

**SEARCHING FOR THE ORIGINS OF THE UNIVERSE:
AN UPDATE ON THE PROGRESS OF
THE JAMES WEBB SPACE TELESCOPE**

HEARING
BEFORE THE
SUBCOMMITTEE ON SPACE
COMMITTEE ON SCIENCE, SPACE, AND
TECHNOLOGY
HOUSE OF REPRESENTATIVES
ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

MARCH 24, 2015

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**SEARCHING FOR THE ORIGINS OF THE
UNIVERSE:
AN UPDATE ON THE PROGRESS OF THE
JAMES WEBB SPACE TELESCOPE**

TUESDAY, MARCH 24, 2015

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:04 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Steven Palazzo [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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Subcommittee on Space

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

Tuesday, March 24, 2015

10:00 a.m. to 12:00 p.m.

2318 Rayburn House Office Building

Witnesses

Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, NASA

***Ms. Cristina Chaplain, Director of Acquisition and Sourcing Management, Government
Accountability Office (GAO)***

***Mr. Jeffrey Grant, Vice-President & General Manager, Space Systems, Northrop Grumman
Corporation***

***Dr. John Mather, Senior Project Scientist, James Webb Space Telescope, Goddard Space Flight
Center, NASA***

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, Northrop 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-FY20¹²

	President's Budget Request¹³	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.

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.

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.

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.

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.

Chairman PALAZZO. Before we get started this morning, I would like to welcome a special group of students that we have visiting us here today, Lake Burke High School in Virginia. Welcome to the Science, Space, and Technology Subcommittee on Space. Thank you all for being here. I woke a couple of them up, I see. That is good. We haven't even got started yet.

The Subcommittee on Space will come to order. Without objection, the chair is authorized to declare recesses of the Committee at any time.

Welcome to today's hearing entitled "Searching for the Origins of the Universe: An Update on the Progress of the James Webb Space Telescope." I recognize myself for five minutes for an opening statement.

The James Webb Space Telescope represents a significant investment by the U.S. taxpayer and holds the promise of producing revolutionary science that one day may rewrite textbooks. It could change the way we perceive our universe, as well as our place in it. That is a lot to live up to.

JWST continues the heritage of space-based great observatories. Leveraging the accomplishments of the Hubble Space Telescope, the Compton Gamma Ray Observatory, the Chandra X-ray Observatory, and the Spitzer Space Telescope, James Webb will provide revolutionary astronomical measurements in the long-wavelength visible and the mid-infrared range of spectrum. This will allow scientists to see light from the first stars, view the development of galaxies, and study the development of planets. The infrared range that the telescope will operate in allows the telescope to see through cosmic dust, view faint and dim targets, and observe phenomena such as redshift from the expanding universe. James Webb's unique vantage point from the Sun-Earth L2 is also an ideal location that will enable the observatory to make precise infrared measurements.

The scientific returns from these observations will be compounded even more if James Webb remains on schedule and overlaps with existing observatories that continue to return significant science, or new assets such as the Stratospheric Observatory For Infrared Astronomy and the Transiting Exoplanet Survey Satellite that promise to complement James Webb's capabilities.

This enormous potential is balanced by the sobering history of James Webb's development. Initially planned to cost \$1.6 billion and launch in 2011, the program ballooned to a lifecycle cost estimate of nearly \$9 billion and slipped seven years to a 2018 launch date. James Webb's history is well known, and I do not wish to open old wounds, but Congress would be complicit in any future delays or overruns if it failed to maintain proper oversight of this program.

Despite the significant progress made by NASA and the contractors, the program is not out of the woods yet. It is now entering the critical integration and testing phase where unforeseen problems typically arise. These unplanned technical challenges could threaten the cost and schedule reserves during this critical period. Recent issues with the cryocooler, a critical component that is necessary for proper measurements, reinforce the need for persistent

monitoring and oversight. The sheer technical complexity of this program demands it.

Even after the telescope is fully assembled, shipped to Kourou, and launched into space, all of us will still be crossing our fingers that this massive spacecraft will arrive at its intended destination and execute its intricately choreographed origami-like deployment. Everyone involved in this project is working to make it a success: the engineers and technicians, the contractors, the managers and scientists at NASA, and even the Members and Senators here on the Capitol Hill.

In 2011, the House of Representatives voted to cancel the program after its cost estimates skyrocketed and threatened not only other astrophysics missions, but also Science Mission Directorate activities. The contagion of escalating costs even threatened other national priorities at NASA. Planetary science and even exploration programs have sacrificed funding to buttress James Webb and keep the program on track. With a statutory cost cap of \$8 billion for development, Congress expressed both an endorsement and a limitation. For the sake of all of NASA's programs, I hope that James Webb will launch in line with its updated schedule and current cost projections.

Even after launch, issues related to James Webb will remain. For instance, what will happen to the additional funding poured into the Science Mission Directorate to cover James Webb's overruns? Will the Astrophysics account maintain funding profiles consistent with these augmentations? Will the other programs and projects within the Science Mission Directorate return to their historical proportions after James Webb is launched? Will Exploration programs recoup the funding transferred to the James Webb program, or will these proportions represent the new norm?

With overall budgets remaining flat or only increasing marginally, how the other \$600 million a year devoted to James Webb will be reallocated after launch is one of the most important decisions facing NASA and Congress. In light of decreasing budget requests from the Administration for Exploration, it may be appropriate to reconstitute the programs that sacrificed funding to cover James Webb's cost growth.

Before I conclude, I would like to take the opportunity to thank GAO for their diligent work on the James Webb program. As the program matures, questions are shifting from whether or not the cost, schedule, and technical plans are adequate to whether NASA and the contractors are executing to those plans. I hope GAO will continue to provide this Committee with insight into this complex program so that we can all ensure its ultimate success. I also hope that NASA and the contractors heed the GAO's advice and recommendations. More specifically, I hope that in the future, NASA and the contractors will allow the GAO access to information and personnel so that they can fulfill their statutorily required task to monitor this program on behalf of Congress. GAO's recent report highlighted instances where their access was limited. Transparency and accountability are tenets of sound program management and oversight. I trust that won't be a precedent for future engagements.

[The prepared statement of Mr. Palazzo follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
CHAIRMAN STEVEN PALAZZO

The James Webb Space Telescope (JWST) represents a significant investment by the U.S. taxpayer and holds the promise of producing revolutionary science that one day may rewrite textbooks. It could change the way we perceive our universe, as well as our place in it. That is a lot to live up to.

JWST continues the heritage of space-based "Great Observatories." Leveraging the accomplishments of the Hubble Space Telescope, the Compton Gamma Ray Observatory, the Chandra X-ray Observatory, and the Spitzer Space Telescope, JWST will provide revolutionary astronomical measurements in the long-wavelength visible and the mid-infrared range of spectrum. This will allow scientists to see light from the first stars, view the development of galaxies, and study the development of planets.

The infrared range that the telescope will operate in allows the telescope to see through cosmic dust, view faint and dim targets, and observe phenomena such as redshift from the expanding universe. JWST's unique vantage point from the Sun-Earth L2 is also an ideal location that will enable the observatory to make precise infrared measurements. The scientific returns from these observations will be compounded even more if JWST remains on schedule and overlaps with existing observatories that continue to return significant science, or new assets such as the Stratospheric Observatory For Infrared Astronomy (SOFIA) and the Transiting Exoplanet Survey Satellite (TESS) that promise to complement JWST's capabilities.

This enormous potential is balanced by the sobering history of JWST's development. Initially planned to cost \$1.6 billion and launch in 2011, the program ballooned to a life-cycle cost estimate of nearly \$9 billion and slipped 7 years to a 2018 launch date.

JWST's history is well known, and I do not wish to open old wounds, but Congress would be complicit in any future delays or over-runs if it failed to maintain proper oversight of this program. Despite the significant progress made by NASA and the contractors, the program is not out of the woods yet. It is now entering the critical integration and testing phase where unforeseen problems typically arise. These unplanned technical challenges could threaten the cost and schedule reserves during this critical period. Recent issues with the cryocooler, a critical component that is necessary for proper measurements, reinforce the need for persistent monitoring and oversight. The sheer technical complexity of this program demands it. Even after the telescope is fully assembled, shipped to Kourou, and launched into space, all of us will still be crossing our fingers that this massive spacecraft will arrive at its intended destination and execute its intricately choreographed origami-like deployment.

Everyone involved in this project is working to make it a success. The engineers and technicians at the contractors, the managers and scientists at NASA, and even the Members and Senators here on the Capitol Hill. In 2011, the House of Representatives voted to cancel the program after its cost estimates skyrocketed and threatened not only other astrophysics missions, but also other Science Mission Directorate activities. The contagion of escalating costs even threatened other national priorities at NASA. Planetary science and even exploration programs have sacrificed funding to buttress JWST and keep the program on track. With a statutory cost cap of \$8 billion for development, Congress expressed both an endorsement and a limitation. For the sake of all of NASA's programs, I hope that JWST will launch in line with its updated schedule and current cost projections.

Even after launch, issues related to JWST will remain. For instance, what will happen to the additional funding poured into the Science Mission Directorate to cover JWST over-runs? Will the Astrophysics account maintain funding profiles consistent with these augmentations? Will the other programs and projects within the Science Mission Directorate return to their historical proportions after JWST is launched? Will Exploration programs recoup the funding transferred to the JWST program, or will these proportions represent the new norm? With overall budgets remaining flat or only increasing marginally, how the over \$600 million a year devoted to JWST will be reallocated after launch is one of the most important decisions facing NASA and Congress. In light of decreasing budget requests from the Administration for Exploration, it may be appropriate to reconstitute the programs that sacrificed funding to cover JWST cost growth.

Before I conclude, I would like to take the opportunity to thank GAO for their diligent work on the JWST program. As the program matures, questions are shifting from whether or not the cost, schedule, and technical plans are adequate to whether NASA and the contractors are executing to those plans. I hope GAO will continue

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Chairman PALAZZO. At this time I now recognize the Ranking Member, the gentlelady from Maryland, for an opening statement.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and good morning and welcome to our distinguished panel of witnesses.

Mr. Chairman, I want to thank you for calling this hearing to evaluate the development of the James Webb Space Telescope—known as JWST—and discuss the science that the observatory will enable. This hearing also comes at a fortuitous time, on the eve of the 25th anniversary of the Hubble Space Telescope, and as an aside, I can remember when this exact same discussion, perhaps about the cancellation of Hubble, was part of the conversation in Congress, and thank goodness 25 years later, looking back on that, that we didn't do that because of the amazing, amazing work that has been done and the learning that has taken place over the course of those years, but that was the conversation more than 25 years ago, and a good thing that Congress didn't take those actions.

Launched in April 1990, Hubble was the first major optical space-based observatory orbiting above the distortion of the atmosphere, and above rain, clouds, and light pollution. Many of today's younger generation have grown up with Hubble, and I dare say that most Americans have seen the awe-inspiring image taken by Hubble of the iconic Eagle Nebula capturing the famous "Pillars of Creation."

JWST is the next generation astrophysics observatory following Hubble. More capable and sensitive than Hubble, JWST is optimized to study infrared light from the universe, which will allow JWST to observe the first galaxies formed in the Universe. In addition, JWST will see solar systems forming in our galaxy and possibly detect the presence of liquid water on planets around other stars—an indicator that such a planet may indeed harbor life.

Mr. Chairman, that is exciting and that is why I just can't wait for JWST to be launched and working. But I also recognize, as the Chairman has indicated, that the road to building JWST has not been an easy one. The observatory's history of cost growth and schedule delays has not gone unnoticed by the Congress. An independent review panel found in October 2010 that a substantial funding increase would be needed to complete the observatory. As a consequence, NASA re-baselined the project in 2011 with a lifecycle cost estimate of \$8.8 billion and a launch readiness date of October 2018. Congress indeed has done its share and funded JWST annually consistent with that re-baseline. We need to continue to do so.

The Consolidated and Further Continuing Appropriations Act of 2012 directed the Government Accountability Office to report on the project on an annual basis. I appreciate GAO keeping Congress informed of that. With a launch now a little more than three years

away and major integration tests looming ahead, NASA will be under pressure to demonstrate that it can meet the launch date within the cost estimate, and although the latest GAO report concludes that JWST remains on schedule and on budget, GAO also reported that “technical challenges with JWST elements and major subsystems, however, have diminished the project’s overall schedule reserve and increased risk.”

At today’s hearing, I hope to get answers on the following questions: What progress is being made in preparing scientific investigations and scientists who will capitalize on JWST’s unique capabilities? And with three years until launch, what technical challenges and associated risks still remain? What steps are being taken by NASA and its contractors to ensure that cost and schedule commitments are met? And finally, what is the level of confidence that NASA will be able to meet the October 2018 launch date?

Again, I want to thank our witnesses for appearing before our Subcommittee, and I do look forward to your testimony, and Mr. Chairman, I yield back.

[The prepared statement of Ms. Edwards follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
RANKING MEMBER DONNA F. EDWARDS

Good Morning, and welcome to our distinguished panel of witnesses.

Mr. Chairman, thank you for calling this hearing to evaluate the development of the James Webb Space Telescope—known as JWS—and discuss the science that the observatory will enable. This hearing comes at a fortuitous time, on the eve of the 25th Anniversary of the Hubble Space Telescope. Launched in April 1990, Hubble was the first major optical space-based observatory orbiting above the distortion of the atmosphere, and above rain, clouds, and light pollution. Many of today’s younger generation have grown up with Hubble, and I dare say that most Americans have seen the awe-inspiring image taken by Hubble of the iconic Eagle Nebula capturing the famous “Pillars of Creation.”

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But I also recognize that the road to building JWST has not been an easy one. The observatory’s history of cost growth and schedule delays has not gone unnoticed by the Congress. An independent review panel found in October 2010 that a substantial funding increase would be needed to complete the observatory. As a consequence, NASA rebaselined the project in 2011 with a life cycle cost estimate of \$8.8 billion and a launch readiness date of October 2018. Congress has done its share and funded JWST annually consistent with that rebaseline. We need to continue doing so.

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- *What progress is being made in preparing scientific investigations and scientists who will capitalize on JWST’s unique capabilities?*

- *With three years until launch, what technical challenges and associated risks still remain?*
- *What steps are being taken by NASA and its contractors to ensure that cost and schedule commitments are met? And*
- *What is the level of confidence that NASA will be able to meet the October 2018 launch date?*
- Again, I want to thank our witnesses for appearing before our Subcommittee, and I look forward to your testimony.

Mr. Chairman, I yield back.

Chairman PALAZZO. Thank you, Ms. Edwards.

I now recognize the Chairman of the full Committee, Mr. Smith.

Chairman SMITH. Thank you, Mr. Chairman.

Space exploration is an investment in our future—often the distant future. It encourages innovation and improves Americans' quality of life. It inspires the next generation to pursue careers in math, engineering, science, and technology. The James Webb Space Telescope, or JWST, is an example of such an investment. The astrophysics community identified the program as the top priority in 2001. The telescope will far surpass in size, power, and capability any previous space-based observatory launched by NASA. JWST is set to orbit nearly one million miles from Earth in the Earth-Sun Lagrange point. It is expected to observe the origin of the galaxies, provide insights into the early formation of stars and planets, and characterize exoplanets.

The search for exoplanets and Earth-like planets is a relatively new but inspiring area of space exploration. Scientists have discovered hundreds of planets and solar systems in our own galaxy that we never knew existed. By developing and using new telescopes in conjunction with JWST, we may find biosignatures of life on other planets. For example, when examined from a distance, Earth's atmosphere contains large amounts of oxygen. When looked at through a large infrared telescope, like JWST, this biosignature would be detectable.

The Transiting Exoplanet Survey Satellite, or TESS, is currently on track to launch in 2017. This telescope will survey the brightest stars close to Earth to find exoplanets. The survey will provide prime targets for JWST and future ground-based and space-based telescopes. TESS has a two-year planned mission life. It is critical to launch JWST in 2018, so enough overlap exists with the telescopes to maximize the scientific return.

As the top priority mission in the 2010 astrophysics survey, the Wide-Field Infrared Survey Telescope, or WFIRST, will also contribute to the characterization of exoplanets. If funded properly, it could launch in time to significantly overlap with JWST. This would maximize the scientific return of both telescopes. Each is designed to view different but complimentary parts of the infrared spectrum needed to determine the composition of the atmosphere of exoplanets.

WFIRST could also have a coronagraph for detecting imaging capabilities. This means the telescope will be able to help determine the chemical composition of a planet. The potential science to be gained from the combined use of these telescopes illustrates why it is important JWST be completed and launched in 2018. However, just as important to being launched on time, JWST must be completed within the congressionally mandated spending caps for the

program. If JWST is unable to do this, it affects the ability to build future telescopes, like WFIRST.

I look forward to hearing how development of the James Webb Space Telescope is progressing.

And Mr. Chairman, before I yield back, let me apologize to Members and our witnesses today that I have another Committee that is in the process of marking up a bill that I need to go to and will be back I hope sometime soon. So while this is the most important hearing in D.C. today, I will just have to absent myself for a few minutes, so thank you.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF FULL COMMITTEE
CHAIRMAN LAMAR S. SMITH

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I look forward to hearing how development of the James Webb Space Telescope is progressing.

Chairman PALAZZO. Thank you, Mr. Smith.

At this time I would like to introduce our witnesses. Our first witness today is Dr. John Grunsfeld, Associate Administrator for NASA's Science Mission Directorate. He previously served as Deputy Director of the Space Telescope Science Institute managing the Science Program for both Hubble and the James Webb Space Tele-

scope. Dr. Grunsfeld has worked for NASA since 1992 and is a veteran of five space shuttle flights. Dr. Grunsfeld received a bachelor's degree in physics from the Massachusetts Institute of Technology and both a master's degree and doctorate in physics from the University of Chicago.

Our second witness, Ms. Cristina Chaplain, has been a U.S. Government Accountability Office employee for 23 years and currently serves as the Director of Acquisition and Sourcing Management. In this capacity, she is responsible for GAO assessments of military space acquisitions and NASA. She has led reviews of the Space Launch System, the International Space Station, and the James Webb Space Telescope, among others. Prior to her current position, Ms. Chaplain worked with GAO's Financial Management and Information Technology Teams. She received her bachelor's in international relations from Boston University and a master's degree in journalism from Columbia University.

Our third witness is Mr. Jeffrey Grant. Mr. Grant has served in numerous positions within Northrop Grumman and is currently Sector Vice President and General Manager of Space Systems at Northrop Grumman Aerospace Systems. Prior to joining Northrop Grumman, Mr. Grant was Vice President and Chief Technical Officer for Astrolink International LLC. Before joining the private sector, Mr. Grant served for 21 years in the CIA in the National Reconnaissance Office. Mr. Grant received a bachelor's of science in ocean engineering from the Florida Institute of Technology.

I now recognize our Ranking Member, Ms. Edwards, to introduce our final witness.

Ms. EDWARDS. Thank you, Mr. Chairman.

I am honored today to introduce Dr. John Mather, who is the Senior Project Scientist on the James Webb Space Telescope and a Senior Astrophysicist in the Observational Cosmology Laboratory at NASA's Goddard Space Flight Center. I am also proud to say that Dr. Mather is a resident of the 4th Congressional District of Maryland. Seldom does this Committee—Subcommittee—have the privilege of welcoming as a witness a dedicated federal civil servant who is also a Nobel Prize laureate, but today we do.

Among his many awards and accomplishments, Dr. Mather, along with George Smoot, received the 2006 Nobel Prize in Physics for work in cementing the Big Bang theory of the universe, an effort characterized by the Nobel Prize Committee as “the starting point for cosmology as a precision science.” We welcome Dr. Mather to today's hearing and look forward to his testimony.

Chairman PALAZZO. Thank you, Ms. Edwards.

I would like to remind our witnesses, please limit your testimony to five minutes. Your entire written statement will be included in the record, and at this time we will open testimony to Dr. Grunsfeld.

**TESTIMONY OF DR. JOHN GRUNSFELD,
ASSOCIATE ADMINISTRATOR,
SCIENCE MISSION DIRECTORATE, NASA**

Dr. GRUNSFELD. Chairman Palazzo, Ranking Member Edwards, and Members of the Subcommittee, I am delighted to appear before

you to discuss the status of the James Webb Space Telescope program.

Our mission at NASA is to innovate, explore, discover and inspire. Science at NASA seeks to answer fundamental questions about our universe and our place in it. To view the first stars in the universe, study distant galaxies, probe newborn stars and planetary systems, and measure the composition of the atmospheres of planets around other stars, and to let us study our own outer solar system in detail, as never before possible, we are building the James Webb Space Telescope.

This next great space observatory remains within budget and on track to meet its October 2018 launch date. Built to image and study the faint infrared signals from the earliest stars and galaxies, JWST features a 21.5-foot diameter primary mirror, making this the largest telescope ever constructed for space. JWST will extend our view of the universe, building on the great discoveries made by the Hubble Space Telescope, and as the chairman said, many other observatories, with truly transformational exploration capabilities.

Since re-planning the program nearly four years ago, JWST has remained within its yearly budgets. Critical to our success has been adequate funding reserves, enabling the project to address issues as they arise without deferring significant work. The project has done an excellent job doing this and remains on schedule. The FY 2016 budget request for the James Webb Space Telescope is the same amount called for in the 2011 re-baseline, another indicator that the plan is sound.

JWST is a complex observatory, operating at cryogenic temperatures, the first of its kind. As a result, we included additional schedule reserve above NASA's usual formula, totaling 13 months of funded schedule reserve. This reserve was distributed throughout the span of the project to allow for resolution of issues as they occur. In nearly four years, this reserve has been reduced by only three months so that as of today, we have ten months of funded schedule reserve. In fact, we have more schedule reserve today than we had planned to at this point and more than is customary for NASA missions at this stage.

This year is an important year for JWST development. We will complete all of the planned work on the Integrated Science Instrument Module. The 18 mirror segments will be mounted to their support structure. The five sunshield membranes will be manufactured and work will continue on the acquisition of parts and integration of the spacecraft bus. After 2015, almost all of the manufacturing will be complete. Our future activities on JWST will involve integration of major hardware elements and testing of those components.

As has been noted, there are several technical areas that currently have the greatest attention from management. For example, the Mid-InfraRed Instrument requires a special refrigeration unit, or cryocooler, to cool its detectors to roughly minus 449 degrees Fahrenheit. The design and development of this cryocooler has proven to be quite challenging. Today, two-thirds of the cryocooler hardware has been delivered. The remaining third of the hardware

is undergoing final assembly and testing with a planned delivery in three months.

NASA worked closely with GAO in support of the yearly studies of the JWST program. In response to the latest GAO recommendations, the JWST project initiated a cost-risk analysis of the Northrop Grumman prime contract portion of the JWST program. The results of this analysis show that as of July 2014, the program budget is sufficient to complete the Northrop tasks on schedule including accommodation for anticipated risks. The GAO also recommended NASA make changes to our performance evaluation plans for JWST's award fee contracts. In response, NASA has modified its performance evaluation plans for the NASA-Northrop and NASA-Exelis contracts fee for the award fee determination.

The JWST team has been making exceptional progress with significant accomplishments being realized on all of the project elements. Now, nearly four years into the re-plan, the program is within budget and on schedule with adequate reserves for both budget and schedule. We are soon to enter the exciting and challenging integration and test phase. The rigorous cost, schedule and risk controls that have been employed over the last four years give me confidence that we will be ready to launch this ambitious observatory in 2018.

The scientific promise of the James Webb Space Telescope is great. The team engaged in its development is world-class in its experience and capabilities. Programs like the James Webb Space Telescope demonstrate to the world that NASA leads the way in expanding the frontiers of human inquiry and innovation. When we build projects like JWST, we push industry to stretch beyond their capabilities, and they rise to the task, strengthening our competitiveness.

The success of JWST is a result of a great team working together including your Subcommittee and GAO, and I want to thank you both for your efforts.

I am happy to answer any questions you have about this fantastic observatory. Thank you.

[The prepared statement of Dr. Grunsfeld follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
March 24, 2015

Statement of

Dr. John M. Grunsfeld
Science Mission Directorate Associate Administrator
National Aeronautics and Space Administration

before the
House Subcommittee on Space
Committee on Science, Space and Technology
United States House of Representatives

Chairman Palazzo, Ranking Member Edwards, and other Members of the Subcommittee, I am delighted to appear before you to discuss the status of the James Webb Space Telescope Program, a project that would not have been possible without the consistent support demonstrated by Congress.

Science at NASA seeks to answer fundamental questions about our Universe and our place in it. How did the cosmos evolve from its first moments into the stars and galaxies we now see? What is the nature of the worlds orbiting other stars, and are there any that look like Earth? To study the first stars and galaxies in the Universe and peer into the dust-shrouded environments where planets are born, we are building the James Webb Space Telescope (Webb). Webb will extend our view of the Universe, building on the great discoveries made by the Hubble Space Telescope and other observatories, with truly transformational exploration capabilities.

This next great space observatory, and indeed the world's most powerful planned space telescope, remains within budget and on track to meet its October 2018 launch readiness date. Just as important to the success of the program, NASA will meet the science community's ambitious goals with Webb.

This infrared-optimized observatory, built to see the faint infrared signals from the earliest stars and galaxies features a 21.5-foot diameter primary mirror, the largest space telescope ever constructed. Kept cool via a five-layer, tennis-court-sized sunshield, JWST will use its advanced technology to view the first stars and galaxies in the Universe, study distant galaxies, probe nearby clouds of dust hiding forming stars and planetary systems, measure the composition of the atmospheres of planets around other stars, and let us study our own outer planets in ways never before possible.

I will defer the detailed discussion of Webb science to my colleague Dr. Mather, but want to take this opportunity to tell you about the great progress we are making on the mission.

This year is an important year for Webb development. We like to call 2015 the 'year of telescope assembly,' for it is later this year that the 18 mirror segments that comprise the 21.5-foot diameter mirror will be installed on the composite backplane structure, which is undergoing its final assembly and tests as we speak. Also this year, we will conduct the final test of the science instrument package confirming that these cameras and spectrographs from our U.S. and international partners meet their stringent requirements. Importantly, 2015 is the last year in which the Webb program has significant manufacturing activities. After 2015, almost all of the activities on the program will involve integration and test of major hardware elements and the testing of those integrated components.

Because of the importance and visibility of this mission, NASA briefs this committee's staff on a quarterly basis about progress, issues and concerns with the program. I'm happy to take this opportunity to update the committee members about Webb.

Program Cost and Schedule

Since replanning the program nearly 4 years ago, Webb has remained within its yearly budgets. Critical to the replan is that the budget included adequate funding reserves in each year, enabling the project to address design, manufacturing, or integration issues as they arise without deferring significant work. The project has done an excellent job of managing its budget reserves, and this ability to efficiently address problems as they come up has enabled Webb to remain on schedule for its 2018 launch. The Fiscal Year (FY) 2016 budget request needed to fund Webb is the same amount defined in the profile that came out of the 2011 rebaseline activity, another indicator that the plan is sound.

In 2011, we laid out a plan for Webb that contained funded schedule reserve as well as budget reserves. Traditionally, NASA science missions allot 1 month of funded schedule reserve per year for missions in development, and 2 months per year for missions in their integration phase. Webb is a complex observatory operating at cryogenic temperatures, the first of its kind. As a result we included additional schedule reserve at the time of the replan, totaling 13 months of funded schedule reserve. This reserve was distributed throughout the span of the project to allow for resolution of issues throughout the assembly, integration, and test phases. For example, sophisticated cryogenic vacuum tests are conducted at component levels and in sub-assemblies, before integration and test of the more complex flight articles. This approach allows the project team to build up experience with the hardware and procedures over the whole development cycle to ensure the flight integration and test activities proceed according to schedule as much as possible.

In nearly 4 years, funded schedule reserve has been reduced from the replan total by only 3 months; so that as of today, we have 10 months of funded schedule reserve. This is a good position to be in as we approach our major integration activities. In fact, we have more schedule reserve today than we had planned to have at this stage and more than is customary for NASA missions at this stage.

Hardware Status

There are four main hardware elements of the James Webb Space Telescope: the integrated science instrument module or ISIM, the optical telescope element, the sunshield, and the spacecraft bus. This year we will complete all the planned microshutter array work and infrared detector replacement in the ISIM, which holds the science cameras and spectrographs, and run it through its final test late in the calendar year. The optical telescope element will come together with the addition of the 18 mirror segments to their support structure. The five tennis-court-sized sunshield membranes will be manufactured (one is complete and three more are in process), and work will continue on the acquisition and integration of subsystems like communications, power, and data handling into the spacecraft bus.

In addition to this work developing the flight hardware, we are exercising the operations aspects of the mission through the involvement of the Space Telescope Science Institute (STScI), where software is being written to run tests over the next few years that will mature into the software that runs the observatory once it is operational. This philosophy of having the operational entity being intimately involved in the creation and development of the hardware facilitates a seamless transition of testing on orbit to a functioning science mission.

Program Technical Concerns

There are several technical areas that currently have the greatest attention from program and project management. These include reintegration of the science instruments back into the ISIM for final testing later this year, completion of testing for components within the spacecraft bus that hold the telescope during launch, and delivery of the final portion of a cooling system that is required by one of the science instruments. I would like to briefly summarize where we are in each of these areas.

After two highly successful tests of the science instrument module in 2013 and 2014, NASA performed its planned fixes to three of the science instrument detector systems in December 2014. The process of updating hardware and subsequent testing of the new hardware revealed some additional technical issues that are being fixed prior to re-installation of the science instruments. Solutions have been developed and adequate funding exists to cover those costs.

This spring, NASA will be conducting its final testing on actuators that fasten the telescope and spacecraft bus together for the rigors of launch. Once in space, these

actuators release the telescope so that it is free to extend away from the spacecraft and deploy for operations.

One of the Webb science instruments is sensitive to longer infrared wavelengths than the other three and therefore requires a special refrigeration unit, or cryocooler, to cool its detectors to roughly minus 449 degrees Fahrenheit (or 6 Kelvin). This cryocooler, the first and only one of its kind, is required by the science requirement to observe in the infrared. The design and development of this cryocooler has proven to be quite challenging. Today, two thirds of the cryocooler hardware has been delivered; the remaining third of the hardware is undergoing final assembly and testing with a planned delivery in 3 months.

FY 2014 GAO Report

Since the replan in 2011, NASA has worked closely with the GAO in support of their yearly studies of the Webb program. NASA submitted its formal response to the FY 2014 GAO report on February 9, 2015. In that response we made several points that I would like to reiterate for the committee. Webb is managing schedule, cost, and risk extremely well, and has demonstrated the ability to responsibly apply reserves without deferring work. Through careful management of risk, schedule and cost reserves, the Webb program has maintained the 2018 launch readiness date unchanged since the 2011 replan. As noted before, Webb cost and schedule reserves as of March 2015 are above the 2011 projected cost and schedule reserves for this stage of the project.

The Webb project will continue the approach of incremental testing throughout the remainder of the project, allowing the project to continuously evaluate performance and make course corrections as needed, rather than wait until higher levels of testing are completed. Although no project can prevent all possible delays encountered during integration and test, the practices and procedures put in place by the Webb program have, over almost 4 years, proven to be effective for this complex project.

In response to the December 2014 GAO report, NASA has completed the actions NASA said it would take in response to both recommendations made by GAO. The Webb program and project use a range of tools to assess the performance not only of Northrop Grumman Aerospace Systems (NGAS), but of all major Webb contractors. These analyses use the formalism of Earned Value Management (EVM) metric analysis, including Estimate-at-Completion tracking (which incorporates the current risk posture). NASA also conducts comprehensive schedule analysis and reviews the top program and project risks on a monthly basis. This approach is consistent with NASA best practices and we will continue to use those tools to effectively manage the Webb program.

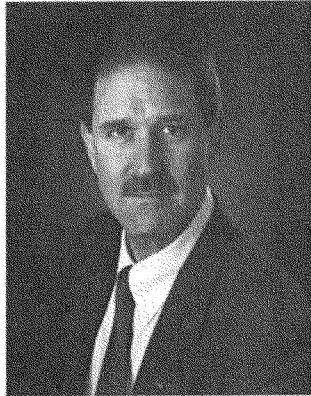
In response to GAO recommendations, the Webb project initiated a cost-risk analysis of the NGAS 'prime contract' portion of the Webb program. The results of this analysis showed that as of July 2014 the program budget is sufficient to complete the NGAS tasks on schedule, including accommodation for anticipated risks. NASA will update this cost-risk analysis when required by NASA program management guidelines.

The GAO also recommended NASA ensures its performance evaluation plans for its award fee contracts reflect total contract performance and clearly describe the contractor performance evaluation process prior to the final evaluation. In response, NASA has modified its performance evaluation plans for the NASA-NGAS and NASA-Exelis contracts to clarify that the criteria contained in the existing performance evaluation plans applied to both the interim evaluations and to total contract performance for the final award fee determination. NASA also provided those modifications to the GAO.

Summary

Webb has been making good progress with significant accomplishments being realized on the science instruments, telescope and sunshield elements. Now, nearly 4 years into its replan, the program is within budget with adequate reserves and is currently carrying more than the planned amount of schedule reserve. We are soon to enter the exciting and challenging integration and test phase when major components are brought together for the first time and subjected to the simulated environments of launch and space. The rigorous cost, schedule and risk controls that have been employed over these 4 years give me confidence that we will meet the challenges we face for launch in 2018. The scientific promise of Webb is great. The team engaged in its development is world class in its experience and capabilities. Programs like Webb demonstrate to the world that NASA leads the way in expanding the frontiers of human inquiry and innovation. Thank you for listening. I am happy to answer any questions you have about this one-of-a-kind observatory.

John M. Grunsfeld, Associate Administrator for the Science Mission Directorate



John M. Grunsfeld was named Associate Administrator for the Science Mission Directorate at NASA Headquarters in Washington, D.C. in January 2012. He previously served as the Deputy Director of the Space Telescope Science Institute in Baltimore, managing the science program for the Hubble Space Telescope and the forthcoming James Webb Space Telescope. Grunsfeld's background includes research in high energy astrophysics, cosmic ray physics and in the emerging field of exoplanet studies with specific interest in future astronomical instrumentation.

Grunsfeld joined NASA's Astronaut Office in 1992. He is veteran of five space shuttle flights, and visited Hubble three times during these missions. He also performed eight spacewalks to service and upgrade the observatory. He logged more than 58 days in space on his shuttle missions, including 58 hours and 30 minutes of spacewalk time. Grunsfeld first flew to space aboard Endeavour in March 1995 on a mission that studied the far ultraviolet spectra of faint astronomical objects using the Astro-2 Observatory. His second flight was aboard Atlantis in January 1997. The mission docked with the Russian space station Mir, exchanged U.S. astronauts living aboard the outpost, and performed scientific research using the Biorack payload. He also flew on Discovery in December 1999, Columbia in March 2002 and Atlantis in May 2009. This last flight successfully serviced and upgraded the Hubble Space Telescope, during which he was lead spacewalker for Hubble servicing activities. In 2004 and 2005, he served as the commander and science officer on the backup crew for Expedition 13 to the International Space Station.

Grunsfeld graduated from the Massachusetts Institute of Technology in 1980 with a bachelor's degree in physics. He subsequently earned a master's degree and, in 1988, a doctorate in physics from the University of Chicago using a cosmic ray experiment on space shuttle Challenger for his doctoral thesis. From Chicago, he joined the faculty of the California Institute of Technology as a Senior Research Fellow in Physics, Mathematics and Astronomy.

For Grunsfeld's NASA astronaut biography, visit: <http://www.jsc.nasa.gov/Bios/htmlbios/grunsfel.html>.

For more information about NASA's Science Mission Directorate, visit: <http://nasascience.nasa.gov>.

Chairman PALAZZO. Thank you, Dr. Grunsfeld.
I now recognize Ms. Chaplain.

**TESTIMONY OF MS. CRISTINA CHAPLAIN,
DIRECTOR OF ACQUISITION AND SOURCING MANAGEMENT,
U.S. GOVERNMENT ACCOUNTABILITY OFFICE (GAO)**

Ms. CHAPLAIN. Chairman Palazzo, Ranking Member Edwards, and Members of the Subcommittee, thank you for inviting me today to discuss the GAO's work on the James Webb Telescope. As you may know, we were reported—we were mandated to report annually on the program after it experienced a 78 percent cost increase over its baseline and a 52-month delay. At the time the program was being re-planned, there were significant concerns raised about optimistic estimates, low reserves, ineffective oversight, and poor communication. In response to our mandate, we have issued three detailed reports on James Webb. Also, we have been assessing James Webb as part of our broader annual assessment of NASA's major projects known as the Quick Look, and I am happy to say that that report is being released today.

This year, we reported that James Webb is still on track with its 2011 cost and schedule baselines. A great deal of progress has been made in developing individual components of the telescope and in overcoming some technical challenges. However, the project is beginning to lose schedule reserve as it has struggled to resolve issues such as workmanship and manufacturing problems with the cryocooler dedicated to the MIRI instrument. We reported that overall schedule reserve had declined to 11 months, and another month was lost since our report was issued. While 10 months is still a lot of time and well within the criteria the program follows, there are still reasons to be concerned about the decline.

First, the project faces the very difficult phases of integration and testing. Most space projects encounter problems they did not expect to encounter in this phase. Second, a number of activities have to happen sequentially. The further you go into integration, the less flexibility you have to resolve problems in parallel. Third, there are several elements near the project's critical path which further limits the project's flexibility.

The types of technical problems James Webb is experiencing are not unusual for a complex and unique project. They are an inherent aspect of pushing technological design and engineering boundaries. What is important when managing such a project is having a good picture of risk, which can shift day to day, and having good tools for mitigating risks as they surface and knowing how they affect your ultimate cost and schedule goals.

NASA has taken an array of actions following the 2011 re-plan to enable the program to have better insight into risk. However, we reported that NASA had not updated the cost and schedule estimate known as the Joint Confidence Level, or JCL, nor had the contractor updated the risk analyses that underpin the estimate. In conducting our work in 2014, we determined that a current and independent cost-risk analysis was needed to provide the Congress with insight into the remaining work on the Northrop Grumman prime contract, the largest and most expensive portion of the work remaining for James Webb.

A key reason for this determination was and continues to be the significant potential impact that any additional cost growth on James Webb would have on NASA's broader portfolio science projects. Our preference would have been for NASA to have updated the JCL and to have addressed the fundamental flaws of documents that supported it. We were unable to conduct this analysis, though, because Northrop Grumman did not allow us to conduct anonymous interviews of technical experts without a manager present.

In order to collect unbiased data, interviewees must be assured that their opinions on risk and opportunities remain anonymous. This is a key best practice and a fundamental part of our methodology. Unbiased data would have allowed us to provide a credible assessment of risks remaining for the work ahead. Any time we are denied access to people or documents, we are concerned since it could be a sign that an entity is afraid of what we will find, but I will balance that by noting that the program and Northrop have been very candid with us in discussions about risk and in supplying information about risk and that our relationships have otherwise been very productive.

Moreover, in response to our findings, NASA agreed to undertake its own cost-risk analysis of the Northrop contract, which was provided to us shortly before the hearing. NASA is also using a new analysis of earned value management data, which should provide the project with additional insight on how current risks affect cost and schedule goals. These analyses look promising, and we look forward to assessing them in our next review. What will be important for NASA is to see the results of these analyses to manage its program and to candidly report on its progress to Congress.

Thank you, and I am happy to answer any questions you have.
[The prepared statement of Ms. Chaplain follows:]



United States Government Accountability Office

Testimony

Before the Subcommittee on
Space, Committee on Science,
Space, and Technology,
House of Representatives

For Release on Delivery
Expected at 10:00 a.m. ET
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JAMES WEBB SPACE TELESCOPE

Project Facing Increased Schedule Risk with Significant Work Remaining

Statement of Cristina T. Chaplain,
Director, Acquisition and Sourcing
Management

GAO Highlights

Highlights of GAO-15-483T, a testimony before the Subcommittee on Space, Committee on Science, Space, and Technology, House of Representatives

Why GAO Did This Study

JWST is one of the National Aeronautics and Space Administration's (NASA) most complex and expensive projects. At an anticipated cost of \$8.8 billion, JWST is intended to revolutionize understanding of star and planet formation, advance the search for the origins of the universe, and further the search for earth-like planets. Since entering development in 1999, JWST has experienced significant schedule delays and increases to project costs and was rebaselined in 2011. With significant integration and testing planned during the approximately 3.5 years until the launch date in October 2018, the JWST project will need to address many challenges before NASA can conduct the science the telescope is intended to produce. GAO has reviewed JWST for the last 3 years as part of an annual mandate and for the last 7 years as part of another annual mandate to review all of NASA's major projects. Prior to this, GAO also issued a report on JWST in 2006.

This testimony is based on GAO's third annual report on JWST (GAO-15-100), issued in December 2014, with limited updated information provided where applicable. That report assessed, among other issues, the extent to which (1) technical challenges were impacting the JWST project's ability to stay on schedule and budget, and (2) budget and cost estimates reflected current information about project risks. To conduct that work, GAO reviewed monthly JWST reports, interviewed NASA and contractor officials, reviewed relevant policies, and conducted independent analysis of NASA and contractor data.

View GAO-15-483T. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

March 24, 2015

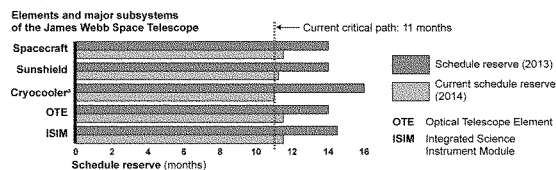
JAMES WEBB SPACE TELESCOPE

Project Facing Increased Schedule Risk with Significant Work Remaining

What GAO Found

James Webb Space Telescope (JWST) project officials report that the effort remains on track toward the schedule and budget established in 2011. However, the project is now in the early stages of its extensive integration and testing period. Maintaining as much schedule reserve as possible during this phase is critical to resolve challenges that will likely surface and negatively impact the schedule. JWST has begun integration and testing for only two of five elements and major subsystems. While the project has been able to reorganize work when necessary to mitigate schedule slips thus far, this flexibility will diminish as work during integration and testing tends to be more serial, as initiating work is often dependent on the successful and timely completion of the prior work.

Schedule Reserve Changes on the James Webb Space Telescope's Elements and Major Subsystems from 2013 to 2014



*The cryocooler chills an infrared light detector on one of JWST's four scientific instruments.

In December 2014, GAO reported that delays had occurred on every element and major subsystem schedule, each was at risk of driving the overall project schedule, and the project's schedule reserve had decreased from 14 to 11 months. As a result, further delays on any element or major subsystem would increase the overall schedule risk for the project. At the time of the report, challenges with manufacturing of the cryocooler had delayed that effort and it was the driver of the overall project schedule. Since the December report, the project's overall schedule reserve decreased to 10 months as a result of several problems that were identified following a test of the Integrated Science Instrument Module (ISIM), which contains the telescope's scientific instruments. ISIM is now driving the overall project schedule. Furthermore, additional schedule impacts associated with challenges on several other elements and major subsystems are still being assessed.

At the time of the December 2014 report, the JWST project and prime contractor's cost risk analyses used to validate the JWST budget were outdated and did not account for many new risks identified since 2011. GAO best practices for cost estimating call for regularly updating cost risk analyses to validate that reserves are sufficient to account for new risks. GAO recommended, among other actions, that officials follow best practices while conducting a cost risk analysis on the prime contract and update the analysis as significant risks emerged. NASA partially concurred, noting that it has a range of tools in place to assess performance and would update the analysis as required by policy. Since then, officials completed the analysis and GAO is currently examining the results.

United States Government Accountability Office

Chairman Palazzo, Ranking Member Edwards, and Members of the Subcommittee:

Thank you for inviting me to testify on the current state of the National Aeronautics and Space Administration's (NASA) acquisition of the James Webb Space Telescope (JWST). As you know, JWST is one of NASA's most complex and expensive projects, at an anticipated cost of \$8.8 billion. JWST is intended to revolutionize understanding of star and planet formation, advance the search for the origins of the universe, and further the search for earth-like planets. Projects of this scale, complexity, and technological sophistication confront a myriad of unforeseen challenges in their ambitious attempts to expand the limits of scientific accomplishment. With significant integration and testing planned until the scheduled launch in October 2018, the success of JWST hinges on the ability of NASA and its contractors to adjust and respond to these challenges in a timely and cost-effective manner. With future NASA missions and exploration depending on the success of JWST, its ultimate outcome will have effects many years into the future.

We have reviewed JWST for the last 3 years as part of an annual mandate and for the last 7 years as part of our mandate to assess all of NASA's major projects.¹ Prior to this, we also issued a report on JWST in 2006. Information on all of our previous work on JWST is listed in the back of this testimony. Over this time, we have seen much progress and the project has addressed many technical challenges. Significant portions of the telescope are built and being tested or are in manufacturing, including the 18 primary mirrors, four scientific instruments, and parts of the sunshield and spacecraft. Today, I will discuss a portion of our recent work on the acquisition of the JWST. Specifically, I will discuss the extent to which (1) technical challenges are impacting the JWST project's ability to stay on schedule and budget, and (2) budget and cost estimates reflect current information about project risks.

My testimony today is based on our most recent report released in December 2014, some limited updated information since the report was published, and prior reports on JWST for background. For our most recent report, we examined monthly status reports from the project and contractors; conducted an analysis of JWST cost reserves; reviewed best

¹H.R. Rep. No. 112-284, at 254 (2011) (Conf. Rep.).

practices for cost risk analyses; and interviewed NASA project, program, and contracting officials, among other actions. Our December report includes a detailed description of our scope and methodology.

All work on which this testimony is based was performed in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

JWST is defined by three elements: the Integrated Science Instrument Module (ISIM), the Optical Telescope Element (OTE), and the spacecraft and two of its major subsystems—the cryocooler and sunshield. See appendix I for a description of all the elements and major subsystems of JWST. Projects managed out of Goddard Space Flight Center, like JWST, are required to reserve extra time in their schedules—which is referred to as schedule reserve—and extra money in their budgets—which is referred to as cost reserve—to address unforeseen technical challenges or absorb additional costs as the project progresses.² For JWST, schedule reserve is held at the overall project level with some reserve allocated to each element and major subsystem. The element or major subsystem with the least amount of schedule reserve determines the project's critical path—the earliest completion date or minimum duration it will take to complete all project activities. Any delay to an activity that is on the critical path will reduce schedule reserve for the whole project, and could ultimately impact the overall project schedule.

Since entering development in 1999, JWST has experienced significant schedule delays and increases to project costs. Prior to being approved for development, cost estimates of the project originally ranged from \$1 billion to \$3.5 billion with expected launch dates ranging from 2007 to 2011. In March 2005, NASA increased the JWST's life-cycle cost estimate to \$4.5 billion and delayed the launch date to 2013. We reported in 2006 that the cost growth was due to a delay in launch vehicle selection, budget limitations in fiscal years 2006 and 2007, requirements changes, and an increase in the project's cost reserves. In April 2006, an

²Goddard Space Flight Center, Goddard Procedural Requirements 7120.7 (May 4, 2008).

Independent Review Team confirmed that the project's technical content was complete and sound, but expressed concern over the project's reserve funding, reporting that it was too low and phased in too late in the development life cycle. The review team reported that for a project as complex as JWST, a 25 to 30 percent total reserve funding was appropriate. The team cautioned that low reserve funding compromised the project's ability to resolve issues, address risk areas, and accommodate unknown problems. The project was baselined in April 2009 with a life-cycle cost estimate of \$4.964 billion—including additional cost reserves—and a launch date in June 2014. Shortly after JWST was approved for development and its cost and schedule estimates were baselined, project costs continued to increase and the schedule was extended.

In response to a request in 2010 from the Chair of the of the Senate Subcommittee on Commerce, Justice, Science, and Related Agencies to the NASA Administrator for another independent review of JWST, NASA commissioned the Independent Comprehensive Review Panel (ICRP). In October 2010, the ICRP issued its report and cited several reasons for the project's problems including management, budgeting, oversight, governance and accountability, and communication issues. The panel also identified changes to address root causes to diminish the risk of future cost increases and delays to the launch date. The panel concluded that JWST was executing well from a technical standpoint, but that baseline funding did not reflect the most probable cost with adequate reserves in each year of project execution, resulting in an unexecutable project.³ Following this review, the JWST program underwent a replan in September 2011. On the basis of the replan, NASA announced that the project would be rebaselined with a life cycle cost of \$8.835 billion—a 78 percent increase—and would launch in October 2018—a delay of an additional 52 months. The replan included 13 months of funded schedule reserve and a 66 percent joint cost and schedule confidence level (JCL)

³James Webb Space Telescope (JWST) Independent Comprehensive Review Panel (ICRP): Final Report (Oct. 29, 2010).

for the revised cost and schedule baselines.⁴ A JCL is the process that NASA uses to assign a percentage to the probable success of meeting cost and schedule estimates as part of the project's estimating process. Currently, JWST makes up a significant portion—approximately 54 percent, or \$6.2 billion—of NASA's 2015 science portfolio's total development cost of \$11.5 billion for major projects.

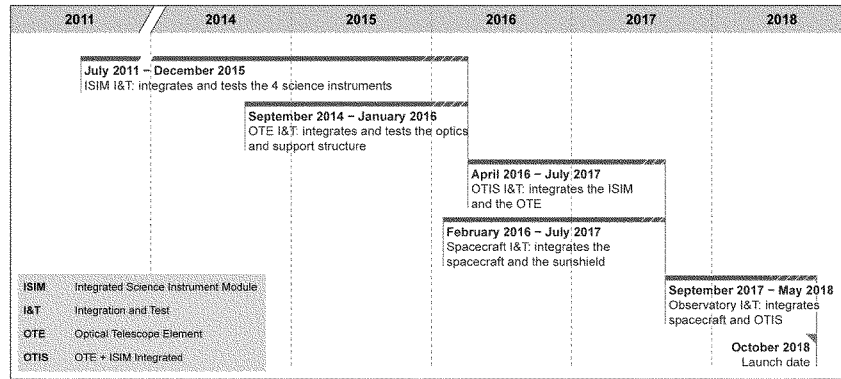
Since 2012, we have reported annually that JWST is on track with respect to its new cost and schedule goals, but have raised questions about the reliability of the project's estimates. In 2012, we reported that the lack of detail in the summary schedule used for JWST's JCL analysis during the 2011 replan prevented us from sufficiently understanding how risks were incorporated, calling into question the results of that analysis and, therefore, the reliability of the replanned cost estimate. We recommended that the JWST project perform an updated JCL analysis. NASA concurred but, to date, has not updated the JCL. In our January 2014 report, our analysis of three subsystem schedules determined that the reliability of the project's integrated master schedule—which is dependent on the reliability of JWST's subsystem schedules—was questionable. We recommended that NASA perform schedule risk analyses on the three specific schedules we examined and any others for which a schedule risk analysis was not performed. NASA concurred and has performed schedule risk analyses on two of the three schedules we examined.

⁴The JCL is a quantitative probability analysis that requires the project to combine its cost, schedule, and risks into a complete quantitative picture to help assess whether the project will be successfully completed within cost and on schedule. NASA introduced the analysis in 2009, and it is among the agency's initiatives to reduce acquisition management risk. The move to probabilistic estimating marks a major departure from NASA's prior practice of establishing a point estimate and adding a percentage on top of that point estimate to provide for contingencies. NASA's procedural requirements state that Mission Directorates should plan and budget programs and projects based on a 70 percent JCL, or at a different level as approved by the Decision Authority of the Agency Program Management Council, and any JCL approved at less than 70 percent must be justified and documented. NASA Procedural Requirements (NPR) 7120.5E, NASA Space Flight Program and Project Management Requirements, paragraph 2.4.4 (Aug. 14, 2012).

**Project Risk
Heightened Due
to Widespread
Use of Schedule
Reserve to Address
Technical Issues**

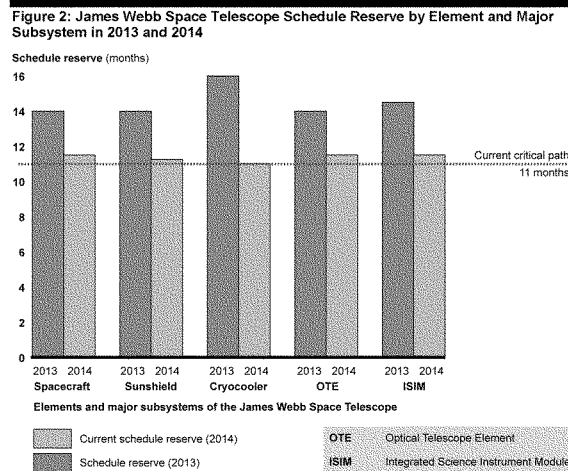
The JWST project continues to report that it remains on schedule and budget with its overall schedule reserve currently above its plan. However, the project is now entering a difficult phase of development—integration and testing—which is expected to take another 3.5 years to complete. Maintaining as much schedule reserve as possible is critical during this phase to resolve known risks and unknown problems that may be discovered. Being one of the most complex projects in NASA's history, significant risks lie ahead for the project, as it is during integration and testing where problems are likely to be found and as a result, schedules tend to slip. As seen in figure 1, only two of five elements and major subsystems—ISIM and OTE—have entered the integration and testing phase. Integration and testing for the spacecraft and sunshield and for the ISIM and OTE when they are integrated together begins in 2016 and the entire observatory will begin this phase in late 2017.

Figure 1: Integration and Test (I&T) Schedule for the James Webb Space Telescope Elements



Source: GAO analysis of NASA data. | GAO-15-483T

In December 2014, we reported that schedule risk was increasing for the project because it had lost schedule reserve across all elements and major subsystems. As a result, all were within weeks of becoming the critical path of the project and driving the project's overall schedule. Figure 2 shows the different amounts of schedule reserve remaining on all elements and major subsystems, their proximity to the critical path, and the total schedule reserve for the critical path at the time of our review.



Source: GAO analysis of NASA data. | GAO-15-483T

The proximity of all the elements and major subsystem schedules to the critical path means that a delay on any of the elements or major subsystems may reduce the overall project schedule reserve further, which could put the overall project schedule at risk. As a result, the project has less flexibility to choose which issues to mitigate. While the project has been able to reorganize work when necessary to mitigate schedule slips thus far, with further progression into subsequent

integration and testing periods, flexibility will be diminished because work during integration and testing tends to be more serial, as the initiation of work is often dependent on the successful and timely completion of the prior work. This is particularly the case with JWST given its complexity.

Challenges with the development and manufacturing of the sunshield and the cryocooler were the most significant causes of the decline in schedule reserve that we reported on in December 2014. The sunshield experienced a significant manufacturing problem during the construction of the large composite panel that forms part of the sunshield's primary support structure. The cryocooler compressor assembly—one component of the cryocooler—delivery is a top issue for the project and its development has required a disproportionate amount of cost reserves to fund additional work, caused in part, by issues such as a manufacturing error and manufacturing process mistake that caused delays to the schedule. The development of the cryocooler has been a concern for project officials as far back as 2006. Since that time, the cryocooler has faced a number of technical challenges, including valve leaks and cryocooler underperformance, which required two subcontract modifications and significant cost reserves to fund. The contractor and subcontractor were focused on addressing valve problems, which limited their attention to the cooling underperformance issue. This raised questions about the oversight of the cryocooler and why it did not get more attention sooner before significant delays occurred. In August 2013, the cryocooler subcontract was modified to reflect a 69 percent cost increase and that the workforce dedicated to the cryocooler effort at the subcontractor increased from 40 staff to approximately 110 staff.

Since we issued our December 2014 report, JWST schedule reserve continued to decline: project schedule reserve decreased by 1 month, leaving 10 months of schedule reserve remaining, and the critical path switched from the cryocooler to the ISIM. The project is facing additional challenges with the testing of the ISIM and OTE and the manufacturing of the spacecraft in addition to continuing challenges with the cryocooler compressor assembly that further demonstrates continued schedule risk for the project. For example, after the second test for the ISIM—the element of JWST that contains the telescope's four different scientific instruments—electronic, sensor, and heat strap problems were identified that impact two of the four instruments. Mitigating some of these issues led to a 1.5-month slip to the ISIM schedule and made ISIM the current critical path of the project to allow officials time to replace the unusable and damaged parts. As a result, ISIM's third and final cryovacuum test scheduled to begin in August 2015 has slipped until September 2015.

The OTE and spacecraft efforts are also experiencing challenges that may impact the schedules for those efforts. For example, it was discovered that over 70 harnesses on the OTE potentially had nicks on some wires and the majority will need to be repaired or rebuilt. The effects of these challenges on the project's schedule are still being determined. Finally, the cryocooler compressor assembly has yet to be delivered and will be more than 16 months late if the current delivery date holds. Since our December 2014 report, the cryocooler compressor assembly's delivery slipped almost an additional 2 months due to manufacturing and build issues and for an investigation of a leak to a joint with the pulse tube pre-cooler.⁵ Currently, the cryocooler compressor assembly is expected to be delivered in mid-June 2015 and is only 1 week off of the project's critical path.

Entering fiscal year 2015, the JWST project had limited short-term cost reserves to address technical challenges and maintain schedule. We reported the project had committed approximately 40 percent of the fiscal year 2015 cost reserves before the start of the fiscal year. As a result, one of the project's top issues for fiscal year 2015 is its cost reserve posture, which the project reported is less than desired and will require close monitoring. At the end of February, project officials had committed approximately 60 percent of the fiscal year 2015 cost reserves and noted that maintaining fiscal year 2016 reserves needed close watching.

**Project Lacked
Updated Cost
Risk Analysis
Despite Significant
Changes to Risk**

The types of technical problems JWST is experiencing are not unusual for a project that is unique and complex. They are an inherent aspect of pushing technological, design, and engineering boundaries. What is important when managing such a project is having a good picture of risks, which can shift from day to day, and having effective tools for mitigating risks as they surface. Using up-to-date and thorough data on risks is also integral to estimating resources needed to complete the project. Given the cost of JWST, its previous problems with oversight, and the fact that the program is entering its most difficult phases of development, risk analysis and risk management have been a key focus of our work.

⁵The overall schedule reserve was not impacted the full 2 months because the project was able to mitigate the delay, in part, by modifying acceptance testing and by identifying a later delivery date to spacecraft integration and testing.

JWST officials have taken an array of actions following the 2011 replan to enable the program to have better insight into risks and to mitigate them. For instance, we reported in 2012 that the project had implemented a new risk management system after it found the previous system lacked rigor and was ineffective for managing risks. The project instituted meetings at various levels throughout NASA and its contractors and subcontractors to facilitate communication about risks. The project also added personnel at contractor facilities, which allowed for more direct interaction and quicker resolution of issues.

However, we reported in December 2014 that neither NASA nor the prime contractor had updated the cost risk analysis that underpinned the cost and schedule estimates for the 2011 replan. A cost risk analysis quantifies the cost impacts of risks and should be used to develop and update a credible estimate that accounts for all possible risks—technical, programmatic, and those associated with budget and funding. Moreover, conditions have changed significantly since the replan. For example, the delivery of the cryocooler compressor assembly is one of the project's top issues and was not an evident risk when the cost risk analysis was conducted in 2011. On the prime contract, our analysis found that 67 percent of risks tracked by Northrop Grumman in April 2014 at the time of our analysis were not present in September 2011 at the time of the replan.

We determined that a current and independent cost risk analysis was needed to provide Congress with insight into JWST's remaining work on the Northrop Grumman prime contract—the largest (most expensive) portion of work remaining. A key reason for this determination was and continues to be the significant potential impact that any additional cost growth on JWST would have on NASA's broader portfolio of science projects. To provide updated and current insight in to the project's cost

status, we took steps to conduct an independent, unbiased analysis.⁶ We were, however, unable to conduct the analysis because Northrop Grumman did not allow us to conduct anonymous interviews of technical experts without a manager present. In order to collect unbiased data, interviewees must be assured that their opinions on risks and opportunities remain anonymous. Unbiased data would have allowed us to provide a credible assessment of risks for Northrop Grumman's remaining work.

NASA and the JWST project disagreed that an independent cost risk analysis conducted by an outside organization at this point in the project would be useful. Neither believed that an organization external to NASA could fully comprehend the project's risks. Further, they noted that any such analysis would be overly conservative due to the complexities of the risks and not representative of the real risk posture of the project. GAO's best practices call for cost estimates to be compared to independent cost estimates in addition to being regularly updated. Without an independent and updated analysis, both the committee members' and NASA's oversight and management of JWST will be constrained since the impact of newer risks have not been reflected in key tools, including the cost estimate. Moreover, our methodology would have provided both NASA and Northrop Grumman with several opportunities to address concerns with our findings, including concerns about conservatism.

After we were unable to conduct the cost risk analysis, NASA decided to conduct its own cost risk analysis of the Northrop Grumman remaining work. However, a NASA project official said that they did not plan to use data from the cost risk analysis to manage the project. Instead, they indicated that they planned to use the information to inform committee members of the project's cost risk and would continue to rely on other

⁶As part of the methodology, we had planned to conduct approximately 30 interviews with different personnel working on the Northrop Grumman contract to assess the probability of different risks in their specific area would occur in order to develop probability distributions for the cost or duration of activities. From this data, collected anonymously in the interviews so the data is unbiased, random simulations would be run thousands of times, creating a new program total cost and duration estimates each time. The end product would have been a range of program costs or completion dates along with the probabilities that these costs or dates will occur. While this step was not essential to accomplish the objectives of our review, it would have provided NASA with an updated level of confidence associated with Northrop Grumman meeting its cost estimate and allowed decisionmakers to determine if additional cost reserves were warranted to mitigate future risks.

tools already in place to project the future costs of the project, such as earned value management (EVM) analysis.⁷ To maintain quality cost estimates over the life of a project, best practices state that cost risk analyses should be updated regularly to incorporate new risks and be used in conjunction with EVM analysis to validate cost estimates. While EVM is a very useful tool for tracking contractor costs and potential overruns, the analyses are based on past performance that do not reflect the potential impact of future risks. We reported that if the project did not follow best practices in conducting its cost risk analysis or use it to inform project management, the resulting information may be unreliable and may not substantively provide insight into JWST's potential cost to allow either Congress or project officials to take any warranted action. To better ensure NASA's efforts would produce a credible cost risk analysis, in December 2014, we recommended that officials follow best practices while conducting a cost risk analysis on the prime contract for the work remaining and update it as significant risks emerged. Doing so would ensure it provided information to effectively manage the program. NASA partially concurred with our recommendation, again noting that it has a range of tools in place to assess all contractors' performance, the approach the project has in place is consistent with best practices, and officials will update the cost risk analysis again when required by NASA policy. We found that NASA best practices for cost estimating recommend updating the cost risk analysis while a project is being designed, developed, and tested, as changes can impact the estimate and the risk assessment.

Since our report was published, NASA completed its analysis and provided the results to us. We are currently examining the analysis to assess its quality and reliability and the extent to which it was done in accordance with NASA and GAO best practices. Our initial examination indicates the JWST project took the cost risk analysis seriously and took into account best practices in the execution of the analysis. The project has also recently begun conducting a new analysis of EVM data which

⁷Earned value management is a project management tool that integrates the technical scope of work with schedule and cost elements and compares the value of work accomplished in a given period with the value of the work expected in that period. When used properly, earned value management can provide objective assessments of project progress, produce early warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion. As a best practice, the work breakdown structure should match the schedule, cost estimate, and earned value management system at a high level so that it clearly reflects the work to be done.

they term a secondary estimate at completion analysis for two of its largest contractors—Northrop Grumman and Exelis—on work to go. This analysis should provide the project additional insight on the probabilities of outcomes while incorporating current risks against the cost reserves that remain. The initial analysis we have reviewed indicates that both contracts are forecasted to generally cost more at completion than the information produced using EVM analysis alone, but within the JWST life-cycle cost. However, we still have work to do to understand how NASA is analyzing the information and what assumptions it is putting into its analysis.

In conclusion, with approximately 3.5 years until launch, project officials have made much progress building and testing significant pieces of hardware and are currently on schedule—achieving important milestones—and on budget. They have also taken important steps to increase their insight and oversight into potential problems. What is important going forward is having good insight into risks and preserving as much schedule reserve as possible—particularly given the complexity of the project, the fact it is entering deeper into its integration and testing cycle, and the fact that it has limited funds available in the short term to preserve schedule. Any cost growth on JWST may have wider implications on NASA's other major programs. While we are concerned about NASA's reluctance to accept an independent cost risk assessment, particularly in light of past problems with oversight, we are also encouraged that NASA took steps to conduct an updated risk analysis of Northrop Grumman's work and that NASA has sustained and enhanced its use of other tools to monitor and manage risk. As we undertake this year's review of JWST, we will continue to focus on risk management, the use of cost reserves, progress with testing, as well as the extent to which its cost risk analysis followed best practices. We look forward to continuing to work with NASA on this important project and reporting to Congress on the results of our work.

Chairman Palazzo, Ranking Member Edwards, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to answer questions related to our work on JWST and acquisition best practices at this time.

**GAO Contact and
Staff
Acknowledgments**

For questions about this statement, please contact Cristina Chaplain at (202) 512-4841, or at chaplainc@gao.gov. Contact points for our Offices of Congressional Relationship and Public Affairs may be found on the last page of this statement. Individuals making key contributions to this testimony were Shelby Oakley, Assistant Director; Karen Richey, Assistant Director; Jason Lee, Assistant Director; Patrick Breiding; Laura Greifner; Silvia Porres; Carrie Rogers; Ozzy Trevino; and Sylvia Schatz.

Appendix I: Elements and Major Subsystems of the James Webb Space Telescope (JWST) Observatory

A complex, multi-faceted structure with various protrusions and recessed areas, representing the Integrated Science Instrument Module (ISIM).	<p>Integrated Science Instrument Module</p> <p>Acronym: ISIM</p> <p>Contractor/Center: Goddard Space Flight Center</p> <p>Description: Combines the 4 instruments</p>	A large, rectangular structure with a prominent central section and various smaller components, representing the Mid Infrared Instrument (MIRI).	<p>Mid Infrared Instrument</p> <p>Acronym: MIRI</p> <p>Contractor/Center: Jet Propulsion Lab and European Consortium</p> <p>Description: Science instrument</p>	A large, rectangular structure with a prominent central section and various smaller components, representing the Near Infrared Spectrograph (NIRSpec).	<p>Near Infrared Spectrograph</p> <p>Acronym: NIRSpec</p> <p>Contractor/Center: European Space Agency</p> <p>Description: Science instrument</p>	A large, rectangular structure with a prominent central section and various smaller components, representing the Fine Guidance Sensor / Near-Infrared Imager and Slitless Spectrograph (FGS/NIRISS).	<p>Fine Guidance Sensor / Near-Infrared Imager and Slitless Spectrograph</p> <p>Acronym: FGS/NIRISS</p> <p>Contractor/Center: Canadian Space Agency</p> <p>Description: Telescope guider and Science instrument</p>	A large, rectangular structure with a prominent central section and various smaller components, representing the Near Infrared Camera (NIRCam).	<p>Near Infrared Camera</p> <p>Acronym: NIRCam</p> <p>Contractor/Center: University of Arizona</p> <p>Description: Science instrument and Wave Front Sensor</p>
A large, rectangular structure with a prominent central section and various smaller components, representing the Spacecraft.	<p>Spacecraft</p> <p>Contractor/Center: Northrop Grumman Aerospace Systems</p> <p>Description: Contains the power, communications, and avionics needed to operate the observatory. Contains the cryocooler needed to achieve MIRI operational temperatures approximating 7 Kelvin</p>	A large, rectangular structure with a prominent central section and various smaller components, representing the Optical Telescope Element (OTE).	<p>Optical Telescope Element</p> <p>Acronym: OTE</p> <p>Contractor/Center: Northrop Grumman Aerospace Systems</p> <p>Description: 18 primary mirror segments, secondary mirror, tertiary mirror, backplane support structure</p>						
A large, rectangular structure with a prominent central section and various smaller components, representing the Optical Telescope & Integrated Science Instrument Module (OTIS-ISIM).	<p>Optical Telescope & Integrated Science Instrument Module</p> <p>Acronym: OTIS (OTE+ISIM)</p> <p>Contractor/Center: Goddard Space Flight Center</p> <p>Description: Hardware configuration created when OTE and ISIM are integrated</p>	A large, rectangular structure with a prominent central section and various smaller components, representing the Sunshield.	<p>Sunshield</p> <p>Contractor/Center: Northrop Grumman Aerospace Systems</p> <p>Description: Tennis court sized series of 5 thin membranes, provides passive cooling to achieve operational temperatures approximating 45 Kelvin for the OTE and ISIM</p>						

Sources: GAO (analysis); NASA (data and images). | GAO-15-483T

Related GAO Products

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Cristina T. Chaplain

Ms. Chaplain currently serves as a Director, Acquisition and Sourcing Management, at the U.S. Government Accountability Office. She has responsibility for GAO assessments of military space acquisitions, NASA, and the Missile Defense Agency. Among other topics, she has led reviews on the international space station, the Space Launch System, acquisition progress for major NASA projects, the James Webb Space Telescope, commercial cargo and crew, NASA contract management, contract terminations and the evolved expendable launch vehicle. In addition to her work on space and missile system development, Ms. Chaplain has led a variety of DOD-wide contracting-related and best practice evaluations for the GAO. Before her current position, Ms. Chaplain worked with GAO's financial management and information technology teams. Ms. Chaplain has been with the GAO for 24 years. She received a bachelor's degree, magna cum laude, in International Relations from Boston University and a Masters Degree in Journalism from Columbia University.

Chairman PALAZZO. Thank you, Ms. Chaplain.
I now recognize Mr. Grant.

**TESTIMONY OF MR. JEFFREY GRANT,
VICE-PRESIDENT & GENERAL MANAGER,
SPACE SYSTEMS, NORTHROP GRUMMAN CORPORATION**

Mr. GRANT. Chairman Palazzo, Ranking Member Edwards, and distinguished Members of the Committee, it gives me a great deal of pleasure to appear before you today on behalf of the men and women of Northrop Grumman who are working on the James Webb Space Telescope, and I am honored to appear with you today with these three other distinguished witnesses.

Mr. Chairman, it has been over just three years ago since I last appeared before the Committee and discussed the program, and I am really pleased to report today that the program remains on track, both in terms of schedule and funding for successful 2018 launch. That is not to say that we have not had challenges. A program of this complexity will invariably be confronted by significant hurdles. We have successfully met the challenges we knew about in 2011 and most of those that have occurred since. The MIRI cryocooler, our latest challenge, has proven a difficult one but one that we continue to make significant progress in completing the last subassembly of that complex cooler.

Those Members of the Committee that were here three years ago may recall the path that we laid out to get to a 2018 launch. It was very challenging, but we communicated that it was executable. We have a solid design as evidenced by the successful spacecraft critical design review that occurred in January of 2014 and a renewed focus and a plan that we are now executing to.

The major technical risk reduction work is in fact behind us and we are now entering the phase of the program where the major risks are in the integration and test phase. Now, despite that, we anticipate that new challenges will emerge, and we recognize the need to do better at addressing these. That is why we continue to incorporate risk reduction activities into the plan to increase our confidence of meeting that launch schedule. For example, the optical telescope pathfinder will be used to trailblaze the optical testing at the Johnson Space Center in 2017, and the sunshield full-scale development model will undergo another full-scale deployment test this summer. In addition, we will be performing early mating of the Optical Telescope Element and the spacecraft bus this summer in advance of the flight mate in 2017.

Mr. Chairman, the 2011 re-baseline has been instrumental in our ability to manage challenges with prudent cost and schedule reserve across the fiscal years. The distributed schedule slack has proven crucial in our ability to manage problems as they have occurred within allowable reserves. In fact, all major subsystems have above plan schedule margin remaining, and we currently are maintaining 10 months of funded slack in our schedule. With less than four years to go before launch, this amount of schedule contingency is appropriate for a program of this type and provides adequate contingency for unexpected challenges that may arise.

Similarly, we continue to evaluate actions to contain cost and our financial controls have been designed to ensure contractual discipline to avoid unintended cost.

I want to assure the Committee at every level that Northrop Grumman remains dedicated to a successful mission overcoming these hurdles. As we move closer to the 2018 launch date, the next few years will be critical. Our immediate focus is finishing the fabrication and assembly of the spacecraft and sunshield, integrating optics onto the assembled back plane and completion of the MIRI cryocooler. The focus will then shift to integration and testing of the Optical Telescope Element, the Integrated Science Instrument Module, and assembling the spacecraft and sunshield into a single system. This Committee's support is essential to keeping the program on cost and on schedule for that 2018 launch.

Mr. Chairman, I hope that my pride and enthusiasm in JWST and our partners is evident. From the technicians in the clean room to our CEO, Northrop Grumman remains fully committed to the success of this mission. I want to assure the Committee that we are taking our role seriously and are doing our part to address the technical and programmatic challenges before us. We remain confident in launching in 2018 within the congressionally mandated development cost.

I look forward to working with NASA as it leads this amazing effort and with the Committee to ensure that this program is a success. So I want to thank you again for asking me to appear before your Committee and welcome your questions. Thank you.

[The prepared statement of Mr. Grant follows:]

STATEMENT BY

MR. JEFFREY D. GRANT
SECTOR VICE PRESIDENT AND GENERAL MANAGER
SPACE SYSTEMS
NORTHROP GRUMMAN AEROSPACE SYSTEMS



BEFORE THE

SUBCOMMITTEE ON SPACE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING ON

JAMES WEBB SPACE TELESCOPE

FIRST SESSION, 114TH CONGRESS
MARCH 24, 2015

**Statement by Jeffrey D. Grant, Sector Vice President and General Manager
Space Systems, Northrop Grumman Aerospace Systems**

**Before the Subcommittee on Space
Committee on Science, Space, and Technology
James Webb Space Telescope**

Chairman Palazzo, Ranking Member Edwards, and distinguished Members of the Committee, thank you for inviting me to appear before you today on behalf of the men and women of Northrop Grumman supporting the National Aeronautics and Space Administration's (NASA) next great observatory, the James Webb Space Telescope (JWST). Before I begin, I would like to thank the Committee for its leadership of our nation's civil space programs. Your steadfast support, especially with regards to JWST, is critical not only to our success, but to that of the nation's scientific and exploration programs.

I am honored to appear before you today with two NASA leaders, Associate Administrator Dr. John Grunsfeld and Dr. John Mather, Nobel Laureate and Senior Project Scientist for JWST, both leading this tremendous scientific achievement for our nation. JWST represents a technological challenge in support of a scientific objective beyond anything attempted before, and without NASA's leadership, specifically the Goddard Space Flight Center, this would simply not be possible. I am also honored to appear with the Government Accountability Office (GAO) Director of Acquisition and Sourcing Management, Cristina Chaplain, whose agency's oversight helps ensure the success of this program. As with any program, especially one this technologically complex, independent reviews are essential. We have, and will continue, to benefit from GAO's candid and straightforward assessments. I appreciate the relationship we have developed and maintained during the course of this program.

I also need to recognize NASA's international partners on this effort, the European Space Agency and the Canadian Space Agency, who are providing key scientific instruments and the launch vehicle for JWST, and the invaluable contributions of the Space Telescope Science Institute, which serves as the Science and Operations Center for the mission. It is truly the dedication of thousands, who are contributing to the success of the mission.

It gives me a great deal of pleasure to appear before this committee for a second time on this program, the first time in December 2011. At that hearing, I told the Committee that we had restructured the program, added new technical and management talent and were frequently reviewing the program with the leadership of Northrop Grumman to ensure we brought all of the capabilities of the company and our partners to perform successfully. I am very pleased to report that over the last three years we have met almost every milestone we planned and remain on track for a launch in 2018.

Mr. Chairman, you requested that I provide testimony on four specific areas: 1) an assessment of the challenges facing the JWST program 2) an update on Northrop Grumman's efforts to meet these challenges 3) an overview of Northrop Grumman's contingency plans, should technical and programmatic continue to consume cost and schedule reserves and, 4) the steps Northrop Grumman is taking to ensure costs and schedules are met.

1) First, an assessment of the challenges facing the JWST program: The complexity of JWST is unrivaled in our history of space exploration. Unlike Hubble, JWST will deploy large optical systems after launch, and is designed to operate at extreme cryogenic temperatures. Also, the primary mirror is more than two and a half times the diameter of Hubble — over 7 times the light gathering capacity, and it will operate from the second Lagrange (L2) point, more than 930,000 miles away from Earth. I am extremely pleased to report that we have overcome all of the major technical challenges on the program and are now in the manufacturing, integration and test phase of the program. And since the rebaselining in 2011, the program has done this within cost and on schedule, meeting all critical milestones.

The Optical Telescope Element (OTE) is unlike any telescope ever built before, both in size and complexity. The surface of the 18 hexagonal beryllium mirrors that form the primary mirror had to be polished to smoothness where the largest surface irregularity was hundreds of times smaller than the diameter of a single bacterium. These 18 mirror segments have been completed and delivered. They will be installed at the end of this year onto a folding backplane, 21 feet in diameter, which will maintain the mirrors' stability to 1 percent of the width of a

human hair. This backplane is in its final stages of assembly and test in Redondo Beach before being delivered to Goddard Space Flight Center for mirror integration later this year.

The detection of infrared light from very distant stars and planets requires that the telescope operate at extremely low temperatures. Shielding the system from the sun's radiant heat required the design and development of a deployable sunshield the size of a tennis court. This sunshield consists of five layers of aluminum and silicon-coated Kapton – each of which are as thin as a human hair and must maintain precise separations upon deployment. Many of you may have seen the successful test deployment of the sunshield last July – truly an astounding accomplishment.

While the sunshield will protect the science instruments from the heat of the sun, these instruments must also be protected from themselves. The electronics, spectrographs, and cameras generate heat internally, which would interfere with the telescope's infrared sensors, specifically the mid-infrared sensor, if not cooled by other means. Cryocoolers are not unique to satellites, and Northrop Grumman has an outstanding record in building these types of cooling systems. The Mid Infrared Instrument (MIRI) however, requires a unique type of cryocooler in that it needs to cool to 6 degrees Kelvin (-449F) from a distance of 30 feet. We, Northrop Grumman, are building this cryocooler under a subcontract to NASA's Jet Propulsion Laboratory for delivery to them in 2015.

Usually a cryocooler is the standard size of a notebook, but this one stretches over 30 feet from the spacecraft up to the instruments stored behind the optics, resulting in a large distributed system that makes it even more complex. A deployable cryocooler that stretches across this span at this low of a temperature has never been done before in the cryocooler business. The technological design for the cryocooler has been approved and is complete, but manufacturing certain components to operate at such extreme temperatures has proven to be a challenge. The MIRI cooler we are building currently represents the largest technological challenge we are facing on the program.

Recognizing these challenges, Northrop Grumman reorganized the MIRI cryocooler program in early December 2014 to increase focus on systematic execution and schedule forecast accuracy, and also brought additional senior technical and management resources in engineering, manufacturing, mission assurance, and leadership, to enable the new organization to be rapidly and effectively implemented. I am pleased to report that as of this testimony, we have delivered all of the MIRI cooler subsystems to Goddard and JPL except one, and the last subsystem is currently in the final stages of integration and test. I am also very pleased to report that the thermal and vibration test data from the flight hardware has shown excellent performance and we remain confident in the hardware meeting not only its schedule requirement, but its technical and mission life needs.

2) An update on Northrop Grumman's efforts to meet these challenges: No program of this magnitude and complexity is without challenges, and we have expected, and experienced them from the beginning. The 2011 restructure of the program has been instrumental in our ability to navigate these challenges, managing cost and schedule reserves across the fiscal years while retiring significant risks. This distributed schedule slack has proven crucial in our ability to manage problems within the allowed reserves. And while we remain hopeful, realistically we understand that challenges on programs this complex will continue to present themselves. An example is the recently discovered workmanship issues with the cryogenic harnesses. Due to escapes in the manufacturing and inspection processes, we will need to replace or repair nearly three dozen of these harnesses on the backplane. We expect this issue to be resolved within the current schedule and cost reserves, but these are the type of challenges that arise during the manufacturing, integration, and test phase.

We also continue to invest resources in risk reduction activities by trailblazing the more complicated processes in advance of flight production increasing our confidence in executing the flight schedule. All of the major subsystems have maintained above-plan schedule margin due to these proactive risk mitigations. For example, the optical telescope pathfinder will be used to trailblaze the optical testing at the Johnson Space Center in 2017, and the sunshield full scale development article will undergo another full scale deployment this summer. Additionally, we will be performing an early mating of the OTE and the spacecraft this summer in advance of the

flight mate in 2017. If and when further challenges appear, we will attack them with the same determination and commitment that has brought us this far. At every level, Northrop Grumman is dedicated to overcoming these hurdles within cost and schedule reserves.

As we move closer to the 2018 launch date, the next few years will be critical. Our immediate focus is finishing fabrication and assembly of the spacecraft and sunshield, integrating optics onto the assembled backplane, and completion of the MIRI cryocooler. The focus will then shift to integration and testing of the OTE and Integrated Science Instrument Module (ISIM), and assembling the spacecraft and sunshield into a single system. This Committee's support is essential to keeping the program on cost and on schedule for a successful October 2018 launch date.

Specific to Northrop Grumman, we are employing over 700 engineers, scientists, technicians and support staff at our Space Park facility in Redondo Beach, California, and have partnered with 511 suppliers across 39 states to complete the work to date. The reach of JWST is nationwide, harnessing the best technical expertise in the nation for this unprecedented developmental and engineering effort. But it doesn't stop there. Like its predecessor, JWST is, and will continue to motivate and inspire the next generation of scientists.

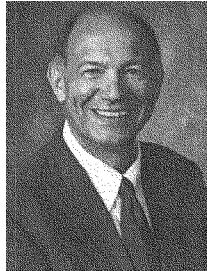
3) An overview of Northrop Grumman's contingency plans, should technical and programmatic continue to consume cost and schedule reserves: We currently maintain 11 months of funded slack in our schedule. With less than three years to go before launch, this amount of schedule contingency is very conservative for a program of this type and, given our experience of more than 50 years developing spacecraft, there is adequate contingency for the unexpected challenges that may arise.

4) The steps Northrop Grumman is taking to ensure costs and schedules are met: A program of this importance and visibility has allowed the prime contract Program Manager Scott Willoughby and the MIRI cryocooler Program Manager Tim Martin to have frequent reviews with all of the senior leadership at Northrop Grumman Aerospace Systems and with the leadership of the corporation. This frequent engagement allows the JWST program managers to

have both top priority and access to the full range of skills required to complete the program. In addition, NASA and Northrop Grumman have involved major leaders in the space and science community to engage personally with the teams working on the program to provide inspiration and vision for how what we are doing is going to change our understanding of our place in the universe.

Mr. Chairman, I hope my pride and enthusiasm in JWST and our team of partners is evident. From the technicians in the clean room, to our CEO, Northrop Grumman is fully committed to the success of the mission, on-time and on-budget. I want to assure the Committee that Northrop Grumman takes it role seriously, and is doing our part to address the technical and programmatic challenges before us. We maintain a high confidence of launch in 2018 within the Congressionally-mandated \$8 billion development cost cap. I look forward to continue working with NASA as it leads this amazing effort, and with the Committee, to ensure that JWST is a success.

I want to again thank you for asking me to appear before your Committee today, and welcome the Committee's questions.



JEFFREY D. GRANT

Sector Vice President and General Manager
Space Systems
Northrop Grumman Aerospace Systems

Jeffrey D. Grant is sector vice president and general manager of Space Systems at Northrop Grumman Aerospace Systems, a premier provider of manned and unmanned aircraft, space systems and advanced technologies critical to our nation's security.

In this role, Grant leads the division which provides space solutions for civil, military and restricted customers.

Prior to this appointment, Grant was vice president of National Systems for Space Systems. His primary responsibilities were the acquisition and execution of all space programs for restricted customers, which includes the design, build, launch and operations of major systems. He also was responsible for new business with these customers as well as the evolution of existing systems, including capabilities enhancements and technology insertion.

Grant also served previously as the vice president of Business Development at Northrop Grumman's former Space Technology sector. In that role, he led the business development function, overseeing Space Technology's strategy formulation, program development, marketing and discretionary investment.

Grant joined Northrop Grumman via the acquisition of TRW in December 2002. Prior to his joining TRW in February 2002, he held a variety of government and private sector positions. Most recently, he was vice president and chief technical officer for Astrolink International, LLC. Astrolink was an international joint venture to develop and operate a global, broadband telecommunications satellite system.

Before joining the private sector, Grant served for 21 years at the United States Central Intelligence Agency in positions at the CIA/National Reconnaissance Office (NRO), Directorate of Science and Technology, and Directorate of Intelligence, Office of Scientific Intelligence. In his most recent assignment at the NRO, he served as director, Office of Plans and Analysis. During his 18 years at the NRO, Grant also served as a program director for a satellite, launch and ground segment development. In addition, he was the chief systems engineer on two space intelligence collection projects involving spacecraft in both geosynchronous and low earth orbits. Grant also led an advanced technology division to develop and test advanced imagery, communication and data processing technologies.

Grant received a Bachelor of Science in ocean engineering from the Florida Institute of Technology. He is the recipient of numerous awards, including the Distinguished Intelligence Medal, the Intelligence Medal of Merit, the CIA's Engineer of the Year, the Intelligence Certificate of Distinction and the CIA Certificate of Distinction. Grant currently serves on the board of directors for the Space Foundation.

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August 2014

Chairman PALAZZO. Thank you, Mr. Grant.
I now recognize Dr. Mather.

**TESTIMONY OF DR. JOHN MATHER,
SENIOR PROJECT SCIENTIST,
JAMES WEBB SPACE TELESCOPE,
GODDARD SPACE FLIGHT CENTER, NASA**

Dr. MATHER. Chairman Palazzo, Representative Edwards, and Members of the Subcommittee, thank you for the warm welcome.

I am pleased to appear before you to discuss the scientific mission of the James Webb Space Telescope. I have been a telescope builder all my life. Since I was about eight years old, I have wanted to know how did we get here. When I was a kid, nobody really knew, so I became a telescope builder. Quite a few years later, I won a Nobel Prize, but despite our progress, profound questions remain, and I think JWST is the most important project I could be working on.

JWST will be the premier observatory of the next decade. To understand JWST's scientific mission, we need to briefly review our current picture of the universe. The picture has been painted almost entirely, thanks to work initiated at NASA and made possible by longstanding Congressional support.

We know today that the universe is nearly 13.8 billion years old. For the first 400,000 years after the Big Bang, the universe had no distinct objects in it and was a hot soup of fundamental particles such as free protons and electrons. Light could not travel very far through that hot soup. Around the 400,000-year mark, the universe went from being opaque to transparent. The afterglow of this era is what we see as the cosmic microwave background. Our NASA team won the Nobel Prize in 2006 for its study of this radiation.

The emergence of the first stars probably came when the universe was a few hundred million years old. We think that these first stars were 30 to 300 times as massive as our Sun and millions of times as bright, burning for only a few million years before exploding in supernovae, but we have never seen them. Even Hubble can't see them. JWST will let us see them.

So why do we need an infrared telescope to see that first light? Imagine light leaving the first stars nearly 13.4 billion years ago and traveling through space and time to reach our telescopes. We are essentially seeing these objects as they were 13.4 billion years ago, but because the universe has been expanding, the light was emitted by these first stars and galaxies as visible or ultraviolet light actually got shifted to redder wavelengths by the time it reached us. So we need to see it in the infrared.

Also, to unravel the birth and early evolution of stars, we need to be able to peer into the hearts of dense and dusty cloud cores where star formation occurs. These regions cannot be observed at visible light wavelengths as the dust makes such regions opaque. JWST's infrared instruments will let us do that.

JWST will also look for planets in other solar systems. The first planet outside our solar system was discovered in 1992. Since then, we have come to the realization that planets are in fact quite common. One essential objective of JWST is to observe planets orbiting

in the habitable zone of their star where it is possible for liquid water and perhaps even life to exist.

An infrared telescope needs to be cooled down to a lower temperature so it does not emit too much of its own infrared light. To make it cold, we need to put it in deep space where it can be shielded from the heat and light of both Earth and the Sun. It needs to be shielded from the infrared energy produced by its own spacecraft, so JWST will have a tennis-court-sized sunshield that will unfold in space. One of JWST's four instruments also requires a refrigerator that uses gaseous helium to keep its detectors at about negative 449 degrees Fahrenheit.

At this point, I would like to show you a 1-minute animation of the deployment of the Webb telescope. Let me see if it going to go. Yes, so it is going. JWST's primary mirror will be composed of 18 hexagonal units made of beryllium, a material light enough that you could pick up one of those units yourself but which can be machined and polished until it has essentially perfect curvature. If you were to stretch this material the length of the United States, the difference between the peaks and valleys would be about three inches. This is an amazing telescope.

JWST is an excellent example of what can be done by international partnerships to solve very difficult engineering challenges. The United States is leading a very capable partnership that includes the European and Canadian space agencies. Scientific discoveries know no boundaries, and international cooperation has been very successful for NASA.

Beyond its scientific returns, JWST will also be an amazing educational tool as Hubble has been. Nearly every science classroom in the country has posters and teaching materials from Hubble. Every astronomy textbook is illustrated with Hubble pictures. NASA materials are proven to be among the most useful to classroom teachers, and JWST will provide great new material.

We are an exceptional country for even dreaming up something like JWST, and we are close to seeing this dream realized. Astronomers will use the telescope to make stunning discoveries and rewrite our textbooks again.

Thank you for listening, and I would be happy to answer any questions you have.

[The prepared statement of Dr. Mather follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
March 24, 2015

Statement of

Dr. John C. Mather
Senior Project Scientist, James Webb Space Telescope
National Aeronautics and Space Administration

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

Chairman Palazzo, Ranking Member Edwards, and Members of the Subcommittee, I am pleased to have the opportunity to appear before you to discuss the scientific mission of the James Webb Space Telescope (Webb).

I've been a telescope builder all my life. Since I was about eight years old, I've wanted to know, "how did we get here?" When I was a kid, nobody really knew. So I became a telescope builder. And now, quite a few years later, I am a Nobel Prize winner. Despite our progress profound questions remain, which is the reason I think Webb is the most important project I could be working on. That's why I'm here.

Webb will be the premier observatory of the next decade. To understand Webb's scientific mission, we need to review in broad brushstrokes our current picture of the Universe. And that picture has been painted almost entirely by the space astronomy program initiated here at NASA, thanks in no small part to longstanding Congressional support, and the powerful curiosity of the American public about the Universe in which we live.

First Light

We know today that the universe is nearly 13.8 billion years old. For the first 400 thousand years after the Big Bang, the Universe was hot, but it had no distinct objects in it. There were no stars, and there were no galaxies. The universe was a hot soup of fundamental particles, such as free protons and electrons. And light could not travel very far through that hot soup.

At around the 400 thousand year mark, the hot soup had cooled enough so that electrons and protons and helium nuclei could pair up to form hydrogen and helium atoms, in a process called "Recombination." As the electrons were now bound to

atomic nuclei, light could travel freely without being stopped by frequent scattering off the free electrons.

The Universe went from being opaque to transparent at this point. The 'afterglow' of this era of recombination is what we can see as the Cosmic Microwave Background, and it is still the brightest radiation in the universe. Our NASA team won the Nobel Prize in 2006 for building and using a satellite called COBE (the Cosmic Background Explorer) to investigate this Cosmic Microwave Background. I was the head scientist for the COBE, and I led the team that proposed it when I was just a few months out of graduate school.

After recombination came the first stars. The emergence of the first stars probably came when the Universe was a few hundred million years old. We think that these first stars were 30 to 300 times as massive as our Sun and millions of times as bright, burning for only a few million years before exploding as supernovae. But we've never seen them; even the Hubble can't see them, and Webb is the only telescope currently planned that could do the job.

The emergence of these first stars marks the end of the "Dark Ages" in cosmic history. Understanding these first sources is critical, since they greatly influenced the formation of later objects such as galaxies. And we would like to know our own history: how did we get here from the early universe?

So why do we need an infrared telescope to see that first light? Imagine light leaving the first stars nearly 13.4 billion years ago and traveling through space and time to reach our telescopes. We're essentially seeing these objects as they were when the light first left them 13.4 billion years ago. But because the universe has been expanding, the light that was emitted by these first stars and galaxies as visible or ultraviolet light actually got shifted to redder wavelengths by the time it reached us. The Hubble has probably seen a few traces of galaxies almost that far back in time. But to really see and understand that light, and the galaxies that came even before those, we need a large telescope mirror and science instruments that see in the infrared: we need Webb!

The Assembly of Galaxies

Today we know from pictures taken with the Hubble that galaxies existed less than one billion years after the Big Bang, relatively soon after the emergence of the first stars. While most of these early galaxies were smaller and more irregular than present-day galaxies, some were very similar to those seen nearby today.

Our computer models tell us that galaxies began to grow when dark matter clumped together under the force of its own gravity. Dark matter is an invisible form of matter whose total mass in the universe is roughly five times that of "normal" matter (that is, the stuff made of "atoms"). It can be thought of as the scaffolding of the universe. In fact, we wouldn't be here (the galaxies wouldn't have formed)

without dark matter. The visible ordinary matter we see then collected inside this scaffolding in the form of stars and galaxies.

This build-up of large systems was accompanied by the formation of luminous stars from gas and dust. We believe that the interaction of stars and galaxies with the invisible dark matter produced the present-day galaxies.

This process of galaxy assembly is still occurring today - we see many examples of galaxies colliding and merging to form new galaxies. In our own local neighborhood of space, the Andromeda galaxy is headed toward the Milky Way for a future head-on collision – just a few billion years from now.

Despite all the work done to date, we still have many questions about the assembly of galaxies. How exactly were galaxies formed? How did we end up with the large variety of galaxies we see today? What is the nature of the relationship between black holes and the galaxies that host them? How did the black holes originally form, and how did they grow so large? These are some of the fundamental questions about galaxies that Webb will tackle. Because Webb will be a facility that can see not only the earliest galaxies to form, but also nearby, older galaxies, it is the first space observatory that can witness the complete life history of galaxies in the universe.

The Birth of Stars and Protoplanetary Systems

Although stars have been the main topic of astronomy for thousands of years, we have begun to understand them in detail only in recent times through the advent of powerful telescopes and computers.

A hundred years ago, scientists did not know that stars are powered by nuclear fusion, and 60 years ago they did not know that stars are continually forming in the Universe. We still do not know the details of how clouds of gas and dust collapse to form stars, or why most stars form in groups.

To unravel the birth and early evolution of stars we need to be able to peer into the hearts of dense and dusty cloud cores where star formation occurs. These regions cannot be observed at visible light wavelengths, as the dust makes such regions opaque, and they must therefore be observed at infrared wavelengths. Webb will allow us to do that.

We also do not understand exactly how planetary systems start to form around young stars, but we do know that a large number of stars like our Sun have planets. The number of confirmed planets and candidate planets is now in the thousands. The continual discovery of new and unusual planetary systems has made us re-think our ideas and theories about how planets are formed. We realize that to get a better understanding of how planets form, we need to have more observations of planets

around young stars, and more observations of leftover debris around stars, which can come together and form planets.

Planets & Origins of Life

The first planet outside our solar system was discovered in 1992. Since then, we have come to the realization that planets are in fact quite common. Most of the confirmed planets discovered so far are large gas giants like Jupiter, although that is because larger planets are more easily detected with current techniques. Thanks to NASA's Kepler mission we now know that small planets (down to Earth-size and even smaller) are much more common than large ones, even though they're hard to find. One essential objective of Webb is to observe planets orbiting in the habitable zone of their star, where it is possible for liquid water and perhaps even life to exist. (For this category of measurement, we need to know where and when to look in advance; Webb is not designed for searches, but rather for detailed observations of the most interesting targets.) We calculate that Webb could even detect the presence of water on a planet somewhat larger than Earth orbiting a star somewhat smaller than the Sun, and tell us whether such a planet could have an ocean. Although Webb was originally conceived for very different purposes, we are very pleased that it will have this capability too.

To trace the origins of the Earth and life in the Universe, we need to study planet formation and evolution, including the material around stars where planets form. A key issue is to understand how the building blocks of planets are assembled. We do not know if all planets in a planetary system form in place or travel inwards or outwards after forming elsewhere. We also do not know how planets reach their ultimate orbits, or how large planets affect the smaller ones in solar systems like our own. Simulations already show that the early Solar System may not have been stable and the giant planets may have migrated significantly, causing a rain of asteroids and comets that left craters on the Earth for hundreds of millions of years.

The dwarf planets and icy bodies in the outer reaches of our Solar System are evidence of conditions when our Solar System was very young. We can directly compare those conditions to the objects and dust observed around other stars. The sensitive instruments on Webb will be able to obtain infrared images of giant planets and planetary systems and characterize their ages and masses and atmospheric constituents by measuring their spectra. Webb will also be able to measure spectra of the dusty disks around other stars to determine the constituents of such disks that give rise to planetary systems.

In addition to studying planets outside our solar system, we want to learn more about our own home. Studying the chemical and physical history of the small and large bodies that came together to form the Earth may help us discover how life developed on Earth. We are especially curious about how and when the water in the oceans was delivered to Earth – was it part of the original formation, or did it arrive later from comets, for instance? Webb will be powerful enough to identify and

characterize comets and other icy bodies in the outermost reaches of our solar system, which might contain clues to our origins on Earth. Importantly, Webb can also be used to study the outer planets and their moons in our Solar System and thereby provide complementary data to NASA missions that have (or will) travel to these bodies to study them.

The Successor to Hubble

Webb often gets called the replacement for Hubble, but we prefer to call it a successor. After all, JWST is the scientific successor to Hubble; its science goals were motivated by results from Hubble. Hubble's science pushed us to look to longer wavelengths to "go beyond" what Hubble has already done.

An infrared telescope needs to be cooled to a low temperature, so it does not emit too much of its own infrared light. To make it cold we need to put it in deep space, where it can be shielded from the heat and light of both the Earth and the Sun. It also needs to be shielded from the infrared energy produced by its own spacecraft. So Webb will have a tennis-court sized sun shield that will unfold in space.

One of Webb's four instruments also requires a refrigerator that uses gaseous helium to keep its detectors at a temperature of about 6 Kelvin (negative 449 degrees Fahrenheit), so it can sense the reddest light that Webb is designed to observe. This capability is key to detecting the first galaxies to form after the Big Bang and all of the aforementioned science goals.

Webb's primary mirror will be composed of 18 hexagonal units made of beryllium – a material light enough that you could pick up one of those units yourself – but which can be machined and polished until it has essentially perfect curvature. If you were to stretch this material the length of the United States, the difference between the peaks and valleys would be about 3 inches. These mirrors are finished and will be installed onto the telescope backplane support structure later this year at the Goddard Space Flight Center.

International Cooperation

Webb is an excellent example of what can be done by international partnerships to solve very difficult engineering challenges. The United States is leading a very capable partnership that includes the European and Canadian Space Agencies. The Canadian Space Agency has spent more on its portion of the Webb telescope (the Fine Guidance Sensor and Near-Infrared Imager and Slitless Spectrograph) than on any other space science project; in return their aerospace industry has been busy and Canadian scientists are guaranteed access to observing time. The European contribution is much larger: they led the development of two of the four flight instruments, and they are providing the Ariane 5 rocket, a launch vehicle that meets Webb's mission requirements and has an excellent record of over 60

successful launches in a row. In return, European scientists are also guaranteed access to Webb observing time.

Each scientific project is different, but scientific discoveries know no boundaries. International cooperation has been very successful for NASA.

Synergy with other projects

Webb was designed to do what could never be done with other equipment, on the ground or in space. It measures infrared light, which is largely blocked by the Earth's atmosphere, and which is strongly emitted by the Hubble and by warm ground-based telescopes.

But just as the Hubble discoveries were followed up by larger ground-based observatories like the twin Keck telescopes in Hawaii, Webb discoveries will be followed up by the next generation of even larger ground-based telescopes like the Thirty Meter Telescope and the Giant Magellan Telescope, now in planning and initial construction. These huge telescopes, offer the capability of very high spectral resolution (number of colors that can be distinguished in the incoming light) and will provide important follow-up data that will complement the data we get from Webb.

Also, just as great sky surveys showed us the most interesting places to look with Hubble, new sky surveys with better detectors at newly accessible wavelengths will find targets for Webb. The Large Synoptic Survey Telescope, planned for first light in 2019, will locate transient objects, things that change or flash, and these new targets will be of prime interest for Webb. The Kepler observatory has already given us a long list of exoplanet systems, and some will be chosen for detailed Webb observations.

The TESS (Transient Exoplanet Survey Satellite), to be launched in 2017, will find closer and brighter exoplanet targets for follow-up by Webb. The WFIRST (Wide Field InfraRed Survey Telescope) recommended by the 2010 Decadal Survey of the National Academy of Sciences would scan much of the sky at infrared wavelengths, revealing new targets and possibly new kinds of rare targets, for Webb to see. Indeed, the entire 2010 Decadal Survey of the National Academy was built around Webb capabilities.

Operating at much longer wavelengths with totally different technologies, radio telescope arrays like ALMA (Atacama Large Millimeter/submillimeter Array) offer dramatic views of the universe as well. ALMA has already revealed an image of a disk of material orbiting a star that may be making planets as we speak. Piecing together the information from a wide range of observatories is part of the cosmic jigsaw puzzle astronomers must tackle to get good answers to tough questions.

The United States possesses an excellent industrial infrastructure to undertake Webb. When we needed beryllium mirrors fabricated to amazing accuracy, U.S. companies had the know-how. When we needed infrared detectors with astonishing sensitivity, U.S. companies had the know-how. When we needed to unfold a telescope much larger than the rocket, U.S. companies had the know-how. Many of these companies are the best in the world at what they do.

STEM education

America's leadership in large-scale science and technology projects depends crucially on the talent and inspiration of our citizens to take on challenges of every sort, from organizational to scientific and technical. NASA's projects inspire the public with their beautiful pictures, their stunning discoveries, and their ability to make the nearly-impossible dreams come true. Children come into science wanting to know what we are made of, how we got here, what is the history of the universe, and where we are going. These are not simple questions, and there are no final answers, but the quest inspires children to learn and adults to continue to learn. People come to the United States from around the world to pursue their dreams, and NASA is one of the reasons.

NASA's Hubble Space Telescope is a prime example of our contributions to education. Nearly every science classroom in the country has posters and teaching materials from Hubble. Every astronomy textbook is illustrated with Hubble pictures. Math teachers use examples from NASA projects to show why children need to know how to measure and calculate. We expect the James Webb Space Telescope will provide similar inspiration for students and teachers around the country.

Summary

We are an exceptional country for even dreaming up something like Webb, and we are close to seeing this dream realized. Well over 1,000 engineers and scientists in the United States, plus our partners in Canada and Europe, have worked to make this possible. Over 10,000 professional astronomers will use the telescope, as they have used the Hubble Space Telescope, to make amazing discoveries, and rewrite our textbooks again.

In 2018, Webb will unfold in space, a million miles from Earth, over a two-week period to begin its planned 5-year primary mission. I am confident that the telescope will work -- and that its scientific payoff will be immense. By bringing home powerful new views of deep space, Webb will change the way we understand the Universe, its history, and our place in it. I am sure you will be proud of the role you will play in making possible the pictures and discoveries that Webb will bring us. Thank you for listening, and I would be happy to answer any questions you have.

Dr. John C. Mather

Dr. John C. Mather is a Senior Astrophysicist in the Observational Cosmology Laboratory located at NASA's Goddard Space Flight Center, Greenbelt, Md. He is also a Senior Project Scientist on the James Webb Space Telescope.

He received a bachelor's degree in physics from Swarthmore College in Pennsylvania as well as a doctorate in physics from the University of California, Berkeley. Dr. Mather's research centers on infrared astronomy and cosmology.

As a National Research Council postdoctoral fellow at the Goddard Institute for Space Studies, New York City, he led the proposal efforts for the Cosmic Background Explorer mission (1974-76), and came to Goddard Space Flight Center to become the Study Scientist (1976-88), Project Scientist (1988-98), and also the Principal Investigator for the Far Infrared Absolute Spectrophotometer (FIRAS) on the Cosmic Background Explorer (COBE).

Dr. Mather and the COBE team showed that the cosmic microwave background radiation has a blackbody spectrum within 50 parts per million (ppm), confirming the Big Bang theory to extraordinary accuracy.

Dr. Mather has served on advisory and working groups for the National Academy of Sciences, NASA, and the National Science Foundation for the Atacama Large Millimeter Array (ALMA), and the Center for Astrophysical Research in the Antarctic (CAMA).

As Senior Project Scientist (1995-present) for the Webb telescope, Dr. Mather leads the science team, and represents scientific interests within the project management.

As winner of the 2006 Nobel Prize for Physics, chosen by the Royal Swedish Academy of Sciences, Dr. Mather shares the prize with George F. Smoot of the University of California for their work using the COBE satellite to measure the heat radiation from the Big Bang.

Chairman PALAZZO. Thank you, Dr. Mather.

I thank the witnesses for their testimony, reminding Members that Committee rules limit questioning to five minutes. The chair will at this point open the round of questions. The chair recognizes himself for five minutes.

Dr. Grunsfeld, GAO's testimony indicates that the JWST program has ten months of reserve left, down one month from December. The program is now entering the critical integration phase and all the subsystems are at risk of becoming the critical path and driving the overall project schedule. This limits flexibility precisely at the time flexibility is most needed. Are you confident that the current plan is robust enough to address the risks facing the program?

Dr. GRUNSFELD. Thank you, Chairman, for that question.

As I mentioned in my testimony, we have a plan that was assembled at the time of the Joint Confidence Level estimate through the 2011 re-plan that laid out how we will use all of our schedule reserve, and that is based on a history of similar projects and something that we have shared with the GAO extensively. That burn-down plan assumes that risk is mitigated as we go along the project to solve problems that we discover, and so far the project has been doing really well on solving problems without using that schedule reserve, and as I mentioned, as a result, we are carrying 10 months of schedule reserve, which is a little bit more than we expected to have at this time. That is the best posture to be in, to have a little bit more schedule reserve than you expect because we are getting into the test and integration phase where things, you know, might pop up that we haven't anticipated with this large, complex observatory, especially as we go into the testing at the Johnson Space Center with the optics starting with the pathfinder and then the optics in a couple of years.

So I am confident that with 10 months of schedule reserve and the known problems we have now that we have adequate schedule reserve for the July 2018 launch—sorry. The October 2018 launch.

Chairman PALAZZO. And this is another question, Dr. Grunsfeld. The President's budget request for Fiscal Year 2016 is for \$620 million. This is consistent with the JWST's 2011 re-plan budget. We are aware that in the original plan, Fiscal Year 2016 was expected to require less funding because development of instruments and components was anticipated to have been completed. However, with so much integration and testing left to complete, are you confident that the \$620 million is still sufficient?

Dr. GRUNSFELD. We have the \$620 in the 2016 request, and the out years, which are notional requests, the same numbers that were in the original re-plan, and in those numbers there is a considerable amount of budget reserve, and in the same way as schedule reserve, that budget reserve is there to solve problems.

Now, in Fiscal Year 2015, we have allocated a lot of that reserve for known problems through the end of the fiscal year, and we plan ahead with known problems to try and use reserves. So at the present time, the \$620 million Fiscal Year 2016 request we believe is adequate to complete all of the work as the funding going out to launch.

Chairman PALAZZO. Dr. Grunsfeld, and this is also for Dr. Mather if he cares to answer, how would a cost overrun or schedule slip affect other Astrophysics projects, Science Mission Directorate programs or overall NASA priorities, and what would NASA cut to ensure that the JWST stays on schedule?

Dr. GRUNSFELD. Well, the first priority is to keep JWST on cost and on budget—sorry—on budget and on schedule, and we are working very hard to do that. We have adequate cost reserves and adequate schedule reserve, I believe, to make the October 2018 launch without, you know, any kind of a cost overrun.

As you know, any time you have a portfolio of projects and programs, and NASA has quite a few, in the event something overruns, you have to look at what the tradeoffs are. I think it is instructive to look at the Astrophysics budget historically over many decades, starting with the great observatories, and certainly through the last ten years, and you will see that if you look at the combination of Astrophysics plus James Webb Space Telescope, that budget has been essentially flat. You know, there were very limited transfers, if any, from other programs into James Webb, and so, you know, the cost growth has been contained within this general Astrophysics budget. So we are confident that with the budget we have and with the schedule reserve we have, we will be able to make it on cost and on schedule.

Chairman PALAZZO. Dr. Mather, would you care to add to that?

Dr. MATHER. I think actually I agree with that he said quite well. Thanks.

Chairman PALAZZO. So no one wants to really throw out there what NASA would cut to ensure James Webb Space Telescope stays on schedule? I don't blame you. Probably not smart.

Ms. Chaplain—and then I will move on to questions—are there any preliminary observations on the updated cost-risk analysis that NASA performed that you can share?

Ms. CHAPLAIN. So we just received the analysis fairly recently. We need to do more in-depth assessments. But on the surface, they look pretty good, and NASA indicated it followed not only its own good practices but GAO's as well, so we look forward to assessing them.

We have also looked at the other earned value management analysis that they are employing that takes earned value management a step further and looks at risks integrated with cost and schedule and can do more predictive things for the program, and on that surface, that looks good as well.

Chairman PALAZZO. Okay. So you haven't had a chance to definitely dig into it to confirm that they followed NASA's best practices as well as GAO's best practices but they told you they did but you are going to dig into it—

Ms. CHAPLAIN. Right.

Chairman PALAZZO. —when you have more time?

Ms. CHAPLAIN. Yeah, we need to look at the underlying data and talk with them about what they did. There are certain methodological things they probably didn't do that we would have done like interview the engineers separately and get a good story on what they thought their costs and risks were at that point, but the methodology they did employ does—is in line with good practices.

Chairman PALAZZO. And so it also would probably be too early to ask you whether or not you have recognize any weaknesses in their analysis?

Ms. CHAPLAIN. Correct. The only—you know, right now we can't say what the weaknesses are. Correct.

Chairman PALAZZO. Well, thank you.

At this time I yield to the Ranking Member, Ms. Edwards.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and again, thank you to the witnesses.

I want to follow up in looking at the schedule reserve in light of what still needs to be done, particularly as we enter the integration and testing phase.

Dr. Grunsfeld, you mentioned—or I think Ms. Chaplain actually mentioned that we hadn't—there hadn't been a JCL since the 2011, and so my question—and I understand that is a really intensive process and we don't want to do something that is going to take us away from the game of actually getting the work done, but what is it that we could learn in a JCL or some formation of that that gives us the kind of confidence that we need going into this integration and testing phase that the reserves that are available are sufficient to meet the problems that inevitably will occur? Dr. Grunsfeld and then Ms. Chaplain.

Dr. GRUNSFELD. The Joint Confidence Level assessment is a great tool and it is based on a probabilistic assessment so looking at the probabilities of future events when you don't know how long individual parts will take to assemble, how much they will actually cost. So it is a great tool after the study phase of a mission when we are actually looking at the designs, and we want to predict, you know, 3, 4, five years out into the future. When you are actually in implementation of a project and you have real hardware and you know what the individual schedules are in great detail, it doesn't make really sense to do a probabilistic forecast because you already have the information that is contained in those probability distributions. So it is really just an inappropriate tool to use in a very mature project.

Now, a cost-risk analysis is a much more sensitive thing—sensible thing to do because now you have actual costs, actual risks. You can't assign probabilities to those risks, and that is what the cost-risk analysis takes into account and is a best practice by GAO.

Ms. EDWARDS. So Ms. Chaplain, do you agree with that?

Ms. CHAPLAIN. We would recommend that you update the JCL at any rate. It is a good practice to be especially updating the cost and schedule estimates themselves, and especially because the program as it has had more experience could feed that experience into the models. Well, you did say it is an intensive process and we recognize that. Once you have the model down and everything in place, it is not as difficult to update. But as far as updating even the cost and schedule pieces of that estimate, it is a good practice to do that on a regular basis.

Ms. EDWARDS. I guess I just wonder if we have some—if there are some elements that we already have in place that allow us the luxury of being able to have a greater confidence in the program and then it is going to meet the cost, the budget and assuming the risks. Dr. Grunsfeld?

Dr. GRUNSFELD. Thank you. I think the salient point is that right now we are in the middle of managing a complex project, and there are various time scales on which we do that. To perform a new Joint Confidence Level assessment, we would end up in some number of months with a new estimate and we could measure against that, but it is kind of like, you know, changing the goalpost over time if we get numbers that are different. We think it is much more sensible and as a practical management approach is—and we accepted the cost-risk analysis but really is to manage the program with the cost, with the reserves, measure how we are doing, and that is why we are using the earned value management, which is a management tool including some predictive measures, and then we can measure whether we are ahead or behind those predictions, and all of the predictions were based on the original JCL. If we ended up somewhere where we had a very large perturbation, then it would make more sense to go back and say okay, based on this, you know, perturbation adjustment, whatever it is where we have to re-baseline, then we would definitely do the JCL. I think in the meantime, based on our program guidelines, we will continue to do the cost-risk analysis and especially continue to manage on the daily, monthly, quarterly basis our earned value management and our standard project management processes.

Ms. EDWARDS. Thank you.

I want to go to Mr. Grant really quickly. So one of the big risks right now is the status of the technical design of the cryocooler, and so I wonder if you can tell me whether the problems that you were faced with are finally behind us? And you indicated in your prepared statement that all the cooler subsystems have been delivered to Goddard and JPL except one. What subsystem is that and when will it be shipped to JPL?

Mr. GRANT. Ms. Edwards, the cryocooler program is a very difficult technical challenge. I think in my prepared statement that I describe it as at operating at 6 degrees Kelvin, very much colder than previous cryocoolers we have built, and it deploys. It is separated from the instrument package by about 30 feet. The mechanical complexities, the heat transfer complexities, the exported force complexities have made this a very challenging job, in fact, more challenging than we anticipated.

We have made great progress, though. We have delivered components to Goddard and to JPL, and we are now down to the CCA. It is the cryocooler assembly that is in test today, bake-out testing, and we are—we have got significant performance measurements made that show it meets its spec, which is great news, and now we are in the final stages of assembly, and we are scheduled to deliver that to JPL in June of this year.

Ms. EDWARDS. So we will be asking about that because I think the problem is that we are gone down now to 10 months of reserve, and the question is, how much of the cryocooler that has been such a problem is going to eat into that reserve to leave enough reserve to stay on budget and on cost for the integration and testing phase, and with that, I think my time is like just done. Thanks.

Chairman PALAZZO. I now recognize Mr. Brooks from Alabama.
Mr. BROOKS. Thank you, Mr. Chairman.

Dr. Grunsfeld and Dr. Mather, will you please provide examples of how the James Webb Space Telescope, the Stratospheric Observatory For Infrared Astronomy, the Transiting Exoplanet Survey Satellite, or TESS, as it is commonly known, will work together in exoplanet research?

Dr. GRUNSFELD. Certainly, and I appreciate that question. The Transiting Exoplanet Survey Satellite is very much like the Kepler satellite that has discovered thousands of planets orbiting stars in our galaxy. Kepler has been staring at a region of space that is rather far away from the Earth, and it sees as the planet goes between us and the stars a little blink of light. The Transiting Exoplanet Survey Satellite is going to be very similar except instead of looking at this one distant region of space and the constellation Cygnus, it is going to survey all the nearest stars around our home solar system, around the Earth, and so it is going to give us the address of where there are transiting exoplanets around each of those stars.

The advantage we have of a planet that transits, that goes between us and the star, is that we can actually then measure the components of the atmosphere as that starlight goes through the atmosphere of the planet, and so having the locations and types of all of these exoplanets will allow the James Webb Space Telescope to do spectroscopy or to break the light from those atmospheres into its component colors and allow us to determine, you know, whether there is water vapor in the atmosphere, whether there is, you know, characteristics that might indicate even high-altitude clouds, for instance, color changes that would tell us the composition of those atmospheres. So this is an extraordinarily exciting possibility.

The Stratospheric Observatory For Infrared Astronomy works in a different wavelength than James Webb Space Telescope. The Hubble Space Telescope operates from the near-ultraviolet to the near-infrared and encompasses the colors that we see—visible light. The James Webb Space Telescope picks up in that near-infrared and extends out to the mid-infrared and the SOFIA observatory extends from the mid-infrared further out, and so there are many objects where we want to do spectroscopy to understand the composition, for instance, of molecular clouds that contain organic materials, very much like what we are made out of, and it will be the synthesis of the Hubble, the James Webb Space Telescope, the SOFIA observatory and also on the ground, the ALMA, Atacama Large Millimeter Array, that is really going to be able to put together the picture of how these objects work—how these objects, you know, were formed, how they evolve, how organic molecules in these objects formed that eventually may have seeded planets like the Earth before we were around.

Mr. BROOKS. Dr. Mather, do you have anything to add?

Dr. MATHER. Yeah, just a few things. One thing to mention about the Stratospheric Observatory is that they can fly frequently with different instruments that are improved as the technology improves, and they have already included—there are some extremely high-spectral resolution equipment. Spectral resolution separates the colors into over 100,000 different wavelengths, and from that you can determine isotopic compositions and all kinds of remark-

able details about the things you are looking at. So it is very complementary to and different from the other observatories we were talking about. So it is not something we could put into the James Webb Telescope.

Mr. BROOKS. As you all may recall, there was an initial problem with the Hubble Telescope that required astronauts going up to fix it. Should we encounter a difficulty with the James Webb Space Telescope and the need to repair it, can it be repaired, and if so, how?

Dr. GRUNSFELD. I have already volunteered that if there is a problem, you all can send me.

Mr. BROOKS. We will need a spacecraft first. I hope NASA still—

Dr. GRUNSFELD. We will need a spacecraft, and if we have problems, it may be a one-way trip, which you all say I will deserve.

Mr. BROOKS. Well, I prefer the two-way trip.

Dr. GRUNSFELD. But the first thing is that we are working extraordinarily hard, and the folks on the project and at Northrop Grumman and all of the contractors to make sure that we don't need to go to James Webb for servicing. There is an enormous amount of redundancy built in for the actuating parts of the James Webb Space Telescope because it does have to origami, unfold like a transformer. So we have dual motors, we have dual sensors, a lot of testing to make sure that everything will deploy as required.

While there is no servicing or fixing designed into it, as a relatively small mitigation, we are putting rendezvous sensors on the outside of the spacecraft so that if we ever had to go there for some reason or if, you know, there was some future reason to go, we would be able to, you know, align a spacecraft for docking. But otherwise there is no planned servicing.

Mr. BROOKS. So if I understand correctly, the James Webb Space Telescope is designed for docking but right now we are inhibited because we do not have a vehicle that can get us there. Is that a fair statement?

Dr. GRUNSFELD. I wouldn't quite say it is designed for servicing or for docking, but because it has a payload adapter ring, which is how it was attached or will be attached to the Ariane 5 rocket, that ring is, by definition, a place that one could interface with, and we just think it is prudent to put on some sensors, some little stickers essentially with fiducial marks so that if we ever did have to go there, we would know how to orient ourselves.

Mr. BROOKS. Thank you, Mr. Chairman. I see my time is expired.

Chairman PALAZZO. I now recognize Mr. Beyer.

Mr. BEYER. Thank you Mr. Chairman, and I thank all of you for being with us today.

I have some science questions on JWST, and now that we have a Nobel Prize-winning physicist here, Dr. Mather, Dr. Grunsfeld said that JWST extends our view of the universe, and you said it the most important project you could be working on, so three quick questions.

Will this give us insight into dark energy and dark matter? Second, the Planck Epoch, zero to ten the negative forty four seconds before the Big Bang, I understand from visiting CERN that we can only get so far back in understanding how close we are to zero.

Does this help us get farther back? And finally, the asymmetry of matter and antimatter, you know, the present and the universe, will this help us understand that fundamental asymmetry?

Dr. MATHER. Gosh, such easy questions.

Mr. BEYER. It is \$8.8 billion.

Dr. MATHER. So I will answer them. For the dark energy, which was discovered based on measurements with the Hubble Space Telescope, we will be able to pursue the same technique only a lot better because we can see farther and we can use infrared light to do it. So we know the supernovae, which are used as standard candles, are better candles, better standards measured in the infrared. So number one, yes, we will pursue the dark energy.

Dark matter is observed indirectly because it has gravitation. So it bends light, and we have seen that in many places, sometimes even—recently we found a supernova that was seen four times in different places as the light was bent four different directions around a galaxy and between. So we will be continuing to pursue that method of measuring the presence of dark matter through its gravitational effects.

About the Planck Epoch, that is probably outside our territory. That is something that we expect to pursue through measurements of the polarization of the cosmic microwave background radiation, and there is already work underway, and there was a probably false alarm about a year ago that I am sure you saw where claims were made about gravitational waves of the early universe. Better measurements will come out soon, I think. We certainly expect them.

About the asymmetry of matter and antimatter, I don't know of any measurement that we could make that would affect that question. It is one of the most puzzling mysteries of science, and we know that there is no place in the universe that has got—that is like a dark matter—sorry—an antimatter galaxy. If there were, we would see an area where the two regions were colliding and there would be annihilation energy coming out. So we are pretty sure the whole universe is full of ordinary matter, and there isn't any antimatter left except tiny traces. So we will work on it but I don't think we are going to answer that question.

Mr. BEYER. Thank you, Dr. Mather, very much.

Dr. GRUNSFELD, I was looking at the very sophisticated piece of literature here, our comic book, and it talks about how JWST is going to be in orbit around this theoretical point L2, a straight line from the Sun to the Earth L2. It is very cool, but what is at L2 that is going to allow that to orbit around? All my understanding of orbiting is, it is based on gravitational forces, and—or is it just self-correcting engines on the satellite itself?

Dr. GRUNSFELD. The L refers to Lagrange, which was a mathematician, and he computed that there would be these points in space where the gravitational force of the Earth and the Sun are balanced such that it is kind of stable so that if you put something there it would stay there. And so if you think about the Earth and the Sun, between the Earth and the Sun there is a point that you can orbit and an object would get dragged along by the Earth at the same speed as the Earth as it rotates the Sun. We call that

the L1 Lagrange point, and we just sent the DSCVR mission there, for instance.

The L2 point is on the other side of the Earth and it is an imaginary point just because there is nothing there—James Webb will be there. But it is gravitationally stable but it is not perfectly stable. If James Webb were to drift off, we would have to fire some little jets to come back, and so that is that point.

Mr. BEYER. Thank you, Dr. Grunsfeld.

And one last question. Mr. Grant, Ms. Chaplain talked about her difficulty doing the anonymous interviews with Northrop Grumman folks without a manager present. We had a lot of discussion here on secret science, on transparency. What was Northrop Grumman's problem with allowing the anonymous interviews or the interviews without managers present?

Mr. GRANT. The issue that we had when this request was made was, a request to interview about 30 of our—we call them CAMs, cost accountant managers, which are reasonably junior employees. They are responsible for small work packages. And I became concerned when the interview technique, it wasn't just anonymous but isolating our junior employees with a group from GAO, and these are people who are not prepared to come testify before Congress or in fact in this kind of environment, and so I had a great fear that this interview technique would result in frankly my employees being very, very concerned. This is not how they would normally do their business. And so in my discussions with Ms. Chaplain, I offered in fact some alternatives. We are very open to having transparency and full access to the data, but this kind of process to our individual employees concerned me enough that I said we will take the management of JWST aside but I wanted somebody from the functional organization so a mechanical engineer assigned to the James Webb Space Telescope program would have his functional manager with him in this interview process. So she is accurate in saying no manager so I was willing to separate the JWST team management from this interview process but unwilling to send these employees in by themselves. So that is the essence.

Mr. BEYER. Thank you, Mr. Chairman.

Chairman PALAZZO. The chair now recognizes Mr. Johnson.

Mr. JOHNSON. Thank you, Mr. Chairman.

Dr. Grunsfeld and Dr. Mather, how would a cost overrun or schedule slip affect other Astrophysics projects, Science Mission Directorate programs or overall NASA priorities? And you can decide who goes first on that.

Dr. GRUNSFELD. Well, Mr. Johnson, thank you for that question. The first part of my answer is that currently we are on budget, on schedule. We have adequate budget reserves and schedule reserves to make our October 2018 launch date.

Mr. JOHNSON. But that wasn't the question. The question was, how would a cost overrun or schedule slip affect those projects?

Dr. GRUNSFELD. In the event we were to encounter some problem that required, you know, a cost overrun or some kind of slip, as we balance all of our projects and programs, you know, we manage sometimes to an ensemble level, and it is just the realities of Federal budgeting process. So if some project does overrun, then we have to look at, you know, future projects typically to delay them

or, you know, change the phasing of funding to allow to keep, you know, the projects that are close to completion on track.

Mr. JOHNSON. Dr. Mather, do you have anything to add to that?

Dr. MATHER. No. He says the same thing I would say.

Mr. JOHNSON. Okay. Do you have a list of what those priorities might be? What would NASA cut to ensure JWST stays on schedule? Do you have any specifics?

Dr. GRUNSFELD. So at the moment, in the Astrophysics budget and the JWST budget, you know, if you look at the sum of those two, you know, that is approximately the historical level of the NASA Astrophysics budget, and as the chairman said in his opening remarks, one of the big questions going forward in future budget eras is where will the funding for the James Webb Space Telescope go as it ramps down from its main development phases, and NASA has not yet decided on what that future mission might be. Several Members have discussed the WFIRST mission, Wide-Field Infrared Survey Telescope. This was suggested by the Decadal Survey on Astronomy and Astrophysics in the last round and is a major priority for Astrophysics and something that we are studying in great detail. NASA has not decided to go forward with that. Once we do decide that that is a new mission and we are examining that, then the launch date for that would be an adjustable parameter based on available budget, technical and, you know, something we would manage too.

Mr. JOHNSON. Okay. Thank you.

Ms. Chaplain, what does GAO see as the greatest risk to the JWST program?

Ms. CHAPLAIN. At this point the greatest risk is on the technical side as they first resolve the technical challenges that face them today like with the cryocooler, and as they get deeper in integration and testing, what problems they might encounter there and how are they going to fix them.

The business side is not as much of a risk at this point because they do have a lot of schedule reserve, they do have pretty good tools in place for managing the program. They are pretty rigorous about tracking what is going on, so in our view, the issues now that we will be intensely focusing on are technical issues as well as risk management issues.

Mr. JOHNSON. Okay. Well, back to you again, Ms. Chaplain. You said your annual Quick Look review of NASA's major programs was just released, so how does JWST compare to other NASA programs in terms of planning, management, performance and execution?

Ms. CHAPLAIN. So it doesn't stack up very well when you consider the cost growth that has already occurred. If you take all the projects together, there is 29—25.9 percent cost growth overall in the development side, but if you took James Webb out of that picture, the cost growth for NASA projects would go down to 2.4 percent. So just its nature, it is a big project on the portfolio. It comprises 33 percent of the major projects right now, so anything that happens there does have an impact on other programs, and that prior cost growth, though it hasn't come back, is still there kind of overwhelming the other projects at this point.

Mr. JOHNSON. Okay. All right. Well, thank you, and thank you all for being with us.

Mr. Chairman, I yield back the remainder of my time.

Chairman PALAZZO. The chair now recognizes Mr. Babein—Mr. Babin. I just wanted to see if you were going to correct me on it.

Mr. BABIN. Thank you, Mr. Chairman.

I would like to thank the witnesses for being here. Reading your bios, very notables, and long ago in the line of questioning, I think Dr. Grunsfeld actually did 58 hours of spacewalking in EVAs to do some of those Hubble repairs. Is that not the case?

Dr. GRUNSFELD. That is correct.

Mr. BABIN. Well, thank you. Thank you for all your distinguished careers, and I appreciate you two, and congratulations on your Nobel, Dr. Mather.

I represent Texas District 36, which has Johnson Space Center in it, and if I am not mistaken, I think some of this testing, quite a bit of the testing, on JWST is going on at Johnson Space Center, which I am very proud to represent and certainly want to see great big things continue to go and happen at JSC.

But in light of all the cost overruns and the problems that we have had, I do have some questions about the project, and I would like to ask Dr. Grunsfeld and Ms. Chaplain how confident you are that JWST has enough resources now, both in terms of cost and schedule reserves, to execute the commitments that we now—that you now have.

Dr. GRUNSFELD. I am very confident that, you know, as of now we have 10 months of schedule reserve and we are maintaining adequate budget reserves to meet the October 2018 launch date. There are a number of issues that, you know, I worry about, if you were to say what keeps me awake at night. We are making great progress on the cryocooler. You know, there are a bunch of technical issues. We have a lot of great communication across the whole project now from, you know, daily meetings that the project manager has and communication with us. We have our new program director. We announced that yesterday, Eric Smith. You know, he has, you know, daily, weekly, monthly meetings. We meet routinely with GAO to talk about our progress. But there are some things that we just don't control, and for instance, one of those is that we have three major tests at the Johnson Space Center in that great chamber A, and we are starting some of the testing now on the pathfinder, and if any of the Members have an opportunity to go there, I highly recommend that you see this. This is where we tested the Apollo Command Module. It is enormous, and that reflects the great size of the James Webb Space Telescope.

But one of my worries has been, you know, that we have three multiple-month test periods at the Johnson Space Center, and having lived there for 18 years, I have had to leave my home occasionally for hurricanes. You know, what happens if we are testing during a hurricane. And so I have interrogated the project on what is our mitigation, and I have been down to the Johnson Space Center several times talking to the engineers and the operators of that chamber, and they have great plans in place, and the James Webb Space Telescope can actually survive through a hurricane without significant interruptions of the testing, and you know, they have

assured me that even those kind of risks are incorporated into our modeling to make the October 2018 launch date. So I am very confident that we have a very sound plan.

Mr. BABIN. That is great. Thank you. And Ms. Chaplain, did you want to add anything to that?

Ms. CHAPLAIN. So 10 months of reserve is a long time, and the cost reserve is very healthy, and I don't often get to testify on programs with that kind of luxury in terms of reserve, but it is also a very complicated program and its test program itself is 7 years—integration and testing is seven years long, and the thing to keep in mind with 10 months of reserve is, you need certain amounts of time for each phase of testing so you can only apply certain amounts of reserves with each phases. So if a major problem does come up, you don't necessarily have 10 whole months to fix it without disrupting other parts of the schedule. So we are still concerned about schedule but they are in a healthy position at this point.

Mr. BABIN. Thank you. Thank you very much.

One other question, and this would be for Dr. Grunsfeld. You actually—both you and Ms. Chaplain addressed this to a certain extent a while ago, but does NASA share GAO's concern about the amount of schedule risk remaining in the program?

Dr. GRUNSFELD. I would say absolutely. In terms of, you know, my personality but also that of Robert Lightfoot, our Associate Administrator, Charlie Bolden, you know, we are all very concerned about the risks and the schedule reserve in the sense that we are for every single program we manage. You know, I generally would not say that I am comfortable with any of our projects because that is just my personality and that is one of the ways that we do so well in managing our projects and programs is, you know, to stay a little bit uncomfortable and keeps us on edge.

Mr. BABIN. I understand.

Dr. GRUNSFELD. I am confident but I wouldn't ever say comfortable until we launch. The best place for a spacecraft like James Webb Space Telescope is in space.

Mr. BABIN. Amen. Thank you very much, all of you, and thank you, Mr. Chairman.

Chairman PALAZZO. Thank you, Mr. Babin.

The chair now recognizes Mr. Posey.

Mr. POSEY. Thank you, Mr. Chairman.

I really appreciate the incredibly wonderful and exciting things that you do and what the James Webb Space Telescope will do for us. Obviously I have a serious interest in gaining and maintaining public support for our space programs. There is a lot of misconception, as you all know. Poll after poll has shown people think we spend as much as 25 percent of our budget on our space program when you know it is less than one-half of one percent, and they hear you are spending over \$600 million more on a space telescope and they say what is in it for me. I mean, how do you articulate to the average American family, who may have no idea what the telescope does, how it is going to benefit them?

Dr. GRUNSFELD. Well, let me start and then maybe ask John Mather to comment additionally.

I mentioned in my testimony that one of the great things we do in this country is challenge industry to do hard things in the name

of science, in the name of fundamental questions about our universe, and when we challenge industry to do that, it forces them to grow. It increases our competitiveness. It also attracts the best and brightest minds to come to the United States and to rise in the United States to help solve these problems, to study astronomy, to study astrophysics so perhaps they can win a Nobel Prize in the future.

Mr. POSEY. But that may be a little bit over the head of the average taxpayer is what I am talking about. This booklet you have is really excellent material for those of us who already have an interest in it and for a teacher who has a chance to maybe impart that hunger into students, but I am just wondering, you know, how we quantify, you know, how it benefits the national security, the economic stability or the survival of the species that we make that connection when we are talking about this expensive product which is very necessary for our future, I think, but that we haven't really managed to connect with the average American about the importance.

Dr. GRUNSFELD. There are some circles where I can talk about the contributions of the James Webb Space Telescope as the largest space telescope we have ever built, segmented optics, the first time we will have flown a large space telescope with segmented optics to, say, national security. The average person that I talk to when I am giving an astronaut talk, you know, they don't have an appreciation of that.

But I am glad you mentioned, you know, the effect on teachers. The Hubble Space Telescope, for instance, reaches more than half a million teachers a year, 6 million students a year, and is viewed by 9 million people, and those—

Mr. POSEY. I heard that. I got that, and I love that—

Dr. GRUNSFELD. —are important.

Mr. POSEY. —but, you know, how do we connect with the average American family who is, you know, worried about their job, you know, worried about feeding their family, being able to finance their kids' education? How can we explain to them that spending the money on this telescope, which I think is very important, obviously, should be that important to them?

Dr. GRUNSFELD. I think, you know, if you talk about NASA, generally my experience has been that people understand why we invest in NASA. We are investing in America's future. We are investing in future technology. We are investing in innovation. And most people have the same questions that we have as scientists, that drove us to become scientists, about, you know, where did we come from, where are we going, are we alone in the universe, and that NASA is providing the tools to answer those questions. Those fundamental questions are the same for everybody, and when you can talk about that we are only spending, you know, less than half of one percent of our Federal investment on investing in the future, I think people do resonate with that.

Mr. POSEY. Doctor?

Dr. MATHER. I would certainly agree that that is why we do it and why the public loves us to do it. I used to ride the subway in New York City and I would be sitting there with my astronomy book, and people would say what is that, tell me about it, where

did we come from. The public is really interested in this, and when they are not working to support their families, they say where did I come from, are we the only ones here in this entire universe or not, and I think we are getting towards being able to answer their questions. People just have a deep passion to know where did we come from, our genealogy, our history, everything about how we got here to this amazing Committee room here in Washington, D.C. They want to know how did that happen. So I think we should help them answer that question.

Mr. POSEY. Thank you.

Ms. EDWARDS. Will the gentleman yield for just a minute?

Mr. POSEY. Yes, I will yield.

Ms. EDWARDS. Mr. Posey, perhaps Dr. Grunsfeld might want to respond to your question by answering us how the JWST program has enabled a number of improvements in measuring human eyes and the diagnosis of ocular diseases and improved surgery for eyes as a connection to people. Dr. Grunsfeld?

Dr. GRUNSFELD. I would love to talk about that. Thank you very much.

You know, sometimes what we call spinoffs are bit tangential, but in this case, and Dr. Mather mentioned it, I was in a very early James Webb Space Telescope meeting where they were talking about the smoothness of the mirrors, and I started scribbling in my notebook to figure out what if you stretched one of those mirrors, a single 1.5-meter beryllium mirror, to the size of the United States, how big would the bumps be, and he already told you, the average bumps would only be about 3 inches tall if you stretched those mirrors to the size of the United States. This is an astonishingly smooth surface. In order to generate that amazingly smooth surface, you know, the engineers at Ball Aerospace had to come up, you know, with algorithms and techniques of measuring what the shape of the mirror is to that extremely fine detail, and that is actually—those tools have already been incorporated into the kind of techniques and tools that ophthalmologists use to measure the shape of the human eyeball in order for the laser surgery and other techniques, you know, to correct human vision. And so there is many, many examples of these kind of things.

Mr. POSEY. Well, that was kind of my point, you know. I mean, listen, we mostly sell steak in space, you know, and Winn Dixie and Publix and all the supermarkets don't advertise steak, they advertise sizzle, you know, and so we are all interested in the steak but the public needs to know a little bit more of the sizzle, you know. And if somebody asks about, you know, decrease the possibility or probability of you going blind because of ocular disease by 50 percent, well, that is something the average guy can identify with, you know, rather than—you know, we talk so often in platitudes.

We want to know where we came from, where we are going to go. We realize that ultimately someday, someday humanity will have to leave this planet or perish, and we know that, but it is so far away that the average family doesn't want to worry about that right now, you know, let 50,000 generations from now worry about that. But we have to make our contribution to getting us off this planet when the time comes as we go.

But I find that it is so important to quantify space's direct benefits to people to gain that public support. Like I said, they want some of the sizzle. You know, the meat doesn't interest them right now. They want the sizzle like supermarkets sell.

Dr. GRUNSFELD. If the chairman would indulge me I have one more small story.

Chairman PALAZZO. The chairman will indulge you.

Dr. GRUNSFELD. Thank you. I was doing an astronaut visit—so I am in a blue flight suit—to a small company outside of Chicago called Numerical Precision, and they are a machine shop, and we were walking through, and one of the engineers, technicians showed me a part that he was building that he was very proud of, and it was a little circular ring, and I don't know why but I recognized it, and it was—most of their work is defense work or much of it. And so I started asking him about it, and this is a company that had made tools that I used on the Hubble Space Telescope and they were very proud of that, and I was there to thank them.

And so I asked him what program is that for, and he said I don't know. His manager said let me look, and he comes back and he says some NASA program, and I think okay, that has piqued my interest, you know, maybe I know this part. And it turns out it was a part for the James Webb Space Telescope. The story the plant manager had told me is that this part was very hard for them to make and it is made by a special technique involving machine tools that only the United States has been able to refine, and he said that by building this difficult part for the James Webb Space Telescope they developed new techniques and they had actually by using those techniques been able to attract a lot of business, and their biggest problem was not the new business but the ability to hire young people to run these machine tools, and he said that by working on NASA projects is one of his biggest draws to be able to bring in young technicians, and these are people with—high school graduates who like to use computers.

Now, I have a son who is soon to be a high school graduate and he spends a lot of time on computers, a little bit different than we expect but he is very talented now at, you know, controlling computers for things like computer games, and he is now also the head of his robotics team in high school, which is a similar sort of thing. So we have plenty of young students who would be great at machining, which is now a very exciting field, and the James Webb Space Telescope helped contribute to this company being able to hire people, and I certainly think jobs are what a lot of people think about, and these are very high-paying jobs.

Chairman PALAZZO. The chair now recognizes Mr. Lucas.

Mr. LUCAS. Thank you, Mr. Chairman, and I appreciate the panel being here and their insights, and if we could for a moment slide perhaps back to a few more nuts and bolts.

The challenge, I think, has been expressed rather clearly by all of you that James Webb is so unique or so different than Hubble in that whatever we put up has to work the first time. Those of us who were paying attention 25 years ago remember the initial trauma after the launch of Hubble, the miraculous repair job and the wondrous things accomplished from there and all of the service work and improvements and additions made, but this is a different

creature. This is a one-time shot. So I listened very closely to Director Chaplain's comments about the seven years of testing and the various components and this and that and the other.

Let us talk for a moment about this cryocooler business because my understanding is, we have to keep James Webb at an incredibly cool temperature to function, and that we are in effect creating technology as we go here or developing techniques to make this possible. Discuss for just a moment how complicated that particular issue, for instance, is, whoever would care to answer the question. Thank you, Mr. Grant.

Mr. GRANT. I will be happy to. At Northrop Grumman Aerospace Systems, we have been building space-qualified cryocoolers now for many, many years, and they have flown successfully on many missions, both scientific and meteorological, and so we build these cryocoolers that operate at very low frequencies or very low vibrations so they don't disturb the imaging system that they are attached to, and they have to operate very efficiently so they have a very efficient conversion of solar power to the mechanical compressor power. The unique elements of the MIRI cooler are, we have to do those things in addition to cooling far colder than we have put a space-qualified cooler at before. Coolers we build and operate today operate at about 70 degrees Kelvin. This one operates at 6 degrees Kelvin. And the whole observatory is operating in the optics at about 40 degrees Kelvin. So the instrument is cooler than the optical background temperature.

Mr. LUCAS. And reminding us that zero Kelvin is absolute zero.

Mr. GRANT. Correct, All molecular motion stops. You know, it is very cold. So it has to operate very cold and has to operate very efficiently. It has to export very low export forces and it has to operate with the cooler separated from the cold head assembly on the instrument module by about 30 feet. So there is an array of technical complexities in this cooler that made it far more difficult than coolers we have built before.

I would say the good news is—well, the program started, and there wasn't even going to be a cooler on it. It was going to be a dewar, a solid block of gas that would be frozen and then sublimated over time to cool the instrument. That would work, but it was very heavy and also runs out of gas. So the cooler has the possibility of operating in fact as some of ours have for decades.

So we went to the cryocooler design in about 2006, if I recall, and since that time, we have made significant progress. Just this past year we got data that confirms its flight performance so we know it gets cold enough, it is efficient and has low exported forces.

So we are at the point now in this development where most of the subassemblies have been delivered and this one last one is in its final stages of integration and test, so we are—it has been a very long, tough, challenging road for us to be on, but as we speak today, we are very close to the last delivery.

Mr. LUCAS. Mr. Mather, thinking back to 20-some years ago when all of the issues were addressed on Hubble and it became kind of a "wow" moment for most of the human race that cared, all goes well, all the targets are met, all the flight operations are smooth, we park it way out there in the proper place, everything

switches on, are we going to have that magnitude of a “wow” moment again?

Dr. MATHER. I certainly expect so. I wouldn't be doing this if I didn't think so, and by the way, I wanted to add one thing to—

Mr. LUCAS. Please.

Dr. MATHER. —his testimony that only one of the instruments requires that cooler. The telescope and the other three instruments cool down by themselves just because they are hidden behind the big umbrella. So there is a risk but it is not a huge risk if there is any problem with that.

So we are certainly going to point the telescope at beautiful things and get great pictures. We expect amazing discoveries ranging from the first stars and galaxies to the formation of stars and planets close to him in places like that beautiful eagle nebula. We certainly want to see those little exoplanets like Earth if there are any orbiting around stars way out there to see if they are wet, like do they have oceans. So there is this huge array of wonderful questions to answer, and I think nature may just cooperate and give us answers. So that is our plan, and I think it will be very exciting times for us.

Mr. LUCAS. So as they would say in the coffee shops back home, if something is winking at us, we will know it.

Dr. MATHER. Yes.

Mr. LUCAS. Thank you, gentlemen and ladies. I appreciate it very much. Thank you, Mr. Chairman.

Chairman PALAZZO. Thank you, Mr. Lucas. We enjoy talking about the nuts and bolts as much as Mr. Posey's steak and sizzle.

I want to thank the witnesses for their testimony and the Members for their questions. The record will remain open for two weeks for additional written comments and written questions from Members.

This hearing is adjourned.

[Whereupon, at 11:34 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. John Grunsfeld

**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE**

*"Searching for Life in the Universe: An Update on the Progress of the
James Webb Space Telescope"*

Questions for the record, Dr. John Grunsfeld, Associate Administrator, Science Mission
Directorate, NASA

Questions submitted by Rep. Steven Palazzo, Chairman

QUESTION 1:

In 2010, The Independent Comprehensive Review Panel (ICRP) found some root cause problems impacting JWST's development and made recommendations and additional considerations in its report. Are any of their concerns resurfacing or has NASA taken sufficient actions to fully address their recommendations?

ANSWER 1:

The ICRP made 22 recommendations in their 2010 report. NASA addressed each of their recommendations (see attachment 1 [NASA Response to Webb ICRP Report.pdf]) and the Webb Program office is responsible for ensuring that the findings addressed by each of the recommendations was or remains satisfied or requires additional attention. No significant departures from the changes made at the time of the rebaseline have been made.

QUESTION 1a:

Who at NASA is tracking the concerns raised by the ICRP to determine whether or not these or any other issues may impact NASA's ability to execute the current plan and 2018 launch date for JWST?

ANSWER 1a:

See ANSWER #1.

QUESTION 2:

GAO was willing to conduct the cost-risk analysis for NASA at no cost. How much did it cost NASA to do this work in-house rather than allow GAO to conduct the review for free and based on their best practices?

ANSWER 2:

NASA devoted its Webb Project risk manager approximately halftime to this work for 6 months. However, even if GAO had conducted its cost-risk study process, it would have occupied the

time of Northrop-Grumman employees, their management, and still involved NASA employee time responding to requests from the GAO for information. It is not the case that a GAO led cost-risk study would have been “no cost to NASA.” Moreover, because of the extensive analyses the project performs monthly (please see answer to question 4) additional costs for a single point metric like a cost risk analysis are hard to justify.

QUESTION 2a:

What account did NASA fund this activity from?

ANSWER 2a:

See ANSWER #2.

QUESTION 3:

The JCL seems like an important tool for understanding the impact that current risks could have on project estimates. If this is the case, why is NASA reluctant to use it as a management tool for continuing to inform both internal and external stakeholders of JWST's current cost and schedule status based on realized and newly projected risks?

ANSWER 3:

NASA first established its JCL policy in 2009 by requiring a JCL of major projects coming to confirmation; this requirement was subsequently expanded to include cost and schedule ranges for projects going through Key Decision Points during the Formulation Phase. NASA's approach to conducting JCLs has evolved as we have gained more experience with them, and there are several improvements in work to further enhance our capabilities. For example, in February 2015, NASA released an updated version of our Cost Estimating Handbook, which provides additional guidance on how to conduct JCLs through a dedicated appendix. GAO previously cited the lack of this document as an area of concern. JCLs can be very complex, so NASA is developing new tools to better communicate risk, such as graphical and tabular reports, as well as new techniques and tools to enable more accurate assessments of complex JCL models. In addition, NASA is proactively identifying areas of improvement and developing solutions to strengthen the community of practice through education, training, data sharing and communication.

QUESTION 4:

Why did NASA initially resist performing a cost-risk analysis to give insight into its current costs that reflect an updated risk posture?

ANSWER 4:

A targeted single cost risk analysis provides only a snapshot in time that can be stale within weeks of being conducted. In addition, a probabilistic cost risk analysis will forecast future

performance based on current risk posture but does not incorporate past performance. In order to measure progress against a plan, manage in a changing environment, and incorporate past performance, a dynamic set of tools is required. Webb employs the following tools for this purpose.

- Webb employs Monthly Contractor Performance Reports including Independent project analysis of raw Earned Value Management (EVM) data from the Northrop Grumman Aerospace Systems (NGAS), Exelis, and JPL/NGAS contracts.
 - This reporting includes a monthly Estimate at Complete (EAC) for each contract which factors in a current risk assessment, detailed trending of metrics, and associated narrative summary.
 - In fact, all performance reporting to-date has provided Webb management advanced notice of any EAC growth before the contractor(s) have officially notified the Project, thus providing the Webb management team to have proactive EAC discussions internally, as well as with the contractor teams.
- Webb employs Monthly Secondary EAC Analysis, which uses a Monte Carlo analysis of EVM data and current risk databases (with review and adjustments by NASA Integrated Product Team leads). This analysis provides a forecast of future performance based on past performance and current risk posture.
 - Analysis of the NGAS Observatory contact is now operational with Exelis to follow soon.
 - Any projected overrun delta to current budget is treated as a threat against project cost reserves.
- Monthly Schedule Analysis and Health Metric Assessment is performed across the project. Weekly schedule status reviews are performed to ensure that progress or the lack thereof is fully understood. Webb also uses the DCMA “tripwire” schedule metrics that provide additional selected measures of schedule management controls, and if ever exceeded, are flags for management attention.

The combination of these various tools provides NASA with monthly assessment of the cost and schedule posture based upon the most recent set of risks and is therefore superior to a traditional cost-risk study.

QUESTION 5:

GAO reported that 70 percent of reserve spending went to areas that were not anticipated as threats. How effective would an updated cost-risk analysis be at capturing these threats?

ANSWER 5:

No cost-risk analysis can or will ever capture unknown-unknowns encountered along the design and development cycle of a first-of-a-kind, one-of-a-kind mission. Cost and schedule reserves are needed precisely for this reason. Updated cost-risk analyses would be no more effective at uncovering unanticipated risks than the process already in use and updated as project personnel identify risks.

QUESTION 5a:

How much of the reserves have been spent funding risks or unknown problems from the Northrop Grumman prime contract and the cryocooler subcontract?

ANSWER 5a:

The majority of project reserves have been spent on items that were never identified as risks in either the Northrop-Grumman or cryocooler contracts. In the past 4 years, approximately 37 percent of the NASA reserves have been spent on the cryocooler while it represented only approximately 1 percent of the project budget.

QUESTION 6:

From your perspective, in which period is schedule reserve most likely to be at risk?

ANSWER 6:

At the time of the replan, schedule reserve was spread throughout the hardware development lines into areas where it was deemed most likely to be needed because they were either new manufacturing practices being employed (backplane, sunshield) or difficult integration and test activities (Integrated Science Instrument Module (ISIM) cryovacuum testing). We projected needing schedule reserve in these different areas and, with excellent management, have been able to conserve some of the early schedule margin and roll through to the next phase. This is why we are still above the projected schedule reserve nearly 4 years after the rebaseline. As we progress, nearly all the activities remaining are integration and testing which, at this juncture, are all unique. The upcoming series of tests at the Johnson Space Center will help us assess the schedule reserve allocation for the Optical Telescope Element and Integrated Science (OTIS) test late in 2016.

QUESTION 6a:

What component presents the greatest risk of entering the critical path?

ANSWER 6a:

The component at greatest risk of entering the critical path is almost always that component with the least manufacturing history and the closest to its delivery. For Webb, the chronology of items could be forecast as, the cryocooler, the ISIM, the Optical Telescope Element (OTE), the sunshield, the combined OTE and ISIM, and finally, the complete integrated observatory.

QUESTION 7:

Why does NASA believe an independent cost-risk analysis conducted by an external party would not be useful?

ANSWER 7:

To the response to Question #4 we add the following: Risks are added as they arise by subject matter experts involved with daily work on the project. No external source would possess the deep knowledge of the current system status held by those involved in the work. Similarly, external cost analysts would not have the required knowledge to define risk profiles, especially at the current stage of integration and test when no analogous efforts exist in work databases. Webb is a first-of-a-kind new design system with advanced technologies, making it very difficult for an external party to perform such an analysis without substantial assistance from subject matter experts directly involved in JWST. If the tools that NASA uses to monitor performance were to indicate that the program was going to miss either its cost or schedule commitments then an external assessment would be warranted.

QUESTION 8:

GAO's testimony noted that a current cost-risk analysis had been performed, but that JWST does not plan to utilize the analysis for project management purposes.

- a. Why do project officials believe that the information from the updated cost-risk analysis is not useful?

ANSWER 8a:

Please see response to Question #4. Additionally, the recently completed cost-risk analysis duplicated results already being derived by the existing analyses described in our response to #4.

QUESTION 8b:

What other tools does the project intend to use and why?

ANSWER 8b:

Please see response to Question #4.

QUESTION 9:

If JWST does not plan to utilize its cost-risk analysis for project management purposes, how can Congress receive an early indication of project status to take swift action if project progress begins to decline?

ANSWER 9:

NASA provides monthly Earned Value data, schedule data, cost data, technical data, and risk data to the GAO who conduct analyses of these data. Additionally, the GAO receives monthly review data from the project presented to the GSFC center management and the monthly review by the Program Office which conducts independent assessments of the cost and schedule posture

of the Project. GAO personnel are invited on a quarterly basis to attend the Flight Program Review conducted by the Science Mission Directorate of the Webb program. NASA also offers quarterly updates to Congressional staff wherein program status is reviewed and staffers are able to interrogate the Program Director and Program Manager about cost and schedule.

QUESTION 9a:

If there is a cost overrun or schedule delay coming, can we trust that the tools NASA uses to assess the project's status will provide early indications so that proactive measures can be taken?

ANSWER 9a:

NASA has developed and maintained estimate-at-complete (EAC) figures for its contracts. These forecast the final costs given the known risks and historical performance of the contractors. To date, these indicators show that the project has adequate reserve to cover EAC costs. These data are provided to the GAO on a monthly basis. In addition to these project-performed analyses, the GSFC Chief Financial Officer (CFO), HQ Program office and Agency CFO also either provide independent analyses or oversee the products. Our management approach adopted after the replan has accurately predicted the program performance (cost and schedule). We therefore trust this approach would provide us with early indicators of problems in either cost or schedule.

QUESTION 10:

The JWST testing and integration phase is complex and difficult. What gives you confidence that JWST will function properly when launched and deployed?

ANSWER 10:

Webb has employed a development philosophy that utilizes pathfinder hardware to lead flight hardware elements as well graduated sequences of integration and testing for major components that uses ever increasing degrees of fidelity to flight hardware. We also use the agency mandated review process to ensure that each integration and test (I&T) activity is ready to begin. This methodology experienced its most recent success during the second cryovacuum test of the ISIM wherein the longest and most complex cryogenic test ever conducted at GSFC on over \$1B worth of flight hardware achieved all its objectives and finished on schedule.

QUESTION 11:

JWST is a complex telescope. As integration and testing continues, how challenging would it be to disassemble the Integrated Science Instrument Module or any other part of the telescope should a problem arise?

ANSWER 11:

The later any disassembly occurs in any space mission, the more risky and costly it becomes. It is difficult to assess *a priori* how risky and costly it would be without a specific problem to address.

QUESTION 11a:

How does this complexity impact cost and schedule reserve planning?

ANSWER 11a:

The cost and schedule reserve impacts depend critically on the nature and timing of the problem. One area where cost and schedule reserve planning were changed because of complexity was in how the ISIM was funded. Traditional instrument development would have planned for a workforce decline rapidly after science instrument delivery. However, we planned for a constant level of effort, at the peak value, following instrument delivery because of the inherent complexity of the instruments themselves and the associated ISIM cryovacuum testing. This assumption has been validated. By keeping that workforce ready to tackle issues as they arose in integration and testing we have kept the ISIM on schedule for its April 2016 need date (with schedule reserve). No program can ever anticipate every risk. Our philosophy has been to distribute schedule reserve preferentially to those areas where we are doing something for the first time.

QUESTION 12:

Over 70 wiring harnesses on the Optical Telescope Element were delivered with significant defects. What is the status of correcting this problem?

ANSWER 12:

Workmanship issues were discovered on some harnesses provided to NGAS from a subcontractor, TekData, that called into question all the harnesses from TekData. There are 76 harnesses, all of which get installed on the telescope backplane structure and deployment tower. Upon inspection, it was determined that ~37 harnesses will need to be completely rebuilt: ~26 will be rebuilt by TekData with improved oversight by NGAS and NASA, and ~11 will be rebuilt by GSFC. An additional ~19 need repairs and that work will be split between TekData and GSFC. The remaining ~20 are undergoing additional inspection to determine their disposition.

QUESTION 12a:

How could correcting this problem affect the cost and schedule reserves?

ANSWER 12a:

The impact to cost reserves is relatively small; it is expected to be <\$2M. The impact to the OTE schedule reserve will not be small, ~1 to 2 months. However, the OTE is not on the mission critical path and the project is working mitigations, so this recovery activity should not cause the OTE to become a critical path activity. Thus, incurring additional costs to rebuild the harnesses saves schedule, which in turn has a lower overall cost impact.

QUESTION 13:

Technical challenges associated with the cryocooler placed that element on the critical path.

a. When will the cryocooler be delivered, and how much of a delay does this represent?

ANSWER 13a:

The current predicted date for cryocooler delivery is August 2015. This is a delay of over 2 years from its original delivery date established in the 2011 replan.

QUESTION 13b:

Has NASA's oversight been sufficient?

ANSWER 13b:

NASA, JPL and Northrop-Grumman have added experienced personnel (management, quality assurance, and process engineers) to the oversight team. This build-up has occurred over time as problems continued to be identified in the areas of workmanship, quality control, and work pace. Both JPL and Northrop-Grumman have made numerous management changes to their team over the years as well. NASA senior management engages in weekly telecons with the JPL and Northrop-Grumman counterparts to discuss cryocooler issues. The NASA Administrator conducts bimonthly calls with Northrop-Grumman CEO to discuss the cryocooler.

QUESTION 13c:

In hindsight, what should have been done differently to prevent some of the problems that occurred?

ANSWER 13c:

The assumed benefits of heritage cryocooler work for the MIRI cryocooler design and development were clearly overestimated. The technology readiness level (TRL) 6 gate for the cryocooler employed a different production method than was ultimately required. Additionally, the TRL 6 gate was primarily concerned with proving technical performance and did not consider manufacturability as part of the readiness measures. The contract that JPL signed with

Northrop-Grumman lacked sufficient tools to incentivize performance later in development. As a consequence, Northrop-Grumman can no longer earn fee.

QUESTION 14:

Would you please provide us with examples of the types of education and public outreach activities the JWST program is involved in, or plans to be involved in?

ANSWER 14:

Specific examples of Webb education and outreach activities are provided in the attached report, "2014 Year-End Report for James Webb Space Telescope Public Affairs/Education and Public Outreach." We expect the program to continue to play a role in SMD education and outreach activities. This participation would be within the framework of the newly restructured SMD education program, and specific details on future activities will not be available until after the selection of awards under SMD's Education Cooperative Agreement Notice.

**NASA's Detailed Response
to the
James Webb Space Telescope Independent Comprehensive Review Panel Report**

NASA appreciates the insightful recommendations of the Independent Comprehensive Review Panel (ICRP) for the James Webb Space Telescope (JWST) project. In response, NASA has identified the following actions that have been taken or are underway. NASA agrees with the ICRP recommendations and summarized below are detailed responses grouped under the headings cited in the ICRP report.

Baseline Funding (Recommendations 1-4)

1. Develop a new baseline cost and schedule plan-to-complete that incorporates adequate contingency and schedule reserve in each year.
 - NASA is currently developing a new baseline estimate for JWST. Starting with the current status in the development phase, this baseline will be developed based on a new bottom-up, requirements-driven, joint cost and schedule confidence calculation. The bottom-up approach will be similar to that which has been done since the award of the prime contract in 2002 as part of the annual budget submittal except that the prime contractor team (along with some of the key subcontractors) will be directly involved in the development of the new baseline. The baseline will include an Estimate At Complete (EAC) for the in-house work developed by the technical lead for each in-house Work Breakdown Structure (WBS) element, and the contractor EAC for each out-of-house WBS element. NASA will use these inputs along with an analysis of the cost and schedule implications of threats and liens (a joint cost-schedule confidence level calculation) to establish a new baseline with adequate reserves in each year.
2. Include a realistic allowance for all threats in the yearly budget submission.
 - The joint cost and schedule confidence level (JCL) calculation will be based on current hardware status and the remaining work-to-go, liens, threats, and risks.
3. Budget at 80 percent confidence, and require 25 percent reserves in each year through launch.
 - NASA agrees and will plan for reserves consistent with an 80 percent cost and schedule confidence level including adequate reserves in each year.
4. Commission a new ICE, reconcile the new plan with it, and update the plan appropriately.
 - NASA agrees in principle, but the Agency has moved beyond just independent cost estimates (ICE) which provides an estimate of the life cycle cost with no insight into an appropriate phasing of funds for each year to an approach where the project creates an integrated cost-schedule-risk model (a JCL) that can be assessed by the Standing Review Board-- independent technical, cost, schedule and risk experts, -- and Agency management. This approach enables the Board's assessment to focus on the executability of the project's plan and agreement or disagreement with the project's own assessment of its risks and how well their plan can accommodate risks that are realized.

In establishing the new baseline, the project will factor in the current status of the flight hardware. The plan will incorporate the technical progress achieved to date with over 74% of the JWST hardware design completed and ready for fabrication, in fabrication, test, or delivered. Examples of the hardware status are as follows: (1) the Integrated Science Instrument Module (ISIM) flight structure completed fabrication and has undergone two cryogenic tests at operating temperatures, and will be delivered to ISIM Integration and Test in May 2011; (2) the Near-Infrared Spectrograph (NIRSpec) and Mid-Infrared Instrument (MIRI) flight instruments are fully integrated and are in environmental acceptance testing in Europe; (3) the primary mirror segments have been through cryogenic testing, the Engineering Development Unit (EDU) and five of the flight segments have completed fabrication process and have been optically coated; (5) the flight tertiary and fine steering mirrors have completed the fabrication process and have been optically coated and are undergoing final environmental testing prior to Optical Telescope Element (OTE) integration; (6) the OTE flight structure is in final assembly; (7) 5 percent of the spacecraft bus subsystems have been through CDR with flight build pending the new baseline; and, (8) the sunshield flight membranes are in assembly. Additionally, two special cryogenic tests were successfully performed for design verification: (1) a one-third scale sunshield and (2) a full scale observatory core area (top of spacecraft bus to bottom of ISIM). The final section of this document provides additional information on JWST technology advances made in 2010.

The new baseline, along with the results of the Standing Review Board's independent review of the project's plan and its joint cost and schedule confidence calculation, will be reviewed by the Agency and, if approved, will be included in next year's annual budget request.

Independent Analysis Capability (Recommendations 5-6)

5. 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.
 - NASA agrees: IPCE is the Agency's lead for cost estimating policy, the development of tools and methodologies, and independent Program/project assessment. IPCE is working closely with the JWST project to enhance the use of all IPCE capabilities.
6. Hold IPCE accountable for developing ICEs for major milestone reviews, reporting directly to the Agency Program Management Council (PMC) and not simply acting as a support organization to the SRB.
 - NASA agrees. NASA will revise its NASA Space Flight Program and Project Management Requirements (NPR 7120.5d) so that the Associate Administrator can direct IPCE to develop an ICE to support consideration of a project approaching a key milestone in addition to the normal Standing Review Board assessment.

In 2008, at the time of the JWST Preliminary Design Review/Non-Advocate Review (PDR/NAR) and Confirmation Review, the Agency did not have in place a strong, robust independent analysis capability. The Agency had begun requiring projects to be budgeted at a 70 percent cost confidence level in 2006, but did not add the requirement for a joint cost and schedule confidence level until 2009, when the methodology was robust enough to put into practice. The JWST confirmation budget would have benefited from a JCL because it would have explicitly factored schedule risks and properly phased reserves into the approved cost estimate.

The Agency is continuing to improve its capability and processes in budget estimation and monitoring, assessing and reporting internally and to OMB and Congress. The Agency now requires all projects with a Life Cycle Cost (LCC) over \$250M to develop a JCL as part of the confirmation process and for independent analysis, assessment and reporting on the JCL calculation at the time of the Agency Confirmation PMC. The Agency will evaluate changing its policy to require an 80 percent joint cost and schedule confidence level for complex, high priority projects and is continually improving independent review processes to increase rigor at decision gates. As an example, in a recent review where the Standing Review Board chair and the programmatic assessment team could not reach agreement on the risk in the project's plan, the programmatic assessment was presented independently to the decision authority for consideration.

The NASA Science Mission Directorate (SMD), in the context of changing the management structure for JWST (see below) is moving rapidly to provide the kind of rigorous, independent assessments of cost and schedule performance that the ICRP correctly noted were lacking. Working with IPCE, SMD has arranged for experienced personnel to be dedicated to JWST cost and schedule analysis for the duration of the JWST development. These personnel will report to the new JWST Program Director at NASA Headquarters.

Project Management (Recommendations 7-12)

7. Restructure the JWST Project Office at GSFC to ensure that the Project is managed with a focus on the LCC and LRD, as well as on meeting science requirements appropriate to the Implementation Phase.

- NASA has put a new Project Manager and Business Manager in place, as well as additional resources staff, to improve the management and focus of the Project Office.

8. Fund all existing deferred work in FY 2011 to get the Project back on track.

- NASA's ability to implement this recommendation is tied to a final enacted FY 2011 appropriation from Congress. The new baseline being developed will include scheduling of completion of the previously deferred work as part of the overall set of tasks to be accomplished.

9. Implement a threats and liens system that is consistently applied across all elements of the Project.

- NASA agrees, and this is being implemented by the Project. The liens and threats system employed by the project is uniform across the hardware and software elements, regardless of which entity (government, industry or international partner) is performing the work.

10. Assess and track the likelihood of threats at the GSFC management level to more clearly delineate the process for transitioning from threats to liens.

- NASA agrees and this is being implemented for JWST and other projects at GSFC. Goddard is developing a uniform definition for and approach to defining threats and liens.

11. Manage and assess contingency in terms of its adequacy to cover unknown and as yet unrecognized threats using the industry standard process of assessing the dollarized Earned Value (EV) of existing threats.

- NASA agrees and will use this type of assessment as one factor in determining adequate contingency levels for JWST. In addition, and where appropriate, NASA will use knowledge from previous missions to assess the adequacy of its contingency posture for JWST program elements.

12. Accelerate the spacecraft element schedule to more closely bring development into alignment with other Project elements.

- NASA will evaluate the spacecraft development schedule along with the other elements of the project in developing the new baseline and will bring all elements into alignment with the new baseline schedule.

NASA is in the process of implementing the ICRP's recommendation for a project-level system to identify and quantify threats and liens and will use this information to develop and maintain an adequate reserve posture for JWST. In parallel with Headquarters, the Director of the Goddard Space Flight Center (GSFC) will dedicate personnel to perform analogous cost and schedule assessments at the project level.

Program Management (Recommendation 13)

13. Move the JWST management and accountability from the Astrophysics Division to a new organizational entity at Headquarters having responsibility only for the management and execution of JWST.

- NASA agrees and has implemented these changes. The management of JWST at Headquarters has been reorganized accordingly. JWST is now a stand-alone program, with an experienced Program Director reporting to the NASA Associate Administrator for programmatic oversight and to the Associate Administrator for the Science Mission Directorate for technical and analysis support. A similar approach proved successful in the past with both the Hubble Space Telescope and the Mars Exploration Program at critical junctures in their execution. As noted above, the JWST Program Director will have the support of a dedicated cadre of experienced cost and schedule analysts.

Governance and Accountability (Recommendations 14-16)

14. Revise the wording of the Agency's Center responsibilities document, NPD 1000.01a, to correctly and unambiguously reflect clear lines of authority, accountability, and responsibility for program execution.

- NASA agrees and took action in 2009 to clarify Center responsibilities. Revisions to Agency governance documents to reflect this direction are under review. This inconsistency and lack of clear understanding of the role of the Center Director began in 2005, when NASA's program/project governance paradigm was changed in response to the CAIB findings about independence of the technical and programmatic authorities and the need to establish an independent path by which the Agency's engineers could raise issues related to safety or performance. The policy, established in 2005, created two clear reporting lines with Headquarters Mission Directorates responsible to implement programs and projects through program offices at Centers, and Center Directors responsible to provide skilled personnel and institutional resources to these projects and assure that activities at their Centers are implemented

in accordance with accepted professional standards and NASA requirements. This policy was clarified by Administrator Bolden following his confirmation in 2009 affirming that both Center Directors and Mission Directorate Associate Administrators report directly to Office of the Administrator. The Center Director has a unique role as the only person who can ensure proper planning and execution of activities requiring constructive integration across Programmatic, Technical and Institutional Authorities. The Center Director is therefore responsible and accountable to the Administrator for the safe, effective and efficient execution of all activities at his Center.

15. Assign management and execution responsibility for the JWST Project to the GSFC Director, with accountability to the Science Mission Directorate Associate Administrator at Headquarters.

- NASA agrees that the GSFC Director is responsible for the management and execution of the JWST Project and accountable to NASA Headquarters but not to the Science Mission Directorate Associate Administrator but to the NASA Administrator. NASA has implemented requisite changes at both GSFC and Headquarters. Administrator Bolden made it clear that the Center Directors are responsible for work that is done at their Center on projects and programs, including management. Changes to the Agency's governance documents to reflect this direction are in the process of being implemented through the Agency policy process. NASA has reorganized the JWST project at GSFC to report directly to the Center Director. In order to have fresh but experienced management to lead the JWST project through its critical integration and test phase, a new JWST Project Manager at GSFC was brought on board. In addition, a new business manager was assigned to the JWST Project at GSFC to place added emphasis on cost, schedule and risk performance assessment. These changes were made in addition to the naming of a new Integration and Test Manager at JSC (reporting to the Project Manager) as a result of the Test Assessment Team report.

16. Ensure that the Project Office, the Center, and the Agency are each held directly responsible for conducting in-depth analysis and projections of monthly JWST Project cost and schedule performance.

- NASA agrees and this recommendation is being implemented. We are establishing the program office and analysis capability using the Science Mission Directorate analysis team. Additionally, NASA HQ will use the IPCE and OCFO organizations for strengthened surveillance.

Communications (Recommendations 17-19)

17. Improve communications between the JWST Project and both GSFC management and NASA HQ SMD.

- NASA agrees and communications have improved (see paragraph below).

18. Assign at least one senior GSFC project person to be resident at NGAS throughout the Project. Consider having an NGAS manager resident at GSFC.

- NASA agrees and is working the details to implement this recommendation.

19. Conduct monthly or bi-monthly JWST Executive Project meetings, attended by the NASA Associate Administrator and the President of NGAS.

- NASA agrees and has implemented these regular senior level meetings (see paragraph below).

NASA agrees that the current venues for communications and current on-site activities such as Ball Aerospace resident office and NGAS JWST East Coast Office could be improved and is moving aggressively to augment these arrangements. The ICRP recommended Executive-level meetings among Headquarters, GSFC and the prime contractor. The first such meeting under the new governance approach for JWST was held on December 1-2, 2010, with the NASA Associate Administrator, the new JWST Program Director, and the GSFC Center Director traveling to California to meet with the senior management of the prime contractor to lay out the way forward for JWST management and organizational communication. Senior level management reviews are being planned on a quarterly basis between NASA HQ, GSFC, other NASA Centers, and contractors. . In addition to these more formal reviews, communications between senior level management is now occurring when necessary as issues and concerns arise.

Potential Risk in Integration and Test Phase (Recommendation 20)

20. Implement the TAT Report recommendations to substantially reduce the scheduled test time by running complementary testing off the critical path and by more effective sequencing of certain critical cryogenic and optical test segments.

- NASA agrees and will factor into the development of the new baseline the recommendations from the TAT Report. NASA is already well underway in implementing the TAT Report recommendations, including changing JWST Project plans for thermal vacuum testing at the Johnson Space Center to prioritize tests, reduce risk, and minimize the amount of time it takes to complete the testing. NASA has also augmented the project integration and test management at GSFC by two senior positions: (1) a senior manager who will focus on the verification program across the entire project, and (2) an experienced integration and test manager who will focus exclusively on the integrated Optical Telescope and Science Instrument Module test program.

System Engineering (Recommendation 21)

21. Establish a plan that provides the required level of experience and that involves the appropriate NGAS personnel before changing the system engineering accountability.

- NASA agrees and has completed implementation of this recommendation to establish a plan that provides the required level of experience and involves appropriate prime contractor personnel before changing system engineering accountability. Key features of this plan were one subject of the December 1-2, 2010 Executive-level meeting with the prime contractor.

Project Scientist and Science Team (Recommendation 22)

22. Strengthen the role and the independent voice of the science team in the Project.

- NASA agrees, and has added a Deputy Senior Project Scientist/Technical position to the project science team. This individual will be responsible for day-to-day interactions with senior project management on all aspects of the mission; scientific,

technical, budgetary, and schedule. This individual will also regularly meet with other members of the project science team to insure rapid and substantive communication between the science and cost/schedule/risk worlds. This new position will assist the Senior Project Scientist in better integration of the science activities with the hardware development activities and enable closer coordination and understanding of technical drivers to science performance so fully informed decisions can be made.

NASA's Webb Telescope Technological Advances in 2010

The James Webb Space Telescope will explore deep space phenomena from distant galaxies to nearby planets and stars as never before. It will give scientists clues about the formation of the Universe and the evolution of our own solar system, from the first light after the Big Bang to the formation of star systems capable of supporting life on planets like Earth. Components of JWST were under development last year, and those developments are continuing in FY 2011.

Several of the technological advances made on the JWST in FY 2009 paved the way for more progress in FY 2010. In FY 2009, several critical design reviews were completed on the backplane, integrated science instrument module (ISIM) and Optical Telescope Element (OTE). There were also primary mirror advancements and construction of a full-scale simulator.

This year, one of the most significant mission milestones occurred when the JWST passed the technical portion of the Mission Critical Design Review (MCDR). The programmatic portion of the MCDR was not completed (overtaken by ICRP and other reviews). This milestone signified the integrated observatory will meet all science and engineering requirements for its mission.

The technological successes achieved in FY 2010 included the completion of the first flight and engineering test mirrors, testing on the sunshield, infrared instruments and various components of the space telescope.

Mirrors

This year, great progress was made on the development of the telescope's 18 primary mirrors. Of the 18, the first flight mirror segment and one engineering development unit were polished to their exact prescriptions and verified at operational cryogenic temperatures at the X-ray and Cryogenic Facility (XRCF) at NASA's Marshall Space Flight Center. These mirror segments, as well as the tertiary and fine steering mirrors, also progressed to the last step in the mirror manufacturing process, undergoing an ultra-thin coating of gold to increase reflective properties.

Four more flight primary mirror segments (of the 18) have completed coating and are awaiting verification. These milestones set the stage for the remaining flight segments to follow in the polishing and coating process.

Sunshield

The Sunshield passed its critical design review, certifying that its design is complete and it meets mission requirements. The Sunshield also passed a Light Detection and Ranging (LIDAR) shape measurement test to ensure that it can withstand the cold temperatures of space.

Engineers tested a 1/3 scale model of the sunshield in a thermal vacuum chamber, verifying that the design can block and redirect the sun's energy before it reaches the telescope. This is significant because the infrared instruments need to operate in cold conditions. Three sunshield test articles underwent launch depressurization simulations to verify how the intricately folded sunshield membranes will perform under a rapid loss of pressure during launch. A LIDAR test was conducted on layer 5 of the sunshield (the coldest layer) near its cryogenic operating temperature, approximately 77K (-320.8°F) to confirm the computer model prediction of its shape at those temperatures in space.

Instrument Progress

Throughout FY 2010, the test models of the JWST telescope cameras were delivered to NASA's Goddard Space Flight Center in Greenbelt, Md. for testing and integration into the Webb telescope's main frame known as the ISIM.

The Structural Thermal Model of the Mid InfraRed Instrument (MIRI), a pioneering camera and spectrometer, arrived from the Science and Technology Facilities Council's Rutherford Appleton Laboratory (STFC/RAL) in the United Kingdom. The Near-Infrared Spectrograph (NIRSpec) Engineering Test Unit instrument arrived from its manufacturer in Germany. The Near-Infrared Camera (NIRCam) Engineering Test Unit arrived from Lockheed Martin in Palo Alto, Calif. The microshutters were shipped from the European Space Agency (ESA) for installation into the NIRSpec instrument. The Canadian Space Agency delivered a test unit of the Fine Guidance Sensor. All of these components were brought to the largest clean room at NASA Goddard as engineers tested them and verified their operation.

Progress was also made on the deployment tower assembly which is a 9.6 foot telescoping tower that supports the primary mirror. The deployment tower test article, the outer cylinder of a composite structure, was successfully tooled and bonded. Finally, engineering model testing was completed for the spacecraft's Command and Data Handling system, the electronic brain that sends science data to the ground station.

**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE**

*“Searching for Life in the Universe: An Update on the Progress of the
James Webb Space Telescope”*

Questions for the record, Dr. John Grunsfeld, Associate Administrator, Science
Mission Directorate, National Aeronautics and Space Administration

Questions submitted by Rep. Donna Edwards, Ranking Member

QUESTION 1:

What is the Space Telescope Science Institute doing to build on the success of the student projects on Hubble to develop learning opportunities enabled by JWST? How will students participate in activities that reinforce STEM skills?

ANSWER 1:

Science, inspiration and awe have been the hallmarks of the Hubble Space Telescope’s images, but to turn these qualities into trusted and resilient educational impacts required a new model for STEM Education. First, Hubble had to build a partnership between forefront scientists and educational specialists. Second, this partnership had to develop relevant, effective and field-tested educational tools. And finally to bring these tools into our nation’s classrooms and effect change, using only a small percentage of the Hubble budget, needed an approach that leveraged off existing educational structures and programs, and exploited teacher training institutions and State Departments of Education. Today, this model of field-tested, highly-leveraged Hubble- based programs and materials, which enhance STEM education initiatives, is used by over 500,000 teachers in the classrooms of over 6 million kids nationwide *each year*.

While still a few years from the James Webb Space Telescope (Webb) launch, Space Telescope Science Institute (STScI) is already incorporating Webb technology and science themes into this well-established network of education products. The Webb mission provides an opportunity for students and educators to explore the amazing technical solutions NASA researchers and engineers are developing as they design, build, and test Webb. By structuring educational activities for Webb around real-world engineering applications, students can participate in interdisciplinary projects and design challenges that reinforce STEM skills, work in cooperative teams as engineers and scientists do, and solve the real-world challenges related to the Webb mission.

1. An example of this is the James Webb STEM Innovation Project (SIP) – an interdisciplinary, standards-based project that focuses on the engineering aspects and potential scientific discoveries of JWST, while incorporating elements of project-based learning. STScI has developed the JWST SIP to promote enthusiasm for space exploration, introduce the education community to Webb, and engage the education community in the adventure

of scientific discovery to be enabled by the Webb mission. This program is based upon the success of the Hubble Early Release Observations (ERO) Student Pilot Project that STScI developed for Hubble.

The SIP provides an opportunity for students and educators to explore the challenges currently facing NASA researchers as they design, build, and test Webb. Students in participating schools use skills from multiple subject areas to research an aspect of the Webb's design or potential science and create models, illustrated essays, or technology-based projects to demonstrate their learning. By structuring standards-based educational activities around the observatory's design and potential science, students are able to work in cooperative teams as engineers and scientists do, and participate in interdisciplinary projects and design challenges that reinforce STEM skills as they solve real-world challenges.

The Webb SIP began as a pilot in 2011. Currently, the Webb SIP is underway in all 50 states with over 500 schools signed on to participate. Additional information on the Webb SIP and its growth over time is available at <http://amazing-space-stem.stsci.edu/jwst/>.



Students in the Webb SIP program combine skills from multiple areas to create STEM projects related to Webb

2. STScI has already incorporated Webb informal science education components into the network of science centers, planetariums, natural history museums, nature centers, national parks, observatory visitor centers, libraries, and similar forums patronized by public audiences, who are seeking to broaden their understanding of science and nature that have been developed for Hubble education in the past two decades.
3. STScI has also started using the same education infrastructure of multimedia, graphics and other education tools that have been developed for

Hubble education programs. An example of this the highly successful ViewSpace network, an internet-fed streaming technology which transforms a small corner of an exhibit hall or planetarium lobby into an ever-changing kaleidoscope of inspiring and educational presentations of the latest and most beautiful data in astronomy and space-based earth science. ViewSpace is used in over 200 venues, reaching nine million viewers per year.

Proposal evaluation in response to the SMD Science Education solicitation is presently underway. Future STScI involvement in Webb STEM activities is contingent upon it having submitted a successfully peer-reviewed proposal to this process.

QUESTION 2:

What specific steps are NASA and its contractors taking to ensure that cost and schedule commitments are met? What contingencies are being considered by and available to NASA and its contractors if these commitments cannot be met?

ANSWER 2:

In addition to the normal monitoring of contractor cost and schedule performance via earned value management metrics, the project office conducts its own analyses of those data and produces two forecasts for estimate at complete costs. These predicted costs are compared with available resources both at the contractor and NASA to ensure that sufficient budget and/or schedule are available. If NASA reserves (either cost or schedule) are requested to remedy a contingency, they must be approved by a project management board. If funds beyond those available to the project manager are required, the project office submits a written request and justification for release of HQ Webb program office reserve.

QUESTION 3:

In Mr. Grant's prepared statement, he acknowledges that manufacturing certain components' to operate at such extreme temperatures has proven to be a challenge to his company. He provided as examples the MIRI cryocooler and recently discovered workmanship issues with the cryogenic harnesses. How confident are you that Northrop Grumman has effective processes and procedures in place to identify and resolve workmanship issues so that cost and schedule are not negatively impacted?

ANSWER 3:

Northrop-Grumman and JPL have placed senior and experienced hardware delivery managers in leadership positions for the cryocooler. Two thirds of the cryocooler hardware have been delivered, but the remaining component is still experiencing cost and schedule difficulties as it completes its final integration. NASA is working with JPL and Northrop-Grumman to seek schedule savings in the later testing phases of the cryocooler plans.

QUESTION 4:

The Independent Comprehensive Review Panel (ICRP) found in 2010 some root-cause problems impacting JWST's development and made recommendations and additional considerations in its report.

- a. Are any of the concerns they identified (in areas such as deferred spacecraft work, communications issues among NASA, contractors and scientists, and producing an independent cost estimate) still manifesting themselves or has NASA taken sufficient actions to fully address the Panel's recommendations?
- b. Is NASA formally tracking the concerns raised by the ICRP to preclude them from creeping up on the JWST project and thus negatively impacting the agency's ability to execute the current plan and enable a 2018 launch date? If not, why not?

ANSWER 4a&b:

The ICRP made 22 recommendations in their 2010 report. NASA addressed each of their recommendations (see attachment 1; [NASA Response to Webb ICRP Report.pdf]) and the Webb Program office is responsible for ensuring that the findings addressed by each of the recommendations was or remains satisfied or requires additional attention. No significant departures from the changes made at the time of the rebaseline have been made.

QUESTION 5:

NASA's records show that in Fiscal Year 2013, out of 41 high level milestones, 38 were completed and 3 were deferred to the following year. However, in Fiscal Year 2014, out of 36 milestones, only 23 were completed and 11 were deferred.

- a. What is the reason for that negative performance trend?

ANSWER 5a:

In 2014, 7 of the 11 deferred milestones were related to the cryocooler. Excluding those, the number of deferred milestones is consistent with prior years' performance. Six of the 11 deferred milestones have been completed so far in FY 2015. Two of those 6 were deliveries of cryocooler hardware.

QUESTION 5b:

What is the current projection on the percentage of milestones in Fiscal Year 2015 that will be completed?

ANSWER 5b:

As of the end of March 2015, 52 percent of the FY 2015 milestones have been completed and none are predicted to be deferred at this point.

QUESTION 5c:

How many milestones may be deferred?

ANSWER 5c:

As of mid-April 2015, no milestones are currently deferred into FY 2016.

QUESTION 5d:

How confident are you that these projections will materialize?

ANSWER 5d:

The items most at risk for deferral are the cryocooler compressor assembly (based upon its historical schedule performance) and initiation of ISIM cryovacuum test #3 (based upon extra time needed for work on the NIRCcam and NIRSpec following cryovacuum test #2). At present, however, neither is expected to be deferred into FY 2016.

QUESTION 6:

During your interchange with Congressman Posey, I asked you to describe how JWST has enabled a number of improvements in ophthalmology.

- a. Are there additional areas in human health that will benefit from technologies that were developed for JWST?

ANSWER 6a:

At this time, NASA is unaware of any additional human health benefits arising from Webb developed technologies.

QUESTION 6b:

Is NASA documenting and sharing those benefits?

ANSWER 6b:

NASA documents its spinoffs on the web at spinoff.nasa.gov and in annual spinoffs publications that can be as large as almost 200 printed pages.

QUESTION 7:

GAO said in its report that in response to its concerns about the absence of an independent cost risk analysis, NASA stated that it would conduct its own cost risk analysis but that the JWST project did not intend to use it to manage the project. Additionally, GAO said that while the project would consider updating the cost risk

analysis in the future, it had not committed to regularly updating the analysis. I understand that NASA's cost risk analysis was just provided to GAO prior to this hearing.

- a. Can you explain why NASA doesn't intend to integrate the results of the analysis into its management of the JWST project? What do you intend to use the cost risk analysis for?
- b. Does NASA plan to update the cost risk analysis it recently completed? If not, why not?

ANSWER 7a&b:

A targeted single cost risk analysis provides only a snapshot in time that can be stale within weeks of being conducted. In addition, a probabilistic cost risk analysis will forecast future performance based on current risk posture but does not incorporate past performance. In order to measure progress against a plan, manage in a changing environment, and incorporate past performance, a dynamic set of tools is required. Webb employs the following tools for this purpose.

- Webb employs Monthly Contractor Performance Reports including Independent project analysis of raw Earned Value Management (EVM) data from the Northrop Grumman Aerospace Systems (NGAS), Exelis, and JPL/NGAS contracts.
 - This reporting Includes a monthly Estimate at Complete (EAC) for each contract which factors in a current risk assessment, detailed trending of metrics and associated narrative summary.
 - In fact, all performance reporting to-date has provided Webb management advanced notice of any EAC growth before the contractor(s) have officially notified the Project, thus providing the Webb management team to have pro-active EAC discussions internally, as well as with the contractor teams.
- Webb employs Monthly Secondary EAC Analysis, which uses a Monte Carlo analysis of EVM data and current risk databases (with review and adjustments by NASA Integrated Product Team leads). This analysis provides a forecast of future performance based on past performance and current risk posture.
 - Analysis of the NGAS Observatory contract is now operational with Exelis to follow soon.
 - Any projected overrun delta to current budget is treated as a threat against project cost reserves.
- Monthly Schedule Analysis and Health Metric Assessment is performed across the project. Weekly schedule status reviews are performed to ensure that progress or the lack thereof is fully understood. Webb also uses the DCMA "tripwire" schedule metrics that provide additional selected measures of schedule management controls, and if ever exceeded, are flags for management attention.

The combination of these various tools provides NASA with monthly assessment of the cost and schedule posture based upon the most recent set of risks and is therefore superior to a traditional cost-risk study.

QUESTION 8:

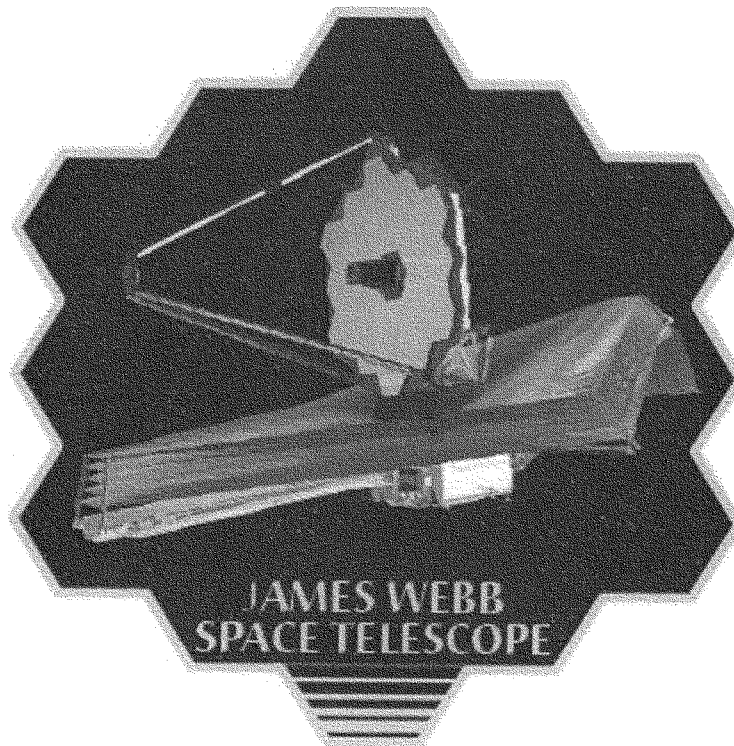
GAO reported that the JWST project and NASA disagreed with the approach of having an independent cost risk analysis conducted by an outside organization and that neither believed that an organization external to NASA could fully comprehend the project's risks. Furthermore, both felt that any such analysis would be overly conservative due to the complexities of the risks. Without an independent and updated analysis, how can Congress be assured that JWST will be delivered within budget and on time knowing that the impact of newer risks, as GAO stated, has not been reflected in key analyses?

ANSWER 8:

New risks are constantly being identified and factored into project planning every month. The monthly processes used for project management are more suitable for decision making than the "frozen in time" snapshot used in a cost-risk analysis. Indeed, a cost-risk analyses could be detrimental to understanding the actual risk posture of a project because it uses only a single point in time and relies on best effort estimates for risk probabilities and does not factor in actual performance trends. Please also see the answer to question number 6.

2014 Year-End Report for James Webb Space Telescope

Public Affairs/Education and Public Outreach



**Lynn Chandler
NASA Public Affairs Officer for the
James Webb Space Telescope Program
December 31, 2014**

Summary

The James Webb Space Telescope (JWST) Public Affairs, and Education and Public Outreach team had an extremely busy year in 2014 as we continued to spread the word on the continued progress being made. All mirrors and flight instruments are at Goddard and the backplane pathfinder will leave in early 2015 to go to Johnson Space Center.

In 2014, the focus was on testing. All science instruments began their testing as an integrated science payload and the Integrated Science Instrument Module completed the CVRR2 test. All four JWST science instruments—the near-infrared camera (NIRCam), near-infrared spectrograph (NIRSpec), mid-infrared instrument (MIRI) and the fine guidance sensor/near-infrared imager & slitless spectrograph (FGS/NIRISS) were being tested and that will continue into the next year. A lot of work and testing was performed on the backplane pathfinder and placement of the mirrors, and deployment of the secondary mirror. Work continues on the sunshield and the spacecraft.

In 2014, the team participated in at least 26 outreach events, led 68 tours, completed 27 press releases, photo features and/or web features, gave numerous presentations, participated in several television interviews, completed various recorded interviews, led several educational events, and made major improvements to the web site.

This past year, we also hosted visits from several Congressional and White House staffers, the NASA Advisory Council, senior NASA leaders, as well as many other high level visitors. The Goddard Visitor Center also led daily tours to see JWST.

The traveling exhibit was seen by thousands of people when it was on display Lowell Observatory in Flagstaff, Arizona.

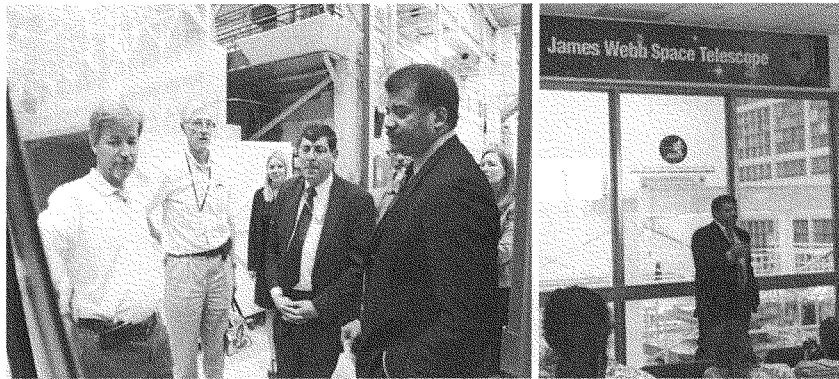
JWST reached millions of citizens as it was heard on radio, seen on TV, read in print and on-line. JWST was featured prominently in the Baltimore Sun and the Washington Post.

Our social media has grown a great deal over the past few years. We started 2014 with just over 104,000 Twitter followers and have ended the year with almost 157,000. On Facebook, we started 2014 with just over 159,000 followers and are ending the year with just over 260,000. Our number of YouTube followers increased by approximately 2,500 this year, and we have had nearly 609,000 views of our videos. We had nearly 2.2 million views of our images on Flickr by the end of 2014. Our Google Plus account has had 1.1 million views of our profile and content. Our Instagram account has grown from 2,249 followers at the start of 2014 to 7,500.

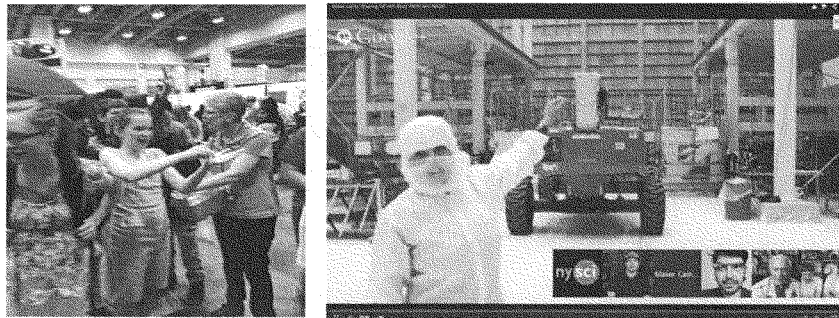
As testing and integration continued at Goddard, we continued making improvements to the viewing area. Next year, we are especially looking forward to assembling the mirror, manufacturing the spacecraft and the sunshield as well as continuing testing and integration.

The EPO/PAO team includes members from NASA Public Affairs and EPO, NGAS, Ball Aerospace, STScI, University of Arizona, Excelis, CSA and ESA. Team members include – NASA- Lynn Chandler, Amber Straughn, Rob Gutro, Maggie Masetti, Jon Gardner, Dee

Kekesi, Mike McClare, Laura Betz, Chris Gunn, Desiree Stover, Steve Sabia, Nasreen Alkateeb, Colleen Quinn-House, Ryan Hannahoe, Scott Wiessinger, Harley Thronson, Frank Reddy, Phillina Tookes, Janice Phipps-Harmon, Mark Clampin, Matt Greenhouse, Felicia Chou, Eric Smith, Janet Newton and Kimberly Anderson; NGAS –Alberto Conte, Christina Thompson, Lon Rains, Carleen Beste; STScl – Matt Mourtain, Jason Kalirai, Bonnie Eisenhamer, Massimo Stiavelli, Denise Smith, Bonnie Meinke, Stephanie Smith, Ray Villard, Cheryl Gundy and Mary Estacion; Ball Aerospace- Roz Brown and Denise Henry; University of Arizona – Don McCarthy, George Rieke and Larry Lebofsky, CSA- Ruth Ann Chicoine; ESA - Inka Eichhorn, Markus Bauer; Exelis- Irene Lockwood and Heidi Hammel of the SWG.



Neil deGrasse Tyson visited and addressed the JWST staff



Crowd at Makers Faire in Silver Spring

Laura Betz participated in Google+ Hangout with Buzz Aldrin



South by Southwest Festival



Emily Calandrelli from Fox's
Xploration Outer Space

The report is divided into the following sections:

1. Outreach Events
2. Tours
3. News Releases/Web Features/Photo Features and Media Results
4. Website/Social Media
5. Multimedia
6. Education
7. Presentations
8. Products
9. In-Reach
10. Plans for 2015

1. Outreach Events

At most of these major outreach events, JWST personnel were responsible for staffing the booth and providing interactive hands-on activities. The real benefit to the public is interacting and talking with our scientists, engineers and outreach specialists. The booth also includes a 1/20 scale model of JWST, a television screen showing JWST related videos, an Infrared Camera demonstration, a mirror display, social media, samples of our hardware, lithographs, factsheets, bookmarks and other outreach materials that are available for distribution.

Outreach Events

January

Goddard hosted hundreds of attendees from the American Astronomical Society Conference and gave them a tour of JWST as well as presentations.

February

NASA Administrator Bolden and Senator Mikulski visited JWST to view progress and congratulate the team for the delivery of all flight instruments and primary mirrors to Goddard

March

JWST at South by Southwest Festival in Austin, Texas

Approx. 6,000 visitors, JWST mirror exhibit, pull-up banners, large touch screen, talks, social media

April

Delivered keynote address on JWST at the USA Science and Engineering Festival at the the Extreme STEM (or X-STEM) Symposium

JWST at the US Science and Engineering Festival in DC

Approximately 500,000 visitors

Gave keynote address at the California State Science Fair in Los Angeles

Approximately 2,000 students, teachers and parents

Astronomy & Aerospace Day at the Museum of the Rockies. 1,200 attendees

May

Participated in the "Search for Life in the Universe" panel at the Space Symposium in Colorado Springs

June

Dr. Neil deGrasse Tyson visited JWST and Center Management

Hosted a NASA Social for JWST - 30 social media users attended the full-day event

JWST participated in the Astronomy Night on Mall

July

Google + hangout for Maker Camp with Buzz Aldrin

Summer Institute in Science Technology, Engineering, and Research (SISTERS)

USS Intrepid's Science and Spacefest in NYC

Conducted the Space Symposium "Search for Life in the Universe" panel at NASA headquarters. Broadcast live on NASA TV and archived on YouTube

JWST presentation for students and camp facilitators from the UNESCO Center for Peace Summer Camp program.

August

Aspen Science Festival in Aspen, Colorado

Aerospace Careers

Google+ Hangout with teachers of Stewart Middle Magnet School (Tampa, FL)

September

JWST Booth at Silver Spring Maker Faire

JWST presentation for Paul's Place in Baltimore, MD.

October

Presentation and booth at World Space Week at Air and Space Museum

STScI worked with John Hopkins Univ. Mechanical Engineering design team for deployable model

Google+ Hangout regarding the sunshield deployment test

November

Participated in STEM event at Howard County Schools

December

2. Tours

Recognizing and anticipating that we would be presenting JWST to various audiences on a regular basis, we developed a diverse cadre of JWST spokespeople. Several of our people have successfully completed a public speaking/media training class. This class helped develop their messaging and talking points for JWST. To date more than 25 people have completed this course and are giving JWST talks on a regular basis.

These talks/tours are held in building 29 at Goddard overlooking the vast cleanroom that houses the hardware. Enhancements to this viewing area have continued throughout this year. Most recently installed a monitor displaying a conversation between President Kennedy and James Webb.

Most of these tours/talks are at the request of the Government and Community Relations Office, Center Director or VIP Tours from Office of Communications. Listed below are some, but not all, of the higher-level tours that were given this past year:

We also have a webcam online which shows the large cleanroom at Goddard, where Webb's hardware is being built and tested! The screenshot from the webcam updates every minute. [View the webcam!](#) We encourage our visitors to follow our action on this webcam.

January

National Nuclear Security Administration; AAS Attendees; NYU Scholars; Swiss State Secretary for Education, Research and Innovation; and Astronaut Class of 2013

February

Science Policy Fellows: American Association for the Advancement of Science; President and CEO of the National Aeronautic Association; NYU's Sheikh Mohammed Scholars; and Space Industry Study Program at the Eisenhower School of the National Defense University

March

REAL Montana Program, University of Montana; NASA Mid-Level Leadership; Agency HR working group; Emerging Technologies and Research Advisory Committee; Korean Transport Safety Authority; University of Notre Dame; RHG Memorial Symposium Univ. of Illinois student tour; and RHG Middle School students

April

MyCOE/SERVIR International Students; Einstein Distinguished Educator Fellows; Agency CIO; Spanish Deputy Minister of Defense; Chairman of India Space Research Organization; University of Maryland; and Optimus Prime/NASA competition winners

May

Public Affairs Specialists, U. S. Army Corps of Engineers; Partnership for Public Service Fellows; Green County, PA School District; ASPIRE Program; 42nd Aerospace Mechanisms Symposium; and Canadian Space Agency delegation

June

American Institute of Physics; Director & CEO, Institute for Human & Machine Cognition; NASA Academy; STEM Challenge Team, Allendale Columbia School; Acting Director of Office of Geospatial Intelligence Management of National Geospatial Agency; U.S. Air Force Strategic Policy Fellows; and Minister for Research & Higher Education, Romania

July

AIAA Regional Science Group; Congressional Fellows; Dept. of Education, Green Ribbon Schools; and OMB

August

Astronomical Society; University of Buffalo, School of Engineering and Applied Science;

NASA Triennial Health Physics Group; Asymmetric Warfare Group, Ft. Meade; George Washington University Group; and NASA Headquarters Office of Chief Financial Officer and colleagues from Goddard's CFO.

September

Office of Assistant Secretary of the Army, Installations, Energy & Environment/Pentagon; Japanese Delegation; JAXA Procurement Group; Norwegian Association; NASA Rep to Russia and OIR staff; OHCM Group; AIAA Working Group on Space Simulation; NASA Enterprise Architects and Chief Technology Officers; and Director, SciFest Africa

October

University of MD, College Park Scholars Public Leadership Program; Israeli Delegation; Office of Safety and Mission Assurance; American Physical Society Task Force on American Innovation; and Spanish Delegation

November

DSCOVR Family and Friends Day; DISCOVR Media Day; NOAA NESDIS; Embassy of Sweden – Office of Science & Innovation; Royal Society of Chemistry; and International Workshop on Instrumentation for Planetary Missions

December

Ohio University students; Orion Social VIP Tour; Baltimore Lab School; and Office of Personnel Management

3. News releases/web features/photo features/media results

JWST had an extremely busy year and all of the major milestones and most of its significant activities were reported in press releases, web features and photo releases resulting in a tremendous increase in media coverage. Our intent was to capture all of the major milestones accomplished in 2014, while informing the public about JWST as often as possible and continuing to get the word out to the public. Several of the releases were written and released jointly with our partners, specifically NGAS, MSFC, CSA and Ball Aerospace. Listed below are most of the releases:

January

James Webb Space Telescope Passes a Mission Milestone

<http://www.nasa.gov/press/2014/january/james-webb-space-telescope-passes-a-mission-milestone/#.UuaKJhAo6Uk>

NASA Discusses James Webb Space Telescope Progress

<http://www.nasa.gov/press/2014/january/nasa-discusses-james-webb-space-telescope-progress/#.UulurLRgvZg>

RELEASE/VIDEO OF PROGRESS EVENT:

RELEASE TEXT: <http://www.nasa.gov/press/2014/february/nasa-administrator-bolden->

[senator-mikulski-view-progress-on-james-webb-space/](#)
 VIDEO OF PROGRESS EVENT FROM GODDARD:
<https://www.youtube.com/watch?v=k6ve3E7O1Dk>

February

New Video Goes "Behind the Webb" To See 100 Points of Light

<http://www.nasa.gov/content/goddard/new-video-goes-behind-the-webb-to-see-100-points-of-light>

YOU TUBE VIDEO: <http://youtu.be/OHvem1iU1iQ>

DOWNLOADABLE VIDEO:

http://webbtelescope.org/webb_telescope/behind_the_webb/episodes/22

Reflecting on Webb's Progress

<http://www.nasa.gov/content/goddard/reflecting-on-webbs-progress/>

NASA Time-lapse Video Shows MIRI Installation on Webb Telescope

<http://www.nasa.gov/content/goddard/nasa-time-lapse-video-shows-miri-installation-on-webb-telescope/>

March

Media, Public Invited to Visit NASA's James Webb Space Telescope Exhibit at South by Southwest

<http://www.nasa.gov/press/goddard/2014/march/media-public-invited-to-visit-nasas-james-webb-space-telescope-exhibit-at-south-by/>

The Amazing Anatomy of James Webb Space Telescope Mirrors

<http://www.nasa.gov/content/goddard/the-amazing-anatomy-of-james-webb-space-telescope-mirrors/>

April

Webb Telescope's Heart Complete, Final Instrument Installed

<http://www.nasa.gov/content/goddard/webb-telescopes-heart-complete-final-instrument-installed/#.U16jVIU-fkl>

James Webb Space Telescope Highlighted at USA Science and Engineering Festival

<http://www.nasa.gov/press/2014/april/goddard/james-webb-space-telescope-highlighted1/#.U16jtYU-fkl>

May

Examining NASA's "Star Catcher" in a New "Behind the Webb" Video

<http://www.nasa.gov/content/goddard/examining-nasas-star-catcher-in-a-new-behind-the-webb-vide/>

PHOTO FEATURE: The Webb of a Thermal Cage

<http://www.nasa.gov/content/goddard/the-webb-of-a-thermal-cage>

PHOTO FEATURE: Mock the Bus: NASA's James Webb Space Telescope

<http://www.nasa.gov/content/goddard/mock-the-bus-nasas-james-webb-space-telescope>

June

Feature and video: Webb's Fully Integrated 'Heart' Lowered into the Chamber

<http://www.nasa.gov/content/goddard/webbs-fully-integrated-heart-lowered-into-the-chamber/#.U58HCyjCD1c>

Video: <http://svs.gsfc.nasa.gov/vis/a010000/a011500/a011570/>

Feature/Video: Webb Telescope Microshutters Journey into NASA Clean Room

Story: <http://www.nasa.gov/content/goddard/webb-telescope-microshutters-journey-into-nasa-cleanroom/#.U6hGk7HCD1c>

Video: <http://youtu.be/ElbUoHsydvU>

July

Testing Completed on NASA's James Webb Space Telescope Backplane

<http://www.nasa.gov/press/2014/july/testing-completed-on-nasas-james-webb-space-telescope-backplane/>

Discover the "X-Factor" of NASA's Webb Telescope in "Behind the Webb" Video

<http://www.nasa.gov/content/goddard/discover-the-x-factor-of-nasas-webb-telescope-in-behind-the-webb-video/>

Photo Feature NASA's Webb Sunshield Stacks Up to Test!

<http://www.nasa.gov/content/goddard/nasas-webb-sunshield-stacks-up-to-test>

August

James Webb Space Telescope "Pathfinder" Backplane's Path to NASA

<http://www.nasa.gov/content/goddard/james-webb-space-telescope-pathfinder-backplanes-path-to-nasa>

A "NIRSpec-tacular View" of NASA's Webb Telescope Instrument

<http://www.nasa.gov/content/goddard/a-nirspec-tacular-view-of-nasas-webb-telescope-instrument>

September

NASA Engineers Conduct Low Light Test on New Technology for Webb Telescope

<http://www.nasa.gov/content/goddard/nasa-engineers-conduct-low-light-test-on-new-technology-for-webb-telescope/>

Photo: James Webb Space Telescope's "Mirror Mattress"

<http://www.nasa.gov/content/goddard/james-webb-space-telescopes-mirror-mattress/#.VBL5VBDupMc>

October

NASA Webb's Heart Survives Deep Freeze Test

<http://www.nasa.gov/content/goddard/nasa-webbs-heart-survives-deep-freeze-test/>

Webb Telescope Mirrors: Stepping Stones to the Cosmos

<http://www.nasa.gov/content/goddard/webb-telescope-mirrors-stepping-stones-to-the-cosmos>

NASA's Webb Telescope Pathfinder Telescope Fully Assembled

<http://www.nasa.gov/content/goddard/nasas-webb-telescope-pathfinder-telescope-fully-assembled/>

November

NASA's Webb Telescope Mirror Tripod in Action

Feature: <http://www.nasa.gov/content/goddard/nasas-webb-telescope-mirror-tripod-in-action>

Video: <https://www.youtube.com/watch?v=xq0KYi09pIY>

Northrop Version:

<http://www.northropgrumman.com/Capabilities/JWST/Pages/NASA%27sWebbTelescopeMirrorTripodinAction.aspx>

DECEMBER

NASA's Webb Telescope ISIM Gets Cubed for Gravity Test

<http://www.nasa.gov/content/goddard/nasas-webb-telescope-isim-gets-cubed-for-gravity-test>

Media Coverage

Space News, Aviation Week, Spaceflight Now, Space Ref, Space.com, Phys.Org, SatNews, Space Daily, Toronto Star, Wall Street Journal, Chicago Tribune, Reuters, Baltimore Sun, Huffington Post, Washington Post, Cornell Chronicle, Sacramento Bee, Times LIVE, Berthoud Recorder, Portland Tribune, Red Orbit, Nature, CBC, Astronomy Magazine, Popular Mechanics, Wired, Digital Journal, Boxden.com, Forbes, Southern Maryland Online, Daily Record, Arkansas Matters.com, Optics.org, SPIE Newsroom, Controlled Environments Magazine, Deccan Herald, Consumer Electronics Net, NC State University Technician Online, Information Week, High Performance Composites, Washington Business Journal, Machine Design, FCW.com, Yahoo News, Science Recorder, Optics.org, Market Watch, Scientific American, Forbes, National Geographic, Discovery News, ECNmag.com, Capital News Service, Smithsonian Air and Space, International Business Times, Mother Nature Network, Aerospace Today, Fox News and Fox 45

Links to some of the bigger stories of 2014:

Xploration Outer Space aired on Fox TV on December 6

<http://www.hulu.com/watch/723509#details=expand->

National Geographic –Building the Largest Space Telescope Ever
https://www.youtube.com/watch?v=mmguh7eks_U

Washington Post - http://www.washingtonpost.com/national/health-science/webb-space-telescope-promises-astronomers-new-scientific-adventures/2014/11/17/4b2533f0-4e64-11e4-babe-e91da079cb8a_story.html

The Baltimore Sun <http://www.baltimoresun.com/health/maryland-health/bs-hs-webb-space-telescope-20140314,0,4758829.story>

Saylor Google Hangout <https://www.youtube.com/watch?v=hXRrkmBkpIM>.

Google's Maker Camp Hangout with featured Buzz Aldrin..
<https://www.youtube.com/watch?v=7CDwz-bZtBc>

Wired, How a Superchilled Telescope Will Look Back at the Dawn Of the Universe:
<http://www.wired.com/2014/11/james-webb-telescope/>

Reuters <http://www.reuters.com/video/2014/12/22/nasa-prepares-for-next-phase-of-hubble-s?videoId=351303201>

4. Website/Social Media

See Appendix A for detailed Website/Social Media Report

<http://www.jwst.nasa.gov/>

Improvements continued this year on NASA's JWST website. The website is updated regularly with the latest news, images, videos, animations, newsletters, and bios. The website itself received a facelift with an interactive front page. This went live on New Years Eve 2013. This was the first full year with the updated design. Over 2014, the webcam experience has been improved (with new updates to it to come in 2015), as well as kept all the homepage features up to date.

The Space Telescope Science Institute (STScI) also has a web site at <http://www.WebbTelescope.org>. This site includes factsheets, videos, bios and other JWST content.

Our social media sites are available at the following links:

<http://twitter.com/NASAWebbTelesc>
<http://www.facebook.com/webbtelescope>
<http://www.youtube.com/user/NASAWebbTelescope>
<http://www.flickr.com/photos/nasawebbtelescope/>
<https://plus.google.com/+NASAWebbTelescope/>
<http://instagram.com/nasawebbtelesc>

We held several Tweepchats in 2014. They include:

SXSW: Finding Life on Other Planets:
http://jwst.nasa.gov/faq_tweetchat4.html

USA Science & Engineering Festival:
http://jwst.nasa.gov/faq_tweetchat6.html

Sara Seager: Search for Life:
 Part 1: http://jwst.nasa.gov/faq_tweetchat5.html
 Part 2: http://jwst.nasa.gov/faq_tweetchat7.html

We participated in Google's Maker Camp G+ Hangout. Dr. Marc Kuchner talked about JWST: <https://plus.google.com/events/c54ip10t979uflkn1jb95o647gk>

Dr. Amber Straughn was a guest on the DOTNET Rocks podcast, which reaches 150,000 developers 3 times a week. <http://www.dotnetrocks.com/default.aspx?showNum=1052>

In June, we held a very successful all-day NASA Social where we had approximately 30 social media users come to NASA Goddard for a tour, presentation, and to interact with members of the James Webb Space Telescope team. Represented at the social were many of the partners involved with JWST: NASA, NASA HQ, ESA, CSA, Northrop Grumman, and Ball Aerospace.

5. Multimedia

If you want to excite and engage the public it is imperative that you have animations, visualizations and movies to show them. The saying used to be "a picture is worth a thousand words", well now the saying is a video is worth a million+ words" and if they can't see it you can't sell it. As a result, our multimedia team has created several new products this year.

Multimedia

February

New Video Goes "Behind the Webb" To See 100 Points of Light

<http://www.nasa.gov/content/goddard/new-video-goes-behind-the-webb-to-see-100-points-of-light/#.VJSEwZAOKA>

NASA Time-lapse Video Shows MIRI Installation on Webb Telescope

<http://www.nasa.gov/content/goddard/nasa-time-lapse-video-shows-miri-installation-on-webb-telescope/#.VJSEapAOKA>

April

Webb Telescope's Heart Complete, Final Instrument Installed

<http://www.nasa.gov/content/goddard/webb-telescopes-heart-complete-final-instrument-installed/#.VJSC35AOkA>

May

Examining NASA's "Star Catcher" in a New "Behind the Webb" Video

<http://www.nasa.gov/content/goddard/examining-nasas-star-catcher-in-a-new-behind-the-webb-video/>

June

Webb's Fully Integrated 'Heart' Lowered into the Chamber

<http://www.nasa.gov/content/goddard/webbs-fully-integrated-heart-lowered-into-the-chamber/>

Webb Telescope Microshutters Journey into NASA Clean Room

http://www.nasa.gov/content/goddard/webb-telescope-microshutters-journey-into-nasa-cleanroom/#.VJR-_JAOkA

July

Discover the "X-Factor" of NASA's Webb Telescope in "Behind the Webb" Video

<http://www.nasa.gov/content/goddard/discover-the-x-factor-of-nasas-webb-telescope-in-behind-the-webb-video/>

August

James Webb Space Telescope "Pathfinder" Backplane's Path to NASA

<http://www.nasa.gov/content/goddard/james-webb-space-telescope-pathfinder-backplanes-path-to-nasa/>

November

NASA's Webb Telescope Mirror Tripod in Action

<http://www.nasa.gov/content/goddard/nasas-webb-telescope-mirror-tripod-in-action/#.VJRvSki7IGc>

To see all videos produced in 2014, go to <http://jwst.nasa.gov/videos.html>

Photography

2014's progress was captured in stunning photography. Some of the pictures appeared in the Washington Post and Wired

April

James Webb Space Telescope's Near Infrared Spectrograph Installed

<http://www.nasa.gov/content/james-webb-space-telescopes-near-infrared-spectrograph-installed/#.VJSDGJAOkA>

Engineers Install Near Infrared Camera into the Heart of Webb Telescope

<http://www.nasa.gov/content/goddard/engineers-install-near-infrared-camera-into-the-heart-of-webb-telescope/#.VJSDupAOkA>

May

The Webb of a Thermal Cage

<http://www.nasa.gov/content/goddard/the-webb-of-a-thermal-cage/#.VJSCNJAOkA>

June

Mock the Bus: NASA's James Webb Space Telescope

<http://www.nasa.gov/content/goddard/mock-the-bus-nasas-james-webb-space-telescope/#.VJSBqpAOkA>

Testing Completed on NASA's James Webb Space Telescope Backplane

<http://www.nasa.gov/press/2014/july/testing-completed-on-nasas-james-webb-space-telescope-backplane/#.VJR-nZAOkA>

July

Revolutionary Microshutter Technology Hurdles Significant Challenges

<http://www.nasa.gov/content/goddard/revolutionary-microshutter-technology-hurdles-significant-challenges/>

NASA's Webb Sunshield Stacks Up to Test!

<http://www.nasa.gov/content/goddard/nasas-webb-sunshield-stacks-up-to-test/#.VJR0g5AOkA>

August

James Webb Space Telescope "Pathfinder" Backplane's Path to NASA

<http://www.nasa.gov/content/goddard/james-webb-space-telescope-pathfinder-backplanes-path-to-nasa/>

James Webb Space Telescope "Pathfinder" Backplane in the Cleanroom

<http://www.nasa.gov/content/james-webb-space-telescope-pathfinder-backplane-in-the-cleanroom/#.VJRy8JAOkA>

Making Room for Webb's Mirrors

<http://www.nasa.gov/content/goddard/making-room-for-webbs-mirrors/#.VJRyqZAOkA>

A "NIRSpec-tacular View" of NASA's Webb Telescope Instrument

<http://www.nasa.gov/content/goddard/a-nirspec-tacular-view-of-nasas-webb-telescope-instrument/#.VJRycpAOkA>

September

James Webb Space Telescope's "Mirror Mattress"

<http://www.nasa.gov/content/goddard/james-webb-space-telescopes-mirror-mattress/#.VJRx8pAOkA>

NASA Engineers Conduct Low Light Test on New Technology for Webb Telescope

<http://www.nasa.gov/content/goddard/nasa-engineers-conduct-low-light-test-on-new-technology-for-webb-telescope/#.VJRyLZAOkA>

October

NASA's Webb Telescope Pathfinder Telescope Fully Assembled

<http://www.nasa.gov/content/goddard/nasas-webb-telescope-pathfinder-telescope-fully-assembled/#.VJRwFUi7IGc>

Webb Telescope Mirrors: Stepping Stones to the Cosmos

<http://www.nasa.gov/content/goddard/webb-telescope-mirrors-stepping-stones-to-the-cosmos/#.VJRwoEi7IGc>

James Webb Space Telescope's Heart Survives Deep Freeze Test

<http://www.nasa.gov/content/goddard/nasa-webbs-heart-survives-deep-freeze-test/>

James Webb Space Telescope Sunshield Test Unfolds Seamlessly

<http://www.nasa.gov/content/james-webb-space-telescope-sunshield-test-unfolds-seamlessly/#.VJRxq5AOkA>

Media resources created and made available on SVS site:

<http://svs.gsfc.nasa.gov>

This site is the repository for all media resources

Also, the Webb telescope program pictures can be seen on our Flickr page at:

<http://www.flickr.com/photos/gsfcc/sets/72157623037106357/show/>

7. Education

JWST Education Products

A new ViewSpace feature about JWST was developed in 2014. The feature, called "The Webb Space Telescope: Reflecting a Hidden Universe," introduces how Webb will use infrared light to penetrate the dark clouds of dust present in the universe in order to study the infrared-emitting objects within. Additionally, a JWST update was created for ViewSpace in June, 2014.

JWST Professional Development

Google+ Hangouts for Stewart Middle Magnet School

STScI's education team provided two JWST professional development Hangouts for educators at Stewart Middle Magnet School. A content presentation, "From Hubble to

Webb: More Than Meets the Eye,” was followed by a content update on Webb to support the educators in implementing the JWST SIP project with students.

Webinar for Pennsylvania’s MSP Educators

STScI’s education team provided a web-based professional development presentation to educators participating in the Pennsylvania Three Region Math and Science Partnership (MSP) program. The “From Hubble to Webb: More Than Meets the Eye” presentation served as follow-up to in-person workshops and provided content updates about JWST.

JWST Science Briefings

Two JWST Science Briefings were held by STScI in 2014. Dr. Gerard Kriss, an astronomer and Lead of the JWST NIRCам Team at STScI, gave a presentation entitled “Looking Forward to our Deepest View of the Universe: Science with the Near-Infrared Camera on the James Webb Space Telescope.” Dr. Alex Fullerton gave a presentation entitled “Delivering JWST Science, from Exoplanets to First Light: The Near-Infrared Imager and Slitless Spectrograph (NIRISS).” Science Briefings provide science content information to informal educators and are based upon current astronomical research while emphasizing Hubble, Webb, and other Great Observatories.

JWST Student Programs

The James Webb STEM Innovation Project - Update

The James Webb STEM innovation Project (SIP) is an interdisciplinary, standards-based project that focuses on the engineering aspects and potential scientific discoveries of JWST, while incorporating elements of project-based learning. The SIP provides an opportunity for students and educators to explore the challenges currently facing NASA researchers as they design, build, and test JWST. Currently, over 500 schools in all 50 states are participating, or signed on to participate in the project.

Tampa Students Complete “Space Week” Programs for the JWST STEM Innovation Project

During 2014, Stewart Middle Magnet School and Blake High School for the Arts in Tampa, FL presented a combined series of “Space Week” programs with astronomy, engineering, and space intertwined with fine arts, music, and dance. The “Space Week” programs were developed as part of STScI’s JWST STEM Innovation Project (SIP).

AKAdemy Girls: JWST Exhibition

STScI staff attended an exhibition of student projects hosted by the AKAdemy After-School Program in Baltimore City. Students showcased their projects and a video after completing their participation in STScI’s JWST STEM Innovation Project.

AKAdemy serves girls in grades 6 – 8 and, since 2000, has served over 200 at-risk middle school girls.

Windsor Mill Middle School: JWST STEM Innovation Kick-off Event

STScI staff provided a JWST infrared light and career presentation for students and educators at Windsor Mill Middle School in Baltimore, MD. Students and educators were informed about the upcoming James Webb mission during a “New Adventures with the James Webb Space Telescope” presentation. The presentation was provided as part of kick-off event for the school’s participation in STScI’s ongoing JWST STEM Innovation Project.

USA Science & Engineering Festival Expo

STScI education, outreach, and scientific staff worked together to host a booth and hands-on demos during the third USA Science and Engineering Festival Expo in Washington, D.C. The activities demonstrated how space telescopes operate in different wavelengths of light and how astronomers use filters to investigate the universe and study different regions of the electromagnetic spectrum. Hubble images were used to extend the activities and discuss expected findings from JWST.

Astronomy Night on the Mall

STScI’s Office of Public Outreach participated as exhibitors during Hofstra University’s Astronomy Night on the Mall in Washington, DC. STScI staff demonstrated several hands-on activities related to light and color, multiwavelength astronomy, and that featured both the Hubble and James Webb missions. STScI staff also provided telescopes and expertise for night sky viewing opportunities.

2014 Women’s Science Forum

STScI’s YAE program and education team hosted two Women’s Science Forum events for middle and high school students. This year’s events featured science presentations by Dr. Elena Sabbi and Dr. Amber Straughn. Presentations were followed by hands-on activities, where students were able to build spectroscopes, explore the spectra of different light sources, and learn how spectra are used as a tool to identify elements. Students also participated in STEM career activities, where they were able to interact with women who work at STScI.

SEMAA STEM Extravaganza

STScI staff participated in the Science, Engineering, Mathematics and Aerospace Academy (SEMAA) STEM Extravaganza in partnership with the Maryland Space Grant Consortium. STScI and Space Grant staff hosted a booth where families could participate in hands-on activities and demonstrations and learn about various careers in space science. The booth also featured an infrared camera demonstration that was used to explain the operation of the future James Webb Space Telescope and how it compares to Hubble.

JWST Junior Achievement Presentation

Members of STScI's education team provided a JWST-themed student workshop for visiting students from Seton Keough High School's Junior Achievement program. Students participated in a discussion about the James Webb Space Telescope that featured an interactive infrared camera demonstration to illustrate the observatory's infrared capabilities. Students also completed a design challenge that reinforces the importance of prototyping and working together in a team.

Howard Community College STEM Festival

STScI staff participated in the second annual Howard Community College (HoCo) STEM Festival. STScI staff presented two 30-minute presentations to parents and students that described how current Hubble science will be extended with JWST observations.

Girl Power

STScI staff hosted a booth with hands-on activities and spoke to girls and their parents about astronomy and associated STEM careers. There was a specific focus on careers critical to supporting NASA missions such as JWST. Student activities involved explorations with filter glasses, "hidden messages," and LED lights.

Girl Scout STEM camp

STScI education staff presented hands-on activities for a Girl Scout Science, Technology, Engineering and Math (STEM) Camp. The participating scouts were introduced to light filters and completed several multiwavelength activities.

NASA Science4Girls JWST Event at Eldersburg Library

STScI's education team provided a student workshop for a NASA Science4Girls JWST event at the Eldersburg Library in Sykesville, MD. STScI staff conducted an hour and a half workshop entitled "New Adventures with the James Webb Space Telescope."

YAE Hispanic Science and Engineering Forum

STScI education staff participated in the first Hispanic Science and Engineering Forum sponsored by STScI's Youth for Astronomy and Engineering (YAE) program. This full-day event featured science presentations and interactive, hands-on activities related to science and engineering for middle and high school students and their parents. Attendees were informed about the JWST mission and participated in an interactive infrared camera demonstration.

STEM Night at Windsor Middle School

STScI education staff astronomer Dr. Jason Kalirai participated in the first Annual STEM Night entitled “Passport to the Future” that took place at Windsor Mill Middle School in Baltimore, MD. The presentation included visuals of infrared images and how they related to the future James Webb Space Telescope mission.

X-STEM Astronomy Night at Bel Air Middle School

Members of STScI’s education team provided an interactive infrared camera demonstration at Bel Air Middle School during an X-STEM Astronomy Night event. The demonstration highlighted the operations of JWST. The event also showcased student projects about JWST, such as a tessellation project that focused on Webb’s primary mirror.

Pursuing A Dream Career Event

STScI staff participated as exhibitors for the Pursuing A Dream Corporation in Washington, D.C. This half-day event, for elementary and middle school students and parents in Washington, D.C. and surrounding areas, involved several hands-on activities and career explorations. STScI staff led several activities to demonstrate how light is used as a tool by astronomers.

Pursuing a Dream Corporation’s STEM Bonanza

STScI staff participated in the STEM Bonanza in Washington, D.C. Students investigated how astronomers use filters and telescopes to study the universe and make discoveries. Students were able to make their own discoveries by using filters to decode hidden messages.

Dream and Flourish After-School Presentation

STScI staff presented a JWST-themed career day talk to the Dream and Flourish after-school program at Windsor Mill Middle School in Baltimore, MD. The presentation included visuals of infrared images and how they related to the JWST mission.

STEM Career Presentation at Reservoir High School

STScI’s education team participated in the annual “STEM Series” event at Reservoir High School in Fulton, MD. Team members worked together to develop and provide a presentation entitled “Careers in Space Science” that included several hands-on activities and demonstrations about the electromagnetic spectrum. Students heard two presenters discuss science, technology, engineering, and math (STEM) careers at STScI.

Career Fair at Middleborough Elementary School

STScI staff presented at the Bi-Annual Career Fair at Middleborough Middle School located in Essex, Md. The career day presentation included a brief introduction of

JWST and a hands-on activity where students measured full-scale JWST mirror segments.

Lansdowne Middle School JWST Event

STScI provided JWST presentations for two art classes at Lansdowne Middle School. The two 45-minute presentations included a discussion of the James Webb Space Telescope and featured a hands-on demonstration with the infrared camera.

Science Night at Atholton Elementary School

STScI staff participated as speakers for the PTA/School Science Night at Atholton Elementary School, in Columbia, MD. Students and parents were able to rotate to various stations every 10-20 minutes. Students were able to explore with the hands-on activities related to light and color.

STEM Career Day at Brock Bridge Elementary School

STScI's education team participated in the 3rd Annual STEM (Science, Technology, Engineering and Mathematics) Career Day at Brock Bridge Elementary School in Laurel, MD. Presentations on light and color were made to three classes of third-grade students. These students completed several hands-on, multiwavelength activities, including explorations with filters.

STEM Night at Mountain Christian School

STScI education staff participated as speakers during the Mountain Christian School STEM Night in Fallston, MD. Students and parents were able to rotate to various stations and participate in activities related to the electromagnetic spectrum. Students explored hands-on activities related to light and color.

YAE Astronomy Clubs

The YAE program is one of the local student initiatives within STScI's Office of Public Outreach. Four YAE astronomy club sessions were held in 2014. Students participated in hands-on, multiwavelength activities under the guidance of STScI scientists, educators, and other content experts. Students completed spectroscopy activities, explored filters, and learned about telescopes and lenses.

YAE Engineering Clubs

STScI's YAE program provides opportunities for its participants to be exposed to activities and experiences that are representative of the work done by individuals in the astronomical and engineering fields. Four engineering club sessions were held in 2014. Club activities consisted of hands-on activities about models that involve students working in small teams. Students completed a "Marshmallow Challenge" and a JWST deployment activity.

Classroom Visits

STScI's Office of Public Outreach works closely with Institute scientists and content experts to provide the latest information about JWST and STEM careers to various audiences. Throughout 2014, STScI-OPO's Outreach Specialist and other Institute staff visited classrooms and provided JWST updates along with STEM career presentations to K-12 students and educators. These talks were provided as part of an ongoing collaboration between STScI's Office of Public Outreach and local area schools.

NIRCam

Hosted an intensive 3-day Train the Trainer workshop for adult Girl Scout leaders that emphasizes broad-based STEM education in the context of astronomy held at the research-grade 1.54-m Kuiper Telescope. The ~15 attendees, from around the US, joined our existing network of 250 GSUSA who will continue to relay the science results and implications of NIRCam and JWST after launch.

NASA's Partnership with the New York Film Academy

Students from the NYFA began work on highly sharable videos of JWST as a part of their class project. NASA provided the students with existing resources and videos to draw from for their projects. Northrop Grumman provided tours to the New York Film Academy students. The students are working on storyboarding and developing scripts for their projects. Here is a link to the NYFA release on their visit to Northrop: bit.ly/1yKtkeY.

7. Presentations

Members of the Science Working group, our engineers and outreach specialists are out giving JWST presentations/talks on a regular basis. The audience size varies from 50 to 500. On numerous occasions at outreach events, someone from the public informs us that they have already heard about JWST because they attended a JWST presentation. Listed below are some, but not all of the talks:

JWST talk at Village Learners Place; Keynote address at Morgan State University STEM fair; Magic in the Mirror presentation at Little Thompson Observatory; "Science with the Hubble Space Telescope IV: Looking to the Future" in Rome; Lehigh University; Aspen Science Festival in Aspen, Colorado; Aerospace Careers; Google+ Hangout with teachers of Stewart Middle Magnet School (Tampa, FL); Presentations at Morgan State Univ; East Los Angeles College; World Space Week at Air and Space Museum; NYU and USF; Engineering Club for Youth for Astronomy and Engineering Program

8. Products

Most of our existing items can be found at <http://www.jwst.nasa.gov/public.html>

9. In-Reach

Staffed a JWST Booth at the Goddard Science Jamboree.

Several JWST articles have appeared in the Goddard newsletter, Goddard View,

Published an article on the JWST mission "NASA's James Webb Space Telescope Hitting Major Milestones" for the Code 400 newsletter The Critical Path.

National Geographic's cover photographer Jim Richardson gave a talk on science and imagery to the entire center called Seeing Science: Visualizing technical stories for National Geographic.

Dr. Neil deGrasse Tyson visited with Goddard's Space Flight Center Director Chris Scolese and the James Webb Space Telescope team at Goddard. Tyson spoke to the team and toured our testing facilities and received a JWST presentation.

<http://www.nasa.gov/content/goddard/dr-neil-degrasse-tyson-visits-nasa-goddard/#.VJSCAJAOKA>

10. Plans for next year include:

Participation at South by Southwest.

Participation in World Science Festival

Complete work on Phase II of the JWST Exhibit at the Goddard Visitor Center

Continue plans for a JWST exhibit with the Smithsonian Institute Travelling Exhibits (SITES) program

Include JWST in all events and activities planned for promoting the 25th anniversary of Hubble Space Telescope.

Continue to capture the progress in news releases, videos, photos and spread the word about JWST to the widest audience possible

Responses by Ms. Cristina Chaplain

**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE**

“Searching for Life in the Universe: An Update on the Progress of the James Webb Space Telescope”

Questions for the record, Ms. Cristina Chaplain, Director, Acquisition and Sourcing Management, GAO

Questions submitted by Rep. Steven Palazzo, Chairman

1) How has NASA responded to the recommendations GAO made in its last three annual reports on JWST?

a. If there are recommendations that were not acted on, was NASA’s explanation for not doing so satisfactory?

In our three annual reports on JWST, we have made 10 total recommendations to NASA on JWST. NASA has concurred with 6 and partially concurred with 4. To date, NASA has implemented 1 of the 10 recommendations.

NASA’s response regarding not implementing recommendations is mixed, and not satisfactory in some cases. Of the 9 recommendations not yet implemented, 2 are from our December 2014 report, which NASA has taken action on but we have yet to assess. The 7 remaining recommendations from our two previous reviews of JWST that have not been implemented are listed in the table below.

Recommendation	Status
<i>James Webb Space Telescope: Project Meeting Commitments but Current Technical, Cost, and Schedule Challenges Could Affect Continued Progress; GAO-14-72</i>	
<p>1. In order to ensure that the JWST project has sufficient available funding to complete its mission and meet its October 2018 launch date and reduce project risk, the NASA Administrator should ensure the JWST project has adequate cost reserves to meet the development needs in each fiscal year, particularly in fiscal year 2014, and report to Congress on steps it is taking to do so.</p>	<p>NASA informed us that with respect to fiscal year 2015, the funding level requested by NASA is consistent with the 2011 replan, and NASA will closely manage fiscal year 2015 unallocated future expenses. These actions are consistent with the normal budgeting process for NASA and do not indicate NASA has taken any additional steps to provide the project with adequate cost reserves for fiscal year 2015. Additionally, the project is reporting on its unallocated future expenditures status to Congress on a quarterly basis.</p> <p>The project is facing a similar challenge with low levels of unallocated future expenditures in fiscal year 2015 that need to be addressed.</p>

2. In order to help ensure that the JWST program and project management has reliable and accurate information that can convey and forecast the impact of potential issues and manage the impacts of changes to the integrated master schedule, the NASA Administrator should	NASA concurred with this recommendation and has performed schedule risk analyses on two of the three schedules we examined – the Optical Telescope Element and the Integrated Science Instrument Module. We communicated to NASA that there was no need to conduct an assessment on the cryocooler component unless a schedule
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<p>perform a schedule risk analysis on OTE, ISIM, and cryocooler schedules, as well as any other subschedules for which a schedule risk analysis was not performed. In accordance with schedule best practices, the JWST project should ensure that the risk analyses are performed on reliable schedules.</p>	<p>risk analysis was to be performed on an updated, reliable schedule. We are currently assessing these schedule risk analyses to determine if they were conducted following best practices.</p>
<p><i>James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration; GAO-13-4</i></p>	
<p>1. To ensure that the JWST life-cycle cost estimate conforms to best practices, and to provide high-fidelity cost information for monitoring project progress, the NASA Administrator should direct JWST officials to improve cost estimate documentation and continually update it to reflect earned value management actual costs and record any reasons for variances.</p>	<p>The agency has taken steps toward implementation of this recommendation by performing analysis of earned value management data for most contracted and internally performed work, but not all. The JWST project has begun collecting earned value management data for the cryocooler development effort, a component that is experiencing technical issues, and is conducting internal analysis of this data. The agency has plans to develop an analysis tool for work being performed by a non-profit organization in development of the JWST ground systems. However, we have received no indication from project officials that they will use this information to update the cost estimate.</p>
<p>2. To ensure that the JWST life-cycle cost estimate conforms to best practices, and to provide high-fidelity cost information for monitoring project progress, the NASA Administrator should direct JWST officials to conduct a sensitivity analysis on the number of staff working on the program to determine how staff variations affect the cost estimate.¹</p>	<p>The agency partially concurred with this recommendation, citing it met the intent, but the agency has not implemented this recommendation. For example, NASA stated that it took a number of steps to determine how staffing variations affect its cost estimate and to ensure the project has sufficient cost reserves to address changes in workforce requirements. The analysis performed, however, was a part of the cost/schedule risk assessment that was based on information at too high a level of detail to sufficiently account for risk. In addition, the JWST project has used a significant portion of its cost reserves to address technical issues, leaving very little available to address changes in workforce</p>

¹ A sensitivity analysis identifies key elements that drive cost and permits analysis of different outcomes and is often used to develop cost ranges and risk reserves.

	requirements.
<p>3. To ensure that the JWST life-cycle cost estimate conforms to best practices, and to provide high-fidelity cost information for monitoring project progress, the NASA Administrator should direct JWST officials to perform an updated integrated cost/schedule risk analysis, or joint cost and schedule confidence level analysis, using a schedule that meets best practices and includes enough detail so that risks can be appropriately mapped to activities and costs; historical, analogous data should be used to support the risk analysis. (Note: This recommendation refers to the need for a new Joint Cost and Schedule Confidence Level (JCL) assessment. The JCL is more comprehensive than the cost risk analysis that NASA conducted in that it also includes an assessment of schedule risk.)</p>	<p>The agency concurred with this recommendation, but has not implemented it. NASA stated that it performs monthly integrated programmatic and cost/schedule risk analysis. For example, the project identifies risks, assesses encumbrances to its cost reserves, tracks actual costs against planned costs, and performs earned value management and schedule analyses. However, the project does not pull this information together in an integrated assessment to gain a picture of overall progress, which would be in line with cost and schedule risk analysis best practices. In addition, the JWST Program Manager stated that the agency only requires that a JCL be performed at project confirmation and when a project is rebaselined.</p>
<p>4. To ensure that technical risks and challenges are being effectively managed and that sufficient oversight is in place and can be sustained, the NASA Administrator should direct JWST officials to schedule the management review and approval to proceed to integration and test (key decision point D or KDP-D) prior to the start of observatory integration and test effort.</p>	<p>In commenting on this recommendation, the agency partially concurred but has not taken actions to implement this recommendation. The agency cites that the Standing Review Board's outbrief of the results of the System Integration Review to the NASA Associate Administrator prior to the start of observatory integration and test meets the intent of this recommendation. The Standing Review Board's outbrief to the NASA Associate Administrator is a courtesy and no action is required at that time. NASA policy, however, clearly states that the key decision point should be held prior to the beginning of integration and test activities. The JWST project has this management review and approval approximately 2 months after the start of observatory integration and test.</p>
<p>5. To ensure that technical risks and challenges are being effectively managed and that sufficient oversight is in place and can be sustained, the NASA Administrator should direct JWST officials to devise an effective, long-term plan for project office</p>	<p>The agency concurred with this recommendation, but has not implemented it. The JWST project manager stated that the project received its expected travel budget for fiscal years 2013 and 2014, as well as a commitment from NASA to continue funding the project in full since it is one of</p>

oversight of its contractors that takes into consideration the anticipated travel budget reductions.	the agency's priority missions. The agency does not expect to have travel budgets affect its oversight capability for the duration of the development effort through launch in 2018.
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2) Has GAO been denied access to personnel or data in the past when trying to conduct a cost-risk analysis?

a. What is the limitation on GAO's authority or access for this particular work product?

GAO's authority generally provides GAO access to records of contractors or their subcontractors that pertain to transactions involving the contracts or subcontracts and to interview their employees about these transactions, but does not provide GAO with specific authority to determine who can be excluded from a meeting.

b. What needs to be done to ensure GAO can get this information in the future?

To get the information necessary to conduct a cost risk analysis while following best practices, GAO would need to be granted authority to specify who can and cannot be in a room for meetings. However, this is the first instance conducting this type of work where we have had a contractor who refused to limit their management presence as requested. In the past, GAO has been able to meet individually with employees from other organizations—government and contractor—and has not had this problem. GAO will continue to monitor the situation to determine if additional resistance from organizations to conducting these types of interviews develops.

c. Do you believe the actions recently taken by NASA address your concerns with the cost-risk analysis? Do they also address your concerns with updating the Joint Confidence Level?

After we were unable to conduct our own independent cost risk analysis, NASA decided to conduct its own cost risk analysis of the contractor's remaining work. NASA has completed the analysis and provided the results to us. We have not completed our assessment of NASA's cost risk analysis. As part of our current review in 2015, we will be requesting additional detailed documentation of the methodology, assumptions, and underlying data.

d. NASA cited concerns with an outside organization conducting the cost-risk analysis given the complexity and uniqueness of JWST. What is your response to those concerns?

As we note in GAO's *Cost Estimating and Assessment Guide* (GAO-09-3SP), case studies have shown a clear pattern of higher cost estimates from independent sources than from program offices. An independent team is more objective and less prone to accept optimistic assumptions. We believe our risk analysis methodology can be applied to projects regardless of size, complexity,

or uniqueness. Our plan for the JWST risk analysis was to collapse detailed program risk data into high level categories, and then map interviewee responses to these categories. In the interest of complete transparency, we met with Northrop Grumman officials several times to explain our approach and mathematical methodologies, and promised thorough documentation of all assumptions, calculations, and results. In addition, we collaborated with them on how to summarize their detailed risk data. At no time did any Northrop Grumman official object to our approach, our summarization and application of risk data, or our interview questions. Northrop Grumman voiced their concerns about our methodology only after GAO objected to Northrop Grumman's need to have a manager present during the interviews.

3) Has NASA sustained the reforms it implemented in response to the independent review conducted in 2010?

a. What more can be done?

NASA has sustained some of the reforms it implemented in response to the Independent Comprehensive Review Panel (ICRP) from 2010. However, we do not track them specifically. We know some of the recommendations have been implemented and sustained based on the information we receive monthly from the project. Specific examples include moving management and accountability from the Astrophysics Division to a new organizational entity at NASA headquarters, and incorporating the project scientist's independent views in every monthly status report.

For more information on how NASA has sustained its reforms based on ICRP recommendations, we recommend this question be directed to NASA.

4) From your perspective, which is the most difficult period ahead where schedule reserve is most likely to be at risk?

Currently, the schedule risk lies in the coming integration and testing periods, especially the last 3 (integration of the Optical Telescope Element (OTE) and instrument suite known as the Integrated Science Instrument Module (ISIM), spacecraft integration with the sunshield, and observatory integration and testing where the entire telescope will finally be put together). During this phase, there will be less time to address unknown technical challenges as work becomes more serial in nature.

One specific concern we raised in our 2012 report was the final event in the combination of the OTE and ISIM, known as OTIS. The testing effort, slated to begin in 2016, is a lengthy cryo-vacuum test—the first time that the optics integrated with the instruments will be tested at operational temperatures near absolute zero (less than -400 degrees Fahrenheit)—that takes approximately 3 months, due to the requirements of the test. If an issue were to arise during this test that requires shutting the test down and working on the hardware, the chamber would have to be slowly warmed to a temperature safe for removal of the hardware from the chamber, the necessary work performed, and the 3-month test process would need to begin again. This could easily exhaust the available

schedule reserve, which is currently 3 months that is held at the back of the schedule before OTIS needs to be integrated with the spacecraft and sunshield. Prior GAO work shows that it is during integration and test when problems are commonly found, and schedules tend to slip.

Finally, the deeper the JWST project is into integration and testing, the more likely a delay may use schedule reserve. For example, if one activity is delayed, it can delay every subsequent activity until a problem is addressed since work is so serial in nature. Additionally, the workaround opportunities will be fewer and there will simply be less time to address issues.

5) Given the testimony of the other witnesses, do you believe the cryocooler issues are behind NASA now?

We do not believe the cryocooler manufacturing issues are behind NASA and its contractor and subcontractor. At the time of the testimony, the expected delivery was June 16, 2015; however, additional problems have occurred that have delayed its delivery and reduced the project's schedule reserve from 10 to 9.75 months. The cause of this slip stemmed from the need to perform a 'bakeout' of the compressor assembly to remove moisture, which took longer than expected. As a result, the cryocooler is again the critical path and is now scheduled to be delivered on July 28, 2015—6 weeks later. Currently, there are other known issues that may use additional schedule reserve including incorrect alignment of plumbing lines that connect the different parts of the cryocooler.

While the delivery of the compressor assembly appears to be months away, the potential for significant challenges will remain once it is delivered. Currently, there are over 9 months of acceptance and end-to-end testing that need to be completed before the Jet Propulsion Laboratory (JPL) has proven that the cryocooler is ready for integration into the JWST during spacecraft integration and testing. At any point in this test flow, challenges may arise that could delay the cryocooler further if problems are found.

6) In GAO's December 2014 report, it's mentioned that "manufacturing error and manufacturing process oversight" are two causes for the 2014 cryocooler replan failure.

a. Would you please describe what specific manufacturing errors occurred?

An example of a specific error that occurred relates to manufacturing the flight compressor assembly for the cryocooler. According to JPL officials, the contractor deviated from the accepted packing procedure used with the verification model. An X-ray inspection showed that the deviation resulted in insufficiencies, or "voids," in the packing of the erbium nickel canister in the pulse tube subassembly, which would have had unacceptable negative impacts on flight performance. According to JPL officials, the voids occurred because not enough packing material was inserted. To correct this, the flight compressor was switched with the spare, which had not yet been packed. JPL officials said the

correct procedures used for the verification model would be followed on the new flight spare and corrections would be made to the incorrectly packed unit. However, this issue resulted in a three week impact to the schedule. Additionally, NASA put one additional NASA employee in place at Northrop Grumman to focus on processes and control issues to identify and prevent issues like this from recurring.

b. Please give an example of what types of challenges occurred in manufacturing process oversight.

A subcontractor employee conducted unauthorized work on a subassembly for the cryocooler compressor component, which resulted in exposure to possible contamination. According to JPL officials, the work began when the employee was alone and working near the flight compressor assembly. This work was halted by a quality assurance employee who discovered the work was under way. According to JPL officials, the employee mistakenly proceeded with the work though the formal approval for the execution of the work had not been given. After a three week investigation, it was determined that no contamination occurred, and it was acceptable to use the subassembly. The project was able to recover most of the time lost by adjusting the hardware flow and adding holiday work.

c. How can this be prevented or mitigated going forward?

JPL and Northrop Grumman have taken steps since the events that led to delays on the cryocooler compressor assembly noted above to this question to improve oversight and processes. For instance, Northrop Grumman has replaced its program manager and added a new manufacturing lead to the cryocooler team to bring more experience to the work. JPL has also placed an experienced project manager as an on-site representative at the contractor facility to supplement other personnel who were at the facility. Additionally, NASA's on-site representative continues to identify process and control issues to improve how Northrop Grumman conducts its business. Despite these actions, the cryocooler has continued to lose schedule and is again the critical path of the project. Going forward, frequent and quality communication among the cryocooler team as well as adherence to standards and instruction is necessary to prevent and mitigate further delays.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

“Searching for Life in the Universe: An Update on the Progress of the James Webb Space Telescope”

Questions for the record, Ms. Cristina Chaplain, Director, Acquisition and Sourcing Management, GAO

Questions submitted by Rep. Donna Edwards, Ranking Member

- 1) **You reported last December that GAO initially planned to conduct an updated cost risk analysis on the Northrop Grumman prime contract that would have provided an updated level of confidence associated with the project meeting its cost estimate. You also reported that GAO was unable to execute its methodology because Northrop Grumman declined to allow GAO to conduct an independent, unbiased analysis that included anonymous interviews with contractor technical experts on the project to discuss the project's risks.**

- a. **Do you believe Northrop Grumman's refusal to allow GAO to conduct anonymous interviews with company technical experts reduces confidence in the project's cost risk posture?**

As mentioned in my testimony, we are concerned anytime GAO is denied access to people or documents. During risk interviews, GAO guarantees interviewees anonymity and non-attribution. Interviewees must be assured that their opinions on project risks remain anonymous in order to collect unbiased data. If an interviewee is accompanied by someone in a position of authority, GAO cannot guarantee the interviewee's responses are unbiased.

Finally, I would note that we made no assumptions prior to our analysis of whether our results would disagree with or validate Northrop Grumman's own contingency calculations. While an independent cost risk analysis may have contradicted Northrop Grumman's stated risk position, it may very well have validated it. Had we conducted the analysis and gotten similar results, we would have more confidence in Northrop Grumman's purported risk position and, thus, the project's risk position since the majority of cost remaining is on the Northrop Grumman prime contract.

- b. **Does GAO commonly conduct anonymous interviews as part of its oversight of NASA and Department of Defense projects? If so, can you provide some examples of when it has been done?**

We have not yet conducted independent cost or schedule risk analyses of NASA or DoD projects. However, DOD programs do update cost estimates, so there is less need for this type of analysis from GAO. We have previously conducted anonymous risk interviews for our schedule risk analyses in *Air Traffic Control Modernization: Management Challenges Associated with Program Costs and Schedules Could Hinder NextGen Implementation* (GAO-12-223) and *VA Construction: VA Is Working to Improve Initial Project Cost Estimates, but Should Analyze Cost and Schedule Risks* (GAO-10-189). In the case of FAA, we interviewed 16 people about project risks anonymously, including FAA officials and contractor personnel from Raytheon. In the case of VA, we interviewed 14 people about project risks anonymously, including VA resident engineers and contractor personnel from Clark-Hunt Construction and Parsons Corporation.

- c. Is NASA's recently completed cost risk analysis an adequate substitute for what GAO was planning to do?**

We have not completed our assessment of NASA's completed cost risk analysis. We will be requesting additional detailed documentation of their methodology, assumptions, and underlying data as part of our annual review of JWST in 2015.

- 2) The Independent Comprehensive Review Panel (ICRP) found in 2010 some root-cause problems impacting JWST's development and made recommendations and additional considerations in its report.**

- a. Are any of the concerns they identified (in areas such as deferred spacecraft work, communications issues among NASA, contractors and scientists, and producing an independent cost estimate) still manifesting themselves or has NASA taken sufficient actions to fully address the Panel's recommendations?**

NASA has addressed some of the panel's recommendations and has sustained them over time since the replan. Please see the detailed response to question 3 of Chairman Palazzo's concerns on this same issue.

- b. Is NASA formally tracking the concerns raised by the ICRP to preclude them from creeping up on the JWST project and thus negatively impacting the agency's ability to execute the current plan and enable a 2018 launch date? If not, should it?**

We are not aware of NASA tracking the ICRP recommendations in any systematic way. However, this question is better directed to NASA for a complete answer.

Responses by Mr. Jeffrey Grant

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

“Searching for Life in the Universe: An Update on the Progress of the James Webb Space Telescope”

Questions for the record, Mr. Jeffrey Grant, Sector Vice President and General Manager, Space Systems Division, Northrop Grumman Aerospace Systems

Questions submitted by Rep. Steven Palazzo, Chairman

1.

Contractor workmanship issues and overly optimistic assumptions led to problems with the development of both the sunshield and the cryocooler. In some cases this has impacted the project’s cost and schedule reserves.

a. What is Northrop Grumman doing to address these issues going forward?

Programs of this magnitude and complexity are understood to have challenges in their development cycle due to the first of a kind nature of their technology. Northrop Grumman expected, and has experienced, challenges during the design and build of JWST and these challenges were accounted for in the cost and schedule reserves allocated in the 2011 replan.

We continue to aggressively and proactively invest in risk reduction activities that increase our confidence in executing the flight schedule. Our risk reduction activities tackle head on the more complicated processes in advance of flight production thereby increasing our confidence in a successful program execution. This is specifically the case for the sunshield and the cryocooler which are our immediate focus, together with the integration of the optics onto the assembled backplane.

For each of these critical subsystems we developed pathfinder hardware that has undergone rigorous testing in flight conditions and has returned essential information in preparation for the actual tests to be conducted over the next few months and years.

This approach has allowed us to maintain above-plan schedule margins on all major subsystems within the standard established by NASA for this program. If and when further challenges appear, we will resolve them with the same determination and commitment that has brought us this far. Northrop Grumman is dedicated to overcoming these hurdles within cost and schedule reserves.

2.

Why did Northrop Grumman prevent GAO from accessing its employees for the purpose of conducting a cost-risk analysis?

- a. If this information is something Congress asked GAO to pursue again, on this program or another in the future, would Northrop Grumman provide the necessary access? Why or why not?

Northrop Grumman did not prevent the GAO accessing our employees as they were conducting their cost-risk analysis. They have had routine access to many NG employees and we were prepared to offer access to these employees but not under the terms the GAO demanded.

We were fully prepared to have the GAO team (about 6 people at Space Park plus others via phone) interview over thirty of our technical specialists. What we were not prepared to do, however, was for these individuals to be interviewed in isolation. We were sensitive to the GAO's request to interview these junior employees without representatives from the JWST program management present, so we offered to have the employees interviewed with their functional management present. This offer was rejected. We have been and will remain supportive of the GAO in their review of the program but not under the extremely unusual conditions requested.

Over the past few years we have worked well with the GAO in support of their oversight function in providing them all of the requested data products, access to the program management team, tours of the facilities that are producing JWST, and periodic tag ups throughout their review process. We will continue to work with them to ensure they have access to all data for any of their future requests. We acknowledge the importance of the GAO on programs like JWST and we will continue our transparent approach to delivering the required documentation in reply to future GAO requests.

We will continue our collaborative and mutually beneficial relationship and reengage with the GAO in May of this year at our facility. As they lay out their agenda for this year's review we will work closely with them ensuring their ability to assess program risks remains intact.

3.

What is Northrop Grumman doing to control costs and stem delays in regards to JWST?

- a. What is the likelihood Northrop Grumman is going to overrun its contract?
- b. What are the potential ranges of an overrun or delay?

The JWST program is managing schedule, cost, and risk extremely well. We have executed the program within the reserves established in the 2011 replan. Since then, the JWST program remains on track to an October 2018 launch readiness date while addressing new challenges and reducing future risk.

As stated in the response to question number one, the reserves on the program have been sufficient to resolve technical issues as they arise and to enable investment in risk reduction activities, further increasing the confidence in the to go work.

- a. According to our latest Estimate at Complete our Variance at Complete is significantly lower than the funding reserves available. We have strong confidence we will complete the program within the available funds and time allotted in the contract.
- b. Our current Estimate at Complete (EAC) reflects our latest estimations on the contract execution requirements. Based on this EAC, we believe we will execute the contract in time for a 2018 launch within the available funding.

4.

In their December 2014 report, GAO indicated that 67 percent of risks Northrop Grumman tracked in April 2014 were not present in September 2011, when the replan was announced. What is the status of those risks now?

- a. How confident are you that the cryocooler can be delivered by June 2015 as currently expected?
- b. Will the steps you are taking to accelerate delivery of the cryocooler introduce risk to the program?
- c. If there is less testing, does that reduce confidence in the cryocooler's ability to work properly?

A one of a kind undertaking like JWST requires a living and robust risk mitigation process. As a result of this process, risk is collectively identified and managed to ensure the program stays on track.

As we progress in the different phases in the program, new risks will be identified and retired in each of these phases. Therefore, it is to be expected that many of the new risks in 2014 were not present in 2011 since they represent unique risks to particular phases of the program. Many of these risks have been managed and retired since.

- a. Based on the latest development (a bakeout taking an additional 40 days), the cryocooler is scheduled to deliver in August 2015.
- b. We are not introducing new risk to the program. What we are currently doing is implementing options such as 2nd and 3rd shifts or weekend work to minimize any schedule impact.
- c. We have not reduced the level of testing in the cryocooler; therefore, we have confidence the cryocooler will work as intended.

5.

In your testimony you mentioned that Northrop Grumman expects to deliver the last component of the cryocooler assembly in the next few months. Why are you confident that the most recent cryocooler replan and delivery date will solve the cryocooler problem?

a. What is this confidence based on?

Our team continues to make significant progress with integration of the 1st flight cryocooler assembly and commenced integration of all subsystem components. This has allowed numerous less-impactful (non-technological) issues to be flushed out and resolved without impact to the final delivery. The last critical part of the cryocooler is scheduled to be delivered in August 2015.

a. Our confidence is based on the fact that what drives the delays is the process itself (bakeout time required is longer than originally anticipated), which is a time issue and not a technical issue. In addition, the flight spare is immediately behind the first flight article delivery.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

“Searching for Life in the Universe: An Update on the Progress of the James Webb Space Telescope”

Questions for the record, Mr. Jeffrey Grant, Sector Vice President and General Manager, Space Systems
Division, Northrop Grumman Aerospace Systems

Questions submitted by Rep. Donna Edwards, Ranking Member

1.

The 2010 Independent Comprehensive Review Panel (ICRP) report on JWST discussed that the JWST science team *“is in a good position to provide inputs to difficult trades involving Observatory performance”*.

- What is the extent of direct communication between Northrop Grumman and the JWST Science Working Group?
- How often does Northrop Grumman provide in-depth briefings to the JWST Science Working Group?
- Does Northrop Grumman work directly with the JWST Science Working Group to get their input on trade-offs and potential solutions to technical issues? If not, does NASA provide you with inputs from the Science Working Group?

The interface to the Science Working Group (SWG) is primarily handled by NASA Goddard Space Flight Center. Northrop Grumman supports NASA as required in the communications with the SWG. In addition, key members from the SWG (Dr. John Mather, Dr. Mark Clampin, and Dr. Matt Greenhouse) attend Northrop Grumman program status meetings on a regular basis. Furthermore, program status is communicated to members of the SWG on a monthly telecom.

As technical issues arise concerning Observatory performance, the members of the SWG are engaged.

2.

In your prepared statement, you acknowledge that “manufacturing certain components to operate at such extreme temperatures has proven to be a challenge”. You further state that “Northrop Grumman reorganized the MIRI cryocooler program in early December 2014 to increase focus on systematic execution and schedule forecast accuracy, and also brought additional senior technical and management resources in engineering, manufacturing, mission assurance, and leadership”. You also indicate that you recently discovered workmanship issues with the cryogenic harnesses and “Due to escapes in the manufacturing and inspection processes, we will need to replace or repair nearly three dozen of these harnesses on the backplane”. What is Northrop Grumman doing to improve workmanship issues on JWST?

The JWST program requires a one of a kind manufacturing process throughout its development. As a result programs of this magnitude and complexity are rarely met without challenges. We continue to aggressively and proactively invest in risk reduction activities that increase our confidence in executing the flight schedule. Our risk reduction activities tackle head on the more complicated processes in advance of flight production thereby increasing our confidence in a successful program execution. This is specifically the case for the sunshield and the cryocooler which are our immediate focus, together with the integration of the optics onto the assembled backplane.

For each of these critical subsystems we developed pathfinder hardware that has undergone rigorous testing in flight conditions and has returned essential information in preparation for the actual tests to be conducted over the next few months and years.

This approach has allowed us to maintain above-plan schedule margins on all major subsystems well within the golden standard for cost and margin required by NASA. If and when further challenges appear, we will attack them with the same determination and commitment that has brought us this far. Northrop Grumman is dedicated to overcoming these hurdles within cost and schedule reserves.

The cryogenic harnesses are procured items built by a supplier. Upon recognition of the issue we have assigned resources at the supplier’s facility to oversee the production and to more rigorously inspect product quality before it leaves the supplier’s facility.

3.

In response to Representative Beyer's question on "what was Northrop Grumman's problem with allowing anonymous interviews or the interviews without managers present", you indicated concern that interviews would be with junior employees "who are not prepared to come testify before Congress". You said you offered GAO the alternative of having somebody from the functional organization be with the interviewee. What are some examples of the greater knowledge and perspectives these functional managers would have provided to GAO?

Over the past few years we have worked well with the GAO and we will continue to work with them to ensure they have access to all data for any of their future requests. We acknowledge the importance of GAO on programs like JWST and we will continue our transparent approach to delivering the required documentation in reply to future GAO requests.

We will continue our collaborative and mutually beneficial relationship and reengage with the GAO in May of this year, ensuring their ability to assess program risks remains intact.

At Northrop Grumman, our functional managers are the owners of the processes executed on programs and maintain the in-depth knowledge of these processes. As a centralized organization, they have perspective over a large set of programs executing these processes through all phases of execution. If the GAO had allowed these individuals to be present during the interviews with our employees, a more accurate assessment of the overall "risk" to the JWST program would have been highly likely.

Responses by Dr. John Mather

**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE**

*"Searching for Life in the Universe: An Update on the Progress of the
James Webb Space Telescope"*

Questions for the record, Dr. John Mather, Senior Project Scientist, James Webb Space
Telescope, NASA

Questions submitted by Rep. Donna Edwards, Ranking Member

QUESTION 1:

As is the case with Hubble, a pool of JWST General Observers will be selected yearly. Current science policy states that General Observers on JWST will have a 12-month exclusive right to their data, although the Director of the Space Telescope Science Institute, the entity in charge of selecting research proposals, can recommend different lengths for this period. The Director recently recommended reducing the period to 6 months.

What is the status of NASA's decision on whether to reduce General Observers' exclusive data use period from 12 to 6 months?

ANSWER 1:

The JWST Program Director consulted the JWST Science Working Group for their assessment of pros and cons for the recommended change; they endorsed the change. We similarly consulted with the NASA Advisory Council's Astrophysics Subcommittee; they also endorsed the recommended change. Finally, the Astrophysics Division Director and SMD Associate Administrator also approved the proposed change. NASA will forward all this information to our international counterparts for their use.

QUESTION 2:

How would the reduced time period affect the amount of data publicly available to support subsequent proposal cycles?

ANSWER 2:

By shortening the exclusive use period, particularly in the first cycle, there will be more data for proposers to access when they write their cycle 2 and cycle 3 observing proposals. This change will mean that a minimum of 80% of cycle 1 data will be public for use in cycle 3 proposals.

QUESTION 3:

Is the user community, including our international partners, supportive of a reduced exclusive use period?

ANSWER 3:

See the answer above for the US community position. Currently, the Canadian Space Agency (CSA) and the European Space Agency (ESA) are working with their communities and advisory bodies to arrive at a position. NASA anticipates that both agencies will be able to report back by the end of 2015 on their results.

QUESTION 4:

There is a process used for Hubble observations that allows for more than one instrument to be operated at a time. These parallel observations increase Hubble's scientific productivity by enabling two instruments to collect data on interesting objects or regions of the sky.

Will similar parallel observing be possible on JWST?

ANSWER 4:

The ability to implement parallel science observations is supported by the observatory hardware. At present, the observatory software system is capable of obtaining science and calibration observations at the same time (i.e., in parallel), but not capable of simultaneously conducting science observations with multiple instruments.

QUESTION 5:

What benefits would it have for JWST's science productivity?

ANSWER 5:

Observing more than one science field at a time will increase the amount of data in the science archive available for interested scientists. Experience with Hubble and other Great Observatory archives has shown how this increased data availability increases science productivity for the mission (as measured by number of publications).

QUESTION 6:

What is the relative priority being given to enabling parallel observing on JWST?

ANSWER 6:

Parallel science observing is a lower priority than existing mission requirements. Parallel science observing on James Webb would represent a new capability (scope growth) and would be a lien

on existing mission reserves. The costs to implement the required changes are strictly in software, primarily at the STScI. The project is evaluating this potential capability along with other higher priority items that would require reserve funding (in order to meet the existing mission requirements).

**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE**

*"Searching for Life in the Universe: An Update on the Progress of the
James Webb Space Telescope"*

Questions for the record, Dr. John Mather, Senior Project Scientist, James Webb Space
Telescope, NASA

Questions submitted by Rep. Steven Palazzo, Chairman

QUESTION 1:

In your testimony, you described JWST's ability to potentially see some of the first stars in the universe. Please explain how JWST will do this, and how this could impact the fields of astronomy and astrophysics.

ANSWER 1:

The emergence of the first stars probably came when the Universe was a few hundred million years old. Understanding these first sources is critical, since they greatly influenced the formation of later objects such as galaxies.

Imagine light leaving the first stars nearly 13.4 billion years ago and traveling through space and time to reach our telescopes. Because the universe is expanding, the farther back we look, the faster these objects (like the first stars and galaxies) are moving further away from us, which means that their light is being shifted towards the red. Their light is what we call "redshifted."

Redshift means that light that is emitted by these first stars and galaxies as visible or ultraviolet light, actually gets shifted to redder wavelengths by the time we see it here and now. For very high redshifts (i.e., the farthest objects from us), that visible light is generally shifted into the near- and mid-infrared part of the electromagnetic spectrum. For that reason, to see the first stars and galaxies, we need a powerful near- and mid-infrared telescope, which is exactly what JWST is. This will impact the fields of astronomy and astrophysics because currently, the epoch of galaxy formation is completely hidden from our view. It is only at infrared wavelengths that we can see the first stars and galaxies forming after the Big Bang. And it is with infrared light that we can see stars and planetary systems forming inside clouds of dust that are opaque to visible light.

The JWST is the first telescope to have the power to observe these objects. It must be very large, because the objects are far away and faint, and it must cover the right infrared wavelengths, as noted above.

QUESTION 2:

How is the science potential of JWST impacted by schedule slips and cost overruns?

- a. Have there been any occasions where you have felt that the quality of the science has been compromised in order to complete development on schedule and within cost?

ANSWER 2a:

Since JWST's re-baseline in 2011, the program has been on schedule and within cost and as such, there have not been any occasions where the quality of science and/or science objectives have been compromised in order to complete development. In fact, since its confirmation to enter into development in 2009, there have been no occasions where the science capability of the mission has been threatened by a push to maintain cost or schedule.

QUESTION 3:

How far could science potentially advance with the overlap between JWST and the new ground-based observatories you mentioned in your testimony?

ANSWER 3:

JWST is designed to be complementary to existing and future ground-based facilities, making observations that are not possible from the ground. It measures infrared light, which is largely blocked by the Earth's atmosphere, and which is strongly emitted by the Hubble and by warm ground-based telescopes.

But just as the Hubble discoveries were followed up by larger ground-based observatories like the twin Keck telescopes in Hawaii, JWST discoveries will be followed up by the next generation of even larger ground-based telescopes like the Thirty Meter Telescope and the Giant Magellan Telescope, now in planning and initial construction. These huge telescopes offer the capability of very high spectral resolution (number of colors that can be distinguished in the incoming light), better angular resolution using adaptive optics, and greater light gathering power due to their great size, and will provide important follow-up data that will complement the data we get from JWST. But because they are on the ground, their view is still obscured by the atmosphere, and their sensitivity is limited at infrared wavelengths by their own thermal emissions.

To illustrate the potential for complementary science, the Astronomy and Astrophysics Advisory Committee, which evaluates ground- and space-based programs by NASA, NSF, and the Department of Energy, commissioned an extensive report on the complementary natures of JWST and a 30-meter ground-based telescope (available at http://www.nsf.gov/mps/ast/aaac/reports/gsm-t-jwst_synergy_combined.pdf). This report found that "operating together the two telescopes will greatly enhance our ability to answer fundamental questions about origins - the origin of the Universe, of stars and galaxies, of

planetary systems, and of life itself - beyond what either telescope on its own would be capable of doing.”

QUESTION 4:

Is there a plan to overlap JWST with other science missions and observatories in the study of dark matter?

ANSWER 4:

As mentioned in question 3, JWST is designed to be complementary to existing and future ground-based facilities, making observations that are not possible from the ground. However, JWST and other telescopes cannot directly see "dark matter," the unseen matter that makes up a large fraction of the mass of galaxies and clusters of galaxies, but JWST will be able to measure its effects. One of the best ways to measure mass is through the gravitational lens effect. As described by Einstein's General Relativity theory, a light beam passing near a large mass will be slightly deflected, because space-time is disturbed by the presence of mass. By taking pictures of distant galaxies behind nearby galaxies, astronomers can calculate the total amount of mass in the foreground galaxies by measuring the disturbances in the background galaxies. Because astronomers can see how much mass is present in stars in the foreground galaxies they can then calculate how much of the total mass is missing, which is presumed to be in the dark matter. JWST will be particularly well-suited for this type of measurement, because its very sharp images will allow very small disturbances to be measured, and because it can see so deep into space, giving it access to many more background galaxies to measure disturbances caused by this gravitational lensing effect. Also, JWST will observe many facets of galaxy evolution and scientists will be able to compare these observations to theories of the role that dark matter played in that process, leading to greater understanding of the amount and nature of the dark matter in galaxies.

Although this is not widely recognized, the universe would not have galaxies and stars today without dark matter. The dark matter has the gravity that causes the primordial gases to flow together and make galaxies and then stars. So we owe our existence to the dark matter, even though we can barely detect its presence today, and have never found a single particle of it in a laboratory. JWST's ability to study the history of galaxy formation will be a strong test of this idea.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

STATEMENT SUBMITTED BY FULL COMMITTEE RANKING MEMBER
EDDIE BERNICE JOHNSON

Good morning. I want to join Chairman Palazzo and Ranking Member Edwards in welcoming our witnesses. I look forward to hearing from each of you today.

We are here to discuss the James Webb Space Telescope-JWST-which is scheduled to launch in October of 2018. This morning's hearing is not the first this Committee has held on JWST. We held a hearing in December 2011 after the project was replanned following an independent review that found significant cost and schedule growth. Today we will hear how well NASA and its main industry partner, Northrop Grumman, are sticking to that plan. And given the complexity involved in building and testing a telescope of JWST's magnitude, it should come as no surprise that we will also hear of the many challenges that need to be addressed before the project is completed. I hope we can be assured today that NASA and its partners are taking all necessary steps to keep JWST on track.

We need to provide the necessary Congressional funding to ensure this project gets completed on time and on budget, consistent with the National Academies' decadal survey that ranked this telescope as the top priority for space-based astrophysics over a decade ago. I am pleased that Dr. Mather, the 2006 Nobel Laureate in physics, is here today to tell us about the transformational science that JWST will carry out, including making observations that will teach us about how galaxies, stars and planets formed—the very roots of our Universe. I also hope to hear about JWST's capabilities for studying extrasolar planets for clues that could signal the potential for life there. The nation has taken on an impressive challenge in developing, building, and completing JWST, and we need to be good stewards of our taxpayers' investment in this project.

That said, I have no doubt that JWST's discoveries will rewrite the astronomy textbooks, just as the Hubble's science has already done. I can't imagine a better legacy. Because somewhere in a backyard, on a school playground, or in a bedroom with an open window on a dark starry night, there's a child who wonders what the Universe is all about, and JWST's observations will feed that child's imagination and hunger for knowledge. Thank you and I yield back the balance of my time.

