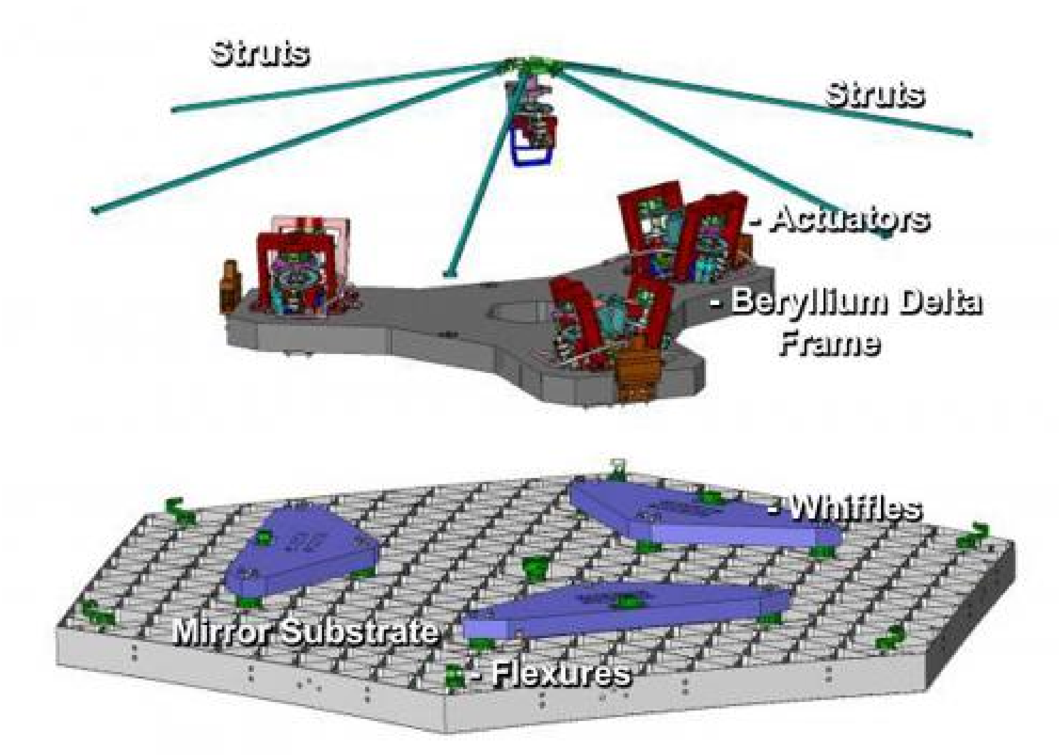
The amazing anatomy of James Webb Space Telescope mirrors

March 20 2014



This is a diagram of the anatomy of a James Webb Space Telescope Mirror.
Credit: ASU/NASA

When you think of a mirror, there really isn't that much needed to describe it, but when you look at a mirror that will fly aboard NASA's next-generation James Webb Space Telescope, there's a lot to the anatomy of a mirror.

NASA's Webb telescope includes a primary, secondary and tertiary mirror. Although the relatively small secondary and tertiary mirrors are unique, it's the expansive primary mirror that has the most complicated anatomy with a number of components operating together to make the telescope work.

The mirrors were built by Ball Aerospace & Technologies Corp., Boulder, Colo. Ball is the principal subcontractor to Northrop Grumman for the optical technology and lightweight mirror system. Ball Aerospace also developed the secondary mirror, tertiary mirror and fine-steering mirror.

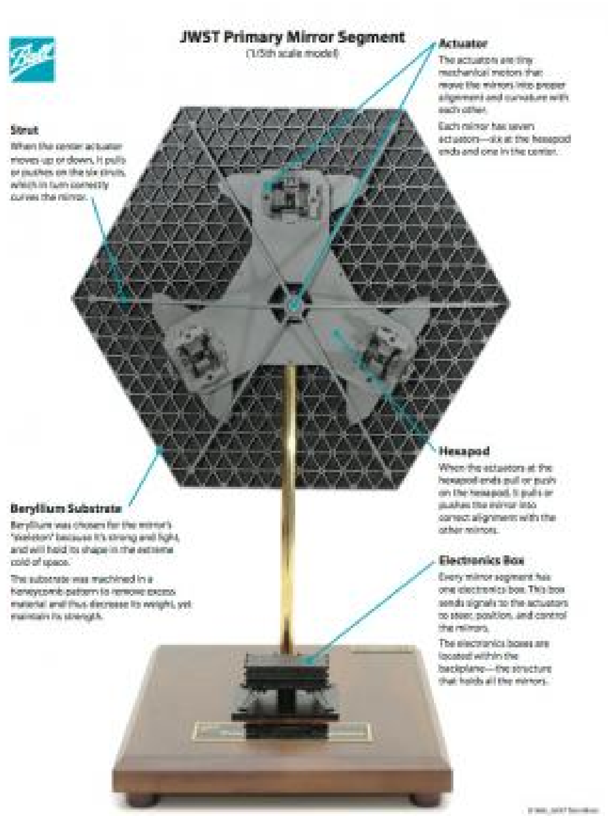
The raw power of any telescope is determined by the size of its main optic—the bigger the first or "primary" optic, the better—and in the case of large telescopes, the optic is a mirror. Webb's primary mirror measures 6.5 meters (21 feet, 4 inches) across, and although that's respectable by ground-based telescope standards, it is absolutely huge for a space telescope. A mirror this large and in space is needed to capture the light from the most distant galaxies and stars in the universe, but it would too big to launch into space if it were one single piece, so that's why Webb's is composed of 18 smaller lightweight "segments" that can be folded up to fit into the nosecone of a rocket. Each of Webb's 18 hexagonal-shaped primary mirror segments measures just over 1.3 meters (4.2 feet) across, and weighs approximately 40 kilograms (88 pounds). All of the 18 primary mirror segment assemblies that will fly aboard NASA's James Webb Space Telescope have already arrived at NASA's Goddard Space Flight Center in Greenbelt, Md.

Each of the 18 mirror segments is not "just a mirror" but is a complex assembly of technologies that allows all of them to work together as one. Each mirror has an "anatomy" of many parts, from the reflective gold-coated Beryllium substrate or layer, down to a Beryllium structure of "whiffles" and a "Delta frame," plus precision actuators to position and shape the mirror, mounted on Backplane Interface Flexures.

"The complexity of the mirror assemblies comes from the fact that they are designed to be very lightweight, work at cryogenic temperatures below -400F, survive launch vibration and forces, be align-able on-orbit via actuators, and then stay aligned for up to two weeks as though they are a single large mirror," said Lee Feinberg, NASA Optical Telescope Element Manager for the James Webb Space Telescope at the Goddard Space Flight Center in Greenbelt, Maryland.

Beryllium Mirror Substrate (Smooth mirror surface)

The Beryllium Mirror Substrate is the part of each mirror segment that acts as a mirror in the classic sense. Each substrate is nearly 2 inches thick with a highly-polished and exquisitely smooth "front" reflective side and a "back" side that is precision machined into a sort of egg crate-looking structure to make it lighter weight than it would be if solid. The reflective surface is polished to an "average" roughness of only 20 nanometers (i.e., 20 billionths of a meter) and coated with a microscopically thin layer of pure gold to maximize its ability to reflect infrared light. Beryllium is the material of choice because is it extremely stiff and lightweight, and it behaves very stably and predictably at Webb's extremely cold operating temperatures.



This is a labeled image of a model of a primary mirror segment. Credit: Ball Aerospace

Beryllium Whiffles

The opposite side of the smooth surface Beryllium Substrate is mounted on three triangular Beryllium Whiffles that look like the openings in an egg crate. Each of the whiffles are about 1 foot wide and 2 feet long. The whiffles spread the load or mass (because the mass has no weight in space) from underlying structures and mechanisms to minimize distortion in the mirror. Beryllium was chosen because it is strong and light, and will hold its shape at extremely cold temperatures.

Beryllium Delta Frame

The Beryllium Delta Frame or BDF is the main intermediate structure for each of the 18 primary mirror segments, and it is about 2.5 feet wide and shaped rather like a regular triangle or "delta." The BDF connects the reflective mirror or substrate and whiffles to actuators.

Actuators

Actuators are tiny mechanisms composed of precision motors and gears used to move and shape the reflective mirror surface of the substrate. Actuators align the 18 primary mirror segments in positions to focus on an object in space.

Each of the primary mirror segments has six actuators that enable it to move and rotate so that all 18 can be aligned to each other to act as one giant mirror. Also, each primary mirror segment has one special "force" actuator attached directly to the middle of the backside of the shiny mirror and via long, thin Beryllium struts to the edges of the mirror segments. Each force actuator enables all 18 segments to have the exact same "center of curvature" such that they will all focus at the same point

These mirror actuators are one of the Webb's many new inventions. They enable the miniscule movements on the scale of nanometers that are necessary to achieve optical perfection. A nanometer is one billionth of a meter, or one millionth of a millimeter. To put this in perspective, consider that a typical sheet of paper is about 100,000 nanometers thick. Moreover, these actuators must operate reliably and repeatedly at the extreme "cryogenic" temperatures of only tens of degrees above absolute zero.

After Webb unfurls in space and cools down to its operating temperature, engineers on the ground will send commands to move all the actuators and co-align all the mirrors in a process that will take about two months. Then, once the Webb is fully-operational and being used for scientific observations, mirror alignment will be fine-tuned about once every 10 to 14 days. Thanks to this new technology, Webb will be the first space observatory to use an actively-controlled, segmented primary mirror.

Technicians and scientists check out one of the Webb telescope's first two flight mirrors in the clean room at NASA's Goddard Space Flight Center in Greenbelt, Md. Credit: NASA/Chris Gunn

Backplane Interface Flexures

The Backplane Interface Flexures connect a primary mirror segment to the telescope structure called the backplane. The backplane holds all 18 of the primary mirror segments. Flexures allow for expansion and contraction that occurs with temperature changes—especially the big cool downs that happen in pre-flight testing on the ground and the one big cool down that will occur in space as the observatory goes from room temperature after it leaves its launch vehicle to around 50 Kelvin (minus 390 degrees Fahrenheit) and below for operations. The flexures themselves are precision-machined blades that function as finely-tuned springs.

However, there are flexures everywhere in each primary mirror segment and not just where they connect to the Backplane.

It All Works Together

The purpose of all this new and specialized technology is to work in concert to enable great scientific advancement. The Webb will be the premier astronomical observatory of the next decade. It will study every phase in the history of our universe, ranging from the first luminous glows after the Big Bang, to the formation of stellar systems capable of supporting life on planets like Earth, to the evolution of our own Solar System.

The Webb telescope is a joint project of NASA, the European Space Agency and the Canadian Space Agency.

Provided by NASA's Goddard Space Flight Center