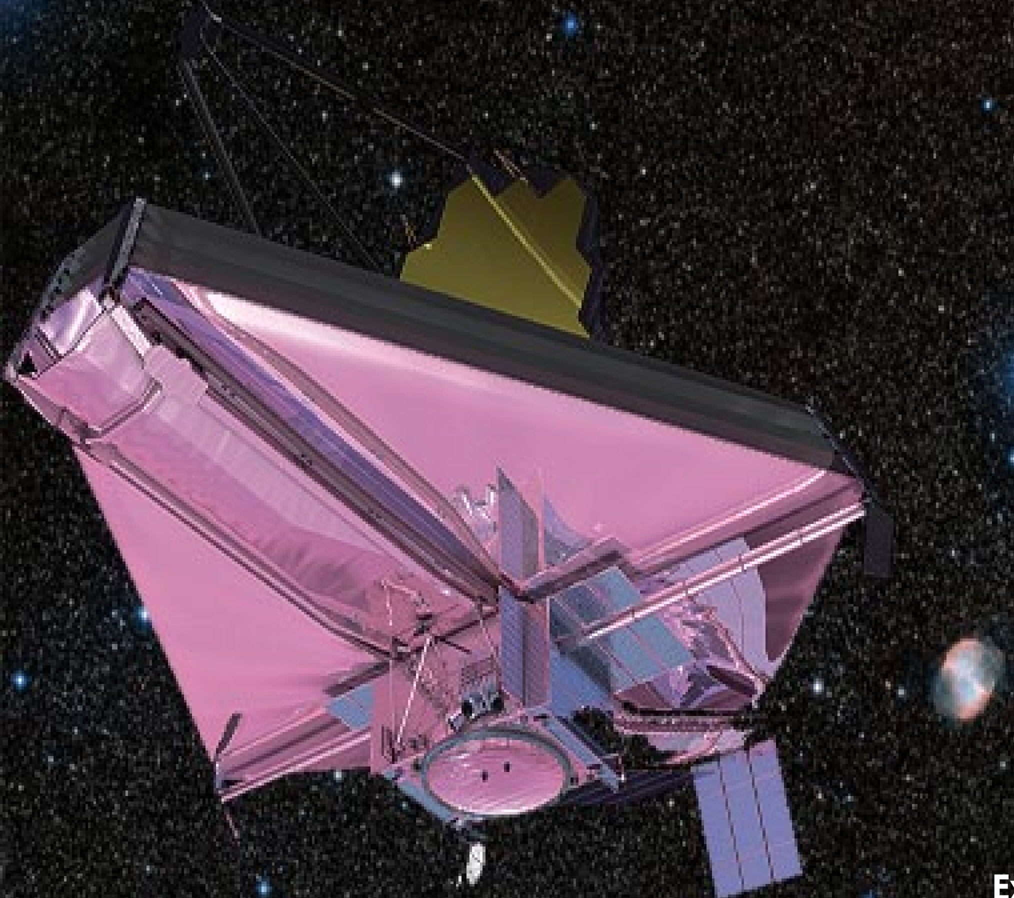
Worldwide Satellite Magazine February 2012

SatMagazine



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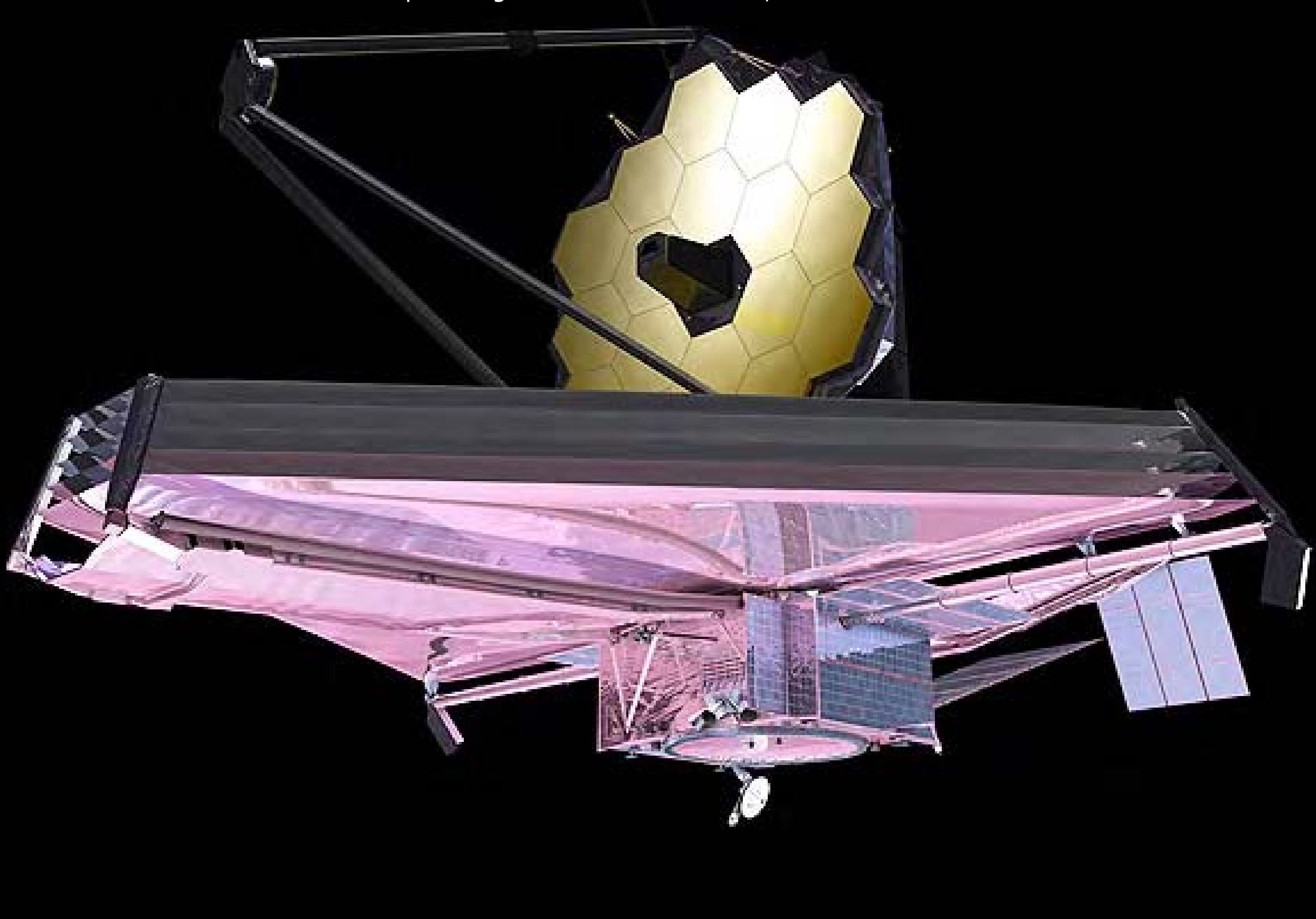
The Untold Story Of NASA's James Webb Space Telescope

by Scott P. Willoughby, V.P. + Program Manager,
James Webb Space Telescope, Northrop Grumman Aerospace Systems

The abundance of recent news about NASA's James Webb Space Telescope barely scratched the surface of what's really happening with this unique space-borne observatory. The most important story about the Webb is how far along it is, and how individual components are rapidly moving toward integration into subsystems and systems.

In 2011, the program made amazing technical progress in many areas. By far the most stunning accomplishment has been the completion of the telescope mirrors. All 18 hexagonal primary mirror segments were polished to accuracies measured in mere atoms, together with the other three mirrors that make up the telescope: the secondary, tertiary and fine steering mirrors. The secondary, a convex mirror and the most challenging, was completed with a surface figure accuracy that exceeds its requirement. The last group of six primary mirror segments just completed final cold verification test at Marshall Space Flight Center in Huntsville, Alabama.



Although presenting a set of far different complex challenges, the five-layer sunshield has also made an important transition: from sub-scale testing to full-size layer testing. The first measurement of the 3D shape of a full-size membrane was made to ensure it will meet very demanding alignment and clearance tolerances. This is the last step before the flight sunshield is fabricated and represents years of painstaking work and innovative engineering. Never before has such a huge expanse of material been engineered to perform to the requirements of such a unique mission.

The spacecraft design and propulsion systems are rapidly advancing, and the flight software that will enable the telescope to communicate with the ground station has been verified. Flight units and test units of the four science instruments are in various stages of integration and performance testing. The telescope is on track for the next step in its evolution — integration — where the parts are assembled and tested as a system.

As a lesson learned from the ***Hubble Space Telescope***, the strategy of tackling the most difficult technical challenges first was adopted by the Webb team. The most critical and technically daunting aspect of the telescope is its primary mirror.

Mirror, Mirror — Who's The Most Perfect Of Them All?
Technology for lightweight mirrors in space telescopes has been in some form of development since 1998, when NASA was part of the *Advanced Mirror System Demonstration* program, a project funded by a multi-agency government group.

In 2003, a year after **Northrop Grumman Aerospace Systems** was selected to build ***Webb***, a panel of experts from the contractor team, NASA and the science community began looking at mirror materials specifically for this telescope. The two mirror technology candidates, beryllium and glass, underwent rigorous tests, studies and analysis: beryllium won because it performed so well at extremely cold temperatures. Webb will operate in deep space at what are called cryogenic temperatures, near minus 400 degrees Fahrenheit.

Once beryllium was identified, the mirrors began a long, Earth-bound journey, trucked across the country for 14 stops in 11 different locations, some several times.

Powder from a beryllium mine in Utah was pressed into huge mirror blanks at **Brush Wellman** in Elmore, Ohio. The blanks were then shipped to a new online facility at **Axsys Technologies**, Cullman, Alabama, where the blanks were machined to a honeycombed structure on a thin face-sheet to reduce mirror weight and retain stiffness.

The lightweight blanks were then shipped to **L-3 Integrated Optical Systems — Tinsley** in Richmond, California, for precision grinding and polishing — a difficult task because beryllium is extremely hard and takes a long time to polish. The operation must also be done carefully to produce smooth mirrors with the right shape, or optical prescription, for their operating temperature despite being polished at room temperature in a process known as cryo-polishing. The mirrors underwent their first super-cold test in the *X-ray and Cryogenic Facility* at **Marshall Space Flight Center**, where they were measured to see how they change shape as they cool. That information was used in the next polishing cycle so that when the mirrors cool during the next test, they "distort" into the right prescription.

Every polishing cycle is a complex operation with many different steps. Each mirror segment underwent very exacting testing and measurement about 100 times. Verifying that the mirrors are polished to tolerances of millionths of inches required extremely sensitive equipment. Temperature variations, air turbulence or floor

Primary mirror segments outside a chamber in the X-ray and Cryogenic Facility at NASA's Marshall Space Flight Center, Huntsville, Alabama. All primary segments are chilled to near minus 400 degrees Fahrenheit to insure they perform as expected in the deep cold of space. Credit: MSFC/NASA

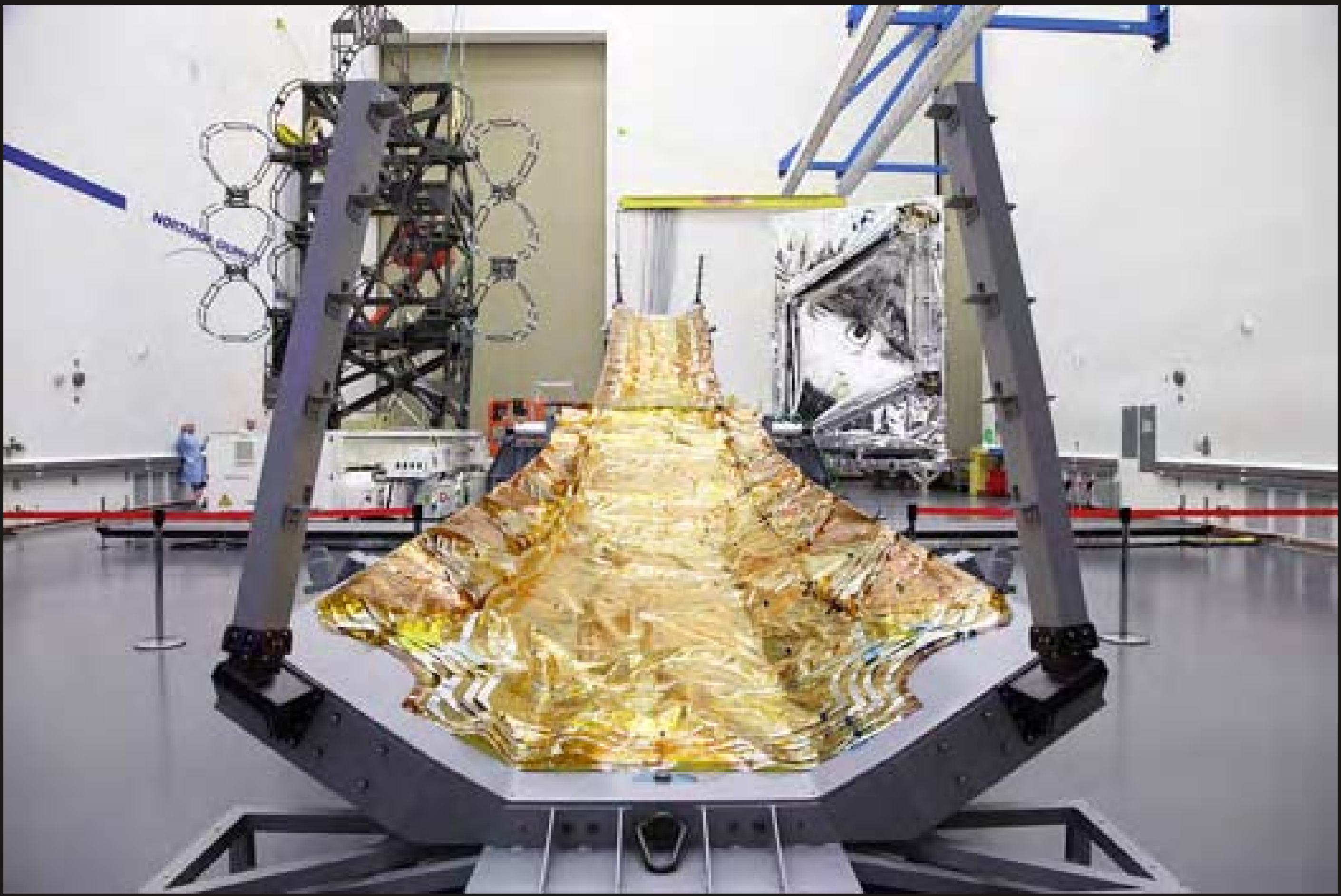
vibrations can throw off the accuracy of these nanometer-scale measurements, so L-3's polishing facility was especially designed to eliminate or minimize these effects. The size of each mirror segment also drove requirements for polishing equipment. These new manufacturing processes had to be created just for Webb's large optics.

After the polishing process was complete, the mirror segments were sent to **Quantum Coating** in Moorestown, New Jersey, where a microscopically thin coat of gold was evaporated onto the mirror's surface to maximize its ability to reflect infrared light. The segments made a final trip to Marshall to confirm performance after coating. At the end of this process, which concluded in December 2011, the segments are finished with component-level testing.

Backed By Strength + Precision

In parallel with mirror manufacturing, two support structures, one for on-the-ground assembly and the other simulating a flight structure, were making headway to completion. The larger structure is a giant structural steel frame for integrating the mirrors, their support structure the mirror backplane, and the science instruments. Installed in the clean room at NASA's **Goddard Space Flight Center**, the platform was constructed by Northrop Grumman's partner, **ITT Exelis,** to support the weight of the entire optical telescope, a load of more than 3.7 metric tons. ITT also built and demonstrated the mirror installation equipment, which consists of an overhead tracking system and a robotic arm with micro-positioning capability.

The other completed support structure is the backplane pathfinder, a test version of the flight backplane that is designed to support the weight of the mirrors, instruments and other elements during launch and hold the 18-segment, 21-foot-diameter primary mirror nearly motionless while the telescope peers into deep space. The backplane must meet exacting thermal stability



The Webb Telescope Integrated Validation Article (IVA) with folded sunshield test membranes in open position in the high bay at Northrop Grumman, Redondo Beach, California. Engineers use the IVA for fit checks and tolerances between the membranes and the structure that holds them. In the background at left is a mockup of the structure that supports Webb's primary mirror. Credit: Northrop Grumman.

requirements. For example, it must not change shape by more than 38 nanometers (about 1/1000 the diameter of a human hair) while the telescope is operating, even though it will experience temperatures colder than -400 degrees Fahrenheit.

The pathfinder backplane is a full-scale engineering model of the central section of the flight backplane and will be used to demonstrate integration and test procedures prior to their use on the flight telescope. The pathfinder consists of 12 of the 18 hexagonal cells (the center section) of the telescope. It will support a subset of two flight-spare primary mirror segment assemblies, the secondary mirror and aft optics subsystem. The pathfinder is made of the same material with the same tolerances as the flight backplane.

With A Sun Protection Factor Of 1.2 million

After years of tackling the myriad engineering challenges that accompany a layered sunshield as large as a tennis court, the Webb team has moved forward into an important new testing phase. The sunshield material, made of a tough plastic film, Kapton ®E, is only one-to two-thousandths of an inch thick, about as thick as a human hair, and covers a surface area the size of a tennis court. The layers are separated from each other and held in place by spreader bars and deployable booms. The sunshield keeps the telescope in shadow to operate near absolute zero, so Webb's science instruments can see far into the most distant galaxies.

In September, 3-D shape testing of full-size templates, or pattern membranes, began at partner **Man-Tech International**'s facility in Huntsville, Alabama. These tests tell engineers how the full-size sunshield layers will behave once deployed. Test results are compared to computer models to validate the computer models. A high-precision laser radar tool creates a 3D map, or picture, of the material surface. This map will be compared to computer models to see if

Technicians at ManTech International's facility in Huntsville, Alabama, check the layer 3 sunshield test membrane mounted on a fully simulated flight structure. Each of the five tennis court-sized sunshield test layers will be 3D shape-tested to validate computer models. Photo credit: Northrop Grumman.

the material behaved as the model predicted, and was able to meet critical clearances with adjacent hardware. The test will be done on all five template layers of the sunshield. The month-long testing used flight-like material for the sunshield, and a full-scale test frame and hardware attachments. Each sunshield layer is stitched together like a quilt from over 52 individual pieces because no manufacturer makes Kapton sheets as big as a tennis court. The completion of full-size testing of sunshield layer-3 is the final step of the sunshield's development and gives engineers the confidence and experience needed to manufacture the five flight layers.

The Origami Telescope

After all five layers of the full-size template sunshield complete testing and model analysis, they will be sent to Northrop Grumman's high bay in Redondo Beach for yet another fit check. The sunshield layers are folded, much like a parachute, so they can be safely stowed for launch. Work has been ongoing using the Sunshield Full-scale Mockup test article to test the fit between aligning and attaching the folded membrane layers to the sunshield support structure. Checkouts like these allow engineers to validate the sunshield design and prove out processes developed specifically for Webb well before tackling flight production.

Starting early next year, the sunshield layers will be very precisely aligned on a giant 2,000-pound platform. Each one of five templates or pre-flight model layers will be spread out on the table where holes will be made in the exact locations needed to attach the layers to the structure for launch. To ensure proper fit and function, the hole positions are different for each layer and their locations are controlled to a small fraction of an inch. Hole positioning is a critical task because all the holes in five folded membranes must align, so that the sunshield layers are held in a predetermined configuration to survive launch so that they can later unfold in a carefully orchestrated way. The process will begin with the first of five template membranes in January 2012

Technician checks layer 3 sunshield test membrane mounted on a fully simulated flight structure at ManTech International 's facility in Huntsville, Alabama. Credit: Northrop Grumman.

and continue through the year, interspersed with fit checks on the full-size telescope mock-up. Construction of the five flight membranes is scheduled to begin in mid-2013.

Suspended In Space, Held In Place

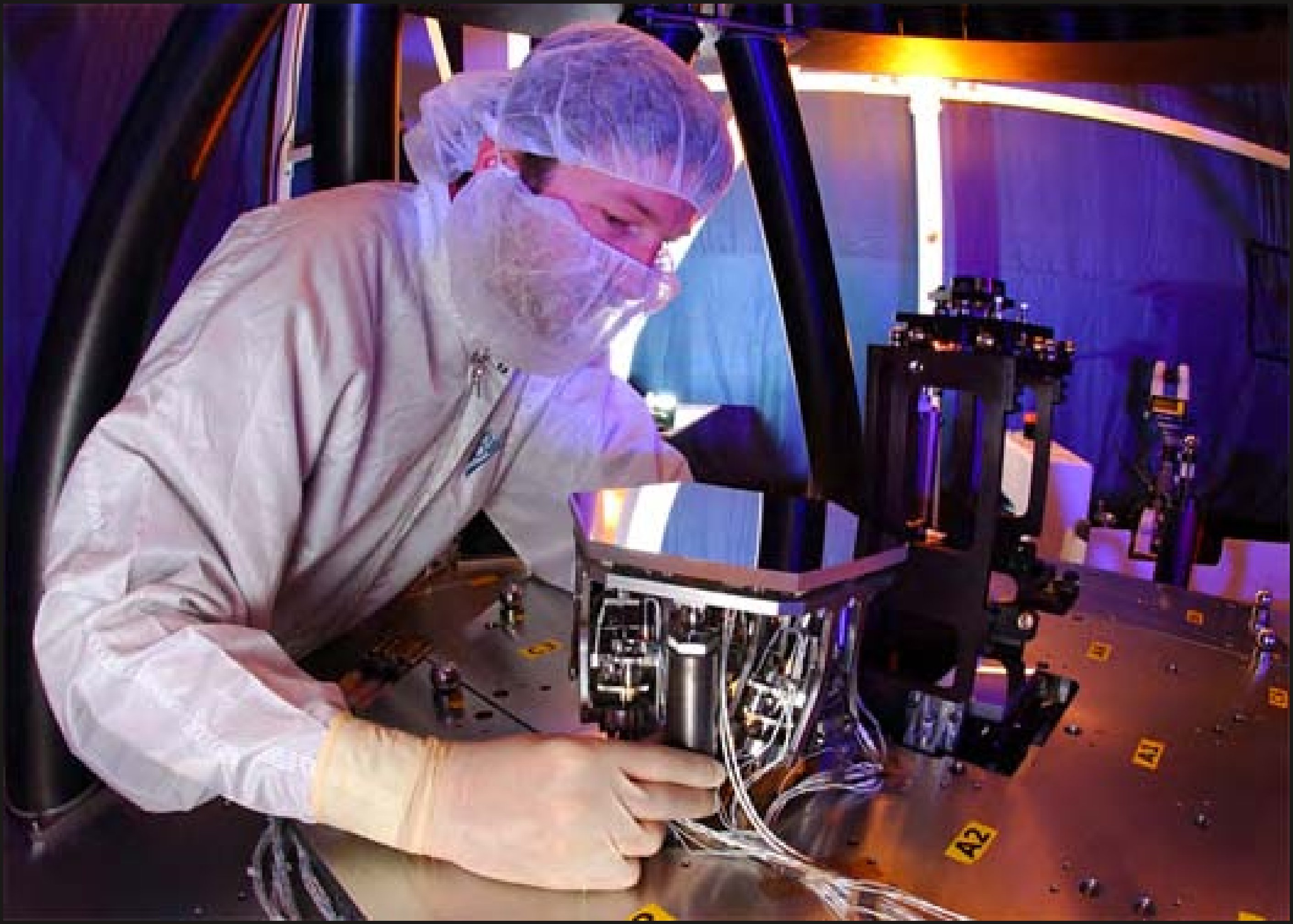
Supporting the sunshield and telescope is the spacecraft, which is moving forward through design reviews in the run-up to the Critical Design Review (CDR). The spacecraft has completed five of 12 subsystem Critical Design Reviews. These are:

Command and Data Handling Subsystem
Attitude Control Subsystem
Deployment Control Subsystem
Flight Software Build 1
Flight Software Build 2

In addition, work has continued beyond subsystem CDR maturity. Engineers have verified the flight software responsible for ground commands and science data delivery meets mission requirements. Launch and deployment software verification testing will begin by next summer, followed by software for attitude and thermal control. Early completion of flight software verification testing achieved cost savings and significant risk retirement for the program.

Four spacecraft structure sub-assemblies have passed critical design review, representing substantial progress for the bus design:

- The primary structure that supports the observatory during launch and operations. This 350 kilogram graphite composite structure is designed to support 6.5 metric tons.



Technician working on a early, sub-scale, test JWST mirror segment. Photo courtesy of Northrop Grumman.

- The propulsion structure module, which supports the spacecraft propulsion subsystem responsible for orbit insertion and maintenance.
- The cone assembly, which mates the primary observatory support structure to the Ariane 5 launch vehicle.
- The spacecraft to telescope isolator, which reduces vibration between the spacecraft and telescope.
- A sunshield support structure sub-assembly
- The support structure for the communications downlink antenna to the Deep Space Network.
- The support structure for the cryocooler which cools the Mid-Infrared Instrument (MIRI)

The spacecraft's propulsion system is moving forward with a critical design review confirming a thermal upgrade to 16 monopropellant rocket engine (MRE-1) thrusters. They were modified to withstand the high temperatures on the spacecraft generated by both the sun and reflected heat from the sunshield. The 6-inch long MRE-1 thrusters provide one pound of thrust each to unload momentum and provide precision attitude control on-orbit. Propulsion engineers have also completed building four flight Secondary Combustion Augmented Thrusters, which provide eight pounds of thrust each and supply orbit maintenance after the launch vehicle finishes its burns.

Tools For Discovery

Webb's four instruments are designed to work primarily in the infrared range of the electromagnetic spectrum, where light becomes heat. They will also have some capability in the visible light range. The *Near Infrared Camera* (**NIRCam**) engineering test unit has undergone performance evaluation at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The University of Arizona and Lockheed Martin are constructing the flight instrument. The *Near Infrared Spectrograph* (**NIRSpec**) flight instrument has been assembled and is now undergoing testing in Europe. The *Mid-Infrared Instrument* (**MIRI**) flight unit construction is complete and has finished its cryogenic performance tests at the **Rutherford Appleton Laboratory** in England.

The *Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph* (**FGS/NIRISS**) is currently being tested in preparation for delivery to Goddard in summer 2012.

Putting It All Together

Although much work remains to be done, the telescope's engineering design has been proven through component-level testing. As that is completed, the Observatory moves into its all-important integration and test phase, when components become subsystems and subsystems become whole, ready for testing at a systems engineering level.

Webb is unique in the history of space telescopes. There is no mission planned either by NASA or any other space agency that can achieve Webb's science goals. These goals are transformative and will open a new era in astrophysics. Webb will see the first galaxies; study the assembly and evolution of galaxies and the role of dark matter, stars, and metals; characterize the nature of liquid water on planets around other stars and reveal the births of stars and planetary systems.

Through one-of-a-kind design, careful planning and rigorous testing, the James Webb Space Telescope is on track to fulfill its purpose and give us a story to tell that surpasses our wildest imaginings.

About the author

Scott P. Willoughby is the vice president and program manager for the James Webb Space Telescope Program at Northrop Grumman Aerospace Systems. The program is currently on contract for the design, development and delivery of the Observatory to NASA's Goddard Space Flight Center. Scott has had a leadership role on the Webb telescope program since September 2009 when he was named program manager. In his more than 20 years with the company, he has held roles at increasing levels of responsibility in integration and test, production and supply chain, product design/development, and systems engineering.

Previously, Scott served as the P858 program manager in Advanced Concepts, Technology and Emerging Systems. His primary responsibilities were to drive process improvements and delivery of this critical and strategic program. He oversaw program management including financial management, capital, human resources, customer and subcontractor interfaces and all levels of contract management.

Prior to that, Scott was program manager for the Advanced Extremely High Frequency (AEHF) program, where he led the team on early deliveries to the prime contractor for two AEHF payloads, Flights 1 and 2, and positioned the program for a subsequent early delivery of Flight 3.

Earlier in his career, he was responsible for the Milstar operations program at AS, which included payload support for a constellation of five operational satellites.