National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

JUN 26 2018

Reply to Attn of: Science Mission Directorate

Summary of NASA responses to Webb Independent Review Board Recommendations

Following the agency's review of the mission's remaining tasks and recent integration and test challenges, NASA has established March 30, 2021, as the new launch date for the James Webb Space Telescope (Webb), the next great astronomy observatory. This date is consistent with the findings of an Independent Review Board (IRB), set up on April 2018, and chaired by retired Aerospace Executive and Member of the Academy of Engineering, Tom Young. As a result of the delay, Webb's total lifecycle cost to support the March 2021 launch date is estimated at $9.66 billion. The development cost estimate to support the new launch date is $8.8B (up from the $8B development cost estimate established in 2011). Along with the IRB's broad-view assessment, NASA also considered data from the project's Standing Review Board (SRB). Both review panels had concluded that a 2020 launch date would have been feasible before the recent acoustics test anomaly.

By setting this new launch data, NASA also agrees with a central finding of the IRB that the development of this telescope should move forward because of the exceptional potential and science insight the James Webb Space Telescope promises. The value of Webb was confirmed by NASA Administrator Jim Bridenstine: "Webb is a top priority mission that has great national importance for the agency and it will move forward. Webb will leave a legacy of exceptional science and cutting-edge technical innovations in the years ahead and will inspire future generations of astronomers, explorers, scientists, artists, and engineers."

In response to my charge, the IRB identified a variety of factors influencing mission success, leading to findings and recommendations to NASA over a wide range of technical, organizational, and other factors. NASA fully accepts the intent of all the IRB's recommendations (*italicized*), has already started implementing most of them, and NASA's response **(bold)** to each is provided below. The full IRB report is also available. The newly established launch date, cost commitment, and our responses to the IRB report were approved by the Agency Program Management Council.

I want to thank the IRB members for their critical analysis of the project as a whole. They have provided us with valuable independent insights that will help ensure the success of this crucial mission. In fact, some of the recommendations are aligned with actions already taken by the project team prior to receiving this report.

Webb's world-class science, from detecting light from the first stars and galaxies in the distant universe to probing the atmospheres in nearby exoplanets for possible signs of habitability, will underpin many other astrophysics projects that will use its high-caliber capabilities to enhance their science return. I look forward to the successful completion of this important mission.

Thomas H. Zurbuchen, Ph.D.
Associate Administrator,
Science Mission Directorate

Attached: NASA's Response t IRB recommendations

NASA's Responses and Actions Already taken in response to the recommendations of the Independent Review Board.

Commissioning Risks:

1) *NASA should designate a Commission Manager.* **Agree. The project will identify a Commission Manager who has extensive systems engineering experience with JWST.**
2) *NASA should implement sunshield hardware and simulation elements to aid in sunshield anomaly identification and resolution.* **Agree. Will adjudicate as part of the review and implementation of the "top ten" mission enhancement effort. At the request of the IRB, the "top ten" mission enhancements were identified by NASA, Space Telescope Science Institute (STScI) and Northrop Grumman Aerospace Systems (NGAS) as activities beyond the current work scope that would enhance mission success if implemented.**

Human Mistakes During Integration and Test:

1) *Northrop Grumman Aerospace Systems (NGAS) should establish corrective actions in processes, training, personnel certification, individual accountability and a robust testing, analysis and inspection process.* **Agree. NGAS stood down operations and performed an independent set of reviews and rewrites of all propulsion procedures including feedback from the performers. Also, applied Integration & Test (I&T) procedure expertise to manufacturing operations. To further enhance robustness in I&T, NGAS will be incorporating cross program independent reviews of the table top and pre-task briefing processes.**
   - **Will ensure that, in addition to formal training and certification to processes, that critical operations also require individual performers to have expertise and prior successful execution of the tasks.**
   - **A process is in place to recognize and reward performers who say 'Stop'. Additionally, brought in outside program leadership to meet with the performing organizations to hear feedback and incorporate into actions.**
   - **Recently, instituted an accountability process with checklist insuring independence of quality inspectors. Reinforced the importance of independence to insure first time success.**

Embedded Problems:

1) *Goddard and NGAS conduct an audit including forensic engineering, hardware pedigree assessment, drawing checks, etc., to identify potential embedded problems.* **Agree. Activities initiated: solicited support from GSFC Engineering Directorate and NGAS engineering organization for an independent set of eyes. This activity will include a comprehensive review of designs, processes, and tests to uncover embedded problems.**

- **Prioritize completion to support upcoming testing. NASA is auditing NGAS's verification processes of soft structure installation. Soft structure is more complex, and involves more organizational hand-offs than hard structure items.**
- **NASA is auditing launch vehicle interfaces based on Falcon 9 Zuma incident.**

Residual Risks:

1) *GSFC should conduct an audit of the JWST project residual risk, reviewing the objective evidence of (a) the completed Test As You Fly (TAYF) and Single Point Failures (SPFs) mitigation plans, and (b) failure corrective action effectiveness to determine the "as built" residual risk.* **Agree. Project actively pursuing. Every year or after key test we review the complete risk list for accepted, watch, mitigated, and open risks for currency and relevance. Mission System Engineer (MSE) reports project status every month to the GSFC Engineering Directorate including any changes to TAYF and SPF waiver accuracy / risk level based on results of test, inspection or verification activities. The MSE is the project Independent Technical Authority and is a key member of this process.**
2) *The Project should reconcile the "as built' residual risk with the expected "as designed" residual risk.* **Agree. The project continuously reviews the "as-built" hardware compared to the "as-designed" assumption via the weekly Architecture Working Group (AWG). The status of "as-built" Single Point Failure verification is a monthly AWG topic.**

Mission Success Dependence on Launch Vehicle:

1) *The Launch Services Program (LSP) shall be accountable for JWST launch success at the same level of responsibility they have for U.S. launches, or NASA should contract with Aerospace Corporation for similar accountability.* **Agree with the intent of this recommendation. NASA is working with ESA to establish a "Mission Success" plan. It is important that any additional assessment be focused, concise, and bring value to the mission. A well-meaning assessment, if applied in the wrong areas, could be counterproductive and prove to be a distraction to the entire team. LSP's extensive experience can increase the likelihood of mission success in certain key areas while ESA maintains accountability for the launch service. ESA and CNES (government, not industry) are the design and qualification authorities for the highly reliable Ariane 5 and they have an appropriate set of checks and balances with Arianespace (industry).**

Transport and Spacecraft/Launch Integration:

1) *NASA should define security requirements and plan for JWST transport to launch site.* **Agree. The project engaged United States Air Force (USAF) Transportation Command in 2015 to perform a risk assessment of the transport ~1 year before the launch readiness date. NASA is working with ESA on the details of security arrangements based on the threat analyses and identifying ways NASA can assist ESA in protecting the spacecraft and conducting launch site operations for JWST.**

2) *NASA should develop contingency operations and sparing plan for spacecraft/launch site operations.* **Agree. Contingency operations and equipment sparing plans are being developed for the launch site.**
3) *NASA should develop "pathfinder" JWST simulator and contamination protection systems for integration "dry runs."* **Agree. Pathfinder plans for launch site operations are underway and will be performed prior to Observatory shipment.**
4) *NASA should assess shipping vessel contamination environment and develop contingency plans for off-nominal shipping operation.* **Agree. The JWST shipping container is very robust, so particle monitoring of the exterior to the container should not be necessary. Erring on the side of caution, the Project will place a witness plate in the hold area of the ship for information.**

Mission Operations:

1) *It is critically important that GSFC JWST Project Office maintain responsibility and provide adequate support to ensure Space Telescope Science Institute (STScI) mission operations readiness.* **Agree. The project maintains the responsibility for mission operations.**
2) *The Project should review all simulators/testbeds and required usage against pre-launch tests and rehearsals, post-launch deployment anomaly resolution, fault isolation and correction.* **Agree. An assessment of the readiness of the simulators and testbeds and their usages is being adjudicated as part of the "top ten" mission enhancement activity described above.**
3) *The GSFC JWST Project Office should develop a staffing plan that meets the needs of I&T and operational readiness.* **Agree. The project has a staffing plan to support all the activities leading up to launch and has been coordinating with the I&T team to ensure the proper support.**
4) *The Project should develop and approve a transition plan that defines the level of mission operations responsibility for STScI as a function of time with independent gate reviews at transition points.* **Agree. The project is developing a transition plan that describes the changes in responsibility once commissioning is complete.**

JWST Reporting:

1) *NASA should implement JWST reporting structure as represented by accompanying diagram in the IRB report.*
2) *NASA should revise NASA policy directive consistent with recommendation.* **Agree with the intent of these two recommendations. The Program and Project understand the fundamental concern of the IRB and are developing a plan to better communicate the organizational roles and responsibilities at the Program and Project level.**

Management Communications:

1) *The GSFC and NGAS Project Offices should be established as consistent and factual source of all JWST mission status.* **Agree. Program Office and Project will collaborate in communicating mission status.**

2) *Communications of status and details appropriate for stakeholders needs to be presented clearly and frequently.* **Agree. The Program Office Communications Plan will target the release Webb features at the conclusion of major milestones or as often as there is substantive material.**
3) *NASA HQ should be responsible for developing a "communication plan" (messaging strategy) for JWST.* **Agree. The completed Webb Communications Plan is in review, and will be signed soon.**
4) *Communicating complexity, risk and science return for JWST is critically important.* **Agree. Program Office Communications Team reviewing the Webb Communications Plan with the entire Webb team.**
5) *Same criticality and assessment charts used for all JWST reporting.* **Agree. Assessment charts will accurately communicate JWST status and risk in a consistent manner. Where there might be differences in risk posture, there may be legitimate differences (such as when HQ is holding UFE to mitigate a risk at the project level) in how the risk is being communicated. In those cases, the differences will be transparently identified at all levels within NGAS, the Project and the Program.**

Mission Success:

1) *Management unambiguously emphasize the priority of mission success to "working level" personnel.* **Agree. Mission success is the highest priority. As an example, during the OTIS vibration anomaly the project focused on mission success. The investigation took the required time to thoroughly resolve the issue.**
2) *Employees must feel empowered to stop or slow down if the pace or procedures can jeopardize mission success.* **Agree. NGAS (and GSFC) will continue to emphasize the importance of stopping or calling attention to a concern. NGAS also provides special recognition and rewards for individuals who do so.**
3) *NASA assess "top ten" mission success enhancements (see the three charts associated with the recommendation in the report) and implement where appropriate.* **Agree. The "top ten" mission enhancement list described above is being implemented by the project and program office.**

Responsible Design Engineer (RDE) Role:

1) *RDEs be involved and responsible for their element through the successful commissioning of the observatory.* **Agree. This is GSFC standard approach to responsible engineers and NGAS is adopting this and bringing back any key RDEs who have left for other assignments at NGAS.**

I&T Staff Adequacy:

1) *The project should augmentation I&T staff; this critically important to execute the I&T program.* **Agree. NGAS has already started augmenting the I&T staff.**

Employee Morale:

1) *Augment I&T staff to achieve more realistic work schedules.* **Agree. The project and NGAS have already adjusted I&T work activities to a sustainable schedule considering the new launch date.**
2) *Implement strategies for improving team morale, such as periodic science lectures for NGAS personnel and families.* **Agree. The project will bring world-class scientists to facilities where key hardware has been built and tested, including to NGAS.**

Engagement of Science Community:

1) *Assure consistent, sustained and meaningful engagement of the Science Working Group (SWG).* **Agree. Reinstitute weekly teleconferences (started June 18), and three face-to-face meetings per year.**
2) *Appoint an executive committee of NASA-selected members of the SWG to act as conduits to broader community on mission challenges.* **Agree. Plan with the full SWG at their next meeting (July) how to most effectively harness their time and talents to act as conduits to the broader community on mission challenges.**

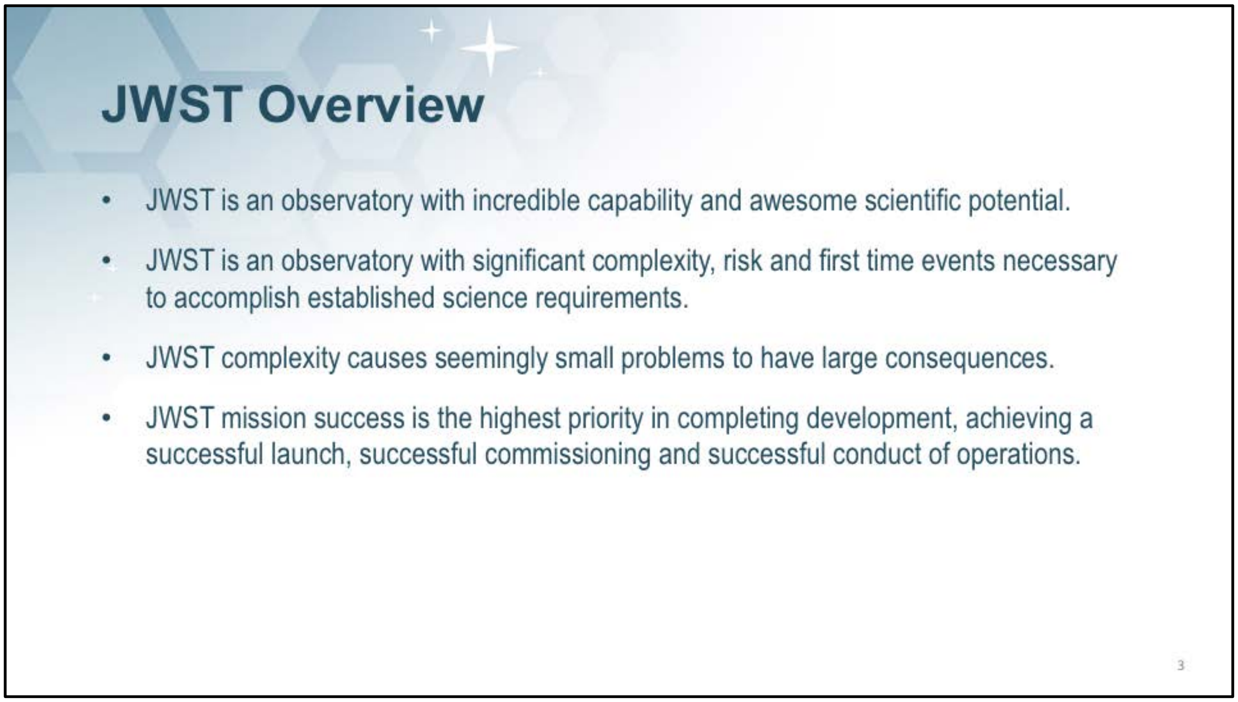
James Webb Space Telescope

Independent Review Board

Report

May 31, 2018

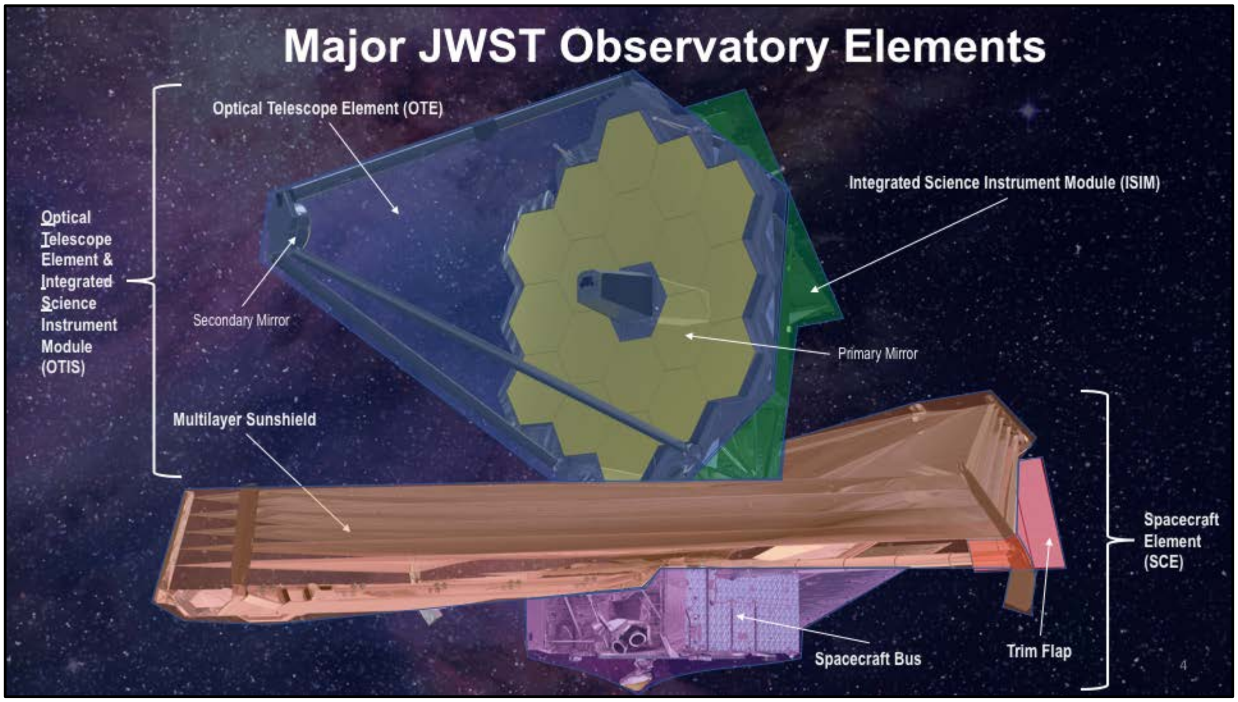
Table of Contents



This is an important chart to give a macro view of JWST. The statement of incredible capability and awesome scientific potential was initially thought to be "over the top." After discussion, the Webb Independent Review Board (IRB) clearly believes that "awesome" is a correct assessment of the JWST scientific potential. To achieve this potential requires an observatory with significant complexity and risk. It is easy to defend that JWST has the highest complexity and risk of any civil space robotic system. Clearly, it is in the top few. The complexity and risk must be considered in all decisions that affect JWST mission success.

The observation that there are no small JWST integration and test problems was not initially recognized by the Webb IRB, and this also may be true of others involved with JWST. It is a most important observation that will be apparent in subsequent Findings and Recommendations. It is caused by the complexity and highly integrated nature of the observatory. Specifically, it implies, as an example, that a very small human error or test anomaly can impact the schedule by months and the cost by tens of millions of dollars.

Each member of the Webb IRB believes that cost and schedule are important elements of a space project and must be responsibly managed. Throughout much of the life of a space project, cost, schedule, technical performance, risk and requirements can be responsibly managed without compromising mission success. All projects reach a point in their development where this trade can no longer be made without adversely impacting mission success. JWST has reached this point and must now be completed within the principle that mission success is the top priority and is more important than cost and schedule.

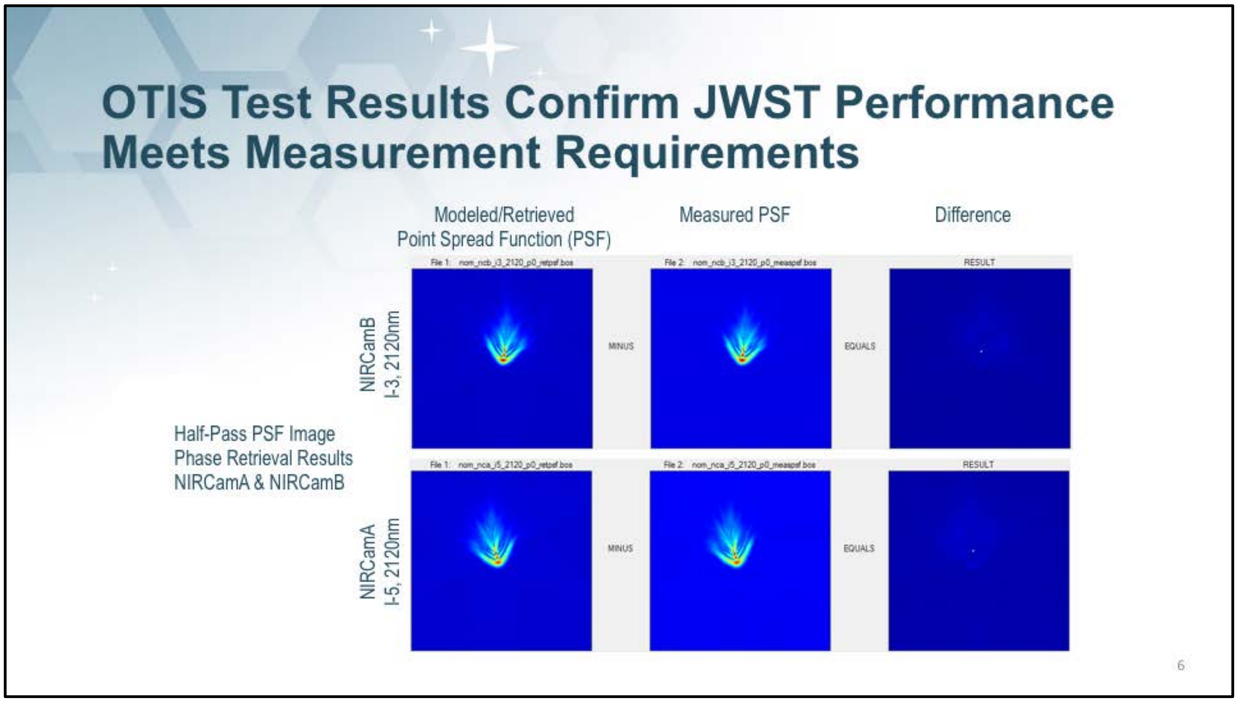


There are two primary elements of the JWST observatory. The first is the combined Optical Telescope Element and Integrated Science Module, or OTIS. The second is the Spacecraft Element (SCE), which is the combined Spacecraft Bus, Trim Flap, and Multilayer Sunshield.

JWST is among the most complicated scientific experiment ever attempted. It is important to recognize that the challenges associated with this complex observatory are being undertaken in order to achieve transformative scientific discoveries, from the earliest state of the universe, to the birth of galaxies, stars & planetary systems, as well as the characterization of habitable environments in the solar neighborhood.

Captions for images that illustrate Webb's diverse science objectives, from left to right:

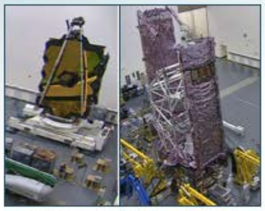
- A schematic that illustrates how Webb will be able to see back in time to when the first bright objects (stars and galaxies) were forming in the early universe.
- New General Catalogue (NGC) 3344 is a glorious spiral galaxy around half the size of the Milky Way, one of many galaxy types whose origins will be studied.
- The Pillars of Creation in the Eagle Nebula captured in infrared light by Hubble. The light from young stars being formed pierce the clouds of dust and gas in the infrared.
- An artist's conception of Pulsar (PSR) B1257+12's system of planets, which does not involve a main sequence star like our own, but rather, a pulsar.



Extensive testing of OTIS and the JWST instrument suite provides high confidence that the mission will achieve all of the highly ambitious science goals.

In particular, end-to-end testing indicates that there are no performance problems.

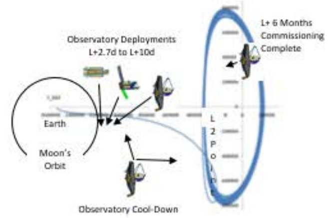
JWST Mission Work to Go



Integration and Test
- Spacecraft Element (SCE) Integration and Test
- Observatory Integration and Test
- Operational Readiness Verification
- Certification of Readiness for Shipment

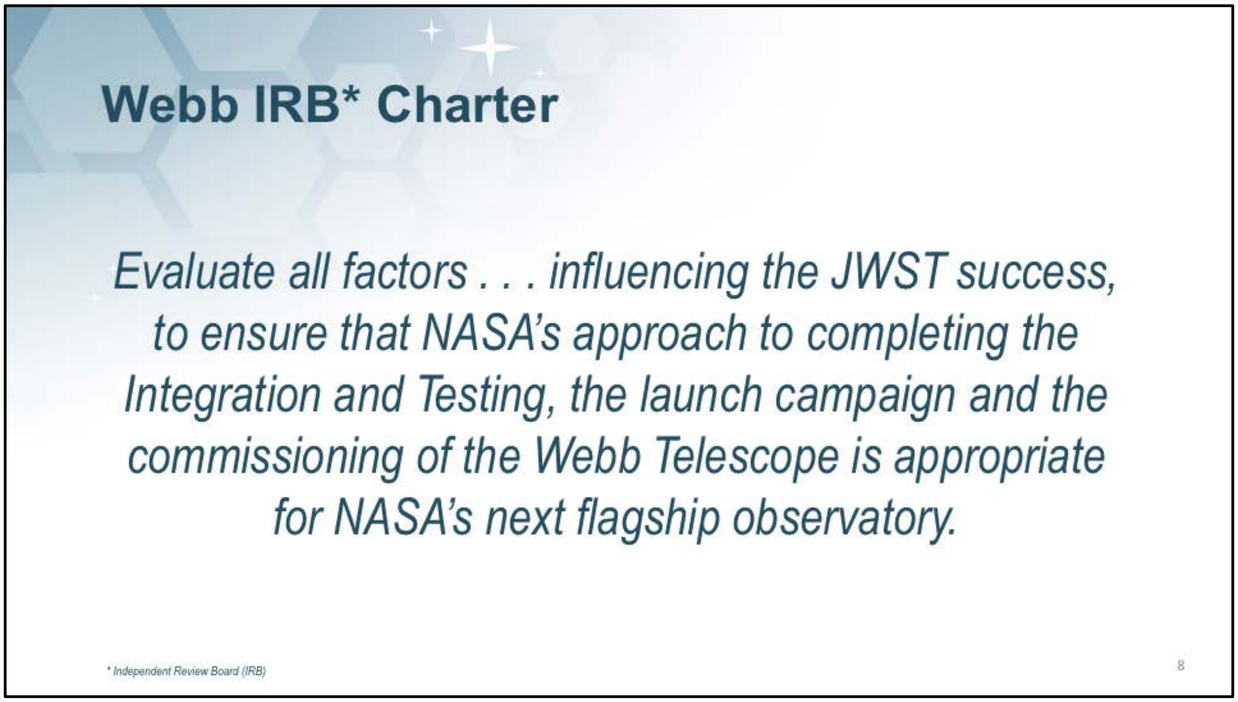
Shipment
- Observatory and equipment ship from Long Beach, CA through the Panama Canal to the Port of Pariacabo in Kourou, French Guiana
- MN Colibri Shipping Vessel operated by Compagnie Maritime Nantaise

Launch Campaign
- European Space Agency (ESA) Space Port in French Guiana
- 62 days at space port where Observatory and Ariane 5 Launch vehicle are prepared and launched

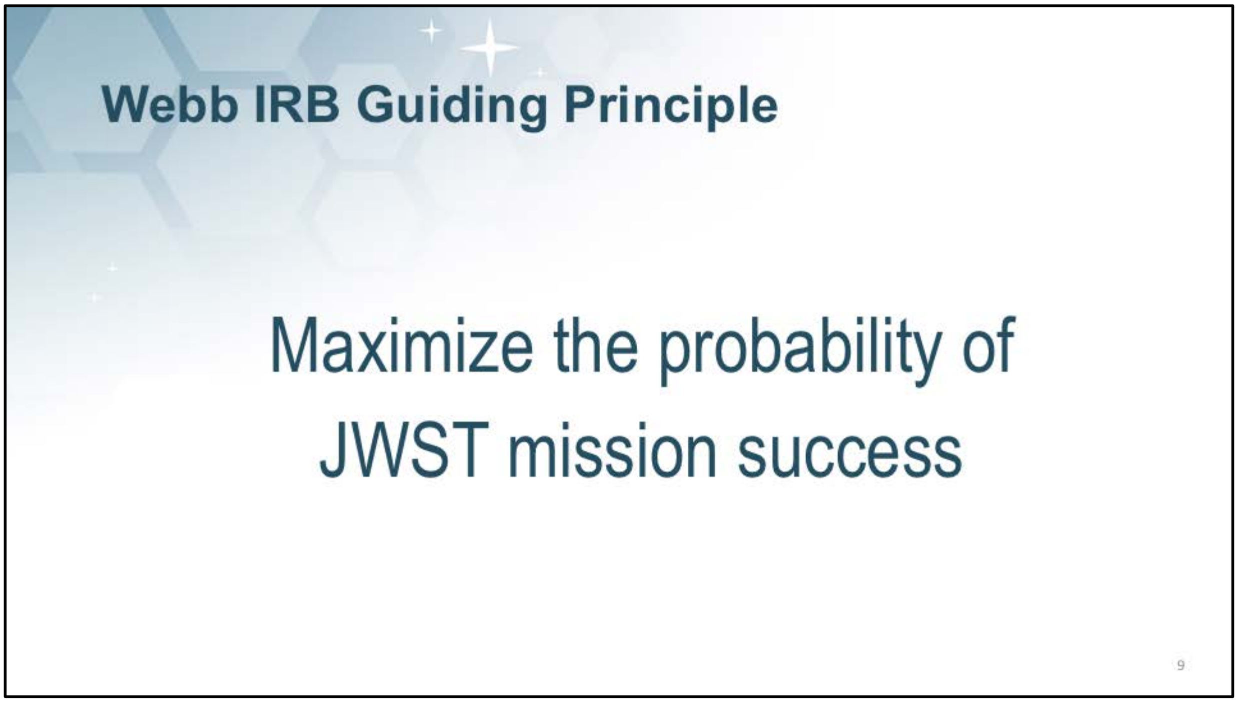


Observatory Commissioning
- 13 days early commissioning for deployment of sunshield and telescope assembly
- 165 days cooldown of telescope and commissioning of instruments

7



The Webb IRB Charter is taken from the Terms of Reference established by NASA. It requires that the Webb IRB evaluate all factors influencing JWST mission success from the beginning of the review in April 2018 through completion of the observatory's commissioning, at launch plus six months.

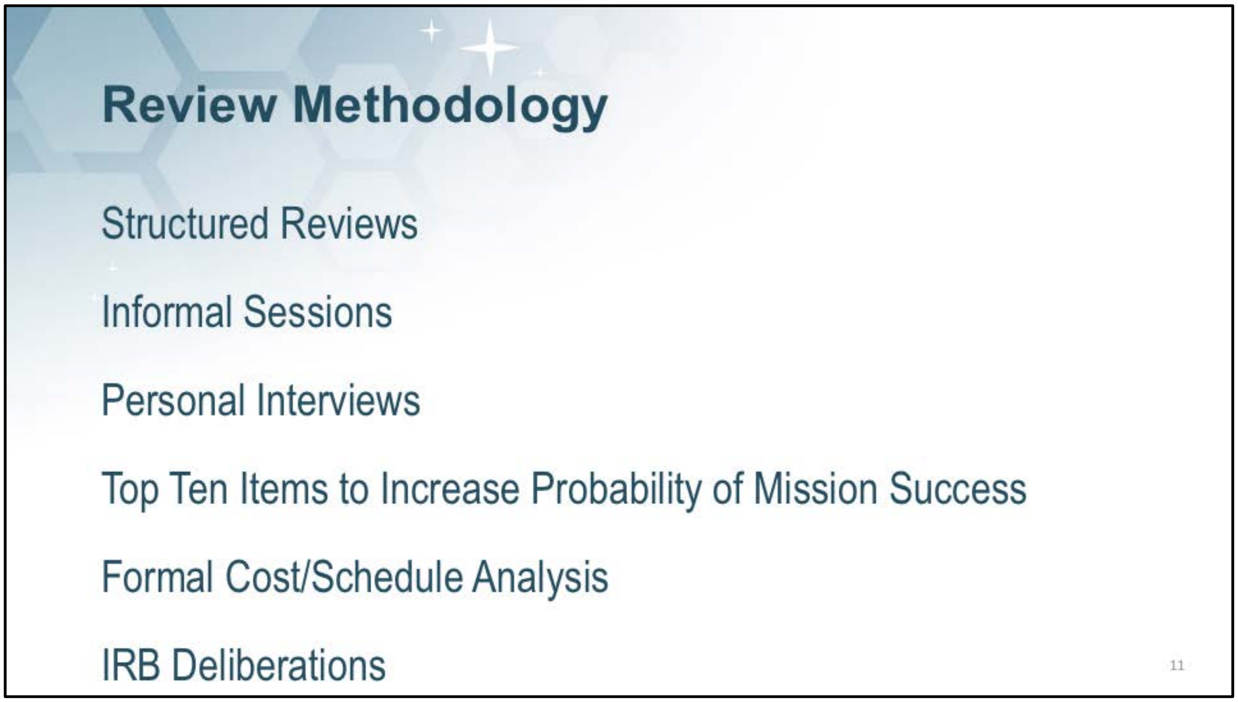


The Webb IRB conducted the independent review consistent with the principal that the resulting Observations, Concerns, Findings and Recommendations had relevancy to maximizing JWST’s probability of success.

The Webb IRB wants to emphasize that the independent review was a mission success review, not a failure review.

Brief biographies for each board member are provided in the Appendix. The contributions of Dan Woods, Review Manager, and John Karcz, Executive Secretary, were extraordinary. This review would not have been possible without the support of these two exceptional individuals.

The support of NASA, Northrop Grumman Aerospace Systems (NGAS) and the Space Telescope Science Institute (STScI)was critical to accomplishing the independent review. JWST implementation was at maximum intensity during the time the review was being conducted. The incredible people at these organizations went the “extra mile” to ensure that the Webb IRB was adequately informed and that all questions and requests for additional information were answered. The Webb IRB is indebted to all who supported our effort so well.



A very deliberate and focused methodology was used by the Webb IRB in the conduct of the review. There were numerous structured reviews characterized by organized presentations and considerable discussion. Informal discussions were important to ensure that Webb IRB members had a good understanding of topics pertinent to mission success. Personal, not-for-attribution interviews were held with several selected individuals. These individual interviews were invaluable to understanding the perspectives of key JWST participants. The interviews were with individuals representing various JWST levels of responsibility.

During the course of the review, it became clear that the set of mission success enhancements that could be identified by ten board members within two months would be limited. NASA Headquarters (HQ), Goddard Space Flight Center (GSFC), NGAS and STScI were requested to develop sets of “Top Ten Items to Increase Probability of Mission Success” if cost and schedule were not constraints. The Webb IRB subsequently decided that the NASA HQ list not be included in this report since NASA HQ is the recipient and implementation authority for the Webb IRB report.

Most-probable cost and schedule estimates are critically important to the mission success of a major space project and were part of the scope of the review.

Deliberations, discussion, debate and arguments within the Webb IRB were extremely important to developing credible Findings and Recommendations. The purpose of the many hours of deliberation was to achieve understanding, not compromise or consensus.

Schedule

DATE	LOCATION	SUBJECT
April 4-6	NASA HQ/GSFC	Brief on JWST Program
April 10-12	NGAS (Redondo Beach, CA)	Brief on JWST Program
April 16	Telecom/Webex	Webb IRB Preliminary Discussion of Cost/Schedule
April 26-27	GSFC	Brief on Launch Vehicle/Sunshade/Top Ten (NGAS/GSFC/SMD)
May 3	STScI	Brief on Ground Segment and Operations
May 8-10	NASA HQ	Webb IRB Cost/Schedule Discussion and Develop Observations, Findings, Concerns, and Recommendations
May 18, 24, 28	Telecom/Webex	Deliberate on Webb IRB Report
May 31	GSFC/NASA HQ	Present Final Report to Project, Center Director, JWST Program Director, SMD Astrophysics Director, SMD Associate Administrator
June 7	NASA HQ	Present Final Report to NASA Administrator and NASA Associate Administrator
Late June	NASA HQ	Publicly release final report and Agency response

12

It was clearly recognized that JWST is in a critical phase in its development and any impact by an independent review board must be timely. This resulted in a two-month review schedule. While the schedule was demanding, the Webb IRB believes it was adequate to accomplish the established charter.

Accomplishments

- The Webb IRB interacted with extraordinary project personnel at NASA Goddard Space Flight Center (GSFC), Northrop Grumman Aerospace Systems (NGAS) and the Space Telescope Science Institute (STScI).
- All science instruments have been delivered and successfully integrated into the Science Instrument Module.
- OTIS has been successfully tested and delivered to NGAS.
- All SCE hardware (spacecraft and sunshield) development is complete.
- Ground segment mature including science and flight operations planning.
- . . . and more.

13

A report on JWST mission success would not be complete without acknowledging the exceptional accomplishments that have been realized.

The skills and experience of the key personnel assigned to work on JWST are commensurate with the importance and complexity of the mission. The project offices at each institution are led by individuals who have demonstrated leadership skills honed by experience with other missions. Each institution matrixes personnel to support the project, in areas such as mechanical and electrical engineering, integration and test and quality assurance. In their interactions with the Webb IRB, the team members demonstrated unwavering commitment to the mission and a depth of understanding of the technical requirements and challenges of JWST.

The collective team has achieved significant milestones in the program. There were important precursor technology developments that led to implementation and integration of some very complex components. While those listed are the top highlights of the JWST program, there are many more achievements that collectively contributed to readiness for integration and test.

Summary and Conclusion

- JWST is an observatory with incredible capability, awesome scientific potential and significant complexity, risk and first-time events.
- OTIS Integration and Test (I&T) is complete and has demonstrated the exceptional science capability of the system.
- Significant launch date delays and resulting cost caused by human errors, embedded problems, excessive optimism in I&T planning, lack of sunshield experience and system complexity have occurred. Small I&T problems can have a major impact upon schedule and cost.
- JWST inherent risk requires mission success be the highest priority in completing JWST development.
- The Webb IRB believes that implementing all recommendations contained in this report will contribute to maximizing the probability of mission success.
- Eliminating the schedule and cost impact of human errors and embedded problems is critical to completing the successful development of JWST.
- The Webb IRB believes that JWST should continue based on its extraordinary scientific potential and critical role in maintaining U.S. leadership in astronomy and astrophysics.

14

This report contains numerous recommendations all directed toward contributing to the maximization of JWST mission success. The Webb IRB strongly recommends that all the recommendations be implemented.

Observations and Concerns

<u>Technical</u>

- JWST "Firsts"
- Deployment risks
    - Observatory deployments
    - Sunshield deployments
- Commissioning complexity demands integrated, focused leadership
- Human mistakes during I&T
- Embedded problems

15

The Webb IRB developed a set of technical, management and cost/schedule Observations and Concerns. The criterion for inclusion was relevance of an item to JWST mission success. This set of Observations and Concerns provided the foundation for Webb IRB Findings & Recommendations. Each item will be individually discussed on subsequent charts.

Observations and Concerns

Technical (cont'd)

- Residual risks
  - Test As You Fly (TAYF) exception closure
  - Single Point Failure (SPF) mitigation (344 SPFs)
  - Failure corrective actions
- Ariane 5 launch vehicle essential to mission success
- Transportation and spacecraft/launch integration preparations
- Mission operations preparation for potential anomaly resolution

Observations and Concerns

Management

- Reporting complexity
- Communication confusion – external of the project
- Understanding responsibility for mission success at all levels
- Responsible Design Engineers (RDE) role
- I&T Staff Adequacy
- Employee morale due to high demands of I&T and schedule delays
- Engagement with Science Working Group (SWG)

Cost/Schedule

- Significant schedule delay and cost growth

17

JWST "Firsts"

- Sunshield has no significant legacy.
- NASA experience with actively controlled segmented mirrors.
- NASA spacecraft launched on Ariane 5.
- NASA spacecraft transported by water from California to Kourou, French Guiana (South America) via the Panama Canal.
- NASA spacecraft processing and launch integration at Kourou, French Guiana.
    - Topex/Poseidon launched from Kourou, French Guiana in 1992 on an Ariane 4.
- Flight operations conducted by STScI.
- Large and complex observatory operations at Lagrange Point 2 (L2).

18

JWST has a large number of "firsts" that require special attention to ensure that the absence of experience does not have a negative impact upon the probability of mission success. It is important to recognize a particular activity is a "first" so it can receive appropriate attention.


Findings and Recommendations
19

Findings and Recommendations (Commissioning Risks)

Findings

- Observatory commissioning will take six months.
- Commissioning risks are dominated by the fact that verification by TAYF cannot be accomplished at the system level.
- Commissioning entails multiple deployments with significant risk due to a large number of SPFs.
- Sunshield deployment is mandatory for JWST success and a demanding part of commissioning.
- Working groups and other functions are appropriately focused upon individual elements of commissioning.

20

Commissioning is the set of activities undertaken after launch to prepare for nominal science operations. It includes the solar array and antenna deployments, sunshield deployment, OTIS deployments, thermal cool-down, telescope focusing and science instrument checkout and operational preparation. The sum of these activities takes about six months.

Commissioning risks are dominated by the fact that verification by test as you fly cannot be accomplished at the system level. This requires that significant mitigation actions must be undertaken to ensure the residual risk of this phase is brought to acceptable levels.

Many of these activities are mission critical, but the highest risk, highest criticality event is sunshield deployment, driven by the complexity of the deployment and the large number of deployment mission critical single point failures.

Sunshield deployment takes place in the first month of commissioning. It has the positive characteristic that it is NOT time critical. The vehicle is stable for long durations both before the sunshield deployment, and between individual activities during the deployment.

The JWST project has concentrated significant efforts and resources on the commissioning phase, with a heavy emphasis on the deployments.

Findings and Recommendations (Commissioning Risks)

Findings (cont'd)

- Commissioning, though significantly longer in duration, has integration and complexity characteristics similar to the Entry, Descent and Landing (EDL) phase of Mars lander missions.
- The Mars Program has found placing EDL under the leadership of a "world class" systems engineer with total responsibility for EDL critical to achieving success.
- Contingency planning is a most important part of commissioning.
- Successful resolution of potential sunshield deployment anomalies may require sunshield hardware elements to replicate the anomaly.

21

Both the JWST Commissioning Phase and Mars landers' Entry, Descent and Landing (EDL) are characterized by (1) being mission critical, (2) being the highest risk operational point in the mission, (3) having a significant number of single point failures, almost all of which are mission single point failures as well, (4) being impossible to test as you fly, and therefore having a significant number of test as you fly exceptions and resulting mitigations, and (5) being highly integrated activities.

Because of these characteristics, the Mars lander missions have placed EDL under the leadership of a single "world class" systems engineer. This individual reports to the Project Manager and has total responsibility for EDL throughout the system design and throughout the life cycle – design, design verification and validation, EDL testing during system integration and test, operational planning, operational testing and rehearsals, and operational execution.

As with all critical flight sequences, contingency planning is an important part of commissioning preparation. That planning must include a comprehensive survey of the possible flight contingencies, how they will be unambiguously recognized utilizing the flight telemetry, what are the possible operational recovery responses, and how will the contingencies, their recognition and recovery be replicated on the ground prior to response execution on the flight vehicle.

Findings and Recommendations (Commissioning Risks)

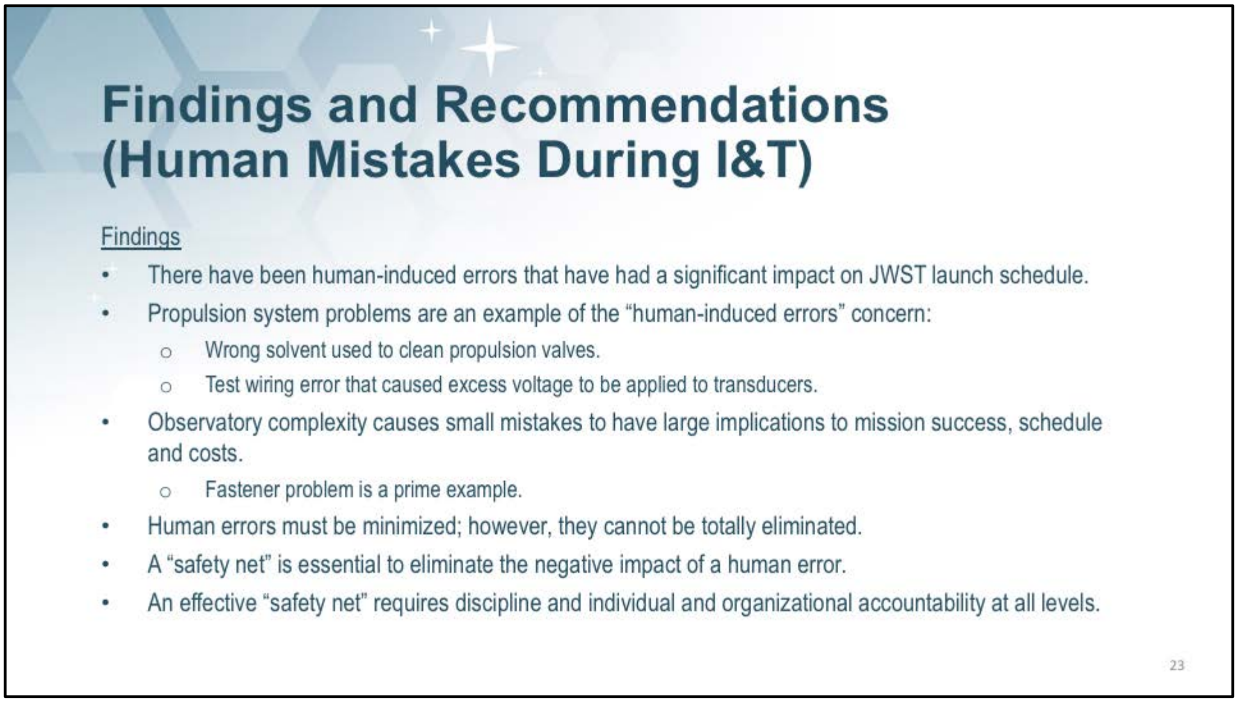
Recommendations

- Establish the position of Commission Manager reporting to the GSFC JWST Project Manager. The Commission Manager position must be filled by “world class” systems engineer with total end-to-end responsibility for commissioning success.
- Determine and implement the required sunshield hardware and simulation elements necessary to support the potential for sunshield anomaly identification and resolution.

22

The Webb IRB recommends that JWST responsibility for commissioning mirror the Mars lander’s approach to EDL, and that a Commissioning Manager be appointed with total end-to-end responsibility for commissioning success. This individual needs to be a “world class” system engineer with experience and technical knowledge of the JWST design and have the necessary leadership credentials. This position needs to report to the project manager.

The JWST project needs to ensure that the required capabilities are in place to replicate contingencies, their recognition and recovery on the ground prior to response execution on the flight vehicle. In particular, because of the complexity and critical nature of the sunshield deployment, the ground hardware and simulation elements for the sunshield should be reviewed by the project to determine whether they are adequate for high confidence flight contingency recognition, recovery and response. Any identified deficiencies in the ground suite of capabilities needs to be rectified and tested for adequacy prior to launch.



Space is a “one strike and you’re out business.” Hundreds of people can perform thousands of tasks correctly, but ultimately a mission failure can result from one person making one mistake that goes undetected. Or, if the mistake is caught in an advanced stage of a system’s development, the result can be large cost and schedule increases. Human-induced errors can result from a flawed process, touch labor not properly interpreting the process or not properly following it, technicians not being trained and certified to execute a process, and functional organizations like Quality Assurance not properly verifying that a process has been implemented correctly.

There have been several JWST Project problems due to human-induced errors that had substantial cost and schedule impact. In one case, an improper solvent was used to clean propulsion system valves that had been stored. The error was a failure to check with the valve vendor to ensure the solvent to be used was recommended and would not damage the valves. The valves had to be removed from the spacecraft, repaired or replaced, and reinstalled.

Another human-induced error was improper test wiring that caused excess voltage to be applied to transducers. The error resulted from an improper interpretation of a process step. The error should have been detected by the inspector, who did not inspect, but relied on the technician’s word that he had done the wiring correctly. Another seemingly small mistake that had a large impact was discovered after the SCE Acoustic Test. To address a risk that fasteners for sunshield membrane covers might snag the membrane, the fastening lock nuts were tightened only to be flush with their bolts. Unfortunately, this compromised the locking mechanism, and after the test, loose hardware was found in the lower area of the spacecraft.

Despite best efforts, humans will, on occasion, make mistakes. Those mistakes must be detected and corrected by an effective safety net. The safety net consists of:

- Processes that produce predictable, repeatable results, that are not subject to interpretation, and that represent the collective learning experience of the organization, including from preventive/corrective action from past failures and anomalies.
- Individuals who are properly trained in the processes, follow them in a disciplined way, and authorized to call a halt if something in the process doesn’t seem right.
- Accountable individuals in functions, like Quality Assurance, who ensure that procedures have been properly followed prior to sign-off.
- Verification and Validation testing to ensure system requirements are met.
- Independent analysis or inspection to supplement testing when necessary.

Findings and Recommendations (Human Mistakes During I&T)

Recommendations

- NGAS functional organizations establish corrective actions in the following areas:
  - Processes – ensure current, accurate, implementable and not subject to interpretation.
  - Training – small errors produce large consequences.
  - Personnel certification – ensure people capable of performing the task at hand.
  - Discipline – ensure individual accountability and follow the process, call a halt if the process appears questionable.
  - Failure-proof “safety net” – testing, independent analysis, inspection.

24

The Webb IRB recommends that NGAS review processes/procedures to be sure they are current, accurate and implementable. The Webb IRB has noted two examples of human induced errors resulting from incomplete procedures (e.g., requiring that the solvent selected for cleaning valves be recommended by the vendor) or processes that could be misinterpreted (e.g., the improper wiring that caused excess voltage to be applied to transducers). Both examples resulted in substantial schedule and cost increases.

The Webb IRB recommends that individuals at the working level be trained to understand that, on JWST, seemingly small errors produce large consequences.

The Webb IRB recommends that individuals scheduled to perform tasks on the observatory be properly trained, capable, and certified to perform those tasks and properly supervised. Those not properly certified must not be allowed to perform tasks that could result in damage to the system. This is an especially critical discipline to maintain, particularly on second or third shift activities and when schedule pressure exists (which will likely always be the case on JWST Integration & Test (I&T) and when supervision may be thin.

The Webb IRB has noted lapses in individual accountability that have substantially increased schedule and cost and, potentially, increased risk. The Webb IRB recommends that discipline be continually instilled in the workforce such that people feel accountable and own what NGAS is relying on them to do. A signature sign-off must mean something. With this ownership mindset, people must believe they are empowered to call a halt to the execution of a process if it doesn’t look right or they don’t completely understand what they are being called upon to do.

The Webb IRB recommends that NGAS management maintain a failure-proof safety net to ensure mission success. This safety net encompasses testing, independent analysis, and inspection to ensure that the system design meets all of its requirements and any workmanship errors are detected and corrected.

Findings and Recommendations (Embedded Problems)

<u>Findings</u>

- Embedded problems pose a significant risk to JWST schedule, cost and mission success.
  - Propulsion valve problem not detected until assembly on spacecraft.
  - Fastener issue not detected until acoustic test.

<u>Recommendation</u>

- GSFC and NGAS conduct an audit including forensic engineering, hardware pedigree assessment, drawing checks, etc. to identify potential embedded problems.

25

Embedded problems, that is problems that are in the as-built observatory that have not been detected through analysis, inspection or test activities, pose a significant mission success risk to JWST (if undiscovered before launch) or a significant cost and schedule risk (if discovered during the "to-go" work between now and launch).

The propulsion valve issue mentioned before and most recently the sunshield fasteners that came loose during acoustic testing of the Spacecraft Element are two examples of problems that were discovered later in the development phase than they should have been, with subsequent large impacts on cost and schedule for the remedial actions required. These experiences raise the possibility of other such issues remaining in the design at this stage.

To attack this, the Webb IRB recommends GSFC and NGAS conduct an audit to identify potential embedded problems still remaining in the observatory.

Findings and Recommendations (Residual Risks)

Findings

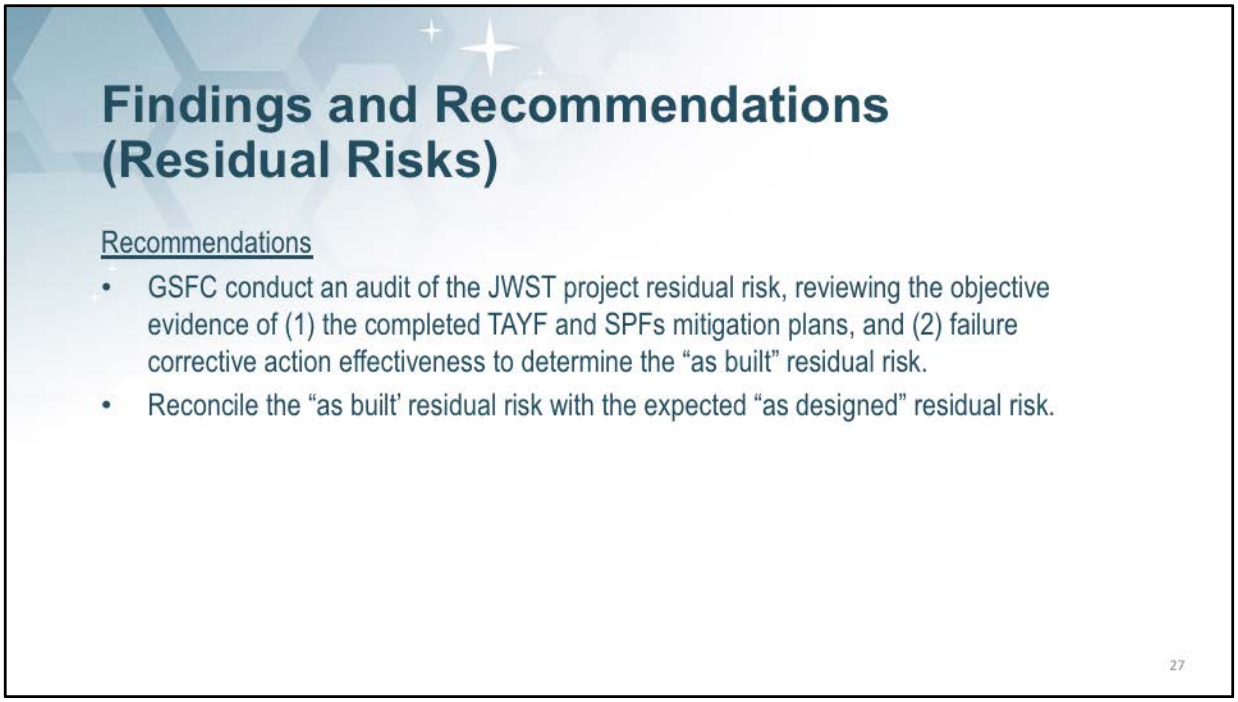
- Maintaining insight into residual risk is particularly difficult with a large, complex mission with long duration development like JWST.
- GSFC, NGAS and JWST Project have a mature process for identifying, processing and adjudicating TAYF waivers, SPF waivers and processing and adjudicating test failures, constituting the “as designed” residual risks.
- GSFC, NGAS and JWST also have mature processes for monitoring these risks over time in order to determine, at the end of the development, the “as built” residual risks arising from these same items.

26

All space missions have residual risks. They come primarily from (1) inability to Test As You Fly (TAYF) the vehicle because of the fundamental lack of facilities, or the inability to match the actual environment the vehicle will be in; (2) the existence of Single Point Failures (SPFs); (3) test anomalies with uncertain effectiveness in the corrective actions; or (4) unverified failures–anomalies where the root cause of the failure cannot be determined.

Maintaining insight into residual risks is more difficult with a large, complex mission such as JWST. These missions are usually expensive, highly visible to the public and political leadership, and very important to the agency. This difficulty is exacerbated by the long duration of the development, where personnel turnover and the cadence of issues/problems being worked makes it more difficult to maintain visibility.

The JWST project through both GSFC and NGAS have a mature and integrated process for processing and handling "as designed" residual risks, particularly in the design process and the test phase, and have mature processes for monitoring these risks over time in order to determine, at the end of the development, the “as built” residual risks arising from these same items.



Although the GSFC processes are mature, because of the JWST project's duration, complexity, cost and visibility, GSFC should undertake an audit of the JWST project residual risk, reviewing the objective evidence of (1) the completed TAYF and SPFs mitigation plans, and (2) failure corrective action effectiveness to determine the "as built" residual risk. Once done, they should then reconcile the "as built' residual risk with the expected "as designed" residual risks such that the residual risk posture clearly identifies 1) TAYF and SPF mitigation actions that were not successfully completed or completed with liens, 2) test failures that occurred where the corrective action is incomplete or uncertain, 3) unverified failure occurrences, and 4) unexpected vehicle behavior during test that is accepted "use as is."

Findings and Recommendations (Mission Success Dependence on Launch Vehicle)

Findings

- Ariane 5 is a "world class" launch vehicle with excellent management.
- JWST Project Office has good working relationship with ESA.
- The JWST Ariane 5 launch vehicle will be among the last Ariane 5 launches.
- Ariane 6 is planned to be operational at the time of the JWST launch.
- NASA Launch Services Program (LSP) Office has a rigorous mission assurance process to support flight readiness certification for NASA missions.
- For JWST launch vehicle, LSP is in an advisory role.
- Aerospace Corporation has a rigorous mission assurance process to support flight readiness certification for national security missions.

28

The Ariane program is run by the European Space Agency (ESA) in partnership with the French Space Centre National D'Etudes Spatiales (CNES). The program provides access to Space with the Ariane launchers from the European spaceport in Kourou, French Guiana. Arianespace, a commercial subsidiary of CNES, handles the production, operations and marketing for the Ariane launch vehicles.

NASA has manifested instrument payloads on ESA-developed and Ariane-launched spacecraft over the years. However, the only NASA developed spacecraft where NASA played a major role was the Earth Science Topex/Poseidon mission, a NASA/ESA collaboration successfully launched in 1992 on an Ariane 4. One of the communication satellites on board the January 25, 2018 launch included a NASA instrument called Global-Scale Observations of the Limb and Disk (GOLD) as a hosted payload. The launch resulted in an anomaly being investigated by ESA.

For NASA launches, the Launch Services Program (LSP) approves mission unique requirements, implementation, and launch, and has insight into almost all aspects of the launch vehicle and provider on NASA's behalf. For these launches, LSP a) conducts mission analysis and planning to meet spacecraft customer requirements, b) has ownership of mission requirements on the vehicle, c) provides approval of spacecraft integration, d) has insight into the launch vehicle resulting in NASA independent recommendations and launch readiness verification, e) independently evaluates fleet technical standards for adequacy and compliance to contract, f) applies consistent mission success processes across all families of launch systems, and g) has go/no-go authority for Flight Readiness Certification and during the launch countdown. Significant results of the LSP certification and technical oversight efforts are reported to the Flight Planning Board (as required) and in the Launch Readiness Review Process. These functions (or their equivalent) are fulfilled for JWST by ESA/CNES Arianespace, with limited visibility by LSP.

The Webb IRB is concerned with the limited visibility into Ariane processes and the analysis of data and information encompassed by the LSP responsibilities for NASA missions. The LSP processes are designed to catch the kinds of issues that led to the recent Ariane anomaly and that escaped their mission assurance processes. Another Webb IRB concern is that the transition from Ariane 5 to Ariane 6 is scheduled to take place during the timeframe of the JWST planned launch dates. The viability of inventory and competition for resources could be a risk to JWST.

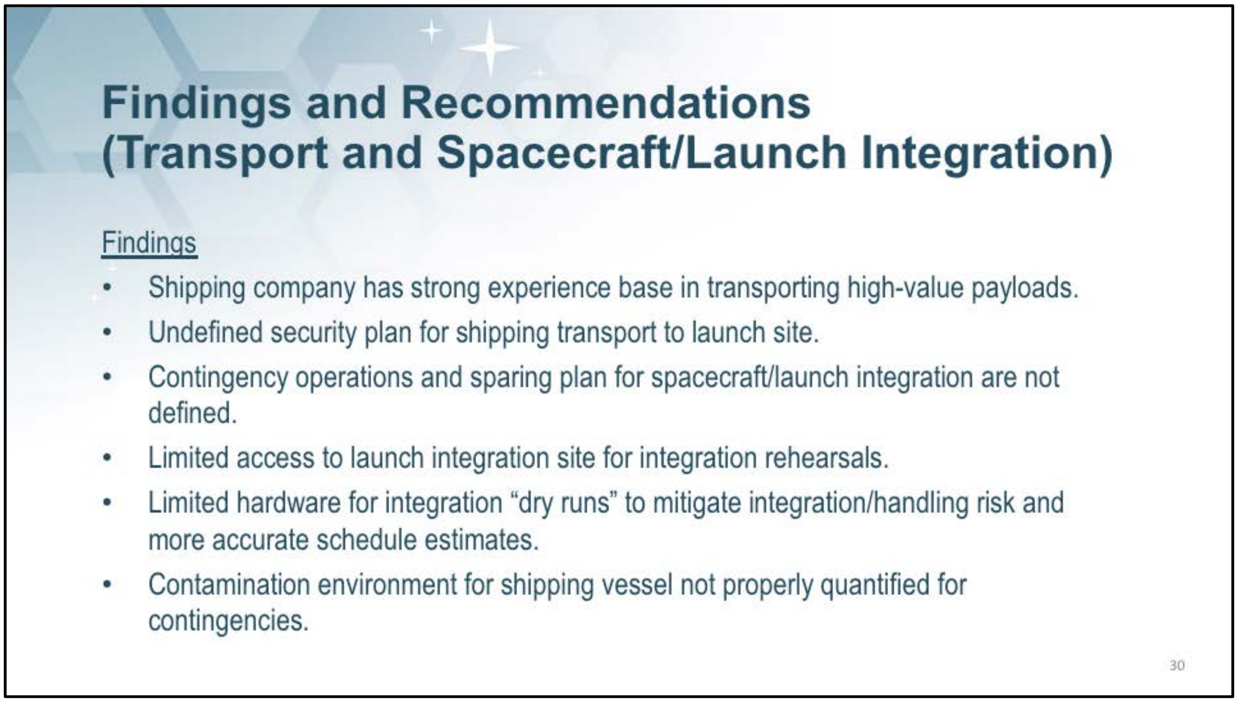
Findings and Recommendations (Mission Success Dependence on Launch Vehicle)

Recommendation

- LSP shall be accountable for JWST launch success at the same level of responsibility they have for U.S. launches, or NASA should contract with Aerospace Corporation for similar accountability.

29

The documented role for LSP in JWST is “Advisory.” In practice, LSP seems to have access and visibility into the processes, procedures, the resolution of technical issues and anomalies, and has been allowed to participate in some independent review discussions. NASA-ESA agreements for JWST define the meetings that NASA can participate in, and specifically where NASA is a formal board member with NASA authority during polls at the Flight Readiness Review (FRR) and Launch Readiness Review (LRR) (or their equivalents). The “Advisory” role, however, does not allow the depth of understanding, insight, and independent checks and balances to ensure the highest practicable probability of launch success through focused approvals and widespread technical insight, formal multi-discipline engineering evaluations and recommendations, and authority during formal polls leading to certification for launch—the role and mission of LSP for NASA missions.



The shipment of the JWST observatory and related assets are the responsibility of NASA, who will benefit from Arianespace's extensive experience in the support and/or shipment of assets from various parts of the world either by sea or air. Arianespace's experience includes rocket subsystems, ground spacecraft systems, support equipment, fuel, etc. The record of success in accomplishing these aspects of the missions is noteworthy, as is the customer orientation of the personnel entrusted with interfacing with the customers. Planning for the JWST mission is far along, with well-established relationships (NASA, ESA, NGAS, Arianespace, CNES) between the parties. Interactions also occur regularly, including site visits and Technical Interface Meetings (TIMs) at Arianespace, CNES, and the European spaceport.

The route for the shipment of the observatory from the Port of Los Angeles in Long Beach, CA through the Panama Canal and to the Port of Pariacabo in Kourou, French Guiana is well planned and will be executed via a NASA contract with the Compagnie Maritime Nantaise, the company that operates the ships. Shipment of the integrated observatory by air was not possible, although some ground support (e.g. fuel service carts and fuel) will be shipped by air. The Webb IRB found that the efforts to understand and plan the route and risks were excellent. The Project conducted early characterization of the structural loads environments by instrumenting a loaded vessel with multiple accelerometers and correlating the loads environment with sea states throughout the voyage.

The area of greatest discussion and concern was the security of the route, the organizations that the Project plans to use to conduct the assessments [e.g. Department of Defense (DoD) and/or Department of Transportation (DoT)] and whether another party within NASA should conduct an independent assessment. In addition, the decision authority within NASA for approval of the route, the approach, and the level of public exposure of the asset was not clear.

The launch site processing activities were found to be well planned, although questions remain as to the adequacy of schedule margins and the planning for contingency operations in a facility more accustomed to the processing of commercial payloads.

Of a lesser concern was that the Project did not characterize the contamination environment, primarily because of the self-protection provided by the observatory shipping container.

Findings and Recommendations (Transport and Spacecraft/Launch Integration)

Recommendations

- NASA define security requirements and plan for JWST transport to launch site.
- Develop contingency operations and sparing plan for spacecraft/launch site operations.
- Develop "pathfinder" JWST simulator and contamination protection systems for integration "dry runs."
- Assess shipping vessel contamination environment and develop contingency plans for off-nominal shipping operations.

31

JWST is an extremely high value asset. NASA should consider conducting an independent assessment of the shipping route and the level of security required, and whether the activity is announced as part of the Education and Public Outreach initiatives for JWST. The plan and approach should be approved by the Science Mission Directorate (SMD) Associate Administrator (AA) and the NASA AA.

The European Space Port facilities and personnel have been demonstrated through numerous successful launch operations and launches. Although they are experienced with the processing and launch of scientific observatories, the predominance of their experience is with commercial assets. The JWST observatory is a large observatory with stringent handling and contamination control requirements. It would be prudent for NASA to rehearse the complete end-to-end flow and operations, including contingencies in the event that the observatory should have to go back in the flow and/or be accessed for anomaly resolution or repairs that can be accomplished at the launch site. The effectiveness of repairs will require detailed knowledge of inventory hardware, some of which should be included as part of the shipment of equipment.

The JWST Project has done an excellent job at characterizing conservatively the structural mechanical signature of the shipping vessel at sea. The Project has also taken great care in the design and procedures related for the safe shipment of the observatory in its shipping container during all phases. It would be of benefit to also characterize the shipping vessel environment for contamination and contamination sources to properly prepare for and respond to anomalous conditions encountered during the process.

Findings and Recommendations (Mission Operations)

Findings

- First time STScI will be performing flight operations.
- There is no high fidelity test bed that represents the entire observatory during operations, in particular to deal with commissioning and anomaly training, identification and resolution.
- Competition exists for human resources predominately NGAS RDEs to support I&T, launch operations and operational readiness exercises and rehearsals.

32

While STScI is experienced in operations for science campaigns (e.g., for the Hubble Space Telescope) this is the first time they are responsible for fielding a Flight Operations Team (FOT) which will ultimately be responsible for daily operations of a spacecraft. This requires that they develop the unique skills required of operations personnel for JWST, practiced during operational readiness exercises, rehearsals, and other opportunities. It also requires that they create a culture that supports the daily cadence of spacecraft operations.

The ability to simulate observatory functions is essential to understanding interactions among components, anomaly investigation, and training of operations personnel. While the JWST project has various simulators and testbeds that help with observatory testing and training, there is no testbed that encompasses the total observatory flight system. This is particularly true of components relating to the sunshield. Additionally, the simulators that represent the flight components/subsystems are not always high fidelity. The lack of fidelity inhibits understanding and can prevent the team from stressing the system and simulating possible anomalies that could occur.

The I&T, launch operations, operational readiness exercises and mission rehearsals often rely on the same set of engineers or engineering skills. As these can happen in parallel, there is pressure on individuals as well as on the institution to provide the appropriate expertise.

Findings and Recommendations (Mission Operations)

Recommendations

- Critically important that GSFC JWST Project Office maintain responsibility and provide adequate support to ensure STScI mission operations readiness.
- Review all simulators/testbeds and required usage against pre-launch tests and rehearsals, post-launch deployment anomaly resolution, fault isolation and correction.
- GSFC JWST Project Office develop a staffing plan that meets the needs of I&T and operational readiness.
- Develop and approve a transition plan that defines the level of mission operations responsibility for STScI as a function of time with independent gate reviews at transition points.

33

STScI is developing a cadre of trained professionals to operate JWST. It is incumbent on GSFC, which has overall mission operations responsibility and a long history of mission operations, to ensure that STScI is prepared for its role in all phases of the mission. During commissioning, the ops team will consist of GSFC engineers and scientists, NGAS, Ball Aerospace Technology Corporation, the Jet Propulsion Laboratory (JPL) and instrument engineers, and the STScI FOT. After commissioning, while the FOT will play the prominent role, there will undoubtedly be need for them to call on other expertise to confirm their analyses of observatory performance or when anomalies arise.

The partners in the project have all identified the desire for improved simulation capability. Improvements should be implemented wherever possible.

The GSFC Project Office, in conjunction with NGAS, should review activities required pre-launch, for both the number of people required to accomplish them, and the relative timing of the activities. Where conflicts occur, the timing should be adjusted and/or personnel should be added to support the activities effectively.

Some planning on transitioning post-commissioning operations responsibility to STScI has already occurred, and it will continue. The Webb IRB recommends that the transition be documented in a formal plan that is independently reviewed. At minimum, the plan would cover governance, roles, responsibilities and criteria for transition. It is possible that there will be more than one transition gate—or point of handing over responsibility to the FOT—that will occur. The readiness at each gate should also be independently reviewed.

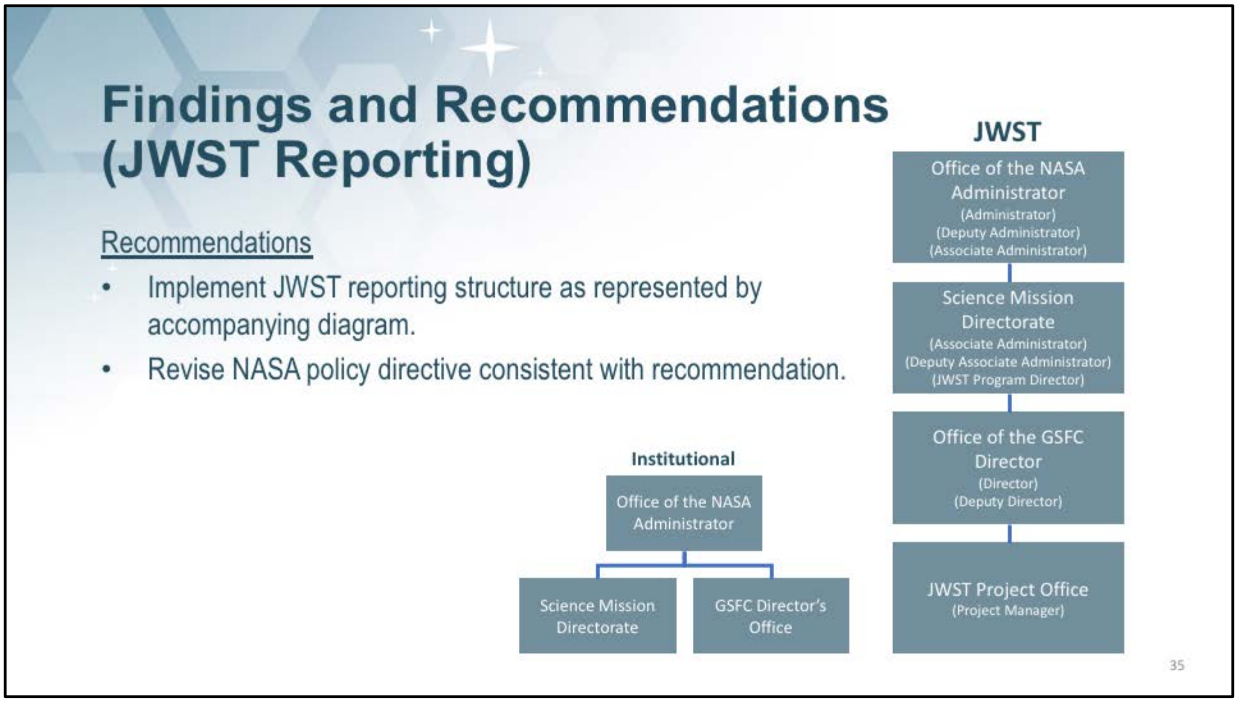
Findings and Recommendations (JWST Reporting)

Finding

- Current NASA reporting structure is complex, confusing and ineffective.

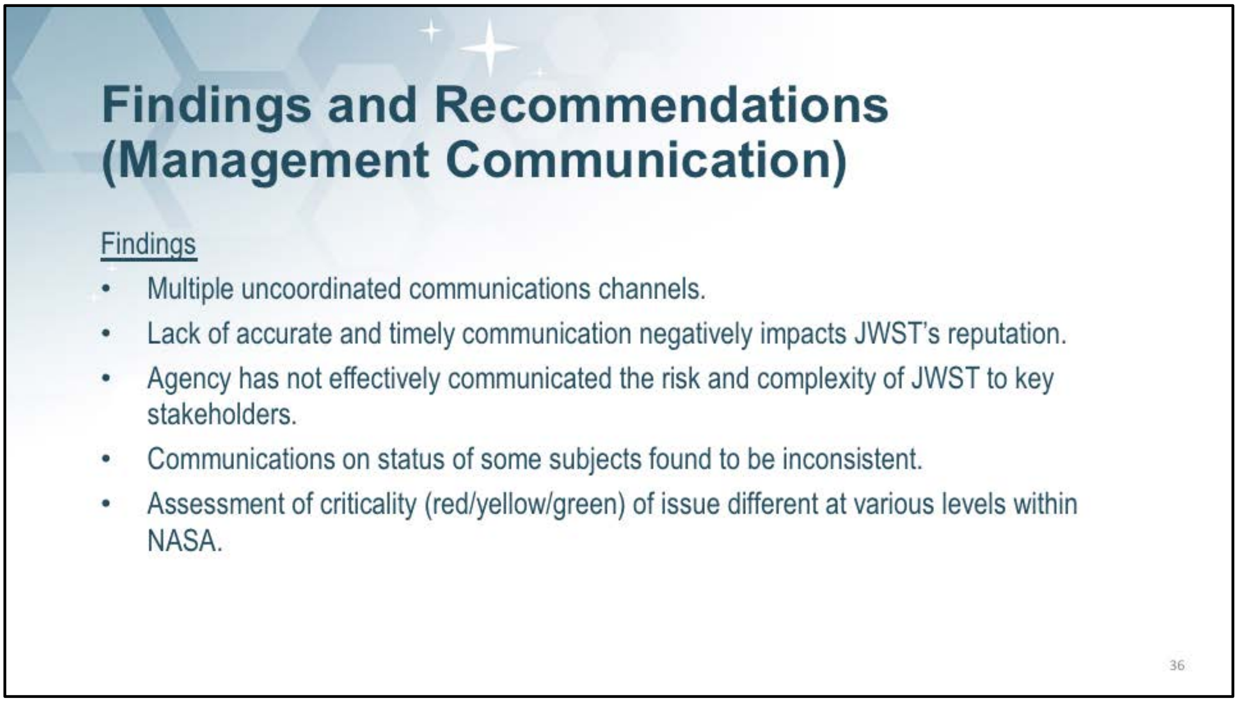
34

The Webb IRB found the current management concept and reporting structure to be complex, confusing, and inefficient. As examples, some described the Goddard Center Director as responsible for JWST mission success, and others indicated the position was only responsible for providing staffing and facilities. Some cited the JWST Program Director as reporting to the NASA AA and others said the position reports to the SMD AA. In summary, the Webb IRB found that considerable time and effort was being spent trying to understand the JWST management and reporting.



Instead of trying to understand prior history, the Webb IRB chose to define the management and reporting believed to be necessary to maximize the probability of success. Specifically, the JWST program in total is the responsibility of the SMD AA, who reports to the NASA Administrator/Deputy Administrator/AA. The JWST Program Director supports the SMD AA in implementing the JWST Program. The Goddard Center Director is responsible for all aspects of the JWST Project, reporting to the SMD AA. Responsible for Project implementation is the JWST Project Manager, reporting to the Goddard Center Director. To further clarify the Webb IRB recommendation, it is anticipated that a considerable fraction of the SMD AA's time (approximately 25 percent) and the Goddard Center Director's time (approximately 50 percent) will be devoted to JWST. This is thought to be consistent with the JWST complexity, risk and national importance.

The Webb IRB recognizes that for institutional management, the SMD AA and Goddard Center Director report to the NASA Administrator.



Communication with key stakeholders, including the science community, Congress and NASA leadership, has been variable, and at times, inconsistent. For example, members of the Science Working Group and other key stakeholders communicated that they were caught completely by surprise by the recent announcement of significant launch delays. Moreover, the Webb IRB found that there were differing perceptions of project status (i.e. progress or lack thereof against plans and other commitments, issues, risks, and corrective actions) in various parts of GSFC, HQ and NGAS.

Project reports at the GSFC monthly reviews and reports at the SMD Flight Monthly Reviews were found to be consistent in presenting technical and programmatic status and risks, albeit with some minor changes in the explanations or rationale. The bigger discrepancies were found in the summaries provided at SMD Quarterly Reviews and above, where the summaries could be interpreted as de-emphasizing the severity of the technical and programmatic status, issues, and risks. The Webb IRB also found the “scoring” of concerns to be confusing or inconsistent. For example, a “Yellow” used in some cases was considered a “Minor Issue,” where the NASA review practice is for yellow to indicate “Status is Cautionary,” signaling that there are known findings which may compromise project success, while communicating that mitigation approaches have been identified and clearly communicated to address those findings. In these cases, the project manager is vested with the full authority and/or resources required to implement the mitigations. A “Red” score is considered to represent that the “Status is Unsatisfactory,” where there are known issues which will likely preclude project success, but either mitigation approaches have not been identified or the project manager is not vested with the authority and/or resources required to implement the mitigations. GSFC and/or NASA HQ may have potential solutions or resources to deal with “Cautionary” or “Unsatisfactory” conditions, but the descriptions up and down the reporting chain should be accurate and consistent.

JWST is the most complex space system that NASA SMD has ever built. The mission risks inherent in the complexity of JWST cannot be underestimated and should be communicated clearly within NASA and to other stakeholders. Small problems can represent significant delays and cost for JWST; understanding the complexities of the observatory system helps provide the proper context and perspective.

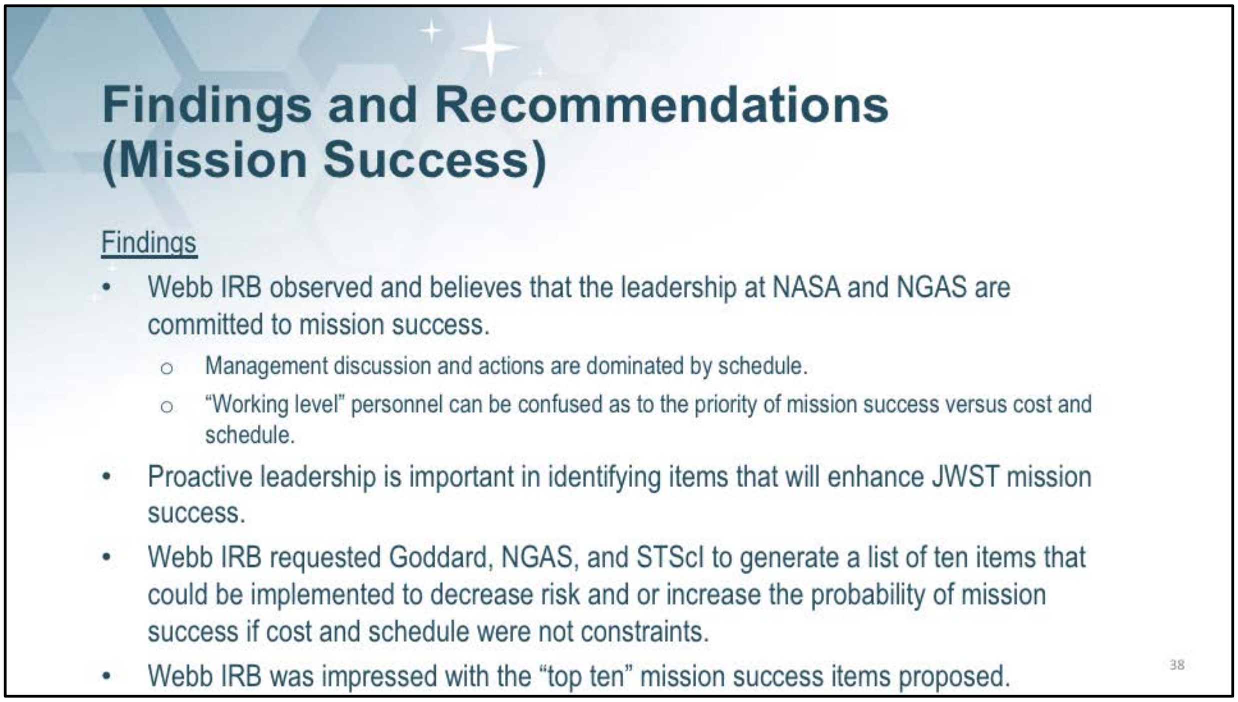
Findings and Recommendations (Management Communication)

<u>Recommendations</u>

- GSFC and NGAS Project Offices established as consistent and factual source of all JWST mission status.
- Communications of status and details appropriate for stakeholders needs to be presented clearly and frequently.
- NASA HQ should be responsible for developing a “communication plan” (messaging strategy) for JWST.
- Communicating complexity, risk and science return for JWST is critically important.
- Same criticality and assessment charts used for all JWST reporting.

37

Moving forward, it is essential that the GSFC and NGAS Project Offices establish a coherent, agreed-upon and factual narrative on status and communicate it regularly across to all relevant stakeholders. JWST reporting should be based on a common set of assessment criteria and charts. NASA HQ, using the Project Office input, should be responsible for JWST’s status reporting to the NASA AA and other stakeholders and for an effective communication plan.



The Webb IRB guiding principal, as stated earlier, is to "maximize the probability of mission success." This principal was adopted by the Webb IRB because of the Nation's substantial investment in JWST to date, the observatory system's complexity, its resultant risk, and the anticipated unprecedented science return once the system is successfully deployed and made operational.

The visibility of JWST and considerable public interest concerning the project's cost and schedule make it critically important for people at all levels working on JWST to understand that mission success is the most important objective. In particular, people at the working level, as they make decisions and work on the system, must not assume increased mission risk by prioritizing schedule and cost objectives above mission success. Any action that could increase mission success risk must therefore be raised to a management level that has the resources to mitigate that risk. This approach will ensure that risk choices made at the working level do not become a "relief valve" for schedule and cost challenges such that the Project Manager loses control of the risk baseline.

From the discussions the Webb IRB has had with NASA HQ, GSFC and NGAS leadership, the Webb IRB believes that leadership in all organizations understand the project's risk posture and have placed the proper level of importance on mission success through careful risk analysis and the associated implementation of risk mitigations. Proactive leadership at all levels is especially important in identifying items that will enhance the probability of JWST mission success. Recognizing this, the Webb IRB invited GSFC, NGAS, and STScI to each generate a list of items that could, if implemented, decrease risk and increase the probability of mission success if not constrained by cost and schedule. All three organizations identified impressive lists of top ten mission success items that are currently being assessed for implementation.

Findings and Recommendations (Mission Success)

Recommendations

- Management unambiguously emphasize the priority of mission success to “working level” personnel.
- Employees must feel empowered to stop or slow down if the pace or procedures can jeopardize mission success.
- NASA assess “top ten” mission success enhancements (see following three charts) and implement where appropriate.

39

It is imperative that management continue to emphasize the priority of mission success over cost, schedule or other factors when communicating with working level personnel. Employees must understand the importance of their actions and personally own each activity performed. As part of this process they should also know that they are empowered to call a halt when they feel there is a risk being taken that could jeopardize mission success.

One critical outcome from the Webb IRB efforts to date has been the identification of the mission success enhancements listed on the next three charts. The Webb IRB recommends that NASA assess these enhancements and implement them where appropriate.

Top Ten Items in Order of Priority to Enhance Mission Success (GSFC)

1. Responsible design engineering sustainable work week
2. Additional spacecraft-OTIS integration risk mitigation
3. Sunshield venting model validation testing
4. Additional fault management peer reviews
5. Augment vigilance for single point failures
6. Additional Non-Explosive Actuator (NEA) characterization and support
7. Visualization tools for operations
8. Dynamic flight simulator for deployments
9. Improved Engineering Model Test Bed (EMTB)/Observatory Test Bed (OTB) simulators
10. Augmented sunshield mechanical simulators

Top Ten Items in Order of Priority to Enhance Mission Success (NGAS)

1. Employee financial incentive for skill retention
2. Increase bench for RDEs and key engineers
3. Move from 6-day workweek to 5-day workweek
4. Commissioning risk mitigation
5. Execute final JWST post observatory environmental test from Mission Operations Center
6. Incorporate/Repair all known issues/concerns/DRs prior to observatory environments
7. Additional EMTB testing
8. Review sunshield deployment from start to finish
9. Upgrade Integration Validation Article (IVA) test articles
10. Deployment test risk mitigation

Top Seven Items in Order of Priority to Enhance Mission Success (STScI)

1. Augment testing for risk reduction
2. Improve fidelity of simulators
3. Improve the STScI power system
4. Improve communications with NGAS
5. Archive instrument design information for future use
6. Extend scientific capabilities of data management and archive
7. Preparatory funding for Early Release Science programs.

42

Findings and Recommendations (Responsible Design Engineer Role)

Findings

- In practice, RDEs have not been required to maintain consistent involvement with their element through all phases of the project.
- RDEs have a unique critical understanding and concern for the elements for which they are responsible.
- RDE involvement in I&T, launch operations and commissioning is a major contribution to mission success.

Recommendation

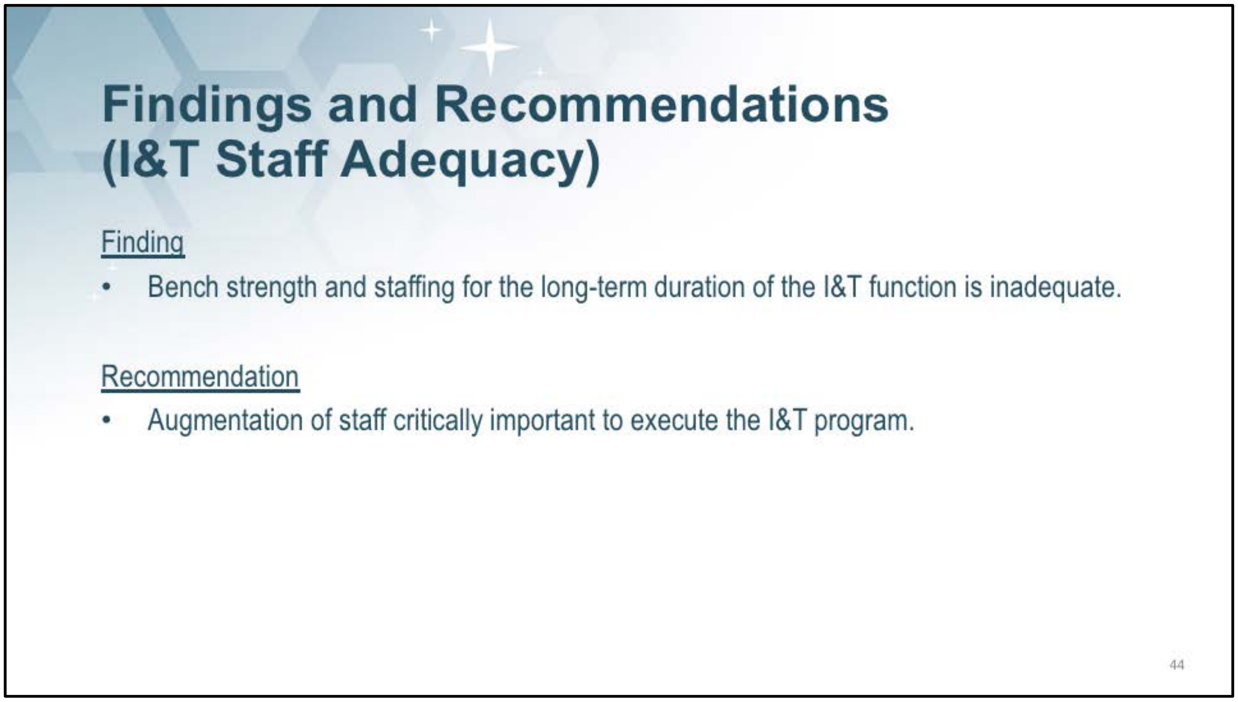
- RDEs be involved and responsible for their element through the successful commissioning of the observatory.

43

The role of the cognizant engineer is a key element in the safety net designed to enhance mission success. A properly trained and experienced engineer is assigned for each component or piece of software in a system, and that person should be responsible for ensuring the integrity of that item through design, fabrication, test, and operation. At NGAS, cognizant engineers are called “Responsible Design Engineers” (RDEs).

Items are often handed off from one process to another through the design, fabrication, and test phase of a development program. The Webb IRB recommends that the RDE “own” the item and ensure that none of these steps endanger the item or adversely affect its performance. The RDE must be available to respond to any issues associated with the item. This includes disposition of any non-conformances, test issues, anomaly resolution, and root cause and corrective action efforts. Prior to any test, an RDE should review the test procedures and ensure those conducting the test are properly certified to do so.

RDEs must be carefully selected, trained, and chartered in a way that clearly defines their responsibilities. In the past at NGAS, RDE responsibility ended with the completion of design and test. It is critical that RDE responsibility for maintaining the integrity of an item continue through successful integration and test and the commissioning of the observatory.



From discussions with the GSFC project, GSFC Quality Assurance personnel, and various people from NGAS, the Webb IRB concluded that the bench strength and staffing for the long-term duration of the I&T function are inadequate. The project needs to ensure that the right personnel and appropriate level of effort are maintained throughout SCE and Observatory I&T.

NGAS has taken steps to improve its JWST I&T work schedule to lessen the impact on its personnel, including allowing some shifts to be staffed by “volunteers.” NGAS also recently put in place additional floor-level management with the appropriate expertise and authority to make real-time decisions, a move that helped to streamline the overall I&T flow. Even so, it appeared that there were insufficient personnel with the necessary expertise to fully staff the second shift. The third shift was even leaner, and focused on “special” activities that need to be worked. The Webb IRB recommends that NGAS re-look at staff allocations and add staff where appropriate to make their I&T flow more robust, efficient and flexible.

The Webb IRB also recommends that RDEs maintain consistent involvement with their element through all phases of the project (see previous chart).

Findings and Recommendations (Employee Morale)

Findings

- NGAS I&T working level morale is not great.
  - I&T is an inherently stressful and demanding environment.
  - Current work schedules require significant overtime, limiting time off.
  - Recent problems and schedule slippage are extending the time when the team is performing I&T.

Recommendations

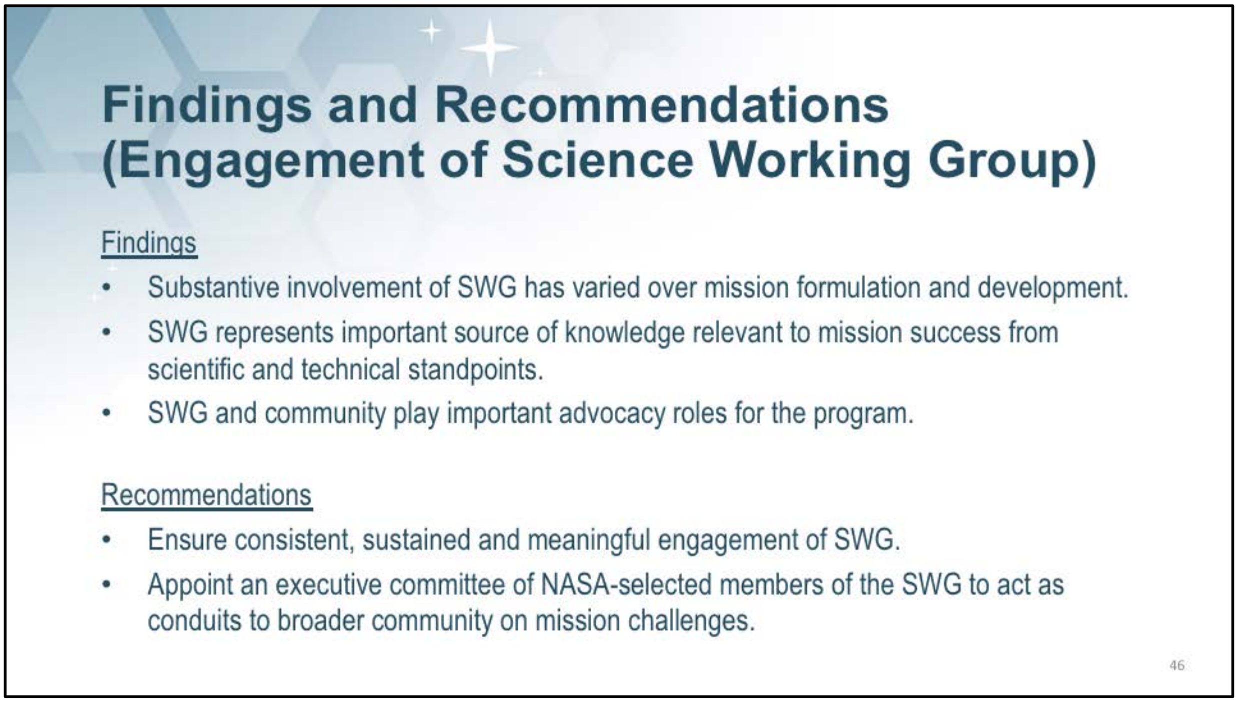
- Augment I&T staff to achieve more realistic work schedules.
- Implement strategies for improving team morale, such as periodic science lectures for NGAS personnel and families.

45

Recent I&T activities have required an extended period of second shifts combined with overtime. The pressure has taken a toll that is reflected in both morale and overall team performance. NGAS recognized the impact of prolonged work stress on team morale and took some steps to rationalize the work load through operational changes on the floor in combination with adding personnel. GSFC is also providing supplemental personnel. Although the added GSFC staff does not directly change the amount of work to be done, the added insight has helped to improve procedural documentation and has helped to reduce associated implementation errors.

Sustained work stress and reduced team morale are tightly coupled just as improved team morale and improved team performance are tightly coupled. Thus, the schedule delays up to now plus the potential for other schedule delays means that a proactive series of stress mitigations will be essential if any level of sustained improvement in team performance is to be realized. The stress affects everyone but has the greatest impact on the many members of the team who are young with young families. It is not realistic to expect a 40-hour week during the I&T phase of the mission, but it is reasonable for management to implement a strategy, including adding additional I&T staff, that gives team members days or even weekends off, while also having some days of normal length.

Team morale-building outside of the work environment is also recommended. Science lectures by John Mather, Marcia Rieke and other JWST scientists can be helpful in connecting the team's work to what will be an exciting ground-breaking mission. Inviting the families to these events and other open-house activities that include food are additional ways for the team to feel engaged.



The GSFC Project Science Team provided the Webb IRB with a comprehensive list of engagement activities of the JWST Project with the science community. The number of activities and level of serious and substantial engagement has varied over the long mission development period. Of late, the level of interaction of the JWST Project with the Science Working Group (SWG) has been inadequate. Most importantly, the responsiveness of the GSFC scientific leadership to concerns raised by the SWG has been inadequate, and has led to a lack of trust between GSFC scientific leadership and the broader community. It is important to remember that the SWG holds important and unique knowledge that is an asset to the mission. In addition the science community is geographically diverse and plays a critical role in advocacy for the mission. It is essential for project scientific leadership at GSFC to recognize that they must include the SWG and other stakeholders in a substantive way in decision making, and reverse the appearance in the community that the GSFC scientists are marginalizing the SWG and other stakeholders in substantive decisions involving the scientific direction and execution of the project.

There is everything to be gained by regular and meaningful interactions with the SWG and by serious consideration of any ideas that emerge which could improve the chances of mission success and efficiency of science operations. The Project should also appoint a small Executive Committee of the SWG to receive detailed information on the conduct of the Project. The Executive Committee could serve a useful role in communicating with the scientific community when mission challenges or opportunities arise, and if well-chosen, could act as advocates for policy makers and other key stakeholders.

Schedule and Cost

47

Schedule Analysis Context

- JWST launch schedule (October 2018) remained unchanged for several years following the 2011 rebaseline.
- I&T issues resulted in significant erosion of the launch date.
  - Human errors
  - Embedded problems
  - Lack of experience in areas such as the sunshield
  - Excessive optimism
  - System complexity

48

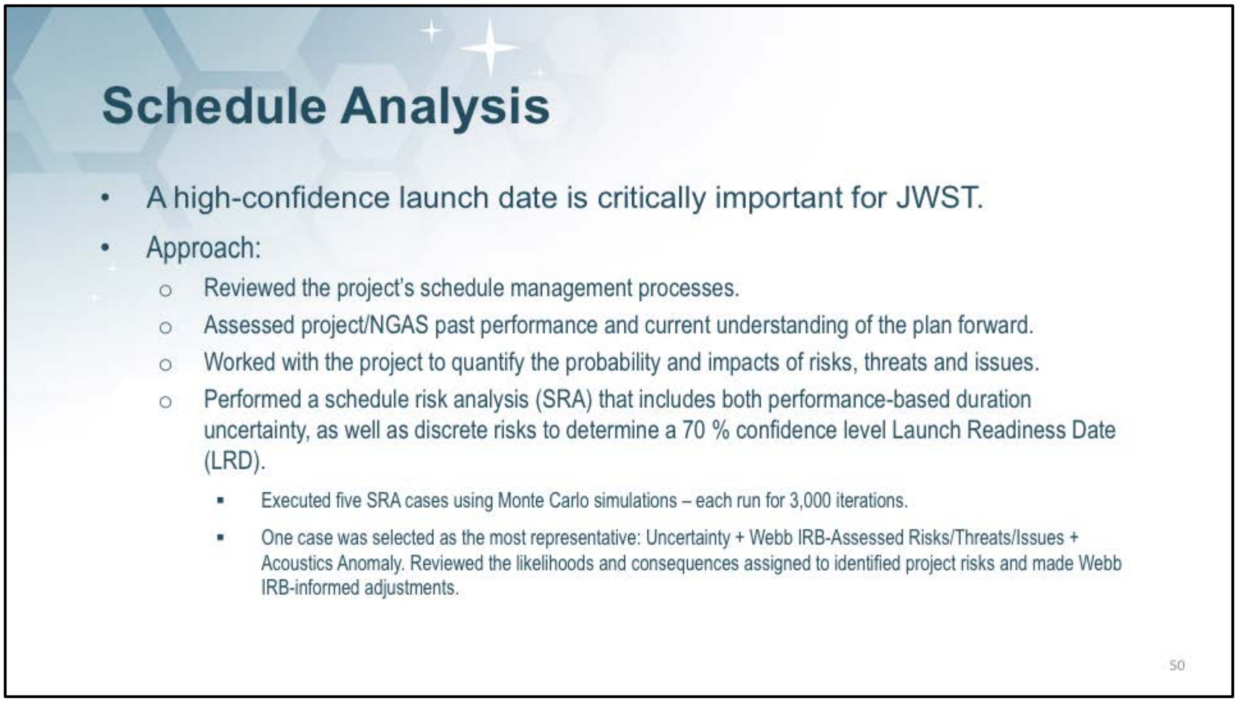
JWST has been challenged by a variety of schedule issues in recent years. Several complications involved the sunshield. The first sunshield-deployment exercise took longer than expected, and post-test analysis showed that the duration would not get better. Additionally, tears during testing required repair, and snags required implementation of preventive measures. The propulsion system experienced both the transducer problem and the valve-leak issue. Ultimately, it was determined that the voltage and improper solvent issues were due to poorly-written work procedures. The recovery from the pressure-transducer issue was inefficient because early welds were defective and had to be replaced with brazed joints.

In addition to the anomalies and issues leading to critical path changes, NGAS experienced slower than planned execution rates in fourth quarter of FY17 that resulted in further erosion of schedule margin. The project did not have a comprehensive understanding of the risks/issues they were facing and how the risks/issues could ultimately affect the project schedule. As recently as February 2018, the schedule was in a state of flux. NGAS schedule performance continued to be poor at roughly 50% efficiency. NGAS SCE I&T performance improved to 90% efficiency in March 2018 with the completion of both the shock and acoustic tests. However, the full extent of the acoustics test anomaly that resulted in fasteners coming loose during the test is still under investigation for schedule impact.

The Webb IRB's primary concern is that the project will forego assurance of mission success to regain schedule. The Webb IRB wants to make certain that this does not happen. Now that risks have been realized and corrective actions identified, NASA needs to ensure that the project has the resources (budget, manpower) available to implement those corrections moving forward.

Schedule Analysis Context

- Confidence and stability in the launch date requires specific actions.
  - The impact of human errors and embedded problems must be eliminated.
  - Lack of experience, excessive optimism and system complexity must be recognized in establishing revised launch date.
- A future I&T problem can have a major impact on the schedule.
- Caution above and beyond that required for a less complex mission must be implemented for each step in I&T, shipment to the launch site and launch preparations.

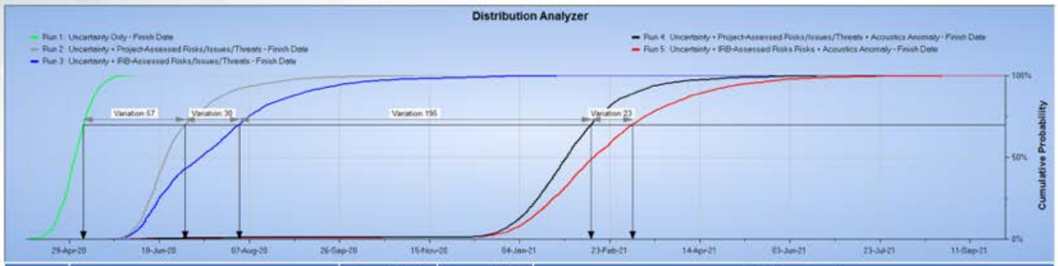


The Webb IRB determined that the project has robust scheduling processes. The schedule is mechanically sound, passing a standard health check with minimal "errors." It is also developed to the right level of detail for Observatory I&T with a daily cadence of activities, and includes activities replanned to reflect more realistic durations. The Webb IRB also analyzed changes in the Project's internal schedule that moved the Launch Readiness Date (LRD) from October 2018 to January 2020 (prior to the Acoustics Test Anomaly). The changes were easily traceable between the two most current versions of the integrated master schedule and reflected the messaging the project provided about duration changes in activities and the addition of mitigations due to recent schedule risks. The Webb IRB observed that 70% of scheduled work is based on calendars with 6-day or 7-day workweeks and 20% of remaining milestones and activities start or finish on a weekend or holiday. There was also no margin to the Observatory Ship Date. Concerns related to these observations include reduced flexibility for surge time (and contingency for performance issues), employee burnout, and availability of key personnel for all shifts.

The project monitors near-term milestones on a weekly basis. The Webb IRB analyzed overall project and NGAS-specific performance looking at earned value data, including the Schedule Performance Index (SPI) and Cost Performance Index (CPI), as well as the Current Execution Index (CEI) data, which calculates the ratio of tasks actually accomplished versus the tasks scheduled to be accomplished. Positive schedule performance was observed prior to initiation of spacecraft/sunshield integration and test. The negative schedule performance over the past year due to technical issues and mistakes improved in March, but the project was still experiencing issues. For the nine months from July 2017 to March 2018, the project showed an average Current Execution Index (CEI) at ~ 50%. Although the project experienced a recent increase in efficiency (i.e., March 2018 CEI = 90%), the potential for additional technical challenges with significant schedule (and cost) impact remains.

Schedule Risk Analysis Results

- Based upon a review of the most representative cases, current views as to project status, identified risks, and Webb IRB judgment, the most probable launch date is March 2021.



Run #	Run Description	Deterministic Date	Deterministic Probability	Confidence Level				
				20%	30%	50%	70%	80%
Run 1	Uncertainty Only	31-Jan-20	<1%	24-Apr-20	27-Apr-20	02-May-20	06-May-20	09-May-20
Run 2	Uncertainty + Project-Assessed Risks/Issues/Threats	31-Jan-20	<1%	11-Jun-20	14-Jun-20	21-Jun-20	02-Jul-20	12-Jul-20
Run 3	Uncertainty + Webb IRB-Assessed Risks/Issues/Threats	31-Jan-20	<1%	15-Jun-20	21-Jun-20	10-Jul-20	01-Aug-20	13-Aug-20
Run 4	Uncertainty + Project-Assessed Risks/Issues/Threats + Acoustic Test Anomaly	31-Jan-20	<1%	10-Jan-21	17-Jan-21	30-Jan-21	12-Feb-21	21-Feb-21
Run 5	Uncertainty + Webb IRB-Assessed Risks/Issues/Threats + Acoustic Test Anomaly	31-Jan-20	<1%	17-Jan-21	27-Jan-21	14-Feb-21	07-Mar-21	23-Mar-21

51

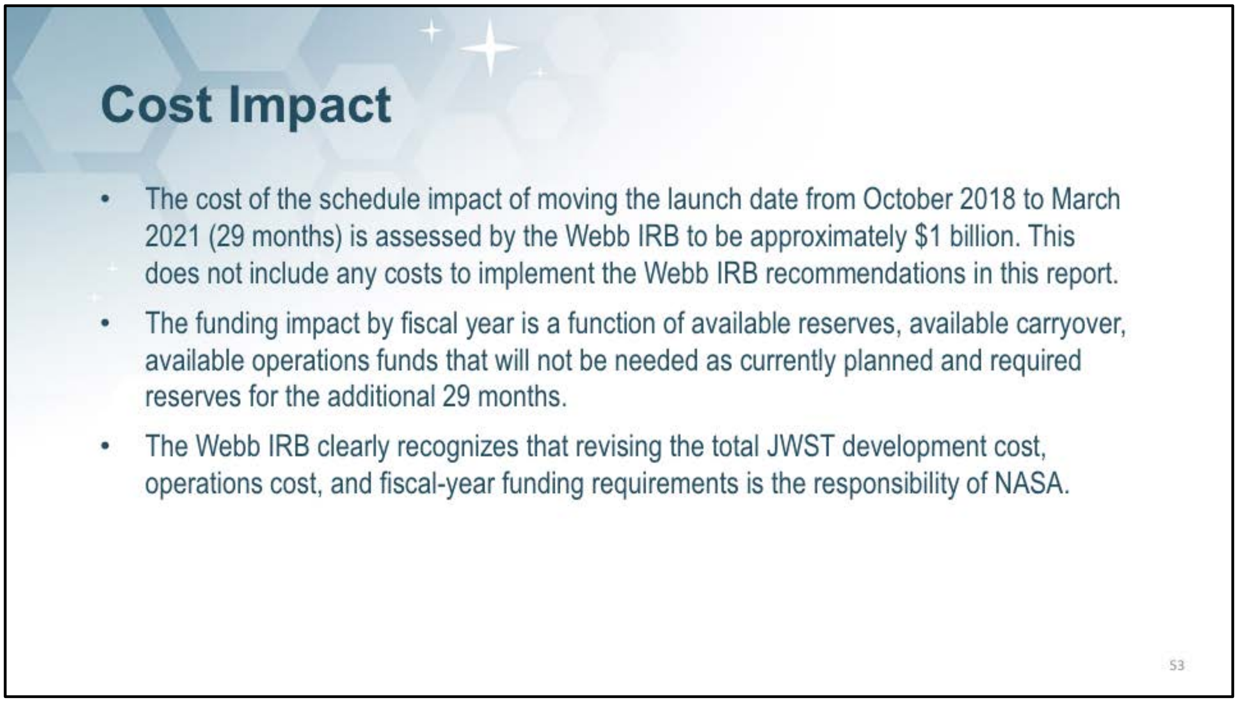
The Schedule Risk Analysis (SRA) results represent 5 different cases as follows:

- Run 1 illustrates the SRA with only Webb IRB-assessed duration uncertainty factors applied.
- Run 2 illustrates the SRA with Webb IRB-assessed duration uncertainty and project-assessed risks, issues, and threats applied.
- Run 3 illustrates the SRA with Webb IRB-assessed duration uncertainty and Webb IRB-assessed risks, issues, and threats applied. The associated 70% confidence level date is August 1, 2020.
- Run 4 illustrates the SRA with Webb IRB-assessed duration uncertainty and project-assessed risks, issues, and threats applied. It also includes the Acoustics Test Anomaly.
- Run 5 illustrates the SRA with Webb IRB-assessed duration uncertainty and Webb IRB-assessed risks, issues, and threats applied. It also includes the Acoustics Test Anomaly. The associated 70% confidence level date is March 7, 2021, and the 80% level is March 23, 2021.

Launch Date Recommendation

- The Webb IRB recommends the launch date be established as March 2021 (based upon the Project's 5/18 assessment of the impact of the membrane cover assembly acoustic anomaly).
- The Webb IRB clearly recognizes that the establishment of a launch date is a NASA responsibility.
- Examples of risks that are not included in the recommended March 2021 launch date are:
  - I&T errors with multi-month impact.
  - Additional sunshield deployments beyond the currently planned two. (Potential impact approximately 3–5 months each.)
  - Removal of a spacecraft subsystem. (Potential impact approximately 6–12 months.)
  - Removal of a science instrument. (Potential impact approximately one year.)

Based on its analysis, the Webb IRB has identified a recommended launch date. There are a number of potential risks that cannot be effectively modeled that are not included in the analysis.



The cost impact was calculated as a function of the Webb IRB's assessment of the potential schedule impact to the project. Given that recent anomalies, human errors, and potential threats and risks are impacting work during I&T, the cost of moving the launch date to accommodate necessary rework and risk mitigations was calculated using the project's average burn-rate ($34.7M) over the past seven months (FY18). The expected impact of moving the launch date from October 2018 to March 2021 (29 months) is approximately $1 billion.

Summary and Conclusion

- JWST is an observatory with incredible capability, awesome scientific potential and significant complexity, risk and first-time events.
- OTIS Integration and Test (I&T) is complete and has demonstrated the exceptional science capability of the system.
- Significant launch date delays and resulting cost caused by human errors, embedded problems, excessive optimism in I&T planning, lack of sunshield experience and system complexity have occurred. Small I&T problems can have a major impact upon schedule and cost.
- JWST inherent risk requires mission success be the highest priority in completing JWST development.
- The Webb IRB believes that implementing all recommendations contained in this report will contribute to maximizing the probability of mission success.
- Eliminating the schedule and cost impact of human errors and embedded problems is critical to completing the successful development of JWST.
- The Webb IRB believes that JWST should continue based on its extraordinary scientific potential and critical role in maintaining U.S. leadership in astronomy and astrophysics.

This report contains numerous recommendations all directed toward contributing to the maximization of JWST mission success. The Webb IRB strongly recommends that all the recommendations be implemented.

APPENDICES

Terms of Reference

Biographies

Acronyms

55

Terms of Reference

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

MAR 27 2018

James Webb Space Telescope Independent Review Board

Terms of Reference (ToR)

I. Background

NASA is conducting final integration and testing of the James Webb Space Telescope (JWST), a major astrophysics facility that responds directly to the recommendations of the 2000 National Academies' Decadal Survey, *Astronomy and Astrophysics in the New Millennium* (AANM). JWST is the top priority recommendation for major initiatives in the AANM Decadal Survey "to detect light from the first stars and to trace the evolution of galaxies from their formation to the present". In September 2017, it was announced that the Webb mission launch readiness date was slipping from the original mission baseline of October 2018 to early 2019. Currently, the launch readiness date is expected to slip to mid 2020 and its development cost is likely to exceed the $8 billion limit set by Congress in PL 112-55.

A cost and schedule assessment conducted by the project to evaluate the schedule risk associated with work remaining for Webb determined the new launch readiness date. An independent review conducted by the Webb Standing Review Board (SRB) updated the project's determination.

II. Terms of Reference

NASA is establishing the *JWST* Independent Review Board (IRB) to evaluate all factors, including those identified by the project and SRB, influencing *JWST*'s success, to ensure that NASA's approach to completing the integration and testing (I&T), the launch campaign, and the commissioning of the Webb Telescope is appropriate for NASA's next flagship observatory.

The *JWST* IRB will document the results of its review in a presentation and a non-consensus final report. The IRB may develop observations, findings, concerns, and recommendations as part of its assessment.

III. Management

The convening authority for the *JWST* IRB is NASA's Science Mission Directorate (SMD) Associate Administrator (AA). As such, the IRB will report to the SMD AA. The review panel shall be comprised of members with considerable current experience in program and project management, systems engineering, schedule/cost management, integration and testing of large space systems, and the science and instrument domains relevant to the *JWST* science objectives.

The SMD AA and the GSFC Director will assure the necessary support for the *JWST* IRB. The IRB Chair and the Executive Secretary will support all activities of the IRB and coordinate production and ensure the quality of review deliverables. The non-consensus final report will be verbally given to the SMD AA, Astrophysics Director, GSFC Director, and other stakeholders followed by the provision of a non-consensus final written report.

IV. Notional Schedule

The review panel will conduct the assessment over an eight-week period from initial meeting to completion of the non-consensus final report. The final schedule will be determined following discussions between the *JWST* IRB, SMD AA, Astrophysics Director and GSFC Director.

ASAP	Select and appoint panel members
Week #1	Days 1-2 (NASA HQ): • *JWST* IRB organization kickoff meeting • Meeting with SMD AA, *JWST* Program Office, and Astrophysics Director • Meeting with *JWST* Standing Review Board Days 3-5 (GSFC): • Meeting with GSFC Director and *JWST* Project Manager • Meeting with *JWST* Project Office
Week #2	Meeting with Northrop Grumman (Redondo Beach, CA)
Week #3	Additional IRB meeting based on results of prior meetings with NASA SMD, GSFC, Northrop Grumman, and the *JWST* SRB
Week #4	Additional IRB meeting based on results of prior meetings with NASA SMD, GSFC, Northrop Grumman, and the *JWST* SRB
Week #5	Develop and discuss draft findings for report; draft any final questions for further discussion
Week #6	Complete draft report
Week #7	Brief non-consensus final report to NASA SMD and GSFC
Week #8	Prepare non-consensus final report; print & deliver to SMD AA

V. Deliverables

- Presentations to NASA AA, SMD AA, Astrophysics Director, GSFC Director, and other stakeholders summarizing the review results
- Non-consensus final report with observations, findings, concerns, and recommendations consistent with Section II above.

VI. Personnel

The *JWST* IRB membership includes:

- Chair: Tom Young
- Executive Secretary: Dan Woods
- Project Management/Systems Engineering/Integration and Test: TBD (four members)
- Science: TBD (two members)
- *JWST* SRB Chair: Paul Mezzanaghey
- Cost and Schedule: (one member)

Approved:

Thomas H. Zurbuchen, Ph.D.
Associate Administrator
Science Mission Directorate

3/22/18
Date

Webb IRB Biographies

William F. Ballhaus, Jr. – Dr. Ballhaus is the former president/CEO of The Aerospace Corporation, Corporate VP Engineering & Technology at Lockheed Martin, President of two Martin Marietta divisions, director of NASA Ames, and Acting NASA Associate Administrator for Aeronautics & Space Technology. He is a graduate of the University of California at Berkeley where he earned a Ph.D. in engineering and BS (honors) and MS in mechanical engineering. Dr. Ballhaus is an Honorary Fellow of the AIAA and served as AIAA president for the 1988–1989 term. He also is a member of the National Academy of Engineering and served two terms on its Council. Dr. Ballhaus currently serves on several boards/councils, including the NASA Advisory Council and the Board of OSI Systems, a publicly traded company. He chairs the Board of the University Space Research Association and has served on the science advisory boards for DoD, NOAA, and the Air Force. He served on the Boards of Draper Labs, Lincoln Lab, Aerospace Corp and chaired the Space Foundation Board.

Steve Battel – Mr. Battel is a graduate of the University of Michigan with 41 years of experience as a system engineer, designer and manager for NASA and DoD space projects. He is recognized within the space community for his science and engineering leadership related to the development of innovative electronic systems and scientific instrumentation for Earth observing, planetary geochemistry, space physics and astrophysics applications. President of Battel Engineering since 1990, Steve previously held research, engineering and management positions at the University of Michigan, the Lockheed Palo Alto Research Laboratory, the University of California, Berkeley and the University of Arizona. Steve is a member of the National Academy of Engineering (NAE), a Fellow of the AIAA, a Fellow of the AAAS, a Senior Member of IEEE and a member of Sigma Xi. He is a former member of the Space Studies Board (SSB) and a current member of the Aerospace Science and Engineering Board (ASEB) for the National Academies. He has participated in more than 90 review and advisory boards for NASA missions with current involvement in Parker Solar Probe, Europa Clipper, GOES, TDRS, ICON, RESTORE-L, Mars 2020, Landsat9, NISAR, SWOT, WFIRST, PSYCHE and IXPE.

Webb IRB Biographies

Orlando Figueroa – Mr. Figueroa is a retired NASA Senior Executive with over 33 years of experience in the management, planning and development of scientific space programs, missions, and related technologies. He is the founder of Orlando Leadership Enterprise, LLC.

Mr. Figueroa's experience in federal service includes serving as the NASA/GSFC Deputy Center Director for Science and Technology, GSFC Director for the Applied Engineering and Technology Directorate; NASA/HQ Deputy Associate Administrator for Programs in the Science Directorate, Director Solar System Exploration Division, Director for Mars Exploration; and Deputy Chief Engineer for Systems Engineering; NASA/GSFC Director of Systems, Technology and Advanced Concepts, and Explorers Program Manager.

Mr. Figueroa has received numerous achievement and performance awards, including the Service to America Federal Employee of the Year Medal and NASA Presidential Rank Awards, and he received an honorary doctorate degree in science from Dominican College in New York in 2004.

Fiona Harrison – Dr. Harrison is the Benjamin M. Rosen Professor of Physics and the Kent and Joyce Kresa Leadership Chair of the Division of Physics, Mathematics and Astronomy at the California Institute of Technology, Pasadena. She is the principal investigator of NASA's Nuclear Spectroscopic Telescope Array (NuSTAR), a small explorer-class mission launched in 2012. Harrison's primary research interests are in experimental and observational high-energy astrophysics. In addition, she has an active observational program in gamma-ray, X-ray and optical observations of gamma-ray bursts, active galaxies, and neutron stars. Harrison was awarded the Robert A. Millikan Prize Fellowship in Experimental Physics in 1993 and the Presidential Early Career Award in 2000. She was named one of America's Best Leaders by U.S. News and the Kennedy School of Government in 2008, and received the NASA Outstanding Public Leadership Medal in 2013. She received her Ph.D. in physics from the University of California, Berkeley. She was elected to the National Academy of Sciences in 2014, and currently she is chair of the National Academies' Space Studies Board.

Webb IRB Biographies

Michele T. King – Ms. King is a PMP and CSEP-certified programmatic analyst for NASA with experience in engineering, risk management, schedule risk analysis, and project management. She currently serves as the lead for the Agency's Schedule Initiative under NASA OCFO's Strategic Investment Division. She contributes to the Agency's Programmatic Assessment Capability Leadership function, helping to enhance and develop new programmatic standards, policies, and capabilities across the Agency. She is also leading the Agency-wide Schedule Community of Practice (SCoPe). Ms. King is a member of numerous Working Groups internal and external to NASA, including Agency working groups for Risk Management, EVM, and PP&C, as well as for GAO and the JSCC's Scheduler's Forum. Ms. King has served as a programmatic risk analyst, supporting the Agency's independent review process for a variety of programs/projects through the IPAO. She led the development of the NASA handbook on Program/Project Management of Problems, Nonconformances, and Anomalies for the NESC. Ms. King holds both a B.S. and an M.E. in Mechanical Engineering from Old Dominion University in Norfolk, VA. She has been recognized for her work by NASA and the local engineering community, having received the following honors: *NASA Top Community Support Award, IPAO Certificate of Recognition,* and *Doug Ensor Young Engineer of the Year Award*.

Paul K. McConnaughey – Dr. Paul K. McConnaughey is the Associate Director, Technical, in the Office of the Center Director at NASA's Marshall Space Flight Center in Huntsville, Alabama. He currently chairs NASA's Standing Review Board for the James Webb Space Telescope. Originally from the Midwest, he earned his bachelor's degree from Oregon State University in Corvallis, and his master's degree and doctorate from Cornell University in Ithaca, New York. After earning his doctorate, Dr. McConnaughey spent three years as a professor of soil physics and mathematics at Mississippi State University in Starkville. He joined Marshall in 1986 as an engineer in the Systems Dynamics Laboratory. Dr. McConnaughey has held various leadership positions of increasing responsibility, including Manager of the Structure, Mechanics, and Thermal Department, and being selected as Marshall's Chief Engineer in 2007. He also served as the director of System Engineering and Integration and the chief engineer of the Exploration Systems Development Division at NASA Headquarters in Washington until from 2012 to 2015.

Webb IRB Biographies

Dorothy (Dolly) Perkins – Ms. Perkins retired from NASA/GSFC in December 2007 as Deputy Center Director – Technical, where she supported the Center Director in overseeing all new business ventures, flight project activities, and partnerships. Since her retirement she has served on several NOAA and NASA independent review boards. Previously she was Director of Flight Programs and Projects at GSFC. Prior to that she served as Deputy Associate Director of Flight Projects for Earth Observing System Operations where she led the recovery and successful implementation of the largest (at that time) civilian information system in the world (the EOS Data and Information System), responsible for multi-satellite operations, and processing and distribution of scientific data for Earth science researchers and policy makers. While working at NASA she was awarded the Presidential Rank Awards for Distinguished Executive and for Meritorious Executive, the NASA Distinguished Service Medal, the NASA Outstanding Leadership Medal, and two Exceptional Service Medals. She holds a B.A. in Mathematics from Wellesley College in Wellesley, Massachusetts.

Peter C. Theisinger – Mr. Theisinger is an employee of NASA's Jet Propulsion Laboratory. His prior positions have included: Manager of the Mars Science Laboratory Project, Director for the Engineering and Science Directorate, Deputy Director of the Mars Exploration Directorate, Manager of the Mars Exploration Rover Project, Deputy Manager of the Systems Division, and Project Engineer for the Mars Global Surveyor spacecraft development project,

Mr. Theisinger has been involved in the systems design and development of interplanetary spacecraft systems since he originally joined JPL in 1967. He has worked on a variety of missions, including the 1967 Mariner mission to Venus, the 1971 Mariner orbiter mission to Mars, the 1977 Voyager mission to the outer planets of the solar system, and the 1989 Galileo mission to Jupiter.

His awards have included the NASA Exception Engineering Achievement Award, NASA Outstanding Leadership Award, and NASA Distinguished Service Medal. He was awarded the Smithsonian National Air and Space Museum Lifetime Achievement Award in 2017.

Webb IRB Biographies

Thomas Young – Tom Young is the former director of NASA's Goddard Space Flight Center, former president and COO of Martin Marietta, and former chairman of SAIC. He retired from Lockheed Martin in 1995. During his NASA career, he served as deputy director of the Ames Research Center, director of the Planetary Program, and mission director of the Viking Mars Project.

Mr. Young has been a member of the board of directors of the Goodrich Corporation, SAIC, Marin Marietta, Cooper Industries, Dial Corporation, Salomon Corporation, and Potomac Electric and Power Company. He is a member of the National Academy of Engineering and a member of the Virginia Academy of Science, Engineering and Medicine.

He received as B.S. degree in aeronautical engineering and a B.S. degree in mechanical engineering from the University of Virginia and an M.S. in management from the Massachusetts Institute of Technology as a Sloan Fellow.

Maria Zuber – Maria Zuber is the E. A. Griswold Professor of Geophysics and Vice President for Research at MIT. Zuber's research bridges planetary geophysics and the technology of space--based laser and radio systems. She has held scientific leadership roles on ten NASA missions, notably serving as Principal Investigator of the Gravity Recovery and Interior Laboratory (GRAIL) mission.

Zuber's awards include the James R. Killian Jr. Faculty Achievement Award, the highest honor the MIT faculty bestows to one of its own. She is a member of the National Academy of Sciences and American Philosophical Society, and is a fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, the Geological Society of America and the American Geophysical Union.

Vice President Zuber is the first woman to lead a science department at MIT and the first to lead a NASA planetary mission. In 2004, she served on the Presidential Commission on the Implementation of United States Space Exploration Policy. In 2002 Discover magazine named her one of the 50 most important women in science and, in 2008, she was named to the USNews/Harvard Kennedy School List of America's Best Leaders. In 2013, President Obama appointed her to the National Science Board, and she served as Board Chair from 2016-2018.

Acronyms

- AA – Associate Administrator
- AURA – Association of Universities for Research in Astronomy
- CEI – Current Execution Index
- CNES – French Space Centre National D'Etudes Spatiales
- CPI – Cost Performance Index
- DoD – Department of Defense
- DoT – Department of Transportation
- EDL – Entry, Descent and Landing
- EMTB – Engineering Model Testbed
- ESA – European Space Agency
- FOT – Flight Operations Team
- FRR – Flight Readiness Review
- FY – Fiscal Year
- GOLD – Global-Scale Observations of the Limb and Disk
- GSFC – Goddard Space Flight Center
- HQ – Headquarters
- I&T – Integration and Test
- IRB – Independent Review Board
- ISIM – Integrated Science Instrument Module
- IVA – Integration Validation Article
- JPL – Jet Propulsion Laboratory
- JWST – James Webb Space Telescope
- L2 – Lagrange Point 2
- LRD – Launch Readiness Date
- LRR – Launch Readiness Review
- LSP – Launch Services Program

Acronyms

- MN - Maritime Nantaise
- NASA – National Aeronautics and Space Administration
- NEA – Non-Explosive Actuator
- NGAS – Northrop Grumman Aerospace Systems
- NGC - New General Catalogue
- NIRCamA – Near Infrared Camera A
- NIRCamB – Near Infrared Camera B
- nm – nanometer
- OTB – Observatory Test Bed
- OTE – Optical Telescope Element
- OTIS – Optical Telescope element & Integrated Science instrument module
- PSF – Point Spread Function
- PSR - Pulsar
- RDE – Responsible Design Engineers
- SCE – SpaceCraft Element
- SMD – Science Mission Directorate
- SPF – Single Point Failure
- SPI – Schedule Performance Index
- SRA – Schedule Risk Analysis
- SSC – Spitzer Science Center
- STScI – Space Telescope Science Institute
- SWG – Science Working Group
- TAYF – Test As You Fly
- TIMS - Technical Interface Meetings