

James Webb Space Telescope (JWST) Optical Telescope Element (OTE) Architecture and Technology¹

Lee D. Feinberg, JWST Optical Telescope Element (OTE) Manager
Code 443, NASA Goddard Space Flight Center
Greenbelt, MD 20771
Lee.D.Feinberg@Nasa.Gov

Abstract—The James Webb Space Telescope (JWST) Optical Telescope Element (OTE) is the first NASA segmented space telescope and is planned for launch in 2011. The telescope architecture was recently finalized with the selection of the primary mirror material. This presentation reviews the telescope architecture and discusses the remaining key technological challenges of this element.

1. INTRODUCTION

NASA plans to launch the James Webb Space Telescope into space in less than a decade. The observatory will be launched in a stowed configuration on an Ariane expendable rocket and will deploy to its full 6.6 meter diameter on its way to reaching its final destination at the L2 Lagrange point. This location provides an optimal location for passively cooling the telescope to approximately 30 Kelvin using a deployed sunshade. The cryogenic temperature of the telescope was chosen to allow it to operate in the near- and mid-infrared (.7 μ m-28 μ m) where the blackbody emission of warmer mirrors would swamp the scientific objects. These wavelengths are critical to achieve the major science objectives of the telescope because of the fact that starlight from the earliest light in the universe is red-shifted into these wavelengths. The scientific goals are shown in Table 1 below.

Table 1: JWST Science Goals:
First Light (After the Big Bang)
Assembly of Galaxies
Stars and Stellar Systems
Planetary Systems and the Origins of
Life

Due to the mass and volume requirements of the rocket, the telescope will be deployed and have a primary mirror comprised of 18 light-weighted hexagonal-shaped segmented mirrors that will be aligned in space. The mirror technology was recognized as a critical technological challenge and through an early start and significant investments NASA has brought the technology readiness of the lightweight cryogenic mirrors to a level commensurate with programs much further along in their design cycle. In

addition, NASA and prime contractor investments in the wavefront sensing and control technology needed to align and phase the mirror segments is also at a fairly advanced state of readiness.

The JWST program recently entered into Phase B. In addition, the international partnerships have been firmed up and the key contractors for the telescope, spacecraft, ground system, and instruments have all been selected. The prime contractor for the telescope and spacecraft is Northrop Grumman Space Technologies and its key subcontractors are Ball Aerospace and Eastman Kodak.

During the past year, NASA and its prime contractor Northrop Grumman Space Technology have successfully completed a series of architecture studies that has resulted in the final telescope architecture. The rest of this paper will discuss the critical architecture decisions that have been made and the remaining technological challenges ahead.

2. ARCHITECTURE

The first architecture study resulted in the decision to baseline the primary mirror collecting area at 25m². The 25m² was chosen because it met the level 2 requirements, provided potential cost savings, and perhaps most importantly provided mirror schedule risk reduction. The decision to baseline the 25m² aperture size was accompanied with the decision to perform a follow-on segmentation trade comparing the initial 36 segment architecture with an 18-segment telescope architecture. One advantageous aspect of the 18-segment solution is that it most easily accommodates the use of 6-degree-of-freedom hexapod mounts on each mirror (as opposed to the four degree of freedom mounts more accommodated by the 36 segment architecture). Because the hexapod mounts can correct for all rigid body motions, they provide significant I+T and on-orbit risk reduction relative to a 4-degree-of-freedom mount. However, the hexapod mounts added some additional complexity and thus it was recognized that these issues needed to be considered as part of a larger segmentation trade.

Thus, the second key architecture study, the segmentation trade, was kicked off after the primary area study was complete. The study initially considered 18, 30, and 36 segment solutions but quickly focused on just the 18 and 30 segment options. The study considered a full set of observatory system considerations including sunshield packaging, mass, composite backplane complexity (the structure that holds the primary mirror segments), wavefront sensing and control, integration and test, hexapod system considerations, and mirror production considerations. The mirror production considerations were slightly complicated by the fact that the program was still carrying two mirror technologies at the time. After considering all of the system issues and fabrication issues unique to both mirror materials, the final decision was to baseline the 18 segment solution which included the hexapod mounts.

At about the same time as the segmentation trade, a team of optical designers was hard at work determining the prescription of the telescope. A key consideration of this design effort was the F-number of the telescope. The team agreed to baseline an F/20 design that did not add any additional risk to the telescope (eg, the primary mirror) but that satisfied the desires of the science instruments. The team spent several months optimizing the design, including laying out the instrument field-of-views and optimizing the alignment sensitivities of the aft optics and pupils.

The final architecture trade decision was the choice of the primary mirror material. The trade was significantly aided by the results of the Advanced Mirror System Demonstrator (AMSD) program, an aggressive mirror technology effort that NASA embarked on early in Phase A. In fact, the trade was timed to make just-in-time use of the cryogenic results of both mirror material options. These cryogenic results proved extremely important in the final selection of Beryllium over glass. The cryogenic results highlighted how the Beryllium mirror's wavefront stability at 30-55K and how its high thermal conductivity proved to be significant technical advantages for the JWST application. However, the trade study also included programmatic considerations such as schedule and facilities where glass had advantages. However, in the end a panel of 18 experts assembled by the NGST and NASA OTE Managers recommended the Beryllium option for technical reasons. This recommendation then became the basis for NGST selecting Beryllium as the material for JWST and for NASA approving this decision.

The overall JWST telescope architecture is summarized in Table 2 and is shown in Figure 1. The telescope is a three-mirror anastigmat that includes a fine-steering mirror. The telescope is an F/20 design and the primary mirror and secondary mirror are deployed in space using mechanisms. The primary mirror is deployed through the use of two wings of three mirror segments each. The secondary mirror requires a more complicated sequence in which it is

deployed into capture range. Further details on this architecture can be found on the JWST web page (WWW.JWST.Nasa.gov).

Table 2 Telescope Parameters

F/# = F/20
 Design Type: Three Mirror Anastigmat (TMA)
 # of Primary Mirror Segments: 18 hexagonal
 Size of PM Segments: 1.315m flat to flat
 Mirror Material (all): Beryllium
 PM Physical Aperture = 6.6m
 Primary Mirror Collecting Area: ≥ 25 sq. meters
 OTE Wavefront Specification: 131nm
 Encircled Energy: 74% in .15arcsec radius at 1 micron

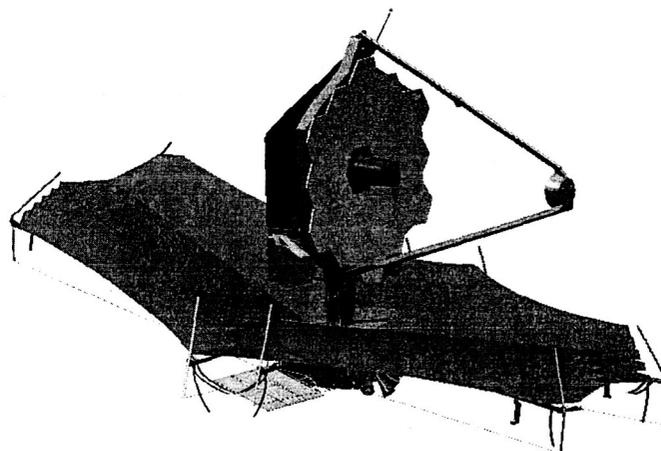


Figure 1 Telescope Architecture

3. TECHNOLOGY AND CHALLENGES AHEAD

There two major technology challenges for the JWST telescope are the lightweight mirror technology and the wavefront sensing and control algorithms and hardware. The mirror technology is challenging because of the need for low areal density mirrors that can operate at cryogenic temperatures. As a result of AMSD, this technology is fairly far along. A picture of the Beryllium AMSD mirror segment is shown in Figure 2. The AMSD mirror shown met nearly all JWST specifications and was very close in

size to the actual JWST mirror segments. The mirrors were extremely repeatable and stable at cryogenic temperatures. At this point in time, most of the remaining technology efforts are focused on optimizing the production of 18 of these mirrors and on a demonstration of an EDU that is built exactly to flight specifications.



Figure 2 AMSD Beryllium Mirror

The second key technological challenge, the wavefront sensing and control system, has been demonstrated piecemeal using the Wavefront Control Testbed (WCT) at GSFC and testbeds at Ball Aerospace. However, these testbeds had a limited number of mirror segments ranging from three to six. Thus, Ball Aerospace is building an 18 segment testbed that is a scaled model of the telescope and which will certify the algorithms to be used on JWST. The wavefront sensing and control system utilizes phase retrieval algorithms that were demonstrated during the spherical aberration prescription retrieval on HST. The system also makes use of grisms for coarse aligning the mirror segments before phase retrieval is employed. The main instrument for JWST, the Near Infrared Camera (NIRCAM), is used as the sensor for wavefront sensing and control.

BIOGRAPHY

Lee Feinberg is the NASA OTE Manager for the JWST



telescope. In his previous position at NASA, Lee was the Assistant Chief for Technology in the Instrument Technology Center at GSFC. Before that Lee was the acting Instrument Development Office head for the Hubble Space Telescope Project. While on HST, Lee also served as the STIS Instrument Manager and played a key role in the optics and testing of COSTAR and WFPC-2. Lee also led the

Conceptual Study Team for the HST Wide Field Camera-3. Before coming to NASA, Lee worked at the University of Rochester's Laboratory for Laser Energetics, at Booz, Allen and Hamilton, and at Ford Aerospace. Lee has a BS in Optics from the University of Rochester and a MS in Applied Physics from the Johns Hopkins University.