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

"The Next Great Observatory: Assessing the James Webb Space Telescope"
December 06, 2011 Hearing
Testimony

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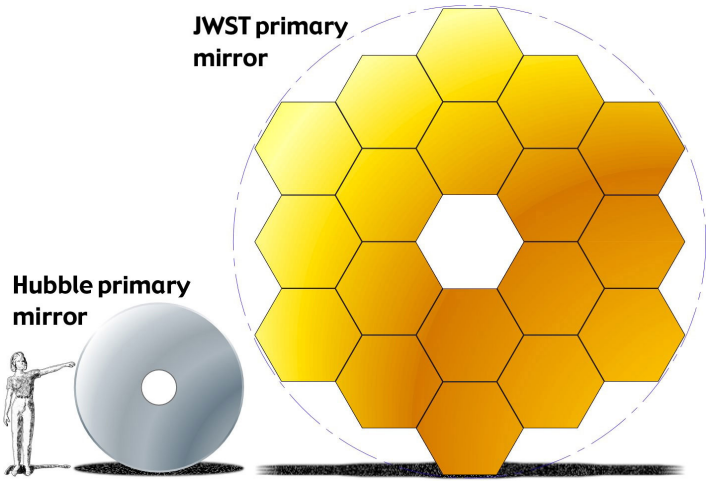
Chairman Hall, Ranking Member Johnson, distinguished Members of the Committee, thank you for inviting me to testify. I appreciate the opportunity to respond to your questions regarding the James Webb Space Telescope and the opportunity to highlight its importance to our nation. I would also like to thank 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.

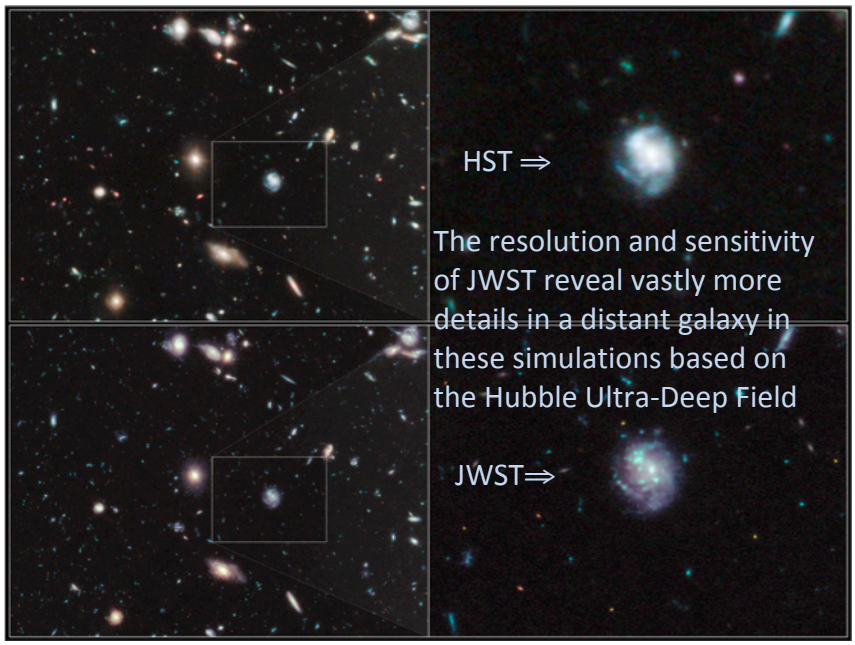


The James Webb Space Telescope: Hubble's successor as the next Great Observatory

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.

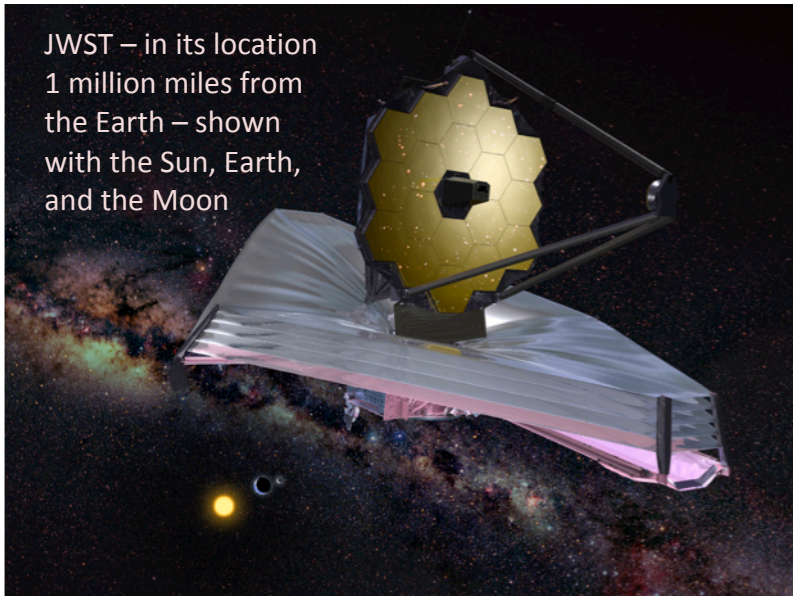


Yet it is not just science and education that is enhanced by these Great Observatories. Such projects led to the development of numerous cutting-edge technologies by our industries. US companies have generated patents from their work on the Great Observatories. These enhance the ability of industries 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 – in its location 1 million miles from the Earth – shown with the Sun, Earth, and the Moon

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.

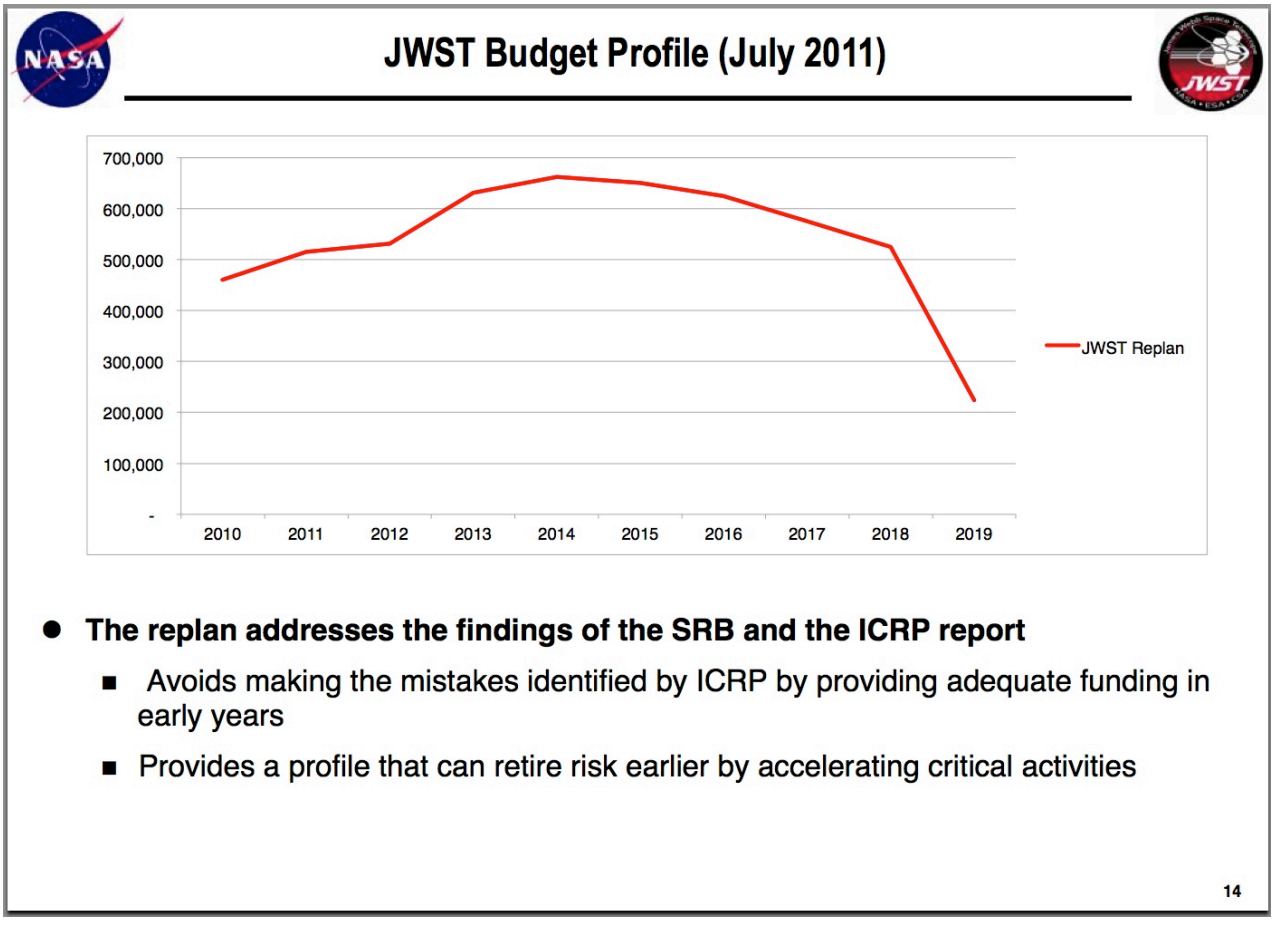
It appears to me from all that I have seen that considerable effort was made to meet both the detailed statements and to encompass the spirit of the ICRP recommendations. NASA derived a budget that was conservative, with a very balanced reserve situation from now through to launch, with both cost and 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.