Statement of

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before the

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

July 25, 2018

In March, NASA informed Congress about a schedule delay and potential cost increase for the James Webb Space Telescope, NASA's next great observatory. Since then, the agency has been working to understand the causes of the delay, determine steps necessary to ensure mission success and improve our estimates of the time and cost necessary to complete development, launch, and commissioning. NASA is committed to successfully completing Webb, an international program with partners from Europe and Canada, and sharing its unprecedented and certainly incredible view of the early Universe and observations of exoplanets with the scientific community, U.S. taxpayers, and the world.

Successfully implementing the Webb mission is a high priority and critical to maintaining national leadership in the space sciences. Webb was the highest priority major initiative of the National Academy of Sciences' 2001 decadal survey, *Astronomy and Astrophysics in the New Millennium*. Webb is designed to see the Universe's first stars and galaxies, to reveal how the familiar night sky of galaxies and stars came to be, and to take the next giant leap in characterizing planets orbiting other stars (exoplanets) and searching for Earth-like planets. Webb plays a significant role in the Astrophysics program. For example, the Transiting Exoplanet Survey Satellite that launched in April 2018 is designed to provide a pipeline of target exoplanets that are well-suited for characterization using Webb.

While Webb will transform our understanding of the Universe, to achieve its objectives it must necessarily be sophisticated. In fact, it is the most challenging science mission and the largest observatory that NASA has ever developed. Webb's mission requires a very large telescope optimized to make observations in the infrared portion of the spectrum. The telescope and its instruments need to be extremely cold to limit the amount of infrared light emitted by the telescope itself. Both the primary mirror and the sunshield it uses to keep cool are larger than the fairing of any rocket yet flown. The mirror and sunshield will be folded to fit inside the fairing, and they will deploy after launch into their final mission configurations while Webb is maneuvering to its operational location in space over 1 million miles from Earth. There is significant risk associated with these deployments, and every effort must be made to ensure they occur as planned. Developing the observatory required the maturation of new technologies to enable Webb's next-generation instruments, mirrors and mirror system, telescope structure, sunshield, and thermal-control systems. Each of these technology advancements is required to

provide the Webb observatory with the capabilities needed to see the first stars, to characterize exoplanets, and to achieve Webb's other science objectives.

Webb is in the final stages of its development. All of its hardware has been fabricated, and the flight hardware and software are undergoing the last major steps of its integration and testing (I&T) phase. The observatory is currently integrated into two elements. One element is the Optical Telescope Element / Integrated Science Instrument Module, called OTIS. OTIS is comprised of the Optical Telescope Array, itself made from 18 precision mirror segments aligned to achieve the sensitivity of a single large mirror, and four state-of-the-art infrared science instruments. The other element is the Spacecraft Element, which is composed of the spacecraft (solar arrays, communications, propulsion, power, command and data handling, etc.) and the five-layer, tennis-court-sized sunshield. Both elements now reside in a single clean room at the observatory contractor, Northrop Grumman Aerospace Systems (NGAS), in Redondo Beach, California. OTIS has completed testing that simulates the conditions of launch and of space with excellent results. The Spacecraft Element has been completely assembled and is currently undergoing similar testing. Once testing of the Spacecraft Element is complete, the two elements will be joined together into the full observatory and put through a series of tests as an integrated system. The observatory will be shipped by sea to French Guiana where it will be launched on an Ariane 5 rocket. In space, Webb will undergo six months of commissioning, including deployments of the observatory's mirrors, sunshield, and a number of smaller systems, as well as powering-up, testing, and calibrating the observatory's five instruments and multiple observing modes.

Early this year, NASA recognized that it would take longer to complete the Spacecraft Element I&T than previously estimated. Problems during I&T caused significant delays, and the team discovered that certain tasks—in particular deploying and re-folding the sunshield—would take significantly more time and possibly more funding than previously estimated.

Due to the schedule delays and possible cost increase, NASA formed an Independent Review Board (IRB) chaired by A. Thomas Young, a distinguished leader of the aerospace community, member of the National Academy of Engineering, former director of NASA's Goddard Space Flight Center, and former president of Martin Marietta. The IRB's charge was to evaluate all factors influencing Webb's success, to ensure that NASA's approach to completing I&T, the launch campaign, and commissioning would maximize the likelihood of mission success. NASA also requested the IRB to provide an independent assessment of the schedule and cost necessary to complete Webb's development including launch and commissioning. The IRB was asked to conduct its review quickly since the project was at a critical stage. The IRB members are an impressive set of well-known experts across engineering, science and management fields, and NASA appreciates the hard work they put into the task. In spite of the disruption to their lives, they accepted the challenge of conducting a thorough review on a relatively short timeline, recognizing the importance of Webb's success to NASA and the Nation.

While the IRB was meeting, a new issue was discovered. During acoustic testing of the Spacecraft Element—a test that subjects the hardware to the intense sound levels that it will experience during launch—a number of fasteners for covers that protect the sunshield membranes until deployment in space loosened and detached, falling onto or near the sunshield

and spacecraft. Determining the cause and solution to the problem took time and significantly extended the schedule necessary to complete I&T. This additional work added six months beyond the delays already evident when the IRB convened. The Webb project team is currently correcting the problem, searching for any potential related issues that might be present, and preparing the Spacecraft Element to repeat acoustic testing and complete the remaining Spacecraft Element testing in preparation for integration with the OTIS.

Mr. Young's testimony will discuss the IRB Report, and I recommend reading this thoughtful and useful report to obtain a full understanding of their findings and recommendations. The IRB submitted their report to NASA on May 31. The IRB made 32 recommendations, all aimed at maximizing the likelihood of Webb's success. In their report, they found that issues including human errors, embedded problems (lurking undetected problems, like the fastener issue revealed by the acoustic test), excessive optimism in I&T planning, the lack of sunshield experience, and system complexity significantly impacted the development schedule. Two examples of human errors highlighted by the IRB were damage to propellant valves caused by cleaning with an improper solvent and damage to pressure transducers due to application of excessive voltage during testing. A fundamental observation was that due to the scale and complexity of Webb's development, small mistakes often lead to large impacts on schedule and cost. A central focus of the IRB recommendations was the reinforcement of figurative safety nets to catch human errors that happen during I&T. In addition, the IRB focused on enhancing efforts to reveal embedded problems that may be hidden in the observatory, and to mitigate the impacts of any embedded problems on the schedule and cost of completing observatory development. The IRB also reaffirmed Webb's incredible scientific potential and its critical role in maintaining U.S. leadership in astronomy and astrophysics. Thanks to the IRB members' extensive experience and independent perspective, their findings and recommendations provide NASA with a clear and actionable roadmap of the areas where we should focus as the Webb team works to complete development.

In June, NASA provided a report to the Committee on Science, Space and Technology as well as other Congressional Committees describing the actions we are taking in response to the IRB's recommendations. NASA accepts all of the IRB's recommendations. NASA already is fully implementing all of the recommendations except two, with plans to respond to those as well.

Some select IRB recommendations are: 1) due to the complexity of Webb's commissioning, especially the deployment of the telescope and sunshield, NASA should name a world-class system engineer as "Commissioning Manager," with total end-to-end responsibility for commissioning success; 2) Northrop Grumman Aerospace Systems (NGAS) and NASA should take a number of actions to address human errors during I&T and embedded problems, to prevent them or, if that fails, to catch them before they arise in a context in which they would affect schedule, cost, or mission success; and 3) NGAS should take steps to ensure that certain important engineers are present at critical stages through the rest of development.

As part of the review, the IRB requested the Webb teams at each of the major organizations developing Webb (NASA's Goddard Space Flight Center, Northrop Grumman Aerospace Systems, and the Space Telescope Science Institute) identify additional activities that would enhance mission success if implemented, without regard to any impact on cost and schedule.

One of the IRB's recommendations was that NASA evaluate those mission success enhancing activities and implement them as appropriate. NASA used a cost versus benefit analysis to decide which of those mission enhancements could be implemented. The small set of exceptions are items that would either take too long to implement or would not provide a net benefit to mission success after taking all considerations into account.

The IRB's analysis of the schedule found that the Webb project's scheduling process was robust. However, the IRB's schedule estimate included some differences from the previous Webb schedule estimates, including uncertainty in the durations of tasks, and likelihoods of risks and threats. The largest contribution to the shift in the IRB's schedule from previous NASA estimates was due to the fastener issue that occurred during the IRB's deliberations and after NASA's schedule announcement in March.

The IRB's cost estimate accounted for the continued workforce needed to complete development throughout the duration of the delay, which is characterstic given the mature stage of development for the project.

NASA greatly appreciates the IRB's thorough and thoughtful analysis and the care they put into developing their recommendations and explaining their results. Their efforts will be invaluable to ensuring Webb's success as it progresses through development to become an operational scientific observatory. We have made the IRB's report available to this Committee and the public.

NASA has incorporated the IRB's schedule analysis along with other inputs to determine a revised estimate of Webb's launch date and the cost necessary to complete the mission. NASA has established March 30, 2021, as Webb's new launch date with 80 percent confidence. This new date is consistent with the findings of the IRB. It includes time to accommodate the technical issues and over-optimism identified by the IRB, addresses the fastener issue encountered during acoustic testing, and reestablishes appropriate schedule reserves.

While both the IRB's schedule analysis and NASA's revised launch date include significant margin for problems that may arise while completing development, neither accommodates the time required to recover from unknowable future events such as another several-month delay due to human errors or embedded problems of the sort that have cost so much time recently. The estimates assume that the corrective actions taken based on the IRB's recommendations will significantly reduce or eliminate the likelihood of such events, and we must ensure that they do. Additionally, they do not accommodate the time required to recover from a significant spacecraft subsystem or instrument problem where the element needs to be removed from the observatory for corrective action. Removing an embedded element could add several months to the schedule, or, in the case of an instrument, potentially more than a year. It should be noted that no program typically adds schedule margin for such significant hardware anomalies because such anomalies are very rare.

As a result of the additional time needed to complete development of Webb, additional funding is required. To support the March 30, 2021 launch date and five years of science operations, we

estimate that Webb's new life-cycle cost will be $9.663 billion. The estimated development cost, including launch and commissioning, to support the new launch date is $8.803 billion, up from the $7.998 billion development-cost estimate established in 2011. Over Webb's lifetime, about $837 million in new funding will be necessary beyond previous requests, including $813.8 million in development funding and $23.5 million in additional funding for Phase E (operations and closeout). The increase in cost accommodates the additional time required to complete development of Webb, implement the IRB's recommendations, incorporate additional activities to enhance mission success identified by project in response to the IRB, and replenish reserves at all levels of the project (NASA Headquarters, Goddard, and Northrop Grumman). The revised estimates do not require a change to the budget request for Fiscal Year (FY) 2019.

We anticipate that the cost growth on Webb will have implications for other missions and programs. We expect the most serious repercussions to occur in FY 2020 and FY 2021, due to the estimated $490 million of additional funding required for Webb in those years above the prior planning budget. We have not yet determined what the impacts will be on other NASA programs and projects, but our plan will be informed by the priorities established through the National Academy's decadal surveys. We look forward to providing our plan for successful completion of Webb to this Committee as part of the FY 2020 budget request.

NASA also recognizes that the lessons learned here have similarities to other issues we are seeing around NASA's development programs for large, complex space systems and it is imperative for NASA to not only internalize these messages to lasting effect on Webb, but also across all of NASA's programs. We have talked about these results concerning development, management and the U.S. industrial base with all of our agency leaders. I have asked my team to communicate these lessons directly to NASA development personnel in an appropriate forum. This is an important opportunity for us to get better, an opportunity we do not want to miss.

The successful completion of the James Webb Space Telescope is critical to advancing our understanding of the Universe. Webb will conduct world-class science, answering questions about our place in the universe and rewriting textbooks for years. The data acquired with Webb will underpin many future projects. Notwithstanding the issues encountered during integration and testing of the Spacecraft Element, the superb performance of Webb's telescope and instruments during testing have made us eager to put them to use in space to address fundamental science questions. The IRB put it succinctly—Webb has "awesome scientific potential." Despite the recent challenges, NASA is confident that Webb will achieve mission success. That confidence is increased with the implementation of the IRB's recommendations, and mission success must be NASA's driving consideration moving forward. Along with the scientific community and the public, we are disappointed that completing Webb is taking longer and costing more than expected, but NASA is absolutely committed to successfully completing, launching, and commissioning Webb, and to carrying out its important scientific mission.

We ask this Committee, Congress, the scientific community, and the public for their continued support as we work to do everything necessary to make Webb successful. We appreciate your understanding of the complexity of what is required to ensure Webb's success, and we will continue to do everything possible to be good stewards of the resources with which you have entrusted us. I assure you that, in the end, Webb will be worth the wait.