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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

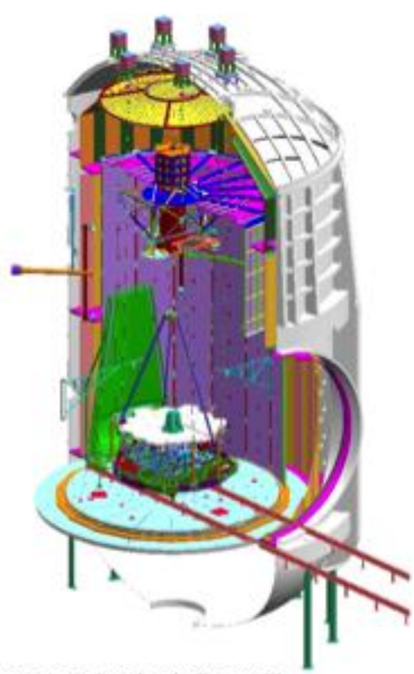
- Mounting support
- Actuators, position readout electronics and cabling to control position of mirror to within 10 nm
- Adds ~ 50 lbs total mirror assembly weight
- Operating temperature: ~40K

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.