIRST will move beyond the pre-formulation stage.

Independent Comprehensive Review Panel (ICRP)

In a letter to NASA in June 2010, Senator Barbara Mikulski (D-MD), Chairwoman of the Senate Appropriations Subcommittee on Commerce, Justice, Science and Related Agencies requested an independent review of the JWST program citing concerns about continued growth in cost and delay in schedule. The letter requested an independent panel review the root causes of the cost growth and schedule delay, to assess NASA's plans for completing development and testing of the telescope, to review possible changes to the telescope, and to provide a cost to launch.[8]

NASA subsequently commissioned an Independent Comprehensive Review Panel (ICRP) led by John Casani, Special Assistant to the Director at the Jet Propulsion Laboratory.[9] The ICRP report revealed poor budgeting and program management, not technical performance, as the root cause

[7] http://ngst.gsfc.nasa.gov/status.html
[8] http://www.nasa.gov/pdf/499224main_JWST-ICRP_Report-FINAL.pdf, Appendix E, p. 44
[9] A copy of the report can be found here: http://www.nasa.gov/pdf/499224main_JWST-ICRP_Report-FINAL.pdf

for JWST's woes. At the outset, it was determined that JWST did not have a proper budget baseline and that budgeted reserves were insufficient. They found that costs were managed on a year-to-year basis, which led to deferred work and corresponding increases to life cycle costs. The cost of deferring work further reduced reserves available in later years, resulting in a project life cycle cost that continued to spiral out of control. The ICRP, however, did not find the funds spent as wasted. Cutting-edge hardware had been delivered and tests were underway.

Specifically, the ICRP provided NASA with 22 recommendations as to how to get the program back on track and outlined what it thought to be a new cost-to-launch budget profile for a launch in 2014. In summary, the report states:

Based on the issues present in the current plans to complete, the Panel has identified changes to address the root cause issues discussed in the report, plus ones that could be implemented to diminish the risk of future cost increases and delays in the launch date. These are summarized below.

- *Move the JWST management and accountability from the Astrophysics Division to a new organizational entity at HQ having responsibility only for the management and execution of JWST.*
- *Restructure the JWST Project Office at the Goddard Space Flight Center (GSFC) to ensure that the Project is managed with a focus on the Life Cycle Cost and Launch Readiness Date, as well as on meeting science requirements appropriate to the Implementation Phase.*
- *Assign management and execution responsibility for the JWST Project to the GSFC Director, with accountability to the Science Mission Directorate Associate Administrator at HQ.*
- *Establish the Office of Independent Program and Cost Evaluation (IPCE) as the recognized Agency estimating capability, responsible for validating the most probable cost and schedule estimates developed by projects and for developing Independent Cost Estimates (ICE) for major milestone reviews.*
- *Develop a new JWST baseline cost and schedule plan-to-complete that incorporates adequate contingency and schedule reserve in each year. Include a realistic allowance for all threats in the yearly budget submission. Budget at 80% confidence, and require 25% reserves in each year through launch. Commission a new ICE, reconcile the new plan with it, and update the plan appropriately*.[10]

NASA agreed with all of the recommendations presented by the ICRP and made several changes even before completing its re-plan of the program. Accordingly, NASA:

- Elevated program visibility, reporting, performance assessment and cost control;
- Replaced all JWST senior management at both GSFC and Headquarters;
- Elevated JWST to a division level within Science Mission Directorate that reports directly to the NASA Associate Administrator; and
- Used ICRP cost and schedule estimates as one of the inputs to develop the new baseline.

[10] JWST-ICRP Final Report, October 29, 2011, p. 9

Summary of JWST Breach Report and Re-Plan

Pursuant to Section 103 of the NASA Authorization Act of 2005 (PL 109-155), NASA is required to provide Congress with a new cost and schedule baseline for major programs that exceed costs by more than 15 percent or schedule by more than 6 months. NASA notified Congress on October 28, 2010, that the agency anticipated JWST would breach both its cost and schedule baselines and deferred its formal response until it could conduct a complete assessment.

In response to the ICRP report and as part of the required report to Congress, NASA delivered a *Cost and Schedule Analysis Report for the James Webb Space Telescope* (Breach Report) to Congress on October 21, 2011, which estimated the full life cycle cost of the mission to be $8.835 billion with a launch date of October 2018.[11]

According to NASA's report, the newly programmed JWST baseline:

- Represented a high confidence, realistic schedule with adequate reserves that launches JWST as soon as possible.
- Presented a funding profile that was adjusted to reduce risk and provide adequate early year reserves.
- Included a Joint Cost and Schedule Confidence Level (JCL) analysis consistent with an 80 percent confidence level; and
- Was reviewed by the JWST Standing Review Board (SRB) – NASA's independent external review board – with findings and recommendations factored into final plan.

The new baseline required approximately $1.2 billion in additional funding in FY12-FY16 above the President's FY12 Budget Request. See Table 1.

Table 1. James Webb Space Telescope Budget Since Re-Plan – FY12-FY20[12]

	President's Budget Request[13]	Appropriated Funding
FY12	$373.7	$518.6
FY13	$627.6	$627.6
FY14	$658.2	$658.2
FY15	$645.4	$645.4
FY16	$620.0	-
FY17	$569.4	-

[11] http://www.jwst.nasa.gov/resources/JamesWebbSpaceTelescopeIndependentComprehensiveReviewPanelReport.pdf

[12] National Aeronautics and Space Administration FY12, FY13, FY14, FY15, and FY16 Budget Estimates – Science Mission Directorate

[13] FY17-FY18 are notional

FY18	$534.9	-
FY19	$305.0	-
FY20	$197.5	-

Analysis of Alternatives

As part of the required Breach Report in 2011, NASA asked the Aerospace Corporation to conduct an analysis of alternatives (AOA) to JWST to ensure that all possible options were given proper consideration. In summary, the AOA:

- Reviewed four categories of observatories (airborne, ground, space and variants to the JWST baseline) and assorted combinations thereof;
- Measured performance of alternatives against JWST Level 1 science requirements; and
- Distilled alternatives down to 12 potential options based on ability to meet the mission science requirements and technical feasibility to analyze in further detail

The results of the analysis concluded that the JWST baseline continues to be the best value. Specifically, the Aerospace Corporation found that none of the alternatives provide the equivalent Level 1 science requirements at a lower cost or at an earlier full operational capability date. Furthermore, while alternative designs might lower costs in one area or another, the science that must be given up to accommodate those designs rendered the alternative undesirable based on the science requirements articulated in the National Academies' Decadal Survey. Furthermore, many of the 2011 decadal survey recommendations are predicated on the groundwork that is to be laid by JWST.

Issues

- What are the chief technical and programmatic challenges facing JWST?
- How are these challenges being addressed?
- How could these challenges affect cost and schedule reserves?
- How will JWST observations compliment other missions, and what impact could a schedule delay have on science derived from these complementary measurements?
- What impact would a delay in JWST launch, or increase in JWST's cost, have on other Science Mission Directorate priorities?

Appendix A

FY12 Appropriations

On July 7, 2011, the House Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies reported an FY12 appropriations bill that provided zero funds for JWST. As stated in the report:

> *The James Webb Space Telescope (JWST) Independent Comprehensive Review Panel revealed chronic and deeply rooted management problems in the JWST project. These issues led to the project cost being underestimated by as much as $1,400,000,000 relative to the most recent baseline, and the budget could continue to rise depending on the final launch date determination. Although JWST is a particularly serious example, significant cost overruns are commonplace at NASA, and the Committee believes that the underlying causes will never be fully addressed if the Congress does not establish clear consequences for failing to meet budget and schedule expectations. The Committee recommendation provides no funding for JWST in fiscal year 2012.*
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> *The Committee believes that this step will ultimately benefit NASA by setting a cost discipline example for other projects and by relieving the enormous pressure that JWST was placing on NASA's ability to pursue other science missions.*

On September 15, 2011, the Senate Appropriations Subcommittee on Commerce, Justice, Science and Related Agencies reported an FY12 appropriations bill providing a total of $530 million for JWST, a number reflected in the NASA re-plan but not officially requested by the Administration. Per the report:

> *The Committee strongly supports completion of the James Webb Space Telescope [JWST]. JWST will be 100 times more powerful than the Hubble Space Telescope and is poised to rewrite the physics books. Last year, the Committee asked for an independent assessment of JWST. That assessment, led by Dr. John Casani, found that while JWST is technically sound, NASA has never requested adequate resources to fund its development. As with many other projects, budget optimism led to massive ongoing cost overruns because the project did not have adequate reserves or contingency to address the kinds of technical problems that are expected to arise in a complex, cutting edge project. Without funds, the only other way to deal with problems is to allow the schedule to slip. That slip, in turn, makes the project cost even more, when accounting for the technical costs as well as the cost of maintaining a pool of highly skilled technical labor through the completion of the project.*
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> *In response to the Casani report, NASA has submitted a new baseline for JWST with an overall life cycle cost of $8,700,000,000. NASA has assured the Committee that this new baseline includes adequate reserves to achieve a 2018 launch without further cost overruns. The Committee intends to hold NASA and its contractors to that commitment, and the bill caps the overall development cost for JWST at $8,000,000,000.*

On November 17, 2011, the House and Senate agreed to final FY12 appropriations for NASA as part of a "mini-bus" that included funding for Agriculture, Commerce-Justice-Science (CJS), and Transportation-Housing and Urban Development (T-HUD). The bill ultimately yielded to the Senate version, providing JWST with the full amount needed as cited in the re-plan. However, very specific language about how Congress expects NASA to manage the program was included in the conference report. It states:

> *James Webb Space Telescope (JWST).—According to the recent JWST budget replan, the program's lifecycle cost estimate is now$8,835,000,000 (with formulation and development costs totaling $8,000,000,000). This represents an increase of $1,208,000,000 over the previous lifecycle cost estimate, including an increase of $156,000,000 above the budget request for fiscal year 2012. In order to accommodate that increase in this agreement, the conferees received input from the administration and made reductions to the requested levels for Earth and planetary science, astrophysics and the agency's budget for institutional management. Although the amounts provided for these other science activities still constitute an increase over the fiscal year 2011 levels, the conferees note that keeping JWST on schedule from fiscal year 2013 through the planned launch in fiscal year 2018 will require NASA to identify another $1,052,000,000 over previous JWST estimates while simultaneously working to meet the deficit reduction requirements of the Budget Control Act of 2011 (P.L. 112–25). As a result, outyear work throughout the agency may need to be reconsidered. The conferees expect the administration to come forward with a realistic long-term budget plan that conforms to anticipated resources as part of its fiscal year 2013 budget request.*
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> *To provide additional assurances that JWST's management and funding problems are under control, the conference agreement includes language strictly limiting JWST formulation and development costs to the current estimate of $8,000,000,000 and requiring any increase above that amount to be treated according to procedures established for projects in 30 percent breach of their lifecycle cost estimates.*
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> *In addition, the conferees direct the GAO to continually assess the program and to report to the Committees on Appropriations on key issues relating to program and risk management; achievement of cost and schedule goals; and program technical status. For its first report, the conferees direct the Comptroller General to assess: (1) the risks and technological challenges faced by JWST; (2) the adequacy of NASA's revised JWST cost estimate based on GAO's cost assessment best practices; and (3) the extent to which NASA has provided adequate resources for and is performing oversight of the JWST project to better ensure mission success. The first report should be provided to the Committees no later than December 1, 2012, with reports continuing on an annual basis thereafter. Periodic updates should also be provided to the Committees upon request or whenever a significant new finding has been made. NASA is directed to cooperate fully and to provide timely access to analyses, data, applications, databases, portals, reviews, milestone decision meetings, and contractor and agency personnel.*