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THE NEXT GREAT OBSERVATORY: ASSESSING THE JAMES WEBB SPACE TELESCOPE

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

TUESDAY, DECEMBER 6, 2011

Serial No. 112–55

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PRINTING OFFICE

72–165PDF WASHINGTON : 2011

For sale by the Superintendent of Documents, U.S. Government Printing Office
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THE NEXT GREAT OBSERVATORY: ASSESSING THE JAMES WEBB SPACE TELESCOPE

TUESDAY, DECEMBER 6, 2011

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, DC.

The Committee met, pursuant to call, at 2:05 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Ralph Hall [Chairman of the Committee] presiding.

RALPH M. HALL, TEXAS
CHAIRMAN

EDDIE BERNICE JOHNSON, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Full Committee Hearing

The Next Great Observatory: Assessing the James Webb Space Telescope

Tuesday, December 6, 2011
2:00 p.m. to 4:00 p.m.
2318 Rayburn House Office Building

Witnesses

Mr. Rick Howard, Program Director, James Webb Space Telescope, National Aeronautics and Space Administration

Dr. Roger Blandford, Professor of Physics, Stanford University and Former Chair, Committee for the Decadal Survey of Astronomy and Astrophysics, National Research Council

Dr. Garth Illingworth, Professor & Astronomer, UCO/Lick Observatory, University of California, Santa Cruz

Mr. Jeffrey D. Grant, Sector Vice President & General Manager, Space Systems Division, Northrop Grumman Aerospace Systems

HEARING CHARTER

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

The Next Great Observatory: Assessing the James Webb Space Telescope

TUESDAY, DECEMBER 6, 2011
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Introduction

In 2001, the James Webb Space Telescope (JWST) 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*. Originally estimated by the decadal committee to cost $1 billion and to be launched in 2007, JWST was dubbed as the next Great Observatory that will be three times more powerful than the Hubble Space Telescope in the infrared and eight times more powerful than the Spitzer Space Telescope.

However, after high-level scrutiny arising from years of program cost and schedule overruns, NASA recently developed a revised plan for JWST that—if fully funded—would enable completion and launch by October 2018. The revised budget life cycle costs now total just over $8.8 billion.

The purpose of the hearing will be to receive testimony from NASA, academic, and industry stakeholders on the progress and remaining challenges associated with completing JWST by the target launch date of October 2018, and at a cost no greater than $8.85 billion.

Witnesses

- **Mr. Rick Howard**, Program Director, James Webb Space Telescope, National Aeronautics and Space Administration
- **Dr. Roger Blandford**, Professor of Physics, Stanford University and Former Chair, Committee for the Decadal Survey of Astronomy and Astrophysics, National Research Council
- **Dr. Garth Illingworth**, Professor & Astronomer, UCO/Lick Observatory, University of California, Santa Cruz
- **Mr. Jeffrey D. Grant**, Sector Vice President & General Manager, Space Systems Division, Northrop Grumman Aerospace Systems

Overarching Questions

- What confidence should Congress have in the new cost and schedule estimates for JWST?
- What are the chief technical and programmatic challenges facing JWST? Does the re-plan address systemic issues with the program and put it on a path for success?
- What attributes of JWST merited its selection as the top-priority large-scale mission in the decadal survey *Astronomy and Astrophysics in the New Millennium* released in 2001? Are those reasons still valid today? Does the fact that JWST has not been completed as envisioned in the previous decade affect the recommendations in the most recent decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics*, released in 2010?

Background

Previously known as the Next Generation Space Telescope (NGST), the James Webb Space Telescope (JWST) was planned as the follow-on space telescope, building on the successes of the Hubble Space Telescope. The main technical features of JWST include a 6.5 meter diameter mirror optimized for observations in the infra-

red 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. These features are expected to produce unparalleled scientific discovery, glimpsing back to the origins of the galaxies, and providing insights into the early formation of stars and planets.

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 NAS as top-priority in Decadal Survey, *Astronomy and Astrophysics in the New Millennium*; estimated cost is $1 billion.
- Summer 2002—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 prime contractor.
- March 2005—NASA identified further cost growth, increasing 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 concern centered on the program's early year funding constraints.
- July 2008—Program confirmation review placed the baseline life-cycle cost at $5 billion with a launch date of June 2014.
- June 2010—Senator Barbara Mikulski (D–MD), Chairwoman of the Senate Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies, requests an independent review of the program; NASA commissioned an Independent Comprehensive Review Panel (ICRP) led by John Casani, Special Assistant to the Director at the Jet Propulsion Laboratory.
- October 2010—ICRP report delivered to NASA and to Congress; NASA notified Congress of increase to cost baseline of over 15 percent and delay to schedule baseline of over six months, triggering a "Breach Report" (more below).
- September 2011—JWST re-plan approved with new baseline of $8.8 billion total life-cycle cost with launch readiness date of October 2018.

Astronomy and Astrophysics Decadal Surveys

The 2001 Decadal Survey, *Astronomy and Astrophysics in the New Millennium*, identified the then-called Next Generation Space Telescope (NGST) as the top-priority for large-scale missions for the decade 2001–2010. Although the Hubble Space Telescope continues to provide excellent science, the NGST would be far more sensitive and be able to see light in the infrared that Hubble could not. Pursuing NGST was the next logical step in advancing scientific discovery and was believed to have sufficient technology readiness to make the telescope affordable. The decadal survey estimated NGST would cost $1 billion and be ready for launch in 2008.

Despite changes to the program in the ensuing decade—including revised cost and schedule baselines, as well as de-scoping the segmented mirrors from an 8 meter to 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* (Astro2010) 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 Survey Telescope (WFIRST). WFIRST would conduct exoplanet and dark energy research. It is now expected that WFIRST cannot begin development until after JWST is launched.

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 minimum cost to launch. NASA subsequently commissioned an Independent Comprehensive Review Panel (ICRP) led by John Casani, Special Assistant to the Director at the Jet Propulsion Laboratory. A copy of the report can be found here: *http://www.nasa.gov/pdf/499224main_JWST_ICRP_Report-FINAL.pdf*.

The ICRP report revealed poor budgeting and program management, not technical performance, as the root cause 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.[1]

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

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

Summary of JWST Breach Report and Re-Plan

Pursuant to Section 103 of the NASA Authorization Act of 2005 (P.L. 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 six 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 estimates the full

[1] JWST-ICRP Final report, October 29, 2011, p. 9.

life-cycle cost of the mission to now be $8.835 billion with a launch date of October 2018.

Table 1:
JWST Life-Cycle Cost
As in Breach Report (October 2011) *

Budget Authority ($millions)	Spent to Date	FY 2010 Actual	FY 2011 Enacted	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	Budget to Complete	LCC Total
Revised Profile	2,552.30	461.4	515.3	527.6	627.6	659.1	646.6	621.6	2,223.60	8,835
PBR** FY12			471	375	375	375	375	375	2,346.00	
Delta to PBR			44.3***	152.6	252.6	284.1	271.6	246.6	1,251.80	

* See Appendix 1 for a complete historical overview of budgeted costs for JWST
**Presidential Budget Request (PBR)
*** Congress approved an updated FY11 operating plan to reprogram the additional $44 million

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

- Represents a high-confidence, realistic schedule with adequate reserves that launches JWST as soon as possible.
- Presents 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% 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.

As evident in Table 1 above, the new baseline will require approximately $1.2 billion in additional funding in FY 12–FY 16 (above the President's FY 12 request). NASA is proposing that funds be redirected from within its budget so that half would come from the Science Mission Directorate (with the exception of Earth Science) and half from the Cross-Agency Support account. NASA and the Administration continue to discuss the budget adjustments with the final determination to be reflected in the budget request for fiscal year 2013. The fiscal year 2012 budget as passed by Congress on November 17, 2011, reflects the additional funds needed for JWST in FY 12 by providing $529.6 million.

Analysis of Alternatives

As part of the required Breach Report, NASA asked the Aerospace Corporation to conduct an analysis of alternatives (AOA) to JWST to ensure that all possible options were given proper consideration. As 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 determined by the National Academies Decadal Survey process. Furthermore, many of the 2011 decadal survey recommendations are predicated on the groundwork that is to be laid by JWST.

Program Design Elements and 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 has to undergo extensive testing. Currently a template membrane has been 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 1/3-size scale model was constructed to test deployment and undergo thermal testing in a cryogenic chamber. Construction on the final sunshield has not yet started.

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. JWST's primary mirror is made up of 18 individual hexagonal segments that fold up inside the rocket; 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 but six have completed testing and are ready for final assembly. The final six will be tested at cryogenic temperatures with final adjustments made by the end of this calendar year.

Scientific Instruments

The Integrated Science Instrument Module (ISIM) contains four science instruments and a guide camera. The ISIM and science instruments are 90% complete and are undergoing integration at the Goddard Spaceflight Center. The NIRSpec instrument was found to have quality issues, which will delay its delivery. However, this delay is captured in the new re-plan and should not affect overall schedule.

- *Mid-Infrared Instrument (MIRI)*—provided by the European Consortium with the European Space Agency (ESA) and by the 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 and faintly visible comets as well as objects in the Kuiper Belt. MIRI's camera will provide wide-field, broadband imaging similar to those the public has come to expect from Hubble. The spectrograph will provide new physical details of the objects it will observe.
- *Near-Infrared Camera (NIRCam)*—provided by the University of Arizona is Webb's primary imager, detecting light from the earlier stars and galaxies. 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.[2]

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. For this reason, design of the bus only recently began final critical design review that is scheduled for late 2014.

Assembly and Testing

A majority of the hardware for JWST has been constructed. However, due to the nature of the telescope's orbit nearly one million miles from Earth and the requirement that it operate in temperatures approaching −400 degrees Fahrenheit, NASA has no "second chance" to make sure JWST performs as planned. 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, and as the complete telescope. In addition, hardware such as platforms and machinery must be specifically made to accommodate construction of the huge telescope.

Goddard Space Flight Center 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 test-

[2] *http://www.jwst.nasa.gov*.

ing ensures that JWST can withstand the stress of launch and the extreme conditions in space.

Johnson Space Center will then test the entire assembly in a large 120-foot-tall vacuum chamber originally used for the Apollo program. The chamber is currently being modified to ensure testing at the proper cryogenic temperatures and should be ready for use by summer 2012. 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.[3]

Recent FY 2012 Appropriation Activity

On July 7, the House Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies reported an FY 2012 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, the Senate Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies reported an FY 2012 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, the House and Senate agreed to final FY 12 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

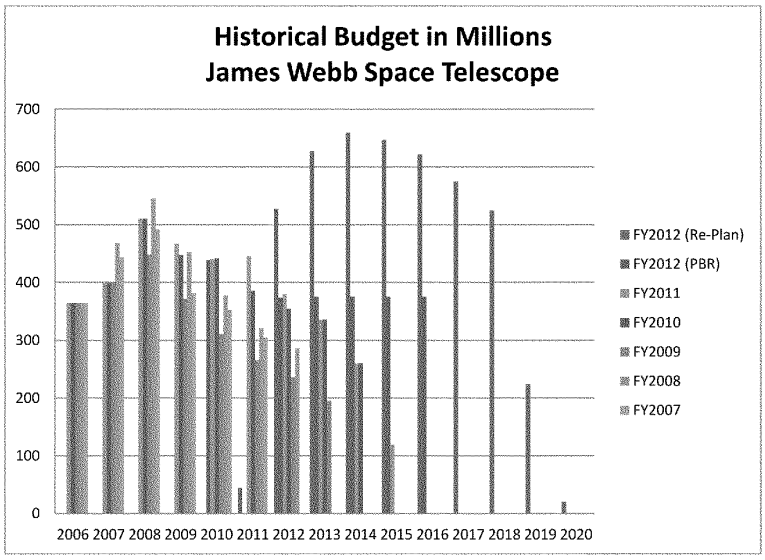
[3] *http://ngst.gsfc.nasa.gov/status.html.*

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.

APPENDIX 1[4]



The chart above depicts total costs to go for each year as outlined in each fiscal year budget request. The chart does not reflect actual expenditures, which through fiscal year 2011 totaled $3.536 million.

[4] Chart derived from data obtained from:
http://www.govbudgets.com/project/Science/James_Webb_Space_Telescope/James_Webb_Space_Telescope/James_Webb_Space_Telescope_(JWST)/

Chairman HALL. Okay. The Committee on Science, Space, and Technology will come to order, and I say good afternoon to everyone. We were scheduled for this morning. My script says—if I stayed with the script, I would be telling you good morning. Being of unsound mind, I don't read the script.

Welcome to today's hearing entitled "The Next Great Observatory: Assessing the James Webb Space Telescope." In front of you are packets containing the written testimony, the biographies, and the truth in testimony disclosures for today's witnesses.

And we will be making opening statements, and I will recognize myself for five minutes for an opening statement.

I would like to thank all the witnesses for taking time from their very busy schedules to appear before our Committee to discuss the James Webb Space Telescope, and I realize considerable effort goes into the drafting and writing of the statements, but they are very helpful to us. They are helpful to these folks that aren't here that have conflicts, and they are at other hearings right now, or they would be here, but they get your copies. They have the copy of what you have submitted to us, and we thank you for that.

I want you to know that your testimony, your wisdom, and your experience is going to be invaluable to us because we have you here because we think you probably know a lot more about what we are doing than we do, and we realize you are giving up valuable time to prepare for this, to travel here, and to grace us with your presence. And your experience will be invaluable to help our committee and our Congress as we deliberate in the months ahead on related issues to NASA and its portfolio of programs.

The James Webb Space Telescope has been identified by the astrophysics community as its top priority program since 2001, and just recently NASA itself named JWST as an agency priority. The telescope would far surpass in science, power, and capability any previous space-based observatory launch by NASA and will enable the new observations into the deepest corners of our universe, and I suspect it will be at least a generation or two before a successor mission is even contemplated.

The potential new knowledge that will be returned is, in my mind, difficult to imagine, while observatories are designed and built to answer one set of questions. The record is replete with discoveries that even the builders of telescopes never contemplated.

But that is not why we are here this morning. Sadly, the James Webb Space Telescope is another case study of NASA's mismanagement of a flagship mission where original costs and schedule estimates are grossly understated, project execution is a litany of missed signals and deferred work, and senior agency oversight is invoked only after the project files breach reports. The resulting disruptions and breakage do tremendous collateral damage to other agency programs and missions as management just struggles to find the resources to return JWST to a sound footing.

Not too many years ago, NASA's stakeholder community would not be overly surprised with cost and schedule slippages. This seems to be an accepted way of life that technically challenging missions were expected to exceed original estimates, but Congress' tolerance for these type of overruns has run out.

I support the James Webb Space Telescope. The science enabled by this mission will be extraordinary, but given Congress and the White House's struggles to bring our federal budget under control, there are members who have a tough time continuing to vote for a program that requires another infusion of over a billion dollars. Some of us argued that we should cut our losses and move on. Others have suggested that we are rewarding bad behavior by continuing to invest in the mission. In my view, NASA's latest re-plan for the James Webb Telescope is the agency's last opportunity to hold this program together.

I am anxious to hear from our witnesses about their assessment of the steps taken by the agency to ensure high confidence in the costs and the schedule estimates going forward and in the project's new management structure. I am also anxious to hear about the biggest challenges still confronting the program.

Mr. Howard, don't take this personally, but I want the record to note that NASA's testimony was provided to our Committee late yesterday afternoon contrary to Committee rules and past practice. By holding back testimony, Members and staff were afforded only a handful of hours to review and analyze Administration statements undermining the ability of the body to engage in a well-informed dialogue with Executive Branch witnesses. The White House's process for vetting testimony of agency witnesses continues to frustrate this Committee and frustrates Congress. This is not the first time testimony has arrived only hours before the scheduled start of a hearing, and I urge the White House to exercise greater diligence, and I doubt seriously if they will listen to me.

My thanks, again, to the witnesses.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF CHAIRMAN RALPH M. HALL

Good afternoon. I'd like to thank our witnesses for taking time from their busy schedules to appear before our Committee to discuss the James Webb Space Telescope. I realize considerable effort goes into the drafting and writing of statements, and I want you to know that your testimony, wisdom, and experience will be of invaluable help to our Committee and Congress as we deliberate in the months ahead on issues related to NASA and its portfolio of programs.

The James Webb Space Telescope (JWST) has been identified by the astrophysics community as its top priority program since 2001, and just recently NASA itself named JWST as an agency priority. The telescope would far surpass in size, power, and capability any previous space-based observatory launched by NASA and will enable new observations into the deepest corners of our universe, and I suspect it will be at least a generation or two before a successor mission is even contemplated. The potential new knowledge that will be returned is, in my mind, difficult to imagine. While observatories are designed and built to answer one set of questions, the record is replete with discoveries that even the builders of telescopes never contemplated.

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My thanks again to our witnesses.

Chairman HALL. And now I am honored to recognize Ms. Johnson for her opening statement.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and I want to say good afternoon to our witnesses, and I join Chairman Hall in welcoming you. I look forward to hearing from each witness today.

As Chairman Hall has stated, we are here to review the status of the James Webb Space Telescope, which has been the subject of much attention over the last year and a half as NASA has wrestled with cost growth and schedule delays on the project. NASA has now developed a plan for getting the project back on track, and Congress has provided the agency with the funding that it has requested for the JWST in fiscal year 2012.

I look forward to hearing about the re-plan from our witnesses as well as about any challenges and risks that still exist.

In that regard, Mr. Chairman, I believe that this Committee is going to need regular updates on this project from NASA so that we can have confidence that its milestones are being met and so that we can have early warning of any problems that may develop. I want to work with you and the agency to ensure that we get those status reports on a regular basis.

It is very important that NASA ensure that this project proceeds without further turmoil. As we will hear today, the telescope's project's cost growth will have a negative impact on all of NASA science activities, not just those in its astrophysics division. In dealing with the cuts that will be required, I think it is important that NASA allocate the cuts to its science programs in a balanced manner that doesn't unduly target any single area such as NASA's planetary science program. I look forward to hearing more about NASA's offset proposal in today's hearing.

In closing, as we take a look at the status of the James Webb Space Telescope and the issues the project needs to address, I hope that we don't lose sight of why the United States is undertaking this complex mission in the first place. The National Academies has rated it as a top priority for the Nation's future astrophysics program, and the scientists here today will be able to tell us about

the path-breaking scientific research it is being designed to carry out.

But there is something at stake beyond the exciting scientific breakthroughs and promises. Mainly, like the Hubble Space Telescope before it, it will have the ability to inspire coming generations to dream and to want to undertake careers in science and technology. It is clear that for many of our young scientists and engineers to be a starry-eyed, starry night, or a picture of the galaxy obtained from a telescope like Hubble and perhaps some day from the JWST is the spark that will start them on their way. In the midst of our scrutiny of the issues surrounding this, I hope that we don't forget that simple truth.

I thank you, again, to our witnesses for agreeing to testify today, and with that, Mr. Chairman, I yield back my time.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF RANKING MEMBER EDDIE BERNICE JOHNSON

Good afternoon. I want to join Chairman Hall in welcoming our witnesses. I look forward to hearing from each of you today.

As Chairman Hall has stated, we are here to review the status of the James Webb Space Telescope, which has been the subject of much attention over the last year and a half, as NASA has wrestled with cost growth and schedule delays on this project.

NASA has now developed a plan for getting the project back on track, and Congress has provided the agency with the funding that it has requested for JWST in fiscal year 2012. I look forward to hearing about the re-plan from our witnesses, as well as about any challenges and risks that still lie ahead.

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But there is something at stake beyond the exciting scientific breakthroughs it promises—namely, like the Hubble space telescope before it, it will have the ability to inspire coming generations to dream and to want to undertake careers in science and technology. It is clear that for many of our young scientists—and engineers-to-be, a starry night or a picture of a galaxy obtained from a telescope like Hubble—and perhaps someday from JWST—is the spark that will start them on their way. In the midst of our scrutiny of the issues surrounding JWST, I hope that we don't forget that simple truth.

Thanks again to our witnesses for agreeing to testify here today, and with that, I yield back the balance of my time.

Chairman HALL. I thank you. The gentlelady yields back. If there are other Members who wish to submit additional opening statements, the statements can be added to the record at this point or whenever you present them.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE AND AERONAUTICS
ACTING RANKING MEMBER JERRY F. COSTELLO

Chairman Hall, thank you for holding today's hearing to receive testimony on the progress and challenges of the James Webb Space Telescope (JWST).

NASA's astronomy and astrophysics program has revolutionized our understanding of the origins and evolution of the universe. The program has made incredible progress, including the scientific breakthroughs of the Hubble Space Telescope and the five Nobel Prizes in Physics awarded to U.S. scientists for discoveries enabled by NASA. JWST holds the promise of building on these successes and maintaining our ingenuity and scientific leadership, in cooperation with international partners.

While JWST holds great promise for the future of astronomy and astrophysics, the project has gone well over budget and is far behind schedule. I am pleased that following stringent review by NASA and third parties, the agency is implementing necessary changes to bring the project back on track. But while NASA and its contractors are moving in the right direction, we must match those technical achievements with real progress on the management and cost control of these challenging projects if we are going to sustain our scientific and technical leadership.

I look forward to hearing from our witnesses on what steps NASA is taking to ensure JWST and its workforce stay on track for a 2018 launch and how Congress and NASA can work together to sustain the astronomy and astrophysics program in the future.

I welcome our witnesses and look forward to their testimony. Thank you, Mr. Chairman.

Chairman HALL. At this time, I would like to introduce our panel of witnesses. Our first witness is Mr. Rick Howard, Program Manager of the James Webb Space Telescope for NASA, a position he has held since early this year. Previously at NASA, Mr. Howard served as Deputy Chief Technologist, Deputy Director of the Astrophysics Division, and has held a number of positions in the Office of Space Sciences. Mr. Howard is a graduate of the University of Wisconsin, received an M.S. in astronomy from Pennsylvania State University, and Mr. Howard, we welcome you, sir, and thank you. And thanks for the previous visit.

Our second witness is Dr. Roger Blandford, the Director of Cavalli Institute for Particular Astrophysics and Cosmology and the Luke Blossom Chair, I will get all that out in a minute, and the School of Humanities and Science at Stanford University. Dr. Blandford also served as Chair of the National Academy of Sciences Decadal Survey of Astronomy and Astrophysics. Dr. Blandford received his B.A., M.A., and Ph.D. degree from Cambridge University. And welcome, Dr. Blandford. We appreciate your presence here today.

Our third witness is Dr. Garth Illingworth, an astronomer at the University of California Observatories and Lick Observatory. He is principal investigator of a major Hubble Space Telescope imaging program and has been involved with major space and ground projects since the 1970s. He served as Chair of the Astronomy and Astrophysics Advisory Committee and has a long record of involvement in science and astronomy policy. In 2010, Dr. Illingworth served as a scientist member of the Independent Comprehensive Review Panel that reviewed the James Webb Space Telescope Program. Dr. Illingworth was awarded an honorary doctor of science degree in 2010 by the University of West Australia, and we appreciate your being with us today.

Our final witness is Jeffrey D. Grant, Sector Vice President and General Manager of the Space Systems Division, Northrop Grum-

man Aerospace Systems. Mr. Grant has worked for Northrop Grumman since 2002, and previously he worked for 21 years at the CIA and National Reconnaissance Office. He received a B.S. degree from the Florida Institute of Technology and has earned a number of performance awards during his federal service. It is good to have you here.

I had a nice visit with Mr. Grant earlier and found out that his father and I served in World War II, probably at different bases and in different airplanes. I flew hellcats for the Navy, and he flew the PBY, and we talked about the PBY, and he asked me if I would like to have flown the PBY. I said, that is what every Naval pilot wanted to fly because it took off at 90, it landed at 90, it flew at 90, and pilots lived to be 90. So I hope your dad is still with us. I didn't get to ask you about that, and may God bless him.

Okay. As our witnesses should know, spoken testimony is limited to five minutes, after which the Members of the Committee will have five minutes each to ask questions.

I now recognize our first witness, Mr. Rick Howard, to present his testimony. Mr. Howard, you have five minutes, but we don't have a hook. Just do your best to stay as close as you can, but your testimony is so valuable, and your presence is so appreciated, we will have a gentle Chair for you up here. Go ahead now.

STATEMENT OF MR. RICK HOWARD,
PROGRAM DIRECTOR, JAMES WEBB SPACE TELESCOPE,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. HOWARD. I appreciate that. Mr. Chairman and Members of the Committee, thank you for this opportunity to appear before you today to testify concerning NASA's progress and plans to complete the James Webb Space Telescope. Let me begin by expressing NASA's thanks to this Committee and to Congress for its continued support of this program in the fiscal year 2012, budget. We at NASA recognize that we made your already difficult task of funding important programs in these distressed fiscal times even more difficult through our poor past performance on JWST.

We are, thus, even more determined to restore your confidence in NASA by delivering a successful JWST on the costs, new costs, and schedule baseline that we have developed. It is important to remember why we have undertaken this effort. JWST will be the world's premiere space-based observatory and will be both the scientific and technological successor to the Hubble Space Telescope. JWST will be the most powerful telescope ever deployed in space and will have 100 times the sensitivity of Hubble. No other nation on Earth could lead such a pioneering endeavor.

In my written testimony submitted to this Committee, I outlined a new baseline developed for JWST and provided detailed responses to the questions posed to NASA by this Committee. I would like to provide a brief summary of the main points of those responses.

You asked about NASA's justification for continuing JWST. JWST is the primary tool for addressing many of the major questions scientists have about the origins and physics of the cosmos. JWST was the top priority large-mission recommendation in the

2001 decadal survey and was considered foundational in the 2010 decadal survey.

The independent analysis of alternatives submitted to the Congress in October showed that the JWST remains the most cost-effective way to answer these science questions. The JWST team, including more than 1,200 people across the United States, is on a new path and has made good progress in fiscal year 2011 against the milestones that we established back in January of 2011. Concerning the progress or the process we used in developing a new baseline, NASA worked closely with its industrial partners to arrive at a new cost and schedule baseline for JWST by undertaking a thorough, bottoms-up analysis of the work yet to be completed. NASA and our standing—independent standard review board and other independent groups then subjected the resulting baseline to rigorous risks, costs, and schedule analysis. The end result is a robust baseline that NASA is confident we can achieve.

Let me address the work to go and the remaining challenges in the program. A significant portion of the work to go is the integration, tests, and verification of the observatory. This includes the integration and tests of the instruments, the optical performance tests of the full 18-segment telescope at the Johnson Space Center in Texas, and the integration and testing of the spacecraft and sunshield. These efforts represent the major technical challenges remaining in the program.

The major programmatic challenge is maintaining a stable budget environment and consistent support of the program within NASA, the Administration, and Congress. The new baseline is complete, and it is now our responsibility to deliver JWST within costs and on schedule.

Let me close by, again, thanking the Congress for your support of JWST, your willingness to fully fund JW in fiscal year 2012, in support of the new baseline demonstrates your commitment to sustaining this Nation's leadership in space science. NASA is committed to completing this program efficiently and successfully.

Thank you for the opportunity to appear before this Committee today, and I will be pleased to answer any questions you have.

[The prepared statement of Mr. Howard follows:]

Prepared Statement of Mr. Rick Howard, Program Director, James Webb Space Telescope, National Aeronautics and Space Administration

Statement of
Mr. Richard J. Howard
Director, James Webb Space Telescope Program
National Aeronautics and Space Administration
before the
Committee on Science, Space and Technology
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to discuss the history, status, and future direction of NASA's James Webb Space Telescope (JWST) program. JWST will be the next great astrophysical space observatory, 100 times more sensitive than the Hubble Space Telescope. It will observe the first galaxies formed in the early universe and help us understand the phenomena of dark matter and dark energy that shape the universe's evolution and destiny. JWST will operate in deep space, about one million miles from Earth, at a temperature of forty degrees above absolute zero (40 Kelvin). To maintain this temperature, JWST will be shaded from the Sun by a deployable sunshield the size of a tennis court. JWST is the most challenging robotic spaceflight program NASA has ever undertaken, requiring ten new technologies to be developed. It has been extremely challenging to implement, with a higher development cost than expected when NASA first established a baseline in 2008. We recognize the challenges NASA's poor management, cost, and schedule performance on JWST have created for the Congress, especially in the current fiscal environment. The intent of this testimony is to demonstrate that we have changed our management, priority, and approach to JWST, have a new robust baseline, and are ready to continue to demonstrate that we can deliver JWST within cost and on schedule. We owe a tremendous debt of gratitude to the Congress for its support of the plan forward.

The Need for a New Baseline

Overall, while NASA made excellent technical progress on JWST including the maturation of the 10 critical new technologies to enable the mission, our management and cost performance was not what the Nation and the Congress has a right to expect from its space agency.

Earlier informal estimates were based on engineering studies before or in the early stages of the formulation phase of the mission. The 2001 National Academy of Sciences decadal survey first recommended this mission, guessing without the benefit of hard analysis that it would cost about $1 billion (without operations phase costs and in FY2000 dollars). The first estimate made after receiving industry proposals in 2003 was approximately $2.4 billion (without operations phase costs but in real year dollars). Delays in finalizing use of an ESA-contributed launch vehicle and other challenges in the 2005-06 time frame led to an estimate of $3.5 billion (again without operations phase costs and in real year dollars). Recognizing that 10 new technologies had to be developed in order to provide the capabilities necessary to achieve this mission, considerable effort in design and technology work took place during the formulation phase, leading to the 2008 mission confirmation.

NASA utilizes a set of Key Decision Points (KDPs) as "gate reviews" of spaceflight projects. At each KDP a project must demonstrate progress against a defined set of criteria in order to be approved to proceed to the next phase of development. At KDP-C, projects are reviewed to determine their readiness to transition from formulation to development. It is at KDP-C where a life cycle cost commitment is established. KDP-C for JWST was accomplished in 2008, wherein a launch readiness date of June 2014 was established, along with a life-cycle cost of $4.964 billion and a development phase cost of $2.581billion (the difference is that the former includes formulation and operations phase costs). This was the first formal baseline cost and schedule established for JWST.

From mid-2008 through 2010, NASA maintained a focus on science instrument, mirror and sunshade development for JWST. The development challenges were such that the project spent more than expected on these items, resulting in delaying spacecraft development and integration and test planning. Further, during this period the project office and prime contractor failed to communicate clearly with each other and with NASA Headquarters on the technical liens and threats and their associated cost and schedule impacts. This led to an underfunded reserve posture and a growing backlog of work. NASA failed to maintain sufficient insight into the real project status and progress. Even so, the issues on JWST were sufficiently apparent that NASA took action to improve the JWST project's reserve posture in the FY 2011 budget request, and in FY2010 initiated the independent Test Assessment Team activity to review the plans for the Integration and Test phase of the project.

By the spring of 2010 it was apparent that JWST was in trouble and would not be able to deliver on the 2008 KDP-C cost and schedule commitment baseline. The JWST Independent Comprehensive Review Panel (ICRP, described below) was established to identify the causes and recommend the quickest path to launch of JWST. The ICRP report stated that the problems causing cost growth and schedule delays were associated with budgeting and program management, and not technical performance. They stated that the technical performance has been "commendable and often excellent". The ICRP report identified changes that needed to be made in both NASA's management approach and its cost estimating and reserve philosophy on JWST.

Since receiving the report of the Independent Comprehensive Review Panel in September 2010, NASA along with the prime contractor and its subcontractors has been working diligently to define a new program baseline. The new baseline required an increase over the FY 2012 President's Budget Request for the period FY 2012-2016 of $1.2 billion. The new baseline life-cycle cost of $8.835M and launch readiness date of October 2018 accompanies a solid technical baseline and management approach that will allow us to implement this program with high confidence of success.

We have kept the Congress abreast of these developments through the submission of our response to the Independent Comprehensive Review Panel's report in April 2011, the Project Cost and Schedule Analysis Report submitted in October 2011, and numerous briefings to Committee staff in both Houses of Congress.

We are extremely grateful for the support of this Committee and this Congress for NASA and JWST in the FY 2012 budget as we have moved to address the problems of the past and move forward with a robust new baseline for this vital project.

Moving Ahead on a Sound Plan for JWST

Thanks to the support of Congress and the Administration, and to the hard work by NASA, its contractors, and its partners, JWST has moved from "replan" mode to "implementation" mode. With the enactment of the FY 2012 Consolidated and Continuing Appropriations Act (P.L. 112-55), and a new life-cycle cost and out-year funding profile identified in the Project Cost and Schedule Analysis Report submitted to the Congress last month, NASA now has a robust new baseline cost and schedule for JWST. This new baseline provides high confidence that NASA can implement JWST within the resources available in a constrained budget environment and achieve a launch readiness date of October 2018. The following paragraphs provide the rationale for this statement.

First, the JWST program has been subject to rigorous external review. The three key reviews are described here. The first was the Test Assessment Team report requested by the management of NASA's Science Mission Directorate and delivered in September 2010. This Team, chaired by Mr. John Casani of NASA's Jet Propulsion Laboratory, conducted a review of the planned testing of the Integrated Science Instrument Module (ISIM) at GSFC and the Optical Telescope Element/ ISIM (OTIS) testing at JSC. Their report identified some additional tests that should be performed and also identified ways to streamline the test programs and reduce the testing time at both Goddard Space Flight Center and Johnson Space Center. NASA accepted and implemented all the report's recommendations. The second was the Independent Comprehensive Review Panel (ICRP), also chaired by Mr. Casani. The ICRP, established by the NASA Administrator at the request of Senator Barbara Mikulski, Chair of the Senate Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies, reviewed the management, cost, and schedule for the entire JWST program. The ICRP made 22 recommendations to NASA on these subjects, including establishing a separate program office at NASA Headquarters reporting directly to the NASA Associate Administrator to provide a high-level management organization focused solely on JWST, and establishing a funding profile that provides adequate cost and schedule reserves in each year of development. NASA accepted all 22 of the report's recommendations and described our implementation of the actions in a report to the Congress delivered on April 25, 2011. The third external review is the on-going work of the independent Standing Review Board (SRB) chaired by Mr. Jean Olivier. Senior Review Boards are extremely valuable in keeping NASA programs on track because they stay with the program throughout its development phase to evaluate specific critical points in the program's life cycle to verify performance and the path forward. The SRB reviewed the new JWST technical, cost, and schedule baseline as it was being developed, and NASA has been able to incorporate its recommendations in the new JWST program baseline to which we are now working. The SRB will be reviewing the status of the program against the new baseline in April 2012.

The second line of evidence in support of the achievability of the new JWST program baseline is the robustness of the baseline itself. The new schedule for JWST has 13 months of funded schedule reserve available to address any issues that arise in the final development or testing of JWST hardware or support systems. The current cost assessment meets the 80 percent cost confidence level recommended by the ICRP. For the first time in the program's history, adequate cost reserves exist in each fiscal year of the development phase. Finally, all known high-probability technical threats are funded in the base program (not liened against reserves). The NASA Associate Administrator, the JWST Program Director at NASA Headquarters, the JWST Project Manager at GSFC, and the major industrial contractors working on JWST meet quarterly as an Executive Council to review the program's technical, cost, and schedule progress and current issues and concerns and paths toward resolution. JWST is the most challenging robotic spaceflight program NASA has ever undertaken. Because of the reviews described above and the

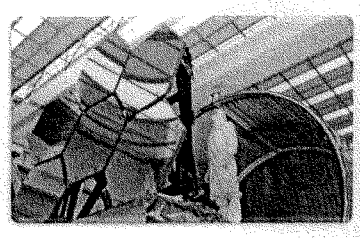
robustness of the new cost and schedule baseline, NASA thoroughly understands how to execute this program and has a solid plan to do so.

The third line of evidence is the progress NASA has made to date. NASA and the JWST program did not stand still while the "replan" was being formulated. Rather, NASA made effective use of the funds the taxpayer invested in JWST in FY 2011. At the beginning of the replan activity, the new JWST Program Office at NASA Headquarters and the revamped JWST Project Office at the Goddard Space Flight Center identified 21 technical and management milestones to be accomplished between January and September of 2011. By the end of September, 20 of the 21 were completed; the remaining one was deferred into FY 2012 due to potential design changes in the ISIM. Among the accomplishments are:

- Completion of flight primary mirror segments manufacturing and polishing;
- Completion of the pathfinder primary mirror backplane support structure;
- Completion and shipment of Ambient Optical Alignment Stand;
- Completion of cryogenic vacuum testing of one-third scale Sunshield
- Advancement of instrument development in support of FY 2012 deliveries; and
- Completion of fabrication and environmental testing of the flight ISIM structure.

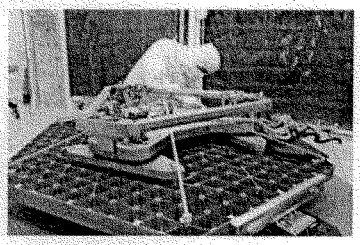
The following graphics and pictures demonstrate not only the complexity and scale of JWST but also the testing that has been done to date and that which remains as we complete the development phase and proceed into the integration and test phase of the program. The figure below shows both the front and back side of the Flight Primary Mirror Assemblies. On the front side is the optical quality surface of the beryllium mirror coated with a thin IR reflecting coating of gold (there are only about 2 ounces of gold in total on the entire JWST primary mirror). However, the real complexity of the mirror segments is on the backside where all the mirror position control electronics and mounting structure are located. Each mirror has 6 degrees of freedom and can be positioned to an accuracy of about 10 nm (roughly 1/1000 of the diameter of a human hair). All are designed to work at 40 Kelvin (- 387° F). The last six of the Primary Mirror Assemblies are now in final testing.

Flight Primary Mirror Assemblies



Front side
- 18 segmented beryllium mirrors (6 shown here)
- Optical surface: thin layer of gold
- Surface figure error (18 segments) < 25 nm RMS
- Beryllium mirror weight ~ 40 lbs
- Operating temperature: ~40K

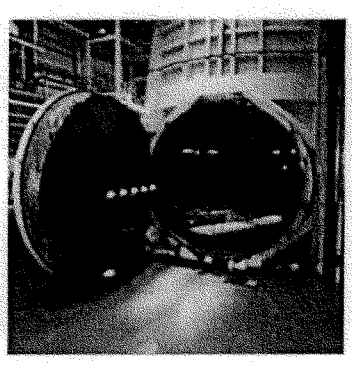
Back side
- Mounting support
- Actuators, position readout electronics and cabling to control position of mirror to within 10 nm
- Adds ~ 50 lbs total mirror assembly weight
- Operating temperature: ~40K

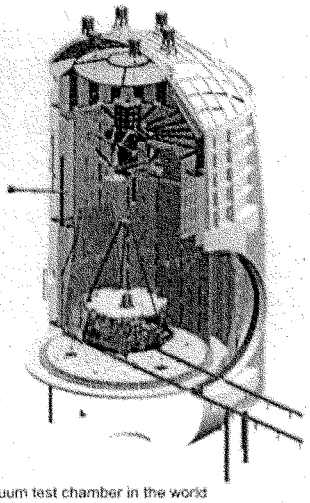


Last six flight mirror assemblies are in their final tests at MSFC

The following figure shows the test chamber that will be used to test the optical performance of the complete JWST telescope with all 18 mirror segment assemblies, secondary mirror, aft optics and flight instruments. This historic human-rated thermal vacuum chamber was used for testing of Apollo-era space vehicles. It is undergoing a $100M upgrade to test JWST down to temperatures of 25 Kelvin. When completed in 2012, Chamber A will be the world's largest cryogenic vacuum test facility.

Optical Testing of Telescope in Chamber A at JSC





- 40 foot diameter door
- 45 feet diameter by 65 feet useable volume at 20 Kelvin (-424 °F)

Chamber A will be the largest cryogenic vacuum test chamber in the world

In short, JWST made excellent technical progress in FY2011 toward the deliveries of hardware on schedules that lead to the new baseline's October 2018 launch readiness date. The new baseline includes a detailed schedule of work that must be accomplished in FY 2012 and beyond, and the JWST Program is well underway on that work.

Answers to Questions Posed By the Committee

The Committee's formal invitation to testify at this hearing included four questions, for which answers are provided here.

1. How did NASA arrive at the latest cost and schedule estimates for JWST, and how confident is NASA that these estimates will not be exceeded? Were they independently verified?

NASA accepted all of the ICRP recommendations and started immediately in November 2010 to develop a new baseline that involved all of the team members (the prime contractor, their subcontractors, NASA-directed contractors and NASA Centers). The objective was to develop a realistic, high confidence work plan and budget and schedule profile that accounted for all the work to go including assessments of known threats, liens, and risks in the program and supported the earliest possible launch consistent with known resource constraints. To minimize difficult near-term budgetary impacts, an initial constraint for the replan was no additional funding in FY 2011 and FY 2012 above the President's Budget Request level, with an unconstrained budget in FY 2013 and the out years. The initial replan was reviewed by the JWST independent Standing Review Board (SRB), which determined that: 1) the FY 2011 and FY 2012 funding levels and reserves were insufficient; 2) the FY 2013-2019 funding reserves should be increased; 3) implementation of the steep FY13 funding increase was high risk; and 4) insufficient FY 2011-2012 funding necessitates delaying critical development activities and increases risk. As a result of the SRB finding, the new NASA Headquarters JWST Program Office revised the initial replan by adding additional Mission Directorate-managed unallocated future expense (UFE) starting in FY2014, adding $56 M of UFE in FY 2012 and shifting $100M of work from FY2013 into FY 2012. The resulting changes to the replan were reviewed by the SRB with a first cut of the areas of work to be accelerated into FY 2012. The SRB determined that between the additional reserves, the work accelerated, and the reduction of the FY 2013 budget and work to be performed in FY 2013, the revised replan was a positive step toward successful planning and implementation of the JWST. The identification of specific work to be shifted is still being discussed and will be finalized in the replan proposal from the prime contractor due in mid-December. The SRB will be reviewing the details of the revised baseline in April 2012. The revised baseline has a cost confidence that betters the ICRP's recommendation of 80 percent, has 13 months of funded schedule reserve against the October 2018 launch readiness date, and has incorporated over $200M of high probability threats (i.e., threats that have a 50 percent or greater probability of occurring) into the baseline funding level (not held against reserves). Given these and other aspects of the replan, NASA feels it is robust and has a high level of confidence that JWST can be successfully completed with this budget and schedule.

2. What are the chief technical and programmatic challenges facing JWST? How does the replan address systemic issues with the program and put it on a path for success?

The main technical challenges facing JWST are completing development and testing of the individual elements in the program (instruments, sunshield, spacecraft, primary mirror backplane support structure) and the integration and testing of the integrated elements (the ISIM, OTE,

OTIS, Spacecraft/Sunshield systems) to validate both the in-space performance and the integrated models of the observatory. There are still significant risks associated with these activities. The project has in the new baseline plans to mitigate or retire these risks. The main programmatic challenges are executing the project on schedule within future appropriations and maintaining the confidence of our stakeholders.

As JWST moves into the integration and test phase a general challenge is putting together and testing the largest space telescope NASA has ever built. These challenges range from technical ones such as testing at operating temperatures to logistical ones such as transporting such a large system. Below are specific examples of the challenges and mitigation approaches in the program:

- Achieve the cryogenic temperatures necessary in the largest cryogenic test chamber in the world so as to enable flight-like performance of the fully integrated telescope and instrument science suite (OTIS configuration) - the project is mitigating this challenge by including extensive pre-test activities and test runs of the facility;
- Verify and validate the performance of the huge and delicate sunshield prior to launch – the project is mitigating this challenge by including additional testing of key sunshield components at cryogenic temperatures to an already extensive sunshield test program;
    - Successfully achieve the necessary operating temperature of the science instrument detector systems (JWST is the largest cryogenic telescope ever built by NASA and the passively cooler architecture is the largest ever flown) - the project is mitigating this challenge by embarking on a thermal margin mitigation endeavor to ensure there is adequate margin on system thermal performance to ensure mission success;
- Build science instrument detectors that meet mission requirements (some of the most stringent ever flown) through all mission life, including after the four year launch delay – the project is mitigating this challenge by procuring a new set of detectors with an "improved" process that should have a more robust design against performance degradation and will have demonstrated proof of the new process by the end of FY 2012, and;
- Timely delivery of the four science instruments – NASA does not control the budget for two of the four instruments and only part of another instrument. The project is mitigating this challenge through extensive communication/coordination with our international partners both at the project and program level and robust schedule margin at the ISIM level. With the four-year slip of the launch date, the ISIM schedule has many months of margin before it will be integrated with the telescope.

The new baseline has adequate flexibility in each fiscal year to resolve unforeseen problems. This includes adequate reserves in the near term years (FY 2012-2013) that are critical to continuing progress, resolving problems and staying on schedule. This is the first time in the history of the program that adequate reserves have been provided in the fiscal years where they can have the most benefit in either fixing unforeseen problems or advancing work that can retire risk earlier or provide additional schedule flexibility later in the program. The project provides close, frank, and open communications with the entire project team to tackle technical challenges as they present themselves so quick resolution can be achieved and schedule performance can be maintained. The project was able to achieve 20 of 21 key milestones identified for FY 2011 in the fiscal year with the impact of the single missed milestone mitigated by plan workarounds so that no additional risk to the project schedule resulted.

NASA has dealt with the systemic issues the program had before the replanning activity in two major ways. First, we changed the way JWST is managed. We established a JWST Program

Office at NASA Headquarters that reports programmatically to the NASA Associate Administrator and draws technical and administrative support from the Science Mission Directorate. The Project Office at Goddard Space Flight Center has a new management team in place. As stated above, the senior NASA officials at Headquarters and GSFC meet quarterly with senior executives of the prime contractor as an Executive Council. These and related management changes are described in the April 2011 report to the Congress detailing our response to the ICRP recommendations. Second, as stated above, NASA has dealt with systemic issues in program reserve levels through the new program cost and schedule baseline that includes adequate reserves in each fiscal year of development. This funding plan is detailed in the Major Project Cost and Schedule Report submitted to the Congress in October 2011. Together, these program management and cost and schedule baseline changes address the key systemic issues that existed prior to 2011.

3. The total life cycle cost is now estimated to be $8.8 billion, of which only $3.5 billion has been spent. Most of the hardware is under development or has been delivered. What work remains to be completed, and at what cost?

A significant portion of the work remaining is integration, test, and verification of the observatory. This includes the integration and testing of the ISIM that has already begun, the optical performance tests of the full 18 segment telescope at JSC, and the integration and testing of the spacecraft and sunshield once the development work on both elements is completed. Development of the spacecraft bus is the least mature major segment of JWST at this point, with spacecraft Critical Design Review scheduled in mid-2014. The continued development and completion of the ground system is another major portion of the work to be completed. The remaining cost-to-launch is about $4.5B. The operations costs for the required 5-year lifetime and 2 additional years of data analysis are approximately $0.8B.

4. What is NASA's justification for continuing to develop JWST?

Based on JWST's scientific promise and the benefits that will accrue to the Nation's scientific and education goals, the excellent technical progress made thus far, and the technologies JWST will provide for future, lower-cost missions, NASA believes the benefits of JWST will still far outweigh the cost.

JWST will be the world's premier space-based observatory with a utility spanning the breadth of astrophysics. It will be the primary tool for addressing many of the major questions scientists have about the origins and the physics of the cosmos, and will be a substantial contributor to many others. JWST will be 100 times more sensitive than the Hubble Space Telescope. Its mirror will have more than six times the collecting area of Hubble and almost 50 times that of the Spitzer Space Telescope. Whereas Hubble observes primarily in the visible and ultraviolet portions of the light spectrum, JWST will specialize in the infrared portion of the spectrum. Because the universe is expanding, the light of the farthest (and earlier) galaxies is "redshifted" from the visible toward the infrared. Thus, JWST will be able to observe the first galaxies formed in the early universe, which Hubble cannot. In addition, JWST will see solar systems forming in our galaxy, significantly advance our understanding of such cosmic mysteries as dark matter and dark energy, and possibly detect the presence of liquid water on planets around other stars—an indicator such a planet may harbor life. Like its Hubble predecessor, JWST will transform our understanding of the universe in ways we cannot yet imagine and open its wonders to students from kindergarten to graduate school. JWST is already inspiring students to consider STEM

degrees and career choices as they see its engineering challenges overcome, and ponder the science questions it is designed to answer.

Such a next-generation space telescope was the top-priority large mission recommendation of the 2001 decadal survey of the National Academies of Science. The 2010 decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics*, built its assessment of scientific priorities and its slate of recommended missions and activities on the assumption that JWST would be operating later this decade. JWST plays a critical scientific role in two of the three themes in the new survey and a strong supporting role for the third theme. Many of the decadal survey recommendations build on groundwork to be laid by JWST for the next decade of astronomical exploration. The essential contribution of JWST to the scientific goals of the current decadal survey is well described by Hammel, et.al., in "Scientific Role of the James Webb Space Telescope in *'New Worlds, New Horizons'*" found at the Space Telescope Science Institute's webpage at: http://www.stsci.edu/jwst/doc-archive/white-papers/.

To date, 75 percent (by mass) of JWST's flight hardware is complete, or ready for production, or undergoing testing. All 18 mirror segments have completed their polishing stages and in total are within the mirror's stringent performance specification. Twelve of those segments have completed cryogenic testing; the final set of six mirrors is being tested now and scheduled to complete testing in early 2012. All of JWST's science instruments will be completed and delivered by next summer. Testing of the one-third-scale model Sunshield is also complete, and testing of the engineering development unit (the template for the actual Sunshield layers) is underway. With the funds provided by the Congress in FY 2011 and FY 2012, modification of the vacuum chamber at the Johnson Space Center continues on schedule and will be completed in 2012. Development of the Ambient Optical Test Stand is complete and it has been installed into the clean room at the Goddard Space Flight Center. In short, JWST hardware continues to make excellent technical progress on a schedule consistent with the new baseline schedule and cost profile. The progress the JWST team has made this last year is another major reason justifying NASA's decision to continue with the program.

Finally, the technologies invented and developed to make JWST possible will also be available for use on future space programs, and have already been applied to other applications. The JWST program has enabled a number of innovations to metrology technology that have applications not just in astronomy and precision mirror fabrication, but in medical device metrology, measurement of human eyes, diagnosis of ocular diseases and improved surgical techniques. That is in fact one of the benefits of flagship class missions—they are technology providers enabling and reducing technical risk of smaller missions that could otherwise never afford to develop such technologies. To enable the capabilities needed to accomplish the JWST science, the JWST team had to invent ten new technologies. These include: micro-shutters with widths the size of a human hair; actuators and bonding materials that will function at nearly -400° F; a folding segmented mirror that has three times less areal density than HST, and a deployable sunshield the size of a tennis court that will prevent heat from the Sun from reaching the telescope and science instruments allowing them to passively cool to forty degrees above absolute zero (40 Kelvin, or - 387° F). One of these new technologies is already in space aboard Hubble in the Advanced Camera for Surveys instrument repaired on the last Hubble servicing mission. Development of these technologies and capabilities has employed over 1200 people in high quality and high technology jobs in 27 states around the country. Use of these technologies on JWST will furnish proof that future missions can employ them on known costs and schedules.

In preparing and adopting the new baseline for JWST, NASA made JWST an agency-level priority. That is, NASA elected to look across the agency portfolio and rebalance among the portfolio elements to find the necessary resources to continue the program.

Summary

As we reported to the Congress last month in the JWST Project Cost and Schedule Analysis Report, NASA concludes that to understand how galaxies, stars and planetary systems formed, to retain leadership in astrophysics, and to provide the crucial underpinning for all of the astrophysics and exoplanets projects that are depending on JWST's results to meet their own requirements, the Nation needs an observatory with the capability of JWST. This assessment is consistent with the recommendations of the broad scientific community as reflected in the National Academy of Sciences astrophysics decadal surveys of 2001 and 2010. An independent team of experts conducted a thorough analysis of alternative concepts that could provide these capabilities in the same timeframe and for the same or less than the cost to complete JWST: there were none. Given the cost-to-go of the new JWST baseline, it remains the most cost-effective way to achieve the astrophysics science community's objectives. The current and out-year funding levels identified in that report are crucial to NASA's ability to implement JWST on this cost and schedule commitment. The history and independent review of JWST has shown that an adequate year-to-year funding profile is necessary to avoid slipping work into the future and incurring schedule delays and cost growth. We believe, along with our independent Standing Review Board, that we now have a robust cost and schedule baseline and a sound technical implementation plan. The Congress and the Administration have given us in FY 2012 what we need to succeed. With your continued support, I am confident we will.

Mr. Chairman and Members of the Subcommittee, I appreciate your continued support of NASA's James Webb Space Telescope program. I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.

Chairman HALL. Thank you, Mr. Howard.

I now recognize Dr. Roger Blandford to present his testimony. Five minutes. Thank you.

STATEMENT OF DR. ROGER BLANDFORD,

PROFESSOR OF PHYSICS, STANFORD UNIVERSITY,

AND FORMER CHAIR, COMMITTEE FOR THE DECADAL SURVEY OF ASTRONOMY

AND ASTROPHYSICS, NATIONAL RESEARCH COUNCIL

Dr. BLANDFORD. Good afternoon, Chairman Hall, Ranking Member Johnson. Allow me to begin by thanking you and your colleagues for your support of the James Webb Space Telescope and for the opportunity to add my personal perspective. I believe that this support is a courageous recognition by you of the scientific importance and value of the telescope and an expression of confidence that NASA now has the management of this project under tight and realistic control.

Webb is a 6.5 meter infrared space telescope. It provides a huge increase in performance over previous telescopes and promises to be a scientific game changer. The two main reasons the 2001 survey chose Webb as its highest priority recommendation are its capacity to trace light back to the first stars and galaxies when the universe was just four percent of its present age and its potential to revolutionize our understanding of how stars and planets form in our galaxy today. These reasons remain valid and are now joined by the opportunity to study the many, now more than 700, exoplanets that have been discovered around other stars.

However, Webb will also operate as an astronomical observatory. Many, and perhaps most, areas of astronomy will be transformed by Webb in much the same way as they have been revolutionized by its predecessor Hubble Space Telescope.

On script to discover is like the realization that 96 percent of the universe is in an unseen dark form, that massive black holes reside in the centers of most galaxies, and that most sun-like stars orbited by planets are likely to be made by Webb.

Decadal surveys compel the astronomy community to plan an executable program for the coming decade and beyond. The astronomy community respects the outcome of these deliberations and acknowledges that the most ambitious projects typically take more than a decade to bring to fruition, which can lead to delays in realizing newer entries into the program.

The American Astronomical Society, which reflects the views of the general astronomy and astrophysics community, continues to support Webb despite the strain its delay is placing on other proposed missions.

For the above reasons, Webb is a cornerstone of the scientific program that was recommended by the 2010 astronomy survey, *New Worlds, New Horizons*. I believe that if Webb were not to be completed, then a very large part of the combined science program of these two decadal surveys would not be executable, and there would be a consequent call to propose new infrared facilities to replace Webb.

I believe that launching and operating Webb would be scientifically transformational and internationally inspirational. It would also make a powerful statement that the United States still has the resolve to execute large, technically challenging, and innovative scientific projects. No other country currently has this capability.

Thank you, again, for the opportunity to address you. I hope that my testimony will be helpful, and I look forward to answering your questions.

[The prepared statement of Dr. Blandford follows:]

Prepared Statement of Dr. Roger Blandford, Professor of Physics, Stanford University, and Former Chair, Committee for the Decadal Survey of Astronomy and Astrophysics, National Research Council

Dr. Roger D. Blandford
Luke Blossom Professor in the School of Humanities and Sciences
Stanford University
and
Chair, Committee for a Decadal Survey of Astronomy and Astrophysics
National Research Council
The National Academies

before the

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

December 6, 2011

Good morning. My name is Roger Blandford and I am the Luke Blossom Professor in the School of Humanities and Sciences at Stanford University. I chaired the 2010 National Research Council's Decadal Survey in Astronomy and Astrophysics, "New Worlds, New Horizons" (NWNH). The National Research Council (NRC) is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine of the National Academies, chartered by Congress in 1863 to advise the government on matters of science and technology.

I thank you for the opportunity to comment on James Webb Space Telescope (JWST) which was the highest priority recommendation in the 2001 decadal survey, Astronomy and Astrophysics in the New Millennium (AANM) and is a cornerstone of the scientific program advanced in NWNH. These comments are largely my own, although at times I will be referring to the findings of the 2001 and 2010 NRC Decadal Surveys.

Chairman Hall, Ranking Member Johnson, allow me to begin by thanking you and your colleagues for your support of this project, most recently through the House-Senate Conference, H.R. 2112 where the budget to complete the project under the NASA "replan" was restored and protection against further cost growth was instituted. I believe that this is a courageous recognition by you of the scientific importance and value of the telescope and an expression of confidence that NASA now has the management of this project under tight and realistic control.

JWST (formerly known as Next Generation Space Telescope) is a 6.5 meter diameter telescope. It is much larger than the Hubble Space Telescope (HST—2.4 meter diameter) and unlike HST, it will observe the universe from near the "second Lagrange Point", roughly four times as far away from the Earth as the moon but along the opposite direction to the sun. It will be protected from the sun by an elaborate sunshield. JWST is an engineering marvel and its 18 beryllium mirrors will be furled up within a rocket for launch and then deployed at its destination. This operation has to work perfectly as there will be no means of servicing it after launch.

The principal scientific goals of JWST are bold and exciting and a culmination of nearly fifty years of extraordinary discovery about the universe and our place in it. They are:

- to observe the very first stars, galaxies and black holes which formed at a time when the universe was about four percent of its present age
- to discover how stars and planets actually form today within our Galaxy
- to study planets orbiting nearby cool stars and assess their habitability

However, JWST will also operate as an astronomical observatory and many, and perhaps most, areas of astronomy will be transformed by JWST in much the same way as they have been revolutionized by HST.

JWST is specialized to observe in the infrared region of the spectrum. This is relevant because, although much light emitted by the most distant galaxies is in the optical and ultraviolet spectral bands, the wavelengths of this light are stretched roughly tenfold through the expansion of the universe into the infrared band, as we push out to greater distance and earlier times. There is a second reason why it is preferred to observe in the infrared and this is that the star-forming regions that will be intensively studied by JWST are filled with tiny grains of dust. These dust grains absorb and scatter optical and ultraviolet light but leave infrared radiation alone, enabling us to see deep inside them at these wavelengths. In addition, the light that is absorbed by dust will be re-emitted at infrared wavelengths and we can also observe the dust itself as a tell-tale tracer of star formation.

As well as being the natural successor of HST, JWST is the infrared successor of the much smaller (0.85 meter diameter) Spitzer Space Telescope, with over 50 times the light-gathering ability and 40 times the resolution as well as the Herschel telescope, led by the European Space Agency, which only observes at longer infrared wavelengths than JWST. Given this huge increase in performance over and complementarity to previous telescopes, JWST promises to be a scientific "game changer".

One reason AANM chose JWST as its highest priority recommendation was its capacity to trace light from the first stars and galaxies during our "Cosmic Dawn" and to watch them grow up and change as the universe expanded. We now have a fairly precise "standard model" of cosmology, which allows us to predict the approximate date when the first stars and galaxies formed. This lies well within JWST's reach and it will be able to observe the resulting "redshifted" optical and ultraviolet light. It will help explain just how the gas in the universe was converted from atomic to ionized form during the so-called "Epoch of reionization" which marked the end of our cosmic "dark age". One of the many important discoveries that have been made in this area since the publication of AANM has been that massive black holes are rapidly grown in the nuclei of galaxies surprisingly soon after the formation of the first stars. We see these as the most distant "quasars" and JWST will help us understand how they formed and their impact on their surroundings.

A second reason for JWST's recommendation in AANM was that it is expected to revolutionize our understanding of how stars and planets form in our Galaxy today. The scientific questions have become much more tightly framed largely through developing the capability to see deeper into the stellar nurseries and measuring stellar masses. The Atacama Large

Millimeter/submillimeter Array (ALMA), a ground-based telescope that was a top priority in the 1991 decadal survey, has just begun Early Science Operation at a site in Chile and is expected to complement JWST in this research.

A third major use for JWST has been largely developed over the past decade. The study of "New Worlds"—exoplanets orbiting other stars—has blossomed. Over seven hundred certified examples are now known, with many more suspected cases under investigation. The diversity of these planets and their host stars is remarkable. Understanding their nature and potential habitability was a major component of the NWNH prioritized science program. As an infrared telescope, JWST is especially well-suited to observe planets orbiting smaller and cooler stars than the sun, that emit mainly in the infrared band. A planet orbiting such a cool star at the right distance should be habitable and perhaps capable of supporting life. JWST has the capacity to see through the atmospheres of many of these planets and determine their composition so as to see if they have life-sustaining oxygen and water, for example. This technique, which was pioneered by Spitzer should work extremely well with JWST exploiting its superb performance in the middle range of the infrared spectrum. JWST also has the capability to observe planetary systems, including those like our solar system, in the process of formation. Here it will be able to observe the extensive disks of gas, stones and rocks, orbiting the host star, out of which planets are eventually assembled. The ability of JWST to tune into different wavelengths enables it to study both the hot regions close to the central star and the cooler parts that are further away.

So, the list of scientific attributes of JWST that justified top ranking in AANM a decade ago, not only remain relevant today but has actually grown. Indeed JWST as well as the ground-based telescope, ALMA, are cornerstones of the recommended new program from NWNH. In terms of the first stars and galaxies, ALMA is expected to detect the cold gas and the tiny grains of dust associated with the first large bursts of star formation. JWST, by contrast, should provide unparalleled sensitivity to the light emitted by the first galaxies and pinpoint the formation sites of the first stars. Furthermore, the highest-ranked, new large space project recommended by NMNH, the Wide Field InfraRed Space Telescope, WFIRST, is expected to complement the targeted infrared observation of JWST with a wide field investigation of dark energy and exoplanet studies. In addition, the highest ranked ground-based recommendation of NWNH, the Large Synoptic Survey Telescope will be the telescope that will find many of the most interesting galaxies and stars that will be followed up in detail by JWST. Likewise, the third-ranked large, ground-based project from NWNH, the Giant Segmented Mirror Telescope was recommended as a spectroscopic complement to JWST. In other words, JWST is central to the scientific program that was recommended by NWNH.

Decadal surveys have been a feature of American astronomy since the 1960s. They compel the astronomy community, through its representatives on the survey committee, to plan a realizable program for the coming decade and beyond. They invariably involve hard choices as the number of feasible missions and facilities greatly exceeds what can be afforded. The astronomy community respects and has always respected the outcome of these deliberations. It recognizes that the process represents the best way to advance the whole field under the constraint of finite resources. The community also acknowledges that the largest and most ambitious projects typically take more than a decade to bring to fruition and that this can lead to delays in realizing newer entries into the program. Space missions, in particular, can encounter unanticipated

difficulties and costs can increase from those advertised when a project is first recommended. Although, the delay in the JWST launch was not appreciated at the time NWNH was written, it was acknowledged that there would be little new activity in space astronomy until JWST was launched, presumably in mid-decade. The American Astronomical Society (AAS) which reflects the views of the general astronomy and astrophysics community, continues to support JWST despite the strain its delay is placing on other potential space science missions. The American Physical Society has also endorsed the program. Importantly, JWST is an international collaboration and our European and Canadian partners have invested heavily in it and have been resolute in their support.

The most recent astronomy and astrophysics decadal survey (NWNH) broke new ground in many ways. It was the most inclusive survey to date through inviting white paper submissions from the astronomical community to help define the science program as well as the challenges in areas such as technology development, education, laboratory astrophysics, etc. – over 450 were received - and through requesting specific mission proposals – over 100 were reviewed. It exposed the freshly recommended projects to an independent cost, schedule and risk assessment and used the results to help define a program that conformed with agency-generated funding projections. The lessons learned from this exercise were shared with the leadership of the following two NRC decadal studies, in planetary science and heliophysics. Following its statement of task, NWNH adopted the performance, cost and schedule of JWST as supplied by NASA as part of its baseline set of programmatic and budgetary assumptions. The survey did not perform any independent study of JWST.

In view of the centrality of JWST in addressing the NWNH- recommended science program, the additional complement of space- and ground-based telescopes and facilities in the recommended program were definitely predicated upon the completion of JWST. I believe that, if JWST were not to be completed, then a very large part of the combined science program of AANM and NWNH would not be executable and there would be a consequent call to propose new infrared facilities to replace JWST. Indeed, if JWST were assumed not to exist at the time of white paper submissions to NWNH, then undoubtedly a similar infrared facility would have been proposed. Since the recommendations of the decadal survey were science-driven, the science priorities would not have changed without a JWST. However, I believe the recommended mission portfolio would have changed.

As I have outlined, JWST is confidently expected to achieve its science goals – explore cosmic dawn, examine stellar nurseries and probe exoplanets orbiting cool stars. However, as has been the case with HST, I expect that its ultimate scientific impact will be even greater including much "unscripted" discovery, Dramatic findings like the realizations that 96 percent of the universe is in an unseen "dark" form, that massive black holes reside at the centers of most galaxies and that most sun-like stars are also orbited by planets are still likely to be made. I believe that NASA should continue to support JWST because of the insight that it will provide into fundamental, longstanding questions of extraordinary scientific and popular appeal and its capacity for opening up discovery space. A considerable effort has gone into developing the NASA replan and, whereas any project can encounter unforeseen problems, JWST is now much better understood than it was a year ago and I am optimistic that it will be able to launch on its new schedule. Further grounds for confidence rest on the extraordinary success rate of recent

space astrophysics missions. The performances of NASA's fleet of currently operating astrophysics missions - Chandra, Fermi, GALEX, HST, Kepler, RXTE and Swift – have all far exceeded scientific expectation. Similar remarks can be made about recently completed astrophysics missions and missions led by other countries with US partnership. Collectively, these voyages of discovery have maintained the long-held position of global scientific leadership for the US in this field.

In summary, launching and operating JWST would be scientifically transformational, internationally inspirational. It would also make a powerful statement that the United States still has the resolve to execute large, technically challenging and innovative scientific projects. No other country currently has this capability.

Thank you again for the opportunity to address you. I hope that my testimony will be helpful and I look forward to answering your questions.

Chairman HALL. Thank you very much.

I now recognize Dr. Garth Illingworth for his five minutes of testimony. Thank you for staying within your five minutes, Dr. Blandford.

STATEMENT OF DR. GARTH ILLINGWORTH,

PROFESSOR AND ASTRONOMER, UCO/LICK OBSERVATORY,

UNIVERSITY OF CALIFORNIA, SANTA CRUZ

Dr. ILLINGWORTH. Thank you, and good afternoon. Chairman Hall, Ranking Member Johnson, Members of the Committee, thank you for the opportunity to testify today regarding the James Webb Space Telescope, and I would also like to thank you for your support of the recent public 2112–55, which included a full amount of funding needed to get JWST back on track for fiscal year 2012. This was a crucial step in setting it on the path for launch in 2018.

The James Webb Space Telescope is Hubble's successor. Webb will explore scientific frontiers that will not be accessible to any other telescope in the foreseeable future. It will seek and find some answers to some of the great questions we have about the universe, many of which were unforeseen when James Webb was conceived.

Yesterday, for example, we saw the announcement of the discovery of a planet, Kepler 22b, in the habitable zone around a nearby star in our galaxy. Only JWST has the capability to see if liquid water exists on nearby planets like this one.

The Nobel Prize was awarded recently to three astronomers who discovered dark energy. Only JWST can take some of the needed steps to advance this field.

Early this year, my team found the most distant galaxy ever, a dwarf galaxy that those that led to the building of the Milky Way; it was a faint blob, very young in its formative years. We did this by looking back through 96 percent of all time to when the Hubble was in its infancy. We cannot go further back with Hubble. Only JWST can explore the first stars and galaxies.

Chairman Hall, you asked me about the major faults identified by the independent, comprehensive review panel, how NASA has responded. The major faults with the JWST Program were not technical but were related to management and budget. The NASA re-plan takes great strides in addressing the major faults identified by the panel. There is now much stronger management and oversight. JWST is now a separate program office at NASA headquarters, with experienced staff led by Rick, reporting to the Associate Administrators of the agency and of the Science Directorate. Key leadership changes were made in the James Webb project at Goddard. Communications have improved.

The JWST Program has developed a far more conservative and robust plan than before and one that is meeting both the detailed recommendations and the spirit of the ICRP's panel report. The excellent progress on some critical technologies like the mirrors and on the recent milestones over this last year also add to the confidence in the program.

Of course, technical and programmatic challenges remain, as one would expect of such a unique program with cutting-edge tech-

nologies that have never been developed before. This is the first time. These challenges, however, do not appear to me to be extraordinary for such a major project at this point. Big projects will always have such challenges.

The most critical factors in my mind for assuring that JWST is launched on schedule and on budget are, one, James Webb needs to be fully funded with adequate reserves in every year. Short-changing James Webb at this point will only create additional budget and management problems in the future.

The James Webb management team must keep all the diverse elements of this program focused on meeting their milestones and schedules during the lengthy period that remains. Both the project and the independent assessment groups must work diligently to identify problems and address them rapidly, and fourth, it is essential the Congress, including this Committee, continue to be engaged and provide the necessary support for NASA to be successful on James Webb.

If James Webb is fully funded, NASA will be on track to launch the largest and most powerful space observatory ever built by late 2018, within the $8 billion cost cap.

Chairman Hall, I thank you and the Committee Members again for your recent support that has set us on the path to making JWST a reality. Launching James Webb will demonstrate again our leadership in science and technology to a world that has been fascinated by Hubble's remarkable results. As others have said, only we, only the U.S., have the capability to do such a mission.

Thank you very much, and I will be pleased to answer any questions.

[The prepared statement of Dr. Illingworth follows:]

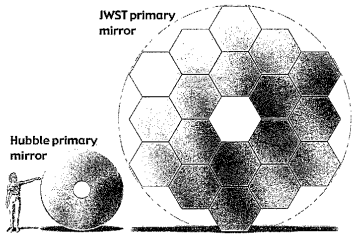
Prepared Statement of Dr. Garth Illingworth, Professor and Astronomer, UCO/Lick Observatory, University of California, Santa Cruz

"The Next Great Observatory: Assessing the James Webb Space Telescope"
December 06, 2011 Hearing
Testimony
Garth Illingworth
Professor/Astronomer, University of California, Santa Cruz

Chairman Hall, Ranking Member Johnson, distinguished Members of the Committee, thank you for inviting me to testify. I appreciate the opportunity to respond to your questions regarding the James Webb Space Telescope and the opportunity to highlight its importance to our nation. I would also like to thank you for your support of H.R. 2112, which supported robust science programs in NASA and NSF, and restored the funding for the James Webb Space Telescope.

The James Webb Space Telescope will be more than just the most powerful telescope ever built. It will, like Hubble before it, be a demonstration of our leadership worldwide in scientific endeavors, of our willingness to take on technological challenges and build a science program that nobody else can build, of our recognition that pushing our industrial base to develop new technologies has value far beyond this telescope, and that the excitement engendered by the scientific results will play a key role in Science, Technology, Engineering, and Mathematics (STEM) education initiatives, inspiring America's future innovators and leaders.

Projects like the James Webb Space Telescope (JWST) pose great challenges, because they are at the cutting edge of technology. Such projects demand the highest level of management rigor to ensure that the American public obtains this remarkable capability expeditiously and cost-effectively. The committee that most recently evaluated this program, and the overall management and budgetary issues that it had developed, was the Independent Comprehensive Review Committee (ICRP). This panel met in 2010, and was chaired by John Casani, a remarkably capable and experienced NASA Project Manager. I was the scientist member of the ICRP, and my role developed to working closely with the Chair in conveying the report to NASA and to key policymakers and funding groups, combining his project management expertise and my scientific project expertise. As the Chair of the Congressionally-mandated FACA committee, the Astronomy and Astrophysics Advisory Committee (AAAC) from 2004 through 2008, I also bring to this discussion science policy experience. The AAAC is responsible for assessing and making recommendations to NSF, NASA and DOE regarding the coordination of, and progress on, the astronomy programs in the Astronomy and Astrophysics Decadal reports.

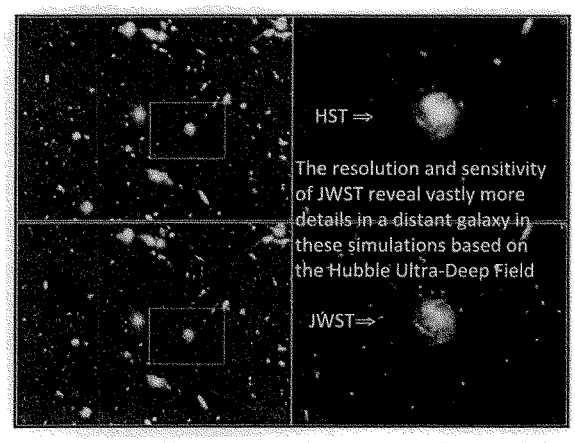


The James Webb Space Telescope: Hubble's successor as the next Great Observatory

The James Webb Space Telescope (JWST) is NASA's next Great Observatory, 100x more powerful than the Hubble Space Telescope, and 1000x more powerful than the infrared Spitzer Space Telescope. The legacy of Hubble will live on in JWST once Hubble reaches the end of its life (likely sometime later in this decade). JWST will take that legacy and move our knowledge of the universe forward in ways that Hubble could never do.

Why are Great Observatories important? The Great Observatories Hubble, Chandra and Spitzer have played a special role in NASA's repertoire of science missions. They return remarkable scientific results, across a wide variety of areas. Thousands of astronomers and planetary scientists have used Hubble, and every year a thousand new requests are sent to NASA to use this incredible facility. Our smaller missions play a key role in advancing our understanding of the universe by focusing on particular problems, like the Kepler mission has done recently with its remarkable discoveries of numerous planets orbiting stars throughout our Milky Way galaxy. Yet the techniques used by Kepler to find planets were pioneered on Hubble. The Great Observatories differ in that they let us explore a wide variety of scientific problems, as the discovery of Dark Energy attested. This totally unexpected result grew from Hubble observations. Hubble and Spitzer have also led us to find some of the youngest galaxies ever, by looking back through 96% of all time to when the universe was in its youth.

These remarkable scientific results, and many, many more like them, have made Hubble a household word across the world and have generated interest and enthusiasm for science that is unmatched. Such visibility and excitement is a key part of building a strong STEM program that is the foundation for our prosperity. For example, several million people visit hubblesite.org *every month*, and Hubble's education program reaches approximately 6 million school children each year! JWST will continue and enhance this investment in our future.

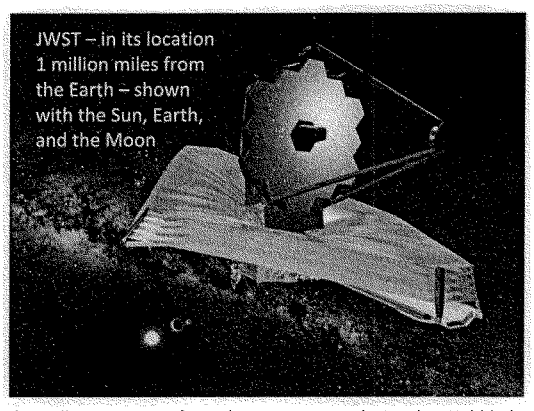


Yet it is not just science and education that is enhanced by these Great Observatories. Such projects led to the development of numerous cutting-edge technologies by our industries. US companies have generated patents from their work on the Great Observatories. These enhance the ability of industries across the nation, both small and large, to fabricate and manufacture items that could not be done by anybody else, anywhere else. The Great Observatory projects are so large and complex that they also push the development of new management approaches.

Each of the Great Observatories was at the cutting edge of technology and posed substantial management challenges, but they nevertheless went on to achieve striking levels of success. The Great Observatories have provided major scientific discoveries that have attracted national and international attention, including this year's Nobel Prize in Physics for the discovery of the acceleration of the expanding Universe. The Great Observatories have demonstrated to the world that the United States has the technological base and management expertise through NASA and its contractors to execute such major projects and

implement uniquely powerful space observatories. Even now, no other nation can execute missions of such complexity. Europe and Canada are important partners who have demonstrated their commitment to JWST. While Canada and Europe are playing key roles, neither their capabilities nor their resources would enable them to do such a mission in its entirety.

Why are we doing JWST? The James Webb Space Telescope is an astonishingly powerful observatory that will be placed nearly a million miles from Earth, beyond our Moon. Its scientific power arises from the size of its mirror, and from the cold temperature of its mirrors and instruments, which run at a chilling –380° F, hundreds of degrees colder than the coldest place on Earth. Cold telescopes have been operated in space before JWST (like Spitzer and the European Herschel), but never one as large nor one with such exquisite optics. And never one with such a large sunshade (the size of a tennis court) to make sure it can keep so cold. JWST's instruments will collect and analyze light in ways that our current telescopes in space cannot do, and will do so to incredibly faint limits, to explore our universe to unheralded depths.



JWST was conceived to answer questions about our origins and our place in the universe. These origins questions lie at the heart of many of our deepest feelings about what it is to be human. The questions that JWST will help answer are very fundamental, like how the Earth formed and how unique it is, and how galaxies like our Milky Way grew from the first galaxies. JWST will search for and find other solar systems and will study planets for signs of liquid water on their surfaces or in their atmospheres. Our galaxy, the Milky Way, grew from the tiny young galaxies that Hubble has revealed. Yet Hubble can only explore the fringes of the dark ages 13.5 billion years ago when the first stars and galaxies formed. JWST is designed to take us back into the realm of the first stars and galaxies. Hubble first revealed to us the mysterious dark energy that today governs the expansion of the universe itself. JWST will take key steps in furthering our knowledge of the role of dark energy and also of the ubiquitous dark matter that dominates the mass in the universe.

The Hubble Space Telescope is widely recognized as being one of NASA's greatest achievements. What is remarkable is that it was done at a total lifecycle cost that is a tiny fraction of NASA's budget over its lifetime. As the successor to Hubble, JWST should carry the torch in the same way for NASA.

As the ICRP noted: "JWST will play a key role in understanding how and when the first galaxies were born, characterizing the planets that are now being discovered around nearby stars, in providing further insights into the nature of the dark energy and dark matter, and into how stars and planetary systems are born. There is no easy path to understanding such complex scientific questions. To do these things at the level needed to advance scientific understanding requires a complex telescope with truly unique capabilities. JWST is that telescope."

JWST and the Decadal Survey: The potential of large, extraordinarily cold telescopes with exquisite optical systems and powerful instruments was recognized over 22 years ago by scientists and engineers at the Space Telescope Science Institute in Baltimore, but the ability to build such a telescope only became possible in the late 1990s. Astronomers recognized the incredible value of such a telescope and selected it

as their top-ranked project in the 2000 Astronomy Decadal Survey "Astronomy and Astrophysics in the New Millennium" (JWST was then called the "Next Generation Space Telescope," or NGST).

The Decadal Survey strategic planning activity involves hundreds of astronomers and is widely seen as one to the most mature and valuable of its type. The desires of scientists for major facilities always exceeds the available resources, and it was recognized as long ago as 1960 that a science community-based effort to develop a prioritized list of programs would be immensely helpful to policy-makers and funders in knowing what the astronomy science community thought were the most important projects. Each decade since then, astronomers have undertaken the huge effort to develop a strategic prioritized plan.

As a result of the recommendation in 2000 for JWST as the top-ranked program, JWST was subsequently adopted into the NASA space science program (as NGST) and began to become a reality through the first part of this century. To do so required the development of ten major new technologies and their maturation to a level suitable for a space mission. The JWST program did this by early 2008 and was subsequently moved into the development phase after its Confirmation Review in 2008.

The scientific promise of JWST was reinforced throughout the recent 2010 astronomy Decadal Survey *New Worlds, New Horizons in Astronomy and Astrophysics* chaired by Dr Roger Blandford of Stanford University, and a witness at this Hearing. The results of this strategic plan were released in 2010. JWST was not explicitly ranked since it was under development and expected to be launched in 2014. As such it was a foundation for the future program. An evaluation of the Decadal report shows that JWST is a cornerstone of the science goals for the coming decade and underpins the report's recommended missions. For example, in the new and exciting area of exoplanets, the 2010 Decadal Survey states that "JWST will be a premier tool for studying planets orbiting stars that are smaller and cooler than the Sun." The importance of JWST for planetary science was also noted in the recent 2011 planetary Decadal Survey *Vision and Voyages for Planetary Science in the Decade 2013-2022* which states that "JWST will contribute to planetary science in numerous ways...." and that "the Hubble Space Telescope has a long history of successful planetary observations, and this collaboration can be a model for future telescopes such as the James Webb Space Telescope."

The decadal planning process produces a prioritized list of missions, and these are normally done in sequence with some overlap. Changes to budgets or mission timescales or both are not uncommon for NASA Space Science and the outcome has usually (but not always) been delays to other missions in the priority queue. This is not desirable and hurts the pace of scientific endeavor in many areas. It is unfortunate that the impact of a more realistic cost for JWST was compounded by our larger national budget problems. However, experience has shown that delays are often unavoidable, and ultimately missions get done if their scientific value is still high.

I will discuss below why we got into this situation with JWST, but more importantly how we can ensure that further problems do not arise. I will do this in the context of the questions that I was asked about the Independent Comprehensive Review Panel's report and the response of NASA.

Has JWST impacted WFIRST? The revised schedule for JWST has also led to discussion within the science community about the Wide-Field Infrared Survey Telescope (WFIRST), the top-ranked mission in the 2010 Decadal Survey. In 2007 the National Academy undertook a study at NASA's request to choose a mission as the next to be done in the Beyond Einstein theme in the Astrophysics Division. The Joint Dark Energy Mission (JDEM) was chosen, but it had not progressed far before the 2010 Decadal Survey was initiated. The Decadal Survey reconsidered the possible suite of space missions for astrophysics, and selected as its top priority an extension of the JDEM concept, called WFIRST. As a result of its high ranking, WFIRST was expected to be one of the first major missions to follow JWST, though a similar European mission (Euclid) was already in progress and was somewhat more advanced in its development. JWST will make significant

steps in characterizing the effect of Dark Energy on the universe, and then it was anticipated that this would have been followed by Euclid and WFIRST, or by some joint program.

With the delay in JWST, the timescale for WFIRST has changed and it too will be delayed. Unfortunately this is not the only question facing WFIRST. The European Space Agency recently approved its dark energy mission Euclid. While different in a number of aspects from WFIRST, that mission will now inevitably launch on a shorter timescale than WFIRST, regardless of when JWST is launched. This has resulted in some discussion regarding what to do regarding WFIRST. The path forward is less clear and needs further consideration by the astronomy community.

Why is JWST important for the US at this time? I have commented above on why the Great Observatories are important for our nation, and also to some extent why JWST is similarly important. Nonetheless, with the current discussion regarding the fiscal situation in the US, it is appropriate to address this more explicitly and directly. Does the same rationale exist for doing another Great Observatory? Should we still do JWST?

I say unhesitatingly "**yes**" that the rationale is even stronger than it was in the past for a new Great Observatory to succeed Hubble. There is deep concern about America's role and place in an increasingly competitive world. Our scientific and technological leadership must be enhanced to remain at the forefront. By making such leadership a key part of our national aspirations we will be strong, and be seen to be strong. STEM education initiatives are even more important than they have been in the past. Technological leadership is increasingly important as China, Brazil, India and other nations become increasingly sophisticated and competitive. High technology jobs also are less able to be "off-shored", pay well and so have a large economic multiplier effect (leading to other jobs locally). Flagship space missions like the next Great Observatory JWST play a crucial and highly visible role in all these areas. It is at times like these that we should strive to do such a mission. *Doing JWST now is vitally important for the nation.*

JWST's Problems: What led to the formation of the ICRP?

As noted above, JWST was the 2000 Astronomy Decadal report's top-ranked project (then still called NGST). JWST was understood then, as now, to be the successor Great Observatory to the iconic Hubble Space Telescope. Work on JWST began by NASA with support from Congress and the Office of Management and Budget (OMB). The prime contractor TRW (now Northrop Grumman) was selected in 2002. Given the complexity of the project, JWST then had a prolonged technology development period. These technology developments took longer and so cost more than initially forecast. NASA Administrator Michael Griffin noted that JWST had been "underfunded" during its early phases. Nonetheless, the continuing scientific discoveries of Hubble, combined with the realization of the scientific potential of JWST, led to support for completing and launching JWST. The JWST project had met the required technology challenges and successfully passed its NASA Confirmation Review in 2008, moving JWST into its implementation phase.

The latest 2010 Astronomy Decadal Survey reaffirmed the scientific importance of JWST as a cornerstone of the Decade's science program. Yet concerns were growing about the budget and launch date. During 2009 and particularly 2010 it was becoming clear that the JWST program was facing significant problems and that its new launch date of June 2014 was increasingly unlikely to be met. Along with that uncertainty regarding the launch date was a growing concern that the total cost of the program had been underestimated.

The support for what JWST could do was increasingly being tempered by concerns about the robustness of the Project's cost estimates. Senator Barbara Mikulski, Chairwoman of the Senate Subcommittee on Commerce, Justice, Science and Related Agencies of the Committee on Appropriations, noted the frustration and concern about the budget problems in a letter to Administrator Bolden requesting an independent review of JWST. She also noted that "The James Webb Space Telescope will be the most

scientifically powerful telescope NASA has ever built—100 times more powerful than the Hubble, which has already rewritten our textbooks."

The Independent Comprehensive Review Panel was thus established in late July 2010 by the NASA Administrator in response to the letter by Senator Mikulski. The Chairwoman's concerns regarding JWST were clearly expressed in her letter. The Panel was asked to address the following four areas:

1. *The technical, management, and budgetary root causes of cost growth and schedule delay.*

2. *Current plans to complete development, with particular attention to the integration and test program and management structure.*

3. *Changes that could reduce cost and schedule or diminish the risk of future cost increases without compromising Observatory performance.*

4. *The minimum cost to launch JWST, along with the associated launch date and budget profile, including adequate reserves*

Results from the Independent Comprehensive Review Panel

The ICRP was a highly experienced group with diverse backgrounds in large space projects. Between the Panel's kickoff meeting in August 2010 and the delivery of the Panel report on October 29, the Panel undertook an intense and focused series of fact-finding interviews and carried out an analysis of data and documents. The Panel took an objective, thorough look at the project, and how it was managed, with the goal of providing recommendations that would lead to a successful launch for JWST at the earliest opportunity and with the smallest additional investment by the nation. The report responded to the areas above, and structured the results of its deliberations as a series of findings, assessments and recommendations.

The focus of the ICRP was on recommendations to fix the management and oversight problems that had arisen in the JWST project. The Panel noted, however, that substantial technical progress had been made on JWST with the $3B spent by 2010. The Panel stated "The technical performance on the Project has been commendable and often excellent." This statement was made again more clearly by the ICRP Chair, John Casani, in his transmittal letter of November 5 to the NASA Administrator "In summary, the Panel concluded that the JWST Project is in very good technical shape. There is no reason to question the technical integrity of the design or of the team's ability to deliver a quality product to orbit. The problems causing cost growth and schedule delays have been associated with budgeting and program management, not technical performance."

The core product of the Panel's deliberations was 22 recommendations that grew out of the Panel's deliberations, findings and assessments. These have been the focus of NASA's response to the ICRP.

In addition, the explicit response to "minimum cost to launch" was also presented. This was the Panel's estimate of the minimum cost to launch JWST, its launch date, and a funding profile to support that launch. The Panel's analysis of this was necessarily limited, given the very short period over which the Panel had for its report. The Panel concluded that the earliest possible launch date was September 2015, and estimated that the lifecycle cost (LCC – which includes post-launch operations) associated with this launch date was $6.5B. The Panel also provided a funding profile that needed to be met to accomplish the launch by this date. Central to this being achieved was a substantial increment in funding in FY2011 (to $710M) and in FY2012 (to $640M) to ensure that the JWST program got back on track.

It is worthwhile to note here the ICRP's cautionary words at the end of subsection 4.4 "Minimum Cost to Launch" on page 10 of its report: "It was not possible to develop an independent and more in-depth estimate in the time available. Given that a bottoms-up cost estimate has not been done since the contract was awarded, a bottoms-up estimate is needed for the entire the JWST Project. The estimate should be

validated by an independent analysis of the basis of estimates and the underlying assumptions and at least two Independent Cost Estimates (ICE). Although not explicitly accounted for in these numbers, there are a number of recognized low probability, high-consequence threats that, should they occur, could cause an additional year delay in launch and a correspondingly higher cost."

How NASA has responded to the recommendations is discussed below in the context of my response to the Committee's three questions to me. The difference between the Panel's assessment of the earliest possible launch date and the corresponding total cost of the JWST program, and what has developed as a result of the bottoms-up cost and schedule effort undertaken by NASA this year, will also be discussed below.

QUESTION 1: What were the major faults cited by the Independent Comprehensive Review Panel that led its members to conclude NASA would not be able to meet the cost and schedule estimates as they existed in 2010? How does the replan address these issues?

Within the limited time available to the ICRP the decision was made by the Panel to focus on the JWST Project following the Confirmation Review in July 2008. Confirmation is a critical milestone in any such project and marks a point where the project is set on a course to a defined launch date with the needed budget and a well-defined budget profile. The ICRP recognized that the prior history is important and that budget problems in particular cannot be fixed rapidly – the pace of the federal budget process necessarily leads to large lag times for fixes to be implemented. With just 2 months of effort it wasn't practical to delve too much into the pre-Confirmation issues. Nonetheless, decisions prior to July 2008 in the Science Mission Directorate played a significant role in the challenging environment faced by the project immediately after Confirmation.

Faults – Lack of reserves and deferred work. My short summary of why the JWST project was increasingly deviating from the Confirmation review baseline during 2008, 2009 and 2010 was that **the JWST project did not have adequate "reserves" in those years, and therefore needed to defer work when problems arose**. Reserves are a crucial part of any large technical project in industry or government, particularly in a new or one-off project. I discuss in more detail below why reserves are needed. The essential point is this: if the reserves are not adequate when an unexpected issue arises, then scheduled work must be deferred. Deferring work is widely known to lead to serious cost implications for large complex projects at the cutting edge of technology. If work must be deferred to fix a more serious immediate problem, then the cost impact to the project overall is, on average, 2-3x the actual cost of the work deferred, because of the impact of the unperformed work on dependent areas. This is well established within the experience of managers of major high-tech projects. Deferral of work quickly leads to serious problems for a project's schedule and budget. The only way to ensure that work is not deferred is to have adequate levels of reserves that can be applied quickly to solve problems.

The reserves for the JWST program were inadequate prior to confirmation. The limited resources and lack of reserves for JWST, particularly from 2005-2008 meant that the JWST project was in a "go as you can pay" mode for its technology development activities. While not ideal, it is not unusual during development *prior* to the Confirmation Review. However, this is not appropriate *after* Confirmation when the Project is now set on a path to build and launch to a budget and schedule. **Adequate reserves in every year are then not just desirable, they are essential if the project is to be completed within cost and to schedule.**

At Confirmation, NASA attempted to rectify the lack of reserves, but it was faced, unfortunately, with a serious constraint in that the 2008 President's Budget Request did not contain adequate reserves for the JWST program. This was the case even though the NASA Administrator Michael Griffin had set the requirement by 2006 that the budgets for all major projects, and in particular JWST, must be developed to a high level of confidence with the appropriate reserves. However, the prior SMD Associate Administrators had not developed a budget by Confirmation for JWST with the reserve level required by NASA policy. At

Confirmation reserves were added, but only in the later years of the five-year NASA budget. Not enough was added in the near-term, in part, apparently, because of the constraints imposed on changes to the funding for JWST by the existing 2008 President's Budget Request (since the SMD-developed budget failed to include the required reserves).

After JWST's Confirmation, SMD tried to fix the reserve situation by adding funds to the JWST program but it proved hard to do so in the near term. This lack of immediately available reserves hindered the project. Efforts were made in 2008, 2009 and 2010 within SMD to reprogram funds and request additional funds, but it was never quite enough. Without adequate reserves, year after year, the Project kept deferring work and consequently digging itself a deeper fiscal hole as described above, until in 2010 the problems became so apparent that the ICRP was formed, following Senator Mikulski's request.

Why are reserves important? In the oft-quoted words from the recent past, projects of this complexity are inevitably faced with problems that fall in the "known unknown" and the "unknown unknown" categories. No project will be free of unexpected issues, especially very complex technologically advanced projects. **This is not a reflection of management incompetence, management inexperience, poor oversight or lack of independent assessment.** Numerous highly experienced and capable companies have experienced major problems with large projects (witness Boeing with the 787 and Airbus with the A380).

A project of the complexity and uniqueness of JWST will always encounter problems that have not been foreseen, and it is to deal with these problems that reserves are needed. Many of us have had first hand experience of this when doing a home remodeling project like a kitchen or bathroom. Something unexpected always seems to arise (often many problems) which cause one to require fixes to plumbing or electrical or structures, none of which were quite accommodated in the original work plan. Imagine what it is like when one is building a brand-new type of machine with technology that is being invented for the very first time, where there are incredibly tight specifications on large numbers of individual items, and where the contractors are not just in one's home town but spread over about 30 states!

The only way to improve the reliability of the projections for launch date and total cost is to adopt a very conservative approach that ensures problems can be fixed quickly and efficiently when they arise. This is what the ICRP highlighted. In fact the first three recommendations reflect the importance we attached to this aspect: (1) Develop a new baseline cost and schedule plan-to-complete that incorporates adequate contingency and schedule reserve in each year. (2) Include a realistic allowance for all threats in the yearly budget submission. (3) Budget at 80% confidence, and require 25% reserves in each year through launch.

Faults – Oversight and Independent Assessment. There was another rather broad issue that suggested to the ICRP why the project was in trouble. This related to the inadequate tracking of progress and problem identification within the Project. This was exacerbated by the lack of cross checks and independent assessments within NASA. Together these meant that the magnitude of the Project's problems was not understood, nor was it realized just how unlikely the 2014 launch date was. The bulk of the ICRP's recommendations related to the need for broader understanding within the Project of the performance of its many subsystems, at its contractors and within GSFC. In addition, a more thorough ongoing independent assessment of the Project's performance was needed to reveal any problems as quickly as possible. The ICRP identified changes that were needed within the JWST Project, with oversight at the GSFC management level, with a restructuring and strengthening of the JWST program office at NASA HQ, and with a strengthening of the role and capabilities for estimation and validation of the Independent Program and Cost Evaluation (IPCE) Office at HQ.

Faults – Communication. A further contributing factor to the problems being experienced by the JWST project was poor communications with the prime contractor Northrop Grumman, with the Astrophysics Division and the office of the Associate Administrator for the Science Mission Directorate at NASA HQ, with the science team, and even within the JWST Project.

How does the replan address these issues? I have been very encouraged by the effort that NASA has undergone to respond to the recommendations of the ICRP. Some could be dealt with very quickly and were rectified very quickly. Others became the focus of longer-term changes.

A significant effort was put in to improve the communications and the relationship with the prime contractor Northrop Grumman. My sense is that this relationship has improved greatly, as have communications between other key elements of the program. Experience shows however, that this will require continual attention to ensure that problems do not arise again.

A very important improvement is the establishment of a JWST Program office at NASA HQ reporting both to the Science Mission Directorate Associate Administrator and the NASA Associate Administrator, right in the Office of the NASA Administrator. In addition, the Project Manager and the Budget Manager within the JWST Project at Goddard Space Flight Center (GSFC) were changed. The GSFC Director took responsibility in his office for an ongoing evaluation and oversight role. These changes were all consistent with the ICRP recommendations. Current indications are that these changes have made substantial improvements in the JWST Program. More definitive results will become available as progress against milestones is evaluated.

One area that I remain somewhat concerned about is that of the Independent Program and Cost Evaluation (IPCE) Office. The IPCE evaluates performance against technical and programmatic milestones. I learnt from a wide range of very experienced people the value this office had provided in the past. It appears not to have been rebuilt to recover those prior capabilities that reportedly have served NASA very well in the past. I understand that part of the challenge is finding senior experienced people who can provide the core of that group's expertise. I hope that IPCE is enhanced in the future and provides senior NASA management the same level of independent insight into its programs (and particularly JWST) as is being implemented by the Center Director for JWST.

The central issue for the JWST project is the robustness of the new budget and launch date. The replan has involved a great deal of effort on NASA's part. The Administrator's commitment to JWST through his characterization of JWST as one of the top three programs for NASA brings a welcome focus. The willingness in difficult budget times to explore an approach where 50% of the needed increase comes from elsewhere in the agency is also greatly appreciated by the science community. For some time it proved difficult to get information about the JWST replan since many of the details were embargoed as part of the process for the FY2013 President's Budget Request. However, we now have seen much more information on the replan in the last few months. This more open appraoch is important and greatly appreciated.

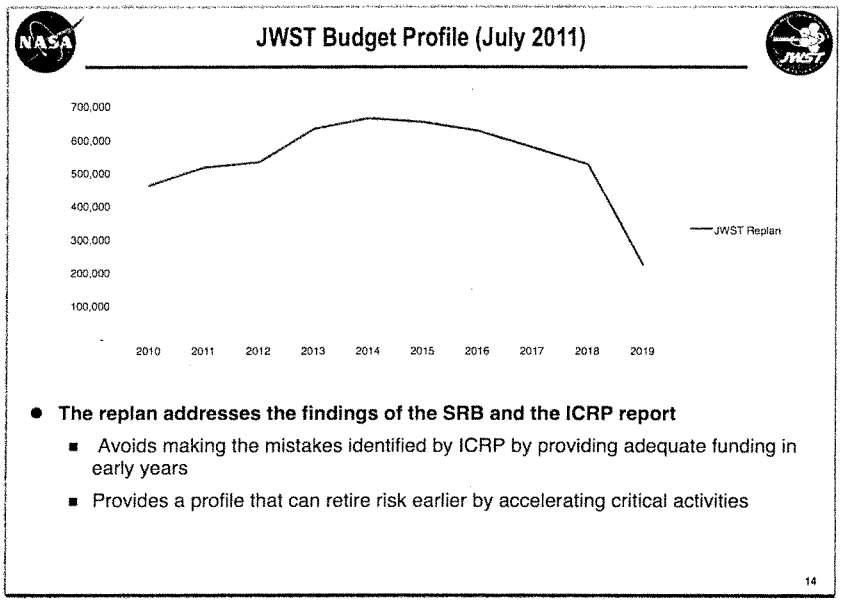
It appears to me from all that I have seen that considerable effort was made to meet both the detailed statements and to encompass the spirit of the ICRP recommendations. NASA derived a budget that was conservative, with a very balanced reserve situation from now through to launch, with both cost and schedule reserve that meet the ICRP's recommendations. I have no doubt that there will be major challenges ahead for the JWST program. The reserve situation should allow these to be met, but no one can give a 100% guarantee that the cost cap can be met or that the launch date will be met under all scenarios. Nonetheless, the replan and the associated budget profile leaves me with high degree of confidence that this program is now on a track to get JWST launched in 2018.

QUESTION 2: How confident are you in the new cost and schedule estimates for JWST?

Since the ICRP report the JWST program, led by Rick Howard at NASA HQ, has undertaken a comprehensive effort to develop a new plan (called the "replan") for finishing and launching JWST. Details of this plan and the associated cost profile and the schedule have been released to the public in several stages over the last few months as OMB approved release of cost projections. What I have seen indicates that NASA's approach is responsive to the recommendations of the ICRP "that NASA do a bottoms-up cost estimate with a high level of confidence, with cost and schedule reserves consistent with the 80% confidence." The replan for JWST has resulted in a lifecycle cost (LCC) of $8.835B with a launch in October 2018. LCC

includes operations and scientific research following launch (about 10% of the total). The total cost to launch is consistent with the $8B cap set by the recent FY2012 appropriation language for NASA, with about $4.5B more needed to reach launch (about $3.5B has been spent to date).

The "replan" schedule, budget, and cost profile appear to me to be broadly consistent with the recommendations of the ICRP, with adequate reserves spread across the program, and not just bunched up at the end near launch. Several cross-checks were performed by other groups with project modeling capability (Aerospace, IPAO and GSFC). I understand that the Standing Review Board (SRB) chaired by Jean Oliver evaluated an early profile developed as part of the replan and declared that it was not executable because of the very fast ramp-up from the President's budget request number for FY2012 to a large "get-the-project-back-on-track" funding level in FY2013. The subsequent revised budget profile, shown here, rectified that problem. As I assess the discussion of the replan in a variety of public presentations made to FACA committees I think that **the JWST program has developed a vastly more robust plan than that following Confirmation, and one that meets both the detailed recommendations and the spirit of the ICRP's report.**



To respond to the question posed by the Chairman let me do it in the context of a series of statements made by the ICRP.

In the ICRP report on page 9 in section 4.3 "Changes to Diminish Risk of Future Cost Increases", the Panel identified a number of changes to diminish the risk of future cost increases and delays to the launch date.

They are (with numbers added here so that I can easily refer to the bullets below):

- *(1) 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.*
- *(2) 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.*
- *(3) Assign management and execution responsibility for the JWST Project to the GSFC Director, with accountability to the Science Mission Directorate Associate Administrator at HQ.*
- *(4) 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 ICEs for major milestone reviews.*
- *(5) 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.*

Of these changes (which were laid out more explicitly amongst the 22 recommendations from the ICRP), my assessment is that (1) and (2) have been done, (3) has been accepted and is being developed more fully as the JWST project begins to work to the replan, but (4) remains a work in progress, and appears to be the one area of the ICRP report that remains "unfinished" in its implementation. (5) is the set of changes most directly relevant to the Chairman's question, though all play a role in developing confidence in the replan. The full details of the replan are expected to be available after the President's FY2013 Budget Request is released early next year and so additional insight will be obtained for (5) after that release, but the replan appears to have been built on the recommendations encompassed within (5).

Some concerns have arisen because of the difference between the ICRP recommendation of a launch in September 2015 with an LCC of $6.5B, and what was the baseline in the replan. As was mentioned above the ICRP estimate was necessarily short and superficial, and was responsive to the request in the fourth item for an estimate of *the minimum cost to launch JWST, along with the associated launch date and budget profile, including adequate reserves.* A key requirement for JWST to launch with minimal delay from the then June 2014 launch date was an **immediate** infusion of substantial funding to get JWST back on track. The ICRP funding profile called for $710M in FY2011 and $640M in FY2012. The ICRP recognized that this was challenging, given the great difficulty associated with increasing funding on a short timescale within the Federal budget process. Since the recommendations were made early in FY2011, during the time when the President's FY2012 budget request was being worked, this added to the challenge. In fact the ICRP noted on page 34 that ....*if no additional funds can be found in FY 2011, further delays in the launch date and significantly increased costs will occur.*

The summary on page 34 of the ICRP's thinking regarding its estimate puts the ICRP $6.5B LCC in perspective: "To get the JWST Project "back on track" in an efficient and cost-effective way toward realizing a minimum cost-to-launch budget requires significant additional funding in FY 2011 and FY 2012 (approximately $250M in each year), This would enable the Project to recover from inadequate reserves and past management and oversight decisions that have resulted in deferral of key work. These estimates lead to a cost-to-launch (FY 2011 through launch plus commissioning) of approximately $2.9 billion. Note that if no additional funds can be found in FY 2011, further delays in the launch date and significantly increased costs will occur. The most efficient approach is to increase the Project's FY 2011 funding."

Given that only a small amount of additional funding could be found in FY2011, and that the increase in FY2012 to $530M was less than the ICRP's recommendation of $640M, it is clear why the launch date moved out and the cost to launch grew significantly from the ICRP estimate.

My assessment is that NASA has taken a uniquely conservative approach to costing this mission and has developed the JWST replan with a high level of confidence that has not been used before for such a major program. I personally am more confident that this program can finish and launch on its scheduled date within the cost cap set by Congress than I have been for many other programs that I have watched during their formulation and implementation phases.

QUESTION 3: What are the chief technical and programmatic challenges facing JWST?

The mirrors and their backplane support were recognized early in this program as being a particularly difficult area, but the decision to work these early was a wise one. Work remains but the delivery of all the mirrors and their overall in-spec performance is a real success story for JWST.

In the past I would have responded that the biggest challenge for JWST was the lack of reserves. Fortunately the ability of the program to respond quickly, efficiently and effectively to problems has greatly improved with the new reserve structure. It is important to fund JWST with the profile developed in the replan so that the ability to respond and fix problems quickly continues over the remaining years of the project. Nonetheless challenges will inevitably occur.

I have enumerated, as requested, the areas that I see as the most challenging. The number of these areas should not be taken to indicate that the JWST Project is in trouble or has an unusually large number of challenging areas. It does not. This is a complex program involving many new developments using cutting-edge technologies. With appropriate management attention, reserves and oversight these challenges can be overcome (and, I expect, will be overcome).

The challenge of testing JWST must sit close to the top of any list of challenges. Unlike Hubble, JWST cannot be serviced and so post-launch opportunities to rectify problems are not available to us. Since JWST operates at such a cold temperature and is so large, the testing regimen is comprehensive and lengthy. Careful and thorough preparation will be needed before testing begins, and focused decisive management will be needed during the test phase. The Test Assessment Team (TAT), also chaired by John Casani, gave visibility to the challenges in this area in their report. This resulted in more attention being paid to planning for this activity. Significant effort is being invested on cryogenic subsystem testing.

The sunshade must also take its place high up in the list of the challenges. This has also been given early attention since the difficulty of building such a huge deployable membrane has been recognized. Extensive development and the production of smaller scale models, plus full-scale structures and membranes, indicate that this is being approached thoroughly and diligently.

The Integrated Science Instrument Module (ISIM) has received some visibility recently. It is a complex and crucial component for the mission since it contains all the science instruments. The science instruments are being readied for delivery so that they can be "integrated" into the ISIM. The ISIM was one of the areas noted by the ICRP as being a significant problem in the past for the JWST project, with large cost growth, similar in percentage terms to that at the prime contractor. A number of issues are being worked, as expected, as the integration and testing proceeds. The most significant problems have been the subject of discussion (the cracked NIRSPEC optical bench, the FGS tunable filter, the Northrop Grumman cryocooler, and, in particular, the Teledyne detectors). Recovery efforts are underway that indicate that these problems can be rectified and will not impact the schedule (the ISIM is not on the critical path). The complexity of the ISIM and the instruments suggests that the ISIM will remain a challenging area that will require close attention by the Project and the Goddard Center.

Other areas that are frequently commented on include the spacecraft that supplies much of the basic infrastructure needs of JWST. This is being developed late in this program (the Critical Design Review is in 2014) because of an early focus on higher risk elements and the limited early funding. The risk of delaying the spacecraft has been recognized and work is being done related to critical interfaces to minimize the problems that could arise in dealing with interfaces to completed systems. The challenges attendant in deploying a large precision optical system and the membrane sunshade are also frequently mentioned.

I have mentioned a number of areas that I see as being in the arena of "challenges" to respond to the question, but I would note that these do not appear to me to be extraordinary for such a major project at this point. The technical successes of the JWST program are real, worthy of praise and a source of national pride. Challenges lie ahead, but that is normal for such a complex project with its many unique technologies. NASA is on track to launch the largest and most powerful space telescope ever built, for less than the lifecycle cost of Hubble in current dollars (which is about $12B).

I will end this section by noting what I see as the most critical factors for JWST to be launched on schedule in late 2018 within its $8B cost cap. These are (i) that JWST be fully funded with adequate reserves, (ii) that the management team keep all the diverse elements of the program focused on meeting their milestones and schedules during the lengthy period that remains, and (iii) that both the Project and the independent assessment groups work diligently to identify problems and then address them rapidly.

Summary

The JWST program at NASA has made exceptional efforts to respond to the concerns expressed last year by policy-makers and funders across the Administration and Congress. In substantial part, this was done by NASA responding very positively and quickly to the recommendations in the ICRP report and acknowledging that substantial changes needed to be made. NASA has taken to heart the need for change and has developed a program that should lead to a successful outcome. As I noted above, my assessment is that NASA has at last taken a uniquely conservative approach to this major mission and has developed the JWST replan with a level of confidence that has not been used before for such a major program. JWST will be a dramatically more powerful successor to Hubble. JWST will demonstrate our national spirit of doing the very best, and will likewise demonstrate our commitment to our scientific, educational, and technological heritage.

I thank the Chairman and the Committee for their interest in JWST, and for this opportunity to help relay my excitement, that of the scientific community, and that of the public about the opportunity that lies ahead. We have been entranced by Hubble, and are looking forward to Hubble's successor, the James Webb Space Telescope, to build on the legacy of Hubble and revolutionize our understanding of the universe of which we are a part.

Chairman HALL. Dr. Illingworth, I thank you very much, sir. Mr. Grant, present your testimony, five minutes. Thank you.

STATEMENT OF MR. JEFFREY D. GRANT,

SECTOR VICE PRESIDENT AND GENERAL MANAGER,

SPACE SYSTEMS DIVISION, NORTHROP GRUMMAN AEROSPACE SYSTEMS

Mr. GRANT. Chairman Hall, Ranking Member Johnson, and distinguished Members of the Committee, thank you for inviting me here today on behalf of the men and women of Northrop Grumman who are supporting the James Webb Space Telescope. I, too, commend the Committee for your continued support and oversight of the space program and especially with regards to your interest in the James Webb Space Telescope. I would also be remiss if I did not recognize NASA's leadership in making the Webb Telescope Program possible and also acknowledge the extraordinary contributions of our innovative science community. It is through our combined efforts and expertise that we come together to build the world's next great observatory.

It was in 2002 when Northrop Grumman, then TRW, was awarded a key contract on the James Webb Program, a larger-than-ever space telescope required to operate at ultra-cold temperatures, designed to explore the first stars and galaxies of the universe, and study extrasolar planets. Without question, these are significant capabilities and it was a significant challenge. The Webb Telescope represents a capability beyond anything attempted by NASA, our Nation, or anywhere in the international community.

As for our role at Northrop Grumman in the Webb Telescope program, the estimated contract value over the lifetime of the program is estimated at $3.5 billion, with nearly half of those funds already applied to advancing key technologies, completing designs, and fabrication of critical hardware.

We currently employ approximately 265 engineers, scientists, technicians, and support staff at our Space Park facility and partner with 193 suppliers in 31 states across the country.

In your invitation letter, Mr. Chairman, you asked that I respond to three specific questions. One, what are the technical and programmatic challenges facing the Webb Telescope Program; two, Northrop Grumman steps to ensure costs and schedule deadlines are met and; three, the role of integration and testing as we move the program towards completion.

As others have testified here earlier, I reemphasize the point, our chief technical challenges on the Webb Telescope, I believe, are in two major areas. One is the completion of the build and testing of the telescope itself, and two, in building and testing the thermal management system. Though much as been accomplished, challenges remain, and we recognize we need to do better moving forward.

In the second area you asked about, we have responded to the Casani Panel findings and have made significant management leadership changes, management oversight changes, and through improved communications and decision-making processes, have

strengthened our relationship between our team, NASA, and our partners.

We continuously evaluate actions to contain costs and have implemented a series of improved financial controls in the form of metrics, reports, and early alerts. These measures have been designed to ensure contractual discipline to avoid unintended cost growth.

The Webb Telescope has a clear path forward and we have evidence that the current plan is proceeding on track.

Lastly, the Webb Telescope Program has a detailed integration test and verification plan which was designed to reduce program risks through methodical, incremental build and tests, retiring risks at each successive integration level of the observatory. These integration and test practices have served our other satellite systems very well as we typically see our satellite systems last for many years longer than specified.

In conclusion, Mr. Chairman, I understand the concerns the Committee has raised and feel confident that Northrop Grumman has taken the necessary actions to address the technical and programmatic challenges before us. We are also taking the proper steps to assure cost and schedule guidelines are met, and we are enabling our team to successfully reach program completion by meeting integration and test milestones for the Webb Telescope. I am honored to join my distinguished colleagues on this panel today, and thank you for asking me to appear before your Committee. I welcome the Committee's questions and ask that my full statement as provided to the Committee be inserted into the record.

[The prepared statement of Mr. Grant follows:]

Prepared Statement of Mr. Jeffrey D. Grant, Sector Vice President and General Manager, Space Systems Division, Northrop Grumman Aerospace Systems

Before the House Committee on Science, Space, and Technology
The Next Great Observatory: Assessing the Next Great Telescope

Chairman Hall, Ranking Member Johnson, 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 James Webb Space Telescope (JWST), National Aeronautics and Space Administration's (NASA) next great observatory. Identified as a top priority for astronomy and astrophysics by the National Research Council, JWST will reach beyond the Hubble Space Telescope, and serve as a key program for the world's ground-based and space-based astrophysics community. I commend the Committee for your continued support and oversight of the space program, especially with regards to your interest in JWST, and appreciate your commitment to further science, technology, engineering, and mathematics education.

I would be remiss if I did not recognize NASA's leadership – notably Goddard Space Flight Center, and the important contributions of the Johnson Space Center, Marshall Space Flight Center, and the Jet Propulsion Laboratory – that make the JWST program possible. Additionally, NASA's international partners, the European Space Agency and the Canadian Space Agency specifically, are providing key instruments and the launch vehicle. This program has also benefited from the invaluable contributions of the Space Telescope Science Institute, which serves as the Science and Operations Center for the mission. Finally, I must also acknowledge the ongoing contributions of our innovative science community. It is our combined efforts and domain expertise that bring us together as we build the world's next great observatory.

In 2002 Northrop Grumman (then TRW) was awarded a key contract for JWST, a larger-than-ever space telescope; required to operate at ultra-cold temperatures, designed to measure and explore the first stars and galaxies born in the universe, study planetary systems similar to our own, analyze the molecular composition of extrasolar planets' atmospheres, and directly image Jupiter-size planets orbiting nearby stars. Without question, JWST represents a challenge and capability beyond anything attempted by NASA, our nation, or anywhere in the international community.

As for Northrop Grumman's role in JWST, the estimated contract value for Northrop Grumman over the lifetime of the program is approximately $3.5 billion, with nearly half of those funds applied to advancing key technologies, completing designs, and fabrication accomplished to date. About half of Northrop Grumman's work is in-house, and half is apportioned to our subcontractors. Projects like JWST, as amazing as our discoveries will be, are about more than the science. This project has created a network of high-tech jobs across the country, capabilities that would not otherwise exist, and will lay the foundation for additional programs that need large deployed optics in space.

We currently employ approximately 265 engineers, scientists, technicians, and support staff at our Space Park facility in Redondo Beach, California, and in our efforts we

partner with 193 suppliers across 31 states that harness the most advanced technical expertise in America. You can tour the country visiting the facilities and laboratories touched by the JWST program, from the JPW Welding Company in Syracuse, New York who created their most high-precision structure ever in order to be able to hold our telescope, or through the L-3 Integrated Optical Systems facility in Richmond, California where there is now a production line to make high precision mirrors. These abilities are cutting edge and uniquely American.

Mr. Chairman, at our most senior levels, Northrop Grumman takes great pride in our role as NASA's partner on the JWST program and remains fully committed to the success of its mission. We are deeply motivated, both personally and financially, to deliver a successful, on-budget and on-schedule mission.

In your letter inviting me to appear before the Committee, you asked that I respond to three specific questions: (1) What are the chief technical and programmatic challenges facing JWST?, (2) What steps is Northrop Grumman taking to ensure costs and schedule are met? How confident are you of the new cost and schedule estimates?, and (3) What is the role of integration and testing for the program completion? I offer responses, along with those of my fellow panelists, to inform the Committee's interest with regards to JWST.

Addressing Technical and Programmatic Challenges

JWST's chief technical and programmatic challenges are centered on building and testing the telescope and the thermal management system. To put our challenges in perspective, the JWST mirror is six times larger than the Hubble Space Telescope mirror and the satellite will weigh just over half as much. This telescope must be packaged for launch on an Ariane V rocket and then deployed a million miles from Earth where it will be operated at approximately 40 degrees Kelvin, which is negative 388 degrees Fahrenheit.

Northrop Grumman worked closely with NASA and our subcontractor partners to design and execute an innovative risk-reduction program to bring the JWST mirrors and thermal management system to maturity long before the Mission Critical Design Review (M-CDR) in 2010. Ahead of M-CDR, we focused on developing and maturing key technologies to reduce our risk position. NASA, Northrop Grumman, and our subcontractors identified the hardest engineering challenges early in the program, and developed effective solutions, which were verified by building and testing the components. As a result, some of the most technically challenging hardware – including the mirrors, components of the backplane, and template sunshield membranes – are complete.

It is hard to overstate the tremendous accomplishments we have made to date. In the early stages of JWST, there were those who doubted that it was possible to polish beryllium mirrors so smooth that the largest surface irregularity on their surfaces would be hundreds of times smaller than the diameter of a single bacterium, yet we have successfully completed all 18 hexagonal mirrors – all with a smoothness well within that requirement. The smaller secondary, tertiary, and fine-steering mirrors that complete the optical path have been cast, machined and polished, complete with their final reflective coating. The Northrop Grumman-led team has achieved what was deemed nearly impossible, and we are now conducting cryogenic testing on all of the JWST flight mirrors. Just as we have made tremendous progress in assembling the telescope, today, in Huntsville, Alabama, we are

testing the template sunshield membranes, the flight-like material of the space umbrella-like shade that will allow JWST to operate at temperatures close to absolute zero.

At Northrop Grumman, our team is focused on all aspects of delivering a successful mission, from our technical progress; such as completing the composite backplane structure and completion of the sunshield, to the integration process; including the hardware assembly from the smallest elements to complex systems, and the testing at each level of our hardware functionality required to ensure mission success. Though much has been accomplished, challenges remain.

One of the most challenging aspects of the JWST mission continues to be thermal management. The observatory endures temperature differences of over 500 degrees from the warm Earth-facing side to the cold cryogenic mirror side. Never before has anyone created a telescope of this size, which can operate at these ultra-cold temperatures, while supporting a state-of-the-art suite of heat-generating cameras, spectrographs, and electronics.

It was challenging to manufacture 18 beryllium mirrors that can hold their shape to better than 20 nanometers at cryogenic temperatures. It was also challenging to design a deployable sunshield the size of a tennis court, but those challenges are behind us. The Independent Comprehensive Review Panel, led by John Casani, recognized these technological achievements and noted "a substantial amount of cutting-edge hardware has been delivered and is now being tested as part of the first steps toward the overall integration and test of the Observatory." The risk reduction investments have enabled the NASA/Northrop Grumman team to solve challenges on the complex and difficult journey to build the most powerful space telescope ever. As the Casani Panel concluded, "...the JWST project has invested wisely in advancing necessary technologies and reducing risk."

Cost and Schedule Steps

Though JWST has achieved incredible successes, the Casani Panel also found we need to do better going forward. Working closely with NASA, Northrop Grumman has implemented changes, which we have been effectively executing. In response to the Casani Panel findings, Northrop Grumman has made significant structural changes; including, improved communications and decision making processes between our team, NASA, and our partners. We have increased the frequency of senior management engagements to streamline program decisions, identifying issues to find resolution.

Additionally, Northrop Grumman manages a consistent and rigorous review system at all levels, from senior monthly program reviews down to weekly written progress reports with actively-managed metrics. We continuously evaluate actions to contain costs, while advancing the observatory beyond design and production already accomplished, moving forward through assembly, integration, and test for launch readiness. We have also implemented a set of improved financial controls in the form of metrics, reports, and alerts. These careful measures have been designed to ensure contractual discipline to avoid unintended cost growth.

JWST has a clear path forward, with evidence the current plan is proceeding on track. Northrop Grumman is, and has been, executing within cost, technical, and schedule milestones since the re-plan that has been in place since the beginning of the year. In

addition, as a result of the management changes, Northrop Grumman – in partnership with our major subcontractor teammates – has made available three near-term 'critical path' development tracks for earlier delivery to NASA. We have been able to achieve these changes thanks to the careful cross-organizational examination that went into our re-plan.

Integration and Testing

For systems comprised of multiple complex components, it is essential to verify that all components precisely fit and operate together to achieve their intended function and performance within the integrated system. This is particularly important for JWST, a system that is not designed to be repaired on orbit. An additional complexity within the JWST program is that the testing that takes place on Earth does not exactly simulate our operational conditions on orbit, such as cryogenic temperatures at large scales and zero gravity. Therefore, the complexity and duration of the ground testing is disproportionately longer for this program compared to other satellite systems.

JWST's long integration, test, and verification span is designed to reduce program risk through a methodical, incremental build and test approach, which retires risk at each successive indenture level of the observatory. We have an extremely rigorous integration and technology flow to ensure that we identify issues at the lowest assembly level possible in order to prevent problems that require us to undo previous assembly. However, the complexity of ground testing is one that we must consistently address throughout the path to launch. We are using the largest cryogenic vacuum chamber in the world at NASA's Johnson Space Center, and even that chamber is not large enough to hold the full-up JWST observatory with the sunshield deployed.

Due to these size constraints, we test the JWST optics (large primary mirror, secondary, and optical components) and instruments at flight temperatures at the Johnson Space Center, but will use a combination of analytical and subsystem tests to prepare the sunshield for deployment in space. As was noted by the JWST Test Assessment Team, also led by John Casani, "the scale, complexity, and cryogenic nature of JWST prohibit and end-to-end system test and instead require an innovative approach to system verification, with more dependence on analysis and piece-wise testing."

At Northrop Grumman's Space Park facility, integration and testing of flight hardware begins with the Optical Telescope Element Structure. This structure supports the six and a half meter diameter large primary mirror, the secondary mirror, and the remaining mirror assembly that brings light to the instruments within the observatory. This complex structure is then delivered to NASA's Goddard Space Flight Center to be integrated with the flight primary hexagonal mirrors, as well as other flight mirrors, to create the fully assembled Optical Telescope Element. Also at Goddard Space Flight Center, the NASA team will be integrating and testing all four flight science instruments, including two from our international partners at the European Space Agency and Canadian Space Agency. The Goddard Space Flight Center will join the fully assembled mirror hardware to the instrument hardware and test this complex system at NASA's Johnson Space Center, where the JWST team is making modifications to create the world's largest cryogenic-chamber.

In parallel, at Northrop Grumman's Space Park our team will be conducting integration and test for the propulsion module, the spacecraft panel, and the sunshield. These

systems will come together in the Spacecraft Element Integration and Test, where the sunshield will be deployed multiple times at room temperature to verify its performance. It is worth noting that a one-third scale sunshield replica has been tested at cryogenic temperatures to further validate our flight analytical models. With both the Spacecraft Element and Optical Telescope Integrated Science systems fully assembled and tested, these two primary aspects of the observatory will meet at Northrop Grumman's Space Park for complete observatory integration and test. From our facility, the final flight JWST will be delivered to our launch site for additional integration and test, and, finally, integration with the launch vehicle itself.

To ensure a comprehensive plan is in place, the program elements have been thoroughly reviewed by experts independent of the core program team, including: the Mission Critical Design Review Board (April 2010), the Test Assessment Team (June 2010), and several Standing Review Boards. Specific integration and verification factors were included in the JWST re-plan, and were derived from bottom-up estimates and confirmed to be at the high confidence level by an independent integrated cost and schedule assessment.

In conclusion, Mr. Chairman, I understand the concerns the Committee has raised, and feel confident Northrop Grumman is doing our part to address the technical and programmatic challenges before us. We are taking the proper steps to ensure cost and schedule guidelines are met, and we are enabling our team to successfully reach program completion by meeting integration and testing milestones for the JWST program. Like all astronomical telescopes that leap over the capability of their predecessors, fundamental breakthroughs will come from the scientific discoveries that JWST will reveal about the universe we live in.

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

Chairman HALL. And I thank you for that and thank you for staying within your time. We are in a different day and time, as all of you know very well, for projecting the needs and selling this Congress and selling the American people on the amount of money that we are going to put into these programs, and we have just gone through increasing the debt allowance there, and then we voted that, and that spawned that famous committee of 12, supposedly six Republicans and six Democrats.

Well, that wasn't really true. There were six Republicans, all right, we could name there. There were six Democrats plus an additional Democrat, who happens to be President of the United States, and these other six Democrats didn't have the power to override a veto of that seventh Democrat. It was a seven to six thrust to start with. So we didn't have a chance to get that off the ground.

But those are the things we are going to be facing in the future, and this is a wonderful program, and all of you have done a good job, Dr. Blandford, especially. You laid out several real reasons why good things are happening and how you want them to continue to happen.

But recent JWST progress reports indicate that I think 75 percent of the hardware is already completed, yet a little less than half the estimated $8 billion development costs have been spent. If so much hardware is completed, why will it cost an additional $4.5 billion to complete it?

Who should I ask that? Mr. Howard?

Mr. HOWARD. Probably me is the right person.

Chairman HALL. Okay. All right.

Mr. HOWARD. So of the $4.5 billion to go to launch in the development phase, the biggest elements of the work to go is the development of the spacecraft, sunshield, and the integration and testing of all of those elements of the observatory. That is the instruments, the instruments and telescope together, and then the spacecraft and the sunshield.

Jeff Grant mentioned a little bit about the complexity of that effort. The integration and test activity is the most complicated endeavor that we have ahead of us. This observatory cannot be tested all fully assembled in the environment that it is going to see in space at 40 degrees above absolute zero. The best we can do is to do subscale tests, subsystem level tests, and tests at the largest level of integration we can, which will be down in the chamber in JSC where the telescope and the instruments will be able to be tested but not the spacecraft and the sunshield. That will have to be done separately. So that is the significant portion of the work to go on this program.

The next largest element of the work to go is the development of the ground system for JWST, which is an activity that is going on at the Space Telescope Science Institute to develop and operate JWST and operate the instruments to be able to provide the observations that the science community will propose to examine.

Chairman HALL. Mr. Illingworth, you are a member of the Independent Comprehensive Review Panel. Right?

Mr. ILLINGWORTH. Yes. That is correct.

Chairman HALL. And what opportunities have you had to thoroughly review the re-plan, and are you satisfied that NASA has put forward a responsible and executable plan moving forward?

Mr. ILLINGWORTH. Mr. Chairman, the committee, of course, was an ad hoc committee that met for 2 months and developed this report, which NASA has been responding to for the last year. So the committee formally has not gathered back to look at the developments.

However, I have tried over the last year to gain as much insight as I can because as a scientist interested in this program, I really want this to succeed. I want NASA to succeed. And so I have been talking to people across the agency trying to understand how things are developing, looking at the material that became available publicly, and as I said in my testimony and I laid out in somewhat more detail, I feel that NASA has actually done a very good job on this re-plan. They have developed a plan that is—I would say uniquely conservative for NASA in the level of reserves and the approach that they are taking. They realized that they had seriously flawed management before the time of the ICRP and are trying to rectify it as Rick said.

So I am highly encouraged by what I have seen over the last six to nine months on this program.

Chairman HALL. You know, how much time do I have? Okay. I got about a minute and a half left. You remember the Augustine Committee and their recommendation that we needed an additional three billion a year for two, maybe three years to save our space station. Our space station is in danger right now, and our whole program is in danger. Our country is in a dangerous situation. Money is going to be hard to come by from this point forward.

I think the last three Presidents have failed, and we, this Committee and the Members of this Committee on both sides, have urged them to put more money into the space program where we could have a chance to save it. That didn't happen, so we have got a bleak future right now for a wonderful project, and I will talk with you more about that later.

I think my time is up, and I thank you.

At this time I recognize Ms. Johnson for her five minutes.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

The Hubble Space Telescope has revolutionized humankind's vision and the comprehension of the universe, and JWST promises to do the same. And while I would like to spend time learning more about the inspiring science that JWST is being built to study, instead we find ourselves focusing on budgets and program challenges.

So I would like to get clear on how we got to this point with JWST, and as Members of Congress we need to understand how this situation can be avoided in the future. And so is this a case of costs being poorly estimated to begin with, leading to insufficient budget and reserves, or is this a case of the program being mismanaged, or is it some combination of the two?

I would like Mr. Howard to start and followed by Dr. Illingworth.

Mr. HOWARD. Okay. I thank you for the question.

The cost commitments by NASA at the time when JWST was confirmed, when we passed the confirmation review in 2008, was

$5 billion. The cost is now $8.8 billion. I could give you lots of reasons and history on how we got to where we are, but this does not excuse the poor management, cost, and schedule performance of JWST over that period of time.

I hope that the details on the history and the changes that we have made that are in my written testimony demonstrate that we have changed the management priority. The management and the priority and the approach and have developed a robust baseline and are ready to demonstrate that we can deliver JWST within cost.

Dr. ILLINGWORTH. Thank you. Let me add to that.

I would say the Independent Review Committee came up with a number of reasons, but let me just very succinctly put the reason, the most clearest and simplest reason I can think of.

At confirmation in 2008, this project went from a phase where it was developing novel, new, extraordinarily high technologies into a phase where it was building hardware, testing that to launch. The project management and the program management overall did not recognize this change of approach, that now they were in a construction phase, they needed to meet deliverables, they needed to stay tightly on schedule, and they could not defer work.

And so the project, I think, was on a path that was never going to meet. We said this clearly in the report. It was never going to meet its launch date given that it was deferring work and driving up the costs as a result.

So it was only when that was identified, NASA took that to heart, and came back with a re-plan that they got to the point where I think they can be on track now to launch this within the cost cap by the 2018 date because they have adequate reserves in there to meet the problems on a yearly basis.

Of course, provided the budget is provided each year after this one that is appropriate as needed for 2018 launch.

Ms. JOHNSON. Thank you. Mr. Howard, what signals did NASA miss about the potential cost growth and other problematic problems that it should have picked up, and what is NASA doing about it now in attempting to manage it?

Mr. HOWARD. I think one of the signals, as Garth mentioned, was the fact that we knew that we had insufficient reserves in the early years in this program, even when it was confirmed, and the attitude was, do the best you can with the budget that you have.

Now, part of that was because this program was managed within the astrophysics division within the science directorate at the agency. That is one of the biggest changes that we have made. This is no longer one mission out of 30 or so that the astrophysics division has to try and balance across its portfolio, and in 2008, 2009 timeframe; just for example, in that one year, astrophysics had five launches that it had to support, including the Hubble Servicing Mission, the Kepler Mission, which we just had a discovery yesterday on, and the Hubble Servicing Mission and Hershon Blanch, and in those—typically in astrophysics, I have been there for 10 years or so, you put your resources on the missions that you have operating, our assets that are in space, that are doing the great science, and then the next thing you do is you put your assets on

those missions that are about to launch and need to be supported to be successful.

And within that constraint that you had, it was very difficult to add additional resources as JWST found and identified problems. One of the biggest changes, in my view, is elevating this program to an agency priority, an agency program where the funding, the additional funding required to complete JWST comes out of both the science directorate as well as other parts of the agency, and that increase in terms of elevating its priority has been significant in terms of being able to address the issues and resolve the budget problems, especially in the near years.

This budget profile, as far as I am concerned, is the best profile as far as reserves in every year that this program has ever had.

Ms. JOHNSON. Thank you very much. My time has expired.

Chairman HALL. The gentlelady's time has expired.

I recognize Mr. Palazzo.

Mr. PALAZZO. Thank you, Mr. Chairman—see an effectiveness of their government. The sentiment is that our process and procedures themselves help cause these problems. Professor Illingworth said in his testimony the pace of the federal budget process necessarily leads to large lag times for fixes to be implemented.

What lessons can we learn regarding our system of budgeting, procurements, and project management based on the James Webb Space Telescope experience? We can start with Mr. Howard.

Mr. HOWARD. Okay. Thank you for the question. I think this is a learning process that we have gone on over a number of years at NASA. When JWST was confirmed to start development in 2008, we did not have the tools in place at the time to look at the—and do an assessment of the cost to go and the schedule to go. We did not have this current policy in place which requires doing a joint cost and confidence, cost and schedule confidence assessment, which is a much more detailed assessment of both the cost and schedule and how they are integrated together and the risks associated with that than just doing what was traditionally done before that, which was just an independent cost estimate.

So the agency has made decisions to proceed under the directions that looks at more detailed cost estimating.

With James Webb we had not done that. We have done that now, so this program and re-baseline was subject to that level of analysis. One thing that has come up from the ICRP report, which I think the agency has to look at, is for these large, complex missions that are very complicated and being done for the very first time with new technologies and completely in areas that we don't have experience in before. Should we be looking at these with a higher level of confidence that we want to assign to them, higher than the 70 percent that is typically used in the agency?

I think that is something for the agency to think about and consider it as we proceed forward.

Dr. ILLINGWORTH. Thank you, and as Mr. Howard said, I think a very important factor here is from the earliest days in programs like this, ensuring that you are working to a high level of confidence. In fact, the agency has adopted 70 percent that the ICRP explicitly said for programs of this nature with their complexity an

even-more conservative approach at the 80 percent level joint cost schedule was more appropriate.

I think if that is done from an early phase and it is recognized by the key players, Congress, the Administration, NASA as the group doing the program, then the budget lag issue becomes a lesser issue. But in the JWST case, it was a catch up that NASA recognized there was a problem but couldn't catch up, and until it got to the point where it became a public issue, and then at that point ICRP got into this, and recommendations were made. I think this was very beneficial. I think it brought it home to a lot of people across the whole of the programs like this, that changes were needed and a more conservative approach was needed, and I am glad to see from what I have watched this year, seen this year that NASA has taken that to heart and really is planning this program with much higher level of reserves to a much greater degree of confidence.

Mr. PALAZZO. Thank you. NASA is planning a number of high-priority missions recommended for the next decade by various decadal surveys. How will James Webb cost overruns affect high-priority missions outlined in the astrophysics decadal surveys such as WFirst, and to the extent you have insight into the other science mission divisions, such as Earth science, helio-physics, or planetary, can you also comment about James Webb's impact to the greater science portfolio?

We start with Dr. Blandford.

Dr. BLANDFORD. Thank you. I think it is clear that it will lead to a deferral of the start of these proposed missions like WFirst, and I think that will also—it will have some impact, although we don't yet as know what the NASA plan is, and this will probably be manifested in the next budget, on missions from other parts of Earth space science.

This is obviously a great disappointment to the scientific community, but I think it is one that they will have to accept, and we will, I hope, build WFirst before too long, and it will have its glorious scientific program ahead of it.

Mr. PALAZZO. Dr. Illingworth, do you have anything to add?

Dr. ILLINGWORTH. Yes. Thank you. I think Dr. Blandford has said it very well. It is a key concern for the community. I think that none of us involved in the James Webb Space Telescope likes to see changes like this happen that push out other programs. It is very regrettable, but the James Webb Space Telescope was the highest priority program, so ultimately, it becomes a question of priorities. When resources are tight, that is where we go. We choose the highest priority. Thank you.

Chairman HALL. The gentleman's time has expired.

The Chair now recognizes Ms. Lofgren, the gentlelady from California.

Ms. LOFGREN. Thank you very much, Mr. Chairman, and I want first to particularly welcome the two witnesses from Santa Clara County, Dr. Blandford up at Stanford, and Dr. Illingworth from the University of California, Santa Cruz, located at the Lick Observatory, also the tip-top Santa Clara County. It is great to have you here.

I think this hearing has been very helpful because obviously we have a number of questions to ask. First, are we on track, what lessons have we learned for the future? And then also I think there is a fundamental question, not for me, but for the country at large, including some of our colleagues of why we are doing this. And only when you see the discovery yesterday by the Kepler Telescope, it renews—my enthusiasm wasn't lagging to begin with, but, you know, in these times, you know, why is this important to America? What does this matter in terms of—make out the case for science but also for society and why we should make this investment.

Dr. Blandford and Dr. Illingworth, if you would.

Dr. BLANDFORD. Perhaps I could supplement. There was actually a second discovery yesterday that was reported, which was by my colleague, Professor Chung-Pei Ma from the University of California Berkeley and her team reporting on the most massive black holes found——

Ms. LOFGREN. Oh, that is right.

Dr. BLANDFORD [continuing]. In the galaxies, now 10 and 20 billions solar masses, beating the previous record of six. So the pace of discovery does not let up in astronomy, and it won't with these wonderful new telescopes. What it does for society, I think there are many answers to that, but undoubtedly it inspires young people, many scientists and technologists, it is an entry point into what they ultimately build careers on. I think the developing high technology is a generator of jobs. I am not economist myself, but I think there is a large multiplier that can come from such projects.

Ms. LOFGREN. Well, there certainly has been with all the NASA programs.

Dr. BLANDFORD. Involving NASA programs and it is inspirational for all of us. I think astronomy is remarkable for how communicable the results of contemporary research—how communicable it has become, and I think the—we can all enjoy at very different levels the results that come from these wonderful telescopes.

Ms. LOFGREN. Thank you. Do you have anything to add, Dr. Illingworth?

Dr. ILLINGWORTH. Yes. Thank you very much for the opportunity. Interesting, I think, today there is going to be an announcement that Hubble scientists have published the 10,000th paper with that telescope. This is absolutely remarkable productivity for an amazing mission.

I think the science is, in a sense, I am questioning, we all know of Hubble and the amazing things it has done, and James Webb is its successor. I think more immediately as you mentioned for the societal interest in this, beyond the inspirational aspect that comes from a science program like this, there clearly are jobs. There are high-technology jobs that are very important that can only be done here. We do them close links with their contractors, and as Dr. Blandford mentioned and my wife has pointed this out to me, too, she is an economist, that there is a multiplier effect which is many times when you do a unique high tech or skilled job like this, and so there are job benefits in the short term and over all time.

Now, after long term are the educational benefits, the STEM issues, doing science and technology education. This is just so critical for us, and missions like this bring into everybody's living

rooms as we have just seen in the last day with announcements of new discoveries, amazing scientific results that only we really can do with these missions.

Ms. LOFGREN. Thank you very much. I am already convinced, but turning to you, Mr. Howard, in your written testimony you mentioned that these missions are technology providers, enabling in reducing technology risks of smaller missions that could otherwise never afford to develop such technologies.

What sort of other benefits may we see from this mission? What were you thinking of?

Mr. HOWARD. Yeah. Thank you for asking that. In addition to developing technologies that other missions, smaller missions just would not be able to do in the timeframe or without the resources that were already invested in missions like JWST, the new technologies developed on these large missions benefit other agencies.

And so a couple of examples are right now we are actually flying on Hubble a technology developed by JWST, an integrated circuit system which was put on for the advanced camera for surveys, when we repaired that on the last servicing mission, is technology that came out of JWST.

In addition to that, the innovations in metrology technology that have been on JW have trickled over into the medical device metrology measurement of human eyes, diagnosis of ocular diseases, and improve surgery, and there is a technology that you wouldn't necessarily have thought applied over, but it is these new innovative metrology techniques that we used to develop the large mirrors that has trickled over into other areas.

Ms. LOFGREN. Mr. Howard, I see my Chairman is about to gavel me out of order. I would welcome the additional lists I think you were about to tell us. If you could send that to us after the hearing, I would love to see it, and I yield back, Mr. Chairman.

Chairman HALL. And I thank you.

Before I recognize Mr. Brooks, I want to recognize Dr. Illingworth mentioned something about his wife. We have a wife here of Congressman Hultgren of Illinois. We are very happy always to have you here.

I recognize Mr. Brooks for his five minutes.

Mr. BROOKS. Thank you, Mr. Chairman, although I believe that is Mr. Buschon's wife.

Chairman HALL. Oh.

Mr. BROOKS. Oh, they are both here. I have been looking to the left—sorry about that.

Now to more serious matters, but we had the White House Christmas party last night. That explains a lot.

The Science, Space, and Technology Committee has put together a timeline concerning the James Webb Space Telescope, and in June of 1997, the original estimate was a launch date of 2007, at a cost of roughly $500 million. In 2001, the telescope was identified by NASA as the top priority in the decadal survey with an estimated cost of $1 billion. In the summer of 2002, we had a mission definition review that indicated the cost was now $2.5 billion with a launch date of 2010, and March 2005, NASA identified further cost growth. Now, $4.5 billion with a scheduled slip of two years to launch date of 2012. We move onto July 2008. We have another

program confirmation review that says that the cost is up to $5 billion and a hope for launch date of 2014. Then we move to September 2011, and we now have a baseline of $8.8 billion total lifecycle cost with a launch readiness date in 2018. So we have had a slippage both in cost and in launch dates.

I want to put that in the context of some of the financial issues that America is facing. As many of you all know, in this last three years we have had budget deficits of $1.4 trillion, $1.3 trillion, and $1.3 trillion. Our accumulated debt is now over $15 trillion and is growing at over a $1 trillion a year rate with no end in sight.

Our interest on our debt was a little over $200 billion in the fiscal year that ended September 30; however, those were at record low interest rates, somewhere in the neighborhood of below a percentage point for short term of treasury bonds, short term being a year or two or less. Long term, it was a little over two percent.

Compare that to Italy, which is a little bit further along the path that America faces with these deficit problems, where their bond rates are now over seven percent.

If something like that were to happen to America, and if we continue on this path, then it will happen to America, you can see our interest on the debt jump from the $200 and something billion dollar range to $600 billion a year or more.

That all having been said, I think you all can get a pretty good grasp that we have some serious financial issues facing us.

Now, what is the reaction that we are looking at right now in the United States Congress? Well, we are looking at spending more money. One hundred and eighty billion dollars of additional debt on our country for this year alone for things like extending the Social Security and Medicare tax break that last year was given to American citizens at a cost, by the way to the solvency of Social Security and Medicare, extending Unemployment Compensation benefits, the sustainable growth rate, fixing that, or the doc fix as it is commonly known, to help ensure that Medicare patients have access to physicians when they need it. The list goes on and on and on.

That having been said, I would like you all's rather quick insight on whether the James Webb Space Telescope is truly the number-one priority for NASA, in which case if we have to reduce funding for NASA because of all these other issues hammering us all at the same time, we will know that you are comfortable with reducing those other items because they are lesser NASA priorities, or if not, what NASA priorities are higher priorities?

And Mr. Howard, if you could please go first.

Mr. HOWARD. Thank you. Sure. I would be glad to. The NASA Administrator has stated that his top three priorities in the agency are JWST, SLS, and MPCV, and certainly as the budget deliberations go on and we see what the actual budget comes in at, that has to be re-looked at see how we can continue to produce, to proceed with those three priorities.

I can't predict exactly what will happen for '13, but I know for in '12, those three programs are funded at the appropriate level to continue forward.

Mr. BROOKS. Mr. Blandford, Dr. Blandford.

Dr. BLANDFORD. It is very hard for me to speak on behalf of the Administrator in NASA. I don't think I can——

Mr. BROOKS. I am asking for your opinion.

Dr. BLANDFORD. My opinion is that science, the space science program, is one of the things that is most important for NASA to do. It does it extraordinarily well, and I hope that in the coming budgets its past successes will be reflected in the future program that is recommended.

Mr. BROOKS. Mr. Chairman, I see that my time has expired. I don't know if——

Mr. ROHRABACHER. [presiding] The Chairman——

Mr. BROOKS [continuing]. We have enough time for the last two witnesses——

Mr. ROHRABACHER. We have a new Chairman now. I am going to make sure that you have the time to make sure that your question is answered by all of the witnesses. Go right ahead.

Mr. BROOKS. Thank you. Dr. Illingworth.

Dr. ILLINGWORTH. Thank you. I recognize what you are saying, and I think that a key path forward out of our problems lies with education, with technical and scientific education, and a skilled workforce. I think that programs like James Webb and many of the other ones in NASA, but particularly the high-priority programs, are absolutely essential to this, and James Webb is a 30th—three percent of the NASA budget and less than 1/10 of a percent of our discretionary budget. It is very small, I think, for the huge gains that it brings for inspiring our younger people to look to the future and improve our scientific and technical education.

Thank you.

Mr. BROOKS. Thank you, and Mr. Grant.

Mr. GRANT. Thank you. I would like to add to the comments made by my colleagues I personally find the program inspirational, and we have, early in the program, built a full-scale model of this James Webb Space Telescope, we have taken it to Seattle——

Mr. ROHRABACHER. If I could take the Chairman's prerogative, we will give him time to get his question answered, not something else. Go right ahead and answer his question.

Mr. GRANT. I believe that inspirational programs should be part of NASA's priorities.

Mr. BROOKS. Well, my question was what are lesser priorities that you believe should be cut, or do you have the James Webb Space Telescope as the top priority, which by inference means everything else is what we should be looking at if we continue with these cost overruns with the James Webb Space Telescope?

Mr. GRANT. I can't answer that question for NASA, for the Administrator, but what I can say is the program that I find inspirational and believe the programs that are——

Mr. ROHRABACHER. If you could, let us get on the question, could you answer that question? James Webb is the number one priority, the rest to be cut?

Dr. ILLINGWORTH. This—as Rick said, the Administrator has clearly stated the top three priorities. I think, as Dr. Blandford said, science plays a truly major role, and we do it through NASA in a uniquely inspirational and powerful way worldwide. Nobody else can do this.

Mr. ROHRABACHER. So do you have——

Dr. ILLINGWORTH. I have to, you know, give high priority——

Mr. ROHRABACHER. So you are not going to answer the question. Would you like to answer the question?

Dr. BLANDFORD. I think the reason why we are having problems with this question is because we are not—I am not terribly familiar, and I don't think he is, with the other two major components——

Mr. ROHRABACHER. All right.

Dr. BLANDFORD [continuing]. Of the Administrator.

Mr. ROHRABACHER. Mr. Howard.

Mr. HOWARD. So one thing I wanted to point out was that the NASA Administrator has decided that funding the additional funds for JWST in this time period still stays within his top-line budget, what he gets.

Mr. ROHRABACHER. Uh-huh.

Mr. HOWARD. And I think it is important to recognize that it was seen as this needs to be an agency solution and not just out of science, not just out of astrophysics, and this is why——

Mr. ROHRABACHER. I don't think that was the question. Could you repeat your question to the witness?

Mr. BROOKS. Thank you. I am trying to get your individual opinions, not your assessment of what NASA's may be, although with respect to Mr. Howard, they may coincide with them, but your opinions as to what priorities should be advanced, and where do you place the James Webb Space Telescope? That is, the James Webb Space Telescope continues with these cost overruns, what in your judgment are lesser priority items that we should reduce funding for in order to fully fund the James Webb Space Telescope?

Mr. HOWARD. And so just let me finish what I was saying, which is I think some of those decisions have already been made, and you will see them in the operating plan that comes forward next month in terms of where the reductions are made in space science across the other divisions in order to pay for the increase in fiscal year 2012 to cover James Webb. That will be in the operating plan.

Mr. ROHRABACHER. I will let the record show that this is a very significant question and that at least three of the witnesses were unable to answer the question.

Mr. Sarbanes.

Mr. SARBANES. Thank you, Mr. Chairman. Thanks to the panel. I am going to try at the end of my five minutes to ask you a question you can't answer so I can get 10 minutes of your time.

I appreciate your testimony, and I know you see strong support for this project by and large here but obviously concern about the cost overruns, and I thank you for addressing those head on and indicating any management lapses that were part of the reason for the overrun are being handled.

I am interested in this—in the telescope for a variety of reasons. One, I am excited by just the pure discovery element of it, which I think can energize a whole new generation of scientists and other careers in the STEM arena, and so certainly as an education driver it is a significant and, I think, meaningful investment for the country to make.

But I am also interested in it as an economic driver. Given the cost associated with it, even with the overruns, I think that the multiplier effect it has in terms of economic opportunities and, frankly, jobs that can be created is significant. I thought I heard in some testimony that there were over 150, up to 200 different companies or suppliers that were part of delivering components for this telescope, and I assume, and I would like whoever would want to address this to do so, I assume that has kind of a pulling effect in terms of those companies that are contributing to the effort are developing technologies for purposes of delivering the products to the telescope, but in generating those technologies, they are creating other opportunities for themselves and for their peers within a particular industry. And that is all about being an economic driver.

So I think one lens through which we can look at this James Webb Telescope is through this lens of it being an economic driver, and particularly an economic driver for the American, for the U.S. economy.

So if you would like to speak to that, I would appreciate it.

Mr. HOWARD. Sure. I will answer that. Thank you. So, as I mentioned, we have over 1,200 full-time equivalent positions across the country that are supporting James Webb right now. That doesn't include an additional 200 or 300 folks that are working at the subcontractors level and the supply chain providing, you know, nuts and bolts and fittings and various things like that.

So it is a fairly large workforce. Of that total there are only 100 civil servants. So all of this effort is being done in the U.S. with the U.S. industrial base and workforce.

Both the high-tech jobs as well as what you think are relatively straightforward jobs like welding structure together that we need to support and build the telescope and hold it on. This is spread across 27 States and the District of Columbia. So the effort is across the entire country and does have that kind of a multiplication factor in terms of the work that is done and the things they learn from that, especially in the technology area where they can then take those, the companies can take those technology advances and apply them to other programs within the United States.

Mr. SARBANES. Mr. Grant, maybe you could speak from the perspective of the contractor in terms—obviously you have a certain expertise already in place, and that is how you get the bids to deliver a product, but in providing the product, I am sure that you are pulling on your own organization to be on the cutting edge, and then you work with other subcontractors and so forth.

So can you talk about that ripple effect? I would appreciate it.

Mr. GRANT. Congressman Sarbanes, one of the examples I would cite is where we have seen the technology that has been invested in JWST come to broader use is just in the area of the optics. We just completed delivery of the last of the flight segments this year, and the segments themselves are about, from a density perspective, 20 times lighter than the comparable optics that you would see on the Hubble Space Telescope. And what that means to the Nation and future systems is that they will be able to harvest that technology and put it into other programs that need comparable large optics or smaller optics at much lighter weights.

And that is something that has taken us a number of years, but like I said, we have successfully delivered all the mirror segments and really demonstrated the applicability of this technology.

Mr. SARBANES. Thank you all very much. I yield back.

Mr. ROHRABACHER. Are you sure you don't have a follow-up question to that? Got lots of time for you.

All right. Mr. Hultgren, please.

Mr. HULTGREN. Thank you, Chairman. Thank you all for being here, and this is really important, and we need to be looking at everything we are doing to make sure that we are doing it as well as we can and especially looking at cost overruns and things, to have that accountability, especially in times like this where times are tight and as we are forced to prioritize.

I do believe so strongly, we have talked, we have had amazing hearings over the last months here in the Science Committee, and really getting back to American exceptionalism historically in science and just wanted to talk a little bit about that and wondered if I could get your perspective of the role that JWST plays really in America being at the forefront of kind of next discoveries.

Hubble, you know, had so many incredible discoveries and would like to kind of get your thought from two perspectives. One, what maybe we could expect from JWST as far as some discoveries might go but then also that our role in this as America, how that plays in the international community of drawing the best and brightest from around the world to be a part of this type of thing.

So I wondered if you could maybe talk about that if any of you have any thoughts.

Dr. ILLINGWORTH. There is no doubt as Hubble's success—Hubble has brought worldwide attention to U.S. scientific leadership and productivity as we travel, and I am sure all of you had this experience, that coming from this country you go abroad, people talk, you talk to them about what I do, and they are just delighted with Hubble. This is so important for us that we have these programs that we can always look up to as demonstrations of our leadership and capabilities in science.

James Webb will be that program. Hubble will not live forever. Probably some time this decade, we will probably see the end of the life of Hubble. At that point, we really would like to have James Webb up there to carry the flag forward for science and for U.S. leadership in this area.

Mr. HULTGREN. Thank you.

Dr. BLANDFORD. Just to add to that, James Webb, I believe, will be the magnet that Hubble is being and will bring people here from all around the world and will be the expression of the ability of the United States to execute a program of this magnitude, and perhaps, if I might use an example, which many of my colleagues work in particle physics, the Large Hadron Collider in CERN has been a magnet for particle physicists all around the world, and that would be a sort of candor example, if you like.

Mr. HULTGREN. Yeah. I feel that one personally. I represent Fermilab, and they are trying to shut it down in the last month, and I have seen so much go on there, and again, that—it is going to happen. My hope is, again, that we are active in drawing the

best and the brightest here to America just as Fermilab had done for 30 plus years.

Continue, I don't know if, Mr. Howard, if you——

Mr. HOWARD. Yeah. I just wanted to add a couple of points.

I actually think that JW is actually worth more to us now than it was in the past in terms of what it will be able to deliver. Probably even more now so now than in the past. Scientifically, it is going to be able to do things that we never thought we could do, make new discoveries of things in the universe, but there are things that have popped up just in the last four or five years in terms of science questions that we can't wait for James Webb to get into orbit to be able to detect.

Water on other planets orbiting other stars. Right now, we have about 50 candidate planets orbiting other stars that look like they could support water, the right Goldilocks' balance between not too hot and not too cold, to be able to support liquid water. It will take JWST 24 hours of observing time to be able to look at one target and say whether or not there is water in the atmosphere of that planet.

By the time we launch, that would be more than 50. I mean, there will be a tremendous number more, maybe two or three times more, candidates that will allow us to be able to look for that question.

That is just one of the sort of important questions that I think James Webb will be able to do as we move forward.

Mr. HULTGREN. I have just a few more seconds, but I wondered if briefly another thing we focused on here is STEM education. It has been touched on briefly, but it is so important, again, for our young people to have something to be inspired by.

I wonder if you could just talk briefly of how you see this playing into STEM education.

Dr. ILLINGWORTH. I would say quickly that with the advent of social media and the dissemination of images and results so quickly, people get involved now in a way that they never did before. So this is becoming crucial to have these results out there with the visual images, the power that they have.

Thank you.

Dr. BLANDFORD. I would like to just say that one of the things that I think NASA deserves great credit for is its attention it has paid over the last 10, 15, 20 years in disseminating, particularly to schools, the results of space explorations. As I said before, these are highly communicable, and they do excite young people and get them started on scientific paths which can lead to all manner of different careers.

Mr. ROHRABACHER. Thank you very much, and now we have Mr. Lipinski.

Mr. LIPINSKI. Thank you, Mr. Chairman. I want to thank all of our witnesses for their testimony, especially Dr. Blandford. I know, you know I have been out to Stanford, and I have met with Peter Michelson and others at the KIPAC Kavli Institute, and I understand the importance of the work that you are doing. It is clear that we are in tough budget times. We have to make sure that taxpayer money is being spent wisely, not being wasted. We need to make difficult choices.

I want to start out, you know, we have had questions about the budget and specifically about what has been learned about the processes. I want to focus first as Dr. Blandford, I just want to make sure this is clear for the record. I know that the 2001 National Academy Decadal Study had the James Webb Telescope as the highest priority. Then the next one in 2010 assumed that the Webb would be launched in 2014, listed WFIRST as the top priority.

So I just wanted to make sure that I am clear. Do you believe that Webb is the top priority right now?

Dr. BLANDFORD. What you said is correct. We took it as a given that Webb would be launched when we created our program, so we did not in any sense cross-prioritize as a committee, and so I cannot speak for the rest of the committee.

My own personal——

Mr. LIPINSKI. In your own personal opinion.

Dr. BLANDFORD [continuing]. Opinion is that the right thing to do is to stay the course on Webb and launch it.

Mr. LIPINSKI. Yes. I understand those things happen because the expectations were that Webb would have been——

Dr. BLANDFORD. Correct.

Mr. LIPINSKI [continuing]. Already was far enough under way, didn't have to be put there as a top priority.

One other thing I wanted to address, when we are talking about what our witnesses can provide for us, I think going back to the question that Chairman Brooks had asked, unfortunately he is not still here, I serve as Ranking Member on the Subcommittee, Research and Science Education Subcommittee, with Chairman Brooks, and I think it is an important question of what difficult choices do we make.

However, I believe that right now the witnesses that we have here today are not the ones to answer a question about what NASA should cut. You know, Mr. Howard, being with—in his position, yes, that could be a question you could answer. The other three witnesses I don't think really are in the position to answer that question, and hopefully if that question does—if the majority wants to have that question answered, that we will have another hearing with the appropriate witnesses for that question. I don't think that the other three witnesses here are appropriate for that question. I think a lot of the other questions that I was going to ask have already been asked.

I just wanted to give, first of all, Mr. Howard, the opportunity, you ran out of time, Ms. Lofgren was asking you about what were some of the things that we had gained already from Hubble, and maybe talk about what we could do with the Webb Telescope.

Was there anything that you wanted to add there that you didn't have a chance?

Mr. HOWARD. I think that was in reference to what we have gained as far as the technology developments for JWST.

Mr. LIPINSKI. Yes.

Mr. HOWARD. One thing that I would want to add is, you are talking about the mirror, the mirror development. This was a very long process of over 10, 15, almost 15 years to develop these mirrors, and initially when this started, this started as a joint tech-

nology activity between NASA, the Air Force, and the NRO to develop large, lightweight segmented mirrors for use in space. And JWST gained a tremendous amount of insight as to the development of those types of mirrors for our application, which is a cryogenic. The DOD has learned a lot from that activity also and continued on with that activity.

So I think that is another good example of the benefits of technology development for these large missions such as JWST, which is not just back into other applications in the United States, for example, in the medical field but in terms of other agencies using and benefiting from those activities.

Mr. LIPINSKI. Thank you, and I just want to use my last time to also say that I think the benefits for STEM education as one of the co-chairs of the STEM Ed Caucus, I think it is very important that we continue to do this work with the Webb Telescope and other work that we are doing to inspire as Dr. Blandford and Dr. Illingworth had talked about, inspiring the—our students today.

Thank you. I yield back.

Mr. ROHRABACHER. Thank you very much, and Mr. Sensenbrenner.

Mr. SENSENBRENNER. Thanks very much. I hate to be the skunk at the lawn party, but somebody has got to be the skunk before we have to go over and vote.

Mr. ROHRABACHER. I think the Chairman already decided to do that.

Mr. SENSENBRENNER. Okay. Well, Mr. Howard, did you ever see the movie called "The Money Pit?"

Mr. HOWARD. Yes. Absolutely.

Mr. SENSENBRENNER. And you remember that the owner of the house started out, and there kept on being problems, and there was more and more money thrown into it, and somehow it never really did get done properly, at least that is how I recall that movie. Is my recollection correct?

Mr. HOWARD. Yes. I think the standard line in that movie was, it is only two more weeks.

Mr. SENSENBRENNER. Uh-huh. Well, you know, I have heard this before with the International Space Station, is that we threw a lot of money into the International Space Station, and it was only getting the Russians to do something, and then there was something else, and then there was something else, and what started out being an $18 billion project ended up being $100 billion project, and its completion date was significantly delayed.

Now, while I recognize, Mr. Howard, that you have only come onboard the Titanic in 2010, after it hit the iceberg, here we are talking about a project that has a $7 billion cost overrun from the initial proposal that we had in 2001. And an 11-year delayed completion since the Webb Space Telescope was originally slated to be launched in 2007.

Now, how can we justify this to our constituents?

Mr. HOWARD. So thank you for that question. I knew it would come sooner or later.

So I think part of this is we have to realize that early estimates on the cost of James Webb going all the way back to the early period of time back in '97, or before period, were just that, estimates,

and the first time that the agency was ready to commit to a price for James Webb was in 2008, and that is the $5 billion.

So there is lots of history that I could go over as to what happened and led from all those early estimates.

Mr. SENSENBRENNER. So what you are telling the Committee is from now on in we shouldn't believe any early estimates before we start appropriating money, and we should get an actual proposal and see what is going to happen based on that?

Mr. HOWARD. I think the early estimates going back to, if you want to go back to where it was around $1 billion, was for a very simple telescope, for a meter telescope with one instrument on it, not a suite of four instruments. It did not have the benefit of having detailed cost assessments on it——

Mr. SENSENBRENNER. Okay.

Mr. HOWARD [continuing]. Nor the industry proposals.

Mr. SENSENBRENNER. Well, you know, the fear that I have is that you are in charge of a program that is going to end up gobbling up resources that are available to other NASA programs just like the Space Station did. Now, I have only got about a minute and 40 seconds left, and I want to put something else on the table.

When the Hubble was launched, we found out when it got up there that one of the lenses was improperly or incorrectly ground, and we had to send the Space Station up or the Space Shuttle up on a real quickie repair mission. We don't have the Shuttle anymore, and what is going to happen if we need to repair the James Webb Space Telescope or we find out that some of the parts in the telescope were not properly done and as a result we are not getting the results out of it that we had anticipated just like what happened before the repair on the Hubble?

Mr. HOWARD. So JWST is designed in such a way that it has adjustments to each of the mirrors so that we can adjust the positions of the mirrors rather than——

Mr. SENSENBRENNER. Again, the Hubble problem was not a problem of the mirrors being improperly adjusted. It was a problem of the mirrors being improperly ground.

Mr. HOWARD. And we have tested that and checked the mirrors. We have just done that down at Marshall at operating temperature, each element individually. We are also going to be testing all the elements together.

Mr. SENSENBRENNER. You still haven't answered the question on how we are to maintain it or repair it or if something comes up that was not delivered according to specifications, what do we do if it is in orbit and we don't have a Shuttle?

Mr. HOWARD. So the answer is that we know that we only have one chance to get this right. It is going out to L–2. It is not going to be in orbit around the Earth. It is going to a distance four times further away than the Moon, and so we are taking every step we can to mitigate the risks to make sure that we do have a system that can work.

Mr. SENSENBRENNER. You have just increased my skepticism given the history, and I have been on this Committee longer than anybody else. I hope that we will have some much better answers. Otherwise I can see another money pit coming up because the Space Station sure was that.

I yield back.

Mr. ROHRABACHER. Thank you very much.

Ms. Edwards.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and thank you to our witnesses, and I apologize that I wasn't here earlier. I did have a chance to review testimony, and just want to reiterate how proud and excited we are that the James Webb Space Telescope is managed and directed out of the Goddard Spaceflight Center in Prince George's County in Greenbelt, Maryland. The project, as you have described, there are 500 jobs that are supported by James Webb in Maryland, 1,200 jobs all across the country, and I am sure you have pointed out in your testimony and response to questions that other than about 100 of those, they are private-sector jobs. And so I think it underscores the importance of the work that we are doing, the phenomenal work that is being done in astrophysics that is actually about job creation, it is about innovation, it is about the 21st century, and so I appreciate that.

My question, and I just wanted to note for the record, one of my favorite pages in the *Washington Post* is in the Metro section. It is the federal workers, and today on the federal worker there is a—Roger Hunter is being highlighted for the work that he has done on the Kepler Space Telescope Project, and we know now about the just-found planet, Kepler 22b, and the excitement that is being generated because we discovered something that we didn't know before with a project that started out where we didn't know what we would necessarily find, and I think that that is the hallmark both of what NASA does and certainly what is taking place with the James Webb Space Telescope.

I want to ask you, Mr. Howard, just a couple of questions, and one has to do with, you know, as the lessons we have learned over this last couple of years with James Webb, you have highlighted the problems already and the difficulties of going from an idea and some initial estimates to a full-blown project and really understanding what the real costs are going to be and then sharing those with us and developing the kind of management strategies that are going to be important going forward so that we don't run into problems.

I wonder if you could tell us about some very specific milestones that we as a Committee can look at over this next year where we can hold the agency accountable, the project management accountable, and know that the James Webb Space Telescope is on track?

Mr. HOWARD. Thank you for the question. As I said in my written testimony in fiscal year 2011, we had 21 milestones that we were tracking and watching to see that we could meet. We met 19 of those ahead of schedule or on schedule. One of those was a month late due to snow, wind, and not fitting into a C–5 transport airplane the way it was supposed to be designed, and one we deferred for good reason because we are in the process of looking at a design change to that unit.

For fiscal year 2012, we have already established about 37 milestones that we have, and of those, the ones that I think certainly that rise to the highest level of scrutiny and we want to watch are the delivery of all four instruments, all four science instruments including the ones from Europe and Canada will be arriving this

year. That will be major milestones to get those in as we can then start the integration and testing of those instruments with the integrated science instrument module where they fit.

Completion of the mirror testing is just about done. That will be ending up within the next few months. That also is a major milestone to get those mirrors all tested.

Completion of the center section of the primary back-up structure, which supports the mirrors, is another major activity that has been going on for well over, almost a year I guess, and should be—will be complete in the flight structure this year, the central core.

And then I would think completion of the fifth sunshade engineering unit that we are doing, full-scale size of the sunshade, layer five is probably the most complicated or one of the most complicated ones that we have, and completing the engineering unit of that full scale and testing to show that it will perform properly in space, I think, is another milestone.

Ms. EDWARDS. Thank you, Mr. Howard, and you can count on me and I am sure others of our colleagues taking notes about those particular of the milestones that you have outlined for this next year and asking you about them, keeping track of them, and I know that you will do the same, because I think that will help give us all the kind of confidence that we need going forward, both in terms of completion but also in terms of the fiscal accountability I think that all of us expect on the project.

I won't have time for the question but really want to underscore the value and the importance, I think, of the private sector workforce, and particularly the work of Northrop Grumman and all of the other attendant folks all across this country who are working on this important project. I look forward to its completion, I look forward to launch, and I look forward to us paying attention to the elements of the project that are going to enable it to go forward.

And I know the difficulty of starting out in one place where you are imaging something and then trying to respond to a Congress to get us to make that investment but because it is science, you don't know what all the variables are until you get into it, and that, I think, for those who are skeptical accounts for some of the differences apart from some other issues that you have outlined that make it really difficult at the very outset of a project like this and its magnitude to fully appreciate what the real cost is going to be in delivering it. And I think that as taxpayers, we are going to see the value for that dollar even if we can't see it right now.

Thank you very much, and I yield.

Mr. ROHRABACHER. Thank you very much, and the Chairman will yield such time as he will consume to himself.

Let me just note for the record that I believe that glossing over incompetence and mismanagement on a scale such as we are talking about today is not a favor to the taxpayer, and it is not a favor to the American Space Program. And using an occasion like this in which we are talking about $7 billion that is now going to have to be taken out of other space programs and using this as an opportunity to puff NASA's basic mission is not doing a favor to America's Space Program, nor to the taxpayers.

We need to get down to business, and that is why I was hoping that there would be an answer to the very significant question that

was poised to the panel, and let me note no one in the panel answered. The only answer that ended up was that we are going to have the answers in a few weeks when we release some kind of a document.

Let me just get right to the matter. We just heard people talking about how great STEM education is rather than this cost overrun and what NASA is doing for that.

Now, is it possible that we are going to have to de-fund all of that great STEM Program and all of this education because of the $7 billion overrun that we are talking about today? Is that possible? If it is the number-one priority, isn't that what we are talking about?

So here we are puffing a very nice, good program for NASA, but at the same time ignoring the fact that this cost overrun may cost us that program.

Mr. Howard, could you name for us some of the programs that are going to be totally de-funded because of this cost overrun?

Mr. HOWARD. The $156 million in fiscal year 2012, which is the increase of JW over the President's budget request, is being split 50/50 between science and the cross-agency support activity. The cross-agency support level with that reduction takes us down to a level for institutional support to the NASA centers. It is about the level that fiscal year 2010 was.

Mr. ROHRABACHER. All right, but what we are talking about is not just that amount of money. What we are talking about is an overall budget in the future that then you have to calculate in which programs will be able to be funded.

Now, like for example, you have the LISA Program, TPF, the SIM, we got International X-ray Observatory, SHIPSAD, all of these are on the line, are they not?

Mr. HOWARD. Some of those missions were not even prioritized in the current decadal if I remember correctly.

Mr. ROHRABACHER. Right.

Mr. HOWARD. SIM has been stopped, was stopped numbers of years ago before we ran into this situation.

Mr. ROHRABACHER. Okay.

Mr. HOWARD. But I think it is important to recognize that in the '12 to '16 timeframe we are talking about $1 billion, still not an insignificant amount of money, that needs to be provided above what was in the President's budget request in that period of time.

Mr. ROHRABACHER. If you try to limit the time period that you are talking about, but if you take a look at the magnitude of the money and how that will affect things, for example, I understand the WFIRST, this Wide Field Infrared Survey Telescope, that is being postponed now, what, for five years, and when you have budgets, you have budgets, and there is an impact when people go over budget.

And you could spend half of the time of this hearing if we want finding how wonderful NASA's basic mission is and how it is going to inspire people, but if we keep having cost overruns, you are going to become the laughingstock of the federal budget process because we will know that we can't count on what you are telling us.

Look, I supported the Hubble Telescope, even after the catastrophic mistakes that were made in that project and which caused

enormous new costs to the project that had to be taken out of other projects, and let me note during that time period I asked, who was responsible, and who was reprimanded, and who was fired?

Now, we have testimony today that this overrun is not being caused by technical difficulties, meaning there has not been some technical thing that we just can't overcome, but instead by, am I correct, Dr. Illingworth, you had suggested that it was budget and management problems?

So maybe say that management has something to do with competence, if someone mismanaged a project of this magnitude, their competence would be called into question. If this was the private sector, it certainly would, and hopefully—this government agency as well.

Who has been reprimanded or fired from NASA for this? Is there an answer?

Mr. HOWARD. Yeah. There is a very good answer to that.

Mr. ROHRABACHER. Okay.

Mr. HOWARD. All of the top management in JWST, both at Goddard and at headquarters, was replaced.

Mr. ROHRABACHER. Okay.

Mr. HOWARD. And there is a new team that is in place, myself being one of them.

Mr. ROHRABACHER. Right. Are they still working for NASA?

Mr. HOWARD. Those people were assigned to other activities, some—yes. All of them, I think——

Mr. ROHRABACHER. All of them are still working for NASA?

Mr. HOWARD. They were all——

Mr. ROHRABACHER. So did they take a pay cut?

Mr. HOWARD. I do not know that.

Mr. ROHRABACHER. Okay. So we know no one lost their job. They just got transferred to someplace, and they are making the same amount of money. When we talk about responsibility and we talk about trying to do our best job for the taxpayer but also for America's Space Program, we are not just talking about balancing the budget here. We are talking about having a viable space program for the United States of America.

I don't think that we can just have three priorities for America's Space Program. I think there are a lot of things to do, and I tried to be, as I say, there is no one been more supportive of space telescopes and astronomy than I have been in my 20 years here.

Six billion dollars more? We are going to take that money from everybody's pocket. All this other puffery that we have heard today will be de-funded because of what we are—because of the incompetence of people that we cannot even take off the payroll.

We need to work together, NASA and Congress, and by the way, I am open, and Ms. Edwards, I think, we suggesting that maybe Congress, there are some things that we were doing that have contributed to some of these cost overruns, providing not as much money as we had promised or something like that. Maybe, Dr. Illingworth, is there something that we have done that has caused this specific overrun? That the Congress has done? The vote has been called, so you are all safe.

Ms. JOHNSON. Mr. Chairman.

Mr. ROHRABACHER. But let me just note, Ms. Johnson has asked for a closing statement, and I think that is absolutely fine, considering how much time I permitted——

Ms. JOHNSON. Thank you.

Mr. ROHRABACHER [continuing]. Someone else to take earlier.

Ms. Johnson.

Ms. JOHNSON. Thank you very much, and thank you, Mr. Chairman, and I am just as concerned about overruns as everyone else, but I wanted to share that some years ago when I was having to wear glasses for nearsightedness, I was always going to sleep, stepping on them, sleeping on them, and would go to another room and left them in another room. And I finally tried contacts. Because of allergies, I didn't do as well with them, and I went to an ophthalmologist who suggested that I get some cornea implants. That research came directly from the telescopic research.

I had to save up my money; the insurance didn't cover it, I paid it from my pocket, $5,000 per eye, and now I can see without any glasses whatsoever.

So that is one thing that this research has brought, and I had to wait in line to get this surgery. It is much in demand, and so I just want to say, Mr. Chairman, that when we know that when research has begun, we have no idea what we are going to find.

Now, I am much more concerned about a first strike in a war that we started and we knew we were getting into war and now that overrun has been almost $100 billion, and so that concerns me a lot more than making mistakes in research.

Thank you.

Mr. ROHRABACHER. I think that is a very good point, and I certainly wouldn't ever ignore that point, and it is a very important point for us to understand, and my closing statement basically is this. I have a seven-year-old son, and I have two seven-year-old daughters, triplets. All right. Well, this weekend, guess what? A glass just fell off the table, and the broken glass is there, and did you drop that glass? Did you push that glass off the table? Oh, the glass just fell off the table. No, the glass didn't fall off the table. He had hit it with his elbow. He actually did something to make the glass fall off the table.

He will learn his lesson. We have got to learn our lesson. We are responsible when there are failures like this. We are responsible for the broken glass. We are responsible when we don't have the money to do other space projects because we have gone along with incompetence and permitted overruns that are unconscionable and de-fund other programs. And when we can't even fire the people and get them off the payroll who are responsible for this type of travesty, we have got real problems. We in Congress have to solve when we have shortcomings as well.

We want to thank all of the witnesses and thank you for putting up with me here at the end. With the questions complete, I thank the witnesses for their valuable testimony and the Members for their questions.

The Members of the Committee may have additional questions for any one of you, and we will ask that you respond to those in writing. The record will remain open for two weeks for additional comments from Members.

This hearing is adjourned.
[Whereupon, at 3:49 p.m., the Committee was adjourned.]

Appendix

Answers to Post-Hearing Questions

Answers to Post-Hearing Questions

Responses by Mr. Rick Howard,
Program Director, James Webb Space Telescope,
National Aeronautics and Space Administration

The Next Great Observatory:
Assessing the James Webb Space Telescope

From Chairman Ralph Hall

1. Despite the tough fiscal environment, NASA received the full amount requested for JWST in FY 2012 as budgeted in the re-plan. However, we cannot be certain that future Congress's will appropriate the amount requested in the out-year budgets. What impact would reduced funding have on your ability to launch JWST in October 2018 as planned?

Response: Stability of the funding profile is a critical factor in determining the success of the new cost and schedule baseline for JWST. Any reduction in future years' appropriations will directly increase the risk of completing the development of JWST within the cost and schedule established in the new baseline. Adjustments to the funding profile from year to year or reductions in funding will nullify the Joint Cost and Schedule Confidence Level (JCL) assessment that was done on the new baseline and assessed by both NASA and the independent Standing Review Board. These assessments were used as the basis of the Agency position that the new baseline is robust and has a high level of confidence. NASA ability to keep the total formulation and development cost capped at $8.0B as directed by Congress would have to be reexamined.

2. During the hearing mention was made of a number of missions that have been impacted substantially by JWST. Mention was made of missions like TPF, SIM, IXO, LISA, and WFIRST, though others were also named, particularly in the planetary arena. Please comment on the impact, if any, that JWST had on the progress on such major NASA science missions.

Response: NASA Astrophysics investments are informed by the National Academy of Science's decadal survey reports. The 2001 report *Astronomy and Astrophysics for the New Millennium,* recommended JWST as its top priority space-based major initiative. Historically, NASA has developed its 'flagship missions' serially. Hubble was the first, followed by the Chandra X-ray Observatory, and later the Spitzer Space Telescope. The NASA Astrophysics budget has never accommodated simultaneous development of flagship class missions. This is done to maintain the community recommended balance between large and small missions in development, missions in operation, and research and analysis funding. All of the other missions mentioned in your question are flagship class observatories, which would have compromised the recommended balance in funding the Astrophysics program. In the most recent decadal survey report, *New Worlds, New Horizons in Astronomy and Astrophysics*, the astronomical community selected WFIRST as the highest priority space-based large-scale activity after JWST. Other missions were ranked third or lower in priority for investment, and in some cases (SIM, TPF, other planet finder missions) dropped completely from mission development recommendations. For example, ESA terminated their participation in LISA and IXO following the low

rankings of those missions in the 2010 decadal survey. Thus, of the Astrophysics missions mentioned above, only WFIRST was directly affected by the expected JWST cost growth and schedule delay in the FY 2012 President's Budget Request, which was released in February 2011 (before the development of the new JWST baseline). Given current fiscal constraints, NASA cannot undertake development of WFIRST until development of JWST is complete. NASA is continuing initial planning efforts to further define WFIRST concepts and science goals. For example, NASA has undertaken a science definition study of WFIRST that will be completed by the end of this year.

From Representative Lamar Smith

1. NASA recently announced that the Kepler Space Telescope has discovered an Earth-like planet 600 light years away whose size and distance from its own star put it in the "habitable zone" to support life. The Hubble Space Telescope has made countless discoveries over the past two decades.
    a. What kinds of scientific revelations might we anticipate with the James Webb Space Telescope, compared to those from Kepler and Hubble? Would you recommend maintaining operations of the Kepler and Hubble Space Telescopes even if funds from those missions are needed to be used to keep JWST on track?

Response: Prior to the launch of Hubble no one knew all the amazing discoveries it would ultimately make. Similarly, JWST's discovery potential is even greater than Hubble's. Like Hubble, JWST will be a general observer facility with observations selected through competitive peer-review. Therefore, we cannot predict exactly what discoveries JWST will make. However, the JWST design has been guided by four scientifically compelling themes: detection and characterization of the first stars and galaxies to form after the Big Bang, the build up and evolution of galaxies across cosmic time, the birth of stars and planetary systems in our Galaxy, and the study of our solar system and of exoplanets. In each of these areas JWST's unmatched combination of wavelength coverage (near to mid-infrared), collecting aperture (6.5m diameter), and sensitivity will permit scientists to see things invisible or undetectable with any existing or planned facility – even Hubble. The Kepler mission is very different from both Hubble and JWST because it stares at one point in the sky and makes extremely accurate measurements of the brightness variations of sources in its field of view. These brightness variations tell us about planets orbiting stars and about how stars themselves vary in brightness with time. While each contributes valuable science, Hubble, Kepler and JWST perform complementary, non-overlapping missions.

The longevity of NASA Astrophysics missions is determined both by the performance of the hardware over time, but also through a peer-review competition with other missions which have met their primary science goals. Every two years NASA conducts a Senior Review of its operating missions in their extended operations phase. The most scientifically useful missions are recommended for extension. Those missions whose scientific return is no longer deemed as compelling receive reduced or no additional funding for extended operations. Thus the decision to extend missions is based upon scientific importance rather than merely the "gap-filling" aspect. Kepler's prime mission is scheduled for completion in November 2012, and continued operation is dependent on results of the Astrophysics Senior Review of operating missions to be held this year. Then Kepler, Hubble and all other Astrophysics operating missions will be reviewed in order to determine whether the continued science return is worth the investment in the context of the entire Astrophysics portfolio.

    b. Could you comment on the role of JWST in maintaining and expanding U.S. global leadership in astronomy and astrophysics?

Response: JWST will be the largest and most technologically complex scientific satellite ever developed. Because of its unprecedented collecting area and cutting edge technology science instruments, JWST will enable science investigations that probe fundamental questions about the origins of stars and galaxies and begin the detailed study of exoplanet atmospheres searching for signatures of life. As Dr. Roger Blandford noted in his testimony to the Committee, JWST is a cornerstone of the 2010 National Research Council decadal survey in Astrophysics. The survey assumed a fully functioning JWST. No other nation could lead the development of a space-based observatory of the complexity and scale of JWST. It will keep NASA and the US on the forefront of space-based astronomy and astrophysics. The new technologies developed for JWST including deployable cryogenic mirrors, microshutter devices, and ultra high sensitivity near and mid infrared detectors demonstrate U.S. leadership in this area. When these technologies are assembled into JWST they will create an observatory with sensitivity 100 times greater than that of Hubble.

As an additional example of U.S. leadership fostered by investments in JWST, ESA and NASA has agreed to discuss US participation in its *Euclid* mission in the area of detectors. The detector electronics ESA is considering are derived from those developed for JWST. Thus NASA and the US astronomy community would gain a "seat at the table" with ESA's *Euclid* science team by virtue of JWST derived technology.

Clearly, Hubble and other Great Observatories have been a huge success and cemented the US leadership role for space astrophysics. JWST will continue that success and position US industry and academia well for the next advances that will follow.

c. How do the Hubble, Kepler and Webb Space Telescopes compare to the capabilities of the European Space Agency's Herschel telescope?

Response: The European Space Agency's (ESA) Herschel Telescope is a 3.5m diameter telescope that operates between the wavelengths 55 to 672 microns (the mid-to-far infrared) and, because it uses stored cryogens, has a roughly three-year lifetime. The angular resolution is at best comparable to ground-based telescopes because of the longer wavelengths and relatively small mirror diameter (for those wavelengths). Herschel will make important advances, but in areas that are distinct from those that JWST is optimized for such as very high angular resolution near infrared observations of faint sources. JWST works from ~0.6 to 28.5 microns (near infrared to mid infrared) and will return images as sharp as those returned today by Hubble. As stated above, Kepler is designed to stare at one specific region of space over its primary mission lifetime, whereas Hubble, Webb, and Herschel are designed to point at many different areas and objects of interest over their lifetimes. Hubble is optimized to observe in the visible and ultraviolet portions of the spectrum. Each of these facilities possesses unique strengths that permit different astronomical phenomena to be studied. They are truly complementary rather than competitive.

d. What are other nations doing in astronomy and astrophysics that could jeopardize America's leadership in the field?

Response: NASA and other space faring nations routinely work collaboratively on missions taking advantage of the capabilities of each organization to improve the science return from most of our missions. Indeed, approximately 85 percent of recent NASA astrophysics missions involved partnerships with other countries. NASA has for years led the world in the development of astrophysics missions in terms of capability. ESA and others are developing increasingly more sophisticated systems that are approaching and in some cases exceeding US capabilities. However, JWST represents an unmatched leap in science capabilities because of its revolutionary technological advances in large deployable mirrors and cryogenic operations.

ESA is moving ahead with its *Euclid* dark energy mission, and NASA (consistent with the recommendation of a recent NRC report) is considering participation at a modest level in that mission. Japan has an active interest in space-based X-ray astronomy, and NASA has long partnered with them in their program. Currently, NASA is developing an instrument to fly on Japan's Astro-H mission in 2014. Both ESA and JAXA have plans for more complex and larger missions in their plans as well.

Other nations have recognized the often broadly applicable technology developed in support of astronomy missions. As they strengthen their investments in those areas (detector development, large mirror construction) they will catch the United States if we do not similarly maintain our investments in leading edge science and technology. Moreover, the world's best and brightest scientists and engineers watch and follow where the most exciting new work is being done. To ensure that we capture those exceptional individuals it is critical that the US be the place where cutting edge work is being performed.

2. Last July, NASA's associate administrator Ed Weiler, who was in charge of NASA's science mission budget of almost $5B annually, called the Obama Administration's flat budget for the James Webb Space Telescope a "road to nowhere" in a press interview. Soon thereafter, Dr. Weiler tendered his resignation, after 33 years of service to NASA.
    a. What are your thoughts of how the Obama Administration handled the budget challenges for the James Webb Space Telescope over the past 3 years?

Response: The Administration has been supportive of JWST. It allowed NASA's process of review and establishment of a new cost and schedule baseline to run its course, then worked closely with NASA to find a solution for funding the new baseline within NASA's top-line budget. The FY 2013 budget request fully supports that new baseline.

    b. Why did the annual funding for the JWST drop during the Obama Administration compared to how much was being spent on the JWST only a few years ago? Shouldn't the funding profile for the Webb telescope have been increasing as the project was ramping up? (FYI:

$438M was spent in FY 2010 for JWST, but only $354.6M was requested in FY 2011)

Response: The Administration's FY 2011 budget request for JWST was $444.8M, up from the $385M that was projected for FY 2011 in the FY 2010 budget request. At that time (February 2010), NASA was still working to the old baseline schedule that assumed a 2014 launch and its associated budget profile. The flat-line budget was a placeholder for the out-years in the FY 2012 budget request pending the re-plan activity. At that time (February 2011), NASA was undertaking a re-plan of the JWST program.

c. Did this flat-line budget from the Obama Administration cause delays to the program? If so, how much delay?

Response: The flat-line budget in the FY 2012 budget request was a placeholder while the new cost and schedule baseline was being developed. The FY 2011 and FY 2012 President's Budget Request funding levels were the only initial constraints in developing the new baseline. The resulting baseline, which included adequate schedule reserves, supported an October 2018 LRD but had an unrealistic funding profile from FY 2012 to FY 2013. The final baseline approved by NASA in September 2011 included adjustments to the FY 2011 and FY 2012 funding that were above the President's budget for those years in order to provide a more executable profile and work plan. To support the October 2018 launch date and the budget profile established in the new baseline, the Administration added $44M in FY 2011. These additional funds, along with those provided in 2012, allowed NASA to accelerate work, retiring risk and saving resources, and to maintain the cost and schedule confidence level of the new baseline.

d. Did the House Appropriations Committee provide an adequate wake-up call for the Obama Administration and Congress that the budget challenge facing the James Webb Space Telescope required fixing?

Response: The Administration had already begun a re-plan of JWST in response to the budget challenges associated with the project. House Appropriations Committee actions regarding the FY 2012 budget lent an additional sense of urgency.

From Representative Larry Bucshon

1. We heard testimony indicating that the James Webb Space Telescope is both grossly over budget and significantly past deadline. Further all of the panelists noted varying degrees of program mismanagement that have resulted in these expenditures and delays. Therefore, I'd like to ask that you supply my office, and this committee with a detailed receipt of how last year's budget was spent. I would like that budget to include detailed explanations of what work was completed and its cost, the cost of the components, labor, materials and how each directly builds toward the hopeful end result of an operational telescope.

Response: The Independent Comprehensive Review Panel report noted the excellent technical progress of the project to-date, but identified several management problems, which have been fully acknowledged and corrected by NASA. Once these corrective measures were put into place early in 2011, the new JWST Program Director worked with the JWST Project Office at the Goddard Space Flight Center and with the prime contractor to identify a set of technical milestones to be accomplished in FY 2011. This served to assure that good progress would be made toward launch while the new baseline cost and schedule was being formulated and reviewed. That list of milestones is shown in the chart below.

JWST FY 2011 Milestones

Month	Milestone	Comment
Jan '11	Ship Mid-Infrared Instrument (MIRI) Focal Plane Electronics to ESA (Rutherford Appleton Lab.) Ball's Flight Actuator Drive Unit Software Test Review	Successfully Completed - 1/24 Successfully Completed – 1/20
Feb '11	Deliver Near-Infrared Spectrograph flight spare detector to GSFC Pathfinder Primary Mirror Backplane Support Structure delivered to Northrop-Grumman Aerospace Sys. Establish No-Earlier-Than Launch Readiness Date (LRD) as part of replan Establish Work Breakdown Structure for new GSFC responsibilities	Successfully Completed – 1/29 Pathfinder delivered to NGAS on 3/25 Based on current funding constraints a NET LRD of Oct. 2018 established, FY 2011 and FY 2012 schedule does not preclude an earlier date if deemed possible in the future – Completed 2/25 Successfully Completed – 2/28
Mar '11	Complete flight ISIM Remote Services Unit Thermal Vacuum testing Deliver Fine Guidance Sensor (FGS) test unit electronics to ISIM Integration & Test (I&T) Complete 2018 LRD budget details	Successfully Completed – 2/19 Successfully Completed – 2/24 Preliminary Budget was presented to Program Office and Center Management on 4/7
Apr '11	Pathfinder Primary Mirror Segment Assemblies complete Deliver ISIM Command & Data Handling test unit to ISIM I&T Complete 2018 LRD project lead Joint cost & schedule Confidence Limit (JCL)	Successfully Completed - 4/25 Successfully Completed – 4/22 Initial JCL run completed – 4/28
May "11	Start flight FGS environmental testing (instrument level) Complete Spacecraft Secondary Mirror Segment Cone Structure internal Design Review 3/4	Successfully Completed - 5/4 Successfully completed – 4/20

Jun '11	Complete Common Command & Telemetry System Build 2.3 Start ISIM level I&T	Successfully completed – 4/13 Successfully Completed - 6/24 Began the ISIM Flight I&T with the integration of the Spacecraft Simulator 2A (SCSIM-2A) into the Flight Electrical Environment.
Jul '11	Deliver ISIM Region 1 Wiring Harnesses Deliver ISIM Structure to ISIM I&T	Successfully completed – 7/22 Successfully completed – 7/28
Aug '11	Spacecraft Flight Software Build 1 Technical Readiness Review	Successfully Completed – 6/30
Sept '11	Deliver Flight ISIM Electronics Compartment to ISIM I&T Deliver flight ISIM Command & Data Handling unit #1 to ISIM I&T	Delayed due to design changes Completed – 9/27

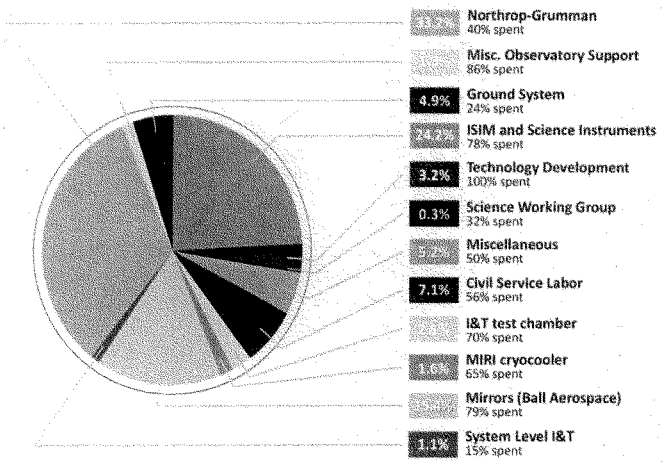
As shown in the chart, all but one of these milestones were accomplished. The cost of these and related activities in FY 2011 is shown in the table below.

JWST FY 2011 Expenditures

	FY11	Actual Obs. FY11
Labor & Related Expenses	21,050	20,800
JWST Program Office	1,300	700
Project Support & MPS	8,192	6,700
Observatory Systems Engineering	10,734	7,200
Safety & Mission Assurance	4,624	3,700
Science & SWG	1,915	1,700
ISIM	80,903	78,800
Observatory	273,394	277,500
OTE	8,673	5,800
Launch Vehicle Accommodations	65	-
Ground Segment	37,244	41,300
Systems Integration & Test	11,049	7,900
OTE/ISIM (OTIS) Integration & Test	14,200	18,300
Contingency	3,414	
Sub-Total JWST	476,756	470,400
JSC Chamber A Mods	38,500	38,500
Total JWST	515,256	508,900

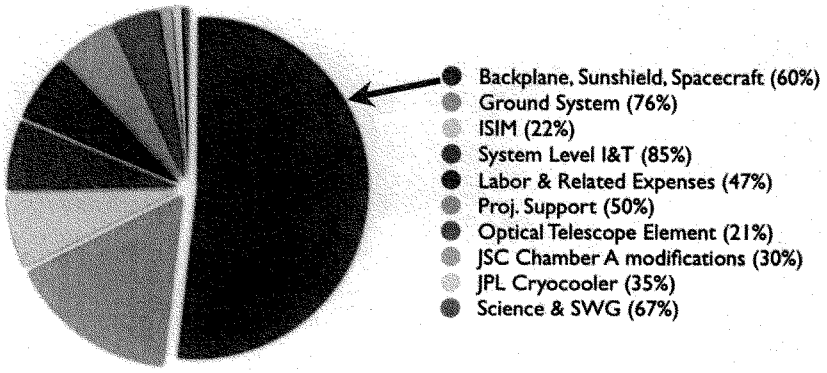
The following chart displays the cost breakdown for the entire amount invested in JWST from its inception through the end of FY 2011.

Cost Breakdown By Element Through FY 2011 ($3.5B total)



Finally, the following chart displays a percentage breakout by cost of major activities of the work yet to be completed on JWST, from FY 2012 through launch and commissioning (i.e., up to the beginning of science operations).

Work-to-Go (FY 2012 through launch and commissioning)



Relative Proportion of Project Funding to Go Percentage Work to Go by Project Element

From Ranking Member Eddie Bernice Johnson

1. The Joint Explanatory Statement of the FY 2012 Commerce, Justice, Science, and Related Agencies Appropriations Conference Committee recently urged NASA to look at lessons learned from reviews of the challenges of prior flagship projects; identify those lessons that address universal management issues; and implement those lessons in flagship projects across the Directorate. How do you plan to undertake the conferees' direction?

Response: NASA is examining its performance on flagship science missions and has already begun changing its processes to better manage technical, cost, and schedule risk. Flagship missions provide significant science return, but cost and schedule management of them has been problematic due to the variety of factors that affect them during their development life cycle. By definition, flagship missions are first-of-a-kind missions that are extending the state of the art in science and technology. In all cases investments are made in the critical enabling technologies to assure that the mission objectives can be achieved. However difficulties still arise as the development progresses because of the complexity of these missions. As an example, the requirement for JWST to operate at cryogenic temperatures meant that many of the traditional manufacturing process and procedures for large space telescopes were inadequate for this temperature regime. NASA and its partners took the leadership in developing these tests and procedures for various elements of the observatory including the composite structures, mirrors, and science instruments. Also flagship missions tend to have longer development times that make them more susceptible to economic changes and leadership changes that can result in challenges for the project. The complexity, uniqueness, and longer development times of flagship missions complicates our ability to establish cost and schedule baselines early in the development cycle. Clearly the results from these missions have proven to be of great value to our nation and the world. As examples consider the long and enormously high scientific productivity of Hubble, Cassini, and other large missions. Their challenging nature is evident as well. In many cases, as with the Mars Science Laboratory, the challenges are technical in nature (for example, in defining optimal heat shield materials, design and manufacturability of wheel actuators, and avionics development).

The steps NASA has taken and is taking to address lessons learned in flagship mission development are summarized here and, for JWST, are detailed in the answers to the questions that follow:

- Establishment of joint cost and schedule confidence level (JCL)-based life cycle cost budgeting that improve the understanding of the complexities and risks associated with a development result in more accurate estimates of cost and schedule as evidenced by the recent performance of Juno;
- Requirement that projects implement Earned Value Management (EVM) systems to weigh technical progress against expenditure of funds on a monthly basis provide early indicators of issues;
- Extended duration Phase B definition and preliminary design to allow for

technology maturation and through system engineering to better characterize the risks to be retired during development and identify unique integration and test needs;

- Use of a formal acquisition strategy process before and during Phase A to define program management structure and Center and contractor roles in a way that best fit the project under consideration;
- Strong independent reviews at key points in the development to verify that the project is making progress per its plan and to offer additional insights based on the independent review teams experience; and,
- Regular reviews with senior NASA management to assure that project concerns are addressed quickly to avoid cost and schedule implications.

Flagship missions enable a broad variety of scientific investigations by carrying large, multi-purpose capabilities like JWST or large numbers of instruments like MSL or Cassini, and are therefore the most scientifically powerful missions NASA undertakes. They accomplish science objectives that no other approach can meet. They also develop technologies that smaller, competed missions can use in the future. As they are by nature one-of-a-kind, they present unique challenges for cost estimation and control. NASA has learned much from those it has developed as well as from JWST now underway, and we are committed to implementing those lessons learned on current and future missions.

2. The report of the Independent Comprehensive Review Panel (ICRP) makes repeated references to the lack of a cost and programmatic analysis capability at NASA Headquarters as a contributing factor in the JWST budget and schedule problems. For example, the ICRP states "*The flaw in the Project Budget should have been revealed as part of the Confirmation process. The fact that it was not reflects the lack of an effective cost and programmatic analysis capability at HQ* [headquarters]. *This too requires immediate corrective action.*" According to the ICRP report, NASA has not had this capability for over a decade.

    a. What has NASA done to act on this recommendation and what, if any, additional plans does NASA have regarding its cost and programmatic analysis capability?

Response: NASA agreed with the ICRP recommendation regarding cost and programmatic analysis capability. NASA has enhanced its programmatic analysis in the new Office of Evaluation, Office of the Chief Engineer (OCE), and the Office of the Chief Financial Officer (OCFO). These offices perform independent analyses and assessments that are reported to NASA senior leaders and program management experts in a monthly Baseline Performance Review and during Key Decision Point reviews. NASA has implemented a cost and schedule database that records key project parameters, such as independent cost estimates and key schedule milestones so analysts may readily analyze and compare ongoing project performance to prior estimates and commitments. Variance analyses are provided to enable managers to identify issues and take action to mitigate their consequences.

b. What has changed in how projects get confirmed at NASA to avoid repeating what happened with JWST?

Response: NASA began to change its policies regarding cost and schedule analysis and assessments made as part of the confirmation process and establishment of a baseline for a mission. The changes mentioned above have been implemented with success on recent projects such as Juno and GRAIL. However, NASA continues to evaluate its performance to improve its program and project management processes to assure that confirmation of a project is justified through analysis. The Policy for NASA Acquisition (NPR 1000.5A) states programs and projects are to be baselined or rebaselined and budgeted based on a joint cost and schedule probabilistic analysis developed by the program or project in accordance with the following:

- Programs are to be baselined or rebaselined and budgeted at a joint cost and schedule confidence level of 70 percent or the level approved by the decision authority of the responsible Agency-level management council. For a 70 percent joint cost and schedule confidence level, this is the point on the joint cost and schedule probability distribution where there is a 70 percent probability that the project will be completed at or lower than the estimated amount and at or before the projected schedule. The basis for a confidence level less than 70 percent is to be formally documented.
- Projects are to be baselined or rebaselined and budgeted at a joint cost and schedule confidence level consistent with the program's confidence level.
- Joint cost and schedule confidence levels are to be developed and maintained for the life cycle cost (at the approved confidence level) and schedule associated with the initial lifecycle baselines (e.g., for space flight programs and projects baselines established at KDP-1 for entry into the development phase of a multi-project program, or KDP-C for a single project).
- A Joint Cost and Schedule Confidence Level is a quantitative probability statement about the ability of a project to meet its cost and schedule targets. Simply put, a JCL is the probability that the cost will be less or equal to the targeted cost AND that the schedule will be equal or less than the targeted schedule date. The process of developing a JCL requires that the project combine their cost, schedule and risk into a complete quantitative picture that helps the decision makers understand the project's prospects for success in achieving their cost and schedule goals. The technique identifies the project-specific risks and allows decision makers to better understand those risks and the context for establishing the project's phased funding requirements.

In addition, the NASA Procedural Requirement for Program and Project Management (NPR 7120.5) is being revised to better identify work that is to be completed during Phase B and more rigorously evaluating whether that work has been satisfactorily completed prior to approving the project for implementation. By better understanding the requirements and the risks associated with projects, the resources and schedule needed to implement the projects can be more reliably sized. Confirmation of significant NASA projects now requires rigorous analyses be performed to confirm that the cost and schedule estimations have incorporated thorough risk assessments. NASA now requires that these analyses of a project's joint confidence levels (cost and schedule) be independently reviewed prior to

confirmation and the results of the review are assessed during the confirmation. NASA has established that some projects, like JWST, should be planned with high confidence levels.

Consistent with these policies and procedures, the revised plan for JWST was approved with a joint confidence level of 66 percent (following Agency policy as described above) and a cost confidence significantly higher than the 80 percent recommended by the ICRP (cost confidence levels refer only to the cost portion of the estimate and are independent of the schedule). The cost profile and October 2018 launch readiness date were found to be a sound plan by Goddard center management, the Science Mission Directorate, the independent Standing Review Board and senior management at NASA Headquarters.

3. The ICRP report raised a number of concerns about the oversight and governance of the JWST project within NASA. Is there an independent body that reviews the progress on JWST, and if so have they reviewed NASA's new plan and cost estimate?

Response: Yes, there is a Standing Review Board (SRB) for JWST that was involved in the review of the new baseline including the risks and risk matrix used to generate the JCL and the results of the JCL. The SRB presented their assessment of the new baseline including the results of the JCL to NASA management as part of the Agency's review of the new baseline. The SRB continues to review the technical and programmatic progress and issues of the program.

a. What was their response to the plan and did they issue any findings and recommendations for NASA on the new plan?

The Standing Review Board issued three findings and one recommendation. The Board found that the project technical baseline reflected that JWST was at the CDR phase of development with some exceptions. They found that NASA had taken positive agency, program, and project-level management steps to reduce program risk. No recommendations accompanied these two findings. The Board found that the replan initially presented to them as constrained by the FY 2011 and FY 2012 funding guidelines was seriously flawed and recommended increasing FY 2011-2012 funding, by applying no less than 30 percent reserves throughout the program to account for unknown risk, and reducing the FY 2013 funding peak by shifting critical efforts into FY 2012 and adjusting the out-year funding profile accordingly. The final plan was reviewed by a sub set of the SRB and agreed that it addressed the SRB concerns.

b. How has NASA responded to those findings and recommendations?

Response: NASA responded to this finding by revising the baseline to provide additional resources in FY 2011 and FY 2012 (including rephasing work content from FY 2013 into FY 2012 which reduced the FY 2013 funding requirement) and adding additional unallocated future expenditures (UFE) in FY 2014 and out. The SRB reviewed this revised baseline and determined that this was a positive step towards successful planning and implementation of JWST. The rephasing of work

along with the additional UFE in the new baseline resulted in a cost confidence level that is significantly higher than the 80 percent recommended by the ICRP. That revised budget profile became part of the new (current) cost and schedule baseline. UFE allocation is phased throughout the project lifecycle to enable management of risks and uncertainties associated with each lifecycle phase. NASA distinguishes UFE funds managed by the project and UFE funds managed by the program responsible for the project. The UFE managed by the project is needed to cover risks and uncertainties that could be reasonably viewed as under the project's control. The UFE managed by the program is needed to address risks and uncertainties that are beyond the projects control i.e. partner's schedule delays or growth in launch vehicle costs.

4. The ICRP noted that the JWST science team had not played a significant role in providing inputs to difficult trade-offs regarding JWST's scientific performance and recommended that their role be strengthened. Please describe what changes have been made to increase the science team's role.

Response: As we reported in our response to the ICRP recommendations, NASA has added a Deputy Senior Project Scientist/Technical position to the project science team. This individual is responsible for day-to-day interactions with senior project management on all aspects of the mission; scientific, technical, budgetary, and schedule. This individual also regularly meets with other members of the project science team to ensure rapid and substantive communication between the science and cost/schedule/risk worlds. This new position assists the Senior Project Scientist to better integrate the science activities with the hardware development activities to enable closer coordination and understanding of technical drivers to science performance so fully informed decisions can be made.

In addition, the Senior Project Scientist at Goddard Space Flight Center now reports directly to the Center Director, and project scientists make monthly technical reports within the project. The science team members work closely with their managerial and engineering counterparts in all areas of the international JWST Project to find technical solutions that ensure that the agreed scientific performance requirements are met.

5. We often hear about the importance of having challenging space projects to sustain the skilled workforce in this nation. What, in your view does JWST mean for our workforce and for those young people who will become our workforce in the future?

Response: JWST is the next-generation astrophysics mission, more powerful than any science mission humans have launched into space. JWST represents a substantial advance in technology and observing capability. JWST will change the way future space telescopes are built and tested because: it represents the first instance of a telescope whose mirror diameter is larger than the launch vehicles fairing and because of its size it cannot be tested as a unit in one test chamber, it therefore represents the first mission that relies on a complex multi-stage integration and test program combined with sophisticated computer modeling to verify observatory performance before launch. Both of these features, rocket fairing

limitations, and vacuum test chamber sizes were fundamental limitations on telescopes before. JWST developed technology along with new processes and procedures to break those limitations and free future scientist and engineers to think about space observatories in a new way. Young scientists and engineers will be able to build on that to develop even more powerful science instruments over the next few decades. Students will be inspired by JWST science results to themselves study science and engineering (as today's early career workforce was inspired by Hubble). They will carry on that legacy of discovery into the middle of this century and beyond.

6. The ICRP recommended that for JWST, a conservative cost and schedule confidence level of 80 percent, rather than the NASA policy of 70 percent, should be followed. Does NASA have guidelines for determining whether a mission should be budgeted at a 70 or 80 percent-integrated cost and schedule confidence level? If so, what are those guidelines?

Response: Yes. NPR 7120.5 has been revised to direct that managers shall plan and budget programs and projects based on a 70 percent joint cost and schedule confidence level (JCL) or as approved by the Associate Administrator. Any joint confidence level approved by the Decision Authority at less than 70 percent must be justified and documented (as was done in the case of JWST). NASA carefully considers risks and external and independent advice when deciding the confidence level and may increase the level to a level, such as 80 percent, when appropriate.

From Representative Jerry Costello

1. What mechanisms has NASA put in place to ensure that the JWST program remains on track for launch in 2018, and what information will Congress need to be able to verify that those milestones are being achieved?

Response: NASA has implemented all the recommendations of the Independent Comprehensive Review Panel report, as we described to the Congress in our report submitted on April 21, 2011. These include: restructuring of JWST program management at NASA Headquarters and establishment of a JWST Executive Committee of senior government and contractor executives that meets quarterly; establishment of a strong system engineering capability on the government side with close collaboration with the prime contractor; and establishment of a cost and schedule baseline with adequate reserves in each year of development and account of liens and threats; strong independent reviews at key points in the development to verify that the project is making progress per its plan and to offer additional insights based on the independent review teams experience; and, regular reviews with senior NASA management to assure that project concerns are addressed quickly to avoid cost and schedule implications. The JWST Program Office at Headquarters and the Project Office at NASA Goddard Space Flight Center closely tracked progress on an identified set of program milestones for 2011 and all but one was completed. The same is being done now for 2012, and the list of FY 2012 milestones is shown in the table below.

JWST Planned FY 2012 Milestones

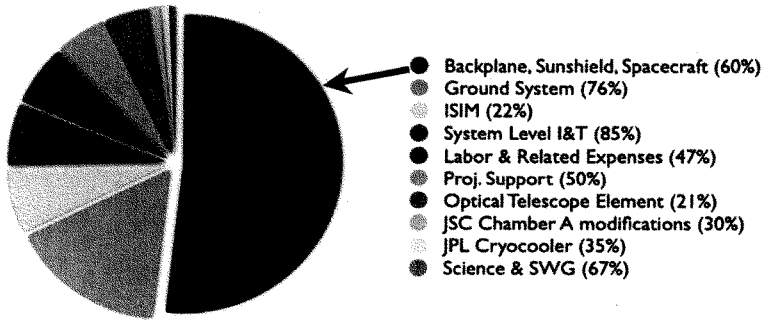
Month	Milestone	Comments
Oct '11	Begin construction of 140,000-lb robotic facility to build segmented main mirror at GSFC	Assembly began 10/4
Nov '11	Complete electronics simulator model for Integrated Science Instrument Module ("ISIM")	Completed 11/15
	Deliver tools for software development environment and verification	Completed 10/27
Dec '11	Install Helium shroud floor at Johnson Space Center thermal vacuum chamber ("JSC TVC")	Completed 10/26
	Determine root cause of NIRSpec optical bench flaw	Completed 12/15
Jan '12	Conduct Critical Design Review for Spacecraft-to-Optical Telescope Element vibration isolation system	Completed 12/15
	Finish building Center of Curvature Optical Assembly ("COCOA") for testing primary mirror in JSC TVC	Completed 1/13
	Review preliminary requirements for ground structure for spacecraft equipment panels	Completed 12/1
	Complete Aft Optic System integration and alignment	Completed 12/2
	Update Program Plan and Program Commitment Agreement to reflect replan	Completed 1/28
Feb '12	Complete assembly and initial testing of main mirrors at Marshall Space Flight Center	Completed 12/19
	Install Helium shroud walls at JSC TVC	
Mar '12	Complete assessment of System Engineering Team thermal margins	
	Deliver ISIM computer #2 to ISIM integration and testing	
	Complete analysis of JSC TVC telescope testing equipment plans	

Apr '12	Receive Flight Mid-infrared Instrument (MIRI) from Europe, first of the telescope's four science instruments Complete Critical Design Review for Sunshield Support Structure Complete all composite parts for mechanism that lifts telescope away from spacecraft after launch (Deployable Tower Assembly)	
May'12	Finish testing the COCOA Measure Sunshield template layer 5 shape to confirm its accuracy Conduct budgetary and schedule review of initial program and project performance since completing the 2011 replan	
Jun '12	Complete modifications of JSC TVC Complete Critical Design Review for telescope-ground communications system Complete designs for structures that will hold telescope inside JSC TVC Complete Preliminary Design Review for equipment that tests Sunshield deployment	
Jul '12	Reach agreement with Program Office on FY13 spending plan Deliver Flight Fine Guidance Sensor Deliver flight software to ISIM Integration and Testing ("ISIM I & T") Complete Solar array Preliminary Design Audit Deliver MIRI Cryo Cooler "Cold Head Assembly" (critical component of MIRI cooling) to ISIM I&T Complete fabrication of end fitting for Secondary Mirror Support Structure	Flight CHA to be delivered in June 2013. No impact, work around in place.
Aug '12	Order remaining JSC thermal vacuum chamber vibration isolators	
Sep '12	Deliver NIRCam, the second of the telescope's four science instruments Deliver telescope simulator for ISIM I&T Start testing of cryogenic camera system, used for subsequent JSC I & T Complete center section of Backplane Support Structure for main mirror Deliver NIRSpec, the third of the telescope's four science instruments	Delivery date moved to 2/13. No impact to, work around in place.

Blue indicates milestones completed ahead of schedule.

Finally, the following chart displays a percentage breakout by cost of major activities of the work yet to be completed on JWST, from FY 2012 through launch and commissioning (i.e., up to the beginning of science operations).

Work-to-Go (FY 2012 through launch and commissioning)



Relative Proportion of Project Funding to Go **Percentage Work to Go by Project Element**

NASA will keep the Congress informed of progress on these milestones and work to go.

2. You have indicated that one of your concerns with the replan's launch date of 2018 is the need for the JWST team to remain focused and motivated to keep the momentum of this year. What is your plan for ensuring that the team stays focused and motivated?

Response: One of the key means to keep the JWST Team focused and motivated is good internal communication. The Project Office meets with the senior staff weekly and with the entire project staff monthly to ensure all information about the project (whether good or bad) is made available. Secondly, the team is very aware of the importance of JWST to not only NASA, but to the Nation and understands the importance of their individual contributions. The budget and stability of the budget provided for JWST makes this new mission baseline executable and allows the project to "do what we say we are going to do." Success in meeting commitments is very positive feedback to a team and keeps it focused on the future. Finally, the delivery of hardware is always a large motivator and builds excitement. During the past year, hardware has begun to arrive at the Integration and Test Facility at NASA/GSFC. During the coming year, science instruments will be delivered and the build up and testing of the instrument module will begin. In addition, many of our contractors now have various components of flight hardware at their facilities (e.g., completion of all telescope mirrors). The entire project is transitioning into the Integration and Test Phase. This is a time of great excitement and keeps everyone focused and motivated.

3. The ICRP report noted that "*A decision on system engineering is a decision on accountability. In a project of this complexity and visibility, it is appropriate for the Government to be accountable. It is crucial, however, that the transfer of responsibility be executed properly.*"
    a. What has been the impact of moving systems engineering accountability from Northrop Grumman to NASA? How did that transfer go?

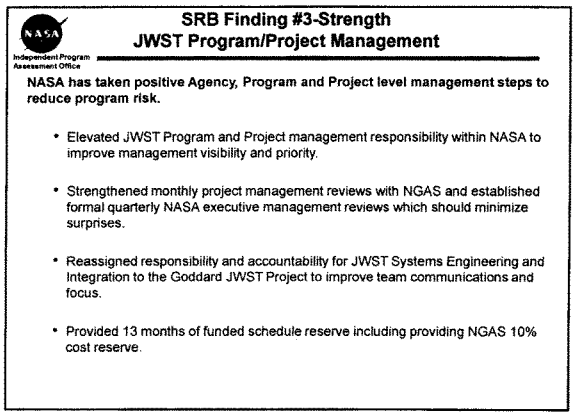
Response: The primary impact of the transition of systems engineering is a more streamlined team in which management of systems interfaces is better aligned with responsibilities. This reduces inefficiencies and risks associated with cross-organizational boundaries. It also reduces the time to make decisions to address system optimization as opposed to segment and element optimization.

The government has responsibility for providing the Launch Vehicle, the Ground Segment, and the Integrated Science Instrument Module. It also has responsibility for the Johnson Space Center and Goddard Space Flight Center (GSFC) test facilities both of which play significant roles in the system level test and verification programs. Decisions involving allocations and interfaces between these segments and the prime contractor provided portions of the observatory have been areas of particular complexity. Negotiations of these interfaces had to cross-corporate and multi-national boundaries. Issues regarding ITAR, and corporate intellectual property were often obstacles that prolonged these efforts. Having GSFC lead the system engineering team responsible for these negotiations improves efficiency as well as minimizes the risks the dropout of critical information introduced by these boundaries.

Overall the transfer of the responsibility of the leadership of system engineering from the prime contractor to GSFC has gone well. There were no significant personnel or organizational issues. Soon after this transfer benefits of the new organization began to be realized. The prime contractor system engineers began to surface and address technical problems, which had long been suspected by the GSFC technical team. The new organization fostered an environment where identifying and addressing technical problems as part of an open, non-organization-centric team was encouraged. Had these problems lingered, the costs of fixing them could have been much higher. The current thermal margin recovery efforts as well as the successful efforts to fix the Star Tracker Assembly mount roll stability are prime examples of this.

b. Has this transition process been examined given its importance to the program? If so, by whom and what were the findings?

Response: The JWST Standing Review Board (SRB) examined the transition of system engineering leadership. Key members of the SRB were present and audited various working meetings that occurred as part of this transition process, among them the working meeting at the JWST Partners Workshop in Houston TX in January 2011. Formal presentations of the transition were made to the SRB during their review of JWST that occurred on March 31, 2011 and May 10, 2011 at the GSFC. The SRB reported their findings to the NASA Science Mission Directorate on June 16, 2011. Finding #3 of their report cited the reassigning of responsibility and accountability for JWST Systems Engineering and Integration to the Goddard JWST Project to improve team communications and focus as a strength. The chart below is an excerpt from that presentation.



Responses by Dr. Roger Blandford, Professor of Physics, Stanford University and Former Chair, Committee for the Decadal Survey of Astronomy and Astrophysics, National Research Council

Dear Mr. Hall

Thank you for your letter of Jan. 18 concerning the hearing "The Next Great Observatory: Assessing the James Webb Space Telescope" held on Dec. 6 2011. You ask several questions. My answers are guided in part by my role in the Astronomy and Astrophysics Decadal Survey "New Worlds, New Horizons in Astronomy and Astrophysics" (NWNH), which I chaired.

Chairman Hall:

1. *Has the experiences with JWST's delays and cost overruns diminished the astrophysics community's appetite for proposing future flagship missions that rely on solving technical challenges to enable mission success? With respect to technical complexity, how does the WFIRST mission compare with JWST? Will it be as challenging a satellite to design and build?*

While I cannot speak for the entire astrophysics community, I can say that the issue of balance between large, medium and small missions was a major consideration in developing the program recommended in NWNH, well before the magnitude of the James Webb Space Telescope (JWST) overrun and delay was understood. This need for balance includes an implicit acknowledgement that some major questions can only be addressed by large missions. Technical readiness was deemed necessary for all the missions that were recommended in NWNH. In particular, the Wide Field Infrared Survey Telescope (WFIRST) was assessed to have medium-low technical risk and medium cost risk and should not present the challenge of JWST. A detailed discussion of this topic can be found on p277 of the NWNH panel reports.

2. *During the hearing mention was made of a number of missions that have been impacted substantially by JWST. Mention was made of missions like TPF, SIM, IXO, LISA, and WFIRST, though others have also been named, particularly in the planetary arena. Please comment on the impact, if any, that JWST will have on the progress of such major NASA science missions.*

NASA responded to the challenge of completing JWST as well as the cuts to the Science Mission Directorate (SMD) FY2012 President's Budget request by ceasing to support the third and fourth NWNH-recommended large space missions, the Laser Interferometer Space Antenna (LISA) and the International X-ray Observatory (IXO) and terminating collaboration with the European Space Agency (ESA) on these projects. The Space

Interferometry Mission (SIM) was not found to be competitive with the recommended missions before the JWST situation was understood. The analysis carried out under the auspices of NWNH found the technical risks of TPF to be too high for inclusion in the program for the next decade. The survey did recommend a robust technology development program to prepare a major exoplanet mission for the next decadal survey committee to consider. Although NASA plans to find half of the additional funds it will need to complete JWST from outside SMD the funds that must be found from within SMD will have to come from other initiatives. Overruns on projects like JWST, combined with cuts to the overall budget, have the consequence that there are insufficient resources to execute the exciting scientific programs recommended in astrophysics, earth science, heliophysics and planetary science.

Rep. Smith:

1. *NASA recently announced that the Kepler Space Telescope has discovered an Earth-like planet 600 light years away whose size and distance from its own star put it in the "habitable zone" to support life. The Hubble Space Telescope has made countless discoveries over the past two decades.*

a. *What kinds of scientific revelations might we anticipate with the James Webb Space Telescope, compared to those from Kepler and Hubble? Would you recommend maintaining operations of the Kepler and Hubble Space Telescopes even if funds from those missions are needed to be used to keep JWST on track?*

As was the case with the Hubble Space Telescope (HST) and Kepler, the most exciting discoveries that are likely to be made by JWST cannot be scripted in advance. Indeed, completely new research fields could be initiated by JWST. It will expand our capability so much that it is confidently expected that its importance will at least equal that of HST. JWST's prime areas of study include the first stars and galaxies, the life histories of stars and galaxies and exoplanets. Kepler and HST will both be subject to the upcoming Senior Review and I must defer to this body. Speaking personally, I believe that most of the missions that will be compared in the Senior Review are unique facilities that are still delivering exciting results at a high rate and I would continue to operate them. There will be few new missions this decade other than JWST and it is vital to maintain a flow of new observational data. I would need a much better understanding of the NASA-SMD budget than I have to prioritize keeping JWST on schedule and supporting successful satellites in orbit.

b. *Could you comment on the role of JWST in maintaining and expanding U.S. global leadership in astronomy and astrophysics?*

JWST is an ambitious, yet achievable, mission and, at this time, only the US has the capacity to execute it. As described in NWNH pp81-85, the rest of the world is catching up fast and I believe that a failure to complete JWST will be an effective surrender of US leadership in space astronomy and astrophysics.

c. *How do the Hubble, Kepler and Webb Space Telescopes compare to the capabilities of the European Space Agency's Herschel telescope?*

Herschel Space Observatory is a 3.5 m telescope operating longward of 65 microns. HST has a smaller aperture operating at much shorter, optical and ultraviolet wavelengths. Kepler is also an optical telescope. JWST is, by far, the most sophisticated of the four with a much larger aperture and operational capability at wavelengths from the red to the mid infrared. They are really complementary and not scientifically competitive.

d. What are other nations doing in astronomy and astrophysics that could jeopardize America's leadership in the field?

The Europeans and the Japanese have broad and strong space astrophysics programs which are already competitive with the US program in many areas. In addition to the missions mentioned above, missions such as CoRoT, Planck, Suzaku, XMM-Newton, are operating successfully and productively. To give three examples, the Europe-led Gaia and Japan-led Astro-H promise to be big successes while the European Euclid mission is likely to follow up largely US discoveries well ahead of WFIRST. Russia, China and India have growing space capabilities. On the ground, Canada, Japan, Australia, Brazil, China and India have great ambitions to join next generation optical telescopes led by Europe and US private organizations. A decision will be taken later this month on whether to host the next international radio telescope, the Square Kilometer Array, in Australia or in South Africa. There are no plans for significant US federal involvement in any of these ground-based projects which represent, as discussed in NWNH, the long term future of fields which the US once led. This message is not being lost on mobile, young scientists.

2. Last July, NASA's associate administrator Ed Weiler, who was in charge of NASA's science mission budget of almost $5 billion annually, called the Obama Administration's flat budget for the James Webb Space Telescope a "road to nowhere" in a press interview. Soon thereafter, Dr. Weiler tendered his resignation, after 33 years of service to NASA.

a. What are your thoughts of how the Obama Administration handled the budget challenges for the James Webb Space Telescope over the past 3 years?

I have no understanding of how the JWST budget has been handled over the past three years beyond public statements made by NASA and the ICRP and TAT reports. It is unfortunate that the budgetary estimates provided by NASA to the decadal survey turned out to be so inaccurate.

b. Why did the annual funding for the JWST drop during the Obama Administration compared to how much was being spent on the JWST only a few years ago? Shouldn't the funding profile for the Webb telescope have been increasing as the project was ramping up? (FYI: $438 million was spent in FY2010 for JWST, but only $354.6 million was requested in FY 20ll).

I have almost no understanding of how NASA manages its budget or the basis for its funding requests.

c. *Did this flat-line budget from the Obama Administration cause delays to the program? If so, how much delay?*

My understanding from the ICRP report is that the JWST delay and over-run is largely attributed to inadequate funding and reserves and management failures over several years. However, you must ask NASA for further quantitative information and a recounting of the history.

d. *Did the House Appropriations Committee provide an adequate wake-up call for the Obama Administration and Congress that the budget challenge facing the James Webb Space Telescope required fixing?*

I believe that actions by the House and Senate did stimulate the critical re-examination of the budget that was described by Dr. Howard at the hearing.

Rep. Hultgren:

1. *Could you comment on the impact that JWST will have on our national STEM initiative in terms of inspiring and attracting the youth of today into fields of science, math and engineering?*

As documented in NWNH, pp104-114, astronomy plays a major role in starting young people along the road to careers in STEM fields. I expect that the impact of JWST will be similar to that of HST due to the quality of the imaging and the accessibility of the underlying questions and answers. Many of my generation were similarly inspired by the stunning results from NASA's early space science missions.

2. *JWST has significant international participation, most notably by the European Space Agency and the Canadian Space Agency. Could you comment on the effect the JWST will have on global cooperation in space and other scientific endeavors?*

JWST has major European and Canadian partners and the collaboration is highly successful. Although the US is currently the only nation that can lead missions of the scale of JWST, it is necessary that they be collaborative. Joint success with JWST will surely facilitate future collaboration. Conversely, whenever the US is unable to maintain its international commitments, it impacts global scientific cooperation negatively and damages the standing of the US.

3. *While our international partners are making valuable contributions to the JWST program, could you comment on the role of JWST in maintaining and expanding U.S. global leadership in astrophysics? What are other nations doing in astrophysics that could jeopardize our global position if the U.S. did not proceed with JWST?*

JWST is an ambitious, yet achievable, mission and, at this time, only the US has the capacity to execute it. As described in NWNH, pp81-85, the rest of the world is catching up fast and I believe that a failure to complete JWST will be an effective surrender of US leadership in space astronomy and astrophysics. The Europeans and the Japanese have

broad and strong space astrophysics programs which are already competitive with the US program in many areas. In addition to the missions mentioned above, XMM-Newton, CoRoT, Suzaku are operating successfully and productively. Planck, Gaia and Astro-H promise to be big successes and Euclid is likely to launch well ahead of WFIRST. Russia, China and India have emerging capabilities. On the ground, Canada, Japan, Australia, Brazil, China and India have great ambitions to join next generation optical telescopes led by Europe and US private organizations. A decision will be taken later this month on whether to host the next international radio telescope, the Square Kilometer Array, in Australia or in South Africa. There are no plans for significant US federal involvement in any of these projects which represent, as discussed in NWNH, the long term future of fields which the US once led. This message is not being lost on mobile, young scientists.

4. *How will JWST contribute to our national objectives in science and engineering?*

JWST is technically challenging on all fronts and developing the capabilities that are needed to build a successful telescope will likely lead to progress in other fields in ways that are not always predictable. Possible examples include beryllium mirrors, remote cryogenic operations and deployment of complex structures. I suspect that others, more closely tied to the project will have a better answer to this important question.

5. *The Hubble Space Telescope has made countless discoveries over the past two decades. Could you comment on the kinds of scientific revelations we anticipate, compared to those from Hubble? What about the serendipitous discoveries that we don't anticipate, imagine or seek?*

As was the case with the Hubble Space Telescope HST, the most exciting discoveries that are likely to be made by JWST cannot be scripted in advance. Indeed, completely new research fields could be initiated by JWST. It will expand our capability so much that it is confidently expected that its importance will at least equal that of HST. JWST's prime areas of study include the first stars and galaxies, the life histories of stars and galaxies and exoplanets. We expect many serendipitous discoveries.

6. *My understanding is that as Hubble expires in the next few years, many of the scientists working on Hubble will transition to JWST. Could you comment on the role that JWST will play in maintaining and expanding our nation's scientific intellectual capability?*

Many astronomers, notably younger astronomers, are already orienting their research to be ready for JWST and exploit its unprecedented capability. For those most directly involved, there is a plan to de-orbit HST at the end of the decade and an expectation that scientists at STScI will transition from HST to JWST. Having this experienced STScI team as well as scientists all over the US work on JWST is one important way to maximize the intellectual return from JWST. Another is to find stable career paths for the best young scientists today. This is the generation which will exploit JWST to the full.

7. *Could you comment on the secondary benefits that will be derived from JWST in terms of new technology development that will enable other scientific, engineering or national security endeavors?*

In general space missions build upon the experience from previous missions and bequeath technological successes to their successors. JWST is technically challenging on all fronts and developing the capabilities that are needed to build a successful telescope will likely lead to progress in other fields. I have no access to the classified program within Northrop-Grumman but I suspect that there is a strong synergy with JWST.

Rep Johnson:

1. *What puts astronomy and astrophysics in the must-have category as opposed to the nice-to-have category? How can I convince my colleagues in Congress and my constituents that JWST is of national importance in these fiscally constrained times?*

The strongest, general arguments for supporting astronomy and astrophysics, as discussed in NWNH pp104-115, are its role in education, its high rate of enduring discovery which keeps public and professional interest high and the technical challenges that it frequently confronts and meets. Support of high technology endeavors, like JWST, usually has a large multiplier when it comes to creating jobs. To me, the strongest argument for staying the course on JWST is that it will be a fantastic telescope that will engender pride in American accomplishment in people from all backgrounds around the world and will lead to stunning discoveries about who we are, where we came from and what else is out there.

2. *We often hear about the importance of having challenging space projects to sustain a skilled workforce in this nation. What, in your view, does JWST mean for our workforce and for those young people who will become our workforce in the future?*

I have discussed above the inspirational impact of JWST. I am really not fully competent to address this question but I believe that, at a technical level, JWST will be a very public *tour de force* that will impact the way difficult, remote, robotic operations such as undersea surveying, nuclear reactor inspection and defense are conducted. Infrared sensor technology is also being pushed by JWST and this has widespread application. Finally projects of this scale invariably lead to advances in data handling and image processing. If this expectation is vindicated, JWST will ultimately be seen as having helped create many exciting opportunities in science and technology for the students of today to join and lead.

3. *Has the science community within NASA or external to NASA been asked for input on how the offsets needed to fund JWST cost increases are to be made within the Science Mission Directorate, especially with respect to astronomy and astrophysics?*

I am unaware of attempts to engage the science community in finding the offsets needed to fund JWST. Such a dialog if it happened is most likely to have taken place under the auspices of NASA's internal advisory committees, the NAC and the APS and you should consult their chairs.

a. *Has NASA or the Office of Management and Budget shared any proposals on how those offsets might be made, and if so, what is your reaction?*

Some actions have already been taken by NASA in response to changes in the FY2012 budget and the JWST overruns. Within astrophysics, these include the disbanding of the LISA and IXO teams. I deeply regret this as gravitational wave astronomy and high resolution X-ray spectroscopy are two exciting frontier areas ripe for exploration and much progress had been made on these proposed missions by many fine scientists working for well over a decade.

4. *Are the National Academies addressing the changes and uncertainty in the astrophysics budget outlook and the associated impact on NASA's ability to implement the decadal priorities your panel identified? If not, should they?*

So far, the National Academies have addressed one issue, whether the US should make a roughly $20M contribution to the European Euclid mission. As anticipated in NWNH, pp101-104, there is an need to set up an independent advisory committee very soon that will address the urgent issues that the US astronomy and astrophysics community now face if budgets and obligations preclude starting on the recommended program. A related issue is that of providing bridging resources for funding young people over the decade as missions disappear before new ones arise. It has proven difficult to reach agreement with the agencies, but I can report that the Committee on Astronomy and Astrophysics, which can fill the role of an independent advisory committee, is now being re-convened.

5. *As part of its work, did your decadal survey committee view the prospects for continued U.S. leadership in astronomy and astrophysics?*

NWNH did consider the prospects for continued US leadership in astronomy and astrophysics, pp79-87.

a. *If budget constraints significantly alter what missions can be accomplished in the next five to eight years, what is the outlook for astronomy and astrophysics?*

NWNH concluded that the rest of the world was already catching up the US quite fast. We also noted that large projects are now mostly multi-national in practice making "US leadership" harder to define and assess. The best young scientific talent should be a significant component of any such definition and it, like capital and jobs, is proving to be highly mobile. The decadal survey was predicated on agency budgets that were allowed to range between optimistic and pessimistic. The present reality appears to be well below the pessimistic plan so that very little can be initiated this decade. There may be relatively few employment opportunities. This will inevitably lessen "US leadership."

b. *What are the risks to U.S. leadership?*

In my view the highest priority to maintain US leadership in astronomy and astrophysics from space is to stay the course on JWST. The next highest priority is to move forward as fast as possible with executing a balanced new program as recommended in detail by NWNH. A balanced program was likewise recommended by NWNH on the ground including constructing the Large Synoptic Survey Telescope. Whole subfields, which the

US has traditionally led, will be lost for a generation if the carefully-proposed, combined NWNH program cannot be started in a timely manner.

c. *What would be the impact of increased international collaboration?*

International collaboration is almost certainly a large feature of any future program. The benefits, as described in NWNH, include pooling of financial and technical resources and executing a broader range of science programs. The disadvantages include the greater cost of and difficulty in managing the program. In my experience, though, the advantages usually outweigh the disadvantages.

6. *While JWST now has a new plan and cost baseline for the implementation of the program, there is still much work to be completed. What happens if JWST runs into costly problems during final development, testing, and integration that exceed reserve levels? What should be the plan?*

I agree that JWST still has a long road ahead of it. However, I do think that Congress has forced NASA and its major contractors to apply and maintain a higher level of reserves for the project. The challenge that I see will be to ensure that NASA has the necessary budget over the next five years to keep to schedule and that it works closely with its contractors and international collaborators to address any problems as soon as they arise.

7. *Some might say that given the cost overruns on the James Webb Space Telescope, we just can't afford to go down that path again with a major flagship such as the Wide-Field Infrared Survey Telescope (WFIRST), or any flagship for that matter. What are your views on that perspective?*

We certainly don't want to go down the path of JWST management for future flagship missions. However, flagships are likely to remain one component of the international space science program because of the crucial scientific role they play. Incidentally, the cost of WFIRST was estimated by NWNH to be $1.6B which, although large in absolute terms, is smaller than the cost of other major missions, and so it was not considered by NWNH, or by NASA, to be a major flagship. ESA has decided to proceed with a mission called Euclid that is similar in scale to WFIRST and has overlap in objectives. ESA classifies Euclid as "mid-scale". ESA is also continuing to develop more expensive large-scale missions called Athena and NGO that are the counterparts of the missions LISA and IXO, that NASA has now, sadly, abandoned. (For comparison, the NWNH-appraised international costs of LISA and IXO were $2.4B and $5.0B respectively.) The capabilities and scientific reach of WFIRST, significantly exceed those of Euclid and the best course is to proceed with a medium-low technical risk and medium cost risk WFIRST as soon as commitments to JWST allow.

Rep. Costello:

1. *What has been the role of America's astronomy and astrophysics activities, such as Hubble, on inspiring the next generation to pursue science and engineering education and careers?*

Kavli Institute for Particle Astrophysics and Cosmology

I believe that HST and other "flagship" missions have had a major role in inspiring young people to consider careers in science and technology and have enriched the lives of all of us by addressing and now answering fascinating and basic questions that engage layperson and scientist equally.

a. *Is there any way to measure how a reduction in the pace of activities or a stand down in flagship missions might affect student interest in science and engineering?*

Anecdotal evidence is strong that this generation of young scientists is as inspired by NASA Science Mission Directorate's extraordinary success in launching, operating and exploiting a fleet of scientific "engines of discovery" just as previous generations have been. However, I do not know of a reliable, quantitative measure that connects the launches of flagship missions to student interest. That interest, though, is clearly manifest through activity on NASA websites and so forth and perhaps NASA communications specialists might have a good answer to this question.

I thank you and your colleagues for your ongoing interest and support of JWST and hope my answers will be helpful. Do not hesitate to get in touch if I can provide further assistance.

I have sent separately some corrections to the transcript of the hearing.

Sincerely,

Roger Blandford

Responses by Dr. Garth Illingworth,
Professor and Astronomer, UCO/Lick Observatory,
University of California, Santa Cruz

Representative Ralph M. Hall
Chairman
Committee on Science, Space, and Technology
U.S. House of Representatives
2321Rayburn House Office Building
Washington, DC 20515-6301

Re: Questions following December 6, 2011 hearing: *The Next Great Observatory: Assessing the James Webb Space Telescope.*

Dear Mr. Hall:

I would like to thank you and the House Committee on Science, Space, and Technology for your interest in, and support for, the James Webb Space Telescope. As the successor to the Hubble Space Telescope, James Webb will demonstrate again U.S. leadership in international scientific endeavors through the excitement of scientific exploration of our Universe. I appreciate and thank you for the opportunity to be a witness in the Hearing on December 6, 2011 on *The Next Great Observatory: Assessing the James Webb Space Telescope.* I am happy to respond to the questions from you and from other Members of the Committee, and do so below. In doing so several themes emerged which I will summarize as follows:

- JWST, as the successor to Hubble, but with 100X its power, will expand U.S. global scientific leadership. Both the European and Canadian space science communities are significant partners with us in JWST precisely because JWST is a unique scientific endeavor that only the U.S. can do.

- The cost growth in the JWST mission has been a wide-spread concern, including for the members of the astronomy and astrophysics community. For over 30 years, the astrophysics community, through its Decadal Surveys, has reaffirmed that what is needed to carry out its scientific objectives are a balanced program of small, medium and large missions and projects. What has become apparent, strikingly, with Hubble, Chandra and Spitzer is that Observatory-class missions ("flagships") are very cost-effective research tools. They cost a lot, but they return remarkable results in many areas for many years while serving a very broad community -- for example the current number of Hubble users exceeds 8,000. While I, and others, remain concerned about cost growth, I still see continuing interest in having flagship missions as a central part of the astrophysics community's strategic plans. Missions like LISA, IXO, TPF (or their equivalents) remain central to community scientific goals.

- The crucial role of the Independent Program and Cost Evaluation office was the center of much discussion within the ICRP and in its final report. The panel was strongly of the view that JWST in particular, but NASA in general, had suffered from the lack of a highly capable team, with experience in managing major high-technology projects, who could provide independent internal

advice on project performance directly to the Administrator. Of all the areas related to "oversight", the one that is most "unfinished", in my view, remains the full implementation of the internal Independent Program and Cost Evaluation office. This is very important and I hope that Congress continues to encourage NASA to fully implement the Evaluation office.

Questions and responses:

From Chairman Ralph Hall

1. Your testimony indicates concern about the capabilities within NASA's Independent Program and Cost Evaluation office. Can you explain to the Committee why you think this office is under-performing and what needs to be done to correct the problem?

The importance of a strong Independent Program and Cost Evaluation office at NASA was highlighted in the Independent Comprehensive Review Panel report. An independent, technically-strong group with budget analysis capability, led by people with project management experience and reporting directly to the Administrator has a crucial role to fill within the Agency. Such a group existed a long time ago (early 1990's) but was effectively disbanded during that decade. The primary reason for my concern is that the Independent Program and Cost Evaluation office has not yet been fully reconstituted. It is "under-performing" because it has not really been reconstituted. Part of the problem appears to be that it is very difficult to find the personnel with the appropriate experience. People with such experience, particularly for leadership positions, are not easy to find and move. I would caution also that this is not a function that should reside in the CFO office. The Independent Program and Cost Evaluation office requires personnel with a particular mix of experience and backgrounds if it is to be as effective and as valuable to NASA as it was before it was disbanded.

A strong Evaluation office was envisaged by the ICRP as a crucial part of improving NASA's track record for all its development programs, though it would have been particularly useful for JWST. For example, it was clear during the discussion within the ICRP that panel members felt that the poor decisions by the SMD AAs in the middle of the decade regarding JSWT (and MSL) were an excellent example of how internal independent oversight could have prevented a major problem. The decisions by the AAs resulted in the budgets for JWST and MSL not meeting the agency policy of budgeting to 70% confidence, particularly in the 2009 budget request. Budgeting to this confidence level is done to ensure that the reserves are adequate for dealing with the expected risks inherent in these challenging programs. Not doing so results in a lack of adequate reserves for these programs. The lack of adequate budget reserves would have been identified sooner had there been a strong Independent Program and Cost Evaluation office. Such a group would have saved NASA significant costs by catching such problems early, especially since work was being deferred because of inadequate reserves. The savings arise since experience shows that deferred work typically costs the project 2-3 times as much because of its impact on the work-flow within the overall program and its schedule. **I hope that Congress continues to encourage NASA to fully implement the Independent Program and Cost Evaluation office.**

2. Has the experiences with JWST's delays and cost overruns diminished the astrophysics community's appetite for proposing future flagship missions that rely on solving technical challenges to enable mission success? With respect to technical complexity, how does the WFIRST mission compare with JWST? Will it be as challenging a satellite to design and build?

The cost growth in the JWST mission has been of wide-spread concern, including for the members of the astronomy and astrophysics community. Nobody likes to see such problems arise. But this has not

changed the astronomy community's interest in flagships – only our determination to try and work with NASA to minimize the cost growth that has occurred in the past. The community interest in flagship missions has been demonstrated repeatedly in our most important strategic plans. For over 30 years, the astrophysics community, through its Decadal Surveys, has reaffirmed that what is needed to carry out its scientific objectives is a balanced program of small, medium and large missions and projects. What has become apparent, strikingly, with Hubble, Chandra and Spitzer is that Observatory-class missions ("flagships") are very cost-effective research tools. They cost a lot, but they return remarkable results in many areas for many years, while serving a very broad community. For example, the current number of Hubble users exceeds 8,000 researchers. **While I, and others, remain concerned about cost growth, I still see continuing interest in having flagship missions as a central part of the astrophysics community's strategic plans. Missions like LISA, IXO, TPF (or their equivalents) remain central to community goals.**

WFIRST will not be as challenging as JWST. While I am not involved in the details of the WFIRST mission, WFIRST looks to me to be a far simpler and lower risk mission than JWST. It uses a small telescope in a wavelength range (optical and near-infrared like Hubble) that allows for much use of heritage technology for its instruments, optical system and components. It does have some challenges. It is ambitious in the size of its camera system, and its optical performance and stability requirements are not easy to meet. The technical heritage for WFIRST is good, but it is not appropriate to say that it will be an "easy" mission to build, test and launch successfully. The same statements regarding technical heritage were made about Kepler, but that suffered substantial cost growth.

I think that there are two important points to make here regarding science missions and the U.S. leadership role. First, significant space science missions, that is, missions that will have an impact on science are by their very nature "one off" endeavors and hence will remain challenging. Doing any significant mission in space is hard. Second, medium or small science missions are also within the capabilities of other space science agencies such as ESA or JAXA, and as the recent debate over ESA's Euclid mission verses NASA's WFIRST mission demonstrates, U.S. leadership becomes a far more complex issue at this scale of science. The U.S. space science program remains unique because of its capability to field uniquely powerful missions such as HST, Chandra, MSL and JWST.

3. In your testimony you noted that the ICRP recommendations regarding independent oversight "remains a work in progress, and appears to be the one area of the ICRP report that remains "unfinished" in its implementation." Please comment further on NASA's actions in this area and why you think that it remains "unfinished."

As I noted above in the response to question (1) from the Chairman, the Independent Comprehensive Review Panel (ICRP) highlighted concerns about the independent oversight of the JWST project. The ICRP identified this broad issue as one of their key concerns, and noted the need for improved oversight in a number of areas. The areas were: (i) a strong JWST Program team at HQ within SMD with the capability to better manage and monitor the execution of the JWST project; (ii) better oversight and assessment of the Project performance within GSFC at the level of the Center Director; (iii) a more effective role for the Standing Review Board SRB; (iv) an independent, internal oversight group reporting to the Administrator.

For (i), a stronger Program team with better oversight within SMD has been implemented. JWST Program Director Rick Howard and his group are doing an excellent job and have brought much stronger management within SMD. The direct reporting to both the NASA AA and the SMD AA (another recommendation from the ICRP) has also played a role in setting the JWST Project on a viable path to

launch. **For (i) the ICRP's recommendations have been implemented.**

For (ii), the Center (GSFC) has taken on a more direct role in the oversight of the JWST Project, but I am not conversant with the details of what has been done or how effective it has been. This might be a useful aspect to ask for further details as part of Congress's continuing interest in the progress of the JWST program. **For (ii) it is clear that significant changes have occurred.**

For (iii), the role of the SRB is an important one. However, it appears to me, the current structure and methodology of the SRB is not working well, either to the member's satisfaction or to the agency's satisfaction. The constraints imposed on a committee that is constituted of non-government employees regarding the reporting of their views (they are a "non-consensus" body) has made the SRB's oversight of the project challenging. In my view, the SRB needs to be restructured to make it more effective and to ensure that its members, or a significant subset, can be more fully aware of budgetary information. It needs people who can be fully informed, in any area and at any time, of the agency's deliberations regarding the JWST Project and its budget. This may require some members who are government employees. Doing so will require some care in their selection to ensure that these members are knowledgeable without being overly conflicted. But within an agency the size and geographical dispersion of NASA, it should be possible to find experienced, highly capable people, who will provide "independent" advice, from Centers other than GSFC. The ICRP did not make a clear recommendation regarding the SRB. The panel recognized the importance of the SRB, and its efforts to provide independent input, but also recognized the constraints that it operated under made it less effective than desired (and were frustrating for the members who clearly cared for trying to help make the JWST Project a success). **For (iii), from my perspective I would say that making the SRB as effective an independent review body as both NASA and the SRB members would like is "unfinished" in its implementation.**

Finally for (iv), the crucial role of the Independent Program and Cost Evaluation office was the center of much discussion within the ICRP and in the final report. The panel was strongly of the view that JWST in particular, but NASA in general, had suffered from the lack of a highly capable and experienced team who provided independent advice on project performance directly to the Administrator. As I noted in (1) above, the mix of skills, backgrounds, and roles makes this distinct from, and outside, the CFO office. **Of the four areas related to "oversight" outside the JWST Project at GSFC, item (iv), the implementation of the internal Independent Program and Cost Evaluation office remains the one that is most "unfinished" in my view. This is very important and I hope that Congress continues to encourage NASA to fully implement the Evaluation office.**

4. During the hearing mention was made of a number of missions that have been impacted substantially by JWST. Mention was made of missions like TPF, SIM, IXO, LISA, and WFIRST, though others have also been mentioned, particularly in the planetary arena. Please comment on the impact, if any, that JWST had on the progress on such major NASA science missions.

When a mission like JWST takes longer to launch concerns arise, appropriately, about the impact on other missions. Experience from 20 years of doing space missions shows us that when ongoing missions are delayed, future missions are also likely to be delayed. A current example would be WFIRST. The Decadal Survey, among others, understood that WFIRST's schedule would be influenced by JWST's schedule. Yet even for a new mission like WFIRST other factors play a role as well (such as the overall funding level for the Science Mission Directorate – SMD, and the funding for the Astrophysics Division, in particular).

While there is a perception that other missions like TPF, SIM, IXO, and LISA, and even some planetary missions, have been impacted substantially by JWST's recent cost growth, the reality is different.

For example, SIM had been supported at a low level for the latter part of the last decade leading up to the Decadal Survey, after its budget was initially set to zero in mid-decade. SIM had suffered several episodes of major cost growth, but its scientific potential and the innovativeness of its science and engineering team led to a desire for it to be considered again in the Decadal Survey. It was thus supported at a small level until the Astro2010 Decadal Survey made its choices. **The Astro2010 Decadal Survey chose not to recommend SIM for construction and launch.**

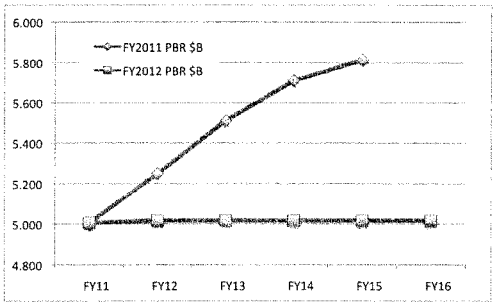
TPF is another exciting mission for studying planets in other solar systems. Two TPF concepts were studied intensively in the middle of the last decade, but it too was eventually impacted by the budget cuts to science in 2005 that resulted from President Bush's Vision for Space Exploration. Furthermore, as the studies progressed, the complexity and technical challenge of a TPF mission was realized. Even its strongest proponents agreed that TPF was likely to "cost more than JWST" because of the challenging technologies. **The Astro2010 Decadal Survey realized that, as exciting as TPF is, NASA needs to do further study before TPF can be considered seriously for a recommendation for implementation through the Decadal Survey process.**

The cancellations of LISA and IXO were more recent. LISA was a highly-regarded mission that was ranked second to JDEM (the Joint Dark Energy Mission, which morphed into WFIRST) in an NRC study in 2007 (*NASA's Beyond Einstein Program: An Architecture for Implementation*) and was again highly ranked in the Astro2010 Decadal Survey. IXO was identified in the Astro2010 Decadal Survey as a future mission that would likely be launched in the next decade. Both missions were to be done collaboratively with the European Space Agency. Both were cancelled early in 2011. These decisions were made before the JWST replan budget was finalized. While anticipation of the increased cost to launch of JWST could have played a role, it was clear that the SMD budget for this decade was already being stressed as a result of the large change to the budget profile for SMD between the President's FY2011 Budget request and the President's FY2012 Budget request. The figure below shows this change. $2.2B was removed from the expected SMD budget over 4 years (or about $3B over 5 years – see the figure below). **While I do not have insight into the details of the decision to cancel NASA participation in IXO and LISA, I suspect that the removal of almost $3B over the next five years in the FY12 Presidents Budget Request from that in the previous (FY2011) budget request for SMD played a major role.**

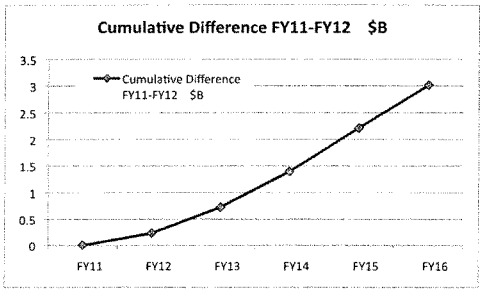
JWST has also been mentioned as the reason for delays (or more recently cancellations) of planetary missions. Again, the increased cost to launch of JWST could have played a role, but it is likely that other factors also played a larger role. MSL had substantial cost growth of over a billion dollars in the few years leading up to its launch. For example, the NASA SMD Planetary Division Director Jim Green said at a large science meeting for planetary astronomers last year that JWST was not the source of their budget problems and that they needed to focus on their Decadal Survey. The scale and frequency of future planetary missions also may have contributed to concern about the likelihood of being able to carry out the full planetary program within a smaller SMD budget. **The unfortunate cost growth of JWST certainly has had impacts, but a considered and thoughtful analysis is likely to show that other factors, particularly changes in the budget projections, have contributed to the changing mission mix in SMD.**

Comparison of FY11 and FY12 President's Budget Requests for SMD (in $B)
Loss of over $2.2B to 2015 (and about $3B to 2016)

	FY11	FY12	FY13	FY14	FY15	FY16
FY2011 PBR	5.006	5.249	5.510	5.710	5.814	
FY2012 PBR	5.006	5.017	5.017	5.017	5.017	5.017



	FY11	FY12	FY13	FY14	FY15	FY16
Cum. Delta	0	0.232	0.725	1.393	2.215	3.012
FY2011 PBR	5.006	10.255	15.765	21.475	27.289	33.103
FY2012 PBR	5.006	10.023	15.040	20.057	25.074	30.091



For FY2011 PBR assume FY15 for FY16

From Representative Lamar Smith

1. NASA recently announced that the Kepler Space Telescope has discovered an Earth-like planet 600 light years away whose size and distance from its own star put it in the "habitable zone" to support life. The Hubble Space Telescope has made countless discoveries over the past two decades.

a. What kinds of scientific revelations might we anticipate with the James Webb Space Telescope, compared to those from Kepler and Hubble? Would you recommend maintaining operations of the Kepler and Hubble Space Telescopes even if funds from those missions are needed to be used to keep JWST on track?

Hubble has been, and is, a remarkable scientific flagship mission that has opened up new horizons in numerous areas (for example, Hubble has: detected planets and provided clues as to their formation; provided remarkable images of our solar system; discovered the most distant, and youngest, galaxies yet seen in the universe; played a key role in the discovery of dark energy; provided insights into the growth of galaxies like our Milky Way). Kepler is a much smaller and more scientifically-focused mission that has revealed just how common planets are in our Milky Way, and how diverse they are. As such it is a very complementary mission to a flagship mission like Hubble. Scientific progress relies on such diversity of scales.

JWST is a flagship like Hubble that will explore our universe in many ways to depths and limits far beyond what Hubble has been able to do. It will unveil the characteristics of planets around distant stars, provide solar system exploration opportunities that complement direct probes, explore the first galaxies and their assembly over billions of years, and continue our efforts to understand dark matter and dark energy. With 100X the power of Hubble and 1000X the power of the Spitzer space telescope JWST will surely bring forth dramatic new discoveries in unimagined areas as well.

The scientific community has always endeavored to work with NASA to balance the funding and support between the scientific opportunities from current missions like Hubble, Chandra, Spitzer and Kepler, and those that offer new capabilities. The science return from the large public investment in our operating facilities needs to be balanced against future opportunities. Hard choices sometimes have to be made through the Senior Review process. NASA does have a history of ramping down still-performing facilities to allow new ones, and this is a process that I support fully. However, I do not see a need currently for reducing the scientific output of two of astrophysics' most productive missions to support JWST, especially when JWST is 6 years away from launch. **If the need for choices to be made between operating missions and new missions arises in the future, the tradeoffs would need to be made involving all the stakeholders, from the science community to NASA to Congress and the public at large who are excited by the results of these missions.**

b. Could you comment on the role of JWST in maintaining and expanding U.S. global leadership in astronomy and astrophysics?

JWST is central to our future leadership. The U.S. leadership globally in astronomy and astrophysics has been demonstrated in many ways over the last decade, through its Great Observatories, Hubble, Chandra and Spitzer, and through its highly productive smaller missions like Kepler, the Fermi Gamma-ray Space Telescope (previously GLAST), and the Wilkinson Microwave Anisotropy Probe (WMAP). Yet these missions have already reached the end of their life or are likely to do so this decade. The Europeans in particular are launching many excellent missions like Herschel and Plank. The Chinese are far behind in space missions and capability, but are moving forward quickly, as they have demonstrated in many areas. The competitive arena in which we still have a winning hand is in flagship missions. JWST, as the successor to Hubble, but with 100X its power will not only maintain but will expand U.S. global leadership in astronomy and astrophysics. **Both the European and Canadian space science communities are significant partners with us in JWST precisely because JWST is a unique scientific endeavor that only the U.S. can do.**

c. How do the Hubble, Kepler and Webb Space Telescopes compare to the capabilities of the European Space Agency's Herschel telescope?

The simplest answer is that these are all very different missions that view different parts of the spectrum.

They are quite complementary and overlap little in their capabilities. For example, the European Space Agency's Herschel telescope is a powerful telescope that works far in the infrared part of the spectrum. Herschel is nearing the end of its life as the cryogens used to cool it for operations run out. Hubble predominantly works in the optical (or visible part of the spectrum, that to which our eyes are sensitive), extending somewhat into the ultraviolet and the near-infrared just outside the range of our vision. Kepler covers a similar range (optical) but is a smaller, simpler and much cheaper telescope that was built to do one task – find planets!

Hubble, by comparison, is an "observatory" that can excel at a huge range of problems. James Webb is also an "observatory", and it will overlap slightly with the spectrum coverage of Hubble, but do it with hugely increased sensitivity from its bigger mirrors and new cameras (being as much as 100X more powerful). But James Webb is unique also since its vision extends into the infrared, overlapping the regions covered by the Spitzer Space Telescope, but with 1000X the sensitivity. While James Webb extends our vision out into the infrared, it does not have sensitivity at the same parts of the spectrum as Herschel (which can only see even further into the infra-red and out to almost radio-like regions). **James Webb also has better sensitivity, makes finer images (i.e., has better resolution) than Herschel, and will last longer.**

d. What are other nations doing in astronomy and astrophysics that could jeopardize America's leadership in the field?

The U.S. undoubtedly still has the leadership position in astronomy and astrophysics. However, as we know from other areas, leadership can quickly move elsewhere if our competitors are determined and consistent in their progress. On the ground Europe is beginning to challenge the U.S. in its nearly 100 year dominance in building large ground-based telescopes. In space, Europe, through its space agency ESA, is moving forward on missions that are very competitive with our small and medium scale programs. Herschel, Planck, Euclid are all missions that match our typical missions in those areas. America's leadership is still assured in astronomy and astrophysics through James Webb. Flagship missions like our Hubble and Chandra could be done by Europe. **But the U.S. has raised the ante with JWST. Nobody else can yet do JWST.** However, leadership can be lost very quickly. Leadership in high-energy (particle) physics devolved to Europe after we terminated the Superconducting Super Collider (SSC). I fully expect China to use its increasing capability and resources to begin major science missions in space in the next decade.

2. Last July, NASA's associate administrator Ed Weiler, who was in charge of NASA's science mission budget of almost $5 billion annually, called the Obama Administration's flat budget for the James Webb Space Telescope a "road to nowhere" in a press interview. Soon thereafter, Dr. Weiler tendered his resignation, after 33 years of service to NASA.

a. What are your thoughts of how the Obama Administration handled the budget challenges for the James Webb Space Telescope over the past 3 years?

The last few years were a very challenging time for JWST. Mistakes were made, problems were not dealt with and management failures occurred. However, like all such major problems in a big project, the root cause lay further back in the past. NASA Administrator Mike Griffin realized early in his tenure that big programs at NASA were being done with inadequate reserves. That is, the mission budgets did not have adequate funds to quickly rectify those known and unknown problems that arise whenever a new, one-off high-technology mission is being developed and implemented. Administrator Griffin established a new agency policy that missions like JWST were to be costed and budgeted to 70% confidence level, so that

there is a 70% likelihood that the project can be accomplished within the allocated budget. It was clear to NASA leadership that JWST was not being budgeted with the reserves consistent with 70% confidence.

Astonishingly for several years the SMD AAs, even into early 2008 with the FY2009 budget, did not follow this direction and JWST was run with inadequate reserves, deferring work when the inevitable problems arose. As the ICRP highlighted, this deferral of work drove up the cost of JWST (such deferral in high-technology projects typically leads to the work costing 2-3X as much because of the impact of delays on other aspects of a very complicated project. The recognition of this problem by the middle of 2008 led to efforts to apply additional reserves to the JWST project. However, the large lag in the federal budget process meant that the adequate reserves could not be made available quickly. Typically it takes 2 years to make major changes. As a result the JWST Project and the Agency continued to dig itself a bigger hole... The inability of the Agency, the Administration and Congress to fix problems like this quickly is unfortunate. **I would hope that lessons are learned from this Project that will allow us to do such high-tech one-off Projects, be they in NASA or elsewhere, in future in a way that does not lead to such cost growth. One key lesson is that adequate reserves be carried by budgeting to a high level of confidence (80% confidence) as the ICRP recommended.**

b. Why did the annual funding for the JWST drop during the Obama Administration compared to how much was being spent on the JWST only a few years ago? Shouldn't the funding profile for the Webb telescope have been increasing as the project was ramping up? (FYI: $438 million was spent in FY2010 for JWST, but only $354.6 million was requested in FY 2011).

Ideally the funding should have been increasing to a broad peak at this point in the life of the project. I am a little confused by the numbers since when I checked the FY2011 request and JWST was listed at $444.8M, following an enacted $440.3 in FY10. For FY12 the requested level did drop, after the ICRP report, to $373.7M. But I understand the point of the questions and so I will respond in this context.

The Independent Comprehensive Review Panel (ICRP) was asked to give a minimum cost to launch and an associated launch date. This we did. However, this estimate by the ICRP ($6.5B and launch in late 2015) had to be developed very quickly, without time for a careful analysis and without any independent cost estimates (ICE). The ICRP estimate required substantial additional funding in FY2011 and FY2012. The Panel recognized that this posed significant problems for Congress, NASA and OMB, since the recommendation was being made early in FY2011 while the FY2012 budget was being worked by OMB and NASA. Furthermore, a detailed cost estimate with reserves for the 80% confidence budgeting that the ICRP felt was more appropriate for such challenging projects (up from the NASA 70%) would take time to do. The Panel discussed this but decided that given the question, and the limited time available, we needed to answer it in as definitive a way as possible, without too many qualifying clauses. And to answer the question that was asked – "give a minimum cost to launch and an associated launch date".

While I do not understand the dynamics and the details, the response of the Administration (OMB and NASA) was to request FY2012 funding that continued JWST, but did not ramp it up to get it "back on track" as the ICRP recommended. Fortunately, NASA, OMB and Congress responded positively to the replan developments and did increment the FY2011 funding in mid-2011 to around $477M through an operating plan change. This was followed by Congressional action in late fall 2011 that gave JWST project the required FY2012 funding needed to put it on a track to launch in late 2018. I was delighted with this outcome and appreciated the very positive response of NASA, through the replan, to the ICRP recommendations. Similarly, **I was delighted with the response of Congress to NASA's replan and the broad-ranging input from scientists and the interested public, and to the support for JWST in the FY2012 budget request from the Administration.**

c. Did this flat-line budget from the Obama Administration cause delays to the program? If so, how much delay?

I think it is always fair to say that when the budget does not match the needs of the Project, and work has to be deferred, the launch date will almost invariably slip. However, as discussed above, there was uncertainty about the total cost to launch and the launch date while NASA undertook its extensive replan. One could understand how this could lead to a cautious approach to funding in the near-term. From my perspective, however, given my experience on the ICRP, it was unwise to keep the budget so low when the ICRP had clearly indicated that JWST badly needed a funding increase to get them back on track. I think it would have been prudent and cost-effective to ramp up the funding in an effort to get JWST back on track while awaiting the details of the NASA replan. The Independent Comprehensive Review Panel did indicate that if the ramp-up in funding needed to get JWST back on track was delayed, that launch would be delayed – and by an even larger increment. While the delay in ramping up funding did have an impact, I suspect that it was not large since the Administration and Congress did provide additional funding later in FY2011.

d. Did the House Appropriations Committee provide an adequate wake-up call for the Obama Administration and Congress that the budget challenge facing the James Webb Space Telescope required fixing?

Congress has played a very important role in helping identify the problems with the JWST program and in getting it back on track to launch. The House Appropriations Committee did initiate an intense and wide-ranging discussion of JWST and its role in the nation's scientific arsenal. It, along with the earlier requests from the Senate for clarification on what was happening on JWST, led to a much broader understanding of the issues surrounding the JWST project and ultimately what was needed to complete and launch a mission of JWST's size and scientific importance. By early 2010 it was clear to Congress that NASA needed further funding increments to deal with the obvious problems faced by JWST. The incremental nature of the requests and the apparent lack of resolution of the problems led to a letter request from Senator Mikulski to Administrator Bolden for an independent review team to assess the state of JWST. This was the first key step. The ICRP and its report, and the subsequent action by NASA on the replan, was the second key step. However, the outcome of this replan was not widely shared by mid-2011, and the concerns in Congress became very apparent. **The action by the House Appropriations Committee in early July 2011 certainly provided a crucial incentive for NASA and the Administration to explain to Congress what it would take to complete JWST. While it was a challenging period for all, the JWST program was undoubtedly strengthened by the actions of the Congress.**

From Representative Randy Hultgren

1. Could you comment on the impact that JWST will have on our national STEM initiative in terms of inspiring and attracting the youth of today into fields of science, math and engineering?

The best way to comment on the importance of flagship missions like JWST is to summarize quickly what Hubble has done. The excitement and interest that Hubble generates continues to be quite remarkable: beyond its scientific impact, Hubble's education programs reach over 500,000 pre-service and in-service teachers a year in the U.S., and over six millions school children use Hubble material in their STEM curricula annually. It is challenging to convey the excitement of science and engineering to young people (and to people of all ages). Much of science and engineering seems very structured,

focused on detail, and seemingly not very interesting. However, for people of all ages the immensity of the cosmos and the great questions about our place in the universe and our origins are entrancing. It is clear from these numbers that educators and others on the front-line of STEM activities view the results from astronomy's premier flagship Hubble as a key tool for science, math and engineering education. JWST is Hubble's successor, but with 100X its power, its astonishing deployment technology, and its ability to peer into parts of the Universe we have never seen before, will do even more for our national STEM initiative. This YouTube video http://www.youtube.com/watch?v=ihpNNBmJypE gives a sense of the enthusiasm that is already being shown by young people. **For the next generation, JWST is their Hubble 2.0.**

2. JWST has significant international participation, most notably by the European Space Agency and the Canadian Space Agency. Could you comment on the effect the JWST will have on global cooperation in space and other scientific endeavors?

JWST remains a crucial component of our (diminishing) pool of international collaborations in space. Over the last year we have seen major upheavals in our collaborations with the European Space Agency (ESA). A number of joint or collaborative projects have been cancelled by NASA. These include the long-standing gravitational wave mission LISA, a future x-ray mission IXO, and, after a series of changes, cancellation of the joint Mars mission ExoMars. JWST remains a mission where our collaboration with ESA remains strong. And not just with ESA. Both the European Space Agency and the Canadian Space Agency contributions are playing significant roles. It is also a collaboration where our partners are helping the U.S. ESA is providing the launch vehicle (their largest heavy-lift rocket, an Ariane 5), two scientific instruments, and operations staff for JWST at the Space Telescope Science Institute. In value, this contribution is equivalent to the total cost of a substantial space mission within ESA.

The Canadian contribution of the critical fine guidance sensor and a further science instrument constitute the largest space science project supported to date by CSA. The CSA also provides operations staff at the Space Telescope Science Institute. The international contributions have been essential for the development and implementation of JWST. The European and Canadian contributions represent a major commitment of their resources towards a project that will do much to raise the visibility of the U.S. and its technological capabilities. Since the leadership in high-energy physics has shifted to Europe (to CERN) space science remains an area where we still exercise both leadership and cooperation, but this is diminishing. **JWST plays a crucial role model and a very visible example of our interest in maintaining our international scientific collaborations.**

3. While our international partners are making valuable contributions to the JWST program, could you comment on the role of JWST in maintaining and expanding U.S. global leadership in astrophysics? What are other nations doing in astrophysics that could jeopardize our global position if the U.S. did not proceed with JWST?

As I highlighted in the response to the previous question JWST plays a central, and increasingly important, role in maintaining and expanding U.S. global leadership in astrophysics. Our leadership is diminishing as we step back from other collaborations. The U.S. is a partner with Europe, with smaller roles played by Japan and Taiwan, in ALMA, a major radio telescope in Chile. But Europe has decided to go alone with its next major telescope, the European-Extremely Large Telescope. The European Space Agency (ESA) is increasingly moving forward on its own space science missions. These are becoming larger, more ambitious, and more sophisticated. Other nations are doing space science missions or have plans for an increasing space science program (Japan, China, India). We are far ahead, but in a rapidly

changing world economic environment the ability of other nations to compete directly with us will change, not in this decade but certainly in the next two decades. JWST is still far beyond what any other nation can do, but this advantage will not reside with us for the long-term. Launching and operating JWST will both demonstrate our leadership and position us for further advances in the coming decades. JWST will demonstrate leadership, but will also help us keep our leadership.

4. How will JWST contribute to our national objectives in science and engineering?

Our national objectives include scientific and engineering leadership, an educated workforce, high technology capabilities and leadership, and jobs that also create other jobs, i.e., jobs that have a high multiplicative factor. A high-technology space science mission like JWST entails the development of new technologies, new hardware and new testing capabilities in our aerospace industry and their subcontractors all across the nation. Since so much of this is uniquely American it leads to "home grown" solutions, i.e., to home-grown small businesses and high-tech jobs. Small high-tech businesses and their related jobs have a high multiplicative factor that results in other jobs, mostly locally but also elsewhere. Such businesses also use what they have learned to do on a program like this to improve and expand their business and to provide products for other projects, or for unrelated areas where a new market may open up as a result of their expanded capability.

Beyond enhancing our crucial high-technology industrial base, the results and inspirational value of a mission like JWST can be quite profound, as has already been demonstrated by the Hubble Space Telescope. As discussed above, the excitement and interest that Hubble generates continues to be quite remarkable: beyond its scientific impact, Hubble's education programs reach over 500,000 pre-service and in-service teachers a year in the US, and over six millions school children use Hubble material in their STEM curricula annually. As I noted, it is clear that educators and others on the front-line of STEM activities view the results from astronomy's premier flagship Hubble as a key tool for science, math and engineering education. **JWST as Hubble's successor, but with 100X its power, will do even more for our national STEM initiative.**

5. The Hubble Space Telescope has made countless discoveries over the past two decades. Could you comment on the kinds of scientific revelations we anticipate, compared to those from Hubble? What about the serendipitous discoveries that we don't anticipate, imagine or seek?

JWST is incredibly more powerful than our current telescopes. While it is hard to capture the gains in a single number that a new telescope will make compared to existing missions, JWST can be characterized as having about 100X the power of the Hubble Space Telescope and about 1000X the power of the Spitzer Space Telescope. The Hubble Space telescope has revolutionized our knowledge of the growth of the universe, of galaxies like our own Milky Way, of the role that the still-unexplained dark matter and dark energy have played in the life of our universe, and played a major role in the discovery of planets. Yet so much remains unanswered. We know already that JWST will explore parts of our universe that cannot be explored by any other operational or planned observatory or facility. We expect JWST to provide insights into the first stars and galaxies in the universe, to help us understand far better how galaxies assembled from the first tiny objects to the great spiral galaxies of today, to determine the nature of planets around nearby stars and to make major steps forward in measuring how dark energy influences the nature of our universe and in understanding the impact of dark matter on galaxies.

For example when JWST was first conceived we had only just begun to discover planets around other stars. Today we know of thousands, and because of JWST's unique capabilities, this telescope will become a powerful observational tool is searching for liquid water on extra-solar planets – an observation

that was unimaginable a decade ago. Beyond what we know will be important lie the great unknowns of our Universe. The most exciting results usually arise from the unexpected discoveries, i.e., from the serendipitous discoveries. **A telescope that is 100X-1000X better than today's best will no doubt reward us with serendipitous discoveries that we hadn't anticipated or imagined!**

6. My understanding is that as Hubble expires in the next few years, many of the scientists working on Hubble will transition to JWST. Could you comment on the role that JWST will play in maintaining and expanding our nation's scientific intellectual capability?

JWST will clearly play a crucial role maintaining and expanding our nation's scientific intellectual capability. In fact, JWST is already becoming part of the planning and thinking of the scientific community. While Hubble is still a centerpiece of the astronomy community's research program, and a centerpiece of the media interest in astrophysics, we recognize that Hubble is aging and that it could reach its end of life sometime later this decade. Once Hubble expires the astonishing opportunities and productivity of that remarkable space observatory would disappear. Fortunately with a launch date of late 2018 JWST is ideally placed to allow a natural transition of the research focus from Hubble to JWST. This is particularly important. For young scientists starting a career, and for those scientists that are supporting and encouraging students to be interested in science through the visibility of astrophysics, having new results and new data is critical. **For all of us, but particularly for young people making career decisions and for young scientists, JWST will be Hubble 2.0.**

7. Could you comment on the secondary benefits that will be derived from JWST in terms of new technology development that will enable other scientific, engineering or national security endeavors?

One of the challenges for JWST has been developing and demonstrating its new technologies, or ensuring that older technologies can be enhanced to work in the new realms required by JWST. This is the key to scientific advances, since forefront science has always been enabled by technological and engineering innovation. Fortunately, these JWST technologies have now been demonstrated to the level needed for use in the demanding environment of space. American aerospace businesses have made this technology development possible. Interestingly, this also means that they are potentially usable for other missions and programs, or for use in other areas. For example the development of lightweight optical materials and precision control needed for JWST should make newer, more capable imaging systems in space now more affordable. **Many of the small, medium and large businesses that were funded to build some very specialized hardware for JWST are now in a position to utilize that experience and capability in other areas.** And they have the incentive to do so to enhance their business! I expect that Northrop Grumman can supply actual details in this area from their experience with their contractors.

From Ranking Member Eddie Bernice Johnson

1. What puts astronomy and astrophysics in the must-have category as opposed to the nice- to-have category? How can I convince my colleagues in Congress and my constituents that JWST is of national importance in these fiscally constrained times?

This is a very important question and very reasonable question. It is one that scientists often get asked. Usually the person asking the question is supportive and often wants to understand the reasons for their own support better. While I can list many aspects that I think are important for the nation, for education, or competitiveness, and for national prestige that might justify spending money on basic science, it seems to me that the roots of this question lie deep within our nature as human beings. We are innately curious

about our origins, and about our place in this vast cosmos. It is human nature to ask questions and to wonder about our past and our future.

Astronomy and astrophysics has a special appeal. First and foremost almost everyone who is able to stand outside on a dark night and see the stars is left curious about what is up there and whether we are alone. As the Hubble Space Telescope has demonstrated with its amazing pictures, people everywhere can connect directly to the remarkable science from such telescopes. Furthermore, space astronomy, more than any other field, is enabled by technology and engineering innovation – and in turn, missions of the scale of HST or JWST challenges the U.S. aerospace endeavor to push this innovation further. The result is a national (and international) partnership between science, industry and the government to do technologically-advanced projects that have never been done before. JWST is one of those projects. **JWST has the power to inspire a whole generation to recognize the importance of STEM, and may ultimately transform our view of ourselves and our place in the Universe.**

Invariably as a country develops and its people get beyond day-to-day survival, there develops a sense that the nation must reach out and explore with its newly found capabilities. China and India and Brazil are all starting on the path to scientific exploration that we have been on for many decades. For us in the U.S. it is a matter of national pride that as the world's most powerful country we can, and should be, at the forefront of scientific exploration in some areas. Being able to explore the universe in ways that no other country can is good for our national soul and our sense of well-being. We will always face difficulties, sometimes less, sometimes more, but leadership in the quest for knowledge and understanding is something that needs to be continued if we are not to fall behind.

2. The Hubble Space Telescope, which revolutionized the study of the universe, had its own technical and programmatic challenges. Are there differences between the Hubble and JWST in terms of the agency's approach to the programs and their implementation? If so, please describe them.

There are differences between the development of Hubble and JWST. One clear lesson learned from Hubble was "do the technology development before transitioning into construction". SMD AA Ed Weiler took this message to heart a decade ago and encouraged the JWST Project early on to make sure that all the key technologies were all at TRL-6 before Confirmation. They were, as the Technology Non-Advocate Review (T-NAR) highlighted in early 2007 (strictly 9 out of 10 passed but the remaining item, the cryocooler subsequently demonstrated TRL-6 soon thereafter). The early identification of the mirror fabrication and test as being a challenging, long-lead item also led to the mirrors be started on a fabrication and production path well before the formal Confirmation Review that is the traditional start of construction (Phase C/D). So efforts were made "to not replicate the mistakes of the Hubble program". I expect that NASA could give you further examples and details. In many ways JWST started out with the right intentions.

Unfortunately, I think that a serious flaw from the beginning was that the program was "undercosted" because of the very unwise pressure from the NASA Administrator in the late 1990s. Pressure to contain costs is fine, but arbitrary demands to force programs within a cost box that is not established through rigorous analysis are extremely unwise. JWST started out with a cost estimate that was too low. And JWST development began with an unwillingness to acknowledge what was really needed and to provide adequate resources. By the middle of the decade with a further change of NASA Administrator, an effort was made to establish a more realistic cost for JWST. It was unfortunate that the new policy to require all projects to budget to 70% confidence that was adopted by Administrator Mike Griffin was actually not implemented by more than one SMD AA in the middle of the last decade. This culminated in a budget from one SMD AA, the 2009 budget request, which left the science division with an unexecutable

program. This caused in significant part the subsequent large cost growth for both MSL and JWST. I think much has been learned over the last five years about what to do and what not to do for future missions. **My two takeaway messages are (1) budget to 80% joint schedule and cost confidence, and (2) make sure that the agency has strong, internal independent oversight, particularly through an independent Office of Evaluation that reports to the Administrator.**

3. We often hear about the importance of having challenging space projects to sustain a skilled workforce in this nation. What, in your view, does JWST mean for our workforce and for those young people who will become our workforce in the future?

There is little doubt that we can only do space projects because we have a highly skilled workforce who are very experienced. The level of technology for doing space missions, and particularly missions of the complexity of JWST requires a mature industry from the major contractors to small subcontractors who have very particular skills. In addition, it requires the government and industry to have highly experienced managers and their supporting technical teams. We have to grow these teams, nurture them and support them with a breadth of programs. This requires that we have to interest and encourage young people so that when they make career decisions they do so in areas relevant to high technology hardware and software. While is hard to establish a one-to-one link between exciting science and career decisions, the widespread interest in Hubble results suggests it must help greatly in making such decisions if they are disposed to a science or engineering career. JWST will clearly continue Hubble's legacy in this area. Already JWST has generated enthusiasm far beyond the proponents in the astronomy community, as the extensive feedback and support demonstrated by the public last year following the proposed termination.

4. To what extent does the JWST replan address the key findings, concerns, and recommendations of the Independent Comprehensive Review Panel you co-chaired?

a. Are you satisfied with the changes that have been made to date?

I am very satisfied with NASA's efforts on the replan for JWST. I think NASA has responded very well to the recommendations of the Independent Comprehensive Review Panel. **I particularly like the emphasis on setting the program on a budget and schedule track that corresponds to 80% joint schedule and budget confidence.** While the ICRP encouraged NASA to adopt a more conservative budget and schedule process consistent with the challenges of doing one-off high technology projects that must work from get-go in a tough environment, it is clear that NASA was already trying to move towards such confidence levels (from the agency mandated 70%, which replaced a very loose approach that corresponded more with 50%). The only area where I am somewhat concerned at the pace of change is in the area of independent oversight and evaluation. I think that it is very important, as the ICRP stated, that there be a strong, independent technically-competent office that has leadership that is highly experienced in management of complex projects. While budgetary analysis capability is essential in this office, this office should report to the Administrator and needs to be independent of the CFO office. It is *not* a CFO function.

b. How can Congress ensure that NASA has instituted the necessary capabilities and independence in its cost and programmatic analysis so that significant flaws don't get missed again?

This, in my view, is a crucially important question. It is complicated by the relationship between Congress and the Administration, and that between NASA and OMB. At times, Congress is frustrated by the lack of openness in the dialog with NASA. NASA and the Administration face many constraints and are also frustrated by the actions (or inaction) of Congress. Nonetheless, I think that considered and informed "oversight" by Congress is essential to ensure that the appropriate cost and programmatic

analysis capability is in place for major projects. Congress has a very important role in asking the right questions and making sure, to their satisfaction, that the projects are being adequately reviewed and evaluated, without getting into a situation of micromanaging projects. NASA should clearly be responsible for the management of projects once the Administration and Congress have approved the project for development and then construction. Specifically, **I think that the appropriate committees in Congress need to be assured that the three levels of independent technical and cost analysis are in place.** First, through a strong independent assessment function that informs the Director's office at the NASA Center doing the project; second, through a well-informed independent review team (e.g., a Standing Review Board); and third, through a strong independent, internal program Evaluation office that reports to the Administrator and is independent of the CFO office.

5. While JWST now has a new plan and cost baseline for the implementation of the program, there is still much work to be completed. What happens if JWST runs into costly problems during final development, testing, and integration that exceed reserve levels? What should be the plan?

Projects of the scale, complexity and uniqueness of JWST will always run into problems. Nobody can foresee what will prove harder than expected, or what will go wrong, when a project has never been done before. Recognizing this and ensuring that the mission program and project offices have adequate budget and schedule reserves when doing new one-off, high-technology projects will enable most, if not all problems to be dealt with without delays or further funding. Is JWST 100% assured of being launched on time and within budget? Of course not, but it is now far, far more likely for this to happen than the situation with previous flagship missions. Given this, I do not think that NASA needs to "plan" for further cost growth. Provided the Administration and Congress support a JWST budget profile over the next six years at the replan level, further cost increases are unlikely. In the unlikely event that problems arise that will delay launch, the first backstop is the reserves that are part of the current plan. If these prove inadequate, further resources are usually found by delaying future missions. This is undesirable, but it has been a fact of life for major projects in any area, government or private industry. **I consider that the need for further funding for JWST will be quite unlikely provided the replan funding profile is budgeted.**

6. Some might say that given the cost overruns on the James Webb Space Telescope, we just can't afford to go down that path again with a major flagship such as the Wide-Field Infrared Survey Telescope (WFIRST), or any flagship for that matter. What are your views on that perspective?

Flagships are too important, both for scientific productivity and for our national scientific leadership not to continue, but we must do so responsibly. The cost growth in the JWST mission is a concern at any time, but particularly now given the budget challenges. The cost growth has also concerned the astronomy and astrophysics community. Nobody likes to see such problems arise. But this has not changed the astronomy community's interest in flagships – only our determination to try and work with NASA to minimize the cost growth that has occurred in the past. The community interest in flagship missions has been demonstrated repeatedly in our most important strategic plans. For over 30 years, the astrophysics community, through its Decadal Surveys, has reaffirmed that what is needed to carry out its scientific objectives are a balanced program of small, medium and large missions and projects. In one way the astronomy community has been quite responsible and responsive to the current situation. WFIRST is not a major flagship. It was deliberately kept small by flagship standards. I think that the Astro2010 Decadal took a very responsible and responsive approach to the situation for this Decade.

From Representative Jerry Costello

1. NASA's program official has indicated that one of the concerns with the replan's launch date of 2018 is the need for the JWST team to remain focused and motivated to keep the momentum of this year. You were a member of the independent panel that assessed JWST. What, in your view, should NASA be doing to ensure the JWST team stays focused and motivated?

This is a problem that faces most big projects. There are a number of aspects. Congress has imposed a firm $8B cost on the implementation phase of the program, but one that is consistent with the replan that was developed to an 80% joint cost and schedule confidence budget profile. The level of reserves implied by 80% confidence budgeting will allow JWST to have an executable program. Thus the team should now understand that they are not be asked to accomplish the "impossible". They are being funded with what they estimated was the needed budget and schedule.

The most important component of keeping the team focused is to have clearly understood milestones and the appropriate metrics for assessing progress towards those milestones. Progress towards those milestones needs to be monitored and managers need to feel pressure to meet those milestones. The milestones are also much more likely to be met when it is clearly understood by all who is responsible. I suggest that the JWST project continue to announce its milestones in advance as it has done recently. This is a key part of keeping the team focused and motivated. To build confidence, however, the budget reserves have to be intelligently used to allow the milestones to be met. Making this whole process transparent helps keep focus throughout the team. Successes and problems should receive comparable visibility. This requires good communications. A strong systems engineering group that has insight into the entire project plays an important role in ensuring that surprises are minimized.

It is my view that the JWST Project has done or is doing many of these steps, but it will be good to ask those with more project management experience than me, and be assured that this is so. To summarize: Focus on meeting milestones. Focus on deliverables. Focus on accomplishments. Move quickly and decisively to rectify problems. Focus on communicating the activities, milestones and status of the deliverables available to the stakeholders through a timely and transparent process.

Thank you, Mr. Chairman, for the opportunity to respond to your questions, and those of the Members of the Committee. Some corrections to the transcript were sent separately.

Sincerely,

Dr. Garth Illingworth,
University of California, Santa Cruz
Independent Comprehensive Review Panel

Responses by Mr. Jeffrey D. Grant,
Sector Vice President and General Manager,
Space Systems Division,
Northrop Grumman Aerospace Systems

Chairman Hall

1. *What insight has Northrop Grumman had into the re-planning process for JWST?*

Northrop Grumman worked closely with NASA throughout the re-planning process to develop a high-confidence plan for our scope of work on the JWST contract and to ensure consistency with the total program re-plan that NASA was leading. Throughout the development of this re-plan, we held a series of reviews with NASA ensuring that our new plan fits within their top level program plan.

2. *What lessons learned has Northrop Grumman experienced in the course of this program and how will they be applied to program execution moving forward?*

Northrop Grumman is applying lessons learned from our experiences on other NASA observatories, including Chandra, as well as from the JWST program and other major space system programs, to ensure that we achieve the 2018 launch date. We have learned that reducing program risk through a methodical, incremental build and test approach, which retires risk at each successive indenture level of the observatory, is a path that allows us to incrementally approach/solve complex problems in the early stages of the program. Over our decades of experience with programs of similar complexity, Northrop Grumman has developed and maintained a rigorous integration and test process to ensure that we identify issues at the lowest assembly level possible in order to prevent problems later in the buildup of the observatory that would require us to undo previous assemblies.

We have incorporated previously proven methods of testing and validating components, assemblies, and elements on the ground prior to launch. We are also keeping critical employees available to the program to quickly disposition test, integration and operations problems throughout the life of the program.

3. *What incentives have you implemented to ensure lower-level management is empowered to identify and mitigate potential risks/threats before they become a larger issue?*

Northrop Grumman uses a rigorous risk management process, and our Program Manager encourages contributors at every level of the program to actively identify both risks and opportunities for improvement. Through this process, team members are empowered to bring forward risks on an on-going basis, enabling the Program Manager to adjudicate and apply resources as necessary, with emphasis on the risk/opportunity matrix during monthly reviews. Our culture of openness and proactive problem-solving provides the foundation for our Northrop Grumman corporate-wide commitment to values-driven performance.

4. *What kind of cost and schedule reserves are being set aside by Northrop? Are these in addition to the reserves being set aside by NASA?*

For the Northrop Grumman-led portion of the JWST program, which is approximately 40 percent of the remaining Webb program, we hold distributed schedule slack throughout the timeline up through launch, with calculated cost reserves distributed appropriately for a program of this magnitude. Since we have not yet completed negotiations with NASA for the restructured program, we do not have a specific amount set aside, but we have proposed reserves that provide high confidence of executing the program.

Rep Lamar Smith

1. *NASA recently announced that the Kepler Space Telescope has discovered an Earth-like planet 600 light years away whose size and distance from its own star put it in the "habitable zone" to support life. The Hubble Space Telescope has made countless discoveries over the past two decades.*
    a. *What kinds of scientific revelations might we anticipate with the James Webb Space Telescope, compared to those from Kepler and Hubble? Would you recommend maintaining operations of the Kepler and Hubble Space Telescope even if funds from those missions are needed to be used to keep JWST on track?*
2.
    a. *Could you comment on the role of JWST in maintaining and expanding U.S. global leadership in astronomy and astrophysics?*
    b. *How do the Hubble, Kepler and Webb Space Telescope compare to the capabilities of the European Space Agency's Herschel telescope?*
    c. *What are other nations doing in astronomy and astrophysics that could jeopardize America's leadership in the field?*

Identified as the top priority for astronomy and astrophysics by the U.S. National Research Council, JWST will provide scientists with the capacity to reach beyond the Hubble Space Telescope and Kepler Telescope, to serve as a key observatory called for by the world's astrophysics community. JWST will provide observational capabilities far beyond anything previously attempted by NASA, our nation, or anywhere in the international community. JWST operates at ultra-cold temperatures, to measure and explore the first stars and galaxies born in the universe, and is designed with the unique capability to study planetary systems similar to our own, analyze the molecular composition of extrasolar planets' atmospheres, and directly image Jupiter-size planets orbiting nearby stars.

JWST plays a critical role in U.S. technological and engineering leadership in the world. Northrop Grumman currently employs approximately 280 engineers, scientists, technicians, and support staff at our Space Park facility in Redondo Beach, California, and in our efforts we partner with 193 suppliers across 31 states that harness the most advanced technical expertise in America. JWST is enabled by talented women and men serving as scientists and engineers across the country in key facilities and laboratories. As one of the nation's top science programs, JWST provides opportunities for, and benefits from, the highly skilled engineers we rely on to build the nation's national security and defense programs. This program, like the Great Observatories that came before it, ensures the U.S. maintains global leadership in astronomy and astrophysics.

3. *Given your experience with building our nation's spy satellites for the National Reconnaissance Office, would you be willing to comment on the need for American technological leadership in space telescopes and capabilities created by the Webb space telescope?*

The aerospace industry relies on national investment in cutting edge technologies such as those that are being demonstrated on JWST. These technologies keep our country at the forefront of innovation, enabling advances in both science and national security. Specific examples of how these technologies are relevant to numerous mission areas can be made available through other communications.

4. *Last July, NASA's associated administrator Ed Weiler, who was in charge of NASA's science mission budget of almost $5 billion annually, called the Obama Administration's flat budget for James Webb Space Telescope a "road to nowhere" in a res interview. Soon thereafter, Dr. Weiler tendered his resignation, after 33 years of service to NASA.*
    a. *What are your thoughts of how the Obama Administration handled the budget challenges for the James Webb Space Telescope over the past 3 years?*
    b. *Why did the annual funding for the JWST drop during the Obama Administration compared to how much was being spent on the JWST only a few years ago? Shouldn't the funding profile for the Webb telescope have been increasing as the project was ramping up? (FYI: $438 million was spent in FY010 for JWST, but on $354.6 million was requested in FY2011)*
    c. *Did this flat-line budget from the Obama Administration cause delays to the program? If so, how much delay?*
    d. *Did the House Appropriations Committee profile an adequate wake-up call for the Obama Administration and Congress that the budget challenge facing the James Webb Space Telescope required fixing?*

As noted in NASA's FY12 President's Budget request documentation released in February 2011, the JWST project development cost was in the midst of being developed as part of the re-planning activity that completed in 2011. Subsequent to the release of the NASA's FY12 Budget Request, NASA has completed and delivered a new JWST project cost and budget profile which allows for the earliest launch date at the lowest at-complete cost.

Northrop Grumman continuously evaluates actions to contain costs, while moving forward through assembly, integration, and test for launch readiness. Our JWST team manages a consistent and rigorous review system at all levels, from senior monthly program reviews down to weekly written progress reports with actively-managed metrics. However, as is the case of all projects, adequate and timely funding is required to meet schedule and program cost targets

Randy Hultgren

1. *Could you comment on the impact that JWST will have on our national STEM initiative in terms of inspiring and attracting the youth of today into field of science, math, and engineering?*

JWST, like Hubble before it, will bring the excitement of scientific discovery to people around the world, especially to students participating in Science, Technology, Engineering, and Mathematics (STEM) education initiatives, inspiring our country's future innovators and leaders. Federal investments in basic scientific research, such as through major programs like JWST, inspire current and future generations of young people to pursue careers in STEM fields. Hubble's impact on the public has been culturally transformative. Hubble has inspired school children across the country and around the world. JWST is the "Hubble" for the next generation of young scientists and engineers. Northrop Grumman and our industry partners rely on this pipeline of young people that keep America internationally competitive and prepared to meet our scientific, engineering, and national security needs.

2. *JWST has significant international participation, most notably by the European Space Agency and the Canadian Space Agency. Could you comment on the effect the JWST will have on global cooperation in space and other scientific endeavors?*

NASA's international partners, specifically the European Space Agency and the Canadian Space Agency, play a vital role in the JWST program by providing key instruments and the launch vehicle, and indeed the program is a model of successful international collaboration.

3. *How will JWST contribute to our national objectives in science and engineering?*

JWST was identified as the top priority for astronomy and astrophysics by the National Research Council, and will serve as a key observatory for the world's ground-based and space-based astrophysics community. The aerospace industry relies on national investment in cutting edge technologies, as exemplified by JWST, to fulfill the national objective of being at the forefront of innovation in science and engineering. JWST and similar programs provide a training ground for the highly skilled engineers Northrop Grumman relies on to build the nation's national security and defense programs.

The JWST program is trail-blazing as a technological endeavor, opening up a host of new capabilities that have potential to enable us to better serve our nation's defense and security. The Hubble Space Telescope was recently recognized for contributions to the ten thousandth science paper and NASA's science program contributed to nearly seven and a half percent of the peer review science papers in space science in 2011. These are representative of the legacy that JWST will continue into the next decade for U.S. leadership in space science.

4. *Could you comment on the secondary benefits that will be derived from JWST in terms of new technology development that will enable other scientific, engineering or national security endeavors?*

Future space programs will benefit from the technologies developed for JWST, and are in fact already being used today in other industries. For example, in the field of medical technology, innovations developed for JWST are being applied to the measurement of human eyes, diagnosis of eye diseases and improved surgical techniques. Investments in major undertakings such as JWST

bring breakthroughs to areas where independent technology development is not affordable. The new inventions required to build JWST include: micro-shutters with widths the size of a human hair; actuators and bonding materials that will function at nearly -400° F; a folding segmented mirror, and a deployable sunshield the size of a typical classroom that will passively cool the telescope to forty degrees above absolute zero.

Bernice Johnson

1. *The ICRP report cites confusion over how "threats" that might result in a funding or schedule impact get tracked and communicated to the NASA Program office and when they should be held as "liens" in the JWST budget. What steps have Northrop Grumman and NASA take to clarify this confusion so that both the government and contractor are "on the same page"?*

Northrop Grumman has greatly improved our communication with NASA regarding program cost and schedule performance measures. Every month in a business splinter meeting, we jointly review in detail the program performance to date and any forecast risks to program cost and schedule performance. We review liens and threats using common standards, and reach mutual agreement on the appropriate classification at each monthly meeting. Specifically, the expected value of threats is continuously compared to the program reserve, by fiscal year, insuring appropriate management attention by both Northrop Grumman and NASA. In addition, senior management from NASA and Northrop Grumman communicate weekly to ensure all program issues are being addressed in a timely manner.

2. *One aspect of the JWST program that has been deferred is work on the spacecraft bus. How are you ensuring that this critical element is not shortchanged in any attempt to keep to the program schedule? How are you mitigating the risks of this delayed start on the spacecraft element?*

We delayed the bus development to make more progress in the more technically challenging elements of the program (i.e., optics) and now that we have completed much of the optical development, we are accelerating work on the bus development. The schedule for completion of the spacecraft bus was a particular focus area for the re-plan effort. The spacecraft bus is making significant progress and is on schedule to be completed in time to be integrated with the Optical Telescope Element and Integrated Science Instrument Module after this hardware has completed cryogenic testing at the Johnson Space Center facility.

3. *While confident of its re-plan of JWST, NASA is understandably concerned about the impact of delaying launch by three years. For example, the agency is concerned about the potential loss of key government and contractor personnel due to periods of low or little activity, long storage period for the Integrated Science Instrument Module, Mission and Actuator, and the need to reevaluate sparing philosophy and parts aging/obsolescence.*
    a. *Do you share these concerns?*

b. *What mitigating actions can be taken, particularly by the Northrop Grumman team, to mitigate the effects of this delay?*

JWST is the peak professional experience for most of those actually working on the hardware and this is confirmed by our very low attrition rate. The program is keeping critical employees available to the program to quickly disposition test, integration and operations problems quickly throughout the life of the program. The JWST Program Office even maintains a contact list for retirees with key domain knowledge, so they can be rapidly contacted if anomalies emerge during the JWST lifetime.

Northrop Grumman, together with NASA, has evaluated the processes required to minimize impacts associated with the plan to launch in 2018. On the question of storing flight hardware, each JWST mirror segment has its own environmentally-controlled storage container in which humidity and contamination are controlled to maintain a safe environment for as long as required. After completion, all mirrors are stored in their containers in an environmentally-controlled highbay. Independent expert panels have reviewed the long-term storage of the observatory's 18 primary mirror segments, the secondary mirror, tertiary mirror, and fine-steering mirrors and have determined the storage plans do not pose any additional risk to the 2018 launch readiness date. The plan was subsequently addressed and approved at the Primary Mirror Segment Assembly Critical Design Audit and succeeding reviews.

4. *We often hear about the importance of having challenging space projects to sustain a skilled workforce in this nation. What, in your view, does JWST mean for our workforce and for those young people who will become our workforce in the future?*

JWST, like Hubble before it, will bring the excitement of scientific discovery to people around the world, especially to students participating in Science, Technology, Engineering, and Mathematics (STEM) education initiatives, inspiring our country's future innovators and leaders. Federal investments in basic scientific research, such as through major programs like JWST, inspire current and future generations of young people to pursue careers in STEM fields. Hubble's impact on the public has been culturally transformative. Hubble has inspired school children around the world and JWST is the "Hubble" for the next generation of young scientists and engineers. Northrop Grumman and our industry partners rely on this pipeline of young people to generate the next generation workforce that sustain our critical skills and keep America internationally competitive and prepared to meet our scientific, engineering, and national security needs.

Jerry Costello

1. *NASA's program official has indicated that one of the concerns with the re-plan's launch date of 2018 is the need for the JWST team to remain focused and motivated to keep the momentum of this year. How will you keep your Team, including subcontractors, motivated and focused?*

From our most senior levels down to the hands-on technicians who assemble each part of JWST, Northrop Grumman takes great pride in our role as NASA's partner on JWST. We are fully committed to the success of this mission. We are motivated, personally, professionally, and financially, to deliver a successful mission that is on-budget and on-schedule. With recognition and appreciation to the support of this Congress in maintaining the funds our teams need to execute this mission, we will deliver this ground-breaking observatory at the earliest possible date and at the lowest cost.

With the appropriate funding profile in place, the Northrop Grumman team is highly motivated to continue on the path of taking on significant work this year and every subsequent year to launch. With a steady flow of important program milestones planned ahead of us, our team is able to stay focused on completion of the design, build, assembly into subsystems, test and verification of the flight observatory. The current JWST plan allows our company to call upon the variety of skill sets required to appropriately address each of these phases in a manner consistent with our heritage experience on major space missions.

2. *The ICRP report noted that "A decision on system engineering is a decision on accountability. In a project of this complexity and visibility, it is appropriate for the Government to be accountable. It is crucial, however, that the transfer of responsibility be executed properly." What has been the impact of moving systems engineering accountability from Northrop Grumman to NASA? Who did the transfer go?*

Northrop Grumman's successful partnership with the NASA systems engineering team has demonstrated successful execution within the new systems engineering structure for the past year and a half. Northrop Grumman, in close collaboration with NASA, is effectively addressing the technical and programmatic challenges before us. The transfer occurred without any problems of note.

Appendix 2

Additional Material for the Record

Ten New Technologies Developed by and for JWST

The James Webb Telescope will have a unique and profound role in transforming our understanding of astrophysics and the origins of galaxies, stars, and planetary systems. In order to carry out its mission, several innovative and powerful new technologies ranging from optics to detectors to thermal control systems are being developed. The ten technologies and their roles in JWST are:

• **Segmented Beryllium Primary Mirror:** Vital to the mission because they enable a large, lightweight mirror to be formed of 18 mirror segments. The segmented mirror approach allows us to build a primary mirror both large enough to collect sufficient light to conduct the science and light enough to launch. Further, without the thermal performance of beryllium, we could not maintain a good optical surface in the super cold temperatures JWST will experience.

• **Composite Backplane Structure:** First time a composite structure is being used in space to hold very lightweight mirrors. Structural elements must be stable against movements caused by temperature changes in order to hold the mirror segments into the shape required for Webb to function. Any movements in this large (~20 foot) structure must be limited to much less that the width of a human hair at temperatures only 40 degrees above absolute zero.

• **Mirror Phasing and Control Software:** Software techniques and technologies needed to control the mirrors and the small motors that can push on the mirrors to bring them into perfect optical alignment. There's no App for that!

• **Cryogenic Application Specific Integrated Circuit:** These were required to eliminate many meters of cabling that are a source of heat and introduce electronic noise into the science data. Thus mass and excess heat were eliminated and the signal to noise performance was improved. The cryogenic electronics developed for JWST found their first use in the last servicing mission for Hubble when engineers for that mission saw the improved performance they enabled.

• **Micro-Shutters**: Developed at NASA GSFC, these are crucial for JWST's NIRSpec, the European science instrument they reside in. They enable careful selection of targets on the sky for spectroscopic investigation. They are the key element that will enable JWST to trace the history of galaxy formation, one of its two main distant universe goals.

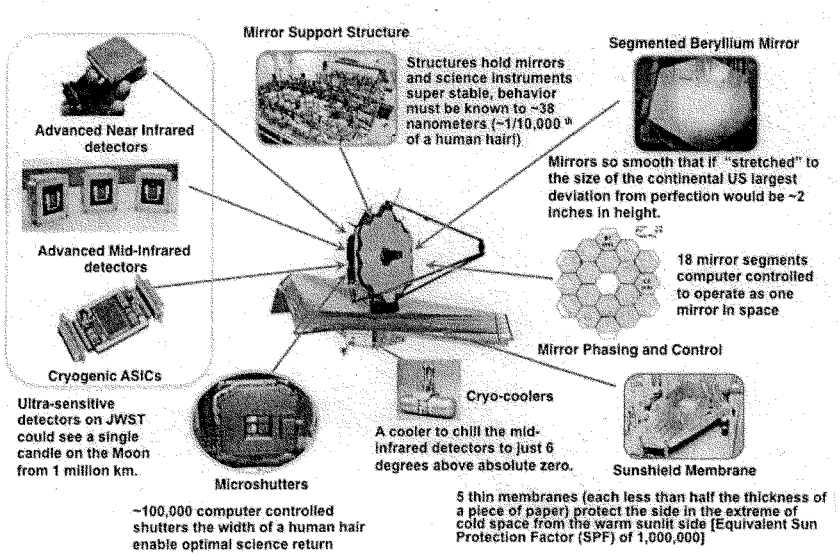
• **Sunshield Membranes:** Never before used in space, these structures shield the telescope from heat sources (Sun, Earth, Moon) and make the telescope's functioning possible. Amazingly, these structures are the size of tennis courts but with "plastic baggie" thickness!

• **Near Infrared Detectors:** JWST needs extraordinarily sensitive detectors to record the faint signals from far-away galaxies, stars, and planets, and it needs large-area detector arrays to efficiently survey the sky. JWST has extended the state of the art for infrared detectors by producing arrays that are both lower noise and larger format than their predecessors. Already, some spare engineering-grade detectors are going to be used to produce ground-based science using telescopes in Arizona.

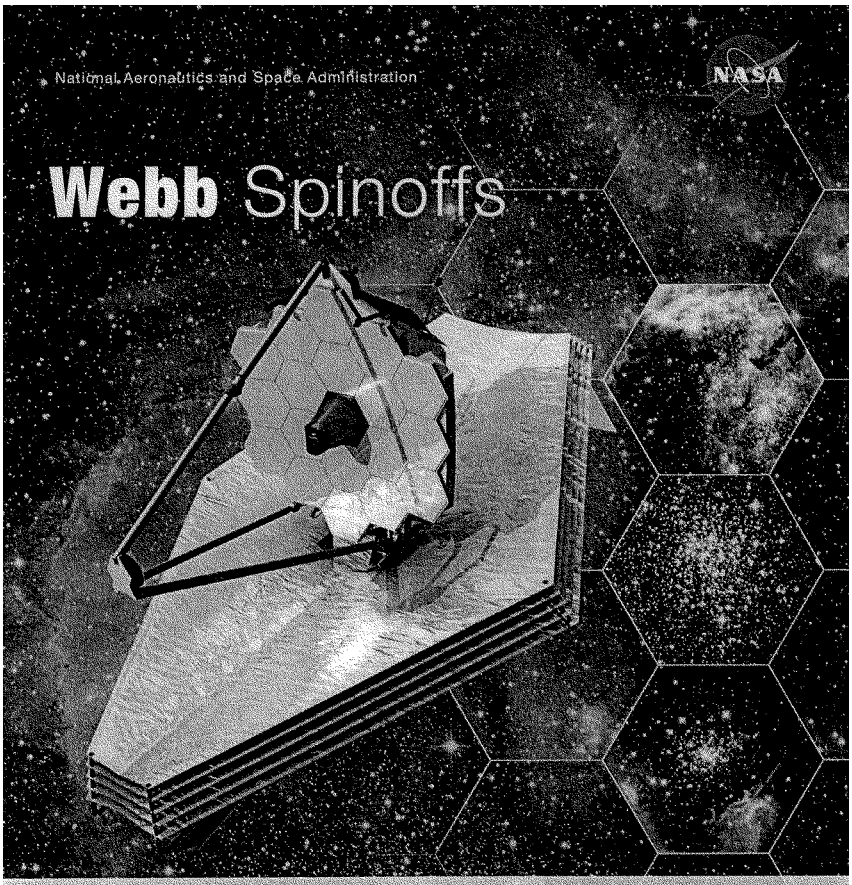
• **Mid-Infrared Detectors:** Like the near-infrared detectors above, JWST needs extraordinarily sensitive detectors to record faint signals from distant objects. Unique (but coordinated) technology developments were required for near and mid-infrared because entirely different materials are suited to different wavelength bands.

• **Cryo-cooler for Mid-Infrared Instrument:** In order for mid-infrared detectors to function they must be cooled. Missions have used very large and massive cryostats (i.e. giant thermos bottles filled with solid hydrogen or some other coolant) in the past. These cryostats have limited life. JWST has developed refrigerators, "cryo-coolers", that do not have this limitation. There is no need to take large volumes of coolant into space to maintain the appropriate temperature.

• **Heat Switches:** These can be used to allow the observatory to cool down in very highly controlled manner, which is important for how the telescope cooling occurs after launch and how contaminants migrated from hotter to colder observatory elements. These were developed and confirmed, but later design changes obviated their need. Future space missions may take advantage of this technology.



Location of New Technologies on JWST



The James Webb Space Telescope is a large, infrared optimized space telescope and is the scientific successor to Hubble. Webb will find the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy. Webb will peer through dusty clouds to see stars and planetary systems forming, connecting the Milky Way to our own Solar System. Webb's instruments will work primarily in the infrared range of the electromagnetic spectrum, with some capability in the visible range.

Webb will have a mirror that is 6.5 meters (21.3 feet) in diameter and a sunshield the size of a tennis court. The mirror and sunshield are larger than the width of the rocket used to launch them, so they will be folded up for launch and will deploy once Webb is in space.

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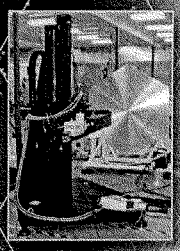
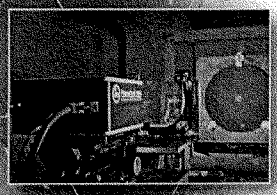


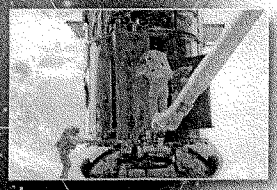
Measuring Eyes: New Wavefront Optical Measurement Devices Lead to Medical Spinoffs

To accurately measure the shape of Webb's mirrors during manufacturing, significant new improvements have been made in the area of wavefront sensing technology. The measurement device is called a Scanning Shack-Hartmann Sensor. "The Webb telescope program has enabled a number of improvements in measurement technology for measurement of human eyes, diagnosis of ocular diseases and potentially improved surgery," said Dr. Dan Neal of Abbott Medical Optics Inc. in Albuquerque, NM. The Webb improvements have enabled eye doctors to get much more detailed information about the shape of your eye in seconds rather than hours. Four patents have been issued as a result of innovations driven by the Webb telescope program.



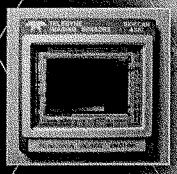
Laser Interferometers: High Speed Optical Sensors Lead to Commercial Applications

One of the toughest challenges for Webb engineers was to find a way to test mirrors and composite structures at the incredibly cold -450 degrees F temperature they will operate in space. With desired precisions of nanometers, vibration is a constant problem. To solve that problem, 4D Technology Corporation of Tucson, Arizona has developed several new types of high-speed test devices that utilize pulsed lasers that essentially "freeze out" the effects of vibration. According to 4D Technology CEO James Millerd, "The JWST program has been a tremendous benefit to creation of new technology and jobs beyond its direct funding...4D has gone on to generate over $30 million in revenue from a wide range of applications within the astronomy, aerospace, semiconductor and medical industries based on the technologies developed for JWST."



Restoring Hubble: Integrated Circuits Used in Camera Repair

Webb investments in cryogenic Application-Specific Integrated Circuits (ASICs) led to the development of the ASICs that are now flying on the Hubble Space Telescope. This is a unique example of "future heritage": a program in development (Webb) invented a technology for a program well into the operations phase (Hubble). ASICs are small, specialized integrated circuits that enable an entire circuit board's worth of electronics to be condensed into a very small package. Webb's investments into this technology allowed the ASICs to be programmable, which was important in the repair of Hubble's Advanced Camera for Surveys that has produced stunning views of our universe.



Astronomical Detectors: Webb Detector Technology is the Universal Choice

The benefits of the near-infrared detectors developed for Webb's instruments have already spread far and wide in the world of science. "Infrared sensors based on the technology developed for Webb are now the universal choice for astronomical observations, both from space and the ground," said Dr. James Beletic, Senior Director at Teledyne. This technology is also being used for Earth science and national security missions. An early pathfinder version of Webb's HAWAII-2RG 4 Megapixel array has been used in several NASA missions including Hubble, Deep Impact/EPOXI, WISE, and the Orbiting Carbon Observatory, and the HAWAII-2RG is already in use at dozens of ground-based observatories around the world. The availability of these high-performance detectors developed for Webb has been critical to a breathtaking collection of missions, both present and future.

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