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CM FOREWORD

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JAMES WEBB SPACE TELESCOPE PROJECT

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2	Table 4-3	Air Force Weather Service	GSFC/F. Wasiak	6/1/2008
3	5.3.8.9	MO-382 (Raw Data Dump for TFI)	STScI/Stanley	6/1/2008
4	5.7.2.5.1	MO-594 (OTB)	GSFC/F. Wasiak	6/1/2008
5	5.8.1.4	MO-638 (Backup S&OC)	GSFC/F. Wasiak	6/1/2008
6	6.2.3.3	MO-987 Momentum Mngt	STScI/Stanley	6/1/2008
7	6.2.4.3.2.1	MO-774 Checksum Compare Check	STScI/Stanley	6/1/2008
8	C.3	ISIM Modes	GSFC/F. Wasiak	6/1/2008

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1.0 EXECUTIVE SUMMARY

The James Webb Space Telescope (JWST), a general-purpose infrared space Observatory, will be located at the second Sun-Earth Lagrange Point (L2). JWST will be used by international scientists to investigate a wide range of fundamental astrophysical questions ranging from the nature of the first luminous sources of light in the Universe to the nature of planet formation.

A logical successor to NASA's most successful astronomical mission, Hubble Space Telescope (HST), the ~25 m^2 JWST primary mirror will deliver near diffraction limited images (0.1″ at 2μm) to a suite of instruments capable of wide-field imaging and spectroscopy over the wavelength range 0.6-27 μm. Built for the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Canadian Space Agency (CSA) by teams of engineers at Northrop Grumman Space Technology (NGST), the Goddard Space Flight Center (GSFC) and elsewhere, the Observatory will be operated from the Science and Operations Center (S&OC) located at the Space Telescope Science Institute (STScI).

This document describes the operations concept for the JWST mission. This concept is intended to maximize the scientific potential of JWST within a set of overall cost constraints for the mission, both in its development and operational phases. The mission concept is tailored to the primary science themes of the mission:

- First Light in the Universe
- Assembly of Galaxies
- Physics of Star Formation
- Formation of Planetary Systems and the Conditions for Life

The uses of JWST are expected to extend well beyond these themes, and indeed it is reasonable to expect that some major new astrophysical questions will arise between now and 2011, when JWST will be launched. But the capabilities required for these four themes provide a sound basis for a wide range of science investigations.

In order to carry out its scientific mission, JWST will be instrumented with:

- Near-Infrared Camera (NIRCam) - a near-infrared (NIR) camera, being developed by the University of Arizona, providing wide-field medium and narrow-band imaging from 0.6-5 μm.
- Near-Infrared Spectrograph (NIRSpec) - a 0.6-5 μm-wide-field, multi-object, NIR spectrograph being developed by ESA.
- Mid-Infrared Instrument (MIRI) - a combination mid-infrared camera and integral field spectrograph, being developed jointly by NASA and a European consortium, for the wavelength range 5-27 μm.

In addition, the Fine Guidance Sensor (FGS), being built by the CSA to provide fine pointing updates to the Observatory, will contain one or two optical channels that can be used for narrow-band imaging in the NIR. All of the instruments, including the FGS, will be instrumented with array detectors. Although the specific requirements for the detectors are different, all must be kept cold to minimize internal dark current and all contain similar multiplexer-based readouts that facilitate commonality of readout modes.

The elements of the Observatory at L2 are:

- The optical telescope, including a segmented primary mirror, secondary mirror and fine steering mirror
- A cold Integrated Science Instrument Module (ISIM) housing the science instruments and the FGS
- A spacecraft which provides a sunshield to shade the Observatory and a bus for power and Observatory services.

The primary and secondary mirrors will be folded within the faring of the Ariane rocket on which JWST will be launched and deployed on the way to L2. Optics within the NIRCam will be used to co-phase the mirror segments and to maintain the figure during normal operations. The Attitude Control System (ACS) includes reaction wheels for slewing the Observatory from target to target, fixed head star trackers and gyros for coarse attitude control, and the FGS for acquisition of guide stars and for providing error signals. These error signals are processed to drive the fine steering mirror to maintain fine pointing with jitter of 5 milliarcsec or less (MR-174). Science and engineering data are stored on a solid-state recorder and transmitted to the ground via S & Ka-band communication links through the Deep Space Network (DSN), JWST Network Support System (JNSS), to the S&OC (MR-82). Typically there will be daily ground contacts of at least 4-hour duration (MR-352) to provide for uplink of new commands and for downlink of up to 229 gigabits of science data (MR-76) and 6.3 gigabits of engineering data. These contacts will also provide Doppler tracking and ranging data for orbit determination (MR-294). The prime science programs require observations throughout the celestial sphere. Typically, JWST will observe 2-3 target positions per day. Most imaging observations will involve multiple exposures at slightly different pointing positions (dithering) to reach the required sensitivity and to permit removal of spurious, but transient, signals induced as high-energy charged particles pass through the detectors. Acquisition of the science targets with NIRCam and MIRI will be very similar to acquisition procedures used for imaging, long-slit and coronagraphic applications on the HST. The NIRSpec will be more challenging since the programmable Micro-Shutter Array (MSA) is intended to allow an astronomer to obtain spectra of up to 100 discrete objects simultaneously.

The operational approach is science-driven and intended to be simple and transparent for the science user to understand. A significant number (~100 to 200) of investigations will be selected annually based on a competitive peer review. Observers will use a single integrated tool to prepare proposals and to detail approved observations. Following program selection, the S&OC will construct a long range observing plan that observers and planners at STScI will use for detailed planning and scheduling. Commonality of operating modes for the various instruments and of procedures for reducing the data will assist astronomers in understanding how the

Observatory operates. Generation of an observation plan and visit descriptions will be completed shortly before observations are scheduled to take place and uploaded to the Observatory on an approximately weekly basis. Astronomers will not need to visit the STScI S&OC for their observations.

The Observatory is designed to operate primarily from a stored Observation Plan, which controls pointing of the telescope, acquisition of guide stars, and execution of observations by the science instruments. The Observation Plan specifies a sequence of "Visits" to be executed sequentially. A Visit is the collection of spacecraft and science instrument activities that use a single guide star to control pointing and are scheduled for execution as a unit. The activities may be executed sequentially or in parallel with other activities in the visit. Each activity will invoke and pass parameters to a command script, which will invoke and pass parameters to other command scripts or flight software or hardware commands.

There are two main computers on the Observatory:

- The Command and Telemetry Processor on the Spacecraft bus is responsible for the overall health and safety of the Observatory and oversees all of Spacecraft functions, including the primary mirror subsystem, the attitude control subsystem, the solid state recorder (SSR) and the FGS.
- The IC&DH computer executes the Observation plan, requesting services, such as slews, from the spacecraft through the Command and Telemetry Processor, and oversees instrument operations.

Normally, Observatory operations are event-driven, in the sense that one activity (or command, script, or visit) is executed upon completion of the previous activity. Parallel operations are possible, and an activity can be set to wait for completion of parallel activities before execution. Timing constraints or other conditions can also be set on execution of activities; in particular timing constraints for sun avoidance are set on visits to ensure compliance with Observatory health and safety constraints. Failure conditions can also be used to control operations; in particular if a guide star acquisition fails the remaining activities in the visit will be skipped. This mode of operation differs from absolute or relative time driven operations, which require each activity to be executed at a specific time or specific delta time from the previous activity.

The Observatory can autonomously perform some operations that interrupt execution of the Observation Plan, such as momentum dumping or antenna pointing. The propulsion system will be used to dump momentum from the reaction wheels prior to a slew when the momentum exceeds an operational limit, or is predicted to exceed that limit during an upcoming visit. Antenna pointing will be done to maintain pointing error within an operational limit; but since antenna pointing will disturb pointing stability, the antenna will normally be moved between exposures or as necessary during slews.

Command and data communications are generally independent of and do not interfere with the execution of the Observation Plan (MR-135). In particular, communications will be maintained during slews. Most Observatory operations do not require real-time contact; only orbit and flight software maintenance activities and contingency operations (such as recovery from safe-mode) will require real-time uplink. Orbit maintenance activities will be controlled by real-time command and require monitoring by flight operations personnel.

Communications will be established with the Observatory in response to a Communications Schedule coordinated between the DSN and the S&OC. The Observatory will transmit real-time engineering telemetry for the duration of the contact and will transmit recorded data files from the SSR . Since Observatory operations are mostly autonomous, it will not be necessary to staff the flight operations center during most communications contacts. The S&OC will operate autonomously during most communications contacts, and command and data communications will be automated. Flight operations staff will support a normal 8-hour, 5-day workweek to prepare command loads and perform trending analysis of Observatory performance, and will support communications contacts when needed for mission operations. An automated anomaly detection and notification system will ensure that operations personnel are notified and respond to anomalies detected during communications contact.

2.0 INTRODUCTION

2.1 OVERVIEW OF THE JAMES WEBB SPACE TELESCOPE

JWST is a 6-m class infrared (IR) telescope that is being developed by the NASA, the ESA, and the CSA within the framework of the NASA Origins program to study and answer fundamental astrophysical questions ranging from the formation and structure of the Universe to the origin of planetary systems and the origins of life. A scientific successor to the HST and the Spitzer Space Telescope (SST), JWST will be used by international teams of astronomers to conduct imaging and spectroscopic observations in the wavelength range 0.6-27 μm. The Observatory will be located in an orbit near the second Lagrange Point, L2, approximately 1.5 million km from Earth (MR-041). The telescope and instruments will be cold (~30K) and shielded from the heat of the Sun by a large Sunshield. As a result of the low background, the Observatory will achieve unprecedented sensitivity over its entire wavelength range.

A telescope with a segmented primary mirror will deliver IR light to the three main scientific instruments of the Observatory:

- NIRCam - A wide-field Near-Infrared Camera, being developed by the University of Arizona, providing wide-field medium and narrow-band imaging from a 0.6-5μm.
- NIRSpec - a 0.6 to 5 μm wide-field multi-object Near-Infrared Spectrograph being developed by ESA.
- MIRI - a Mid-Infrared Instrument that combines a mid-infrared imager and integral field spectrograph, being developed jointly by NASA and a European consortium, for the wavelength range 5 to 27 μm.
- TFI – the NIR Tunable Filter Imager in the Fine Guidance Sensor being built by CSA.

Many organizations will contribute to this undertaking. NASA has the overall responsibility for all aspects of the Observatory, and will develop portions of it, including the ISIM that will house the instruments and the FGS, as well as communications and ranging support through the DSN. NGST and their industrial partners will build and integrate the telescope and the Spacecraft. In addition to developing one of the instruments and overseeing the European contribution to MIRI, ESA will launch JWST on an Ariane V from Kourou, French Guiana. Finally, the STScI will create and staff the S&OC for the Observatory.

2.2 PURPOSE AND SCOPE

The purpose of this document is to establish the framework for operations of all major aspects of the JWST as an Observatory. It provides an overview of the operations concept, and describes the important features that affect the operation of JWST, both to maximize the science productivity of the Observatory and to minimize the overall cost of the mission. Formal requirements for the document are outlined in the JWST Science and Operations Data Requirements Document.[1]

The Mission Operations Concept describes how JWST will operate as a system. The system, and hence the scope of the document, includes the operation of the JWST Observatory and the entire ground system. The time period covered ranges from the Integration and Test (I&T) phase through the completion of the normal operations phase.

The primary readers are the engineering and scientific staffs of the organizations that will build and operate JWST- at NASA, NGST and their partners at Ball, ITT and elsewhere, the science instrument development teams, ESA, CSA and STScI.

Details of JWST operations will evolve as the design and construction of JWST proceeds, and some of the concepts presented may be modified as trade studies are completed for the mission. This document will then serve as a point of departure for many of the refinements, and as a guide to areas where operations complexity can become an important factor in overall mission cost.

The operations concepts described here will be used to determine capabilities required of ground and flight systems, and identify interfaces between ground and flight systems. This document provides the foundation by operations planning for the spacecraft and ground system can proceed through the official requirements and specification process. Requirements for the mission are documented at the mission/segment/element levels in the appropriate requirement and interface documents.

2.3 DOCUMENT OVERVIEW

This document has been created for JWST scientists and engineers with varying technical backgrounds and very different levels of involvement in JWST. Some readers will not know a great deal about JWST. They will look to the document as a complete introduction to JWST and how it will operate. Other readers will be concerned with specific elements or subsystems of JWST. They will look to see that their subsystem is represented appropriately in the document and to assure that the designs, lower-level operations concept documents, and operational procedures for their element or subsystem supports the overall mission concept. This document is organized into seven major chapters. In order to make good use of his or her time, readers should probably consider which portions of the document are most important for their particular needs. A brief description of remaining chapters of the document is as follows:

- Introduction describes the purpose and scope of this document and provides the structure for the rest of the document.
- Science, Scientists and JWST provides an overview of the science objectives of JWST, of the type of observations are need to carry out these objectives, and of the way JWST will be run from the perspective of the astronomers who will use JWST to realize the science objectives.
- Mission Architecture provides brief descriptions of the various segments and elements of the mission. This includes a description of the Observatory: the telescope, the spacecraft, the ISIM, and the instruments, as well as the ground and launch segments.

- Operations Description provides an overview of the event-driven operation approach that will be used to implement the mission, as well as descriptions of the operations of the elements of the mission, including the instruments, the FGS, the Spacecraft and the ground system. Operations during commissioning and I&T are included.
- Normal Operations provides scenarios of selected processes to illustrate major aspects of the operations concept. These include normal operation of the science instruments and the spacecraft.
- Contingency Operations provides scenarios associated with contingencies, including instrument and spacecraft safings and recovery.
- Integration and Test provides a description of the facilities and operations approach that will be used for I&T. This begins when the spacecraft and ISIM are mated together in the I&T High Bay in California.
- Appendices. There are five appendices:
- List of Abbreviations and Acronyms.
- Requirements Cross-Reference links specific operations-related requirements in the Mission Requirements Documents to the appropriate sections of this document.
- Observatory States and Modes gives formal definitions of the states and modes for the Observatory and indicates how what transitions between them are allowed.
- Day in the Life provides detailed step-by-step descriptions of certain operations, as currently conceived for JWST.
- Endnotes.

2.4 REFERENCE DOCUMENTS

JWST-RQMT-000634	JWST Mission Requirements Document
JWST-RQMT-002558	JWST Project Science Requirements Document
JWST_RQMT-001056	JWST Ground Segment Requirements Document
JWST-PLAN-002040	Observatory Commissioning Plan (OPS-01)
JWST-RQMT-002032	JWST Science & Operations Center Element Requirements Document
JWST-RQMT-000804	JWST Project Science Objectives and Requirements
JWST-HDBK-002046	JWST Observatory Constraints and Restrictions Document

2.5 MISSION OPERATIONS CONCEPTS FOR JWST SYSTEM ELEMENTS

The Mission Operations Concept Document (MOCD) provides an overview for the operation of JWST as a whole and provides a framework for more detailed description of operations of individual portions of JWST. The other important operation concept documents being developed for JWST include:

JWST-STScI-000547	NIRCam Operations Concept Document, P. McCullough et al. 2004

JPL D-25632	(OPS-02) MIRI Operations Concept Document, M. Meixner et al. 2005
JWST-STScI-000403	NIRSpec Operations Concept Document, M. Regan et al. 2004,
JWST-STScI-000047	(SM-02) S&OC Element Operations Concept Document, P. Stanley et al. 2004

3.0 SCIENCE, SCIENTISTS AND THE JAMES WEBB SPACE TELESCOPE

MO-1 JWST is a science mission. It is intended to answer fundamental astrophysical questions, such as how and when galaxies were born. The importance of these questions and the unique capabilities of JWST to answer them led to its selection by the Astronomy and Astrophysics Committee of the National Research Council as the top priority U.S. program in astronomy and astrophysics for the decade 2000-2010. The success of JWST ultimately depends on how effectively, how completely, at what cost, and when JWST addresses these fundamental astrophysical questions

MO-2 A sound operations approach that reflects the science mission of JWST is a basic ingredient for mission success. It affects the design and development cost of the Observatory and the mission. It determines how effectively the operational staff will plan and conduct the observations and whether they can respond to problems once the Observatory has been launched. Perhaps most importantly, the operations approach will determine whether scientists, the ultimate users of JWST, will be able to use JWST to its full scientific potential.

MO-3 To understand the operations approach for JWST, it is necessary to understand the basic science program for JWST, what the science program implies about the observations that are likely to be conducted, and how astronomers will interact with JWST.

3.1 JWST IS THE SCIENTIFIC SUCCESSOR TO THE HUBBLE SPACE TELESCOPE

MO-4 By almost any measure, HST has been NASA’s most significant astrophysics mission. However, almost as soon as HST was launched, the astrophysics community began to consider what capabilities would be needed to take the next major stride beyond HST. In 1989, participants of the Next Generation Space Telescope workshop concluded that future observatories would have larger optics to provide finer angular resolution and would need to have wavelength coverage extending to the mid-IR in order to observe the same features in objects at high redshift (greater distance, further back in time) as HST at lower redshift (between the Milky Way and the epoch when our Sun was born, about five billion light years away).[2] To do this, the telescope and instruments needed to be cold to reduce their own glow and achieve sensitivities limited only by the sunlight scattered in the solar system in the infrared (> 1 µm). Subsequently, a committee -- the HST & Beyond committee - was chartered by AURA, with the support of NASA, to consider “missions and programs in UVOIR astronomy in the first decades of the 21st century.” The committee recommended, “NASA should develop a space Observatory of aperture 4m or larger, optimized for imaging and spectroscopy over the wavelength range 1 to 5 µm.”[3] Moreover, given the unique and important capabilities that such an Observatory might have at shorter and longer wavelengths, they recommended that these should also be developed if they did not substantially increase the cost to the Observatory. The "Dressler Committee" saw the core science program of such a large, infrared-optimized telescope as observing the birth and growth of galaxies at redshifts greater than those that HST and ground-based telescopes could explore.

MO-5 At the time of the HST & Beyond committee recommendations, there were few objects other than bright quasars that were known beyond a redshift of $z \sim 2$, and the study of galaxies beyond $z > 0.5$ was in its infancy. Nevertheless, the HST & Beyond report identified many of the key science areas that have become the defining goals for JWST science, including understanding the formation and evolution of galaxies, using distant supernovae as cosmological probes, and the study of planets and planetary systems. A great deal of scientific progress has been made since then, but the JWST advantages over all other planned facilities remain: its large, diffraction-limited optics that yield Hubble resolution at near-infrared wavelengths, and its low background compared to ground-based facilities.

MO-6 After the initial feasibility study[4] an Ad Hoc Science Working Group (ASWG) was appointed to develop in more detail the scientific vision of the telescope that was to become JWST. The ASWG focused on the defining capabilities of JWST:

- Backgrounds limited only by the zodiacal light from 0.6 μm to 10 μm.
- Large diffraction-limited telescope aperture (6 to 8 m diameter).
- A broad spectral range, 0.6 to 27 μm (MR-107), which complements that of HST (0.12 to 2.4 μm), and follows up the discoveries of SST (3.14 to 180 μm). These would be used to study the early universe and to explore a broad range of discovery space in the MIR, in particular star and planet formation.
- Wide field of view (FOV) cameras and spectrographs for the efficient population studies of faint field objects.

MO-7 Rather than explore every type of observation that would be carried out with a large IR-optimized telescope in space, the ASWG focused on a restricted set of programs that made use of JWST's unique capabilities to answer questions of the broadest possible astrophysical importance. They developed a prioritized list of 22 programs. The ASWG described the motivation behind each program and developed a specific set of observations to carry out each program in a format similar to that used to propose for HST or Chandra X-ray Observatory (CXO) time. We refer the interested reader to the JWST Science Objectives and Requirements[5] for a summary of each of the ASWG core programs and their observing strategies. The programs and the observations were used in formulating the detailed requirements for the mission during the conceptual design phase of JWST, including the requirements for the JWST instrumentation. Based upon the strength of this program and the Observatory's unique capabilities, the Astronomy and Astrophysics Committee of the National Research Council ranked JWST as the top priority U.S. program in astronomy and astrophysics for the 2000 to 2010 period.

MO-8 As one might expect, as time has passed, as the characteristics of the Observatory have changed and scientific knowledge has grown, the details of the programs have changed. But all of the core ASWG programs and most of the remaining programs are represented in the JWST Science Working Group (SWG) Science Requirements Document (SRD). And most, if not all of the requirements for JWST that will be implemented were actually requirements developed in this process.

3.2 SCIENCE MISSION GOALS:

MO-9 The JWST SWG has reformulated the DRM for JWST into four broad themes of scientific research for JWST and modified the program somewhat to reflect increasing understanding of the challenges that JWST can be expected to answer. The Science Requirements Document[6] describes these themes in detail, and will be used for the remaining development of JWST. We summarize the themes in the following sections and indicate how the themes drive the mission operations concept and some of the requirements found in the MRD.

3.2.1 The First Light

MO-10 The emergence of the first sources of light in the Universe marks the end of the "Dark Ages" in cosmic history, a period following the early expansion and cooling of the Universe, when hydrogen and helium recombined but before the creation of denser, self-luminous structures such as stars. The First Light epoch is when it all started and is therefore an essential ingredient to understand how galaxies formed and structures developed in the Universe. The current leading models for structure formation predict a hierarchical assembly of galaxies and clusters. Therefore, the first sources of light should act as seeds for the subsequent formation of larger objects, and from their study we will learn about processes relevant to the formation of the nuclei of present-day giant galaxies.

MO-11 Some time after the appearance of the first sources of light, hydrogen in the Universe reionized. We do not know the time lag between these two events nor whether reionization is brought about by the first light sources themselves or by subsequent generations of objects. Reionization is by itself a period in cosmic history as interesting as the emergence of First Light. The epoch of reionization is the most recent and perhaps the most accessible of the global phase transitions undergone by the Universe after the Big Bang.

MO-12 The First Light programs answer the following questions:

- When did the first luminous sources arise and what was their nature? What were their clustering properties?
- When did reionization occur? Did it occur in two episodes separated by a partial recombination phase?

- Which sources were responsible for reionization? Were they powered by nuclear fusion or gravitational accretion?

MO-13 These observations associated with First Light science involve long imaging and spectroscopic campaigns over a small number of fields at high Galactic latitudes similar to the Hubble Deep Field (HDF). Using broad-band filters in the NIRCam and MIRI, scientists will be able to determine the redshifts of faint sources and whether they are dominated by starlight or non-thermal emission characteristic of quasars. Follow-up observations with NIRSpec and the MIRI spectrograph of the highest redshift candidates will look for the absorption signature of a neutral Intergalactic Medium, the Gunn-Peterson trough, and for the emission lines expected from gas surrounding hot stars (nuclear fusion) or quasars (gravitational accretion). The defining characteristics of these observations are long exposures for each field taking upwards of several weeks per field for imaging and spectroscopy. Astronomers will plan the spectroscopic observations based upon the preliminary analysis of the deep imaging data, and will utilize the multi-aperture capabilities of the NIRSpec to obtain spectra of up to 100 candidates simultaneously.

MO-14 Because of the emphasis on great sensitivity, observations in this theme will require the lowest possible backgrounds and the greatest Galactic transparency at short wavelengths. Figure 3-1 shows a view of the sky in Ecliptic Coordinates (the equator corresponds to the orbital plane of the Earth). The two darkest areas are near the North and South Galactic pole (GN & GS), where JWST would point straight out of the Galactic plane, avoiding the scattering and emission of Galactic dust. The zodiacal background is highest in the plane of the solar system, the region within the dotted area, where the zodiacal light can be more than twice as bright as its value near the Ecliptic poles. The optimum viewing areas are near the Hubble Deep Field North (HDFN) and the Chandra Deep Field South (CDFS).

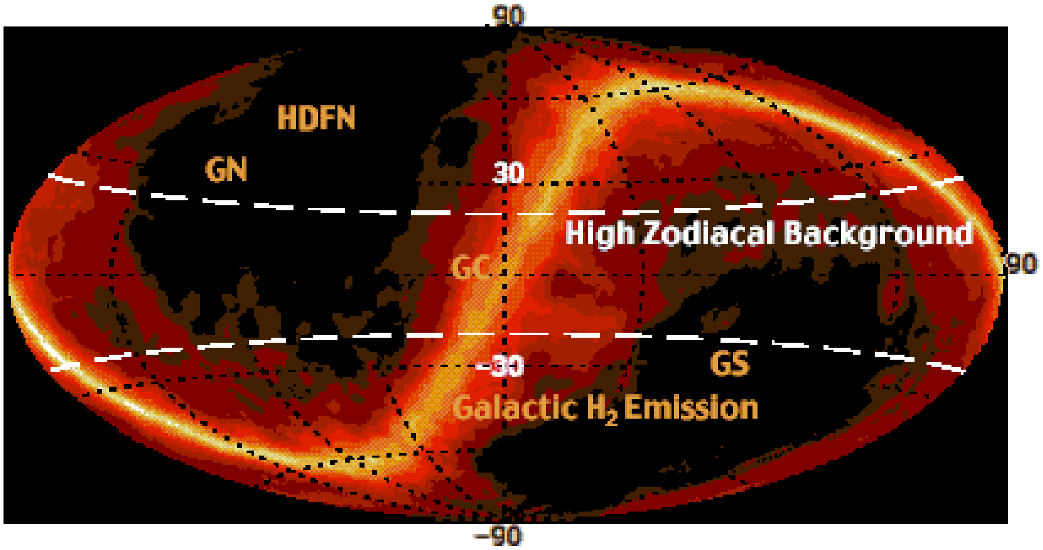


Figure 3-1. Sky Map in Ecliptic Coordinates with Galactic H2 and Regions of High Zodiacal Background Indicated

3.2.2 The Assembly of Galaxies

MO-15 Theory and observation suggest a hierarchical assembly of galaxies. Small objects formed first, and then were drawn together to form larger ones. This process is still occurring today, as the Milky Way is swallowing the Magellanic Clouds, and as the Andromeda Nebula is heading toward a future collision with the Milky Way. Galaxies have been observed back to times about two billion years after the Big Bang. While most of these early galaxies are smaller and more irregular than present-day galaxies, some early galaxies are very similar to recent ones. This is a surprise and raises many questions about their origin.

MO-16 The key objective of the Assembly of Galaxies theme is to observe galaxies back to their earliest precursors so that we can understand how they work.

MO-17 Only JWST can see far enough back in time to do this and answer six fundamental questions through observations of faint galaxies in the redshift range $1 < z < 7$ (from the present epoch to the epoch of reionization).

- Where were galaxies in the Hubble Sequence (spirals, ellipticals, irregulars) formed, when did luminous quiescent galaxies appear, and how does this depend on the environment?
- Where and when are the heavy elements produced and to what extent do galaxies exchange material with the intergalactic medium (IGM)?
- When and how are the global scaling relations for galaxies established?

- Can we confirm the hierarchical assembly of dark matter haloes and luminous galaxies?
- What are the redshifts and power sources of the high redshift Ultra Luminous Infrared Galaxies (ULIRGs)?
- What is the relation between the evolution of galaxies and the growth and development of black holes in their nuclei?

MO-18 Like the First Light theme, the Assembly of Galaxies theme uses deep imaging and multiplexed spectroscopic observations of fields at high Galactic latitudes. However, there will be a greater emphasis on photometric and spectroscopic precision for the brighter objects. The morphologies (shapes) and colors of galaxies as well as the line ratios of H, He, N, O, etc. will be crucial diagnostics.

MO-19 The Assembly of Galaxies programs drive many of the JWST pointing and constraint requirements. The studies in this theme will require the observations of thousands of galaxies in large fields and in distant clusters of galaxies. This will require the patching or mosaicing of 2 to 16 NIRCam and NIRSpec fields for a given general pointing. The emphasis on photometric and spectroscopic precision leads to a requirement on small offset-pointing ("dithering") to reduce systematic errors. The requirement to observe and then follow distant supernovae discovered during the First Light and the Assembly of Galaxies observations drives the need for a large field of regard (Sun constraints) and implies a planning concept that allows for rapid and accurate location of SNe candidates and the intermixing of spectroscopic and imaging programs.

3.2.3 <u>The Physics of Star Formation</u>

MO-20 While stars have been the main topic of astronomy for thousands of years, only in recent times have we begun to understand them with detailed observations and computer simulations. A hundred years ago we did not know that they are powered by nuclear fusion, and 50 years ago we did not know that stars are continually being formed. We still do not know the details of how they are formed from clouds of gas and dust, or why most stars form in groups. We also do not know the details of how they evolve and liberate the "metals" (astronomers' term for all the elements produced by the fusion of hydrogen and helium) back into space for recycling into new generations of stars and planets. In many cases these old stars have major effects on the formation of new ones.

MO-21 The Physics of Star Formation theme will use the JWST NIR and MIR imaging and spectroscopic capabilities to answer the following questions:

- What is the nature of the inflow and collapse of proto-stellar clouds prior to star ignition?

- How does the star-forming environment (metals, density, etc.) affect the numbers and masses of stars formed?
- How does the star-formation mechanism turn off?
- What are the smallest masses of stars or brown dwarfs ("failed stars") that form in isolated systems compared to multiple systems?

MO-22 Observations in this theme will use large NIR and MIRI imaging surveys of nearby star formation regions to identify candidates for spectroscopic follow-up. These are often complex and crowded star fields in which the brightest stars may be many millions of times brighter than the fainter target stars. Identifying and acquiring the target stars, while avoiding optical contamination by nearby bright stars, will be demanding and may place strong roll constraints on certain observations. In the earliest stages of star formation, the dust-shrouded ("embedded") target stars will be much (100-10,000 times) brighter at long MIR wavelengths (~ 20µm) than NIR wavelengths and will be completely obscured at visible wavelengths. Astronomers will use specialized calibrations and data analysis tools to remove the effects of scattered long-wavelength light within the NIR and MIRI spectrographs.

3.2.4 The Formation of Planetary Systems and the Conditions for Life

MO-23 Observations show that most stars are formed in multiple star systems and that many stars have planets. However, there is little agreement about how this occurs, and the recent discovery of large numbers of planets in very close orbits around their stars was surprising. Understanding the origin of the Earth and its ability to support life is a key objective for all of astronomy and is central to the JWST science program. Key parts of the story include understanding the formation of small objects and how they combine to form larger ones; learning how planets reach their present orbits; learning how large planets affect the others in systems like our own; and learning about the chemical and physical history of the small and large objects that formed the Earth and delivered the necessary chemical precursors for life. The JWST observations of objects in our own solar system and planetary systems around other stars will provide data crucial for understanding the origin of planetary systems, the origin of free-floating brown dwarfs ("failed stars") and planets, and the potential for stable habitable regions around other stars.

MO-24 This theme will address the following questions:

- How do planets and brown dwarfs form?
- How common are giant planets and what is their distribution of orbits?
- How do giant planets affect the formation of terrestrial planets?
- What comparisons, direct or indirect, can be made between our solar system and circumstellar disks (forming solar systems) and remnant disks?

MO-25 This theme utilizes the unique imaging and MIR capabilities of JWST to study solar system objects - outer planets and their satellites, comets, and Kuiper Belt objects (mini-Plutos) - and potential astronomical counterparts in the solar neighborhood. In addition to its heavy use of the three JWST instruments, particularly MIRI, this theme stresses the need for moving target tracking at rates sufficient to track the solar system targets, and the coronagraphic capabilities of the two cameras. Moving target tracking introduces requirements that affect both the Observatory and S&OC operations. The Observatory and the FGS must be designed to allow observations with good image quality while tracking. The S&OC must be able to plan observations that require much more precise timing than otherwise, because planetary observations have scientific ephemeris constraints and because guide stars change on relatively short timescales. High-contrast coronagraphy tends to involve relatively short observations, but often requires stable image quality and observations at multiple orientation angles.

3.3 IMPLICATIONS OF SCIENCE FOR THE JWST OBSERVING PROGRAM

MO-26 Although the SRD has distilled the JWST program into four core themes, the expected science program remains quite diverse in terms of the types of observations that must be scheduled with JWST.

MO-27 The program is dominated in terms of time by deep observations that do not have tight time constraints. The majority of these observations will be carried out at high galactic latitude where contamination from the Galactic foreground is low. It is likely that a number of these regions will already have been studied with HST, CXO, SST, and ground based observatories. The deep surveys that will be conducted with JWST will probably involve all of the instruments -- imaging with NIRCam and MIRI, and spectroscopy with NIRSpec. There will be observations covering very small regions, or about the size of the NIRCam FOV that will extend to the limiting sensitivity of JWST, as well as shallower surveys covering larger fields. All of the imaging observations will involve dithers in order to remove pixel-to-pixel variations from the images and many will be mosaiced. These deep fields drive the requirements for optical quality, instrumental sensitivity, and the field of regard. The total observing time at the deepest position will be at least 10^6 s, and will likely be longer than this when observations with all of the instruments are considered. The deep NIRSpec observations will use several grating settings and will need to be carried out at a single orientation angle, which implies that the Observatory must be able to maintain stable pointing with a single orientation for at least 10 days (MR-177).

MO-28 Although the deepest observations will be concentrated at high Galactic latitudes, there are important observations of, for example, individual galaxies and star-forming regions that require access to the entire sky (MR-103). Individual observations of these objects are likely to be shorter than those for the deepest programs, although typical pointings of order 12 hours are planned. While the number of pointings is higher than for the ultradeep observations, the number of pointings is still sufficiently small and the objects significantly unique that efficient use of JWST cannot be guaranteed unless planners can make use of the entire field of regard with a minimum of additional constraints (e.g. having to manage other parameters, such as buildup of momentum in the momentum wheels).

MO-29 Some observations, e.g., the need to monitor SN light curves at high redshift, require very long continuous visibilities, particularly at high galactic latitude where zodiacal and stellar backgrounds are low, leading to a requirement for a minimum of 60 day continuous visibility over at least 50% of the sky (MR-105).

MO-30 Most of the observations that will be conducted with JWST do not have tight scientifically driven time constraints. This means the operations concept can be optimized for observations without time constraints. However, there are induced time requirements associated with planetary observations, and therefore the operations concept must be able to accomplish these as well.

MO-31 In order to carry out the science program envisioned for JWST, the mission lifetime following commissioning must be at least 5 years (MR-044, MR-047). This requirement is based both on direct estimates using the DRM and on the simple fact that without a mission lifetime of this order, there will not be enough time to analyze the first results from the Observatory and to pursue those results to their logical conclusion. Based on the experience obtained with HST and other Great Observatories, the science productivity of JWST will be extremely high at the end of its nominal lifetime and for this reason propellant will be sized to accommodate 10 years of science operations (MR-048).

3.4 SCIENCE MANAGEMENT AND PROGRAM TYPES

MO-32 Like HST, CXO, and SST, JWST will be managed as a “facility class” Observatory, accessible to the international scientific community. The JWST S&OC will manage the overall science mission. The S&OC will solicit proposals for utilizing JWST capabilities and will organize an international peer review system to recommend the best programs. The STScI Director will make the final selection of the science program. The S&OC will assist observers in the development of detailed observing plans and will distribute calibrated data to them after the observations are completed

MO-33 The bulk of the observing time will be awarded via completive selection in annual solicitations beginning a year before the JWST launch. Although the mission is designed around the science themes above and in the SRD, the actual science program will maximize the science productivity of JWST using all of the information that has been gleaned up to and through the launch of JWST. Nevertheless, the following types of programs are anticipated:

- Large programs, similar to the Hubble Key Projects and Treasury programs, and the SST Legacy programs, with total observing times of 10^6 to 10^7 s that will tackle goals similar to those described in the SRD and core ASWG DRM proposals. These programs will involve fairly large teams of astronomers and have special requirements to make the data public quickly to allow both the original proposers and the general astronomical community ready access to the data.
- General observer (GO) programs, with observing times ranging from 5×10^4 - 10^6 s, intended to address more specific scientific goals conducted by small groups of astronomers. Many of these programs will be targeted at the same general themes as the Legacy proposals, but others will be in completely different areas.
- Guaranteed-time observer (GTO) programs that will allow SWG members to accomplish the science goals they proposed when they competed to build instruments or serve as experts during the development phase. These will be comparable in scope to GO programs.
- Archival research (AR) programs that will exploit the data in the JWST archive to accomplish goals that require uniform analyses of large data sets or goals not envisioned by the original observers.

MO-34 Based on the SRD, as well as the Phase A studies of JWST, most observations with JWST will not have tight, astronomically-driven time requirements. There are some, however, and these are basically of two types:

- Time-critical observations are observations that must occur at or near a specific time to accomplish the science objective. A good example of such a program in the HST-era was the impact of comet Shoemaker-Levy on Jupiter. The STScI planned the HST observations to occur at the times of the individual impacts, which were predicted weeks in advance.
- Target of opportunity observations, by contrast, are programs triggered by rare astronomical events, such as a nearby supernova explosion. The time that the supernova explosion will occur is not known in advance, but when it does occur a specific set of observations needs to take place within specific time intervals.

MO-35 Following the Spitzer-model, the first six to nine months of JWST science observations will be dominated by a small number (four to six) of Legacy-style programs and a larger number (~40) of guaranteed science programs. A transition to a larger (100-200) annual number of investigations will occur within a year after commissioning. In order to maintain high efficiency, the number of time critical and target of opportunity observations will be strictly limited throughout the entire program and especially in the first year of science observations.

3.5 THE ASTRONOMERS VIEW OF JWST

MO-36 The primary users of JWST will be scientists, and their interactions with JWST operations will be simple and easily understood. Astronomers will not need to visit the STScI for their observations. As shown in Figure 3-2, the interaction of astronomers with JWST will follow steps that, at least in block form, are very similar to those of other space-based, facility-class astronomy missions, such as HST, CXO and SST.

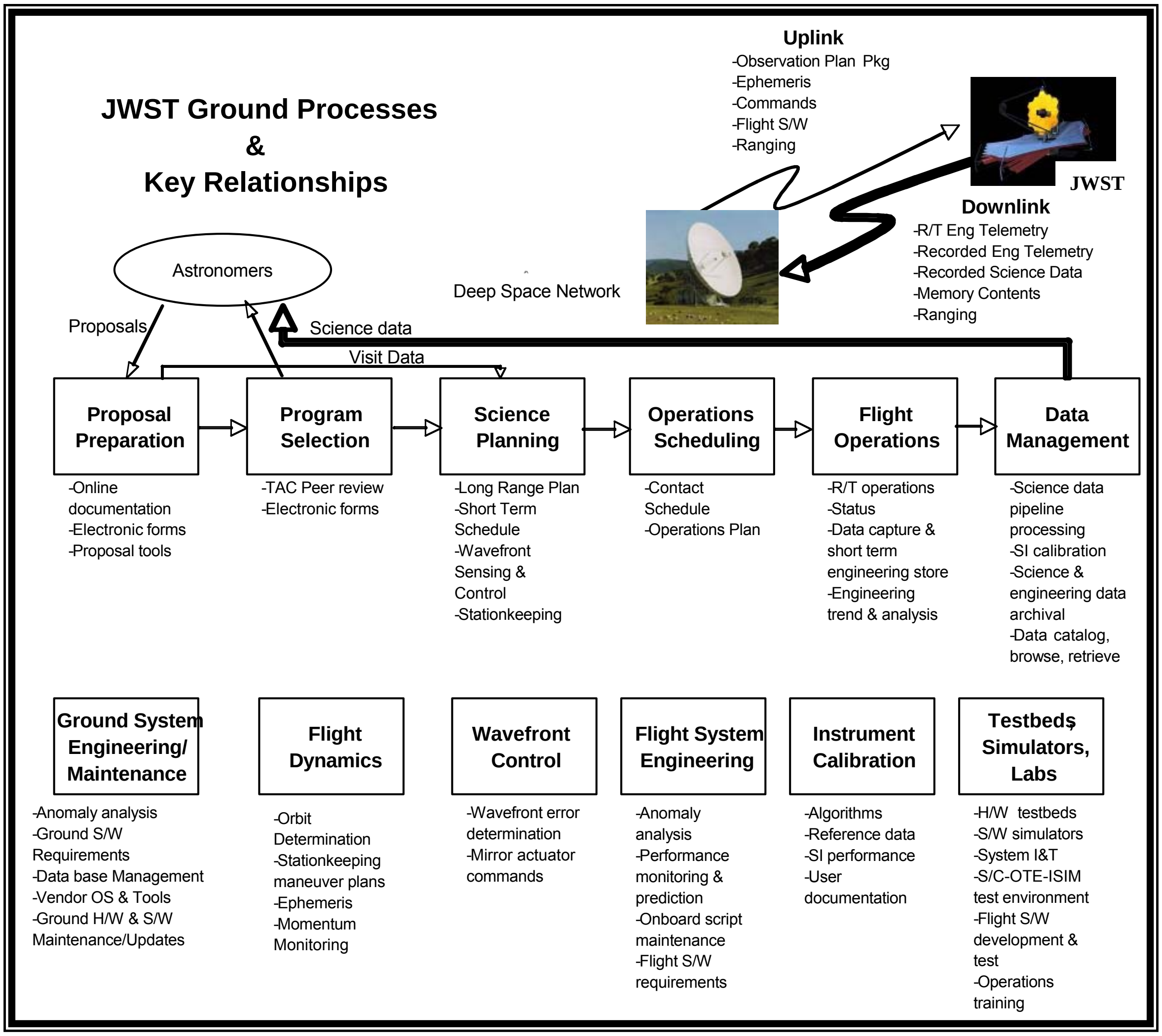
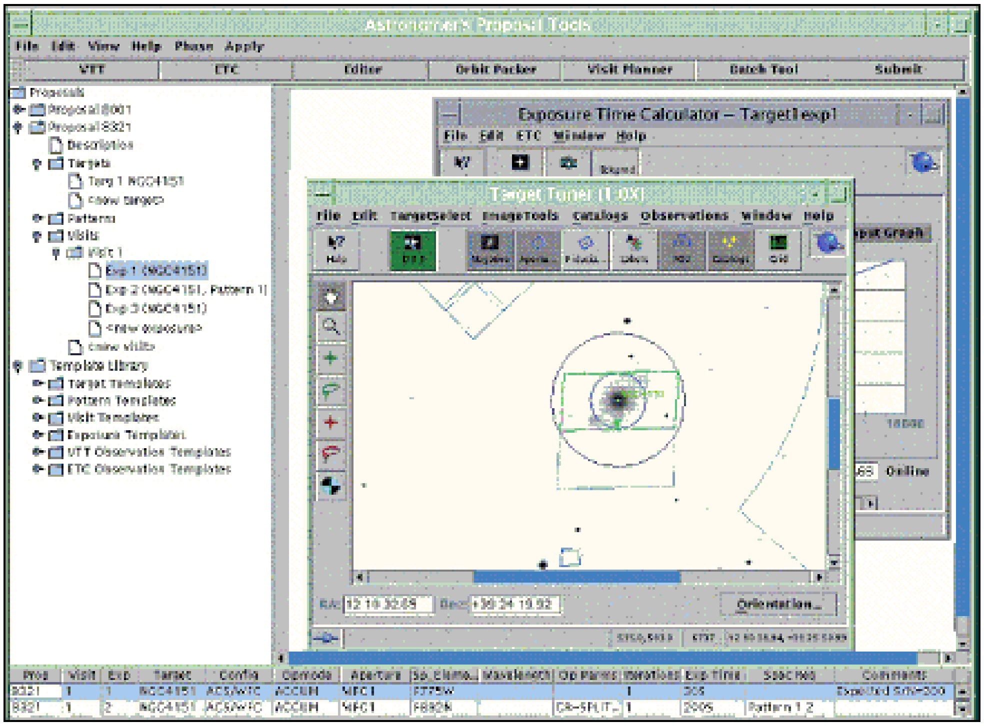


Figure 3-2. The Scientist and JWST

MO-37 In the case of JWST, the STScI will issue a Call for Proposals annually. Each proposal will consist of a scientific justification and a technical specification. The observations in a proposal will be divided up into logical units called "visits", usually all of the activity required to obtain all of the data at one general location in the sky with a single instrument. During the initial portion of the proposal process (Phase I), the astronomer will only be required to enter the portions of a complete observing proposal that are required for scientific and technical assessment of the proposal. Once the proposal is selected, the scientist will provide the missing details that would be required to execute the now-approved observations on JWST (Phase II). In Phase I for example, a proposer intending to carry out multi-object spectroscopy with NIRSpec would need to define the pointing position, gratings, and exposure times so that sensitivities could be estimated, but would not need to define which specific targets in a crowded field would be observed. This approach, largely developed by STScI for HST, has the advantage that proposers will devote most of their efforts creating the strongest science justifications for their programs. Only successful proposers (about one in six) will be required to provide the actual details needed to plan and execute the observations on the spacecraft.

MO-38 Proposers will use an integrated planning tool, consisting of a graphical user interface and associated widgets, including simple exposure time calculators as well as tools for importing sky maps and accurately positioning the JWST apertures on targets (MR-346). The output of such a tool, funded in part by the JWST Project, is shown in Figure 3-3; it is currently being used for proposals involving the Advanced Camera for Surveys (ACS) on HST.



Prop	Visit	Exp	Target	Config	Opmode	Aperture	Sp_Eleme..	Wavelength	Op Parms	Iterations	Exp Time	Spec Req	Comments
8321	1	1	NGC4151	ACS/WFC	ACCUM	WFC1	F775W			1	305		Expected S/N=200
8321	1	2	NGC4151	ACS/WFC	ACCUM	WFC1	F892N		CR-SPLIT..	1	2005	Pattern 1 2	

Figure 3-3. Display for an integrated planning tool being used for ACS on HST

MO-39 Each proposed program might have many visits, each with one or more time windows for execution during the following year(s). Following program selection, the S&OC will construct a long term observing plan that will identify approximately when each approved visit is to be carried out. The long-range plan will consist of not only the approved science programs for JWST, but also the calibrations and most maintenance activities for the Observatory. Observers and planners at STScI will use the long-term schedule for detailed planning. Using the integrated planning tool, observers will fill in all of the missing information needed to carry out their approved programs. Although most of the information to complete the planning of observations will be available within the planning tool, a small team of user support staff will assist in resolving the inevitable scheduling problems and resource conflicts. Once the visit information in a proposal is complete, the visits will be released for scheduling. The observer will be able to monitor the process of his/her visits through detailed scheduling and data taking, but he/she should not need to be actively involved again, until either the data are obtained or an anomaly or change in the long-range schedule requires modifications to the visits.

MO-40 On a cycle matched to the solicitation cycle, STScI will enter calibration and maintenance programs into the system using the same planning tools used by general observers for their science programs. This will save cost and complexity within the S&OC by limiting the total number of planning systems, and will provide better service to users since S&OC scientists and engineers will use the same tools as everyone in the community.

MO-41 The long-range plan and the associated visit information provide the pool of observations used to generate the actual Observation Plan and visit files for the Observatory. The long-range plan will be updated as observations are completed and modified to reflect new proposals as they are approved and made ready for observation with JWST. The Observation Plan will be developed as close to the actual observing time as practical so the latest information about the Observatory can be incorporated into planning, or about three weeks before the observations would actually occur. At this point in planning, the STScI will select the guide stars to be used by the FGS to accurately position the Observatory. In order to achieve high science efficiency, JWST has been designed so that calibration data can be obtained from one instrument while another instrument, the prime-science instrument, is being used for science. During creation of the Observation Plan, parallel calibration observations will be integrated with science observations. The Observation Plan, along with all of the associated information describing each individual pointing, will be uplinked to JWST approximately weekly, during one of the daily contacts with the Observatory. The observations will be conducted and the data will be brought to the ground and archived. As part of the archiving process the STScI will store the science data within 24 hours of receipt from DSN (GS-174) and make an initial version of the science data available to the science team within 5 days (GS-054).

MO-42 The JWST archive will be a part of the Multi-Mission Archive at Space Telescope (MAST). This archive was developed originally for HST but now houses data from a variety of NASA space astronomy missions, including IUE, EUVE and FUSE. The JWST archive will contain the data stored there in its raw form, the calibration files necessary to calibrate the data, and databases that describe the data. All of the data will be stored on "spinning disks" in contrast to the early days of the HST archive when older data had to be stored on shelves and then put back into optical jukeboxes prior to retrieval. When the HST archive was initially built in the early 1990s, users retrieved calibrated science data, but the version of the calibration they retrieved was the version that had been produced at the time of the observation. A user who retrieved data a year after the observation took place did not benefit from ongoing improvements in the calibration pipeline or the results of calibrations that took place at the time of the observations, unless he or she recalibrated the data. However, the price of processing has dropped considerably since then. Now data from the HST archive are normally reprocessed "on-the-fly" each time the data are requested. The same approach will be used for JWST. Users will request data from the archive using web-based tools similar to those that have been developed for HST. Although there will be some users who will want their data on physical media, most will retrieve data directly to their home institution via the Internet. This will be quicker for them, and since no physical handling is required, less costly for the Project. Data retrieval will be restricted to the observers who proposed the program for a proprietary period (usually 1 year), but after that the data will be available to any registered archive user.

MO-43 Once the observer has retrieved his/her science data from the archive, he/she can analyze, publish and publicize the results. The STScI will encourage and provide support to astronomers who wish to make their results accessible to the general public.

4.0 MISSION ARCHITECTURE

4.1 MISSION PHASE DEFINITIONS

MO-44 The JWST Mission will be divided into 5 operational phases: Pre-launch, Launch, Deployment and Trajectory Correction, Cruise and Commissioning, and Normal Operations.

MO-45 1. The "Pre-launch" phase begins with approval to ship JWST to the launch site (at Korou, French Guiana). It includes shipping preparations and transportation, integration of the launch vehicle and upper stage, functional testing and checkout of the space and ground segments of JWST at the launch site, and ends with the actual lift-off of JWST.

MO-46 2. The "Launch" phase begins with launch on an Ariane V and ends when attitude stabilization is achieved using thrusters after upper stage stabilization. During this time, JWST will be launched on a trajectory to L2; the payload fairing will be jettisoned; low rate communications will be established, and the JWST propulsion system will be activated

MO-47 3. The "Deployment and Trajectory Correction" phase begins with thruster-based attitude stabilization and ends with the mirror deployed and with the mirror actuators at the nominal positions for beginning the co-phasing of the segmented mirror. It includes the deployment of the solar arrays, the high gain antenna, and the optical telescope element as well as initial trajectory correction maneuvers. During this phase, high data rate communications will be established, wheel-based attitude control will be established, and the Observatory Reaction Control System (RCS) will be verified.

MO-48 4. The "Cruise and Commissioning" phase begins at the point of initial alignment and phasing of the mirror and ends after L2 insertion when JWST, including the science instruments, has been commissioned for science operations. It includes the initial alignment and co-phasing of the telescope, the determination that the optical performance requirements for the telescope can be met using the fine steering mirror and NIRCam, and the successful checkout of the science instruments and all other subsystems needed to conduct science operations.

MO-49 5. The "Normal Operations" phase begins when the Observatory is declared ready to execute its science mission and continues for the duration of the mission. This phase will include the actual execution of the science program as well as the maintenance, calibration and recovery activities needed to preserve the ability of JWST to conduct the science program.

MO-50 There is an additional phase related to this discussion; that is, the Integration and Test (I&T) Phase. Though this phase is not considered one of the JWST Mission Operational Phases, it is none-the-less an important aspect of the mission operations concept since the procedures and systems used during flight are developed and tested during the I&T phase of the mission. For the purposes of delineating relevant I&T activities in the JWST Operations Concept Document, the “Integration & Test” phase will be considered as beginning with mating of the ISIM and spacecraft modules and covers all testing and integration up to approval to ship JWST to the launch site.

4.2 ENVIRONMENT

MO-51 JWST will conduct normal operations after being placed in an orbit about the Sun-Earth L2 Lagrange point (MR-041). The Sun-Earth L2 Lagrange point is located about 1.5 million km from Earth (four times the distance to the Moon), and JWST will orbit about this point at a distance between about 250,000 km and 800,000 km with a period of about 6 months. The launch trajectory and final orbit for JWST are shown in Figure 4-1.

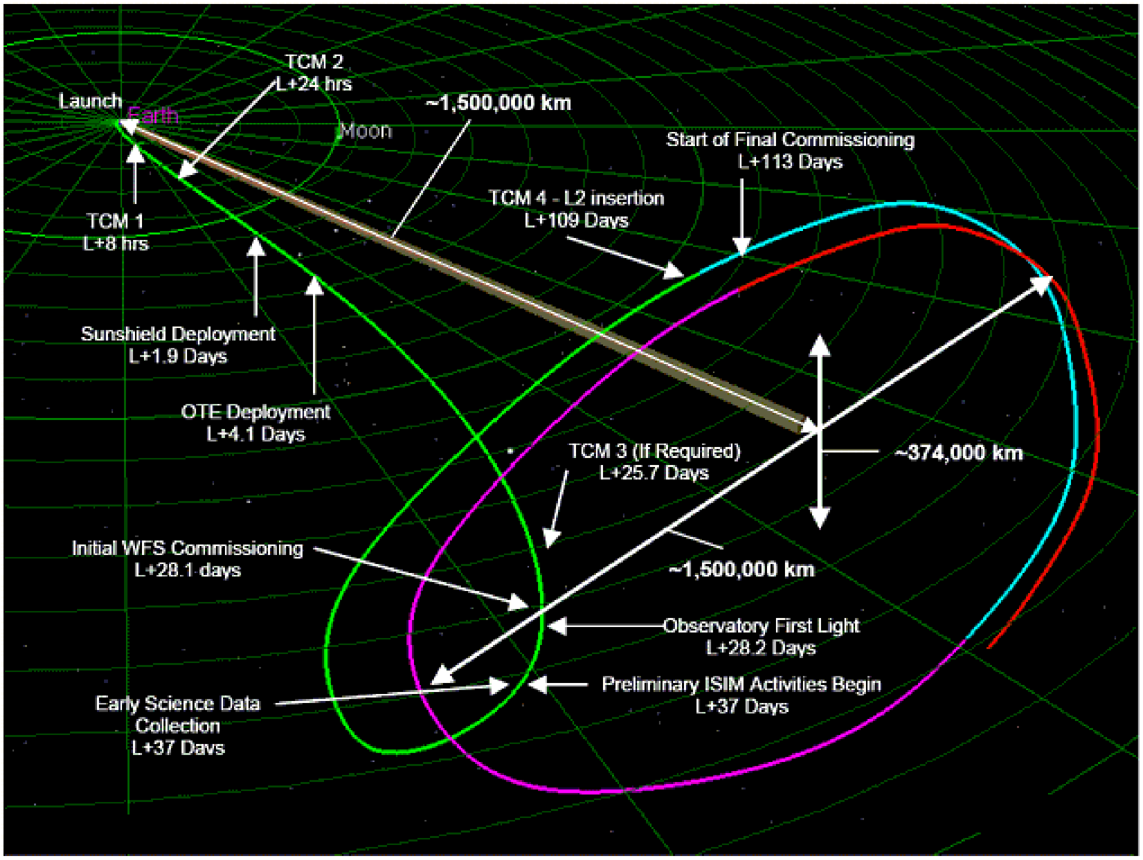


Figure 4-1. Launch Trajectory and Final Orbit for JWST at Sun-Earth Lagrange (L2) Orbit.

MO-52 At the IR wavelengths relevant to JWST, the primary sources of background are zodiacal light and thermal radiation from JWST itself. To reach the sensitivity limits required by the JWST science program, the effects of thermal radiation must be smaller than the effects of zodiacal light; at least at wavelengths shorter than 10 μm. As a result, the telescope and instrumentation need to be maintained at cryogenic temperatures (<100 K). This effectively rules out any low Earth orbit for JWST, since radiation from the Earth is both a significant and highly variable heat source.

MO-53 The Yardstick Mission studies[7] selected the Lagrange L2 orbit, among a number of possible orbits. Some of these, including elliptical orbits in the outer solar system and inclined orbits that would take JWST above the interplanetary dust, could in principle have obtained even lower background than L2. However, overall the L2 orbit is preferred, as it provides the following advantages:

- Telescope shielding for solar radiation also blocks Earth and Moon radiation and provides thermal stability and allows passive radiant cooling
- Long continuous visibility windows for targets, especially at the ecliptic pole
- Easier communications requirements than more distant orbits
- Easier power generation than more distant orbits
- Shorter transfer times (3 months vs. 3 years) than for more distant orbits
- Less propulsion required to attain orbit than more distant orbits

MO-54 The orbit and the steps to insertion for that orbit are shown in Figure 4-1. The main disadvantage of this orbit is that L2 is at a saddle point in the gravitational potential. It is not a stable orbit and requires orbit maintenance, in the form of regular firings of on-board thrusters to maintain the Observatory at L2. Furthermore, to determine the proper thruster firings accurate knowledge of the orbit via ranging is required. A larger orbit minimizes the Delta-V requirements for orbit insertion and maintenance

MO-55 Two types of orbits, halo and Lissajous, exist at L2. Halo orbits result when the period of in-plane and out-of-plane motion are equal; they appear constant in all planes. Lissajous orbits are the natural motion of a satellite around a collinear libration point; they appear constant in the orbital plane of the two bodies, but change shape and orientation within a rectangular area in each of the other planes defined by the two bodies.

MO-56 Lissajous orbits require less station keeping to maintain a stable libration point orbit (Hoffman 8-10). Some families of Lissajous orbits can result in the spacecraft crossing the line connecting the two bodies. In the Sun-Earth orbit, this can result in crossing the Earth shadow, which must be avoided because shadow crossing could last longer than battery charge capacity. However, this can be avoided for the expected lifetime of the JWST. Orbit insertion is more fuel-efficient, especially given the characteristics of the Ariane launch vehicle. A L2 Lissajous orbit with a semi-major axis of 800,000 km has been selected (MR-041).

4.2.1 Natural Environment

MO-57 The natural environment at L2 includes the gravitational fields due to the Earth, Moon, Sun, and planets; plasma, magnetic fields, and energetic charged particles of the solar wind and the Earth's magnetospheric tail; shocked plasma, magnetic fields, and energetic charged particles of the magnetosheath between the free solar wind and the magnetospheric tail; galactic cosmic rays and high energy particles released by solar flares and coronal mass ejections; electromagnetic radiation and thermal conditions due to the Sun; and meteoroids, with components due to the sporadic background and to streams.

MO-58 A spacecraft in an L2 orbit will be subject to the ambient plasma and ionizing radiation environments due to both the solar wind and the geomagnetic tail. L2 lies approximately 236 Earth radii beyond the Earth-Moon barycenter, and orbits of the type considered for JWST typically occupy volumes on a scale of 40 by 60 by 200 Earth radii with the long axis oriented along the direction of heliocentric orbital motion. At the L2 distance the geotail is 45 to 70 Earth radii in diameter, depending on the solar wind dynamic pressure. Its centerline can shift by some 40 Earth radii, depending on the direction of the solar wind. Therefore a spacecraft in an L2 orbit may be immersed in the tail some of the time, immersed in the free solar wind some of the time, and inside the shocked plasma of the magnetosheath between these regions the rest of the time. Within the geotail, the spacecraft will be subject to the different plasma regimes of its complex structure. The spacecraft will require careful design to operate within this extremely dynamic plasma environment without damage from discharge events, contamination, interference with communication and other electronic hardware, and other effects.

MO-59 The JWST will be subject to the effects of energetic particles produced by the Sun, the geotail, and the Galactic cosmic ray background. This energetic particle flux, also known as ionizing radiation, can cause several types of damage, including single event upsets (SEU) to electronic memory and logic components; changes in material and electronic properties due to the total ionizing dose from cumulative penetrations; and changes in the transmission and reflection properties of optical components. Galactic cosmic ray particles are electrons and positively charged ions, the latter consisting of protons (85%), alphas (14%), and heavier ions (1%). Energetic particles also add noise to science observations, either by direct impact with detectors or by production of cascading particle radiation from impact with spacecraft components near the detectors. Intense particle fluxes are produced by solar ejection events, solar flares (which occur frequently) or the more intense coronal mass ejections (which occur several times per year). During these events the solar ion fluxes can exceed the Galactic cosmic ray background by factors of 10^3 to 10^4 for short periods lasting from hours to days. These events will not only overwhelm observation data with noise due to particle impact, but also will significantly increase total ionizing dose and have highest probability of inducing SEUs.

MO-60 The solar wind travels with velocity usually between 300 and 600 km s^{-1}, but solar ejections can travel at speeds up to 1000 km s^{-1}. Since the Earth is about 150 million km from the Sun, the energetic particles produced by a solar event can take slightly less than 48 hours to reach the Earth. Solar ejections are often detected by direct observation of the Sun, and advance warning of the impending impact of solar particles, when available, can be used to place spacecraft in operationally safe states until the solar event is over.

MO-61 In general, an object in orbit further from the Sun than the Earth will have an orbital period greater than that of the Earth. However, at L2 the gravitational attraction of the Earth-Moon system will accelerate the object's motion and keep it moving at the same rate, on average, as that of the Earth-Moon system. This balance can be easily perturbed by the motion of the Earth and Moon about their barycenter, eccentricity of the Earth-Moon orbit about the Sun, passing of planets, and radiation pressure of the ambient sunlight. With JWST the perturbations due to radiation pressure will be substantial because of the large sunshield and the frequent thruster firings to unload momentum from the reaction wheels as they compensate for the rotational effects of radiation pressure on the sunshield. These perturbations would send JWST drifting off into an independent heliocentric orbit, and periodic thruster firings are needed to maintain the JWST orbit about L2.

MO-62 The Earth-Moon system will perturb the JWST orbit due to eccentricity of the Earth-Moon orbit, precession of the Earth-Moon orbital plane (with a period of 18.6 years), and rotation of the Earth and Moon about the barycenter. The planets will also perturb the JWST orbit; Jupiter and Venus are the main sources with variations on order of 2/3 and 1/3 the variations imparted by the Earth-Moon system respectively.

MO-63 Radiation pressure on the sunshield will perturb the JWST orbit, with variations due to changes in the JWST attitude, which changes the direction of sunshield normal with respect to the Sun. The radial component of radiation pressure will perturb the orbit, while the transverse component of radiation pressure will impart an angular momentum that must be compensated by applying torque to the reaction wheels, causing them to spin at faster rates. This angular momentum is unloaded, and the reaction wheels spun down, by firing thrusters and applying opposing torque to the reaction wheels.

MO-64 Biasing the orbit can be used to compensate for mean outward forces associated with planets and radiation pressure on the sunshield. Momentum unloading can be done at spacecraft orientations that result in thruster firings in directions that minimize perturbation. These approaches can help reduce the frequency at which the orbit must be adjusted. Thruster firings for orbit correction will be directed toward the sun to avoid contamination of the OTE, and thrusters are located on the side of the sunshield facing the Sun to keep them within operating temperature limits. As a result, the orbit will be biased to ensure that orbit corrections only require thruster firings in the direction of the sun, which will result in a less stable orbit and more frequent orbit corrections.

MO-65 The plasma environment consists of charged particles that have energies generally less than a few hundred kilovolts. These particles do not have sufficient energy to penetrate spacecraft shielding materials but they can result in a number of important effects that must be considered in the spacecraft design. In particular, these charged particles may impart charge due to differential collection of plasma electrons and ions and loss of photoelectrons. Charging conditions may lead to arcing, re-attraction of contaminants, degradation of optical and thermal performance, and alteration of surface material properties. While usually limited to impact on external surfaces and structures, severe charging can impact internal systems including electromagnetic interference within electronic systems.

MO-66 The magnetosphere is the region where plasma properties are mainly controlled by the Earth's magnetic field. This region is inclined about 11° with respect to the rotation axis of the Earth. Near Earth, the plasma is formed by solar wind and particles from the Earth's ionosphere. At L2, the primary source of plasma throughout the magnetosphere is the solar wind, and the main regions of the magnetotail are the magnetosheath and magnetotail. The magnetosheath has radius of about 640,000 km and is about 3 to 4 times the size of the magnetotail, which varies from 128,000 km to 192,000 km radius at L2, depending upon solar wind densities and velocities. The magnetotail has two main regions: the outer region is the boundary layer and the inner region is the plasma sheet. The plasma sheet varies with the magnetotail and is normally located in a region approximately 64,000 km wide centered in the magnetotail.

MO-67 The magnetotail slants away from the Earth-Sun line due to the orbital velocity of the Earth. This aberration angle varies with solar wind pressure; higher pressure reduces the aberration angle. The magnetotail also slants a few degrees below the ecliptic plane. Finally, transient solar wind disturbances cause changes in both in-plane and out-of-plane aberration angles. Solar wind temperatures and velocities vary on time scales of tens of minutes to days, so prediction of the precise characteristics of the magnetotail is not possible. During solar maximum, in-plane aberration angles are 4˚ on average, and vary from 0 to 10˚. During solar minimum, in-plane aberration angles are 6˚ on average. Out-of-plane aberration angles are 2˚ on average, and vary from -4 to +8˚, with slight variation between solar maximum and solar minimum.

MO-68 Information on the magnetotail plasma environment is based on the ISEE-3 probe, which crossed the magnetotail at around L2, and the Geotail spacecraft, which sampled the magnetotail over a range of distances to about 1.4 million km. The magnetosheath and the magnetotail both show a significant increase in electrons at energies above 1 keV and protons and ions at 0.1 keV, but also a decrease in protons and ions at 1.0 keV.

MO-69 JWST will pass through the magnetotail and magnetosphere during the orbit about L2. Passage through the magnetotail will afford some protection from medium energy solar particles, but will increase the impact of low energy solar particles and may subject JWST to impact from energetic heavy ions and relativistic electrons during magnetospheric storms. The principal impact of solar wind, magnetosphere and magnetotail passage will be degradation of external surfaces and accumulation of charge. These surface and charging effects must be considered during design of scientific instruments and optical surfaces, electrical systems, insulation and shielding, and structures. However, there appear to be no operational implications from passage through the magnetosphere or magnetotail.

MO-70 The sporadic background meteoroid environment is non-isotropic; meteors radiate from 6 distinct sources. Most of the background meteoroids originate in the ecliptic about 18° forward, in the direction of Earth motion, from the direction of the sun and anti-sun, with each direction accounting for 30% of total meteoroid flux, and with an average velocity of 29 km s^{-1}. The next two sources are located 15° above and below the ecliptic in the direction of Earth motion, with each direction accounting for 15% of total meteoroid flux, and with an average velocity of 55 km s^{-1}. The final two sources are located 60° above and below the ecliptic in the direction of Earth motion, with each direction accounting for 5% of total meteoroid flux, and with an average velocity of 35 km s^{-1}. These sources are termed Helion and Anti-Helion, Apex (North and South) and Toroidal (North and South).

MO-71 Meteoroid flux as a function of mass is nearly linear in the range from one gram down to 1 micro-gram, ranging inversely from one part in 10 million to one per square meter per year. Meteoroids can penetrate spacecraft and damage surfaces and interior components, and can produce plasma on impact that results in static electric discharges, current flows, and other effects that may damage electronic systems. Kinetic energy (or "striking power") varies with the square of the velocity, while plasma production varies with the fourth power of velocity. For spacecraft that maintain constant attitude with respect to the Earth-Sun system, protection of surfaces that face in the direction of sporadic background meteoroid sources should be considered, especially in the direction of the Apex sources. However, because JWST changes attitude frequently, there are currently no operational implications from the sporadic background meteoroid environment.

MO-72 The quasi-periodic meteoroid environment is caused by streams of material ejected from short period comets that pass near the Earth's orbit. These streams produce meteor "showers" that are observed on Earth, and normally represent only an increase of a few percent over the background. However, after a recent passage of the parent comet through the Solar System, the density can be increased to result in an "enhanced" shower with meteor rates of several hundred per hour, or a meteor "storm" with meteor rates in excess of 1000 per hour for an observer on Earth's surface. Streams that have the potential for causing enhanced stream or storm activity at L2 include the Quadrantids, K Cygnids, Lyrids, Draconids, Perseids, and especially the Leonids. The Leonids produce major meteor storms at 33-year intervals. The Perseids have an average velocity of 59 km s^{-1}, and the Leonids have an average velocity of 71 km s^{-1}, increasing the striking power and plasma potential over the average of the sporadic background and thus increasing the risk of damage due to penetration.

MO-73 The possibility of damage due to meteoroid impact must be considered during design of Observatory components. A design that provides a "safe" orientation of the Observatory against predictable quasi-periodic streams should be considered, which will allow the Observatory to be oriented with respect to that direction during meteor showers or storms, in order to miniminze the probability of damage.

MO-74 The charged particle environment at L2 will have an important effect on JWST and science observations conducted with JWST. It consists primarily of Galactic cosmic rays, and charged particles emitted from the Sun, and plasma (from the solar wind and Earth magnetotail). The charged particle environment at L2 is considerably more time-variable and somewhat more hostile than in low Earth orbit, because the Van Allen belt reduces charged particles from the Sun. In low Earth orbit, the main temporal variations are associated with passages of the spacecraft through the South Atlantic Anomaly, which can be predicted well in advance. At L2, the environment changes as result of activity on the Sun, which as described briefly below, exhibits general trends based on time in the solar cycle, but is not predictable enough that it can be used for observation planning.

MO-75 The passage of high-energy charged particles (primaries and secondaries) through the IR detectors deposits charge in the active area of the pixels of the arrays, and compromises the data obtained from that pixel as well as adjoining pixels.

MO-76 Galactic cosmic radiation consists mostly of protons (85%) and helium ions (14%) with energy >100MeV at a flux of 4 particles cm^{-2} s^{-1} near Earth. The flux near Earth for particles with energy <1GeV varies with solar cycle, indicating attenuation by the Earth's magnetic field. At L2, the flux for particles with energy >100MeV is about 5.1 particles cm^{-2} s^{-1}. Figure 4-2 shows the integrated Galactic cosmic ray flux at L2 for particles with energies greater than a particular level.

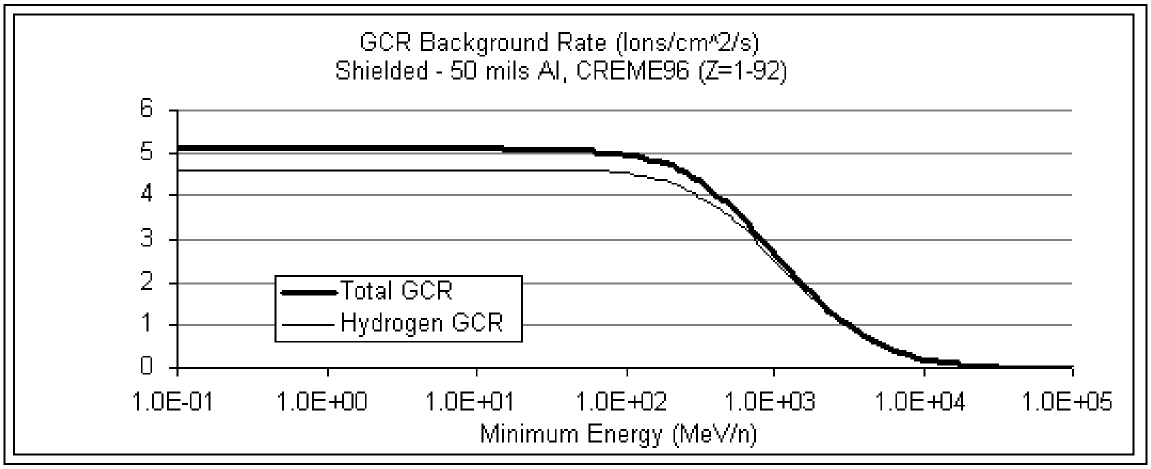


Figure 4-2. Integrated Galactic Cosmic Ray Flux at L2

MO-77 Solar particle events consist of solar flares and coronal mass ejections. Solar flares occur at a rate of 1000 per year and last a few hours. Typical flares have flux levels up to 10^{-4} protons cm^{-2} $steradian^{-1}$ s^{-1} MeV^{-1}, or about 0.4 protons/cm^2/sec. Coronal mass ejections occur at a rate of 10 per year, reach peak levels within hours and last 1-5 days, subsiding nearly linearly. Peak flux levels vary by up to 3 orders of magnitude, but for 90% of the events the flux level of protons with energy >100MeV is up to 2000 protons cm^{-2} sec^{-1}.

MO-78 Solar activity varies with the solar cycle, which has a period of 10-11 years. JWST will be launched near the beginning of Cycle 24. During years of minimum solar activity, solar flux will usually be less than 2 particles cm^{-2} s^{-1}. During years of maximum solar activity, solar flux will often exceed day averages of 5 particles cm^{-2} s^{-1}.

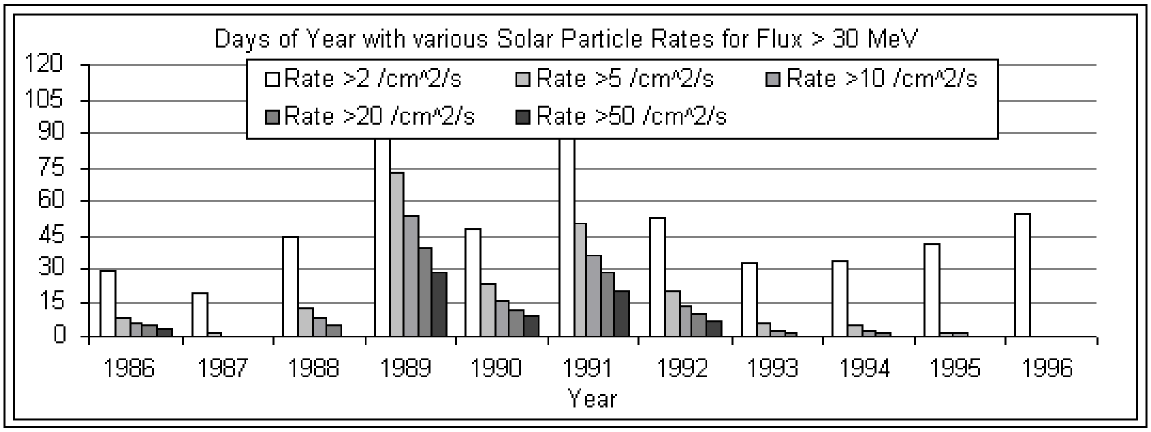


Figure 4-3. Cumulative Distribution of Solar Proton Flux > 30 MeV

MO-79 The impact of cosmic rays on an image is illustrated in Figure 4-4. This figure shows an HST NICMOS dark frame exposed for 2048 seconds, before and after CR-removal. There are about 4,000 CR-affected pixels in the left panel. In the combined dark (right panel) the remaining dark spots are bad pixels.

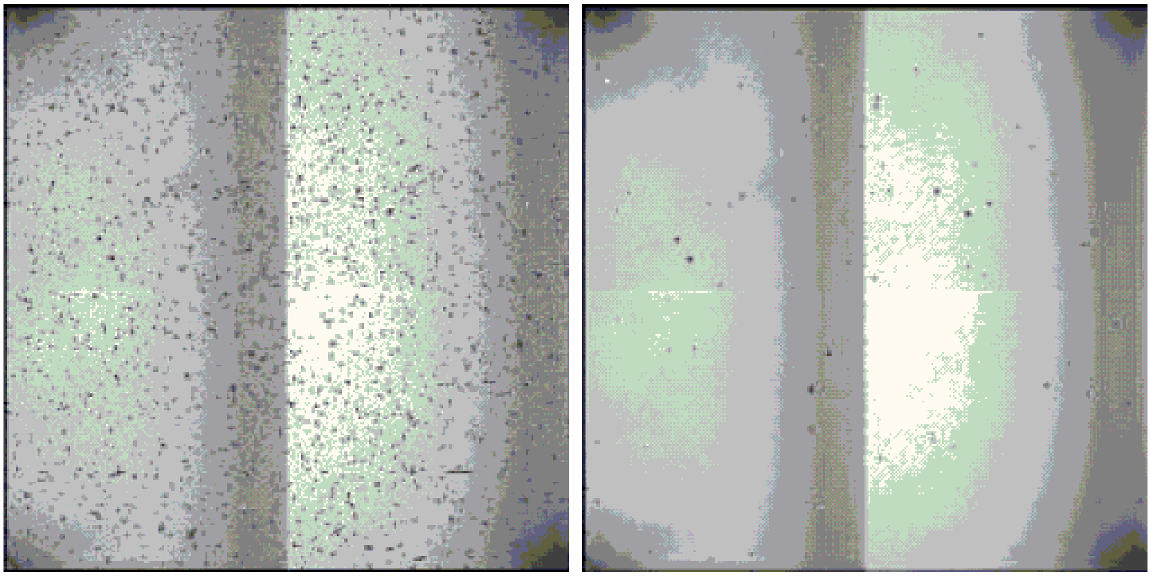


Figure 4-4. NIC2 Dark Frame Showing Cosmic Ray Impacts (Left) and After Removal Showing Bad Pixels Remaining (Right).

MO-80 Charged particles passing through the detectors on JWST will deposit charge into clusters of pixels, which impact the use of those pixels for a specific scientific exposure. An example of the effects of charged particles on a detector is shown in Figure 4-5, which shows data obtained by the University of Rochester in testing the SST NIR InSb 27-μm pitch arrays at the Harvard cyclotron. The typical hit raised 5.3 pixels 5 σ or more above the noise. Rauscher carried out a discussion of this particular data set in the context of JWST.[8] On JWST, the impact is not expected to saturate the pixels, so intermediate readouts of the detectors before and after the impact will be useful to generate a total exposure. Ground data processing will include detection and removal of cosmic rays from the data.

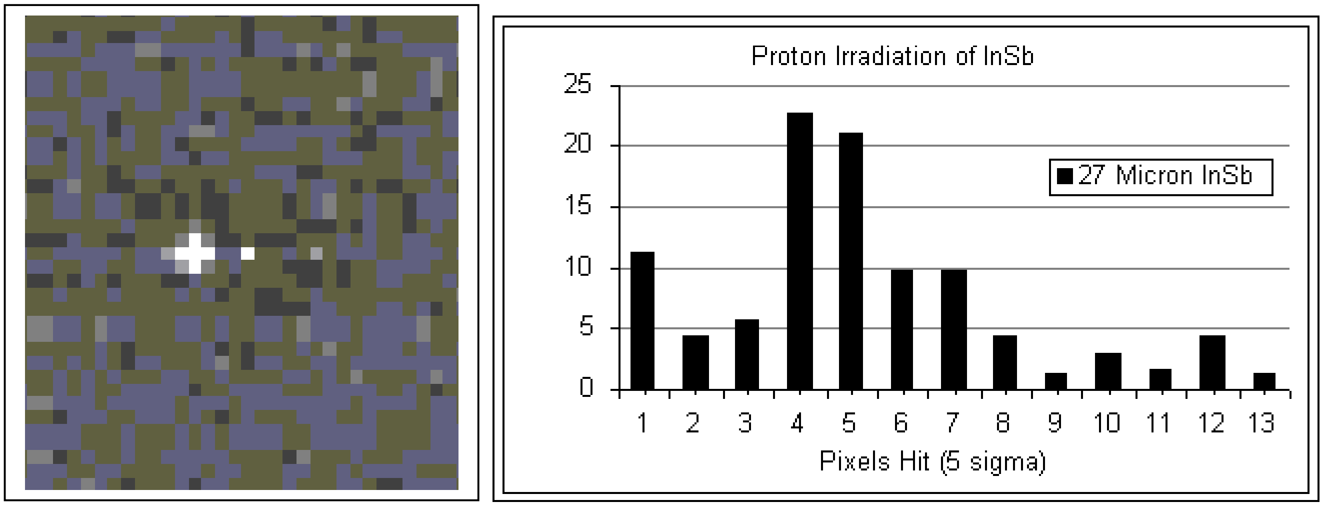


Figure 4-5. University of Rochester test results

MO-81 The estimated impact of Galactic cosmic rays is that ~10% of the pixels will be affected in exposures of 1000 seconds. Solar particle events will increase the number of pixels affected by varying amounts depending on solar activity. During solar maximum ~30% of pixels will be impacted by cosmic rays and solar particles in exposures of 1000 seconds. Various observing strategies can be used to mitigate this problem. Dithering exposures can be used to distribute the impacts of pixel charge dissipation to different parts of the image. Shorter exposures, frequent intermediate readouts, and additional exposure time can be used to offset the exposure time lost to cosmic ray impacts. Shorter exposures and frequent intermediate readouts increase the data storage and communication requirements, while additional exposure time decreases observing efficiency. The Communications and Data Volume Study[9] traded these solutions against a baseline communications allocation to establish a baseline readout strategy of 250-second readouts with a 10% increase in exposure time.

MO-82 There will be times on JWST when the solar radiation background is exceptionally high, and it is expected that observations may effectively be lost due to solar radiation. There are no plans to measure the cosmic ray rate and autonomously respond to these solar storms since there are no on-board monitors of the cosmic ray rate. Instead, observations will be evaluated to determine the extent of data loss and replanned if it is determined that the scientific objectives cannot be met with the data obtained.

MO-83 Solar storms also have the potential to disrupt Observatory operations, through interactions with for example the memory of the IC&DH computers. However, all subsystems are being designed to operate normally through storms. And as a result, it is not expected that the Observatory operations will have to be stopped by ground intervention during solar activity.

4.3 THE TELESCOPE AND SPACECRAFT

MO-84 In this document, and elsewhere the Observatory is defined to be the components of JWST that will reside at L2 during normal operations. The JWST Observatory consists of three elements as presented in Figure 4-6

- The Optical Telescope Element (OTE),
- The Spacecraft Element (the spacecraft bus, and sunshield), and
- The Integrated Science Instrument Module (ISIM) Element, which includes the instruments and associated electronics.

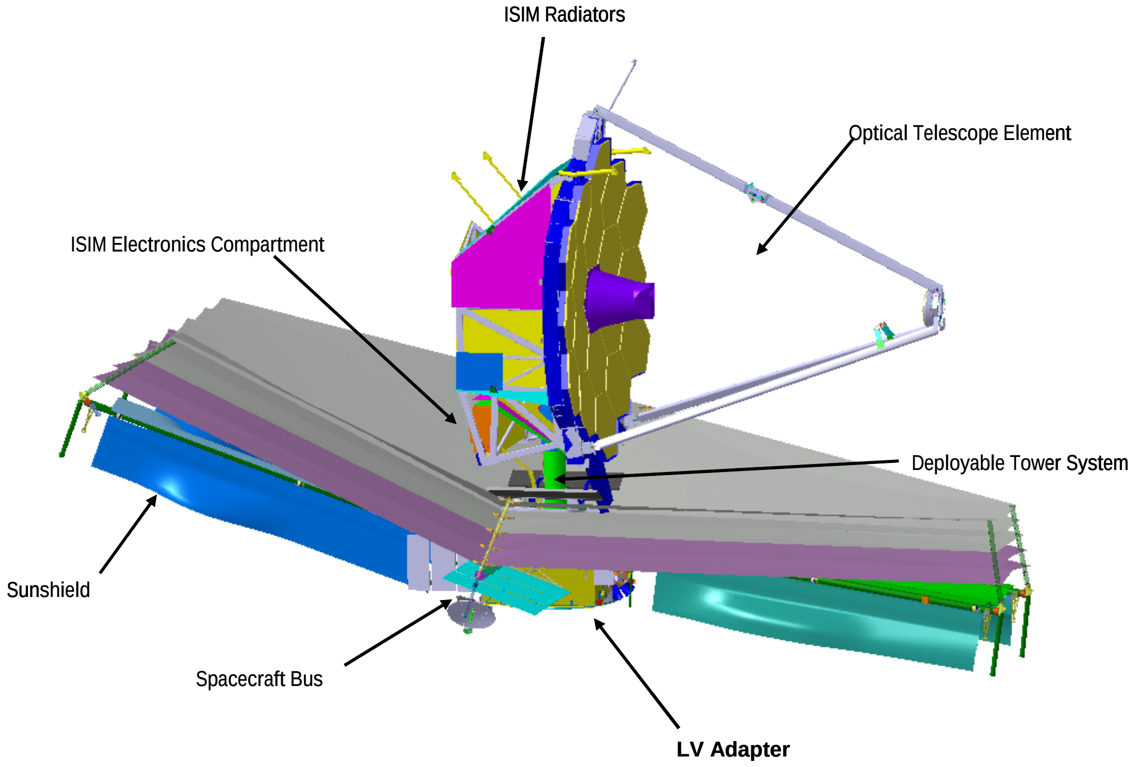


Figure 4-6: Observatory Elements

MO-85 The telescope and spacecraft will be constructed by NGST.

4.3.1 Optical Telescope Element

MO-86 The OTE will be a deployable three-mirror anastigmat (TMA) with a large aperture that collects light equivalent to a 25-m^2 clear aperture but provides higher angular resolution than a circle of that same area. The OTE will provide diffraction-limited performance at 2 µm and a mechanical and optical interface to the ISIM.

MO-87 The OTE will consist of a Primary Mirror, Secondary Mirror, Tertiary Mirror and Fine Steering Mirror. The Primary Mirror has a number of hexagonal mirrors mounted on a backplane that permits independent adjustment of each mirror segment in 6 degrees of freedom plus radius of curvature. The primary mirror segments will be aligned and adjusted to achieve optical performance by a ground-controlled, image-based wavefront sensing and control (WFS&C) process (MR-187). The Secondary Mirror will be mounted on a deployed hexapod with actuators that provide six degrees of freedom for optical alignment and focus. The tertiary mirror will be fixed within the aft optics subsystem and will provide the optical reference for the OTE. The aft optics subsystem will also include a central baffle that will not obstruct the science instrument focal plane assemblies (FPAs), nor the Fine Steering Mirror (FSM). The FSM will be used in a 15.625-Hz fine guidance control loop to provide milliarcsec pointing control for image stability. The OTE electronics architecture requires the FSM to be disabled during PM segment and SM actuator commands.

MO-88 The NIRCam will be used as the detector for WFS&C. It will be equipped with appropriate optical elements to enable Dispersed Hartmann Sensing (DHS)for wavefront control during the Coarse Phasing step of WFS&C commissioning.

MO-89 Key features of the Optical Telescope Element are shown in Figure 4-7.

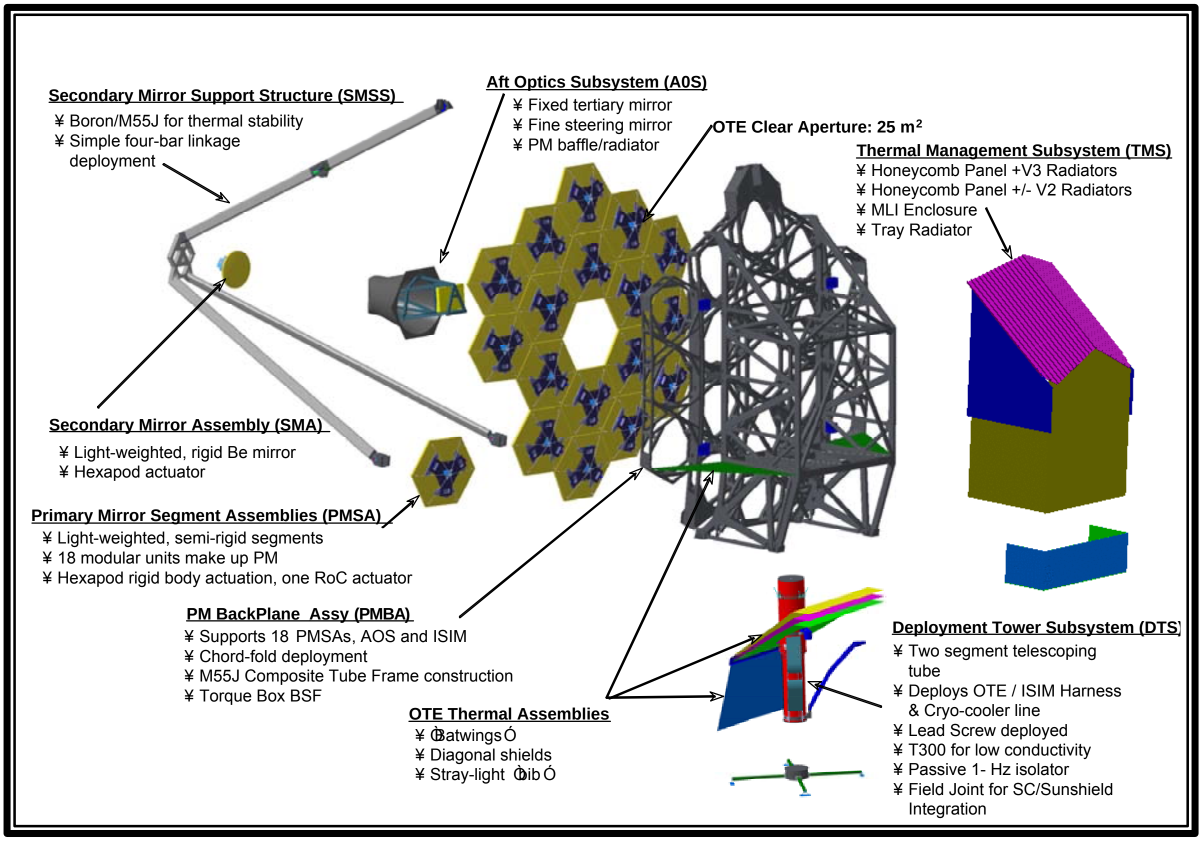


Figure 4-7. OTE Design

4.3.2 Sunshield and the Field of Regard

MO-90 The sunshield shields the OTE and ISIM from the Sun and reduces the stray light of the Earth and the Moon). It prevents light from these sources from reaching the instruments and provides a very stable cryogenic environment

MO-91 The sunshield consists of a number of thin, separated sheets of material that are positioned to direct heat out the open ends of the sunshield. The sunshield is a 3-plane design that can be adjusted at the beginning of the mission to balance the torques created by the effects of radiation pressure on the sunshield. This torque balance will reduce the amount of momentum unloading required and thereby decrease propellant usage and increase observation efficiency.

MO-92 The field of regard (FOR) is the region of the sky in which observations can be conducted safely at any time. For JWST, the FOR is a large annulus that is centered on the position of the Sun. The FOR, as is shown in Figure 4-8, allows one to observe targets from 85° to 135° of the Sun (MR-103, -104, -105). Most astronomical targets are observable for two periods separated by 6 months during each year. The length of the observing window varies with ecliptic latitude, and targets within 5 ° of the ecliptic poles are visible continuously (MR-106). This continuous viewing zone is important both for some science programs that involve monitoring throughout the year and will also be useful for calibration purposes.

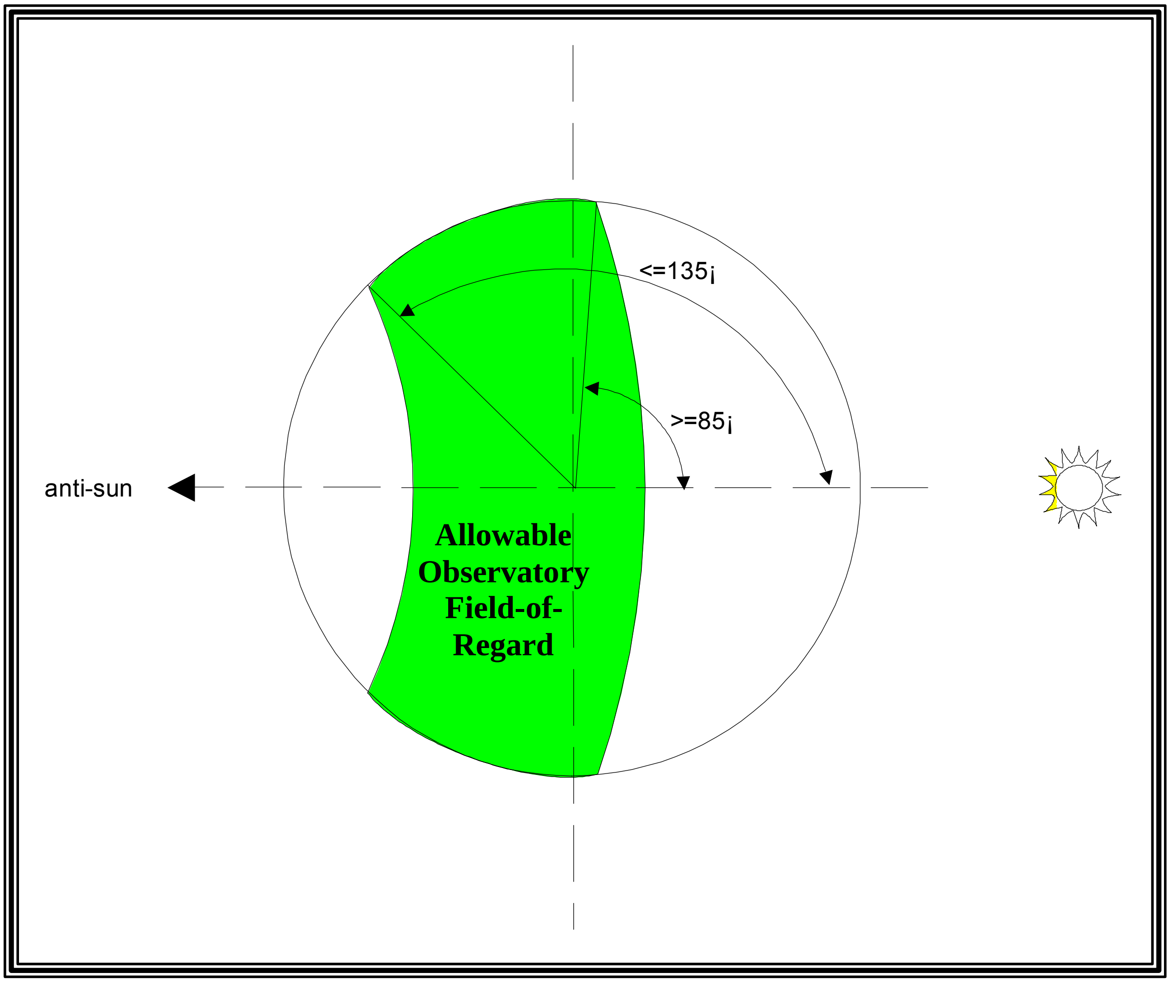


Figure 4-8. The Field of Regard for JWST

MO-93 The sunshield for JWST will provide a 48.9% celestial field-of- regard (FOR) that is greater than the sky coverage requirement (35%, MR-104). This large FOR is required to provide the scheduling flexibility to allow JWST to conduct an efficient scientific program and simplifies orbit station keeping design since it permits a wide range of Sun orientations for thruster firing.

4.3.3 Spacecraft Bus

MO-94 The spacecraft bus provides power to the Observatory, propulsion for orbit insertion and maintenance and momentum unloading, attitude control, thermal control, command and data handling (C&DH), and communications services. The attitude control subsystem (ACS) will provide attitude determination and control and interfaces with the Fine Guidance Sensor (FGS) located in the ISIM and the Fine Steering Mirror (FSM) for fine pointing control during observations. The C&DH subsystem will support command processing for the spacecraft bus, command routing to the ISIM, and telemetry recording and routing to the communications subsystem. The solid-state recorder (SSR) will support a minimum of 471 Gbits of engineering and science telemetry data (MR-130). The communications subsystem can support communications during observations and slews, with a capability to transmit at least 235.3 Gbits of engineering and science telemetry data (MR-076, MR-236) during 4 hours of contact (MR-352).

MO-95 The JWST spacecraft bus is designed for manufacture and operations without imposing restrictive requirements on the OTE or ISIM. For example, the bus height will be constrained to accommodate the simplest deployable OTE. Key features of the spacecraft bus are shown in Figure 4-9. All avionics units are functionally redundant and cross-strapped, and the subsystem supports all Observatory housekeeping functions.

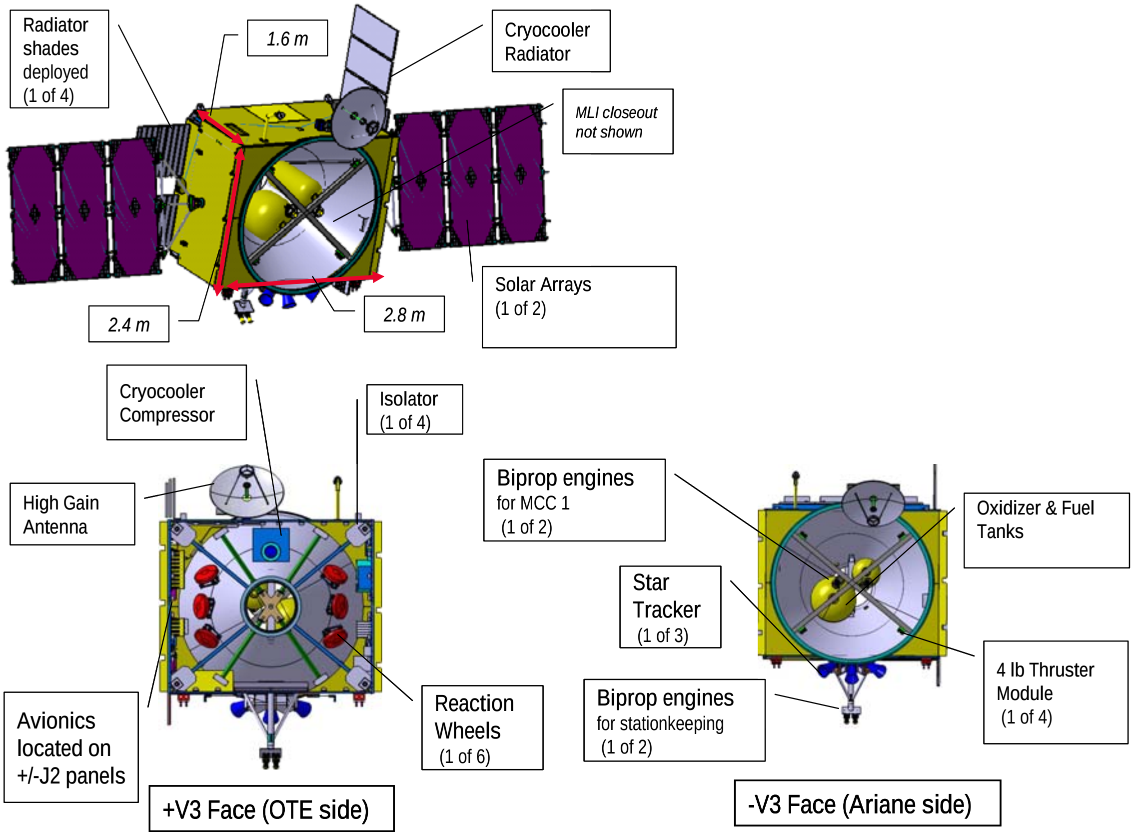


Figure 4-9. Spacecraft Bus Design Features

4.3.3.1 Spacecraft Bus Structure Subsystem

MO-96 The JWST spacecraft structure is the mechanical frame that houses the various electrical and electromechanical systems that are located on the warm side of the spacecraft. This includes the spacecraft and ISIM C&DH systems, the SSR, the ACS system, and the propulsion system used for orbit maintenance and momentum unloading. Other elements, including the sunshield and the solar panels, are attached to the spacecraft bus structure.

MO-97 The design of the Spacecraft Bus structure is intended to minimize the total mass of the Observatory, but to allow easy access for attachment (and removal) of individual subsystems. There are removable panels that allow multiple integration activities to be performed simultaneously. The battery will be mounted in an open frame on the front panel to provide easy access during I&T and at the launch site. A battery radiator panel will assure the battery is maintained at the proper temperature during the launch phase.

4.3.3.2 Spacecraft Bus Thermal Control Subsystem

MO-98 The Thermal Control Subsystem (TCS), described in Figure 4-10, will be a passive radiation system designed to satisfy unique spacecraft thermal requirements imposed by the JWST mission at L2. The spacecraft bus will be continuously illuminated by the Sun, will have a large view factor to the sunshield, and must support a cryogenic OTE/ISIM. The spacecraft-radiated heat will be isolated from the OTE/ISIM. Thermal control of the spacecraft will use the outer surface of the removable side panels, which will provide 30% more radiator area than needed to maintain spacecraft internal temperatures within operational limits. Shades located above the radiator panels improve radiator effectiveness by blocking the view to the warm sunshield. The inertial reference unit (IRU), star tracker assemblies (STA), and battery will be mounted on the front panel. Other spacecraft avionics will be mounted on the radiator panels. Heat pipes will extend from these panels to the radiator surfaces. The battery radiator panel will allow conditioned fairing air to cool the battery prior to launch. A cryocooler inside the spacecraft provides cooling for MIRI.

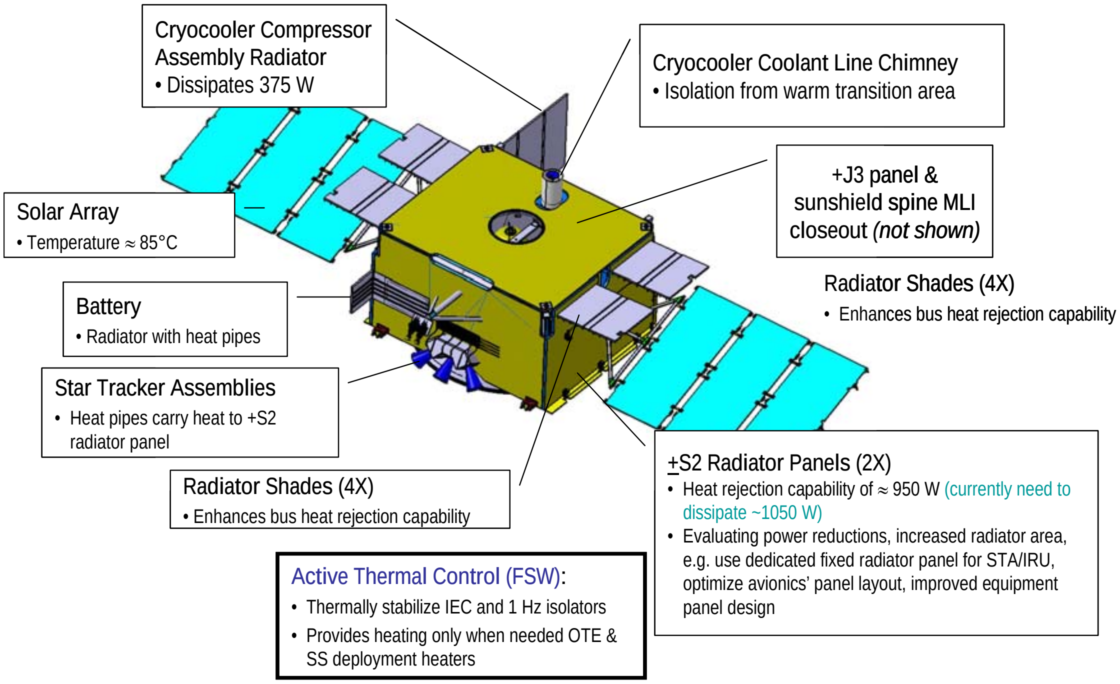


Figure 4-10. Thermal Control Subsystem Architecture

4.3.3.3 Spacecraft Bus Propulsion Subsystem

MO-99 The Propulsion Subsystem provides the means to correct launch vehicle injection errors, to maintain a transfer trajectory into a Lissajous orbit about L2, to keep JWST at L2, and to unload reaction wheel momentum. The Propulsion Subsystem will be a simple blowdown monopropellant system. The upstream propellant tank contains all helium pressurant at Beginning of Life (BOL) and is connected in series to three tanks containing hydrazine.

MO-100 The Propulsion Subsystem provides for maneuvers in any direction. The Dual Thruster Modules (DTM) will provide full thruster redundancy. They will be mounted on the spacecraft bus to avoid introducing contamination or heat sources near the OTE/ISIM. Launch vehicle injection errors will be corrected by locating two 5-lb DTMs on the bottom panel of the spacecraft. These thrusters will perform the initial correction maneuver shortly after vehicle separation, a constraint to prevent the orbit error from growing faster than the maneuver can correct for it. Four 1-lb DTMs will be located on the bottom corners of the spacecraft to provide reaction wheel momentum unloading and reaction control during Delta-V maneuvers. A single 1-lb DTM will be located on a fixed boom, enabling station-keeping Delta-V maneuvers in any direction relative to the Sun. The nominal station-keeping approach uses Delta-V maneuvers at L2 without requiring any component along the Sun line. This will require about twice as much propellant as an unconstrained approach, but will ensure station-keeping maneuvers toward the Sun, which are inefficient, are unnecessary.

4.3.3.4 Spacecraft Bus Attitude Control Subsystem

MO-101 The Attitude Control Subsystem (ACS) will perform OTE line-of-sight pointing and control and will support observation plan executive (OPE) event-driven mission timeline execution. The ACS will perform:

- Slewing
- Attitude determination and control
- Fine guidance control
- Momentum management
- High-gain antenna (HGA) pointing control

MO-102 The ACS will consist of Sun sensors, star trackers, gyros, reaction wheels, software and interfaces to the Fine Guidance Sensor and Fine Steering Mirror. There will be six reaction wheels arranged in a pyramidal configuration mounted on vibration isolating dampers, all operating nominally at biased speed to avoid the excitation of low frequency structural modes. Reaction wheel lifetime should be in excess of the mission duration goal of 10 years. In case of a reaction wheel failure, the failed and opposing wheels in the pyramidal configuration would be shut off, and the ACS would operate using the remaining four wheels.

MO-103 Algorithms for nominal and contingency operations will be implemented in a single-board computer (SBC) within the command and telemetry processor (CTP). A wheel-based Sun-point mode is implemented in the JWST Payload Interface Module (JPIM) of the CTP to provide an additional layer of protection. Sensor and actuator communications are through a 1553 data bus. Guide star centroid data are provided by the FGS directly to the CTP via a 1553 bus. The actuator drive unit (ADU) drives the FSM, OTE mirror actuators, HGA drives, and deployment actuators for the OTE, solar array, and sunshield.

MO-104 The ACS will control Observatory slews in response to commands from the ISIM OPE, Spacecraft CTP or Ground. The slew profile will smooth the acceleration profile to reduce structural mode excitation, and update the slew quaternion to ensure that the Observatory roll angle remains within Sun avoidance constraints. The star trackers will provide star measurements during the slew for attitude updates, improving accuracy and reducing the transient at the end of the slew. The ACS will perform a 90° slew (MR-178) in 44 minutes using six wheels, or 52 minutes using four wheels. At slew completion, the star trackers will maintain three-axis pointing control. Guide star acquisition may then be initiated by ISIM OPE directive.

MO-105 After OTE-to-spacecraft alignment calibration, the spacecraft ACS will point the OTE boresight to within 7″ (1-σ radial) of the intended position prior to guide star acquisition. In the fine guiding mode, using errors generated by the FGS, the pointing system will meet a 7 milliarcsec (1 σ) allocation (the current design has a margin of 2 milliarcsec). This pointing accuracy will support the fine guidance performance accuracy required to meet encircled energy and wavefront error requirements. Based on this pointing allocation, the ACS contribution to fine guidance pointing error will be 20.3 milliarcsec and absolute pointing knowledge will be less than 20.9 milliarcsec. These values relative to the 1″ requirement (MR-173) provide margin for the errors associated with the star catalog used on the ground and the errors in knowledge of the ISIM focal plane pixel locations. Two star trackers are used for attitude reference to obtain OTE field orientation knowledge with accuracy better than 7″ rms (MR-176).

MO-106 The ACS will control small angle maneuvers (MR-179) that are required for guide star acquisition, target acquisition, or dithering.

MO-107 The ACS will unload momentum if the Reaction Wheel Assemblies (RWAs) become saturated. Otherwise, momentum management is performed in the Ground Segment with momentum dumps occurring when scheduled by OPE directive. Planned momentum dumps will occur at the optimal attitude as calculated on the ground. Unplanned momentum dumps executed by the ACS will not be done at optimal attitude and thus could have significant impact on subsequent station-keeping maneuvers and propellant budget. This attitude will be calculated to ensure Sun avoidance constraints are satisfied and to ensure that thruster firings do not interfere with the maintenance of the orbit.

4.3.3.5 Spacecraft Bus Electrical Power Subsystem

MO-108 The Electrical Power Subsystem (EPS) includes the Electrical Power Unit (EPU), solar array and a 37 amp-hour NiH2 battery. The solar array will consist of two units per wing. The solar array will use efficient triple junction GaAs solar cells to power the Observatory. There will be a Solar Array Drive Actuator (SADA) to rotate each wing from a stowed configuration to the operational position. In the stowed configuration, solar cells will face outward to provide limited power for flexibility to respond to on-orbit anomalies or delayed solar array deployment.

MO-109 A 37 amp-hour NiH2 battery will support launch and contingency operations. The battery will condition the bus between 23.1 V at end of discharge to 34 V at end of charge (MR-262). Nominal mission operating voltage with the battery operating at +3˚ C and on trickle charge is predicted to be between 30 and 32 V. The battery will reach 35% depth of discharge (DOD) for a nominal launch, ascent, and solar array deployment.

MO-110 The EPS will use a single-point ground, returning all primary power through the harness back to the return bus in the EPU. This return bus will be common to the EPU chassis, forming the single-point ground for the system. The main power bus in the PCU will be protected from source and load faults by fuses mounted in removable fuse modules attached to the EPU, providing protection during I&T and operations. Circuit protection will be sized to protect cable-wiring harnesses. The battery cabling, battery assembly, and EPU power buses will be double insulated to eliminate single-point failures. The remote Mongoose 5 processor within the EPU provides EPS processing.

4.3.3.6 Spacecraft Bus Communication Subsystem

MO-111 The communication subsystem architecture will provide two-way communications through all operational phases using S-band for command uplink and low-rate telemetry downlink, and Ka-band for high rate telemetry downlink. The S-band uplink frequency will be in the 2025 to 2110 Mhz band, and the S-band downlink frequency will be in the 2200 to 2290 MHz band, allocated to Space Operations, Earth Exploration-Satellite, and Space Research. The Ka-band downlink frequency will be in the 25.5 to 27 GHz band allocated to Earth Exploration-Satellite. (MR-242, MR-250, MR-256).

MO-941 The Ka-band downlink data rate will be selectable for 7, 14 and 28 Mbps, with the lower rates selected when needed to account for transmission loss due to inclement weather (MR-257).

MO-942 The high rate downlink will be used both for playback of recorded telemetry as well as a 40 Kbps real-time telemetry stream. For the deployment and trajectory correction phase (to a range of 200,000 km), real-time telemetry will be downlinked at 2 Kbps using the omni-directional antennas on S-band. For contingency operations, real-time telemetry will be downlinked at 200 bps using the omni-directional antennas on S-band. (MR-260)

MO-943 During normal operations, the command uplink rate will be at least 2 Kbps to the omni-directional antennas, or 16 Kbps to the High Gain Antenna (HGA). These normal operations command uplink rates support a minimum 1 Kbps uplink rate needed to support the high rate downlink communications protocol (CFDP), while the high rate command uplink is needed to support uplink of large volume operations data (calibration files, on-board scripts). For contingency operations, the command uplink rate will be at least 250 bps to either omni-directional antenna. (MR-243, MR-244, MR-245, MR-259).

MO-944 The S-band transponders will be based on standard units compatible with Spacecraft Tracking and Data Network / Deep Space Network (STDN/DSN) that support the ranging function (MR-239).

MO-945 The high gain antenna (HGA) will simultaneously operate at S- and Ka-bands and will support all communications for commissioning and normal operations. A dual-band coaxial feed will directly illuminate the 1-m reflector.

MO-946 The HGA will be articulated in pitch (130°) and roll (70°) for Earth pointing at any observation attitude. This will allow science observations to occur during times when the downlink is being used (MR-135). The DDA will provide pitch articulation from the stowed position. An identical DDA located at the HGA end of the antenna boom will provide roll adjustment.

MO-947 Due to the narrow beam-width of the Ka-band downlink (which is about the same size as the Earth appears from L2), the HGA pointing will need to be adjusted during a communications contact in order to keep the ground station within the beam. The HGA maneuvers will result in a noticeable pointing disturbance, so they will be coordinated with the execution of the Observation. The HGA will not be moved during an up to 10,000 second integraton, and will lead the ground station by up to 1 hour to maintain the HGA within a required 0.3 deg radius of the ground station. The ground station position, JWST ephemeris, and scheduled contact times will be used to keep the HGA pointed at the ground station, and a handshake protocol between the Spacecraft and ISIM will be used to coordinate HGA maneuvers with the execution of the Observation Plan.

MO-948 The two S-band omni-directional (omni) low-gain antennas (LGA) will provide nearly (90%) full spherical coverage in the stowed and deployed configurations (MR-232). The far omni will be mounted on the OTE backplane and will support emergency conditions. The near omni will be located on the spacecraft on the same panel as the

HGA and will provide communications for acquisition and backup operations. A set of switches allow either transponder to connect to either an omni or the HGA.

MO-949 Both command receivers will be powered on at all times (MR-232), but only one telemetry transmitter will operate at any time. Real-time telemetry will be transmitted continuously.

4.3.3.7 Spacecraft Command and Data Handling Subsystem

MO-117 The C&DH subsystem consists of three main components:

- A Command and Telemetry Processor (CTP), the main computer on the spacecraft bus,
- A Solid State Recorder (SSR), the device used to store science and engineering data between ground contacts, and
- The databuses that provide connectivity to all of the various subsystems of the Observatory, including the ISIM.

MO-118 The CTP is the processor that controls the various subsystems on the spacecraft bus described in the previous sections and is the processor that manages the overall health and safety of the Observatory.

4.4 THE INTEGRATED SCIENCE INSTRUMENT MODULE

MO-119 The Integrated Science Instrument Module (ISIM) is the Observatory element that contains the Science Instruments (Sis) and the Fine Guidance Sensor (FGS). It provides the structure and thermal environment for the science instruments and the Fine Guidance Sensors. The ISIM also provides command and data handling for the science instruments and the FGS. Figure 4-11 shows the allocated field of view (MR-369) for each SI in the focal plane.

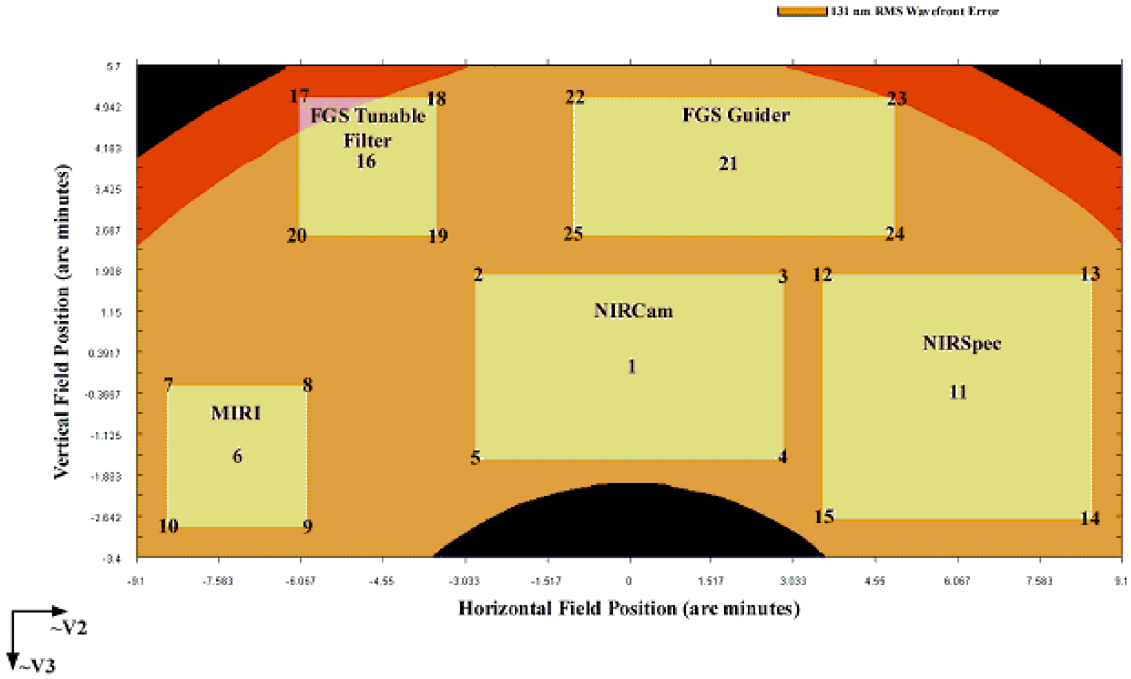


Figure 4-11: The JWST focal plane showing the location of each SI field of view

MO-120 The science instruments form the heart of the JWST payload. The selected instruments provide the wide-field imaging and spectroscopic capabilities over the 0.6-27 µm wavelength range (MR-185, MR-186) required to satisfy the scientific goals discussed in Section 3.2. Table 4-1 summarizes the characteristics of the Near Infrared Camera (NIRCam), the Near Infrared Spectrograph (NIRSpec), the Mid Infrared Instrument (MIRI), and the FGS-Tunable Filter Imager (TFI). The FGS-Guider will provide sufficient field of view and sensitivity to achieve a 95% probability (MR-171) of a successful guide star acquisition at any Observatory attitude. JWST guide stars will be selected by the ground segment from the Space Telescope Science Institute (STScI) Guide Star Catalog (GSC-2).

Table 4-1: Science Instrument Characteristics

Instrument	Wavelength (μm)	Optical Elements	FPA	Plate Scale (milliarcsec /pixel)	Field of View
NIRCam (Short Wave)	0.6 - 2.3	fixed filters (R~4, R~10, R~100), coronagraphic spots	Two 2×2 mosaics of 2048x2048 arrays	31	2.2′×4.4′
NIRCam (Long Wave)[1]	2.4 - 5.0	fixed filters (R~4, R~10, R~100), coronagraphic spots	Two 2048×2048 arrays	65	2.2′×4.4′
NIRSpec	0.6 - 5.0	transmissive slit mask: 4x365x171 micro-shutter array, 200x450 milliarcsec IFU, 5 fixed slits R=100 (prism), R=1000 (3 gratings) R=2700 (3gratings)	Two 2048×2048 arrays	100	3.4′×3.5′
MIRI (imaging)	5 - 27	broad-band & narrow-band filters, coronagraphic spot & phase masks, R~100 (prism) spectroscopy	1024×1024	110	1.3′×1.9′
MIRI (spectroscopy)	5 - 27	integral field spectrograph (R~2000-3700)	Two 1024×1024 arrays	196-273	3.7″×3.7″ to 7.9″×7.9″
Tunable Filter Imager (Short Wave)	1.0-2.1	Order-blocking filters+etalon (R~100), coronographic masks	2048×2048	65	2.2′×2.2′
Tunable Filter Imager[2] (Long Wave)	2.1 – 4.8	Order-blocking filters+etalon (R~100), coronographic masks	2048×2048	65	2.2′×2.2′

MO-121 [1]Use of a dichroic renders the NIRCam long-wavelength field of view co-spatial with the short wavelength channel. [2]Use of a dichroic renders the Tunable Filter Imager's long-wavelength field of view co-spatial with the short wavelength channel.

4.4.1 Integrated Science Instrument Module Design

MO-123 The ISIM contains the science instruments, the fine guidance sensors, their supporting structure and thermal support systems, their control electronics, and the ISIM command and data handling system (IC&DH).

4.4.1.1 ISIM Structure

MO-124 To maintain precise pointing and high image quality, the OTE and the optical elements of the science instruments, including the detector systems, must be aligned and held in position to high precision. The ISIM structure provides the optical metering interface between the OTE and the science instruments. It is also the mounting location for supporting components such as the enclosure, thermal radiators, cryocooler for MIRI, heat straps, and cabling harness. The ISIM enclosure will seal the science instruments off from external light sources. The ISIM structure will allow ISIM installation or removal without degradation, damage or disqualification of flight hardware.

4.4.1.2 ISIM Thermal Architecture

MO-125 The ISIM has a distributed architecture consisting of cold and warm components. The cold portion of the ISIM is integrated with the OTE. This passively cooled cryogenic (37 K) structure is mounted on the OTE backplane. It houses the science instruments and the fine-guidance sensors. Thermal radiator panels that provide passive radiation to cryogenic temperatures surround its exterior. A cryocooler inside the Spacecraft provides additional cooling for MIRI.

MO-126 The ISIM Electronics Compartment (IEC) is mounted to the OTE backplane. This provides a more thermally benign (298 K) environment for the instrument control electronics (ICE) boxes and the Focal Plan Electronics (FPE) that control the detector systems in the science instruments. Power dissipation in this section is limited, however, since it is on the cold side of the Observatory.

MO-127 A warm section (also 298 K) of the ISIM is located in the spacecraft on the warm side of the Observatory. This more benign environment allows for relaxed thermal requirements on major portions of the electronics with higher power dissipation, and it avoids unnecessary heat loads in the cold section.

4.4.1.3 ISIM Electronics

MO-128 The ISIM Command and Data Handling (ICDH) will provide the basic command and telemetry routing and processing functions for the science instruments. It will also provide for event-driven mission timeline execution (MR-190) by an Observation Plan Executive (OPE), and Science Instrument (including the Fine Guide Sensor) applications for operations and target acquisition.

MO-129 The IC&DH computer will oversee the operations of the instruments and manage the event-driven operation of the Observatory through the execution of the Observation Plan and on-board scripts, and will coordinate ISIM and Spacecraft activities by sending requests for services, such as slews, to the CTP. The IC&DH will perform read-out mode processing of the science data, that is lossless compression (MR-188) and formatting of the science data, before transfer to the Spacecraft data recorder. It is mounted in the Spacecraft Bus. Software resident on the IC&DH will analyze portions of the data for target acquisition purposes.

MO-130 Science instrument detectors are controlled by Focal Plane Electronics (FPE) that are mounted on the IEC, providing short cable lengths to the detectors in order to reduce noise while providing thermal isolation.

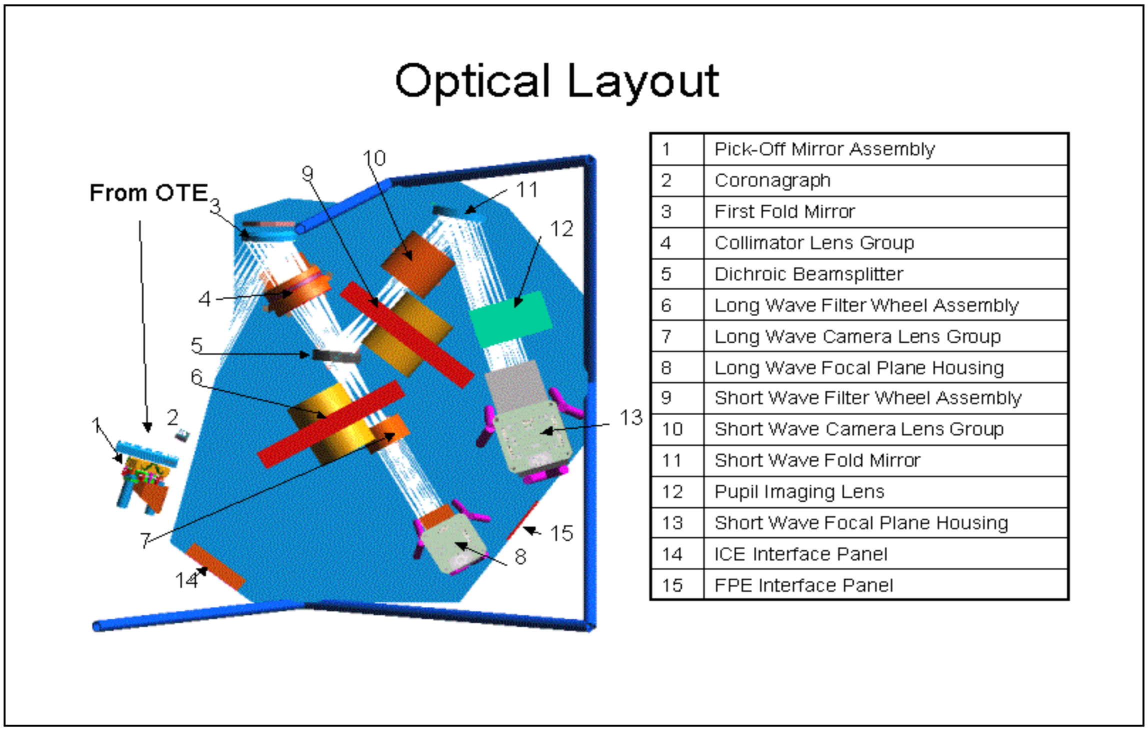
MO-131 The Instrument Control Electronics (ICE) boxes, control science instrument mechanisms, calibration sources, temperature sensors, and heaters; they are also mounted on the exterior of the cold portion of the ISIM.

MO-132 The ICDH unit is connected to the rest of the ISIM electronics by spacewire via the ISIM Remote Services Unit (IRSU), 1553, and various discrete interfaces. The IRSU serves as a spacewire concentrator between the ICDH and the instrument FPEs. This allows for a reduction in the overall cabling needed. The IRSU also collects thermal engineering telemetry of the ISIM subsystems. The 1553 bus provides low-rate command and telemetry between the Science Instruments instrument control electronics and the ICDH. A separate 1553 interface connects the ICDH to the spacecraft C&DH CTP, and a separate Spacewire interface connects the ICDH to the SSR.

4.4.2 NIRCam

MO-134 NIRCam consists of an imaging assembly within an enclosure that is mounted in the ISIM. The imaging assembly consists of two fully redundant, identical optical trains mounted on two beryllium benches, one of which is shown in Figure 4-12. The incoming light initially reflects off the pick-off mirror. Subsequently it passes through the collimator and the dichroic, which is used to split the light into the short (0.6-2.3μm) and long (2.4-5.0μm.) wavelength beams. Each of these two beams then passes through a pupil wheel and filter wheel combination, each beam having its own separate pupil and filter wheel. After this, the light passes through the camera corrector optics and is imaged (after reflecting off a fold flat in the short wavelength beam) onto the focal plane arrays (FPAs).

MO-135 Each of the two identical optical trains in the instrument also contains a traditional focal plane coronagraphic mask plate held at a fixed distance from the FPAs, so that the coronagraph spots are always in focus at the detector plane. Each coronagraphic plate is transmissive, and contains a series of spots of different sizes to block the light from a bright object. The coronagraphic plates also include neutral density spots to enable centroiding on bright stars, as well as point sources at each end that can send light through the optical train of the imager to enable internal alignment checks. Normally these coronagraphic plates are not in the optical path for the instrument, but they are selected by rotating into the beam a mild optical wedge mounted in the pupil wheel that translates the image plane so that the coronagraphic masks are shifted onto the active detector area. Diffraction rings can also be suppressed by apodization at the pupil mask, thus the pupil wheels will be equipped with both a classical and an apodized pupil with integral wedges in each case. Near-Gaussian pupil shapes may also be considered instead of, or in addition to, apodized pupils.



1	Pick-Off Mirror Assembly
2	Coronagraph
3	First Fold Mirror
4	Collimator Lens Group
5	Dichroic Beamsplitter
6	Long Wave Filter Wheel Assembly
7	Long Wave Camera Lens Group
8	Long Wave Focal Plane Housing
9	Short Wave Filter Wheel Assembly
10	Short Wave Camera Lens Group
11	Short Wave Fold Mirror
12	Pupil Imaging Lens
13	Short Wave Focal Plane Housing
14	ICE Interface Panel
15	FPE Interface Panel

Figure 4-12: One of NIRCam's two identical imaging modules. The short wavelength light is reflected from the dichroic (element 5), while the long wavelength light is transmitted through it. Some ISIM struts are shown as blue cylinders around the bench.

MO-136 The instrument is focused by moving the pick-off mirrors. Because of the tilt and slight non-planarity of the pick-off mirror, focusing will result in a small amount of beam-walk at the focal plane, corresponding to a maximum of a few arc seconds over the entire length of the allowed focus travel regime. The short wavelength arm of the instrument also serves as a wave-front sensing guide for JWST; therefore its pupil wheel contains the dispersing element[12] to be used during the coarse phasing of the primary mirror segments.

MO-137 NIRCam contains a number of internal lamps intended for calibration use. Each of the pupil wheels holds a flat-field illuminator. The source for these illuminators will be warm enough to provide flux in all the NIRCam filters, down to 0.6 μm. Rotating the pupil wheel to the integrating cavity position and turning on the source accesses these. These internal flats will be useful for monitoring the basic health and safety of the instrument, as well as for measuring the pixel-to-pixel response of the NIRCam detectors, but are not intended as a substitute for external flat fields taken through the entire optical train of the telescope. In addition, placing the pupil wheel at this location without turning on the source enables dark frames to be obtained.

MO-999 The short-wavelength-channel's pupil and filter wheels contain the elements required for all wavefront sensing and control (WFS&C) functions for JWST, except pupil imagery. These include the grisms used during the coarse phasing of the primary mirror segments, which are used in conjunction with the WFS passband filter in the filter wheel, and weak lenses to be used in routine adjustment of the mirror segments.

Table 4-2. NIRCam Imaging Properties

Wavelength range (μm)	0.6 to 2.3 2.4 to 5
Nyquist λ (μm)	2 / 4
Pixel Format	4096^2 (short λ) 2048^2 (long λ)
Pixel Scale*	0.032″ (short λ) 0.065″ (long λ)
Field (arc min)*	2.2 x 2.2
Spectral Resolution	4, 10, 100

*Assumes telescope diameter of 6.5 m

MO-138 The filter and pupil wheels in each optical train contain a range of wide-band and narrow-band filters. Each wheel has 12 slots. The filters are described in the NIRCam Science Requirements Document.[13] In summary, the short-wavelength arm contains 5 wide-band (R~4), 4medium (R~10), and 4 narrow-band (R~100) filters, while the long-wavelength arm contains 3 wide, 8 medium and 5 narrow-band filters. There is also an extra-wide filter in each channel. The Filter/Pupil Wheels can be rotated in either direction, reducing mechanism motion overhead.

MO-139 The imaging properties of the NIRCam FPAs are summarized in Table 4-2. The instrument contains a total of ten 2k×2k sensor chip assemblies (SCAs), including those in the identical redundant optical trains. The short wavelength arm in each optical train contains a 2×2 array of these SCAs, optimized for the 0.6 - 2.3 μm wavelength range, with a small gap (~3 mm = ~5″) between adjacent SCAs. Since these detectors will be photovoltaic diodes, it is not expected that anneals or other strategies will be required to repair long-term degradation from cosmic rays. The detector mounts also include shielding to reduce radiation damage.

4.4.3 NIRSpec

MO-140 NIRSpec is a near infrared multi-object dispersive spectrograph capable of simultaneously observing more than 100 sources over a field-of-view (FOV) larger than 3′×3′. Three resolving powers, R=100, 1000, and 2700 will be available for observing the spectral ranges 0.6-5 μm (at R=100) and 1.0-5.0 μm (at R=1000 and R=2700).

MO-141 The region of sky to be observed is transferred from the JWST OTE to the spectrograph aperture focal plane (AFP) by a pick-off mirror (POM) and a system of fore-optics that includes a filter wheel for selecting band passes and introducing internal calibration sources. The nominal scale at the AFP is 2.51″/mm.

MO-142 Targets in the FOV are normally selected by opening groups of shutters in a micro-shutter array (MSA) to form slits. The MSA itself consists of a mosaic of subunits producing a final array of approximately 730 (spectral) x 342 (spatial) individually addressable shutters with 200x450 milliarcsec openings and 264x514 milliarcsec spacing. Sweeping a magnet across the surface of the MSA opens all shutters. Individual shutters may then be addressed and closed electronically, as the magnet sweeps back across the array. The nominal aperture size is 1 shutter (spectral) by at least 1 shutter (spatial) at all wavelengths. Multiple spacecraft pointings may be required to avoid placing targets near the edge of an aperture, to observe targets with overlapping spectra, and to fill the gap in wavelength coverage between detectors. The nominal slit length is 3 shutters in all wavebands. In the *open* configuration, a shutter passes light from the fore-optics to the collimator. A slitless mode can be configured by opening all shutters in the MSA. A long slit can also be configured with the MSA.

MO-143 In addition to the slits defined by the MSA, there are five fixed-slits with widths of 100, 200 and 400 milliarcsec in the AFP that can be used for high-contrast spectroscopy. They are placed in a central strip of the AFP between sub-units of the MSA. They are arranged such that at least one fixed-slit will be unblocked, even if the magnet transport arm fails while in motion, and spectra will fall completely on one of the two detectors.

MO-144 The AFP is re-imaged onto a mosaic of NIR detectors (the focal-plane array: FPA) by a collimator, a dispersing element (gratings or a double-pass prism) or an imaging mirror, and a camera. Three gratings are used for first-order coverage of the three NIRSpec wavebands at R=1000 (1.0-1.8μm; 1.7-3.0μm; 2.9-5.0μm). The same three wavebands are also covered by first-order R=2700 gratings for objects in a fixed-slit and the integral field unit (IFU). The prism gives R=100 resolution over the entire NIRSpec band pass (0.6-5μm) but can, optionally, be blocked below 1 μm with one of the filters.

MO-145 The image scale on the FPA is nominally 5.56″/mm, with 18 μm pixels. The detector consists of a mosaic of sub-units, each 2k×2k, forming an array of 2k×4k 100 milliarcsecond pixels with a gap between detectors.

MO-146 There are three basic optical subassemblies - the fore-optics, the collimator and the camera, the latter two of which are three-mirror anastigmats (TMA).

MO-147 The basic elements of the spectrograph are illustrated schematically in Figure 4-13, which shows both the optical subsystems and associated mechanisms. The optical flow is from top to bottom (OTE to the detector FPA). The principal opto-mechanical elements are in the center. The calibration unit contains a number of continuum and line sources that inject light into a single integrating sphere, which in turn feeds into the optical path via a mirror on the back side of the filter wheel.

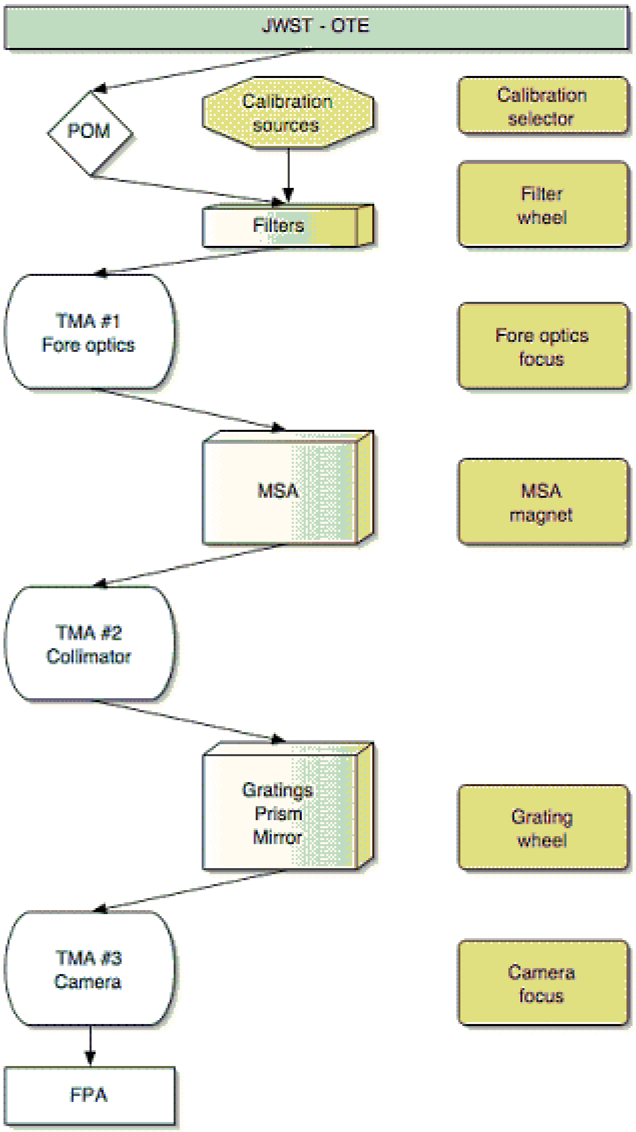


Figure 4-13. A schematic view of NIRSpec showing the main optical elements/ subsystems on the left and the mechanisms on the right.

MO-148 Filter wheel: The filter wheel mechanism allows the selection of one of the long-pass and bandpass filters used for spectroscopic order-sorting and imaging/target acquisition respectively and a (parfocal) clear position. An opaque (dark) closed element that also serves as a relay mirror for the calibration sources occupies one of the eight positions.

MO-149 Fore-optics focus: A mechanism in TMA #1 is used to focus the image from the OTE onto the AFP.

MO-150 Micro-shutter Array: Selected shutters in the MSA are opened/closed using a combination of electrical latching and magnetic forcing. The magnetic field is applied to the shutter array by a linear magnet mechanically driven across the MSA.

MO-151 Grating wheel: The grating wheel allows the selection of one of six gratings, a double-pass prism and a mirror.

MO-152 Camera focus: There is no mechanism for adjusting the focus of the camera inside the NIRSpec.

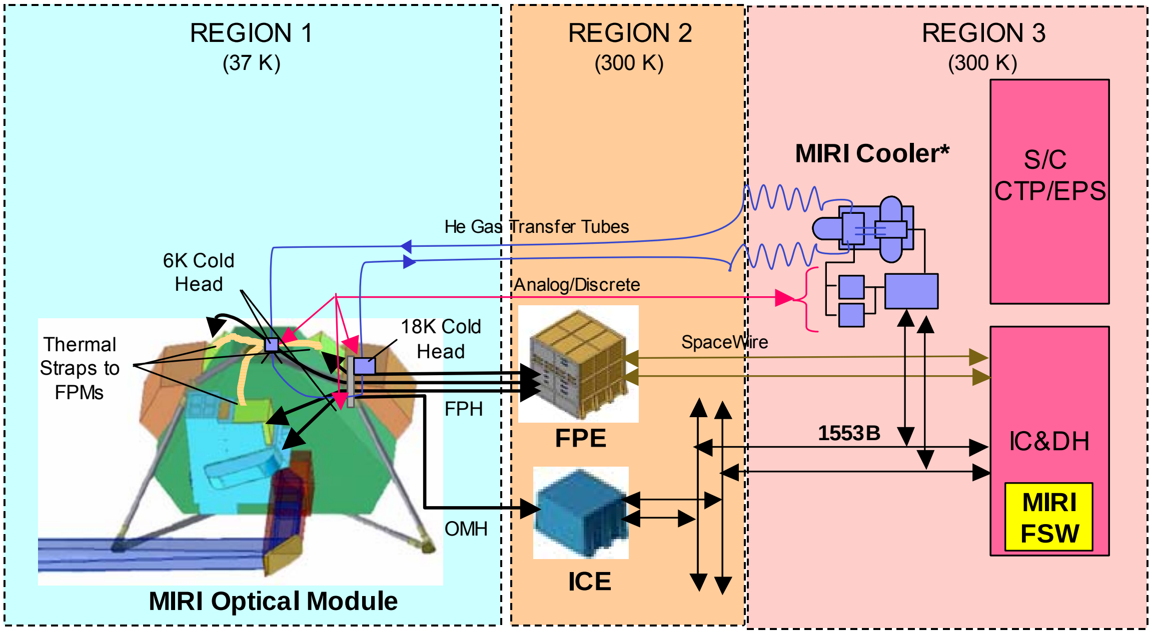
MO-153 Calibration Selector: Calibration light is injected into the spectrograph from a relay mirror placed on the back side of the filter wheel. The selection of one or more lamp sources will be made electrically.

MO-154 Lamps: Continuum and line internal calibration sources are needed for flat fielding, geometric calibration and for wavelength calibration. Their number and characteristics are (**TBD**). It is likely that several continuum sources will be required to cover the full NIRSpec wavelength range. If line sources are constructed from filtered continuum sources, several different sources or filters will be required.

4.4.4 MIRI

MO-155 The Mid-Infrared Instrument (MIRI) on JWST provides imaging and spectroscopic measurements over the wavelength range 5-27 μm. MIRI consists of two subcomponents, an imager (which includes the low resolution spectrograph and the coronographs) and an integral field unit (IFU) spectrograph, and an onboard calibration unit.

MO-950 As shown in Figure 4-14, MIRI consists of an optical bench assembly (OBA) with associated instrument control electronics (ICE), actively cooled focal-plane modules with associated focal plane electronics (FPE), and a cryo-cooler with associated cryo-cooler electronics (CCD). The ICE, CCE and interface with the ICDH. The OBA contains two actively cooled subcomponents, an imager, and an Integral Field Unit (IFU) spectrograph, plus an on-board calibration unit.



*Notional Cooler and Cold Head arrangement shown

Figure 4-14. MIRI functional block diagram

4.4.4.1 MIRI Imager Module

MO-156 The imager module provides broad and narrow-band imaging (5-27 μm), coronagraphy, and low-resolution (R~100, 5-10 μm) slit spectroscopy using a single 1024×1024 pixels Si:As sensor chip assembly (SCA) with 25 μm pixels.

MO-1000 The coronagraphic masks, located along one edge of the focal plane aperture, include three four-quadrant phase masks and one opaque spot for a Lyot coronagraph. The coronagraphic masks each have a square field of view of 26″×26″ and 30″x30″ for the Lyot and are optimized for particular wavelengths (10.65, 11.4, 15.5 and 23 μm). The imager's only moving part is an 18-position filter wheel, allocated as 10 filters for imaging, 4 filter and diaphragm combinations for coronagraphy, 1 neutral density filter, 1 ZnS-Ge double prism for the low-resolution spectroscopic mode (LRS), 1 closed position for darks and 1 for a lens.

MO-1001 The imager will have a pixel scale of 0.11″ and a total field of view of 113″×113″; however, the field of view of its clear aperture is 76″×113″ because the coronagraph masks and the LRS are fixed on one side of the focal plane.

MO-1002 The low resolution spectrograph obtains R~100 spectra in the 5-10 μm wavelength interval, and is optimized for point sources. It has a 5″x0.6″ entrance slit. It uses coupled Ge and ZnS prisms as refractive elements. This optical element is located in the imager filter wheel.

4.4.4.2 MIRI IFU Spectrograph

MO-157 The integral field unit spectrograph obtains simultaneous spectral and spatial data on a relatively compact region of sky. The spectrograph uses four image slicers to produce dispersed images of the sky on two 1024×1024 SCAs to provide R~2070-3730 integral field spectroscopy over a ~λ=5-27 µm wavelength range with a goal of λ=5-28.3 µm.

MO-1003 The spectral window of each IFU channel is covered using three separate gratings (i.e., 12 gratings to cover the four channels). Each grating is fixed in orientation and can be rotated into the optical path using a wheel mechanism (there are two wheel mechanisms which each hold 3 pairs of gratings). The optics system for the four IFUs is split into two identical sections (in terms of optical layout). One section is dedicated to the two short wavelength IFUs and the other handles long wavelength IFUs. There is one SCA for each section. The two sections share the wheel mechanisms with each wheel mechanism incorporating three gratings for one of the channels in the short wavelength section and three gratings for one of the channels in the long wavelength section.

4.4.4.3 MIRI Calibration Unit

MO-158 The calibration unit for MIRI provides uniform illumination for flat field calibration. The source is a blackbody at approximately 500 K, illuminating an integrating sphere. For imager calibrations there are no moving parts. When turned on, the calibration light shines on the pupil of the imager.

4.4.5 The Fine Guidance Sensors and Tunable Filter Imager

MO-159 The Fine Guidance Sensor (FGS) is a CSA-provided subsystem that will be used as the sensor for fine pointing control during all science observations and as a science imager to acquire narrow band NIR images of astronomical objects.

MO-1004 The FGS optical axis is nearly parallel with the Observatory V1 axis. It will operate at ~37K, similar to NIRCam and NIRSpec. The FGS is comprised of two dedicated channels for guiding (designated FGS-G) and two separately packaged channels for science imaging, with tunable filters (designated FGS-TFI).

MO-1005 Each channel will image its field of view onto a 2kx2k pixel array NIR detector. The guider channels each have their own FOV and are sensitive over a pass band from 0.8 to 2.5 µm. The FGS-TF Imager detectors share a single FOV, which is split by a dichroic beam splitter into short (1.0-2.1 µm) and long (2.2-4.8 µm) arms. Figure 4-15 depicts the FGS channels.

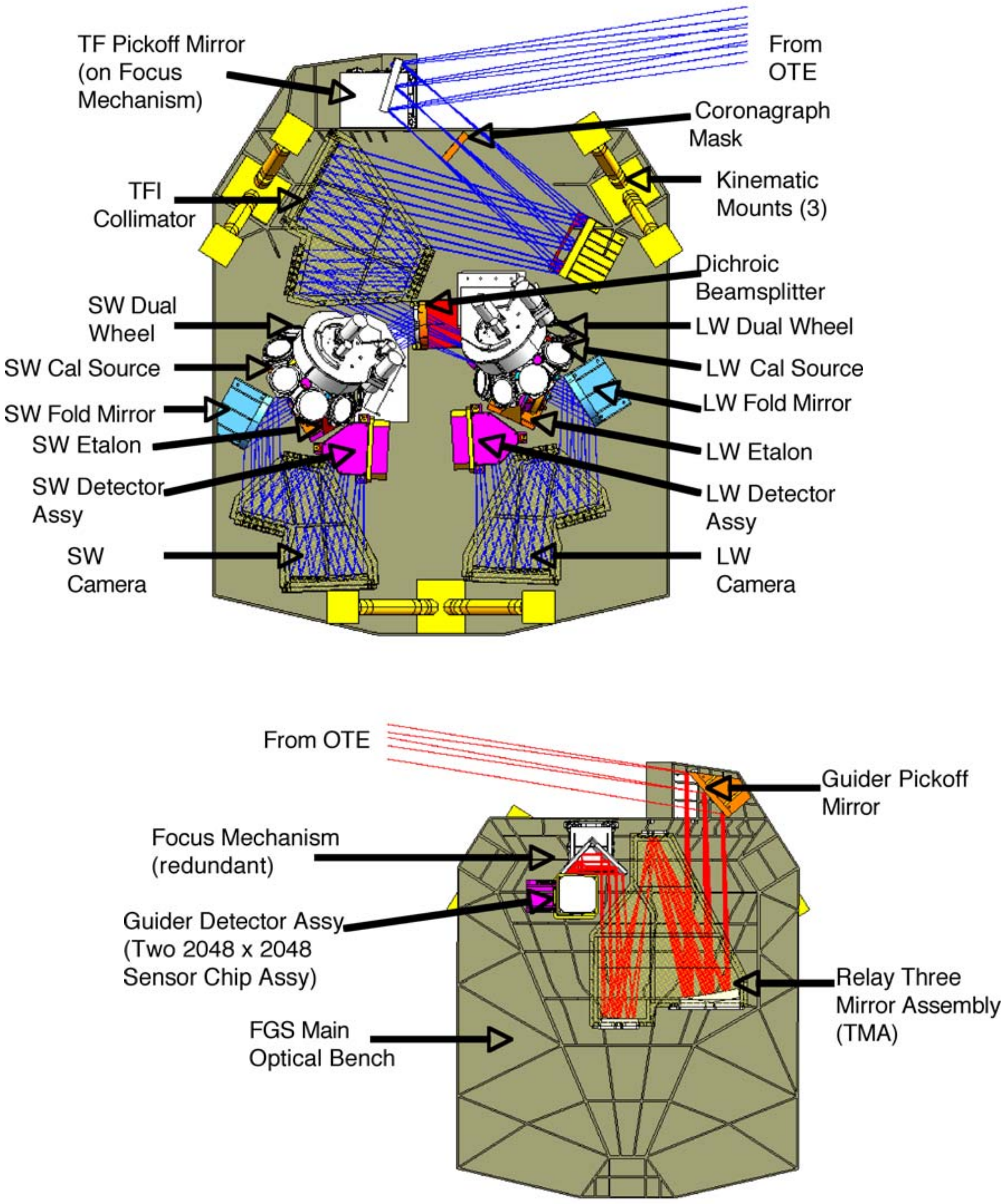


Figure 4-15: Representative architecture of the major components of the FGS. The top panel is viewed from the FGS-TFI side and the bottom from the FGS-Guider side.

MO-160 To enable repeated visits by the same or different instruments, to allow for effective observation of targets of opportunity, and to enable mosaic imaging larger than the fields of view of individual instruments, the Observatory must have at least a 95% probability of acquiring a guide star (MR-171) and maintaining pointing stability for any valid pointing direction. The budget for the FGS contribution to pointing stability under fine guiding is 3.5 milliarcseconds Noise Equivalent Angle (NEA), and pointing control updates are to be at 16 Hz. The 95% probability, the 16 Hz update rate, and 3.5 milliarcsecond pointing accuracy requirements determine the FGS field of view, pixel scale, and sensitivity.

MO-161 Once in fine guidance mode, the absolute pointing accuracy (MR-173) of the Observatory with respect to the celestial coordinate system must be 1” rms, and the relative repeatability of pointings (MR-174) following small slews using the same guide star between different exposures and visits for the same field must be accurate to 0.005” rms. Cataloged guide stars as faint as Jab = 20 will be used for fine guiding, while even fainter cataloged stars can be used for field identification

MO-162 To support dithers and target acquisitions required by science instrument operations, the FGS must be able to support small angle maneuvers (MR-182) up to 0.5″ with 5 milliarcsecond (per axis, 1-sigma) accuracy and offsets of 0.5″ to 20″ with a 1-sigma, per axis accuracy (MR-181 and MR-374) that is better than 10% of the slew amplitude.

MO-163 Tracking of moving targets is not yet included in mission requirements for JWST. However, moving target tracking is required by the SRD developed by the SWG. If this capability becomes a requirement, the FGS will be required to measure the position of a guide star to an accuracy of about 5 milliarcseconds (per axis, 1-sigma) as it traverses a path across the FGS FOV. Tracking rates as large as $0.030''/s^{-1}$ need to be supported to enable observations of nearby asteroids and comets.

MO-167 The FGS-TF Imagers use cryogenic etalons with a spectral resolving power of R~100, and a finesse of 30. The etalons consist of thin substrates with front-surface reflective coatings.

MO-169 The optical path of both channels of the FGS-TFI includes a pupil wheel and a filter wheel. The pupil wheels contain calibration units, neutral density filter and apodization masks for use with the coronograph. The filter wheels contain slots for up to 7 blocking filters. The blocking filters restrict the light entering the etalon to a single order, typically m=3. The filter wheels also include an “open” position which allows broad-band light to enter the etalons.

MO-170 The FGS-TF Imager has wavelength and flat field calibration units located in the pupil wheels. The flat field unit includes an integrating cavity and optics that permit light from it to be integrated into the optical train of the instrument.

4.5 GROUND SEGMENT OVERVIEW

MO-174 The JWST ground segment includes the Science & Operations Center, Flight Software and SI development labs, the Deep Space Network (DSN), JWST Network Support System (JNSS), and GSFC's Flight Dynamics Facility (FDF). The S&OC is responsible for operating the Observatory and enables scientists to plan and complete the scientific investigations for which JWST is constructed while the remainder of the ground segment enables communication with and maintenance of the Observatory. Figure 4-16 depicts the elements of the JWST Ground Segment.

MO-175 The ground system architecture for JWST is fundamentally affected by the architecture of the Observatory, and vice versus. The location of the Observatory at L2 and the utilization of event-driven, rather than time-driven, activity management on the spacecraft will allow JWST to operate autonomously and efficiently for extended periods of time without real-time control. Communications at L2 require large ground stations. The three DSN ground stations are located throughout the globe, and as a result communications contacts will occur during both day and night at STScI, where the S&OC will be located. Communications contacts by the ground system will be automated to permit 8-hour per day, 5-day per week staffing of the S&OC for most operations.

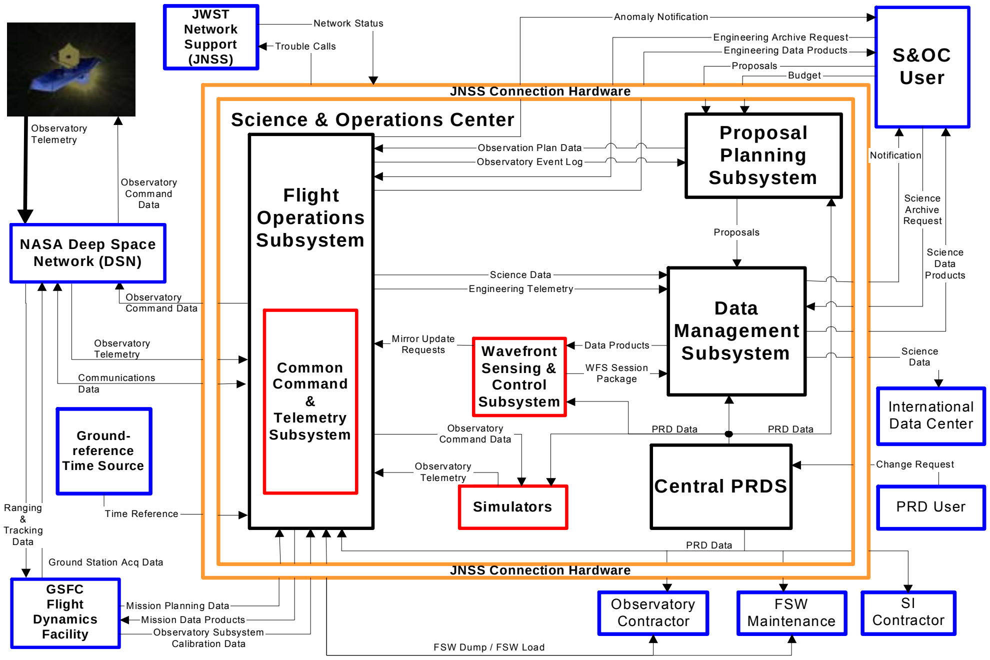


Figure 4-16. Elements of the JWST Ground Segment

4.5.1 Science and Operations Center Architecture

MO-176 The major subsystems of the S&OC include the Proposal Planning, Data Management, Operational Scripts, Project Reference Data (PRD) and Flight Operations subsystems. The Proposal Planning and Data Management subsystems will interface directly with JWST observers. The PRD subsystem provides interfaces to the Observatory, flight software, instrument and ISIM developers. The JNSS provides network connectivity between the S&OC and DSN. The Flight Operations Subsystem provides for communication with the Observatory via DSN.

MO-177 The Proposal Planning Subsystem includes the tools and systems to solicit, select, plan and schedule science, calibration and engineering observations. This subsystem also provides for submitting and administering grants. The Flight Operations Subsystem provides for command control and telemetry processing, mission operations scheduling and real-time and offline engineering data analysis. The Data Management Subsystem archives and distributes the engineering data and archives, processes and distributes the science data. The Project Reference Database Subsystem (PRDS) is the repository for all JWST data and information required for Observatory operations, such as telemetry descriptors, commands, parameters, algorithms, and characteristics. The Operational Scripts Subsystem (OSS) provides the tools necessary to assist in the development, validation and management of onboard scripts and associated CECIL command procedures, as required.

MO-178 Two other special purpose systems are included in the S&OC architecture - a Wavefront Sensing and Control (WFS&C) Executive and Observatory Simulators. The WFS&C Executive will store and process science and engineering data obtained to measure wavefront error (MR-285). Wavefront control output products are produced that will be uplinked to correct the optical figure of the telescope.

MO-179 Two high-fidelity simulators will be integrated into the S&OC: a Software Telemetry Simulator (STS) and an Observatory Test-Bed (OTB). The STS will provide a high fidelity simulation of Observatory operations including command receipt and telemetry transmission in a software environment that allows multiple versions of the simulator to be run for varioua tasks (training, procedure development and test and system test). The OTB will provide high fidelity simulation of Observatory operations and will include similar hardware to the flight systems for non-dynamic and non-cryo systems such as the C&DH.

MO-180 These simulators will be used for:

- On-board script development and test
- Ground system real-time command procedure development and test
- Ground to flight interface development and testing
- Operations staff training
- Post-launch trouble-shooting and maintenance

4.5.2 Communications Element

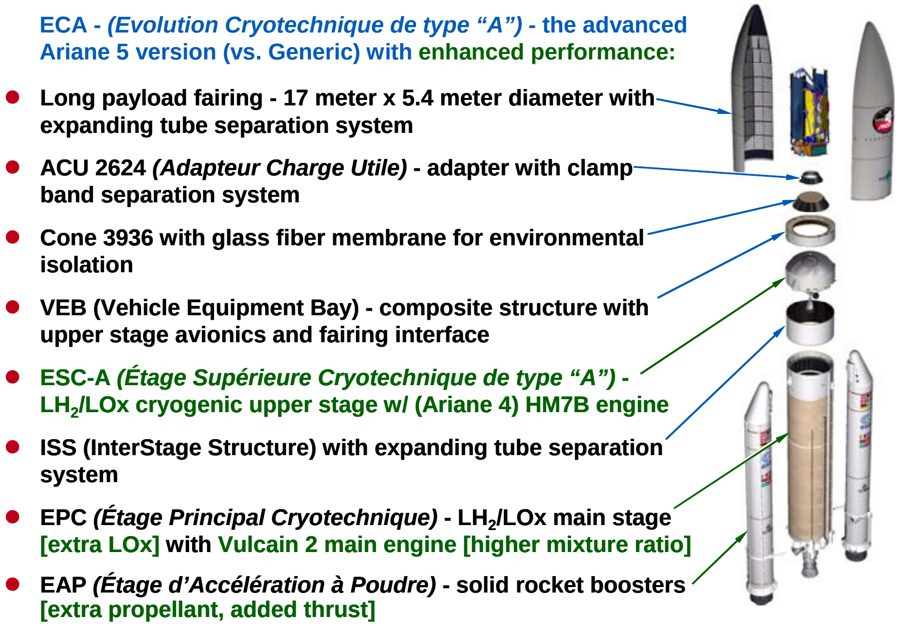
MO-181 The communications element is required to routinely provide a minimum of 4 hours of contact time per day with the Observatory with additional contacts available as needed to address deployment and contingency operations. Emergency operations will initiate continuous communications coverage. Emergency and contingency services will be available within two hours of the time requested. The current concept for JWST communications is to use the JPL Deep Space Network (DSN), an international network of antennas that supports interplanetary spacecraft missions and astronomy observations. The DSN currently consists of three deep-space communications facilities placed approximately 120˚ apart around the world: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. This strategic placement permits constant observation of JWST as the Earth rotates.

4.5.3 Orbit Determination and Control

MO-182 The GSFC Flight Dynamics Facility (FDF) will provide JWST orbit determination and tracking and ranging support. FDF support is available using flight-tested and proven software and flight engineers from the design concept stage through the end of the JWST mission. The FDF will also support the validation of on-board navigation systems, design and implementation of orbit maneuvers through all phases of the mission. After insertion into the L2 Lissajous orbit, ranging information will provide the basis for planning of the Delta-V maneuvers required to maintain the orbit, and for monitoring the results of such maneuvers. Tracking and ranging services are also required for accurate and efficient acquisition of the DSN ground stations by JWST. To obtain the required accuracy for orbit maintenance, tracking and ranging services must be provided by ground stations located in both Northern and Southern hemispheres. A 19-day tracking arc is required to obtain an orbital solution, so station-keeping activities will be scheduled on a 22-day cycle to allow for ground segment processing and planning.

4.6 LAUNCH SEGMENT OVERVIEW

MO-183 The Ariane 5 ESC A (Figure 4-17) is the launch system that will provide JWST a direct transfer to the L2 orbit. The Ariane 5 launch capability to our orbit is 6,800 kg. The Atlas EELV launch capability is 6,305 kg. The current Observatory mass is 6,194 kg (MR-99). The Observatory is designed to withstand the launch environments on either vehicle. Additionally, Observatory and launch vehicle adapter (LVA) interfaces will be designed for either vehicle with minimum modification, should the customer determine that the EELV deployment is desirable.



ECA - *(Evolution Cryotechnique de type "A")* - the advanced Ariane 5 version (vs. Generic) with enhanced performance:

- **Long payload fairing - 17 meter x 5.4 meter diameter with expanding tube separation system**
- **ACU 2624 *(Adapteur Charge Utile)* - adapter with clamp band separation system**
- **Cone 3936 with glass fiber membrane for environmental isolation**
- **VEB (Vehicle Equipment Bay) - composite structure with upper stage avionics and fairing interface**
- **ESC-A *(Étage Supérieure Cryotechnique de type "A")* - LH_2/LOx cryogenic upper stage w/ (Ariane 4) HM7B engine**
- **ISS (InterStage Structure) with expanding tube separation system**
- **EPC *(Étage Principal Cryotechnique)* - LH_2/LOx main stage [extra LOx] with Vulcain 2 main engine [higher mixture ratio]**
- **EAP *(Étage d'Accélération à Poudre)* - solid rocket boosters [extra propellant, added thrust]**

Figure 4-17. Ariane 5 EC-A Launch Vehicle with long fairing

MO-185 The Observatory will be launched from the Guiana Space Centre (CSG), in Kourou, French Guiana, on an Ariane 5 and will be monitored and controlled by the S&OC (with all data passing through the DSN). The support from the elements is summarized in Table 4-3.

Table 4-3. Launch Support Elements

Guiana Space Centre	• Support Observatory to launch vehicle integration • Conduct launch operations
Guiana Space Centre (CGS) (ESA/ESOC/CNES) tracking stations	• Provide to S&OC: Observatory command & telemetry S-Band links during Ariane powered flight phase and initial transfer orbit operations via CGS ground stations • Provide to S&OC: Observatory telemetry during Ariane powered flight phase via Ariane interleave and CGS telemetering receiving stations • Specific ESA/ESOC/CNES ground stations which provide above support are in French Guiana, Natal (Brazil), Ascension Island (United Kingdom), Libreville (Gabon), and Malindi (Kenya)
NASA's Tracking and Data Relay Satellite System (TDRSS)	• Support launch & deployment operations • Provide SSA one-way Doppler measurements during initial launch & early operations • Provide coverage for ~ 3 hours during initial launch & early operations – Provide two TDRSS SV assets – Anticipate two-hour launch window each day – Anticipated support for Launch through L+60 minutes
NASA Deep Space Network (DSN)	• Support launch, deployment, and commissioning operations • Provide continuous coverage through Primary Mirror Phasing actvities; routine 4-hour each day thereafter • Support emergency S & Ka-Band communications when a Spacecraft Emergency is declared • Provide ranging data
Air Force Weather Service (**TBR**)	• Support launch, deployment, and commissioning operations

MO-186 Figure 4-18 shows the Observatory integrated with the LV.

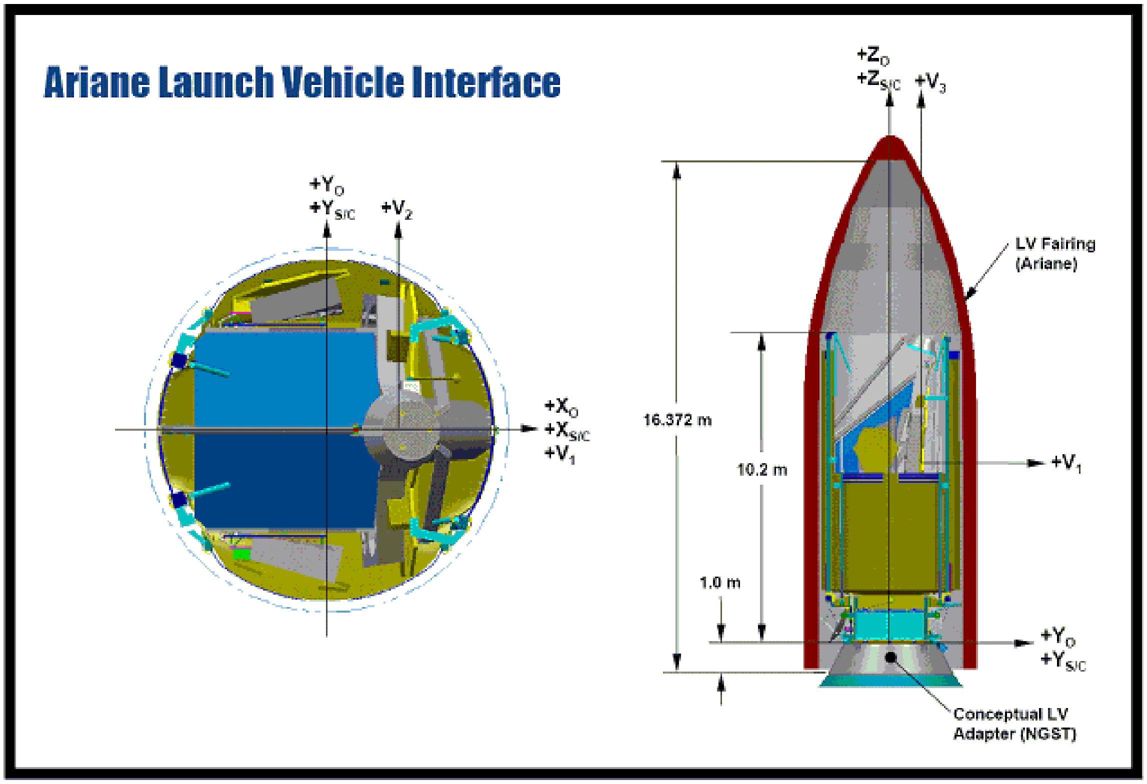


Figure 4-18. Observatory Stowed in Fairing

5.0 OPERATIONS DESCRIPTION

MO-187 The subsystems that constitute JWST, those that will be part of the Observatory at L2 and those on the ground, were described individually in Chapter 4. These systems must operate in close collaboration to produce a successful mission. The operations discussion in this chapter will therefore encompass the whole JWST system, considering how flight and ground subsystems perform together to attain the science mission goals.

MO-188 The actual science executed during the facility-class JWST normal operations phase will largely originate from observations that are solicited and selected by an STScI-led process described in Section 3.4. (MR-344) This observation pool is planned on a yearly basis and then carried out by the Observatory on a weekly basis. The resultant data are characterized and delivered to observers in a form that can be analyzed. The scientific results are then extracted and published in forms that both professional astronomers and the general public can appreciate.

5.1 OPERATIONS GOALS

MO-189 The operations approach for JWST is intended to maximize the science productivity of the mission and is built upon four basic concepts:

1. Observatory operations will support the science capabilities of JWST, as envisaged in the SRD[14].
2. Observatory operations must be efficient, as measured in terms of the fraction of time spent observing high-priority targets, and certainly greater than 70% (MR-102).
3. Observatory operations must keep the Observatory safe, preventing as many problems as possible and providing a robust means of recovering from problems that do occur.
4. Observatory operations must be cost-effective, minimizing life-cycle costs for the mission.

MO-190 These four fundamental concepts are outlined here. Many specific operational topics are discussed later in this chapter in more detail. References to the associated mission level requirements are given in parentheses.

5.1.1 Enable the Core of the James Webb Space Telescope Science Program

MO-191 The major JWST science objectives, as recorded within the JWST Project Science Objectives and Requirements Document[15], have been summarized in Chapter 2 of this operations concept document. They prescribed that the JWST mission operations supply:

- A capability to execute a science program dominated by long observations of very faint objects that do not have tight time constraints.
- Observer support tools to aid the rapid identification of spectroscopic candidates from deep images that result in the scheduling of follow-up spectroscopic observations (MR-345).
- An automatic on-board target location capability to support coronagraphic and spectroscopic observations.
- An ability to plan and execute moving target observations that typically require stringent time constraints.

5.1.2 Maximize James Webb Space Telescope Science by Efficient Science Operations

MO-192 After commissioning, JWST will provide at least 30,556 hours of prime exposure time on scientific targets over 5 years (MR-102). This is based on and will be verified by a hypothetical science program designed with 500, 90 degree slews and 8,000 small angle slews per year. If this ambitious efficiency level is to be met, then the JWST operations concept must aggressively incorporate efficiency savings throughout the entire system.

5.1.3 Maximize James Webb Space Telescope Science by Assuring the Safety of the Observatory

MO-193 The commitment to provide a healthy Observatory for the entire JWST life cycle is fundamental to the mission operations concept. Numerous health and safety checks will be furnished by both the flight and ground systems to ensure that the Observatory will continue to operate. Many of the safety concepts are inherited from previous successful space science missions. The following health and safety characteristics have been incorporated into the JWST operational concept:

- A clearly defined validation process for all Project Reference Database items (MR-302).
- A ground system capability to prevent the transmission of commands that cause irreversible hardware actions unless specifically overridden with Project approval (MR-321).
- Ground verification of all real-time procedures and all Observation Plans prior to uplink (MR-320, MR-333, MR-325).
- On-board command validation and verification that result in the rejection of all illegal commands (MR-147, MR-148, MR-149, MR-150, MR-153).
- An on-board telemetry monitoring capability that results in automatic reactions that complete within sufficient time to prevent hardware damage (MR-195, MR-196, MR-272, MR-276).
- Event and activity logs and event messages to record anomalous occurrences (MR-127).

- A process for rapid acquisition of data downlink and command uplink when an Observatory emergency is declared (MR-355).
- Critical telemetry provided to the ground for anomaly analysis and long-term trending (MR-336, MR-337).
- A ground tool for quick detection of an anomaly from downlinked event data with automatic notification of on-call technical staff (MR-290).
- Ground telemetry monitoring of Observatory operations with alert capability when items violate specified limits (MR-290, MR-337).

5.1.4 Minimize Lifecycle Costs

MO-194 JWST operations must be accomplished in a cost-effective manner. Many of these concepts have been derived from analysis of lessons learned from previous successful space science missions or result from the incorporation of HST heritage systems. Elements of the operations approach intended to assure minimization of lifecycle costs are as follows:

- An integrated set of planning tools for scientists and engineers that is based heavily upon the STScI HST observer planning tools.
- A simple user interface for extracting and analyzing science data that is based heavily upon the STScI HST data processing and archive systems, which includes an automatic process for data archival and retrieval.
- An event-driven operations approach that simplifies scheduling and does not require detailed modeling of spacecraft subsystems within the ground system.
- A high-level commanding concept for science operations in which human-readable ASCII command loads are sent to the IC&DH computer.
- Limiting the need for real-time commanding.
- Using on-board scripts for most on-board tasks for both planned and real-time operations (eliminating the need to code and test two versions for the same command procedure).
- Use of high-level event-driven commanding as soon as possible during commissioning (eliminating the need to develop special procedures for routine tasks executed during commissioning such as science instrument calibration data taking).
- A flight operations system that does not require staffing except in normal working hours
- Use of a heritage flight operations system with command and telemetry components also used during I&T and validation.
- A development approach that is prioritized on the basis of the most-used capabilities required to fulfill the SRD (verifying that the most important operations are supported first).

5.2 OBSERVATORY OPERATIONS

MO-195 As discussed in Sections 4.4.1.3 and 4.3.3, two primary computers - the IC&DH computer and the CTP - control JWST. The IC&DH computer has direct control over the instruments and support electronics located on the ISIM. The CTP is the spacecraft computer used to control the OTE and spacecraft functions and provides safe mode monitoring of the ISIM. Real-time commands from the ground can be routed through the spacecraft bus to either the IC&DH computer or the spacecraft bus.

MO-196 During normal science operations, control of the Observatory timeline is managed through the ICDH. The ICDH sends requests to the spacecraft bus to reorient the spacecraft. The ICDH commands the FGS to acquire and lock on guiding targets. The ICDH also configures the instruments for observing, commanding them to acquire data and to send data to the SSR. In issuing the sequences of commands necessary to conduct normal operations, the ICDH will be utilizing, as will be described in detail below, an Observation Plan (OP) that will normally be uplinked to the Observatory on a weekly basis. The ICDH monitors the health and safety of the instruments and if anomalies occur places them in the appropriate safe configuration.

MO-197 The spacecraft bus carries out activities in response to requests from the IC&DH computer, and monitors the state of the Observatory and spacecraft subsystems to assure that the Observatory can continue to operate normally. If the spacecraft bus encounters an anomaly that threatens the safety of continued operation of the Observatory, it will interrupt the normal operating mode and place the Observatory in a safe configuration.

MO-198 Although the acquisition of science data and the associated attitude timeline will be controlled through the Observation Plan on the IC&DH computer, real-time commands will be used during ground contacts to carry out a number of functions as discussed in section 6.2. Examples of real-time actions include initiating data dumps, modifying onboard flight software and uplinking new operations data such as Observation Plans and associated files. The regularly used real-time commands will for the most part not require an interruption of the science observation plan.

5.2.1 Event-driven operations

MO-199 A key to understanding JWST operations, and in particular normal in-flight operations, is the concept of event-driven operations (MR-161, MR-190). The event-driven operations concept is based upon a command concept that allows the use of command execution status to determine when to execute the next command in a sequence. Thus, a command is issued, the event-driven system waits for that command to complete execution, a telemetry response indicates that the command has completed execution, and the next command is issued. As a result, for commands that have substantially variable execution times, the ground system does not have to precisely model the execution time (which simplifies the ground system) or apply conservative timing estimates (which improves operations efficiency).

MO-951 In the event of an execution error or unsuccessful completion of the command, the event-driven system will detect an execution error or unsuccessful completion through the response in the telemetry packet and will respond depending upon the nature of the failure. In some cases, a failure response is provided and alternative commands can be executed. If alternatives are not provided or are exhausted, subsequent commands can be skipped. Finally, execution of the event-driven commands can be stopped and the event-driven system waits for the ground to respond.

MO-952 The event-driven operations concept is also based upon a command concept that allows the use of subsystem status to control execution of the command sequence. In this case, subsystem status may indicate that a subsystem is not available, not ready or has insufficient resources available. In response, the event-driven system can wait until the subsystem can be used, can skip commands that require that subsystem, or stop execution of the event-driven commands. The OPE determines the appropriate action.

MO-953 The event-driven operations concept provides for the on-board generation of commands from a higher-level description of operations activities (through activity descriptions) that are provided by the ground system. These activities are organized into sequences of activities required to perform higher-level tasks, and allows for specification and coordinated execution of parallel sequences of activities to perform these tasks.

MO-954 Finally, these tasks are organized into a sequence of tasks, each of which must be executed within a time window that reflects any restrictions on when the tasks can be executed. When the system has completed one task, it will wait until the next task can be executed, or if it is too late to execute that task the system will skip to the next task in the sequence that can be executed now or in the future.

MO-955 For an Observatory such as the James Webb Space Telescope, which is pointed at a target for exposures to be taken with a science instrument, a task is called a visit. A science visit is the set of activities required to point at the target (slew, guide star acquisition), configure the science instruments, take exposures, and perform offset maneuvers (dithering) to improve resolution and compensate for detector non-uniformity. The event-driven system accommodates variation in the time required to slew to the target, the time and number of guide star candidates required for guide star acquisition, and the time required to set up the science instrument (e.g. filter wheel rotation) and offset the target within or between science apertures. The event-driven operations concept also allows the event-driven system to wait until there is sufficient storage space on the data recorder, skip activities if the science instrument is not available, or skip the remainder of the visit if the guide star acquisitions fail, or even skip an entire visit if the primary science instrument is not available.

5.2.2 Visits

MO-206 As discussed in section 4.5.1 (see also 5.7.1), the JWST Science and Operations Center (S&OC) will receive requests to utilize the Observatory, in the form of proposals, from both scientific researchers and engineering staff. These proposals will be composed of a number of logical units, or visits. By the end of the planning process, each visit will contain all of the information necessary to schedule and execute the visit. For science operations, the typical visit would consist of a target position specification, a list of exposure specifications using one or more detectors, and some observing constraint specifications (for example, the required vehicle orientation range). Engineering functions, for example attitude control system calibrations, mirror adjustments, science instrument calibrations or orbit maintenance, will also be specified and planned using the visit constructs. The visit construct will be used to specify many commissioning and all normal operations science and engineering requests, except for contingency operations. The scheduling process selects the guide stars and final orientation for each visit and creates sequential lists of visits for execution.

MO-207 Using the information within these visits, visit files will be created by the ground system for uplink to the Observatory. As the detailed knowledge of the hardware and software items will be encapsulated within the Observatory, the visit files will simply contain high-level descriptions of what should be done. The file contents will be human-readable to facilitate interface verification. The visit file will not contain the detailed set of steps required to accomplish each task. The detailed "how" rules will reside within the on-board scripts known as Activity Descriptions (ADs). The visit files will specify the structured list of the activity description that need to be invoked to carry out an observation correctly as well as associated scheduling requirements. The on-board Script Processor (SP), will be responsible for executing the referenced ADs. Most of the information within the visit file (and its syntax) will come directly from the proposal forms; however, there will also be some visit information that will be added by the ground software. For example, any external exposure request must be preceded by requests for a slew and a guide star acquisition. These activity requests will be created by ground system software using the target position specification and the orientation requirements in the proposal.

MO-940 A conceptual Visit File is illustrated in Figure 5-1. It is a simple visit containing a vehicle slew request plus guide star acquisition request followed by a prime MIRI exposure request at three dither points. The first statement includes timing constraint specifications. The on-board activity descriptions SLEW, GSACQ, MIRIMAGE, and DITHER will be executed when this visit is processed. These activity descriptions contain the operational procedure for each activity and will send the appropriate flight software commands.

```
Visit ,V22119 ,early=2011-300/12:00:00 ,late=2011-310/12:00:00
                  ,cutoff=2011-314/00:00:00  ;
Activity ,01 ,SLEW ,ra=197.43 ,dec=65.1 ,roll= 120.0
                        ,fov=MIRI-IMAGE-FIX ,duration=6000s  ;
Activity ,02 ,GSACQ ,guider=FGS1
                          ,gs_ra=197.012 ,gs_dec=65.14
                          ,gs_x=3.4 ,gs_y=2.1 ,gs_cts=1605
                          ,ref1_x=1.1 ,ref1_y=5.1 ,ref1_cts=1007
                          ,ref2_x=1.22, ref2_y=4.5 ,reg2_cts=1505  ;
Activity ,03 ,MIRIMAGE ,filter=F15W ,sample=STEP24 ,exptime=1000  ;
Activity ,04 ,DITHER ,delta_x=0 ,delta_y=+1  ;
Activity ,05 ,MIRIMAGE ,filter=F15W ,sample=STEP24 ,exptime=1000  ;
Activity ,06 ,DITHER ,delta_x=+1 ,delta_y=0  ;
Activity ,07 ,MIRIMAGE ,filter=F15W ,sample=STEP24 ,exptime=1000  ;
```

Figure 5-1. Simple visit file prototype

5.2.3 Observation Plan

MO-208 The set of all approved visits is known as the visit pool. As noted above, it comprises both science and engineering visits. Given the user-specified constraints and the characteristics of the available visit pool, the Long Range Plan (LRP) assigns each visit to a general timeframe within the cycle (typically a year). A Short Term Schedule (STS) (typically 22 days long) assigns each visit an execution window (earliest start time, latest start time, and end time) and puts the visits into a sequential list. An Observation Plan (OP), which contains a time-ordered list of visit names, is created from the STS and uplinked to the Observatory on a periodic basis accompanied by the associated visit files. An OP/visit file uplink will typically occur once a week and will contain about 10 days of observations. The Observation Plans will be human readable and will be transmitted to the Observatory in a file. When each new Observation Plan arrives on the Observatory, it will usually be appended to the current on-board Observation Plan. This will result in seamless Observatory operations from one Observation Plan to the next. The on-board process that is responsible for reading and processing the Observation Plan and the visit files is an Activity Description (AD) known as the Observation Plan Executive (OPE). For more discussion of OPE operations, see the scenarios in Chapter 6.

MO-209 Visits with strict timing requirements (for example, for an occultation observation or a moving target with limited guide star availability) can be easily handled within the Observation Plan. A critically timed visit can be included by selecting the appropriate visit execution window and by placing visits with compatible time windows prior to it in the Observation Plan. The time-critical visit can have a very narrow start time window and the previous visits have end times no later than its earliest start time.

MO-210 It will be possible to change the unexecuted portion of the Observation Plan, as might be the case in the event of a science instrument anomaly or a target of opportunity visit request. In response to a replan, a new Short Term Schedule and Observation Plan will be created. The ground system will request that all visits that follow a specified visit be deleted from the on-board Observation Plan. A deletion request will also be sent for those visit files that are not required by the replan. The new Observation Plan will then be uplinked, along with any new visit files, and appended to the end of the remaining Observation Plan. A target of opportunity visit, which is a visit on an opportunistic target such as a supernova or a gamma-ray burster that can be activated for quick execution by a proposer, can be added by this mechanism. The target of opportunity visit will be uplinked and the on-board Observation Plan replaced with a new plan that includes the target of opportunity visit.

MO-211 The real-time ground system will be capable of responding to anomalies, especially during integration and test, by requesting that observation plan processing stop immediately. The real-time ground system will also be capable of responding to replan situations in a more graceful manner, by requesting that the observation plan processing stop at the end of a specified visit (a "break point").

MO-212 The calibration visits used to characterize science instrument performance will include both external, pointed observations, internal inline calibrations and calibrations executed in parallel with other activities. The external, pointed calibration observations will be planned and scheduled in the same manner as prime science observations. Inline calibrations will generally include exposures using an internal lamp and are considered part and parcel of the prime science visit.

MO-956 Parallel calibration visits will be scheduled differently and will be incorporated into compatible science visits whenever possible and will be executed in parallel with the primary science activities. They could be done in parallel with slews or science data taking. This results in an overall efficient savings. The matching of calibrations to science visits will be done after primary observations have been assigned to an Observation Plan segment during the planning process. As many of these calibrations require periodic execution (for example, one each day or one each week), their attachment must be done once the science visit order is known (i.e., after scheduling).

5.2.4 Certification of Operations Concept

MO-213 JWST Observatory components will be operated in numerous environments: the flight software development labs, the various I&T facilities, the operational FOS, and the operational S&OC. Pre-launch ground testing will include a wide assortment of software and hardware verification activities, as described below in the I&T operations concept section 8.2. “Flight-like” testing, utilizing the high-level interface and flight-compatible on-board scripts and flight-compatible real-time procedures, will be an integral part of most ground test phases. It is advantageous to execute the flight methods as much as possible before launch to validate the operations concepts, and, most importantly, to reduce the risk of in-flight errors.

MO-214 All flight command procedures, both those that will execute on the ground and those that will execute on the Observatory, will be first exercised against simulators before being permitted to control real flight hardware. There will be a rigorous certification and approval process created for tracking all command procedures. Only appropriately approved items will be used to control flight hardware. This holds true even after launch. If modifications are made to any command procedure, then it must be certified against a ground simulator using flight scenarios before being used to operate the Observatory.

MO-215 A portion of ISIM, spacecraft and Observatory I&T will be allocated to implement “flight-like” operations utilizing on-board activity descriptions, visit files, observation plans and routine real-time procedures. There will be day-in-the-life type tests that will simulate typical normal operation days. As the development phase matures, these tests will have higher fidelity culminating with runs using the real flight hardware and the flight ground system. The later versions of the day-in-the-life tests will include proposal processing, event-driven execution of an observation plan, and the calibration and archiving of the resultant data. Incorporating repetitive flight-like testing into the JWST integration and test planning will ensure that the operations concept is consistent with the mission goals.

5.2.5 Health and Safety

MO-216 As the JWST flight system is being built, hardware and software engineers across the Project will compile a list of operational constraints and restrictions. Constraints are rules that if violated are expected to cause permanent hardware damage, while restrictions are rules that if violated are expected to cause irreversible degradation of hardware or instrument capabilities, or disruption in the observatory timeline. Constraints must never be violated, but it will be possible to override a restriction in specific situations with the Mission Operations Manager approval. There will be constraints and restrictions that apply only when the Observatory is on the ground.

MO-217 The complete set of JWST constraints and restrictions for the flight hardware will be published 6 months before Observatory I&T begins. This set will be documented in the JWST Observatory Constraints and Restrictions Document (CARD)[17]. A combination of ground and flight systems will be responsible for protecting JWST health and safety by enforcing the constraints and restrictions. The approved protection design for each item will be documented within a CARD Implementation

Plan. The full implementation of this plan will be completed before Observatory I&T initiates so that testing can be executed with all the necessary health and safety checks in place.

MO-218 The ground system will verify all visit files, activity descriptions, and real-time commands prior to transmitting them to the Observatory (also known as the “first line of defense”). The concept is that safety checks will be performed as early in the process as possible to avoid finding problems late in the operations flow.

MO-1006 The ground will monitor the Observatory safety during communication contacts and will have the ability to notify operations in the event of a detected problem.

MO-219 However, because the Observatory will be out of contact for a large percentage of the time, normal operations is event-driven and the Observatory will be located at L2, it is the flight system’s responsibility to provide comprehensive health and safety monitoring and response (also known as the “final line of defense”). The onboard health and safety monitoring will be provided by flight hardware, flight software, and the activity descriptions. The flight system will reject all hazardous and illegal commands providing enforcement of the CARD rules. There will also be continuous on-board telemetry monitoring of all critical hardware components with rapid automatic reactions to out-of-range limit violations.

MO-220 For many types of spacecraft and ISIM-related anomalies, it will be necessary to halt the OP execution, place the entire vehicle in a safe configuration, and wait for ground interaction. In these cases, ground analysis will be required before a Project-approved recovery plan can be executed to resume normal operations. However, in other well-defined cases, mostly associated with an individual instrument, only the specific hardware and software associated with the problem will be taken offline. In these cases, the on-board OP will continue to execute using the instruments, or portions of instruments, that are available.

MO-221 Each flight system processor will provide event messages to notify the ground of on-board anomalies, failed commands and executed reactions. In addition, there will be the ISIM event message that records the processing of the visit files and the on-board scripts. These messages are included in the engineering telemetry and will be downlinked during each communications contact so that an automatic ground tool can analyze them and notify on-call technical personnel. The ground will initiate an anomaly investigation and once the problem is understood, a recovery plan will be designed and executed. The anomaly description and analysis results will be documented in an electronically accessible archive for reference in future similar situations. For more information about monitoring and reacting to Observatory anomalies, see the contingency operations scenarios in Section 7.

MO-222 STScI staff in the S&OC will also conduct long-term trending analyses of JWST to search for flight hardware and software problems that can develop over an extended time period. The mission engineering telemetry will be easily accessible and ground tools will be created to assist this continuing health and safety analysis effort.

5.3 SCIENCE INSTRUMENT OPERATIONS

MO-223 The operations concept for the JWST science instruments maximizes their scientific productivity, and enables observations that meet the science requirements of the mission. A key element of this approach is to keep operations simple by limiting the number of modes. As discussed by Stockman et al. (2002), a small number of modes not only reduces cost by reducing operational complexity, but it also leads to better calibration, higher reliability of the data products, and greater observational efficiency. As shown in Table 5-1, the JWST instruments share many operational similarities, and so the basic approach to instrument operations will be to keep them simple and similar.

Table 5-1. Basic Operational Features of the JWST Instruments

Operational Feature	Description	NIR Cam	NIR Spec	MIRI	TF
Direct Imaging	Obtain a direct image of the sky	●	●	●	●
Coronagraphic Imaging	Use a Lyot stop or phase mask to block light from a bright object	●		●	●
MSA Spectroscopy	Multi-aperture spectroscopy		●		
Slitless Spectroscopy	Image a field with a dispersing element		●		
Fixed-Slit Spectroscopy	Use a fixed slit for spectroscopy		●	●	
IFU Spectroscopy	Integral field spectroscopy		●	●	
Full-Frame Readout	Use a pattern to read a full frame from the detector arrays	●	●	●	●
Subarray Readout	Use a pattern to read a subarray from the detector arrays	●	●	●	●
Spatial Patterns	Use a predetermined dither pattern to acquire a series of images	●	●	●	●
Dark Frame	Obtain a long-exposure-time image with no light illuminating the detectors	●	●	●	●
Internal Flat	Obtain an exposure with an internal lamp illuminating the detectors	●	●	●	●
Internal Wavecal	Obtain an exposure of an internal wavelength calibration lamp		●		●
Target Acq	Target acquisition procedure (target locate)	●	●	●	●
Wave Front Sensing	Insert optical elements and obtain images to be used for aligning the OTE segments	●			
Raw Data Dump	Obtain detector readouts with no on-board processing	●	●	●	●
Pick-off/fore-optic Focus	Focus and align the pick-off mirrors and re-imaging fore-optics in the instrument	●	●		●
Cryocooler Operations	Control the cyrocooler for MIRI			●	

MO-224 A bullet entry in Table 5-1 indicates that the given operational feature applies to that instrument. These operational features are not mutually exclusive. For example, an instrument taking a direct image will use either full-frame or subarray readout for its detector(s), and it may use a spatial pattern to acquire a series of direct images. Finally, it is likely that each instrument will have a limited set of engineering modes for diagnostic purposes. All the identified operational features will be used during all phases of the mission.

MO-225 The IC&DH computer will control science instrument operations via the OPE. To enable parallel operations, the science instruments are designed to operate in a non-interfering manner (with certain defined exceptions, such as when calibration lamps are operated or mechanisms are in motion).

MO-226 A generic sequence of events in a typical science observation with a JWST instrument would be:

1. The spacecraft slews to a new target field.
2. The FGS performs a guide star acquisition and the spacecraft fine points the Observatory.
3. Configure the appropriate science instrument as necessary.
4. If necessary, take target acquisition images with the visit's prime SI. The IC&DH autonomously processes these data to determine and request the corrective small angle offset to place the science target(s) at the required location in the SI FOV.
5. Configure the instrument for the science observation.
6. Obtain contemporaneous calibration data (e.g., wavelength calibration exposures).
7. Take an exposure and read out the detectors.
8. During and following the exposure, the IC&DH performs any necessary processing of the data and transfers it to the SSR.
9. Perform a small angle offset (dither) as part of the spatial and/or pattern associated with this observation.
10. Repeat steps 5-8 as necessary to complete the requested spatial pattern.
11. Observation is complete. The SI and the FGS are transitioned into standby mode.

MO-227 In the subsections that follow, we first discuss operational procedures that are common to all the instruments: detector operations, target acquisitions, and calibration strategies. This will establish a common nomenclature that will help to keep operations simple and similar. After establishing this common base, we then discuss instrument-specific concepts and strategies. Armed with a basic understanding of the instrument operations, we finish with a discussion of parallel instrument operations and the total data volume.

5.3.1 Detector Readout Strategies

MO-228 Similar technologies underlie all the infrared array detectors on JWST. We can therefore plan to use similar readout strategies for all the detector systems. This has multiple advantages:

1. Using a small number of common readout modes enhances our ability to characterize the instruments and leads to a higher quality data product;
2. Limiting the total number of modes saves both calibration time (improving Observatory efficiency) and money;
3. A common terminology and approach for all the instruments makes science planning easier for the observer.

MO-229 The selected readout strategy and integration time for a given observation should balance the scientific needs of the observing program with operational efficiency. This is straightforwardly accomplished by asking observers to select from a palette of readout patterns and integration times. The MULTIACCUM readout scheme (used by NICMOS on HST) is the basic method we will use to read out the JWST detectors. Users will also be able to select subarrays on the detectors, and if appropriate, the detector electronics gain. Reference pixels will track time-dependent bias levels on all detectors, and, when detectors are not in use, we will clock them using idle patterns to ensure that detector wells do not fill up.

MO-230 Before discussing the various aspects of detector operations in more detail, a common lexicon of terms that can be applied to the operation of all JWST detectors is defined in Table 5-2.

Table 5-2. Common Lexicon of Terms

CLOCK	To address a particular pixel. “Clock” is a verb.
READ	The act of clocking and digitizing pixels in an SCA. “Read’ is a verb.
SAMPLE	The result of a single Analog to Digital conversion.
DWELL	Sample a pixel multiple times before clocking to the next pixel.
nsample	The number of A/D samples per pixel.
FRAME	The result of sequentially clocking and digitizing all pixels in a rectangular area of an SCA. "Full-fame readout" means to digitize all pixels in an SCA, including reference pixels. “Frame” also applies to the result of clocking and digitizing a subarray on an SCA.
GROUP	One or more consecutively read frames. There are no intervening resets. Frames may be averaged to form a group.
nframe	The number of FRAMES per GROUP.
INTEGRATION	The end result of resetting the detector and then non-destructively sampling it one or more times over a finite period of time. This is a unit of data for which signal is proportional to intensity, and it consists of one or more GROUPS.
ngroup	The number of GROUPS in an INTEGRATION.
INTEGRATION TIME	The time elapsed between when a pixel is first read and when it is last read in an INTEGRATION. This time interval is the time relevant for scientific analysis, but note that the actual elapsed time in an INTEGRATION is slightly longer, and it depends on the number and spacing of samples in the INTEGRATION. Using the time variables defined in §5.3.1.1, the integration time is $t_{int} = \mathrm{ngroup} \times t_{group}$, and the extra readout overhead is $\mathrm{nframe} \times t_{frame}$.
EXPOSURE	The end result of one or more INTEGRATIONS over a finite period of time.
nint	The number of INTEGRATIONS in an EXPOSURE. N.B., For NIRCam, NIRSpec, and the TFM, nint is always 1, and an EXPOSURE is equivalent to an INTEGRATION.
EXPOSURE TIME	The total time during an exposure spent accumulating signal from a source. The total elapsed time in an exposure is longer due to readout overheads at the end of each integration period.
TOTAL ELAPSED TIME	The total elapsed time during an exposure, or the “wall clock” time. The TOTAL ELAPSED TIME is the time interval from when the first pixel is read in the first integration to when the last pixel is read in the last integration in an exposure.

5.3.1.1 Full-frame Readout using MULTIACCUM

MO-245 In MULTIACCUM readout, the array is read out non-destructively at intervals defined by the parameters described below during the exposure. Multiple non-destructive frames can be averaged into a group and transferred to the SSR for downlinking to the ground. The ground-based data processing software can then correct bias drifts using the reference pixels and use “up-the-ramp” processing algorithms[18] to reject cosmic rays. Optimal exposure times are determined by how long it takes for background noise sources (sky, the telescope+sunshade, or the dark current) to dominate over the read noise (see Regan & Stockman 2001)[19]. This approach is quite flexible. It allows for a large range of readout patterns now when the detectors do not exist and their optimal operation has not been determined, but it permits us to select a relatively small set of optimal patterns for observations when the instruments are ready for flight.

MO-246 In general, users will not specify individual parameters but will select a pattern from a menu of available exposure options. In MULTIACCUM mode, each pixel is reset and then non-destructively sampled many times during an exposure. Full-frame readout is the nominal readout mode. For MIRI, multiple successive samples can be made on single pixels before clocking to the next pixel. Six parameters determine each pattern, of which four are user-selectable, as defined in Table 5-3.

Table 5-3. Parameters that Determine Pattern

t_{sample}	The delta time between samples. This is not user-selectable, and it is always the same fixed value set by the focal plane electronics.
t_{frame}	The time difference between frames. This also is not user-selectable, and it is always the same fixed value corresponding to the time required to read out the array continuously.
t_{group}	The delta time between groups.
nframe	The number of frames in a group.
ngroup	The number of groups in an integration.
t_{int}	The total integration time for one MULTIACCUM pattern.

MO-253 The type of on-board processing applied to the data is instrument dependent. The plan for NIRCam and NIRSpec is that multiple frames comprising a group are averaged together before they are compressed and stored on the SSR. To improve the dynamic range in an exposure, NIRCam and NIRSpec “frame0”, the first frame in an integration, will be downlinked separately as well as be included in the average of the first group of frames.

5.3.1.2 Subarray Readout

MO-254 In SUBARRAY readout, only pixels that fall within a specified rectangular area of an SCA are digitized. Each pixel within the subarray region is reset and then non-destructively sampled using a MULTIACCUM pattern. Unless reference pixels are adjacent to and included in the rectangular area defining the subarray, they are not sampled in SUBARRAY readout mode. The frame time, or the time required to digitize all pixels within the subarray, is a function of the size of the subarray box. Since subarrays comprise fewer pixels than a full frame, they can be read out more rapidly. This permits observations of bright targets that would otherwise saturate the detector in the exposure time required for a full-frame readout. In addition to the parameters associated with a MULTIACCUM readout pattern, subarrays also require the specification of x and y pixel coordinates of the first column and row read out in the subarray and the number of columns and rows in the subarray.

MO-259 In order to ensure consistent calibration of the SUBARRAY mode, only a few subarrays will be available, and the user will have to select from these predefined sets. The exact number and sizes of the subarrays will be based on the science requirements of individual instruments, the performance of the detector arrays and radiometric models of the Observatory.

5.3.1.3 Detector Electronics Gain Value

MO-260 The “gain” is a selectable parameter in the focal plane electronics for each detector system that governs the amplification of the output voltage from the SCA to the voltage that is applied to the analog to digital converter. Because the analog-to-digital converters have a fixed number of bits of accuracy, for some low-noise detectors it is not possible to sample the read noise at the Nyquist limit and also not saturate the dynamic range of the output digital value for a full-well pixel. At present, each JWST instrument only has 1 gain setting.

5.3.1.4 Reference Pixels

MO-261 All detectors on JWST will incorporate specially engineered reference pixels. Although they do not respond to light, the reference pixels electrically mimic a regular light-sensitive pixel. Using reference pixels, it should be possible to calibrate out bias drifts and many other artifacts having a timescale longer than twice the row rate during detector readout. Examples of the artifacts that might be calibrated out include HST/NICMOS’s “pedestal drifts” and SST/IRAC’s “first frame effect”.

MO-262 Although it is too early to say exactly how reference pixels will be used, it is clear that data from a large number (≥100) of pixels will need to be combined in order to avoid adding noise to the data. This type of processing, including spatial-averaging[20], will be performed on the ground. To enable this ground-based analysis, reference pixels will be sampled and digitized in exactly the same manner as the light sensitive pixels, except as noted above in SUBARRAY mode.

5.3.1.5 Raw Data Dumps

MO-263 The Focal Plane Array Processors in the IC&DH electronics have the ability to combine and difference frames as they acquire the raw digitized detector data. For diagnostic purposes it will be possible to transmit full frames from any selected SCA to the SSR without any intermediate processing. This mode creates a much higher volume of data so this mode cannot be used with as many SCAs as normal operations modes.

5.3.1.6 Idle Patterns

MO-264 An "idle pattern" refers to the clocking sequence that controls a detector while it is not being used for an exposure. This serves to stabilize the detector temperature by keeping the power through the detector relatively constant during and between exposures, and it also ensures that the detector wells do not fill up and induce persistent charge in science and/or calibration exposures. In standby mode during normal operations, when not taking science or calibration data, all JWST detectors will be clocked with idle patterns.

5.3.2 Target Acquisition Strategies

MO-265 Although JWST instruments have a wide variety of observational modes that require special operational procedures to center a target precisely in an instrument's field of view, a small common set of procedures will suffice to enable all these observational modes. In this section we describe these common tools that can be used by all the instruments.

5.3.2.1 General Imaging Target Acquisition

MO-266 Science observations that can tolerate absolute pointing errors of up to 1" will require no special target acquisition procedures following the usual guide star acquisition by the FGS. After the Observatory has entered fine-guidance mode, such observations can commence without further refinement of the target position. This includes imaging with NIRCam, NIRSpec, MIRI and the FGS-TFI. All spectroscopic and coronagraphic observations will require a science instrument assisted target acquisition procedure.

5.3.2.2 Target Locate

MO-267 Observations that require a more accurate positioning of the target in the field of view all share a common step in the target acquisition process that is called a "Target Locate". The purpose of this step is to determine the location of one or more reference targets in an instrument's field of view in the instrument coordinate system.[21] We will describe the general aspects of this process here, and give more detailed information as it relates to each instrument in the following instrument sections.

MO-268 Since a guide star acquisition will position each instrument's field of view to an accuracy of 1″(1-sigma), a relatively small area of sky around each reference target must be imaged and processed in order to determine its location.

MO-269 To locate targets accurately, allowing for the effects of cosmic rays and hot pixels, the IC&DH computer must collect and process multiple SUBARRAY exposures from the science instrument with the specified exposure time, subarray location and size.

MO-270 The target acquisition process must be robust against cosmic rays and detector defects (such as hot pixels). A scenario that might be used for target locate is as follows:

- Obtain two MULTIACCUM exposures, each comprised of a single group at the starting location.
- Combine these, pixel by pixel, using the minimum flux of the two exposures to produce a new image. This processing removes cosmic rays.
- Execute a small-angle maneuver of an integral number of pixels.
- Obtain two more MULTIACCUM exposures, each comprised of a single group at the new location.
- Combine these two images using the minimum flux method as before.
- Register the two cleaned images using an integral pixel shift corresponding to their offset on the sky.
- Combine the two cleaned, registered images using the minimum flux method. This eliminates hot pixels.
- Determine the centroid of each reference object.
- Convert this centroid into coordinates in the instrument's reference frame.

MO-271 The result of this target locate process can then be used as a data element for completing the rest of the target acquisition procedure. The details of the rest of this process depend on the needs of the particular requested observation. We describe these further details below in the specific case of coronagraphic target acquisitions, which are common to NIRCam, MIRI and the FGS-TFI. Details of spectroscopic target acquisitions are described in the NIRSpec and MIRI sections further below.

5.3.2.3 Coronagraphic Target Acquisitions

MO-272 Coronagraphic observations involve locating a target behind a coronagraphic mask with a precision of < 5 mas. The best procedure for achieving this level of precision in a target acquisition is still to be determined. For now, we outline the characteristics of a likely procedure. For MIRI, FGS-TFI and NIRCam this will be a two-step process. The first step locates the target within a pre-defined target acquisition area less than

20″ from the desired coronagraphic mask. For MIRI and FGS-TFI each coronagraphic mask will also have a “sweet spot” located 0.5-1.0″ from the mask center. The second step offsets it to the center of the coronagraphic mask and iteratively centers the target on the mask area as needed.

MO-273 In more detail, this acquisition procedure involves the following steps:

1. Select the desired filter for the target acquisition procedure.
2. For MIRI and FGS-TFI, select a neutral density filter that will prevent the target star from saturating the detector during the subarray exposures used for the target locates. For NIRCam, the target will be observed at an attenuated location in he instrument’s FOV.
3. Slew the telescope to place the target in the acquisition area.
4. Do a target locate, and then determine the offset required to place the target at the sweet spot near the coronagraphic mask.
5. For NIRCam, compute and execute the slew to place the target behind the coronographic mask.
6. For MIRI and FGS-TFI, compute and executed the offset required to place the target in the sweet spot near the coronographic mask and perform another target locate.
7. For MIRI and FGS-TFI, offset the target from the sweet spot to the coronagraphic mask center.
8. Begin science observations.

5.3.3 Spatial Patterns

MO-274 JWST observations will commonly involve a series of exposures at closely spaced locations on the sky. These spatial patterns of observation[22] are useful on small scales (pixel or sub-pixel step sizes) to provide better sampling of the point-spread function. On larger scales (several arcseconds) they help to eliminate cosmic rays and bad pixels, hot pixels, and other cosmetic defects from exposures, to provide sky coverage in the gap regions between mosaics of SCAs in NIRCam and NIRSpec, and to create mosaics of larger regions of the sky than can be viewed at one pointing by any of the instruments.

MO-275 Small-scale, sub-pixel dithers that over-sample an instrument’s PSF require precise motions of 5 mas or better for offsets of <0.5″.

MO-276 Large-scale dithers of 20″ to bridge the gap in the FPA of NIRSpec require a precision of < 10 mas in order to maintain the accuracy with which targets are placed within the MSA apertures. If this is not achieved, it will be necessary to perform a target acquisition following such a dither.

MO-277 To facilitate ground-based processing of JWST data acquired with spatial patterns, observers will choose patterns from a limited menu of possibilities that cover the optimal scientific uses. These patterns will not require special software on-board for execution. Each pattern will be built from a series of standard observations separated by appropriate small-angle maneuver requests and assembled into a visit specification constructed by the ground system in support of the observation plan.

5.3.4 Calibration Strategies

MO-278 Science instrument calibrations are intended to:

- Characterize the instruments during the commissioning phase of the mission,
- Enable the reduction and interpretation of the science data,
- Monitor the functioning of the instrument, and
- Provide all reference files necessary to prepare an instrument for an upcoming observation (e.g., target acquisition).

MO-279 Calibrations for JWST instruments will be typical of those currently used for HST and SST instruments, and they will be conducted like normal science observations. The SI teams and the S&OC will plan calibration observations using the same integrated planning tool used to plan science observations. STScI will coordinate the development of an integrated calibration plan by all the instruments, but commissioning is a PI responsibility. Post-commissioning, STScI will complete and maintain the calibrations for each instrument, with yearly submissions of calibration programs tied to the science program selected by the TAC each year.

MO-280 We will calibrate the JWST instruments using a combination of the following types of procedures:

- <u>External, pointed calibrations using astronomical objects.</u> These will need dedicated spacecraft time and will compete with science observations. They include photometric and external astrometric calibration, and also slit throughput, PSF and focus monitoring. These observations will use the same procedures used for general science observations of celestial targets. To maximize observatory efficiency, we will select external calibration targets that lie in the continuous viewing zone at the ecliptic poles when possible.
- <u>Internal lamp calibrations for flat fields and wavelength calibration.</u> Calibrations using internal lamps cannot be executed in parallel with other observations because of inadequate internal baffling. Many will be executed during slews, which the expected mechanical stability of the telescope will permit.
- <u>Internal Dark calibrations </u>(i.e., light path blocked). These will be executed in parallel with other spacecraft activities when possible.

- Auto and opportunistic calibrations. These are obtained when the science data itself (auto) or another set of suitable science data (opportunistic) is used. These are external calibrations that do not have any specific pointing requirements (such as sky flats), and they have no impact on on-target science efficiency. Ground-based analysis of existing data will determine appropriate data sets that can be used for auto and opportunistic calibrations.

MO-281 According to their applicability we can distinguish:

Calibrations specific to a science program: These will be automatically attached to a specific science program. For example, target acquisition images to verify correct pointing, or wavelength calibrations to establish the zero point of the wavelength scale.

Monitoring calibrations of general use: These will be scheduled at regular time intervals determined by the stability of the instrument characteristic in question. These can, in turn, be separated depending on their suitability to be carried out in parallel mode (as described in §5.3.9).

MO-282 Specific calibration strategies are described in more detail in the document "NGST Calibration Overview"[23].

5.3.5 NIRCam Operations

MO-283 The NIRCam architecture was presented in §4.4.2. A typical NIRCam observation will include observatory actions and actions performed by the NIRCam itself. Examples of observatory actions are slewing to the target and acquiring the guide star. NIRCam actions might include selecting filters, acquiring targets for the coronagraph, and taking exposures.

We describe in more detail the operations associated with each of the NIRCam operational features identified in Table 5-1. Since previous sections have described general aspects of these operational features that are common to each of the science instruments, in this section we concentrate on those operational aspects that are specific to NIRCam. Here we provide only a summary overview. Full details on NIRCam operations can be found in the NIRCam Operations Concept Document[24].

5.3.5.1 Direct Imaging

MO-284 In direct imaging mode, both NIRCam modules and all FPAs will be operated simultaneously and synchronously to provide two 2.2′×2.2′ field at two wavelengths at a time. Filters are selected for the short and long wavelength arms of the instrument. Data are obtained in MULTIACCUM mode. Subarrays may be selected.

5.3.5.2 Coronagraphic Imaging

MO-285 For coronagraphic imaging, the coronagraphic spots will be brought into the NIRCam field of view by selecting the coronagraphic wedges on the pupil wheel. The observer would choose a coronagraphic mask and the corresponding pupil mask plus filter combination. The coronagraph elements are optimized for science programs at 5 and 2-µm, although the focal plane mask can be used with any filter or grism that is not contained in the filter wheel that holds the coronagraphic offset wedge. This mode then requires a target acquisition to place the desired target precisely behind the occulting mask.

5.3.5.3 Full-Frame Readout

MO-286 Full-frame NIRCam data will be obtained using the MULTIACCUM mode for the detector readout. The user will select the readout pattern and the exposure time from a limited menu of choices. Optimal exposure times are determined by how long it takes for background noise sources to dominate over detector read noise. For broadband imaging in NIRCam, this will typically be the time required for a given exposure to become sky-background limited, typically a few tens to a few hundreds of seconds. For medium-band (R=10) and especially narrow-band (R~100) short-wavelength filters and for exposures of a thousand seconds or less, the detector noise will be comparable to or larger than the Poisson noise from the sky.

5.3.5.4 Subarray Readout

MO-287 NIRCam observers will generally select the SUBARRAY readout to obtain shorter exposure times on bright targets. SUBARRAY readouts will also be used as part of the target acquisition process.

MO-289 For coronagraphic observations and for target acquisition procedures, special subarrays will be designated at fixed locations on the SCAs.

5.3.5.5 Spatial Patterns

MO-290 NIRCam observers will select a two-dimensional, sub-pixel dither pattern in order to sample the PSF more finely than the native pixel scales. The native pixel scales provide Nyquist sampling of the PSF at 2 µm and at 4 µm wavelengths, respectively, in the two subsections separated by the dichroic. In each case those wavelengths are nearly the longest wavelengths in the respective bandpass, so most of the bandpass is undersampled spatially. Sub-pixel dithering provides a finer and more uniform sampling of the pixel response, enabling post-observation data processing to obtain higher photometric integrity and higher angular resolution.

MO-291 To eliminate the gaps between the SCAs in the short-wavelength arms of NIRCam, observers will also use a large-scale dither pattern. This two-dimensional pattern will have a scale of ~6″ in each of two orthogonal directions to cover the 3-mm gaps between the SCAs in the short-wavelength FPAs.

5.3.5.6 Dark Frame

MO-293 To obtain dark frame exposure, the pupil wheel is moved to the position of the integrating cavity located within the instrument. All lamps will remain off. A full-frame MULTIACCUM or a SUBARRAY exposure with an integration time specified by the observer is obtained.

5.3.5.7 Internal Flat

MO-294 To obtain an internal flat-field exposure, the pupil wheel is moved to the position of the integrating cavity located within the instrument. The filter wheel is then rotated to the position of the desired filter. The flat lamp is turned on, and a full-frame MULTIACCUM exposure or a SUBARRAY exposure with an integration time specified by the observer is obtained. Since the illumination enters the optical path only at the camera pupil, this mode does not calibrate the full optical path of the instrument, including the coronagraphic masks, thereby necessitating external flats as a supplement.

5.3.5.8 Target Acquisition

5.3.5.8.1 Direct Imaging Acquisition

MO-295 Since the field of view of NIRCam (2.2′×4.4′) is relatively large compared with the Observatory's pointing uncertainty (< 1″), this greatly simplifies acquisition for direct imaging with NIRCam. After the Observatory has entered fine-guidance mode, NIRCam will be able to commence general imaging observations without the need to further refine the target position.

5.3.5.8.2 Coronagraphic Target Acquisition

MO-296 The NIRCam coronagraphic wedge includes a target-acquisition area with a neutral density filter with a large attenuation factor < 20″ from each of the coronagraphic spots. Following the coronagraphic target acquisition procedure, a subarray of 256x256 pixels or smaller will be used for the target locate in this target acquisition area. Since the guide star acquisition will have positioned the target to an accuracy of < 1″ radial rms, this 7.9x7.9 arcsecond-square area will contain the target star more than 99.5% of the time. Subarrays of 16x16 at the sweet spot will suffice for the second step of the target acquisition process.

5.3.5.9 Wave-Front Sensing

MO-297 NIRCam performs a facility function of providing the imagery data for wavefront sensing for the Observatory, in addition to serving as a science imager. Optical elements to be used for wavefront sensing are located in the NIRCam pupil and filter wheels (MR-187). In this mode, the desired element will be put in place, and NIRCam images will be acquired in direct imaging mode. Section 6.1.4 provides further details on Observatory wavefront sensing and control procedures.

5.3.5.10 Raw Data Dump

MO-298 For diagnostic purposes, it is possible to preserve a string of consecutive images with the FPAs without subjecting them to any processing. Because the Raw Data dump mode is equivalent to MULTIACCUM with nframe=1, it is simply another item in the MULTIACCUM menu.

5.3.5.11 Pick-off/Fore-Optic Focus

MO-303 NIRCam's focus can be adjusted only by moving the pickoff mirrors in piston. Because NIRCam is the JWST facility wave-front sensor, refocusing NIRCam requires nearly the same consideration as refocusing the JWST secondary mirror. After commissioning, adjustment of the NIRCam pickoff mirrors should be a rare occurrence; in particular we note that the pickoff mirror's motion should not be part of routine WFS operations.

5.3.6 NIRSpec Operations

MO-305 The NIRSpec architecture was presented in §4.4.3. NIRSpec has a small number of observing modes each of which can be quite complex. We describe in more detail the operations associated with each of the NIRSpec operational features identified in Table 5-1. Since previous sections have described general aspects of these operational features that are common to each of the science instruments, in this section we concentrate on those operational aspects that are specific to NIRSpec. Here we provide only a summary overview. Full details on NIRSpec operations can be found in the NIRSpec Operations Concept Document[25].

5.3.6.1 Planning NIRSpec Observations

MO-333 Multi-object spectroscopy with the MSA will be the most commonly used mode on NIRSpec. These types of observations will require detailed preparation. Apart from the detector readout strategy and the exposure time selection, the following aspects need to be taken into account:

- Accurate coordinates for the targets, and for the reference objects to be used for TA are needed. Although there may be alternatives in specific cases, NIRCam images will be able to provide the required accuracies, and are likely to be used extensively for this purpose. Therefore, prior observations with NIRCam need to be scheduled, executed, and analyzed.

- <u>Target selection and MSA configurations are tied to specific orientations.</u> However, for most of the pointings the OTE has a relatively limited range in roll angle. The observer may specify a specific orientation. If no specific orientation is required, the S&OC will assign an orientation range for use in selecting target and reference objects.
- <u>Targets must not overlap their spectra.</u> To avoid overlap between spectra from two objects, these should not be aligned along the dispersion direction. Since this depends on the spacecraft roll angle, for a low density of objects ($n \leq 10$ targets/FOV), some orientations may be preferred. However the fraction of orientations acceptable to observe all objects simultaneously decreases very quickly with n. Therefore, for large densities all orientations are likely to be equally unsuitable for observing all targets simultaneously, and subsets of targets must be observed sequentially (maintaining the same pointing). The selection of subsets needs to be optimized (e.g. maximize number of objects observed in a given exposure time). This optimization may also take into account that all the objects may not require the same exposure time to reach a given S/N.
- <u>The MSA and FPA do not provide a continuous coverage along the spatial and spectral directions.</u> Therefore, relatively large dithers may be needed, which have to be defined taking into account the restrictions imposed by the FGS.

MO-338 Some of the above issues are closely interrelated. Observers will use a software tool in order to prepare in detail a feasible observing program. This will require a two-step process. In the first step, the observer must discuss the general constraints imposed by the above issues for their particular program, and infer the acceptable orientation angles. After selection, the SOC will prepare a Long Range Plan that sets the particular orientation for the proposed observation. In step 2, the observer will prepare a detailed observation specification including the desired MSA configuration for the assigned orientation.

5.3.6.2 Direct Imaging

MO-306 NIRSpec can be used for direct imaging by opening all the apertures in the MSA and by selecting the mirror position in the grating wheel. This mode is primarily used for target acquisition, for verifying the location of targets in the MSA apertures, and for obtaining zero-point locations of objects observed in the slitless spectroscopic mode.

5.3.6.3 MSA Spectroscopy

MO-307 This option allows simultaneous slit spectroscopy of many objects in the field of view. It requires accurate coordinates for the targets (likely provided via analysis of prior NIRCam observations). When the density of objects is relatively low ($n \sim 10$/FOV), the user may prefer certain spacecraft roll angles. For large densities, it is likely all roll angles are equally unsuitable for observing all the objects in the FOV simultaneously. In that case several exposures are required, each with a different MSA configuration.

Both sub-aperture and large-scale dithering are likely to be used. In particular, long dithers (~20 ″) along the dispersion direction are needed to recover the spectral range lying in the gap between the SCAs.

MO-308 A simplified sequence of events in a typical multi-object MSA observation would be:

1. Guide star acquisition
2. Target acquisition
3. Configure Imaging mode (select filter; configure MSA shutters to form slits; select ‘mirror’ in grating wheel)
4. Exposure to record target locations
5. Configure Spectrograph (i.e. select grating)
6. Take a wavelength calibration exposure
7. Exposure (including sub-aperture dithering)
8. Slew the Observatory along the dispersion direction
9. Reconfigure MSA (same target set)
10. Repeat steps 7-9 until the selected spatial pattern is complete.

MO-309 Observations in this mode must be preceded by a target acquisition as described below. A direct image of the field when the slits are configured (after target acquisition) may be required by the data pipeline.

5.3.6.4 Slitless Spectroscopy

MO-310 In this observing mode, all MSA apertures are opened and a disperser is used. It is likely this mode will be used when the location of the source is uncertain or unknown, and their correct identification is done after data analysis. A major penalty of using this mode in comparison with slit spectroscopy is that the background will be much higher. This mode does not require target acquisition after guide-star acquisition.

5.3.6.5 Fixed-Slit Spectroscopy

MO-311 This mode provides high-contrast spectroscopy in a small field of view. It will be selected when observations of a sole (unresolved/small) object are needed. The user may prefer certain spacecraft roll angles, though this is less likely than in the case of MSA spectroscopy. Sub-aperture dithering is likely to be used. In addition, since a pair of identical fixed-slits are located at less than 20″ apart, large-scale dithers between slits may be also done. The detector can be operated with either full-frame or subarray readouts. This mode requires a target acquisition as described below.

5.3.6.6 Full-Frame Readout

MO-312 For NIRSpec, the MULTIACCUM readout mode suffices to fully enable the science program. Every 50 seconds NIRSpec will send to the ISIM the full frame where it will be either sent to SSR or averaged over four reads then sent to the SSR for later downlink. Both NIRSpec SCAs will be operated synchronously. For typical R=1000 (detector limited) observations, exposure times will range between 1000 and 8000 seconds, with shorter exposures needed for brighter targets.

MO-313 For observations of bright targets, SUBARRAY readout will allow the user to select exposure times intermediate between 40 ms, and the minimum full-frame exposure time, 12 s. To maintain synchronous operation of the NIRSpec SCAs, the same subarray region will be used on each SCA, and they will be read out synchronously during the exposure.

5.3.6.7 Spatial Patterns

MO-314 For NIRSpec, small-scale dithers on the pixel or sub-pixel level will be used to improve the spatial sampling of the line-spread function on the detector as well as to improve the spatial sampling of the targets in the MSA apertures. This can provide improved photometric corrections to the data.

MO-315 Dithers on the several-pixel scale will provide improved corrections for cosmic rays, hot pixels, and cosmetic defects in the SCAs.

MO-316 Dithers on large scales, ~20″, are necessary to fill in data from the portions of spectra that are lost in the gap between the two SCAs. Maneuvers to make these large-scale dithers need to be accurate to < 7.5 mas to avoid the need to perform another target acquisition in the middle of a NIRSpec observing sequence.

5.3.6.8 Dark Frame

MO-318 Science images are calibrated using a dark exposure with readout parameters identical to the science exposure with an integration time specified by the observer. Dark frames may also be taken independent of science exposures for instrument characterization. To take a dark frame with NIRSpec, the ‘dark shutter’ is selected in the filter wheel. All lamps will remain off.

5.3.6.9 Internal Flat

MO-319 To obtain an internal flat-field exposure, the user selects the calibration position on the filter wheel. In this position, a back-illuminated diffuser (that also blocks the external light path) inserts the light from the calibration lamps into the main NIRSpec beam. The observer then obtains a full-frame exposure or a subarray exposure with the integration time they have specified.

5.3.6.10 Internal Wavecal

MO-320 To obtain an internal wavelength calibration, the user selects the calibration position in filter wheel, selects the appropriate dispersing element in the grating wheel, and selects and switches on the matching line lamp for this dispersing element. The observer then obtains a full-frame exposure or a subarry exposure with the integration time they have specified.

5.3.6.11 Target Acquisition

5.3.6.11.1 Direct Imaging Acquisition

MO-321 Since the field of view of NIRSpec (3.4′×3.5′) is relatively large compared with the Observatory's pointing uncertainty (< 1″), NIRSpec will be able to commence general imaging observations without the need to further refine the target position once the Observatory has entered fine-guidance mode. In practice, however, the direct imaging mode of NIRSpec will primarily be used to obtain an image used by the observer after the fact to verify the correct location of the targets in the NIRSpec FOV, and thus will be obtained following a target acquisition used to set up for one of the spectroscopic modes.

5.3.6.11.2 Target Acquisition for Slitless Observations

MO-322 As with direct imaging, NIRSpec will be able to commence slitless spectral observations without the need to further refine the target position once the Observatory has entered fine-guidance mode.

5.3.6.11.3 MSA Target Acquisition

MO-323 Target acquisition will be necessary to place the science targets at their intended positions within the slits of the MSA aperture mask or in one of the fixed slits. The relatively small slits and the large field of view of NIRSpec constrain the required accuracy of the target acquisition procedure (15 mas, 1σ). The accuracy of the target acquisition critically depends on the number of reference targets used, and on the precision of their coordinates. To achieve target acquisition requirements it is necessary that the on-board software be able to perform target locates on at least 5 reference stars, process the coordinates determined for each one to determine the required adjustments in x and y, and request the appropriate small angle maneuver to center the targets in the NIRSpec FOV. To compensate for the non-reproducibility of grating wheel motions, a correction will be applied to the measured position of acquisition targets based on output from an encoder on the grating wheel.

MO-324 The general sequence of events for a NIRSpec target acquisition would be:

1. The Observatory slews to the desired target position.
2. The Observatory and FGS perform a guide star acquisition and enter fine guidance.
3. NIRSpec is configured for direct imaging and the position of the grating wheel is read from an encoder.

4. The IC&DH computer autonomously performs target locates for each of the reference targets given in the visit specification for this target field.
5. The IC&DH computer analyzes the instrument coordinates of the set of reference targets and fiducial slit locations to determine the required adjustments in Observatory pointing in x and y.
6. The Observatory performs a small-angle maneuver using the requested pointing adjustments to center the target field in the NIRSpec FOV.
7. NIRSpec is now ready to observe.

5.3.6.11.4 Target Acquisition for Fixed-Slit Observations

MO-325 Target acquisition for the fixed slits will be identical to that for the MSA.

5.3.6.12 Pick-off/Fore-Optic Focus

MO-331 The focus mechanism in the NIRSpec fore-optics will be used to focus the image from the OTE onto the aperture focal plane.

5.3.7 MIRI Operations

The MIRI architecture was presented in §4.4.4. MIRI has four principal observing modes – direct imaging, coronographic imaging, low resolution slit spectroscopy and medium resolution Integral Field Unit (IFU) spectroscopy. MIRI data are taken in a highly redundant fashion. Sources will be dithered on the focal plane so that each point on the sky is sampled by many different areas of the sensor chip assembly (SCA). For the IFU spectrograph, this accomplishes spectral as well as spatial dithering. MIRI data onboard processing includes loss-less compression with all data sent to the ground by default. A user option will exist to coadd or use groups for particularly heavy data volume science observations, e.g., spectroscopy of planet transits.

MO-339 We describe in more detail the operations associated with each of the MIRI operational features identified in Table 5-1. Since previous sections have described general aspects of these operational features that are common to each of the science instruments, in this section we concentrate on those operational aspects that are specific to MIRI. Here we provide only a summary overview. Full details on MIRI operations can be found in the MIRI Operations Concept Document[26].

5.3.7.1 Direct Imaging

MO-340 In imaging mode, the imager module is used together with a selected filter. The imager field of view is large enough that no target acquisition is required in this mode. The MIRI imager will be used to obtain either well-sampled images for purpose of photometry and super-resolution or more coarsely sampled images for large surveys of the sky. These types of observations will be most widely used in photometric and morphological type studies of distant galaxies, photometry of Galactic star-forming regions and stellar populations in nearby galaxies.

5.3.7.2 Coronagraphic Imaging

MO-341 In coronagraphic imaging, a target is centered on one of the phase mask or Lyot mask apertures with a selected filter in place. A target acquisition is required in this mode.

MO-342 The coronagraphic masks, located along one edge of the focal plane aperture, include three four-quadrant phase masks and one opaque spot for a Lyot coronagraph. The coronagraphic masks each have a square field of view of 26″×26″ and 30”x30” for the Lyot and are optimized for particular wavelengths (10.65, 11.4, 15.5 and 23 μm).

MO-343 The phase masks are useful for investigating regions very close to stars such as the inner regions of debris disks and exoplanets orbiting close to stars. The Lyot mask is useful for investigating the outer regions of debris disks and AGN host galaxies. While the phase masks need to be used in conjunction with their diaphragm and filter combination, the Lyot mask could be used with any choice of filter although it is most effectively used with its diaphragm and 24 μm.

MO-344 For a coronagraphic observation, after slewing to the target and acquiring the guide star, one selects a coronagraphic mask and the neutral density filter. Then a target-locate procedure similar to that described for NIRCam coronagraphic imaging will be applied. The correct diaphragm and filter combination is then selected before exposures are done for as many times as required.

5.3.7.3 Low-Resolution Slit Spectroscopy

MO-345 Low-resolution spectroscopy that is background limited in the 5 to 10 μm wavelength region will be critical for high redshift objects and for Kuiper Belt objects. The LRS mode is for compact (<2″) or point sources only. In the Low-Resolution Spectroscopy (LRS) mode, a target is centered in the slit near the top of the imager field of view and the prism is selected on the filter wheel. A target acquisition is required in this mode.

MO-346 The camera has one slit and a coupled Ge prism and ZnS prism in the filter wheel that enables low-resolution spectroscopy of R~100 in the 5 to 10 μm wavelength range. The slit is ~5″ long and ~0.6″ wide. The spectrum spreads over 380 pixels on the SCA.

5.3.7.4 Medium-Resolution Integral Field Unit (IFU) Spectroscopy

MO-347 IFU spectroscopy will be used to obtain simultaneous spatial and spectral information of target fields, providing the highest spectral resolution of MIRI with R~2070=3730 over a wavelength range of 5-28μm. Targets that will benefit from this capability include fields with faint lines and strong continuum, spectra that are rich in spectral lines and field with fast moving gas or stars. To carry out IFU spectroscopic observations, the user will need to select the wavelength coverage, detector readout mode and the spatial or dithering pattern.

5.3.7.5 Full-Frame Readout

MO-348 The SCAs for both the imager and IFU spectrograph will be operated in a similar fashion. GOs will select from a palette of SCA read out patterns that enables the full MIRI science program and that fall within the general MULTIACCUM framework. The general MIRI timing pattern is defined by three of the MULTIACCUM parameters: 1) the number of samples per pixel, 2) the number of frames during an integration, and 3) the number of integrations during an exposure. There are two readout sequences for MIRI for observations: SLOWMode and FASTMode.

5.3.7.5.1 SLOWMode Readout: Faint Objects, Deep Imaging and IFU Spectroscopy

MO-349 For many MIRI observations, long background-limited MULTIACCUM readout exposures will be the norm. The SLOWMode readout patterns provide patterns appropriate for broadband imaging at short wavelengths ($\lambda<12\mu m$), R~100 spectroscopy and IFU spectroscopy. All the data frames will be sent to the IC&DH, undergo loss-less compression, stored in the SSR, and sent to ground for further processing.

5.3.7.5.2 FASTMode: Bright Objects and Long Wavelength Imaging

MO-350 The FASTMode sequence provides full-frame observations of bright targets in imaging and LRS and IFU spectroscopic modes and broadband imaging at longer wavelengths ($\lambda>12\mu m$), where the thermal background emission from the Observatory rises steeply, saturating the images. In FASTMode, the SCA will be readout as fast as possible then data frames sent to the IC&DH for loss-less compression, stored in the SSR, and then to ground for further processing. The user will have the option to use FASTMode with coaddition for data intensive cases, e.g., spectroscopy of planet transits.

5.3.7.6 Subarray Readout

MO-351 For some observations, the source or background is too bright for non-saturated observations in the minimum exposure time of 3 seconds for the full-frame readout. The SUBARRAY readout pattern permits observers to read only pixels that fall within a specified area of the detector with very short exposure times. To ease calibration requirements, a limited number of subarray options will be provided. Bright targets do not require the bias corrections provided by the reference pixels to achieve the desired photometric accuracy, and so it is not necessary to include reference pixels in the subarray area.

5.3.7.7 Spatial Patterns

MO-352 For the MIRI Imager, small-scale dither patterns provide the most accurate photometry and critical sampling of the Point Spread Function (PSF) at the short-wavelength end of the MIRI bandpass. The pixel scale of 0.11″/pixel provides Nyquist sampling at 7 μm. At the longer wavelengths, the PSF is over-sampled and at shorter wavelengths it is under-sampled. Dithering patterns for the shorter wavelengths will aim to over-sample the PSF. Dithering also provides the means to eliminate cosmic rays, hot pixels, and other cosmetic defects.

MO-353 Mapping larger fields with either the MIRI Imager or IFU will involve separate telescope pointings with small-scale dithering included at each position.

5.3.7.8 Zero-Length Dark Frame

MO-354 For the spectrometer, a dark exposure is obtained by moving the instrument shutter into position and observing the optics with the calibration source switched off. For the imager, calibration dark frames will be obtained by moving the filter to the closed position. All calibration sources will remain off. A full-frame exposure or a subarray exposure consisting of 1 group with a single sample is obtained.

5.3.7.9 Dark Frame

MO-355 For the spectrometer, a dark exposure is obtained by moving the instrument shutter into position and then observing the optics with the calibration source turned off. For the imager, calibration dark frames will be obtained by moving the filter to the closed position. A full-frame or a subarray exposure with an integration time specified by the observer is obtained.

5.3.7.10 Internal Flat

MO-356 To take a flat-field exposure for the IFU, the emitting source in the integrating sphere is turned on, illuminating the IFU focal plane. The desired grating position is selected. The observer then obtains a full-frame exposure or a subarray exposure with the integration time they have specified.

MO-357 In flat-field exposures for the imager, the emitting source in the integrating sphere is turned on. This illuminates the central obscuration of the camera pupil and sends diffuse light to the imaging detector. The observer selects the desired filter, and then obtains a full-frame exposure or a subarray exposure with the integration time they have specified.

5.3.7.11 Wavelength Calibration

MO-358 For the IFU and Low-Resolution Spectrographs, a baseline measurement of the wavelength zero-point and dispersion will be made during ground tests. Celestial sources, such as planetary nebulae, will be used to check the zero point while in orbit and will be measured using the IFU modes.

5.3.7.12 Target Acquisition

MO-360 For direct imaging with MIRI, after the Observatory has entered fine-guidance mode, MIRI will be able to commence observations without the need to further refine the target position.

MO-361 Following the coronagraphic target acquisition procedure, a subarray of 64x64 pixels or smaller will be used for the target locate in the MIRI imager field. Since the guide star acquisition will have positioned the target to an accuracy of < 1″ radial rms, this 7x7 arc sec square area will contain the target star more than 99.5% of the time. Subarrays of 16x16 at the sweet spot near the desired coronagraphic aperture will suffice for the second step of the target acquisition process.

MO-362 To acquire a target for observation with the fixed slit in the MIRI imager, the IC&DH computer performs a target locate using a 64x64 pixel subarray in the MIRI imager field of view. The IC&DH then computes the required offset to place the target in the center of the fixed slit, and requests a small-angle maneuver to center the target in the slit.

MO-363 While the guide star pointing accuracy is adequate to place an object in the long wavelength IFU fields of view, it will be inadequate for the shortest wavelength IFU (~3.7″x 3.7″). Thus for some science applications a target acquisition procedure delivering a slightly higher precision is needed. The baseline strategy for IFU target acquisition uses the MIRI imager for the target locate since parts of the MIRI imager focal plane are within ~30″ of the MIRI IFU spectrometer field center. The first step is to perform a target locate in a suitable filter using a 64x64 pixel subarray on the MIRI imager. The next step is to perform a small-angle maneuver to move the object to the center of the concentric IFU fields of view using our knowledge of the instrument metrology. The precision of the offset here is less stringent than for the coronagraph; target placement accurate to 100 milliarcsec in the IFU is acceptable.

5.3.7.13 Raw Data Dump

MO-364 Typically, no on-board processing is applied to MIRI data, so it essentially is always using "raw data dump."

5.3.7.14 Cryocooler Operations

MO-369 Routine operational requirements for the cryocooler have not yet been established. There will be some active operating of the cryocooler during commissioning while the ISIM is cooling down. However, once MIRI reaches its nominal operating temperature of ~7 K, it is anticipated that minimal commanding of the cryocooler will be required. For example, even during detector annealing operations, the temperature set points of the cryocooler will not be changed.

5.3.8 Tunable Filter Imager Operations

MO-371 As described in Section 4.4.5, the Tunable Filter Imager contains two channels that share the same 2.2’x2.2’ FOV. A dichroic splits the light from the FOV, directing photons with wavelengths between 1.0-2.1 μm and 2.1-4.8 μm down the short and long wavelength arms, respectively. By selecting the appropriate instrumental configuration, narrow band (R ~ 100) images throughout the wavelength range can be obtained. As with the other SIs, observations with the FGS-TFI will be initiated from visit files executed by the OPE.

5.3.8.1 Direct Imaging

MO-372 In direct imaging mode, a particular central wavelength will be selected by inserting the appropriate order blocking filter, and by adjusting the etalon spacing to tune to the desired wavelength. Data are then obtained using either MULTIACCUM or SUBARRAY readout.

MO-373 Observers will specify which central wavelengths they desire for their observation. Based on this information, on-board scripts will establish which blocking filters and etalon separations are needed and will ensure that the appropriate commands for the TFI are prepared. Multiple (~3) observations will be required to mitigate the detuning of the etalon across the FOV.

5.3.8.2 Full-Frame Readout

MO-374 Most observations with the FGS-TFI are taken using a full-frame MULTIACCUM readout. Optimal exposure times are determined by how long it takes for background noise sources to dominate over detector read noise. Since the tunable filters have a resolution R ~ 100, detector dark current will usually be the limiting noise source, and exposures of about one thousand seconds will be typical.

5.3.8.3 Subarray Readout

MO-375 Subarray readouts will be available to enable short exposures of very bright objects that would otherwise saturate the detectors in a normal readout.

5.3.8.4 Spatial Patterns

MO-376 Observations with the FGS-TFI will generally use sub-pixel dither patterns to sample the PSF more finely than is possible with the native pixel scale. This is especially important for the short wavelength channel, where the native pixel scale of 0.065″ pixel^{-1} significantly under samples the PSF. Other advantages of small-scale dithering include eliminating the effects of hot pixels and cosmetic defects in the detectors, averaging over localized flat field uncertainties, and providing improved cosmic-ray rejection.

MO-377 Surveying a region larger than the 2.2’ × 2.2’ FOV of the TFI will require a mosaic of observations from a number of overlapping images at different pointings in a large-scale dither pattern. As the TFI and guider field sizes are the same, this will usually require using different guide stars at the different pointings.

5.3.8.5 Zero-Length Dark Frame Frame

MO-378 The pupil wheels for the TFI contain calibration units that can be used to block incoming light when the lamps are not powered on. A full-frame MULTIACCUM exposure or a SUBARRAY exposure consisting of 1 group with a single sample is obtained. While a true bias frame has no exposure time for all pixels, the reset and read out mechanism for JWST detectors will result in an exposure time of the minimum time required to read either a full frame or the selected subarray.

5.3.8.6 Dark Frame

MO-379 To take a dark frame with the TFI, a calibration unit is selected in the pupil wheel without turning on the lamp. A full-frame MULTIACCUM or a SUBARRAY exposure with an integration time specified by the observer is obtained.

5.3.8.7 Internal Flat

MO-380 To calibrate the small-scale pixel-to-pixel response, the FGS-TFI flat field calibration lamp will be used to produce uniform illumination.

5.3.8.8 Target Acquisition

MO-381 Target acquisitions are not required when the TF Imager is used for direct imaging. The acquisition sequence required for coronagraphic observations is described in § 5.3.2.3.

5.3.8.9 Raw Data Dump

MO-382 For diagnostic purposes, it is possible to preserve a string of consecutive images with the FPAs without subjecting them to any processing. For example, a series of reads of

FPAs will be given every (**TBD**) seconds, and these individual images can be sent to the ground as raw data. A minimum of (**TBD**) and maximum of (**TBD**) integration cycles can be collected continuously.

5.3.9 Parallel Operations

MO-388 Calibration observations are necessary to achieve JWST science goals. However, time dedicated to calibration reduces the time that can be dedicated to science observing. Some calibration observations require pointing the Observatory at specific targets, and these types of observations must interrupt science observations. However, other types of calibrations can be carried out at any, or at least a wide variety of, pointings and orientations and these can in principle be conducted on one instrument while science is being carried out on another instrument (MR-156). The set of calibrations that do not require a specific target comprise a large fraction of the total calibration time, and therefore JWST is being designed to allow these calibrations to be carried out in parallel with science observations. Indeed, to reach a scientific observing efficiency of 70% (MR-102), it will be critical to perform certain calibrations in parallel science observing with another instrument. Furthermore, since parallel calibrations do not compete directly with science observing, they have secondary benefits in terms of improved data quality allowed by more frequent calibration and in terms of risk mitigation against detectors with poor in-orbit stability.

MO-389 JWST is well suited to this approach, since to maintain a stable thermal environment in the ISIM and to avoid turn-on transients, all of the JWST instruments (with the possible exception of MIRI) remain in an operating mode all of the time. As discussed in Section 5.2.3, the OPE is capable of interleaving operations of more than one instrument. The spacecraft bus is sized to handle the data produced. In terms of planning, the instrument being used for science observing, designated the “primary” instrument, will control the Observatory’s pointing direction and will have priority in terms of spacecraft resources. Parallel observation will be attached to the observations with the primary science instrument at a late stage in the planning process, and will only be attached if the resources for the primary science observations are not impacted.

MO-390 The primary candidates for parallels are internal dark calibrations that can be conducted without moving any physical mechanism during the science observations. These require reading out the detector arrays in a very systematic way from day to day. They are very time consuming, but they are basic to understanding dark currents, the nature of cosmic ray persistence, and the growth and decay of hot pixels.

MO-391 A second type of calibration that will be considered for parallel operations are calibrations to measure the large-scale features of the flat field (sky flats). These will be especially time consuming for JWST, since a large number of sky images may be needed to obtain the total counts and pointing variety to have a reliable flat field.

MO-392 Casertano (2001) has performed a preliminary analysis of the calibration needs of JWST instruments. Based on this study, Henry & Casertano (2002) show that parallel calibrations can enhance the science efficiency of JWST by ~10%. This is comparable to the savings obtained in carrying parallel calibration observations with current HST instruments. Many of the existing HST calibrations and activities that are conducted using parallels were not anticipated in the original instrument designs. There would have been a significant decrease in HST observing efficiency without the ability to do these calibrations in parallel.

MO-393 Parallel calibrations will be added to the Observation Plan by the ground segment after primary observations have been scheduled. Since calibrations require significant instrument group support for analysis and generation of calibration reference files, the instrument group will have analyzed similar calibration data to prescribe a standard data analysis approach for using the parallel calibration data.

MO-394 The data processing pipeline to generate and archive the required calibration files will process all parallel calibration data automatically. Initial execution of parallel calibration observations will require specific monitoring by the instrument group, which will implement adjustments that are required for the calibration data pipeline.

5.3.10 Data Volume

MO-395 The daily data volume capability required for JWST operations is 229 Gbits of compressed science data (MR-076) and 6.3 Gbits of engineering telemetry data (MR-236) transmitted to the ground at a nominal data rate of 28 mbps during a single contact (7 and 14 Mpbs are also selectable downlink rates). The science data are compressed by a factor of at least two using a lossless compression algorithm. The engineering telemetry data consists of event messages, health and safety telemetry, and housekeeping telemetry from all Observatory subsystems, and guide star acquisition and tracking data from the FGS.

MO-396 The data recorder will be sized to support loss of a single communications contact without loss of data. Given regularly spaced 4-hour contacts, this implies the SSR will need to have the capacity to store about 48 hours of data. Thus, the data recorder will provide a minimum capacity of 471 Gbits. This does not include any overhead required to packetize the data for downlink, if that is applied to the data prior to storage on the data recorder.

MO-397 Overhead is assumed to be 2% for CCSDS packetization and 15% for Reed-Soloman error correction encoding, which results in a science data downlink requirement of 268 Gbits and an engineering telemetry data downlink requirement of 6.3 Gbits, or a total downlink requirement of ~274 Gbits. This will require a contact of about 3 hours including time required to retransmit packets with uncorrectable bit errors (MR-352).

MO-398 The engineering telemetry data volume was based upon a number of assumptions, which have been updated since the requirements were established. The current assumptions are given below:

MO-399 A telemetry downlink data rate of 40 kbps is required for real-time telemetry (including packetization overhead). We assume that an effective rate of 60 kbps can be written to the data recorder, which will support higher resolution recording of a number of telemetry monitors.

MO-400 The FGS data consists of acquisition and tracking images and centroid telemetry. All images will be handled as science data, while centroid telemetry will be handled as engineering data. For nominal operations we assume FGS image data will consist of two full-frame (single SCA) images per visit and all subarray images from the guide star acquisition, tracking and fine guide. The fine guide images will generate about 4KB of data per second for the duration of the visit. The FGS tracking data, consisting of the guide star centroid at 16 Hz, will be recorded continuously as engineering data.

MO-401 A telemetry packetization overhead of 14% is imposed by the IC&DH subsystems. This is based upon a 6-byte packet header, an 8 byte secondary header containing the time code, and 100 bytes of telemetry day per packet.

MO-402 CCSDS packetization overhead of 2% and Reed-Solomon overhead of 15% is applied to the data during downlink. This is based upon a 2 byte PDU header, 6 byte VCDU header with 4-byte control field, an 8-byte secondary header containing the time code, and 1024 bytes of telemetry data per packet.

MO-403 These assumptions result in 6.3 Gbits of recorded engineering telemetry data per day, with a downlink of 7.4 Gbits including CCSDS protocol overhead, as shown in Table 5-4:

Table 5-4. Data Volume

	Constants	Data Volume
Engineering Data		
Engineering Data Rate (kbps)	60	
Engineering Data Volume (Gbits/Day)		5.2
FGS Data		
Guiding Data Dimension (Pixels)	8x8	
Guiding Data Sample Rate (Hz)	16	
Guiding Data Volume (Gbits/Day)		2.8
Acquisition Images / Day	4	
Acquisition Data Volume (Gbits/Day)		0.3
Overhead		
Engineering Data Packetization (%)	14	
CCSDS Packetization and Reed Soloman (%)	17	
Recorded Data Volume (Gbits/day)		6.3
Downlink Data Volume (Gbits/Day)		7.4

MO-404 The science data volume is based upon the following assumptions:

MO-405 Cosmic ray impact as described in section 4.2.1. The impact estimate assumes a total rate of 10.1 particles cm^{-2} s^{-1}, comprised of a cosmic ray rate of 5.1 particles cm^{-2} s^{-1}, and a solar particle rate of 5 particles cm^{-2} s^{-1} during solar maximum (2012-2014) with 90% confidence.

MO-406 MIRI detectors will have an estimated cosmic ray impact rate of 5.3 pixels per cosmic ray or solar particle. The detectors are Si:As with 25-µm pixel pitch, which are assumed to have similar characteristics to the 27-µm pixel, pitch InSb detectors that were used as the basis for analysis in the Communications and Data Volume Study.

MO-407 NIRCam, NIRSpec and FGS detectors will have a cosmic ray impact rate between 5 and 9 pixels per cosmic ray or solar particle. The detectors are HgCdTe with 18-µm pixel pitch, which will have a lower overall impact probability due to smaller size but may also have a higher impact rate due to charge diffusion.

MO-408 The preferred readout mode for MIRI detectors is a MULTIACCUM mode with images taken every 30 seconds with a maximum integration time of around 1000 seconds.

MO-409 The preferred readout mode for NIRSpec and the FGS-TFI detectors is a MULTIACCUM mode with images taken every ~50 seconds to a maximum integration time of 4000 seconds.

MO-410 The preferred readout mode for NIRCam detectors is a MULTIACCUM mode with images taken every 200 seconds to a maximum integration time of around 1000 seconds. This readout rate is selected to ensure that the additional exposure time (overhead) required to compensate for cosmic ray impact and obtain the desired sensitivity with 95% confidence is less than 5-10% of the total exposure time.

MO-411 Parallel exposures will be taken for the purpose of science instrument calibration. Calibrations that require the use of internal lamps will be taken during slews when possible. Calibrations that do not require specific targets (dark frames, sky flats) will be taken in parallel with primary science exposures when possible. It is estimated that parallel calibrations must be attached to 11-12% of total science time. However, for scheduling flexibility and since not all observations will allow parallels, we assume that the data volume must be available to allow at least 24% of the time during a given day to have parallels.

MO-412 Science data packetization overhead is 2%, and we will maintain a 15% margin on data volume.

MO-413 Cosmic ray impact is mitigated by reducing the time between groups in an integration and by increasing the total exposure time, so that when pixels impacted by cosmic rays are removed, the total exposure time is sufficient to achieve desired signal to noise.

MO-415 As Table 5-5 shows, the NIRCam generates the largest data volume, followed by the NIRSpec, MIRI, and then the FGS-TFI. The maximum data volume requirement is derived from operation of the NIRCam as primary science instrument with the NIRSpec operated in parallel for calibration purposes, to a maximum extent of 24% of the total exposure time.

Table 5-5. Science Data Volume

	Constants	**NIR Cam**	**NIR Spec**	**MIRI**	**FGS TFI**	Total
Exposure Duration						
Dither Time / Integration	30					
Readout Duration		10.5	10.5	3.0	10.5	
Group 0						
Frames / Group		1	1	1	1	
Group N						
Frames / Group		1	1	1	4	
Time Between Groups		200	50	3	42	
Number of Groups		5	80	340	22	
Number of Groups / Integration		6	81	341	23	
Integration Time		1011	4011	1023	935	
Integrations / Day		83	21	82	93	
Compressed Data Volume (Gbits/Day)		167	116	332	144	
Packet & Secondary Header	2%					
Margin	15%					
Instrument Data Volume (Gbits/Day)		196	136	57	169	
Utilization (%)		100%	24%			
Combined Data Volume (Gbits/Day)						229
Overhead						
Science Data Packetization	2%					
Reed-Solomon	15%					
Downlink Data Volume (Gbits/Day)						276

MO-416 The daily data volume is a maximum based upon exposures scheduled for a full day. Normal operations will include a distribution of exposures for each science instrument and less efficient operations due to overhead activities that do not generate science data. The Observatory is required to be 70% efficient, and we assume that 85% of the time the Observatory will be generating science data for primary exposures and calibrations (the other 15% of the time will be devoted to Spacecraft operations). The

DRM provides a distribution of observations among science instruments, and the following table shows the total annual data volume based upon that distribution (this does not yet include FGS-TFI observations):

Table 5-6. Annual Data Volume

	Constants	**NIR Cam**	**NIR Spec**	**MIRI**
DRM Percentage				
NIRCam	51%			
NIRSpec	28%			
MIRI	21%			
Parallel Operations	12%			
Efficiency	85%			
Compressed Data Volume (Gbits/day)		196	136	59
Average Data Volume (Gbits/day)		112	43	13
Annual Data Volume (Tbytes)		4.3	1.7	0.5
Total Annual Data Volume (Tbytes)				6.5

MO-417 This table shows that the annual data volume for compressed science data is 5.7 Terrabytes (assuming compressed data are archived). This data volume is used to size the operational data archive as well as predict the data volume and distribution rate for data products.

5.4 TELESCOPE OPERATIONS

MO-418 Establishing and maintaining the image quality is fundamental to the scientific success of JWST.

MO-419 Maintenance of image quality will be carried through a sequence of wavefront sensing and control visits (MR-285). During normal operations the wavefront sensing and control, like most other calibrations of JWST, will be carried out as part of normal science operations as part of the OP. Once the overall telescope performance is well characterized, wavefront-sensing visits will be organized to occur on a timescale (weekly) that is short compared to the timescale (monthly) of expected changes in the mirror actuator positions.

MO-420 Each wavefront-sensing visit will consist of an observation of a field with one or more bright stars through a standard science filter in series with special WFS weak lenses using NIRCam. In the S&OC, the images will be calibrated and then analyzed by the Wavefront Sensing and Control (WFS&C) Executive. The wavefront error and image quality will be evaluated at predetermined intervals. If the image approaches unacceptable values, mirror actuator commands will be generated by the WFS&C Executive, formatted and uplinked to the spacecraft for execution at the next wavefront-sensing visit. At the next wavefront-sensing visit, the actuator commands will be executed after the first wavefront-sensing observation, and then a second wavefront-sensing observation will be taken for verification. This second observation is planned for each wavefront-sensing visit, but is only executed if actuator commands have been uplinked and executed.

5.5 GUIDER OPERATIONS

MO-421 The FGS is used to identify, acquire, and track guide stars. Using the measured position of the guide star in the FGS FOV, the Attitude Control System (ACS) stabilizes and fine points the Observatory. The guide functions of the FGS are described in this section. The operations of the FGS-TFI included in the FGS instrument to conduct science are described above in section 5.3.8.

MO-422 Essentially all science observations and many engineering activities will require the ACS to be in fine guidance mode. Acquisition of a cataloged guide star by the FGS provides the data for the ACS to correct the absolute pointing of the Observatory to about 1″, and to maintain this attitude to an accuracy of 7 milliarcsecond. To facilitate the identification of the guide star via a pattern match, the FGS is provided with the position and brightness of several (up to 10 TBC) cataloged field stars expected to be in the FOV along with the guide star. To reduce the risk of failed guide star acquisitions, which may occur when the catalog misclassifies unresolved galaxies as stars, up to three guide star candidates are provided, if available, along with their associated reference field stars. Once the FGS acquires a guide star, it reports the star's location in its FOV to the ACS with an accuracy of 3 milliarcseccond (per axis, 1-sigma) at 16 Hz.

5.5.1 FGS Operational Modes & Functions

MO-423 The FGS-Guider will have three operating modes, Off, Standby, and Operate. There will be five functions performed under Operate; Identification, Acquisition, Track, Fine Guiding, and Calibration. The FGS-Guider enters these modes and executes these functions upon receipt of commands from the ICDH. In Off, the FGS-Guider (hardware) is powered down and does not send telemetry. In Standby, flight application software is running and the FGS is ready to transition to Operate to execute any commandable function. The FGS flight software (FSW) actively controls all physical, electrical, and detector conditions to which the FGS-Guider and FGS-TFI performance is sensitive. The FGS FSW will be capable of sending telemetry and receiving commands, calibration data, reference data, and software updates. Standby can be entered only from Operate.

MO-957 The five functions under Operate are the essential elements of stabilizing the Observatory pointing for science observing.

MO-424 1. Identification: The FGS-Guider will obtain a full-frame image of the sky in a specific FOV (Nominally the OPE issues this command after the Observatory has slewed to *and settled* at a desired attitude). The FGS FSW will identify the guide star by application of a recognition algorithm that compares the observed versus predicted relative positions of the guide star and selected reference field stars. The predicted position (in distortion-free local detector space coordinates) and magnitude (over the FGS-Guider pass band) of each star will be provided by the IC&DH to the FGS FSW. The recognition algorithm will accommodate up to 10 reference stars, if available. The identification image is obtained with the Observatory held in coarse guide mode (gyros and star trackers). The criteria for success requires the guide star to be identified, classified as a point source (to the extent possible under coarse guiding), and observed to be sufficiently bright for the FGS-Guider to deliver a useful NEA.

MO-425 2. Acquisition: Acquisition begins with the readout of a 128x128 pixel subarray (large window) centered on the guide star, the expected position of which is provided to the FGS FSW by the IC&DH. The FGS repeatedly determines the position of the guide star in this subarray at a rate of 1 HZ. The ACS can use these centroids for an attitude knowledge update (but not necessarily attitude stabilization). As the guide star's position stabilizes to under 0.1 arcsecs/sec, the subarray is reduced to 32x32 pixels, facilitating finer attitude knowledge. The image data from all subarray readouts, as well as the guide star centroids, are sent to the SSR for eventual downlink.

MO-958 3. Track: The 32x32 pixel subarray containing the guide star is readout every 64 msec. The guide star's position in the array is determined by the FGS FSW and is reported to the ACS. The FGS processor will select a new subarray if needed to maintain lock on the guide star. This allows the FGS to "track" the guide star's image as it moves in the FGS FOV, as will be the case when the ACS fine points the Observatory to remove residual pointing errors at the end of small angle maneuvers or to observe moving targets. Nominally, the ACS operates the fine steering mirror (FSM) in closed loop when the FGS-Guider is executing the Track function, thereby reducing the jitter and drift (i.e., unintended motion) of the guide star's image on the SCA. This allows for a reduction in the sub array size down to an 8x8 pixel array.

MO-426 4. Fine Guiding: The FGS will terminate the Track function and execute the Fine Guiding function when the 8x8 pixel sub array containing the guide star image is at the optimal position for observing the guide star at its desired location for the associated science exposures. In Fine Guiding, the 8x8 pixel subarray containing the guide star is readout every 64 msec. The guide star's position in the array is determined by the FGS FSW and is reported to the ACS for closed loop pointing.

MO-427 5. Calibration: The Calibration function provides the means for the FGS-Guider to obtain the data required by the ground system for calibrating geometric distortion, intra-pixel non-uniformity, flat field response, bias, defective pixel maps, photometric response, and PSF characterization across its FOV. When necessary, these calibration data will be obtained for one channel while another channel observes a guide star in its FOV for Observatory stabilization.

5.5.2 Data Processing during FGS Operations

MO-430 Guider control flight software is hosted and executes within the IC&DH.

MO-431 FGS data are stored on the solid-state data recorder. This includes the identification images, acquisition, track and fine guidance images data, and images taken in Calibration mode. FGS telemetry data, such as guide star centoids, are stored in the engineering data.

MO-432 The readout and control electronics correct each pixel for electronic offsets, and perform the Fowler-sampled readouts. Using programmable algorithms, the FSW rejects cosmic rays, scans the full-frame Identification images for stellar objects, and, when in fine guiding mode, measures the centroid of the guide star position. All raw centroids are corrected for optical and detector distortions.

5.5.3 Spatial Patterns and Small-angle Maneuvers

MO-441 The ACS will control small angle maneuvers (< 20″) that are required for guide star acquisition, target acquisition and spatial patterns (e.g., dithering). Such maneuvers will be completed within 1 minute (MR-179), including settling time and offloading of the FSM. It is not expected that science exposures will be executed during the small slew.

MO-442 For all maneuvers larger than ~half of an FGS pixel that retain the guide star in the same FGS FOV, the FGS will drop lock on the guide star. After the Observatory completes the maneuver the FGS will, upon command, execute the Track and Fine Guiding functions.

5.6 SPACECRAFT OPERATIONS

MO-444 The JWST Observatory performs data collection by the science instruments and transmits that data to the ground. The science instruments collect the mission data and package it for delivery to the spacecraft bus. The CTP on the spacecraft bus manages the data by storing it on a solid-state recorder (SSR) for eventual transmission to the ground segment. During science operations the CTP responds to requests for services from the ICDH computer. But it can also carry out commands under real time command from the ground and acts autonomously in managing the non-instrument specific spacecraft systems, such as the EPS.

5.6.1 Communications

MO-445 The JWST Observatory communications links are shown in Figure 5-2. These communications are discussed in the following sections.

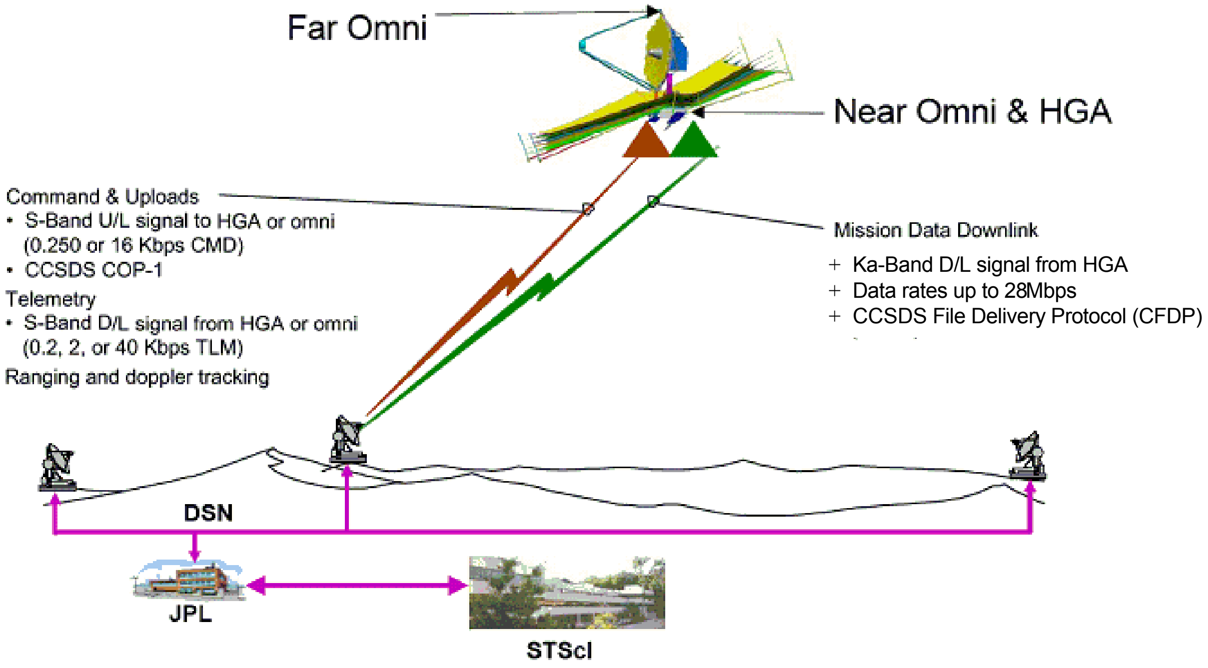


Figure 5-2. JWST Communications Concept

5.6.1.1 Tracking, Telemetry, & Command Operations

MO-446 The JWST communications & C&DH subsystems are optimized to support operations. The communications & C&DH subsystems include two command data rates, three real-time telemetry rates, and 3 stored mission data telemetry rates. This section will summarize operations for the real-time command & telemetry communications links.

MO-447 The Deep Space Network (DSN) will provide communications support for the mission beginning at ~ Launch+50 minutes (MR-082). Communications contact schedules will be coordinated between DSN and the S&OC. Communications contacts will provide a distribution of contacts between Northern and Southern hemispheres over a

21-day period in order to provide ranging and tracking data suitable for orbit determination. Orbit determination functions will be performed by the GSFC Flight Dynamics Facility (FDF), which will receive ranging and tracking data from the DSN and provide acquisition data to the DSN and ephemeris data for ground and flight operations to the S&OC.

MO-448 The Observatory has two S-band omni-antennas, one near and one far; and, one biaxial steerable high gain antenna (See Figure 5-2). Both Observatory receivers are simultaneously enabled for commanding, and will respond automatically to S-Band commands at either selected command rate from the DSN ground stations (Goldstone, Madrid, & Canberra). The S-Band transmitter is always sending engineering telemetry data, regardless of whether the ground stations are actively listening for telemetry. When the Observatory is in line-of-sight of a supporting ground resource and configured for normal operations (HGA Ops), it is able to receive commands and memory uploads at 16 Kbps and sends real-time telemetry at 40 Kbps. Contacts are normally scheduled once per day for mission data playbacks, clock synchronization, and upload of the Observation Plan and related files when needed (at least every 7-10 days) (MR-077, MR-157, MR-208).

MO-449 The system also provides the capability to playback stored telemetry to the ground via S-Band downlink. A special partition on the solid state recorder is used to record critical health and safety telemetry consistent with the low rate downlink available on the S-Band. This allows the S&OC to obtain stored health and status information from the Observatory during a safe mode, or in the event of any problems with the Ka-band downlinks. This capability may also be utilized in the early phases of each mission prior to activating the Ka-Band system.

5.6.1.2 Data Operations

MO-450 The Observatory plays back stored mission data when commanded by the S&OC. Science and engineering telemetry are stored on separate partitions on the solid state recorder in fixed file sizes (nominally 1 Gbit for science, 100 Mbit for engineering). Critical engineering telemetry is stored on a separate partition. When a recorder playback is command, the critical engineering telemetry partition is downlinked first, the full files from the engineering data partition, and then full files from the science data partition. As files are filled on the engineering and science telemetry partitions, they are also downlinked until playback is halted.

MO-959 At times, it will be necessary to obtain partial files from the recorder, especially to support Wavefront Sensing and Control operations during the commissioning phase. At any time, a command from ISIM or the ground can be sent to identify data that must be downlinked even if the file containing the data is not full. These data will be downlinked as a partial file if the file is not full when it is reached during playback.

The complete file will also be downlinked when it becomes full; which will result in the downlink of duplicate data to the ground.

MO-960 Based on the ground station location, a stored ephemeris, and stored contact times, the Observatory will maintain HGA pointing within the half-power beam width for the Ka-Band. Although the JWST communications and C&DH subsystems provide 3 selectable Ka-Band rates, the nominal mission data downlink data rate is 28 Mbps. Lower rates may be selected if needed to establish communications during inclement weather.

MO-451 For DSN ground station pointing, the FDF provides Observatory view periods and ground station acquisition data based upon the Observatory ephemeris. The DSN provides ranging and Doppler tracking data to the FDF for determination of Observatory ephemeris.

MO-452 Recorded telemetry is transmitted by Class 2 CCSDS File Delivery Protocol (CFDP), which is fully acknowledged with retransmission of missing or corrupted packets, from the Observatory to DSN and transferred to the S&OC upon request. During transmission of a CFDP file, the DSN will construct the file from CCSDS packets and pass accounting data to the S&OC. The transaction packets, for acknowledgement of re-transmission requests, are sent from the DSN to the S&OC, where they are formatted as CCSDS commands and sent back to DSN for uplink to the Observatory. Transaction packets are not sent directly from DSN to the Observatory as the S&OC is the sole originator of all commands sent to the Observatory (MR-331). As each file is completed and acknowledged, the file is transferred from DSN to the S&OC. If a file is not acknowledged by the end of the contact, the Observatory retransmit the entire file at the next contact.

5.6.2 Spacecraft Bus Operations

MO-453 The spacecraft bus, a collection of subsystems, supports the science instruments in their performance of the mission and interfaces with the ISIM, FGS, Instrument Control Electronics, Launch Vehicle Adapter, launch segment, and ground segment. As noted earlier spacecraft bus operations are managed by the CTP. The subsystems consist of structure and mechanisms, thermal control, propulsion, attitude control, electrical power and distribution, communications and command and data handling, and spacecraft bus flight software (See Section 4.3.3).

MO-454 This section will describe the spacecraft bus subsystem operational concepts for Attitude Control, Slews, Power, Thermal, and the C&DH Subsystem.

5.6.2.1 Attitude Control

MO-455 The Attitude Control Subsystem (ACS) provides 3-axis attitude determination and pointing control (stellar-inertial with reaction wheels) of the Observatory, and controls the Fine Steering Mirror (FSM) using guide star information from the fine guidance sensor (FGS).

MO-456 Attitude control of the Observatory is provided by an autonomous function of spacecraft bus flight software, which processes data from attitude sensors, pointing commands from the ISIM and ground, and issues commands to actuators. ACS is responsible for maintaining attitude/pointing, slew maneuvers, momentum unloading, thrust vector pointing, Delta-v maneuver control, high gain antenna pointing, and backup modes supporting contingency management.

MO-457 Observatory on-board attitude determination is accomplished using measurements from 2 star trackers and an inertial reference unit. The reaction wheels provide the control torques needed to maintain attitude/pointing as well as orient and execute Observatory slews (detailed in Section 4.3.3.4).

5.6.2.2 Slew Concepts

MO-458 Slews are vehicle maneuvers that orient the Observatory prior to science observations, as part of station keeping, as part of commissioning, and for attitude recovery operations. The spacecraft bus ACS subsystem is responsible for slew maneuvers.

MO-459 Slews may be initiated via the OPE, spacecraft bus flight processor, or ground command. Note that science operations will be suspended during spacecraft bus flight processor or ground commanded maneuvers.

MO-460 A typical slew maneuver begins with a request from the OPE to the CTP to perform a spacecraft slew to a new target. The slew is to a position that places the guide star in the FGS FOV for identification and acquisition and thus at least 21 arcsec from the edge of the FGS FOV. Once the guide star is acquired, an offset maneuver is executed to position the target at the required location within the SI FOV. The OPE provides the target attitude associated with the observation, (right ascension and declination of target in ECI), Roll angle around target (in ECI), SI detector to be used, target position in the SI detector, and the expected visit duration.

MO-461 Commands to prep FGS and FSM, constraint checks (sun avoidance), and momentum checks are performed prior to maneuvers. If moving to the new position would violate a constraint, an error message is generated and the slew command is not processed. If the calculated slew profile will cause the momentum stored by the reaction wheels to exceed predefined limits, momentum will be dumped prior to the slew to target maneuver. At the completion of pre-slew validation checks (and momentum dump, if required), the CTP sets the “Slew in Progress flag” and guides the Observatory from its present attitude to the new target attitude using its star trackers, IRUs, and reaction wheels. Setting the “Slew in Progress flag” notifies Fault Management of upcoming body rate change, enables the spacecraft bus FSW function which points the HGA, and confirms to the OPE that slew is in progress.

5.6.2.3 Power Management

MO-462 As discussed in Section 4.3.3.5, the EPS located on the spacecraft bus provides regulated power to the rest of the Observatory. Normally, the system will function autonomously under control of EPS software running on the CTP. Current sensors within the EPU measure load and battery currents.

MO-463 The solar arrays on JWST will be fixed (at a cant angle of 30°, the midpoint of the range of pitch angles needed for mission operations). The EPS software will adjust solar array power output to meet load and battery charging current demands by digital control of the solar array regulators (SARS). Load management will be performed autonomously based on bus voltage or battery charge and spacecraft operating mode, and allow for shedding loads for survival mode.

MO-464 The spacecraft bus EPS software also provides automatic charge control of the battery. Battery state of charge is calculated on board by integrating battery charge and discharge currents (Amp-Hour Integration). Backup charge control or state of charge initialization is automatic via a battery temperature and voltage (Temperature Compensated Voltage Limit), Amp-Hour charge differential, or Amp-Hour charge to discharge ratio.

MO-465 Although under normal situations, power management will be autonomous, provisions will be made to assure that important functions, including battery-charging rates, can be commanded from the ground, should that be necessary.

5.6.2.4 Thermal Control

MO-466 The spacecraft bus thermal control system (TCS) maintains the temperatures of all bus components within their predetermined thermal limits. The baseline design for thermal control is passive and not controlled by flight software. The thermal radiators are mounted normal to the OTA optical axis looking out across the short dimension of the sunshield. The JWST design uses two robust, lightweight honeycomb shades to prevent unwanted radiation from reaching the spacecraft bus.

5.6.2.5 Command & Data Handling Subsystem Operations Concept

MO-467 The CTP is the primary computer for controlling the spacecraft bus. The CTP autonomously collects predefined health and status telemetry from all spacecraft subsystems. These data are stored in the SSR for playback via the Ka-Band downlink with the mission science data. For contingency operations, these data can be dowlinked as real-time telemetry via the S-Band telemetry link (see Section 5.6.2.6 for additional details regarding SSR operations).

MO-468 On-board command processing consists of receiving, authenticating, and forwarding commands to various Observatory components. Real-Time commanding will not normally be performed without S&OC access to housekeeping telemetry. Anomalies are treated on a case-by-case basis (i.e., spacecraft transmitters are not working and we are trying to switch to the redundant units) and discussed in later sections.

MO-469 The CTP records events containing telemetry necessary to reconstruct spacecraft decisions made during autonomous operations (MR-127). The events will include telemetry threshold triggers and subsequent commands from the spacecraft. These events are temporarily stored on the CTP, periodically stored on the SSR, and transmitted upon command.

5.6.2.6 Data Recorder

MO-470 The SSR will have a 471 Gbit storage capacity, which is sufficient to store at least 48 hours of engineering and science telemetry data. This will support continued execution of the OP in the event that one contact is lost. This could happen due to weather conditions at the ground station, some malfunction of the ground station, or a loss of ground station support as a result of an emergency requirement to support another spacecraft. A 48 hour capability will also provide margin for uneven spacing of communications contacts due to scheduling conflicts with one ground station or due to switching between ground stations (especially when switching between ground stations in different hemispheres which is regularly required for orbit determination).

MO-471 Data can be written to the SSR while data are being read for transmission to the ground. This is necessary because communications contacts are long and efficiency requirements cannot be satisfied if observations cannot be taken while data are transmitted. In particular, this means that high rate data transmission will be available during any normal observation activity (including slews and acquisitions).

MO-472 The spacecraft and ISIM C&DH subsystems will each provide engineering telemetry data (which may include recorded event data) for storage on the SSR. In addition, the ISIM C&DH subsystem will write compressed science telemetry data to the data recorder, and guide star identification, acquisition, and tracking images as science data to the data recorder. Tracking images, and possibly acquisition images, will be buffered by the FGS and written in sizes comparable to the other forms of science data.

MO-473 Data will be transmitted in the following order: real-time engineering telemetry including current event data and the ISIM event messages, recorded engineering telemetry (which may include recorded event data), and science data (which is only available from the data recorder). The ISIM event messages and the event data are transmitted at the start of contact so that the ground system will know how the Observation Plan was executed and whether there were any anomalies that occurred that will require the attention of operations personnel. Engineering telemetry will be read next, so that the ground system will have quick access to that data in order to support quick analysis of any anomalies already reported in the event data (MR-127, MR-131). Each type of data will be read in the order in which it was written, and for many contacts most data stored on the data recorder will be read, transmitted to the ground station, and acknowledged by the ground station. Engineering data are written to the SSR in 100M files. Science data are written to the SSR in 1G files. The last science data written to the data recorder may not fill up a file and will normally be held for transmission to the next contact. The ground will be able to identify and mark data sets for transmission even if they are in less than 1G files.

MO-479 Operations will also perform any necessary maintenance tasks required for solid state recorder operations. These will include reconfiguration of the data recorder in the event that memory is lost to radiation damage or other fault, and configuration of the data recorder partitions to manage critical health and safety telemetry, engineering and science telemetry. Observation time lost to solid state recorder management functions is accounted in the spacecraft allocation of the efficiency budget.

5.6.3 Orbit Maintenance

MO-480 As described in section 4.2, L2 is a saddle point in the gravitational potential and therefore station keeping, in the form of thruster firings, is required to prevent JWST from drifting away from L2. Accurate knowledge of the position and velocity of the spacecraft are required to calculate the thruster firings. The current concept calls for eight station-keeping maneuvers per orbit about L2, or one every 22 days. The FDF at GSFC is responsible for planning the station-keeping maneuvers while the FOT is responsible for developing the associated commands that will be uploaded to the spacecraft. Because of the safety-critical nature of these commands, the δv-maneuvers required for station keeping will be carried out during ground contacts. Station keeping maneuvers occur under ground control with the aid of stored command sequences (SCSs) residing on the CTP. At the absolute time in the associated SCS, the Observatory will maneuver to the appropriate angle and fire the thrusters for the duration specified. Attitude control is maintained with thrusters. Once the burn is complete, the Observatory is maneuvered back to a nominal attitude.

MO-481 Since real-time commanding of maneuvers is required and since in any event, the Observatory will stop science data collection, all satellite maneuvers are commanded from the S&OC. The Observatory will not perform autonomously generated station keeping maneuvers.

MO-482 Additional details regarding orbit maneuvers are delineated in Section 6.2.2.

5.6.4 Orbit Determination

MO-483 The FDF, which is part of the JWST ground segment, is responsible for orbit determination (OD) of the JWST spacecraft. The FDF will obtain tracking measurements of the spacecraft along with spacecraft telemetry data from the S&OC in order to perform the OD.

MO-484 The required tracking measurements consist of range and Doppler measurements accurate to 15 m and 8 mm s^{-1} respectively (3-σ). They will be accomplished using the S-band link (MR-294). The tracking schedule required is one 30-minute pass per day. Tracking stations are required to be in both northern and southern hemispheres, with tracking passes alternating between them.

MO-485 The tracking measurements and the spacecraft telemetry data will be routed to the FDF at GSFC. FDF will determine the JWST orbit to within 50 km and 2 cm s^{-1} (3-σ) RSS.

MO-486 The ephemeris information will be sent to the S&OC in order to facilitate planning of science and engineering activities, and to DSN for ground tracking. The S&OC will uplink the ephemeris to the Observatory where the information will be used by the S/C bus for sun avoidance, HGA tracking and correction of reference star and target positions for velocity aberration (and parallax correction for moving targets).

5.6.5 Momentum Management

MO-487 Reaction Wheels (RWs) accumulate the effects of secular (or non-cyclical) torques while maintaining commanded Observatory pointing. RWs have a limited momentum storage capacity. In order to maintain maximum control authority, which in turn permits maximum spacecraft slew rates during mission operations, RW momentum is unloaded routinely by firing thrusters.

MO-488 The ACS process on the CTP monitors the momentum stored in the reaction wheels and has the authority to initiate momentum dumps. When possible, these will require slewing to a specific attitude. Under normal circumstances, momentum dumping will be a planned activity on the Observation plan. If needed, autonomous momentum dumping will be coordinated with activities occurring on the IC&DH computer. The IC&DH sends a message to the CTP that permits momentum unloading; if the stored momentum exceeds pre-defined minimum limits. Messages of this type would occur before the beginning of any slew and at sufficient intervals to assure the momentum stored does not exceed pre-defined maximum limits.

MO-489 To assure that control authority is maintained at all times, maximum limits will also be defined. If the stored momentum exceeds these maximum limits, the ACS process will automatically initiate a momentum dump regardless of the state of the on-going science observation. The S&OC will also have the capability to cause the ACS to initiate a momentum dump.

5.6.6 High Gain Antenna Pointing

MO-490 The stored science data stream is delivered via Ka-band from the Observatory through a gimbaled high gain antenna (HGA). The Spacecraft will calculate the required gimbal angles to point the HGA toward the selected ground station identified for each (upcoming) contact. The data required to make these calculations are the location of the selected ground station, times to start and end pointing the HGA to that ground station, JWST ephemeris with respect to Earth, and contact times. The spacecraft will calculate the selected ground station position for HGA pointing based on ground station Earth fixed coordinates and spacecraft calculated time. To satisfy the stringent HGA pointing requirements, the HGA will continually track the selected ground station. To avoid disturbing science data collection, the control law that results in movement of the HGA will only be enabled under the following conditions:

1. The ISIM sends a message to the CTP that permits HGA pointing; and, the CTP-calculated pointing error exceeds predefined thresholds (minimum limits). ISIM messages of this type are anticipated to occur every 1000-5000 s as a result of dither activities. The period that HGA pointing will be disabled will not exceed 10,000 seconds.

2. The CTP calculated pointing error exceeds predefined thresholds (maximum limits); and the Observatory is currently in a planned ground contact period.

3. The S&OC sends a command that enables HGA antenna pointing

MO-491 The Ka-Band antenna beam width is about the size of the Earth, but the S-Band antenna beam width is substantially larger than the size of the Earth. When enabled, the HGA will be kept pointed at the selected ground station which is suitable for S-Band communications given the S-Band antenna width. Unscheduled contacts will be established using the S-Band, and contact information will be uplinked to the Observatory prior to establishing an unscheduled Ka-Band contact.

5.6.7 Contingency Management Concepts

MO-492 The spacecraft contingency management is hierarchical, depending on fault severity, to minimize impact to the mission timeline (MR-277). Redundant hardware control paths and power loads are autonomously and progressively configured. Consumables, such as fuel, are conserved (MR-278). Load shedding increases and thruster usage is limited as the level of protection deepens.

MO-493 For spacecraft failure situations, the spacecraft bus provides a combination of hardware and software safing monitors and autonomous response actions known as on-board fault management (OBFM). OBFM directs autonomous reconfigurations of the spacecraft subsystems to “safe modes” to ensure survival without ground intervention, while allowing for ground control of safing actions, as necessary.

MO-494 The spacecraft bus switches between redundant components when OBFM indicates a fault in a component with a healthy back-up, except in the case of a science instrument, which will only be commanded to a safe configuration. After an autonomous action to switch between redundant units occurs, telemetry data are diagnosed on the ground, and commands are sent to the spacecraft to correct the problem (if possible), or to test the unit if a transient event is suspected. If the ground establishes that the original equipment is functional, the S&OC reconfigures the spacecraft per one of the following options (in accordance with established operational procedures):

- Command a "switch select bit" for the on-board redundancy management software to allow automatic switch over to that original unit if/when the second unit indicates failure.
- Reconfigure the spacecraft back to the original hardware.

5.6.7.1 On-board Fault Management (OBFM) Implementation

MO-495 The spacecraft bus provides three levels of autonomous safing. The spacecraft bus is designed such that all phases of operation (from initial Observatory activation before upper stage separation through transfer orbit, deployments, commissioning, and operations at L2) can be handled with these same levels of fault response. The lower the fault level, the less severe the fault response. To minimize disruptions to science data collection, the lowest fault level necessary to ensure Observatory safety will be entered. Lower levels involve less reconfiguration than higher levels; in fact for level 1, science data continues to be collected. Appendix C provides additional details on the Observatory Fault Management.

MO-496 The levels of autonomous fault safing are:

MO-497 **Level-1: Log and Continue.** Level 1 faults do not immediately affect the ability of the spacecraft to support science data collection, as the Observatory remains in Normal Pointing Mode. While there may be a local subsystem response to a Level 1 Fault, there is no change in Observatory Mode. Their occurrence is logged in the fault log and provided in telemetry.

MO-499 The Observatory will usually "fly-thru" Level 1 faults. Individual instruments may have to be safed, but the fault management concept allows for continued operation of the science program using the other science instruments.

MO-500 **Level 2 - OTE and ISIM.** An OTE/ISIM Level 2 response protects the Observatory after experiencing faults that prevent continuing with observations (e.g., FGS failure). This level is entered when either the OTE or ISIM can no longer support the planned science mission. The orientation of the vehicle does not immediately change, but science data collection will not continue. Over time, the vehicle attitude may be adjusted as necessary to ensure the sun constraints are not violated.

MO-501 The Observatory will be placed into Inertial Pointing Mode in response to ISIM or OTE level 2 faults.

MO-502 **Level 2 – Spacecraft.** A Spacecraft Level 2 response protects the Observatory after experiencing spacecraft bus faults that prevent continuing with observations (e.g., a star tracker failure). This response is entered when the spacecraft bus can no longer support the planned science mission yet the safety of the Observatory is not immediately threatened.

MO-503 The Observatory will be placed into Safe Haven Mode in response to Spacecraft level 2 faults. Spacecraft components will be swapped as necessary to isolate any failed or potentially failed components. Level 2 faults are faults that present no immediate threat to the Observatory health but would become life threatening if allowed to continue. The Spacecraft will notify ISIM of the occurrence of a Spacecraft fault that prohibits the immediate continuation of the science mission. ISIM would enter ISIM safe mode in response to this notification. Following a CTP swap, a reconfiguration buffer (RCB) is provided to support Spacecraft initialization following a CTP switch. This buffer contains critical software and hardware status data that is used by the "new" online CTP.

MO-504 For JWST, it is anticipated that Spacecraft Level 2 faults will result in controlling the spacecraft in an independent control mode while maintaining a sun-safe attitude with a combination of coarse and fine sun sensors, inertial reference unit (IRU), and reaction wheels (with all science instruments “safed”). Thrusters are used for momentum unloading. In the event of an anomalous upper stage separation or a fault occurring while thrusters are being used, thrusters can be used to orient solar arrays and secure power margins, followed by an automatic transfer to reaction wheel control to conserve fuel.

MO-505 **Level 3 - Survival.** Level 3 faults protect against failures jeopardizing Observatory safety. This response occurs when potentially catastrophic failures occur on the Observatory. A Level 3 fault can occur once a Level 2 fault has resulted in entry to Survival mode. Level 3 faults are faults that jeopardize the survival of the Observatory in a short period of time and require immediate corrective action. When such faults occur, the Observatory autonomously transitions to Survival Mode.

MO-507 For JWST, Level 3 faults will result in operating on the redundant side (B side) of the spacecraft bus command & telemetry processor (CTP) following a reset of that processor. The B-side then reconfigures hardware by switching to redundant strings as applicable using information available in non-volatile memory to determine the appropriate configuration. It also commands load shedding, notifying the ISIM of imminent removal of power first, and continues to control attitude and power.

MO-511 Table 5-7 summarizes the on-board fault classification levels and responses. In the table, fault conditions are categorized from L1 through L4. The lower the numerical designation, the less severe the fault.

Table 5-7. On-Board Fault Classification Levels

Fault Condition Definition	Spacecraft Response	Example
Level 1 Log and Continue No immediate threat to the Observatory	Stay in current operational Mode	Science Instrument failure
Level 2 – OTE/ISIM No immediate threat to the Observatory	Transition to Inertial Pointing Mode Mission requirements not met	ICDH failure
Level 2 - Spacecraft No immediate threat to the Observatory	Transition to Safe Haven Mode Sun-pointing attitude Mission requirements not met	On board CTP failure
Level 3 Survival Potentially Catastrophic	Transition to Survival Mode Sun-pointing attitude Load shedding Mission requirements not met	Power emergency

MO-512 Hardware and FSW fault monitors have associated preprogrammed command sequences for the safe mode tier selection, redundancy configuration, and load shedding. These monitors use information independent from the data used for control in normal pointing mode. FSW fault monitor threshold and persistency limits are subsystem and mode dependent and designed to avoid false triggers while ensuring timely response to true failures. Software fault monitors have configurable persistency limits and thresholds. The system is designed to give the ground sufficient information to determine the cause of any autonomous reconfiguration. Spacecraft Flight Software accomplishes this by providing data available for inclusion in the real-time telemetry stream. The activity log and fault log provide information about the occurrence of key events and failures of fault triggers. Status words are available to indicate the current status of the Spacecraft subsystems. Additionally, all autonomous fault detection and recovery functions may be reconfigured or disabled by ground command, thereby achieving great flexibility.

MO-513 The most stringent requirement on Observatory contingency management design is protection against sun impingement. Sun position monitors allow for detection of sun position errors. If a thruster failure occurs while thrusters are being fired near the edge of the Observatory FOR, it is possible for the nominal FOR sun constraints to be violated for ~5 minutes. Thermal analysis has been done to verify that this duration of sun exposure will not damage the instruments.

5.7 GROUND SYSTEM OPERATIONS

MO-514 The major subsystems of the S&OC ground system include the Proposal Planning, Operational Scripts, Flight Operations, Data Management and Project Reference Database Subsystems as described in section 4.5.1. Operations of these elements of the ground system are performed to ensure the health and safety of the Observations and accomplish the mission's science objectives while meeting overall mission efficiency and cost requirements.

MO-515 JWST ground system operations are therefore performed on behalf of the international community of JWST users. The different categories of JWST programs were described in section 3.4 and we further define here the different categories of JWST users.

MO-516 General Observers (GOs): members of the international astronomy community who are competing for or have been awarded JWST observing time.

MO-517 Archival Researchers (ARs): members of the international astronomy community using data from the JWST science archive to conduct research. U.S. astronomers may also compete for grant funding for their research.

MO-518 Guaranteed Time Observers (GTOs): members of the Science Working Group who have been granted a specific amount of JWST observing time in return for their contributions to the mission.

MO-519 Engineers & Calibration Scientists: Members of the JWST team who are responsible for assessing and maintaining the health, safety and performance of the Observatory.

MO-520 These categories define groups of users rather than distinct individuals or entities. All users are important, but the GO class represents the largest constituency group as they will define and obtain the majority of the science data over the life of the mission. It is on their behalf that much of the STScI S&OC operations effort will be expended. All users in all categories will be treated equitably with regard to support and resources required to achieve the goals of their observing or archival program; i.e., operations resources and effort that are expended for one program will be expended for all programs for which there is a similar need. JWST Engineers and Calibration Scientists will require access to Observatory capabilities that are not appropriate for science users with special tools and operational processes and procedures likely required to support their efforts on behalf of all JWST users.

MO-521 JWST ground system operations are categorized here as Pre-Observation, Flight, and Post-Observation operations and are presented in the following sections. This is followed by a discussion of the PRDS as the central ground system element used in all phases of operations and then a general discussion of the operations teams directly responsible for the activities.

5.7.1 Pre-Observation Operations

MO-522 Pre-Observation operations are those accomplished using the Proposal Planning System (PPS). The observation cycle starts with developing the pool of available visits either through solicitation and selection of science programs or submission of calibration and engineering programs. A Telescope Allocation Committee (TAC) will review and recommend selection of science programs. A long-range plan is generated from the available pool to create a high-level optimized layout for all visits within a given period (nominally a one-year observing cycle). As each week in the long-range plan approaches, the detailed "weekly" observation plan is developed with final guide selections made. The Observation Plan, integrated with other spacecraft housekeeping activities during Flight Operations Mission Scheduling, drives the operation of the Observatory and acquisition of engineering and science data.

5.7.1.1 Proposal Solicitation and Processing

MO-523 General Observers (GOs) and Archival Researchers (ARs) will be solicited on a routine basis (anticipated as annually) via a competitive process. The astronomical community is notified of the opportunity via a Call for Proposals (CFP) that will define:

- Available observing time in the solicitation cycle,
- Anticipated Observatory capabilities and calibration levels,
- Policies, limitations and evaluation criteria governing selection,
- Instructions and guidelines for completing a JWST Phase 1 Proposal,
- Instructions and guidelines for providing JWST Phase 2 Visit Specifications as necessary & desired,
- Deadline for submission of JWST Phase 1 Proposals.

MO-524 All potential GO and AR investigators will submit Phase 1 proposals that focus on the science justification for and overall needs of the proposed research. For GOs, the Phase 2 visit specifications provide the full details of configuration and requirements to accomplish the science program if selected. While there is generally a desire to limit the information supplied during Phase 1 to only what is required by the selection process, the S&OC will enable but not require the submission of complete Phase 2 visit specifications with the Phase 1 proposals. Submitting Phase 2 visit specifications with proposals will enable the S&OC to reduce the time between proposal submission and observing program execution.

MO-525 Tools will be provided to the community to support development of Phase 1 proposals as discussed in more detail in paragraph 5.7.1.3. The tools will ensure that Phase 1 proposals are complete and specify valid target and Observatory configuration information prior to submission. Documentation describing the capabilities of the Observatory will be provided via a context-sensitive help feature in the tool but this does not alleviate the need to provide expert assistance to the astronomical community during Phase 1 proposal preparation. STScI scientists and operations staff will be required to address questions from novice users and from users proposing complex or unanticipated types of observations. The S&OC must provide support to those having difficulty using the provided tools or interpreting their output. An S&OC Helpdesk will be established for this purpose which will track and monitor closure of questions and issues enabling subsequent improvements to the process, tools and integrated help feature.

MO-526 GO and AR selection will be selected through a competitive, peer review process designed to identify the best and most important science to be obtained that maximizes the capabilities of the Observatory. Based on the history of the Hubble, CXO and SST missions, JWST can anticipate that 700-1000 Phase 1 proposals will be submitted for a one-year cycle with an oversubscription of submitted to accepted proposals in the range of 1:5 to 1:7. The current concept for JWST selection is based on the exemplary Hubble process, which provides for a Telescope Allocation Committee (TAC) and discipline review panels with members solicited from the international astronomical community. As many as 100 members of the community may be involved in the selection process. The review panels perform the initial evaluation, grading and ranking within their discipline while the TAC addresses any special program categories and conflicts between disciplines and ensures an appropriate balance across the disciplines. The TAC then prepares a rank-ordered list of science programs for review by the STScI Director. The STScI Director is the authorizing official in the selection of JWST GO and AR programs. The JWST Archival Research program is not expected to commence until sufficient science data are available for retrieval. Given the plan to start JWST science observing with GTO and JWST Treasury- or Legacy-style programs and the nominal one year data proprietary period, we can anticipate archival research grants being awarded starting the second solicitation cycle.

MO-527 The drivers of the process are to ensure it selects research programs that make major and important contributions to astronomy and is conducted in a manner that is fair and equitable for the community. STScI scientists are permitted to submit proposals but are not called upon to serve on the TAC or review panels. There is considerable effort involved in identifying and resolving conflicts for the TAC and review panel with action taken depending on the level of conflict; e.g.,

- Direct conflict as a PI or Co-I on a proposal,

- Institutional conflict in that there will be a benefit to the reviewer's department if the proposal is accepted,
- Indirect conflict from a relationship between the proposer and reviewer (thesis advisor, relative, etc.).

MO-528 Tools will be required to help identify the direct and institutional conflicts with indirect conflict identification the responsibility of reviewers.

MO-529 To maximize the science return over the life of the JWST mission, observing time will not be rewarded for data already available in the archive or planned to be obtained unless a convincing case is made in the proposal why new data are required. Tools that allow proposers to check for duplication of data will be available during Phase 1 proposal preparation. Guaranteed Time Observers (GTOs) will protect the specific observations they plan to obtain in the upcoming cycle via entry of Phase 2 visit specifications into the system prior to release of the CFP. The selection process must also guard against selecting multiple programs that would obtain the same data even if those data were to be used for very different research purposes. In this case, one program will be selected with the data available for archival research in the next cycle. Duplication tools will be required to help identify these inter-cycle duplications.

MO-530 Capturing review comments and discussion is important to the process in order to provide feedback to the community about their proposed observations. In many cases, the research is valuable but, given the over-subscription, other more highly ranked programs were selected. In some cases, the research topic itself is not felt to be particularly important or the proposal was poorly written and this is important information to share with the proposer. These comments can also be useful when addressing community appeals to the STScI Director.

MO-531 Once Archival Researchers are selected, their next step is into the Grants Management process and retrieval of the data. Once General Observers are selected for observing time, they move into Phase 2 to develop or refine the details of their observing program with information from their Phase 1 proposal loaded into an operational repository that enables the tracking of programs, gathering of program statistics and validation of Phase 2 visits in the next phase.

MO-532 Throughout the observing cycle unexpected astronomical events and phenomena will occur. In order to accommodate these unique opportunities, a percentage (it is 10% for Hubble) of the anticipated observing time will be set aside for awarding to the community as Director's Discretionary (DD) Time. A user interface will be developed that allows for community request of DD Time along with a process within the S&OC for the scientific and operational review of the science program. DD Time is awarded for research opportunities that could not have been foreseen and therefore requested through the normal GO solicitation and selection process. The STScI Director is the awarding and authorizing official and ensures that the same level of review and assessment is applied to these programs as for GO programs. Scientific expertise from within the STScI and from the international astronomical community is used to assess the relative importance of the science. Many DD Time requests have short windows of opportunity with many being classed Targets of Opportunity. If there is no hurry to observe the event or phenomena, the proposer is advised to wait for the next solicitation cycle. Care must be taken throughout this process to avoid introducing duplications of existing awarded Target of Opportunity programs. The DD Time review process must also discern if a proposer was rejected for this same research in the previous cycle and address this issue if it arises.

5.7.1.2 Phase 2 Visit Specifications

MO-533 JWST observations are specified as a series of exposures on a specific target using a specific instrument. There will be a number of parameters that will be specified to define the exposure including the time duration, instrument configuration and observing techniques. The exposures are grouped into sequences that will occur during the same visit to the target, hence the grouping is referred to as a Visit as described earlier in section 5.2.2. Visits are self-contained in that they include all of the information required to obtain the desired data including celestial coordinate information to enable slewing to the target, guide star candidates, instrument configurations, and any observing constraints such as timing and orientation.

MO-534 Phase 2 visit specifications are the only means of initiating acquisition of JWST science and calibration data and will be used by all GOs, GTOs, engineers and calibration scientists. Tools will be provided for Phase 2 visit specifications as discussed in more detail in paragraph 4.6.2.3. The tools will ensure that all Phase 2 proposals are complete and specify valid target and Observatory configuration information prior to submission. The tools will also ensure that visits are consistent with the Phase 1 approved program (e.g., within the awarded observing time) and will confirm that no duplications of pre-existing or planned data have been introduced. Documentation describing the capabilities of the Observatory will be provided via a context-sensitive help feature in the tool but this does not alleviate the need to provide expert assistance to the astronomical community during Phase 2 visit specification. STScI scientists and operations staff will be required to address questions from novice users and from users preparing complex observations.

MO-1007 The S&OC must provide support to those having difficulty using the provided tools or interpreting their output. The S&OC HelpDesk will address as many of the questions as possible or forward them on to identified experts to handle. The S&OC will track and monitor closure of questions and issues enabling subsequent improvements to the tools and integrated help and documentation.

MO-535 Deadlines for submitting Phase 2 visits will be established and enforced, as availability of the full suite of observations is important for entering the Long Range

Planning operational phase. For a nominal cycle, we anticipate that GTOs will submit first followed by the GOs. Once the baseline science program is submitted, the visits will be loaded into an operational repository enabling reporting on and examination of the cycle's science program. With this understanding of the overall science program, S&OC engineers and calibration scientists will define the detailed requirements of the calibration program. While the Call for Proposals included information about the anticipated level of calibration, adjustments are made at this time to ensure that the most commonly used configurations are well calibrated.

5.7.1.3 The Phase 1 and Phase 2 Tool Set

MO-536 The STScI will provide the astronomical community a single, user-oriented interface for the entry and submission of Phase 1 proposals and Phase 2 visits. All Phase 1 proposals and Phase 2 visits - science, engineering and calibration - will be submitted using the same proposal and visit-planning tool. This tool will be based on the latest generation of tools developed for HST and will use terminology and language with which an astronomer would be familiar.

MO-537 For Phase 1, the tool will provide the ability to prepare the requisite entries for the review and selection process but will also provide information that will allow the user to compare different JWST instruments and configurations and to identify the best configuration for the science goal. The latest version of the JWST Astronomers Planning Tool (APT) will be available to the community coincident with release of the Call for Proposal and will include a special categories or features enabled for the observing cycle. The APT will allow users to completely define their visits during Phase 1 if desired

MO-538 During Phase 2, the APT must allow users to completely plan their visits ensuring that all entries are valid and complete. In order to ensure viability of their requested visits, users will be able to view the permitted orientations of the field of view, and exposure time calculators will be linked to appropriate models (e.g., zodiacal, thermal, scattered light backgrounds) as a function of target location and the orbit. Observers will be able to specify orientation requirements for individual visits including specifying a list of multiple possible orientations in priority order in order to improve planning flexibility. Users will also be able to specify timing constraints on a visit. APT will provide feedback to identify how the specified Observatory configuration, visit duration and visit timing and orient constraints interact to limit the scheduling of the visit over an observing cycle. The JWST APT will also depict the availability of scheduling opportunities for the entire program. Users will be able to optimize their time on target by presentation of a graphical representation of exposure times clearly delineated from instrument overheads, small angle maneuver times, etc.

MO-539 The JWST APT will prevent users from requesting incorrect configurations or inappropriate combinations of parameters. User diagnostics and error messages will clearly identify the source of the problem and possible corrective actions with an integrated context-sensitive help feature integrated into the tool.

MO-540 Once users are satisfied with the optimized layout of their visit(s), they will submit them to the STScI for ingest into the operational planning and scheduling system for JWST. The APT will prevent submission of visits with syntactical errors and serious diagnostics such as unschedulable visits due to conflicting observing constraints. The final submission process will also verify that the submitted program is within the allocated time for GOs.

MO-541 The submission process will automatically populate the operational planning and scheduling data repository with the visit specifications. No significant additional processing is anticipated although some technical or scientific review is likely to be required for a small number of irregular or anomalous cases.

5.7.1.4 Long Range Planning

MO-542 The purpose of a Long Range Plan (LRP) is to have a high-level optimized layout for all visits within a given period (nominally a one-year cycle) that can be used by observers and engineers to understand what observations are likely to be scheduled when and to identify portions the schedule that will be particularly resource intensive. When the majority of the anticipated Phase 2 visits are ingested into the operational environment the process of creating the LRP can be initiated. After the first JWST observing cycle, these new visits will be integrated with the existing LRP to gradually transition from one observing cycle to the next. While the cycle will have nominal start and end dates there will not, in practice, exist a hard date of transition. The LRP does not identify the specific order and time that visits execute, but rather defines windows in which visits can be scheduled to meet their observing constraints.

MO-543 Experience with HST has demonstrated that an effective means of ensuring highly efficient scheduling is to oversubscribe the scheduling timeframe with candidate observations. This allows the Observation Plan generation process to “pick and choose” from a larger suite of visits to optimize the contents of a weekly schedule. Assignment of longer plan windows allows flexibility in the planning and scheduling process providing for oversubscription of visits to the scheduling process.

MO-544 Operational studies of representative visits will be necessary to determine the optimum plan window duration for JWST to help achieve an overall science observing efficiency of 70% or greater and a 95% Observatory utilization rate during normal operations. The more tightly constrained a visit, the shorter the plan window even to the point of ending up with absolute time requirements. As these visits limit the process flexibility and will lead to observing inefficiencies the constraints must be driven by strong scientific need. Science and operational staff will be required to iterate with users to address unjustified, overly constrained visits.

MO-545 The geometric characteristics of the sunshield and the Sun Avoidance restrictions causes JWST to have a difficult relationship between target position (specifically ecliptic latitude), orientation flexibility, and the time and duration of the visit. These characteristics will force some observers to request specific position angles or "orients" for their visits. For NIRSpec especially, the possible orients may not be a single angular region. In these cases, following selection of the program in Phase 1, the observer will be given a specific orient at which to plan their visits during Phase 2 visit specification. Long range planning tools will be used to identify and provide the available orientation information.

MO-546 Once an operational LRP is developed, the plan windows for visits will be made available to the users. This will allow users to identify any science issues with the assignments and will allow them to develop their plans for receipt and analysis of their data. Only strong science drivers will be able to change an assigned plan window.

MO-547 The ideal operational environment could be conceived as one in which visits won't change once they are assigned plan windows in the LRP or at least the changes would be limited to those that don't affect plan window assignment. Experience of HST and other NASA observatories has shown this to be an unrealistic concept due to the dynamic nature of the Observatory, its instruments, our knowledge of optimum observing strategies, and even the Universe itself. While many visits won't change, events such as safe modes or visits being bumped from the plan for high priority Target of Opportunity visits can prohibit a visit from completing in its plan window and will require replanning. HST experience has demonstrated the need for an up-to-date, well maintained LRP for the purpose of maintaining an efficient overall plan. The JWST LRP will therefore not be static throughout the year; the operations team will continue to update the LRP with additions, deletions and modifications to the visit pool. Observations are removed from the planning process as they execute and new visits are added for Director's Discretionary Time GOs or activation of Target of Opportunity visits. New calibrations or engineering observations may be needed as well to address unexpected changes in the Observatory over time. The long range planning process and system must be able to accommodate changes in the visit pool with scientific oversight to ensure that maximizing overall mission science return remains the primary driver.

MO-548 The output of long range planning is population of plan window information for each visit in the operational database and provision of that information to the users. It ensures the availability of sufficient candidates visits to the Observation Plan generation process to achieve high observing efficiency. Long range planning will be useful in identifying and resolving conflicts between visits well before the building weekly Observation Plans. While the output product can be defined in simple terms, the process of creating it is one that must be dynamic and robust and driven by science needs of the users. Long Range Planning is also the process of keeping track of hundreds of visits to create a Long Range Plan that will enable science time on target more than 6500 hours per year.

5.7.1.5 Observation Plan Generation

MO-549 The final pre-observation activity performed using the Proposal Planning System is generation of the Observation Plan (OP), the sequence of visits that the OPE will attempt to execute on the Observatory. The OP will be constructed to minimize the chance for observation gaps to achieve a high overall scheduling efficiency. The OP must comply with all mission constraints, mission restrictions unless specifically waived and the constraints for each visit. For each visit in the OP, an earliest start time, latest start time and latest end time is provided and integrated with spacecraft and housekeeping activities to produce the complete script of activities for observation execution. The resulting Observation Plan will represent valid and safe activities and will be transferred to the Flight Operation System (FOS) for additional mission scheduling and uplink to the Observatory.

MO-550 Each OP is expected to last about 10 days and to be generated as close as possible to the planned execution time, consistent with ensuring that JWST will not exhaust the availability of observations before a new OP can be uplinked. Normally, OP generation will occur two to three weeks prior to execution.

MO-551 OP generation will start by accessing the operational database populated from Phase 2 visit processing and long range planning to identify candidate visits with plan windows that overlap the execution time window. As described earlier, more candidate visits than can possibly be scheduled will be identified from this process as oversubscription of the timeframe helps produce high efficiency. The OP generation system will start building an optimized JWST observing week that ensures that time critical and short time window (e.g., less than a week) visits are accomplished as required. The remainder of the OP will include visits selected to pack the week with science, engineering and calibration visits such that the OP meets the required science time on target efficiency criteria. The process of optimizing the observing week will not require human intervention but rather will be a function of the Proposal Planning System.

MO-552 The full duration of the OP will be longer than the time the next OP is planned for uplink. This is to provide for extra visits that can execute in the event that a visit(s) must be skipped due to instrument anomaly or failed guide star or target acquisition to ensure that execution efficiency is as high as scheduling efficiency. These extra visits will be non-time-critical and have a significant portion of their plan window remaining to minimize the risk of having to replan them to a significantly later timeframe.

MO-553 During OP generation, final guide star selections are made for each visit to enable accurate (1″, 1 σ) and stable telescope pointing (7 milliarcsec, 1 σ). This pointing stability will support the fine guidance performance required to meet encircled energy and wavefront error requirements. The guide star catalog is expected to be all-sky and of sufficient density to ensure at least a 95% probability of acquiring a guide star and maintaining pointing stability for any valid pointing direction. In order to support this, three guide stars will be selected for each visit, if available, so that if an acquisition attempt fails on the first candidate, the second candidate will be used and so forth.[29]

MO-554 Once the Observation Plan is filled with visits that require specific external pointing requirements (referred to as prime visits), the opportunity will exist to add a layer of independent visits without external pointing requirements that can be accomplished in parallel with the prime visits. These parallel visits will use a different instrument than the prime visits and will be included only as they do not interfere with or drive the scheduling of the prime visits.

MO-555 The Long Range Plan will identify and resolve many scheduling conflicts in advance, but some may not arise until generation of the Observation Plan. While optimizing the science efficiency of the OP will not require human interaction, resolving short-term scheduling conflicts will require science and operations expertise and resources. Best efforts will be made to ensure that all prime science programs and engineering and calibration visits are accomplished as required within the time and staffing available to the process. In the end, scientific judgment may be required to enable OP generation to proceed with the delivery schedule.

MO-556 While the OP will nominally provide for a 10-day schedule, the scheduling process and tools must be able to generate OPs of varying length and be able to intercept the executing OP at any point. These OPs will be used to interrupt the planned schedule to accomplish a Target of Opportunity visit(s), add engineering or calibration visits to address anomalies and to restart the observing process following Observatory safe mode entries.

MO-557 Throughout the planning and scheduling process, tools will be used to keep track of visits, assess Observatory efficiency and prepare programmatic reports.

MO-558 When the OP is complete and has passed all health & safety and validity checks, Observation Plan data will be transferred to the Flight Operations System (FOS) for inclusion in the uplink activities scheduled for a real-time contact with the vehicle. The Observation Plan data includes all information needed for uplink to vehicle that will be utilized by the JWST as it executes the Observing Plan on-board. Information is also included for engineering and calibration activities as required to support the scheduled observations either for the vehicle and/or for the instrument subsystems.

5.7.2 Flight Operations

MO-559 JWST ground operations are of two types: science operations that plan and conduct the JWST science program - observing celestial objects and gathering data - and flight operations that manage command and control of JWST to maintain the Observatory's overall performance.

MO-560 Science operations (covered in sections 5.7.1 and 5.7.3) hosts astronomers, evaluates and chooses observation programs, schedules the selected observations, generates the Observation Plan with associated schedules & products (which includes selected engineering and calibration operations activities), and stores and analyzes science data from the Observatory. Meanwhile, the Flight Operations Team (FOT) conducts flight operations from a Control Center from within the S&OC. The FOT interacts with the FOS to: (1) receive the Observation Plan (including schedules & products) from science operations planning; (2) to process engineering data and displays; and, (3) to manage flight & ground resources.

5.7.2.1 Mission Planning & Scheduling

MO-561 Mission Planning & Scheduling combines the Observation Plan (described in section 5.7.1) with scheduling for communication contacts with DSN; and, planning orbit and flight software maintenance activities such that housekeeping activities are performed without disruption of the science program. The FOT will develop detailed mission operations schedules to verify that all associated data needed to conduct safe and robust operations is available. The FOT must be able to quickly modify and validate mission operations schedules particularly during deployment and early operations and later during contingency operations. Early coordination with the DSN will be crucial to assure early prioritization of contacts with JWST.

5.7.2.2 Uplink Operations

MO-562 Commands to the Observatory can originate from the S&OC ("real-time" commands), or from the spacecraft bus or instrument processors ("stored" commands). In either case, the commands are initially generated/developed on the ground, and then transferred to the Observatory for real time or later execution.

MO-563 Uplink operations is the mechanism for transferring stored commands to the Observatory and commanding the Observatory in real-time. The process includes three basic subprocesses: Observation Commanding, Housekeeping Commanding, and Contact Support. Each of these suprocesses is described below. This section also concludes with supporting uplink operations concepts.

MO-564 Since, during normal operations, JWST is required to operate independently from the ground, the basic approach to operating the Observatory is through stored commands: either taking the form of the on-board Observation Plan file, visit files, and activity descriptions (ADs); or, stored command sequences (SCSs). As necessary, stored command activities will be supplemented by housekeeping commands (also known as "non-stored" or "real-time" commands).

MO-565 The FOT is responsible for the uplink and verification of all information required to update and maintain the Observatory. JWST is designed so that commands can be uplinked without interrupting OP execution. Successful onboard loading of stored commands and/or memory loads will be validated either through comparison of a ground master image with a dump of the onboard memory contents; or, through memory checksum compares.

MO-566 Access to JWST will be regulated to ensure that only valid and appropriate commands are uplinked. Contingency operations may require non-standard commanding with the system and process requiring a deliberate over-riding of controls.

5.7.2.2.1 Event-driven Operations

MO-567 The Observation Plan Executive (OPE) execution is initiated by ground command. It reads the Observation Plan, determines which visit to execute (based upon a time window associated with each visit), and waits to begin execution if necessary. When the time window constraints are met, the OPE reads the Visit File, and begins executing the Activity Description statements as organized within the Visit File. The Visit File contains structures that identify parallel sequences of activities to coordinate execution. The Observation Plan Executive will execute these parallel sequences as parallel threads.

MO-961 The OPE reads each Activity Description statement, and invokes the identified script using the provided parameters. The script will return execution status to the OPE which will be used to determine whether to execute the next Activity Description in the sequence, skip execution of the sequence, skip execution of the rest of the Visit, or stop execution of the Observation Plan.

MO-962 The Activity Description script will process the parameters passed to it by the OPE and invoke lower-level scripts with the appropriate parameters (including the scripts that construct CCSDS commands or request telemetry for subsystem status or command execution status). Flight software application commands are sent to the ISIM flight software for routing to the proper software module located within the ISIM or the Spacecraft processors.

MO-963 The event-driven system will establish a set of telemetry monitors to be supplied in telemetry packets by the JWST flight software. These will include telemetry monitors that provide certain subsystem status as well as telemetry monitors that provide execution status for all commands that can be issued by the event-driven system. After a script invokes a command request, it will check the execution status as given by the corresponding telemetry monitor in the telemetry packet.

MO-964 The OPE and the Activity Description scripts will create event messages to record their actions for the ground system use. Event messages are generated when an activity starts, when it completes (along with a completion status), and when activities are skipped.

MO-965 When the OPE completes execution of a Visit File (whether successful or not), the Visit File is deleted. Visit Files can only be read once by the OPE. They cannot be reused.

MO-966 While the OPE is running, the ground system can append to the on-board Observation Plan to provide seamless execution. The ground system can replace an unexecuted portion of the Observation Plan to support Target of Opportunity or anomaly recoveries. If required, OPE execution can be stopped by ground command.

5.7.2.2.2 Housekeeping Commanding

MO-569 Housekeeping Commanding is broken into the following subcategories: real-time commands, stored command sequences (SCSs), real-time command scripts, and memory upload commands.

MO-570 **Stored Command Sequences**. An SCS is a group of one or more stored commands used for time-critical stored commanding and executed by an onboard flight processor. Current defined uses for SCSs are onboard fault management response, Observatory Activation and Deployment, selected activities during commissioning, station-keeping Delta-Vs, and anomaly recovery operations. An SCS consists of stored real-time commands (Observatory hardware commands and flight software commands) and flight software commands that control the SCS. Stored real-time commands, when sent via the flight software command processing, will be routed to the specified destination as a regular real-time command as if transmitted from the ground. SCSs are predefined and/or reprogrammed by the S&OC.

MO-571 **Real-time Command Scripts**. Real-time Command Scripts are sequences of commands that are stored in the S&OC and issued by the ground during contacts. Real-time Command Scripts are used to command Observatory subsystems. The scripts allow a high degree of automation, with the assurance of pre-tested command operations that minimizes the chance of operator error. The command scripts are built in advance and verified using tools such as the spacecraft simulators, then controlled by configuration management (CM) and stored for operational use. The Common Command Telemetry System (CCTS) provides an interface to the command database to allow operators to create scripts using the command mnemonics of both the flight & ground systems. When the script is executed, the command bit structures are pulled from the command database and then transmitted to the Observatory or ground as required. The scripts provide messages, which give the status of the progress of the real-time commanding activity taking place, and will generally prompt the operator to "proceed" at logical "wait" points. The scripts can verify telemetry or ground system parameters, and can perform typical logic functions to branch, load data, etc.

MO-572 **Memory Load Commands**. Memory Load Commanding is a software-assisted load of the flight software to RAM memory of an on-board processor or EEPROM. Memory loads are necessary as a normal part of operations. Onboard databases, such as spacecraft ephemeris tables and star tracker databases, will require periodic update. Flight software bugs may also be identified and require update. The purpose of a memory load is to update the flight software resident in a JWST flight processor. Ground procedures will be used to construct JWST memory loads tailored to the destination computer's command format. Memory loads are broken into the following subcategories: Memory loads are broken into the following subcategories: Table Loads (data) and software patches (code).

5.7.2.2.3 Flight & Ground Procedures

MO-573 Procedures indicate to the human operator the manner in which operational management intends to have various activities performed. The intent is to provide guidance to the Observatory operator, to ensure a logical, efficient, safe, and predictable (standardized) means of carrying out the mission objectives. Each procedure provides the FOT crews with step-by-step guidance for carrying out the specific associated activity. Procedures are broken into the following subcategories: Ground Standard Operating Procedures (SOPs) and Flight SOPs.

MO-574 SOPs address nominal and routine operations, special operations, and maintenance. Contingency SOPs are established as well, which includes intermediate details and information necessary to evaluate progress through failure scenarios. SOPs are in the final stage of procedural development; i.e., these are flight ready procedures. It is important to note that real-time command scripts as well as any operation that results in commanding the Observatory and the ground segment are executed by the operator only when specifically called out by an associated Procedure.

5.7.2.2.4 Contact

MO-575 Typically, when one considers the contact phase of Observatory support, they think only of the period of time when up/down-link operations are performed. However, contact includes a short period of time prior to and after for Observatory support to configure resources, send commands, process and route Observatory SOH telemetry and mission data, monitor the status of S&OC and DSN hardware, and release of resources at the end of the support. Specifically, the contact support phase is comprised of three subphases: prepass, pass, and postpass. Each of these subphases is detailed below.

MO-576 Prepass - Fifteen to 20 minutes prior to the estimated time of acquisition (ETA-20) is the timeframe allocated to prepass. During this time the automated processes of the S&OC and DSN ground terminal configure resources, establish data nets, and otherwise prepare for the operational support. These activities continue until complete or until the antenna locks on to the signal being transmitted from the Observatory.

MO-577 Pass - Once the DSN antenna begins conscanning operations the Observatory's downlink signal the pass phase of operations begins. Pass is the actual time that the antenna is being used to support an Observatory operations function. During pass the automated processes of the S&OC transmits Observatory commands per the Contact Support Plan. These commands are routed to the supporting DSN ground terminal and uplinked to the Observatory. Status of the DSN ground terminal equipment is relayed to the S&OC Flight Operations System (FOS) via the DSN Monitor Block once every 5 seconds. Observatory tracking data (range, range rate) are computed and routed from the DSN ground terminal to the GSFC Flight Dynamics Facility (FDF). Telemetry data, transmitted from the Observatory is received at the DSN ground terminal, demodulated, recorded, and retransmitted to the FOS via the JNSS. These activities continue either until the Observatory passes from view of the supporting DSN ground terminal or until contact activities are otherwise terminated.

MO-578 Postpass - Once communication with the Observatory is terminated, the postpass phase begins. Postpass involves an assessment of the success of the contact by the automated processes of the S&OC and DSN ground terminal, confirmation of the next scheduled contact between the FOS and DSN ground terminal, and returning the range resources to control of the DSN. Postpass also includes activities to ensure the successful transfer of recorded science and engineering data from the DSN to the S&OC.

5.7.2.3 Downlink Operations

MO-579 Downlink operations are initiated when the DSN establishes contact with the Observatory. Downlink operations are constrained by the assigned number of contacts per day and the duration of each contact.

5.7.2.3.1 Telemetry Data Management and Monitoring

MO-580 Telemetry generated by the Observatory is classified into two types:

- **File Data** - File data consists of any data maintained or recorded in on-board memory and downlinked during a ground station contact. File data sub-types include recorded science data generated by the science instruments, recorded guiding data generated by the fine guidance sensor (FGS), recorded engineering data (e.g., voltages, temperatures, mechanism positions, relay status, etc.), tables, event data, software code, file directories, etc.

- **Real-Time Data** - Real-time telemetry consists primarily of the engineering data streams generated by the ISIM element and the spacecraft element, which are merged into a single stream for real-time downlink.

MO-581 File data are initially Level-0 processed by DSN before routing to the Flight Operations System (FOS). More on file data management is presented in section 5.7.3.

MO-582 Real-Time data are routed to the Flight Operations System (FOS). Real-Time data are essential for monitoring the health and performance of the Observatory. Upon receipt of Real-Time data, the FOS will perform decommutation and conversion to engineering units for automated analysis and for display during FOT shift coverage.

MO-583 Critical Observatory events requiring ground action are reported in event flags within the Real-Time data. Ground software automatically searches for event flags and notifies support engineers as required. Additionally, Observatory event data are processed and also automatically searched by ground software; notifications will be sent to support engineers as required. The ISIM event messages will also record which visits executed and which were skipped. This log will be processed and automatically searched by ground software.

MO-584 The Flight Operations System will have a readily accessible engineering data store capable of holding approximately one month's worth of engineering data to support rapid access for trending and analysis. The complete engineering data will be stored in the Data Management System archive as described in section 4.5.1. Tools for analysis and trending of engineering parameters are expected to exist in the Flight Operations System and be capable of retrieving data from the Flight Operations System data store or the Data Management System archive.

MO-586 High quality, stable image quality is critical to nearly all aspects of the JWST science mission. Flight experience will determine the period over which the optical quality will remain stable with corrections to the telescope on a routine basis anticipated. A special purpose Wavefront Sensing and Control (WFS&C) system will manage the primary mirror surface figure. It ingests science and engineering data related to wavefront monitoring observations and outputs a primary mirror actuator update request. The request will be reviewed, and if approved, sent to the Flight Operations System for uplink.

5.7.2.3.2 Engineering & Trend Analyses

MO-587 The Flight Operations System will automatically produce trending reports and other analysis products needed by the FOT for monitoring the health, performance and use of the spacecraft. All engineering data monitoring and analysis tools will reside in the Flight Operations System rather than the Data Management System. The Flight Operations Team and Observatory engineers will be able to define routine analysis scripts that run when data are received to produce derived output products for review. Processing will be done “on demand” for spacecraft monitoring, routine queries, trending analysis, retrievals, and reprocessing. Here, “on demand” means at the request of a user or an automated engineering data processing script. All engineering and trending tools must be able to retrieve and process data from the Flight Operations System data store and the Data Management System archive.

5.7.2.4 Ground System Control Operations

MO-588 The FOT is not only responsible for commanding the Observatory but also for controlling the ground resources to implement the mission schedule in support of science data collection and delivery. The S&OC includes functional components to provide the FOT with the capability to monitor and control ground operations, rapidly detect and isolate faults, initiate corrective actions as documented in operations procedures, and report system performance.

MO-589 The FGS provides the capability to either automatically or manually control ground hardware in support of science data collection and delivery. Ground operations software agents reside locally within the FOS to interface with and control the local ground hardware.

MO-590 Ground operations software also includes tools to aggregate the status and control of this equipment and display this information to the FOT crew and the local maintenance personnel at the S&OC. The Ground operations software provides the S&OC with the capability of remotely and automatically controlling space to ground contacts via the mission schedule.

5.7.2.5 Flight Vehicle Simulator Concepts

MO-591 Observatory simulators are required capabilities of the FOS. Two simulators will be integrated into the S&OC: a Software Telemetry Simulator (STS) and a high-fidelity Observatory Test Bed (OTB). The STS provides a software-based high fidelity spacecraft simulation in any of the on-orbit spacecraft bus configurations. A science instrument simulation is provided in the STS. The STS is a tool used in place of the Observatory for executing scenarios for training, emergency procedures, and limited flight and ground software test and validation. The fidelity of the STS will be sufficient to allow AD (onboard script) testing against the flight software applications.

MO-592 The OTB incorporates engineering test units of flight hardware and will simulate the entire operation of the Observatory at a high level: Observatory commands and observation plans received by the OTB will result in simulated Observatory activities and associated telemetry and data. The OTB may also be used in place of the Observatory for executing scenarios for training, emergency procedures, and flight and ground software test and validation; but also provides validation capability for all uploads to the programmable on-board processing elements.

5.7.2.5.1 Simulator Operation

MO-593 Both the STS and OTB will be capable of providing health and status telemetry which is functionally equivalent to flight telemetry representing the simulated operating conditions including response to commands (all spacecraft bus commands and limited payload commands in the case of the STS; with all commands for the OTB). Communications links are emulated and static science data generated to exercise the simulated data management. Each simulator will be configurable to any orbit configuration for spacecraft and science payload simulations.

MO-594 Both the STS and OTB are capable of being configured into one of two modes for command and telemetry formats: Standalone or Laboratory. This will allow operation of the STS & OTB with or without the C&T front-end processors. In Standalone mode, the STS & OTB will accept commands in application packets from the CCTS, and produce telemetry application packets, which the CCTS can process. This mode will bypass and the hardware front end processors. In the Laboratory mode the STS & OTB will accept commands and produce telemetry, as would the Observatory being simulated. Commands will use the CCSDS COP1 protocol. Real-time telemetry will be transmitted in CCSDS CADUs. The OTB will provide a CFDP downlink capability, however, static fill pattern data may be provided as simulated science data (**TBR**).

MO-595 In addition to these modes, the STS and OTB will provide selectable operating speeds of real-time and twice real-time. The faster than real-time operation will be used to accelerate a simulation to shorten less interesting periods of the simulation for more efficient training.

MO-596 The STS and OTB will provide a simulation management interface allowing configuring the initial conditions for a simulation including:

- Spacecraft and payload processors and simulation processors with ephemeris, attitude data, battery state of charge, etc.
- Orbital parameters at a specified epoch
- Fault conditions
- Spacecraft and avionics configuration

MO-597 The STS and OTB may also be synchronized with external events by launching a desired scenario at a specific time. Anomalies may be inserted into scenarios at arbitrary or scheduled times. Finally, this control interface provides the ability to pause and restart at the time of the pause or at a future time.

MO-598 The STS and OTB simulators will be used for the following functions, but not limited to:

- Flight activity description, flight real-time script, and flight real-time procedure development and testing
- Ground System I&T ground-to-flight interface testing
- Pre-launch operations staff training
- Post-launch trouble-shooting and maintenance tasks

5.7.3 Post-Observation Operations

MO-599 Post-Observation Operations are those activities that are accomplished through use of the Data Management System (DMS). The JWST DMS and associated operations are responsible for archiving all of the science and engineering data received from the JWST and distributing that data to all of its various users. The DMS will serve as the permanent store of important mission operations data like orbit products, mirror figure adjustments, event data, etc. that should be recorded over the lifetime of the mission.

MO-600 Once JWST has completed an observation and the flight operations system has captured the data, the data management system will process and archive the science and engineering data and notify users that it is available for distribution.

MO-601 JWST data will be protected from catastrophic failure (such as physical destruction of the online data store) by creation of an offsite, protected environment safe store. Automated processes and data tracking mechanisms will ensure quick and effective creation of removable media copies.

MO-602 Engineering data processing is performed in the Flight Operations System as discussed earlier in section 5.7.3 with the JWST archive providing only for the long term storage and retrieval of data. The science data management process includes all aspects of processing and storage and is described as levels of processing as depicted in Figure 5-3 Science Data Processing Levels.

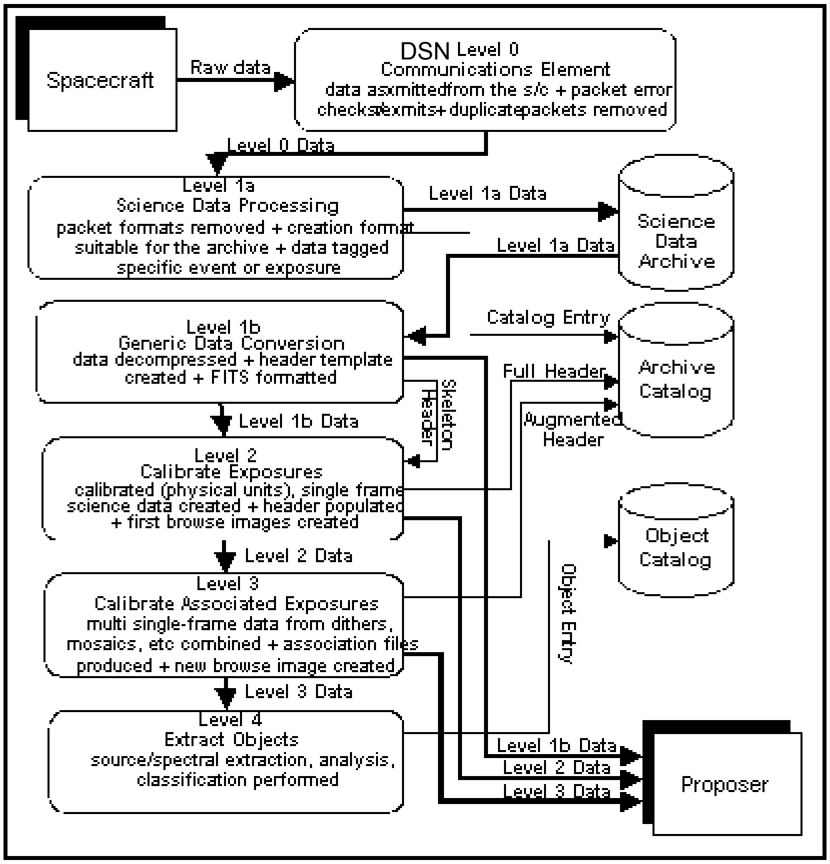


Figure 5-3. Science Data Processing Levels

5.7.3.1 Engineering Data Management

MO-603 The spacecraft event data, ISIM event messages and engineering data stream will be downlinked and processed in the Flight Operations System as described in section 5.7.2.3. These data will be stored in the Data Management System archive in the Level 0 data format, and can be retrieved for processing by the Flight Operations System if it is necessary to obtain archived engineering data for analysis or anomaly investigation. Components of the FOS will be used in the Data Management system to extract telemetry data needed for science data calibration from the Level 0 data format and convert to engineering units using PRD-defined conversions. This data will be archived by the Data Management Subsystem in a format convenient for extraction and use in the generation of calibration reference data, the calibration of science data, and the generation of science data products. This data will be available for distribution in order to provide relevant information about the Science Instruments and Observatory during the science exposures.

5.7.3.2 Science Data Management

MO-604 Science data from the JWST instruments are stored onboard the Observatory and downlinked via a DSN contact as described earlier in section 5.7.2.3 completing the Level 0 processing from Figure 5-3. The science data are then processed through the Flight Operations System and forwarded to the Data Management System for processing and archival. Upon request, the data are retrieved from the archive, processed and sent to the requestor.

MO-605 The Science Data Management System must provide for user access to JWST data within five days of receipt. Unless high quality science data are delivered to the community, the mission serves no purpose. High quality data constitutes complete data sets that have been calibrated to remove instrumental signatures and other artifacts of space observing (e.g., cosmic rays).

MO-606 The JWST science archive will include all exposures over the life of the mission and will be the source for all science data processing. The archive must be large enough to handle the peak data volume of approximately 229 Gbits/day[30] (MR-317). Science data will available for delivery to the observer within five days of observation execution. The science data from many of the JWST GO and GTO programs are expected to be proprietary to the science team for a period of one year then will be made public for use in archival research to registered archive users.

MO-607 Science data will be processed upon completion of the transmission to the S&OC in order to confirm the integrity of the data and to produce the meta-data required for the archive catalog (MR-307). Meta-data includes the archive catalog entries, a preview product for display with the archive catalog browser, an object catalog, and for NIRSpec data, an image map. In addition to the most recent calibration files, the archive will contain a historical record of the calibration files and parameters used to characterize the data (MR-308); this will enable users to understand how changes in the calibration have affected the reduced data. Science data processing will be done on demand for standard science data production, routine queries, archive retrievals, and reprocessing requests (referred to as On the Fly for HST) (MR-315). Files will be delivered to users in FITS-compatible formats (MR-314) so that users can access the data with a wide-variety of analysis software. This approach provides the science user with the most up-to-date processing, including the most accurate calibration files, with which to begin analysis. It also obviates the need for massive recalibration efforts and provides for a smaller archived data volume, as the calibrated data products are not included in the archive. Protections (based on account name) will exist to distribute data to authorized users (MR-316) until proprietary periods have expired. The science data management architecture will however support the distribution of public data to mirror versions of the archive in Europe and elsewhere if that is necessary (MR-310)

MO-608 The JWST ground system will identify each science exposure according to a header, called the science header, which the flight software has prepended to the data for that exposure. This header will uniquely identify each exposure and include links to the observation. There will be no engineering snapshots included with the science data stream. The engineering data stream will be transmitted to the ground before the correlated science data stream for the exposure and the ground system will use timestamps and unique identifiers to correlate the science data with the engineering data stream and combine the two streams for science data processing.

MO-609 Guide star acquisition images will be downlinked separately from the event data and science telemetry and will be stored in the science archive.

MO-610 Science data processing support functions include data decompression, standard calibration processing and data formatting and long-term data archival. The system will perform an automated data quality assessment to assess the completeness of the data set and that it has successfully completed routine processing. Linking and co-processing associated images and the automated source extraction and construction of object catalogs will enhance the quality of the science data. Once the data are archived, the JWST user will be notified that data are available for retrieval. JWST users will retrieve data electronically from the archive and JWST data will be retained online to provide users with quick data access given the need for reprocessing.

MO-611 The S&OC Data Management System includes a science data processing pipeline that is used in Level 2 processing to perform standard calibrations. Standard calibrations vary by instrument and mode and include removal of instrumental signatures such as detector noise and irregularities. Information on general Calibration Strategies and specific Instrument Calibration modes were discussed earlier starting in section 5.3.4. STScI Instrument Scientists Data Analysts performing as JWST Calibration Scientists and Analysts will obtain and analyze science data and engineering data when required to create reference files in the JWST science data processing pipeline. These references files are initially populated with ground-based test results and updated after launch as flight data becomes available. They are updated routinely in flight as Observatory and instrument signatures and sensitivities change. The Data Management System and S&OC processes and procedures will provide for the updating of calibration reference files such that the latest information about the Observatory are available to the community and applied to the data processing.

5.7.3.3 Grants Management & Administration

MO-612 NASA will support the analysis and publication of JWST science by U.S. General Observers and Archival Researchers (GO/AR) via a grant program administered by the STScI. The JWST process and system will be customer-oriented and based upon the successful HST program. The JWST Grants Management System (GMS) will provide a means for grant proposers/recipients and administrators to submit, access, and track their STScI administered JWST grants from their home sites. Tools will also be available to enable efficient and accurate reporting and tracking of grants by the STScI.

MO-613 Grants are awarded to General Observers and Archival Researchers and only those selected and approved enter the Grants Management System and process. GOs and ARs will submit budgets describing the science program monetary needs to successfully analyze the data and publish the results. These requests generally include identification of staff, hardware, software and travel and are submitted for each member of the team receiving financial support.

MO-614 The STScI will convene a JWST Financial Review Committee (FRC) similar to that in use by the STScI for HST. The FRC includes financial, administrative and STScI-internal and external science members. This diverse group is required to assess the compliance of the request with Federal regulations and STScI policies and the reasonableness of the request based on precedence and the understanding of the needs from a science viewpoint. The community must view the FRC as fair and equitable and is viewed as complete and correct by comptrollers and auditors. The FRC is an advisory board to the STScI Director who serves as the authorizing official on JWST GO and AR grants.

MO-615 For GOs the grant submission and review process generally occurs after Phase 2 Visit Specification and receipt of science data. This ensures the science team has the resources required to analyze data during the nominal one-year data proprietary period. ARs are utilizing existing, non-proprietary data from the archive and are free to retrieve the data at any time. We anticipate that only one FRC review will be held to ensure a consistent approach is taken with GOs and ARs. JWST grants will generally be awarded for a standard duration, e.g., 3 years, to provide sufficient time to complete the analyze and publication process. The GMS and administration process will be able to handle grants of varying duration including the ability to extend a grant period, allocate additional funds, or terminate a grant early and return unspent money to the grant pool.

5.7.4 Project Reference Data Management

MO-616 The Project Reference Database (PRD) is the configuration-controlled source of command and telemetry formats and definitions used during development, integration & test and operations of the JWST Observatory and Ground Segment. The PRD includes definitions and descriptions of commands, command parameters, health and safety limitations, related telemetry verifiers, and command sequences and scripts. The PRD includes definitions and formats of telemetry monitors, location in telemetry stream, parameters for conversion to engineering units, health and safety limits, and display page formats. The PRD includes constants that define spacecraft characteristics, ground system characteristics, and constants that define constraints, restrictions and operational limitations. The PRD will contain any constant data that is needed for operation of the Observatory or Ground Segment.

MO-617 The PRD Subsystem (PRDS) will provide configuration control, change management, verification and distribution of the PRD. The PRDS will consist of a set of PRD Tools and a central PRD management system. The PRD Tools will be integrated with the Common Systems (CS) and distributed to development and I&T facilities for local management of PRD data (submission to and retrieval from the central PRD). The central PRD Management System will manage the PRD during development, integration and test, and operations. PRD data will be submitted to the PRDS by development organizations for configuration control, and the PRDS will track validation and certification of the data during I&T. The combination of a common Command and Telemetry System and a central PRD management system ensures compatibility between the I&T and Operations environment and permits validation and certification of PRD data during I&T without the need to convert, validate and certify the data with a separate process for operations.

MO-618 The centralized PRDS concept will enable the rapid update and distribution of data when needed while providing for a rigorous configuration control and data certification process. The PRD is accessed throughout the S&OC and is distributed to other users as needed. In a development and testing mode, developers of the flight and ground systems will have an efficient and reliable means to create or change parameters within the PRD to support specific tests. At the same time, versions of the PRD will be baselined, validated, and deployed throughout the JWST project as the certified set of parameters for use in operating the ground and flight systems.

5.7.5 JWST S&OC Operations Staffing Profiles

MO-619 The STScI provides the science and mission operations staff required to operate the JWST S&OC ground system. The STScI include staff performing work on other missions with some members shared across multiple missions. Specific organization charts and precise staffing numbers should not influence the overall mission operations concepts and requirements and it is not prudent to invest too much into defining these details at this time. However, as cost effectiveness and containment is an aspect of the mission, we present here some general profiles and needs of different science and flight operations teams within the STScI S&OC. Projected staffing numbers in this version reflect the early state of the mission and supporting systems design. We discuss the core competencies required to accomplish the tasks and the features of the mission and systems that will drive resource allocation.

5.7.5.1 Science Operations

MO-620 The STScI operations staff performs the functions related to accomplishing the JWST science program through operation of the PPS and DMS. These activities include

Phase 1 and Phase 2 development support, generation and maintenance of the Long Range Plan and Observations Plans, and science data processing and archiving and subsequent data analysis support. Science operations will include science and technical staff specifically trained to operate the ground system elements for the JWST mission. The number of staff required is dependent on the complexity of the Observatory and observing constraints and the manual intervention required to transition between S&OC processes and systems. The intent is to ensure that people resources are expended on value-added tasks with all routine tasks accomplished automatically. This includes the ability to meet the mission efficiency and data delivery requirements. The Science Operations staff will routinely support an 8-hr/5 day shift including:

- Program Coordinators: provide user support during Phase 1 and 2 and Long Range Planning
- Science Schedulers: resolve conflicts and problems during Long Range and Observations Plan generation
- Data Processing & Archive Specialists: ensure integrity of science data through processing, archive & distribution to users
- Instrument Scientists: ensure proper operation and calibration of Science Instruments.

5.7.5.2 Flight Operations

MO-621 The Flight Operations staff will operate the FOS, the integrated software and hardware system that supports flight operations for JWST for both routine and contingency operations. They are responsible for real-time functions such as ground system and ground station configuration for real-time spacecraft contact, telemetry monitoring, real-time command uplink, data capture and initial processing. Flight Operations with technical support from the Engineering and Science Instrument staff, will perform off-line functions such as monitoring and trending of Observatory subsystems and science instruments.

MO-622 During normal, routine operations, the Flight Operations staff will support 8 hr/5 day shifts (MR-289). The Flight Operations staff on the order of a dozen people will include operations and technical staff trained and certified in the operation of the JWST including:

- Operations Manager
- Instrument and Spacecraft Controllers
- Mission Planner
- Data Management Analyst
- Flight Software Analyst and Technical Manager
- Control Center Operation Engineer.

MO-623 Single shift operations is contingent upon the ability of the Observatory (MR-272) and ground system (MR-320) to protect the health & safety of the mission without human intervention, to autonomously manage data downlink contacts and to provide a mechanism for notifying Flight Operations staff in the event of an anomaly. During early operations, the Flight Operations staff will be augmented by NASA-supplied staff to support 24 hr/7 day operations including:

- Science Instruments Analysts
- FGS Analyst
- Spacecraft & Subsystem Analysts
- Ground Network Controllers
- Ground Station Engineers

5.8 LAUNCH AND EARLY OPERATIONS

MO-624 Launch and early operations (L&EO) include the time period when the Observatory is launched, activated, checked out, calibrated, and commissioned prior to normal operational use. L&EO begins with pre-launch activities and ends when commissioning has been successfully completed.

5.8.1 Pre-Launch

MO-625 Pre-launch operations begin with approval to ship JWST to the Guiana Space Centre (CSG), in Kourou, French Guiana. It includes shipping preparations and transportation, integration of the launch vehicle and upper stage, functional testing and checkout of the space and ground segments of JWST at the launch site, and ends with the start of the final countdown for the actual lift-off of JWST.

MO-626 This section will describe specific pre-launch operations which are performed to prepare the Observatory for launch and on-orbit operation. The major activities to be performed are:

5.8.1.1 Observatory Limited Functional Test

MO-627 At the CSG's specified spacecraft preparation building, a limited functional test will be performed to verify selected electrical parameters and demonstrate that transportation or handling has not adversely affected the Observatory. Testing will be controlled from the CSG via I&T EGSE that was shipped with the Observatory; however, remote monitoring of the Observatory is accessible from the S&OC.

5.8.1.2 Observatory Ground Station End-to-End (ETE) Compatibility Test

MO-628 S&OC/DSN ground terminal compatibility tests are performed to confirm earlier tests at Space Park that the Ground Segment can perform real-time command and control of the Observatory and that telemetry can be received, processed and displayed in the S&OC.

MO-629 Using a subset of the on-orbit operating procedures, the S&OC will generate and transmit commands to the Observatory and receive Observatory telemetry to verify compatibility of processing software and display capability. Test results will be compared with performance data measured during earlier integration system tests. In addition, these tests will confirm authentication process.

MO-630 Complimentary tests to completely verify ETE functionality may include S&OC link tests through each of the supporting ground stations. These tests route commands and telemetry through JPL to CNES, ESOC, and DSN ground stations and back to Observatory simulators resident at the S&OC. As in the case of the Observatory Ground Station ETE Compatibility Tests, these tests will demonstrate that the Ground Segment can perform real-time command and control of the Observatory and that telemetry can be received, processed and displayed at the ground segment, while utilizing CNES & ESOC ground assets.

5.8.1.3 Final Testing at Launch Complex

MO-631 A final aliveness test is performed on the Observatory following Observatory to Ariane 5 mating to verify that key parameters have not changed due to transfer/hoisting operations. Interface verification tests and mission simulation tests come next. Followed by formal readiness/data reviews. NGST/Arianespace/U.S. Government will certify the launch vehicle and Observatory as launch ready. During the countdown (L-12 hours), NGST will monitor Observatory telemetry via an umbilical connector until liftoff. Observatory telemetry will also be monitored remotely at the S&OC.

5.8.1.4 Rehearsals

MO-632 Mission Rehearsals are conducted as scheduled for verification of mission readiness to support Launch and Early-Orbit (L&EO) operations. Rehearsals utilizing Observatory simulators are used to demonstrate the readiness of the Mission Operations Team (See section 5.7.2.2), DSN, and launch operations teams to support Launch and Early Operations.

MO-633 An L&EO training team (known as Training Observers and Directors; TOADs), comprised of specialists with extensive operational backgrounds, coordinates the overall L&EO training activities. TOADs are responsible for generating launch training scenarios, conducting the Mission Rehearsals, and participating in the evaluation of the L&EO participants. During these training sessions, TOADs use the Observatory simulators for simulating the Observatory, as well as ground hardware support specialists to implement ground station contingencies.

MO-634 A mission operations team (MOT), comprised of launch operations specialists, Observatory (spacecraft and science instrument) specialists, and the S&OC's flight operations team (FOT) personnel, will be responsible for command and control of the Observatory during the L&EO operations.

MO-635 MOT members are assigned approximately 6 months prior to launch. In preparation for L&EO activities, the MOT participates in launch & deployment simulations to familiarize them with all related aspects, nominal and non-nominal, of the L&EO operations process. During these simulations as well as the actual launch, the MOT is collocated at the S&OC to facilitate the efficient coordination throughout the team.

MO-636 Training classes prepared by spacecraft, launch vehicle, and science instrument specialists are conducted to update all team members with operational information or provide information outside their fields of expertise.

MO-637 The TOADs conduct combined crew training with the regular operation crews and launch support staff prior to launch. Combined crew training exercises consist of three distinct types:

- A series of Operational Readiness Exercises (ORE) primarily for the FOT crews
- A series of Launch Readiness Exercises (LRE) for the MOT crews
- A series of Inter-Center Exercises (ICE) for all centers involved in the launch and ascent phase

MO-638 These exercises are coordinated from the S&OC with participation by select Centers. Participation with the Backup S&OC facility (**TBR**) is not required because the Backup S&OC facility is not used for launch and early orbit.

MO-639 The ORE allows FOT personnel to train on S&OC equipment using the simulation of an operational on-orbit Observatory and to practice operational scenarios with other S&OC personnel. Crews are exercised in on-orbit nominal and contingency situations, using the primary and support systems at the S&OC, and will verify mission operations procedures. Each crew demonstrates its operational readiness in a final series of formal scenarios culminating in the formal dry run of the test known as the Operational Readiness Demonstration (ORD).

MO-640 The LRE is used to dry run the MOT crews. LREs are used for team building, launch & early mission procedure validation, crew assignment verification, and to validate supporting S&OC equipment. The intent is to have the MOT prepared prior to the inclusion of external launch centers for the first ICE. At the end of the training period, a formal dry run known as the Launch Readiness Demonstration (LRD) proves that the MOT crew, launch & early mission procedure checklists, and S&OC are ready for L&EO activities. The first LRE occurs 6 months prior to launch to allows time to fix any S&OC deficiencies before a pre-launch freeze of the S&OC takes place. The final

LRD typically occurs about three weeks prior to the scheduled launch. While the LRE/LRDs are segmented according to the MOT crew structure, the teams are cross-trained in the event that early mission events shift in time due to anomalies or unforeseen events. Each crew is rehearsed in operational procedures, contingencies, as well as interaction between crews at shift changeover. Training emphasis is on those periods of the launch timeline involving greatest crew activity.

MO-641 The ICE exercises all launch center (program management, spacecraft and science instrument specialists, ground segment specialists, routine flight operations team members, and launch support segment specialists) participants at their interfaces, beginning at the final pre-launch phase (countdown) through ascent phase. ICE objectives are as follows:

- Exercise communications interfaces, who talks to who, when and when not to talk over the voice loops, voice loop protocols, etc
- Develop basic awareness of the pre-launch, launch, and ascent environment
- Develop awareness of the Launch Commit Criteria (LCC)
- Understand launch holds for instruments and consequences
- Exercise nominal and contingency launch procedures

MO-642 The final ICE is a formal Dress Rehearsal (DR) of launch and ascent. This also occurs approximately three weeks prior to launch. The LRD is typically part of the DR. The ICEs emphasize coordination and communication between centers. Introducing anomalies, which affect all the centers involved, stressing the crews with conditions requiring smooth and efficient cooperation, does this.

MO-643 All training exercises include initial briefings, on-console training exercises, a critique following each exercise, time between a series of exercises to revise procedures and correct deficiencies, a final demonstration exercise, a final critique, and time to make final adjustments prior to launch.

5.8.2 Launch

MO-644 Launch operations begin at countdown to liftoff, continues through initiation of Observatory low rate communications, and ends after Observatory separation from the launch vehicle (LV) when attitude stabilization is achieved using thrusters. The first 12 hours of the launch time line are shown in Figure 5-4. The overall deployment and insertion into final orbit around L2 is shown in Figure 4-1.

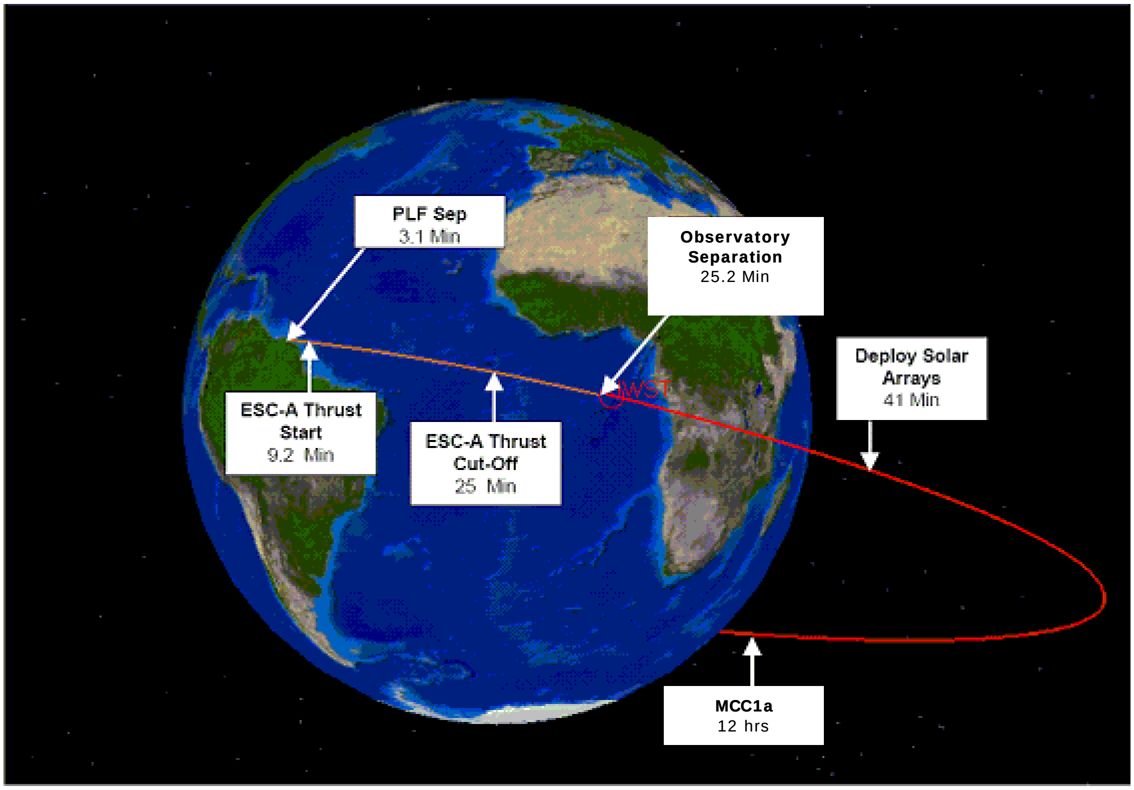


Figure 5-4. Activities during Launch and Early Ascent

5.8.2.1 Communications Plans

MO-645 The current planned ascent trajectory results in the first available DSN ground contact with JWST at Launch+55 minutes. It is critical to ensuring successful activation that a communications plan be established which provides JWST command & telemetry during this important first hour of JWST operations. This section delineates the communication plan options currently being explored.

MO-646 CNES/ESOC. The communication access for JWST via the ESA ground network option provides uplink/downlink access to JWST both while on the LV and following separation from the LV to the start of DSN access (100% coverage).

MO-647 TDRSS. JWST communication access is available via two TDRSS space vehicles. TDRSS GN Mode provides forward/return link access to JWST both while on the LV and following separation from the LV to the start of DSN access.

5.8.2.2 Launch Operations

MO-649 After the Observatory has been integrated with the LV (see Figure 4-18), and prior to the launch, the Observatory is powered to a minimum configuration on the primary side (remaining equipment is off for launch). Such a pre-launch configuration provides sufficient visibility into select Observatory systems during the ascent and for deployment activities with maximum utility.

MO-650 Observatory telemetry to monitor vehicle status will be provided during launch and injection. Transmission of telemetry during this phase will be via the JWST Communications Subsystem. Observatory telemetry transmission to (a) TDRSS assets and (b) ground monitoring stations will be used to the extent practicable during the injection phase. As mentioned above, real-time command and telemetry via TDRSS, CNES, ESOC and Deep Space Network (DSN) ground stations will be used during launch, ascent, separation, and early-orbit activities of the JWST Observatory. After separation from the LV, appropriate deployments shall be initiated by ground command, with exception of Solar Array Deployment which will be initiated autonomously by an on-board sequencer.

MO-651 Once successful RF communications are established (following Payload Fairing (PLF) Separation), an assessment of Observatory state of health (SOH) is performed and any necessary corrective action is taken. Real-time telemetry continues to be downlinked and processed in the S&OC. From these data, the JWST Science & Operations Center (S&OC) element produces real-time plots, statistics files, and archive files for data analysis. The history files and all off-line data collected during this phase are stored in the S&OC for the remainder of the mission.

MO-652 The injection profile shall be designed such that JWST separation from the launch vehicle occurs while in view of a real time telemetry and command capability (either TDRSS or ESOC; Malindi (Kenya) ground station resource).

MO-653 MO-653 The LV standard clampband separation system (ACU 2624) provided by Ariane will be used. Separation initiation and breakwire confirmation will be provided by the LV.

MO-654 After separation from the launch vehicle, critical events shall be initiated while in view of real time telemetry and command capability. Critical events include such activities as: (1) solar array deployment, (2) Delta-V burns, (3) sunshield deployment, and (4) telescope deployment. **Note** that Solar Array Deployment has been classified as a Time-Critical Event. A Time-Critical Event is an event identified by the JWST Team that if missed may result in either a lost or severely degraded mission. As a result, solar array deployment will be initiated by an on-board autonomous sequencer regardless of whether the ground is in communications contact with JWST or not.

MO-655 The launch phase ends after separation of the Observatory from the LV at the pre-determined attitude when attitude stabilization is achieved using thrusters. Observatory separation is initiated autonomously from the LV. Separation is also commandable from the S&OC (either via TDRSS or ESA/CNES Malindi uplink station).

5.8.2.3 Launch Teams

MO-656 The launch service contractor/Government launch team at the CSG conducts the launch countdown. JWST managers with the authority to provide go/no go recommendations for launch are located at the CSG during the countdown and launch. These managers have access to communications networks to coordinate with JWST project managers, operations and engineering teams at the S&OC and the NGST factory during the countdown. The countdown proceeds to liftoff if the Launch Director, launch service contractor, JWST Project, and Ariane-5 launch teams all agree that there are no impediments to launch. Each of these responsible launch teams is required to provide a final go prior to launch.

MO-657 A mission operations team (MOT) (see Figure 5-5), comprised of launch operations specialists, Observatory (spacecraft and payload) specialists, and the S&OC's flight operations team (FOT) personnel, monitor satellite systems during the countdown to verify the health and launch configuration for all systems. The Observatory is commanded to final launch configuration and switched to internal power a few minutes prior to liftoff. NOTE: various Observatory subsystems may be powered on or turned off in order to provide protection from the launch and ascent environments or to comply with other specified requirements.

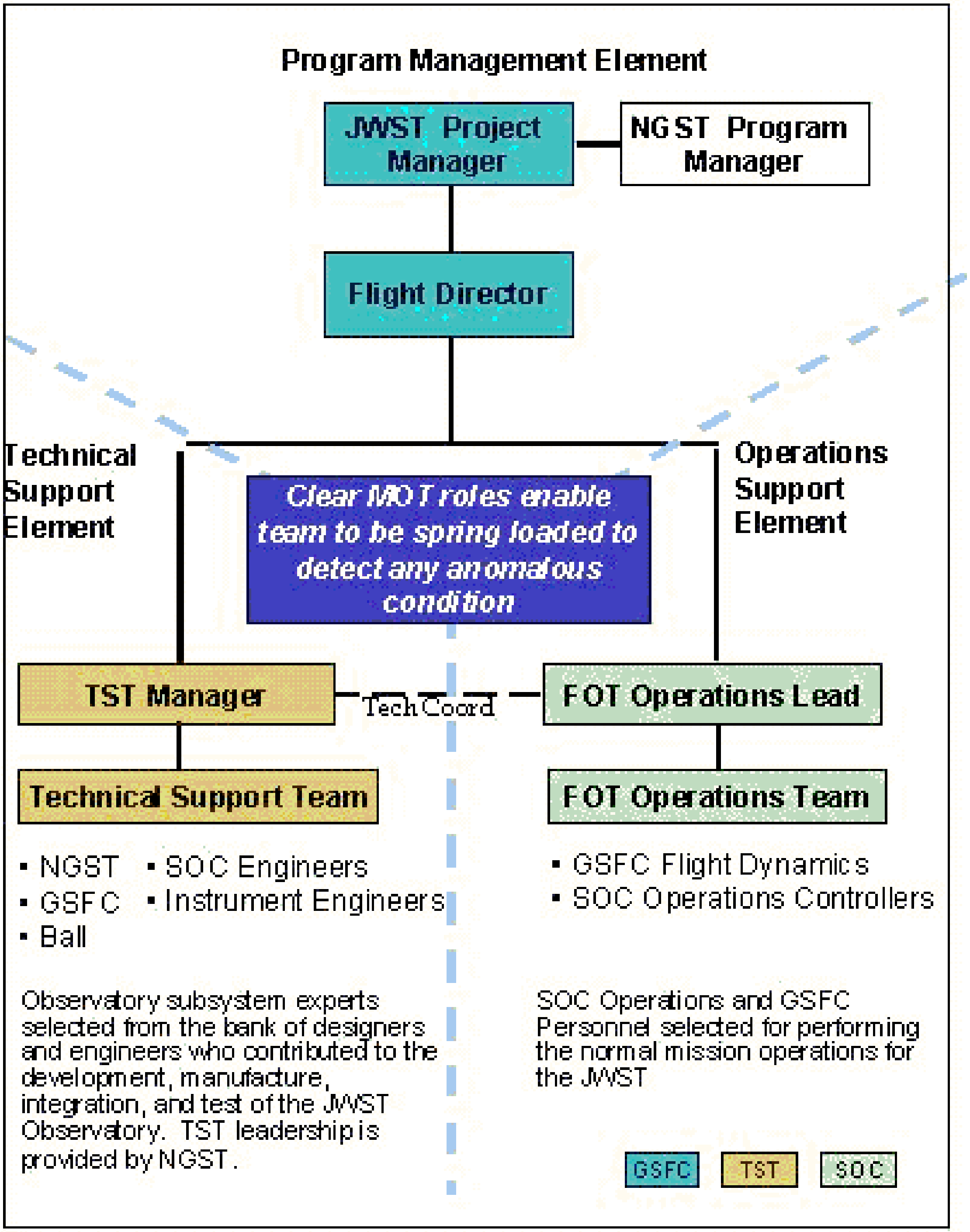


Figure 5-5. Combined Mission Operations Team

MO-658 MOT support to L&EO is actually provided by two MOT crews. Members of the MOT crews are assigned approximately 6 months before launch. MOT crewmembers include the same Observatory specialists who executed the Observatory I&T and ETE testing. Using the integrated team shown in Figure 5-5 results in a greater understanding and level of expertise by GSFC and the S&OC, ensuring knowledge transfer when the S&OC takes full responsibility after commissioning.

MO-659 During the first 15 days, each MOT crew supports launch and commissioning activities, 12 hours/day, to sustain 24-hour operations. After the initial 15 days of L&EO, the MOT crews are reformed into three to four 8-hours/day crews, to sustain 24-hour operations. MOT support will reduce to one crew after the second trajectory correction maneuver. By providing continuous coverage during the critical early orbit period, we ensure specialist support while avoiding the risks associated with relying on single individuals for specific expertise (a single-point failure) (MR-78).

MO-660 During the Launch phase, the MOT is partly or fully responsible for the following:

- Verify proper S&OC configuration prior to launch
- Provide status of appropriate launch critical items to the Mission Director for launch go/no-go decision
- Support verification of proper Observatory configurations during launch and prior to separation.

MO-661 During the L&EO phase, the Technical Support Team (TST) element of the MOT is responsible for commanding event initiation; evaluating Observatory telemetry data in real-time; and assessing subsystem performance using real-time and post facto Observatory telemetry data analysis. The TST directs the FOT in executing the procedure, checklists, scripts, and pass plans that implement the commissioning process, and recommends resolutions to any anomalies with NASA approval before implementation.

MO-662 The flight dynamics facility (FDF) at GSFC provides the TST orbit data necessary to plan, execute, and evaluate the trajectory correction maneuvers. Observatory attitude maneuvers satisfying instrument calibration requirements are executed from TST-approved commands computed from FDF-generated data. The TST also approves the uplink of onboard ephemeris loads to provide accurate orbit data for the instruments during commissioning.

MO-663 The TST provides L&EO direction and oversight including pass plan review and approval. It also records event times and collects necessary performance data to evaluate Observatory operation. Observatory beginning of life performance is baselined and compared to predictions. Differences from predictions are analyzed and recommended changes to the operating limits are generated.

5.8.2.4 Ascent Configuration Approach

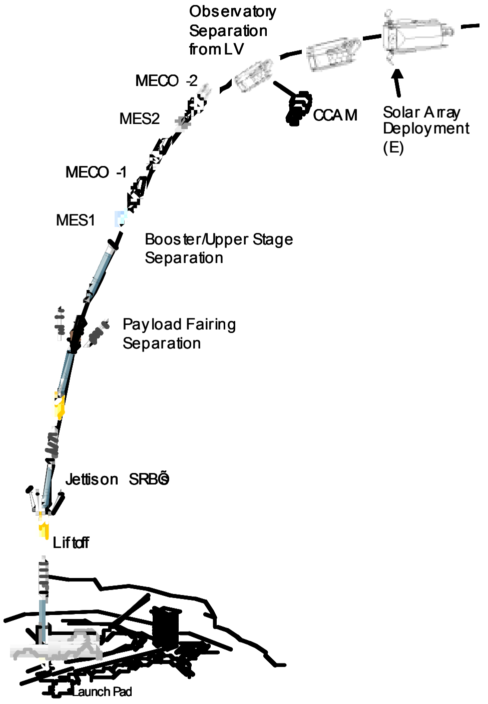
MO-664 The CTP is programmed to configure the Observatory appropriately during the ascent phase of launch. While these Observatory initialization actions may be autonomous, they avoid complexity and do not preclude ground intervention.

5.8.3 Deployment and Trajectory Correction

MO-665 The "Deployment and Trajectory Correction" phase, depicted in Figure 5-6begins with thruster-based attitude stabilization and ends with the mirror deployed with the primary mirror actuators at the nominal positions for beginning the co-phasing of the segmented mirror. It includes deploying the solar arrays, the high gain antenna, and the optical telescope element as well as the (first) trajectory correction maneuver. During this phase, high date rate communications will be established, wheel-based attitude control will be established, and the Observatory propulsion system will be verified.

MO-666 The JWST design includes heaters and other protections so that there are no time critical deployment sequences after spacecraft appendage deployments. There will be a nominal deployment operation timeline, but the deployment of the sunshield, tower, secondary and primary mirrors can be delayed if operational considerations require it.

MO-667 This section will describe the deployment operations, sequence approach, trajectory correction maneuvers (TCM), and ground contact requirements.



- Observatory is powered to a minimum configuration at liftoff
  - CTP, SSR, Rxs, are On
  - Batt connected (Discharging)
  - FSW monitoring Discretes
  - ISIM, Thermal, ACS, are Off
- S-Band commanding &housekeeping tlm available post PLF sep
- Incremental turn-on of ACS, Prop, & Thermal following PLF sep
  - Two increments:
    - ~L+9 (TBR)
    - ~L+19 (TBR)

Figure 5-6. JWST Launch and Deployment Sequence

5.8.3.1 Deployment Operations

MO-668 After separation from the launch vehicle six deployment sequences occur.

MO-669 The first sequence after separation is the **solar array and radiator shade** deployments. The solar array consists of two wings. Each wing has a 6-point hold-down cable release system that is actuated with a non-explosive separation nut device and uses strain energy tape hinges to deploy. A radiator shade is stowed beneath each wing that also uses strain energy tape hinges to deploy. After the solar array and radiator shades have unfolded, the solar array wings are rotated 30° by deployment drive assemblies (DDA) to their final fixed position.

MO-670 The second sequence is the **high-gain antenna (HGA)** deployment. The HGA uses a pitch gimbal mounted at the base of the antenna boom to deploy the antenna away from the launch restraint. The pitch and yaw gimbals are then used for antenna pointing. Both gimbals use the same DDAs the solar arrays use.

MO-671 The **sunshield** deploys to isolate the OTE from solar radiation so it can begin cooling to cryogenic temperature. The sunshield is deployed using four cable driven deployment booms on the forward (+V1) and aft (-V1) sides of the Observatory and 2 telescoping side (+/- V2) booms. The forward booms are deployed first followed by the aft booms. The DTS is then deployed and finally the side booms are deployed. The boom pairs in the forward and aft sections of the sunshield share a motor-driven spool and deploy together as their cables are reeled in.

MO-672 The forward and aft booms have cable-actuated sequencing releases and redundant limit switches at key hinge locations, assuring one deployment motion is complete before the next begins. Once all booms (forward, aft, side) are deployed, the spreader bars are deployed to tension the membranes. Negator springs maintain a constant preload on the membrane. The sunshield is deployed slowly (~30 minutes per 90° of hinge rotation) to ensure controlled unfolding of the five membrane layers. Total deployment takes about 2.5 hours. A motor-actuated jackscrew device at the root hinge of each forward boom is used in a one-time adjustment to optimize the angle of the sunshield forward quadrant for torque balancing.

MO-673 The **deployment tower** moves the OTE away from the spacecraft bus and sunshield to allow it to cool down to its final operating temperature. The two segment deployment tower is extended 1.3 m by a telescoping tube that develops a preload against a stop.

MO-674 The **secondary mirror support structure** deploys the SM to within its wavefront capture range. The SMSS is a four-bar linkage design that actuates at the bottom hinge with a cryogenic stepper motor. The short single strut drives the long dual strut assembly with the forward link strut. This arrangement provides a large mechanical advantage throughout the deployment. The single strut mid-hinge is the only hinge with hard stops and is latched first. The remaining four hinges can latch in any position and are latched as the SMSS approaches its operating temperature. All SMSS latches are cryo-actuated.

MO-675 The **primary mirror** deploys chord wing mirrors to within their wavefront capture range. Each wing is deployed through 103° rotation by a motor-driven hinge and a passive hinge. Each wing is then secured in place by four latches that together make up a micro-dynamically-stable quasi-kinematic interface. Prior to cool down, the latches are engaged but not preloaded. After the OTE operating temperature has stabilized, the latches are driven to flight preloads.

5.8.3.2 Activation Sequencer Approach

MO-676 The incremental activation and configuration of JWST during the Launch phase will be performed via an on-board sequencer, with the Ground serving as the back-up.

MO-677 Activation and Deployment is broken into 30 to 40 tasks, each task representing a set of Observatory actions. After an activity is complete, the Ground will inform the

Observatory of its completion via an EEPROM memory load. This configuration update will enable the observatory to adjust its mode and fault triggers where applicable (e.g., ACS control algorithms will use different constants based on whether or not the Sunshield has been deployed).

5.8.3.3 Trajectory Correction

MO-678 A direct transfer is the fastest route to L2 with fewest launch window constraints. The transfer environment is sufficiently stable for Observatory deployment and completion of pre-commissioning operations. Other trajectories, while requiring less fuel, take more time and, just as important, have varying thermal environments that preclude early deployment and commissioning.

MO-679 Four transfer correction maneuvers (TCMs) are needed to achieve the L2 orbit after separation from the launch vehicle. The first and second trajectory correction maneuvers (referred to as Mid-Course Corrections 1 and 2 - MCC1 and MCC2) are time-critical maneuvers scheduled to occur at separation plus 12 hours and 60 hours, respectively.

MO-680 To accommodate the time-critical TCMs, the ground segment will be capable of performing the following in the first 10 hours after liftoff:

- Perform ranging and ephemeris calculations; make orbit projections and Delta-V calculation
- Generate maneuver plan, generate spacecraft commands, and upload and initiate TCM command sequence

MO-681 MCC1 will be accomplished with two 5-lb DTMs for Delta-V and four 1-lb DTMs for reaction control. After sunshield and telescope deployment, the center of gravity will shift. As a result, additional TCMs will be performed with the four 1-lb thrusters in off-modulation mode for both Delta-V and reaction control.

5.8.3.4 Ground Contact Requirements

MO-682 The S&OC, under control of the MOT, will have primary responsibility for commanding and operating the Observatory with communications support from the DSN network.

MO-683 The DSN network will provide continuous S-Band coverage (24 hours per day, 7 days per week) from launch to the completion of Primary Mirror Phasing activities. This will provide continuous health and safety monitoring and command uplink capability during mission critical activities and through the highly iterative period of primary mirror phasing.

MO-1008 The DSN network will provide continuous Ka-Band coverage (24 hours per day, 7 days per week) from HGA deployment to completion of Primary Mirror Phasing activities. This will, in particular, provide responsive downlink of science data during the highly iterative and interactive period of primary mirror phasing.

5.8.4 Cruise and Commissioning

MO-684 Activities required to commission JWST will be documented in OPS-01, the JWST Observatory Commissioning Plan.

MO-685 Critical first-time and single activities during the early phases of commissioning may be carried out under real time command. However, in so far as possible, commissioning will occur using the visit/activity description architecture of the ISIM, especially for procedures that will need to be repeated multiple times (or for which there are common analogues in normal operations).

5.8.4.1 WFS&C Commissioning Process

MO-686 A simple, graduated process will be employed that satisfies the full observatory optical commissioning requirements from first light through in-service wavefront monitoring and maintenance. It is anticipated that some steps of the characterization process for the telescope may be iterated during the initial commissioning phase. WFS&C commissioning will be carried out using the visit/activity description driven operations from the IC&DH. Figure 5-7 depicts this commissioning process.

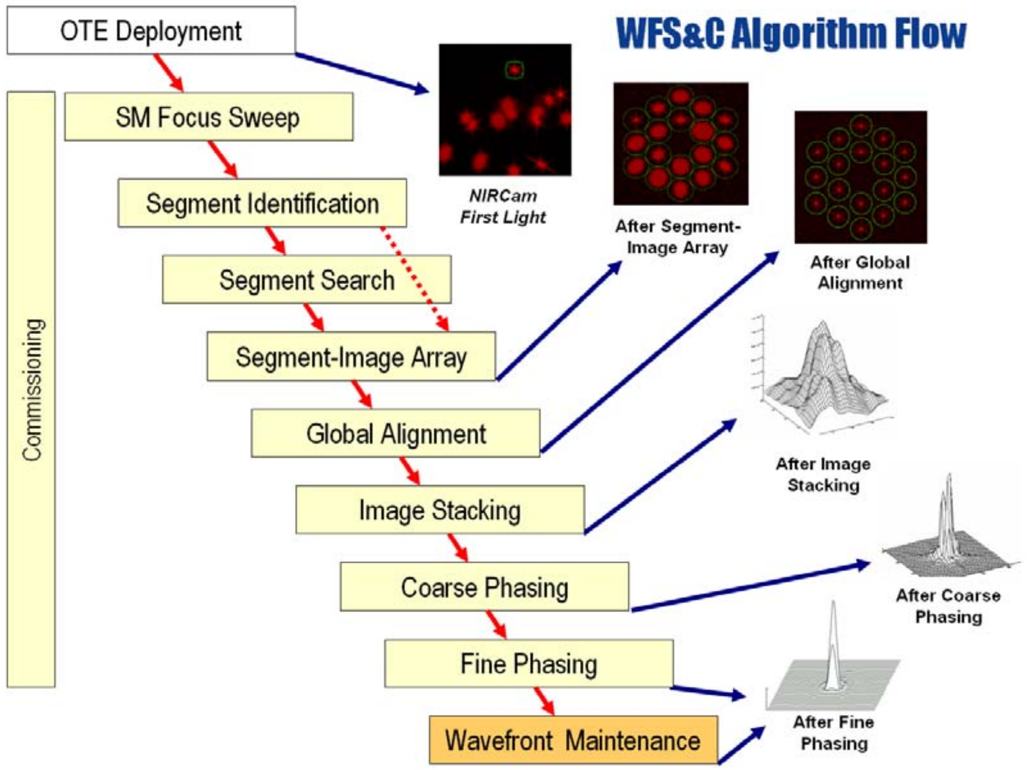


Figure 5-7. Observatory Optical Commissioning Process

MO-687 The WFS&C commissioning process begins upon completion of OTE deployment. The secondary mirror is placed in a suitable initial position with the use of the **Secondary Mirror Focus Sweep**. Next, **Segment Identification** correlates the location of each of the18 individual segment images with its associated Primary Mirror Segment Assembly (PMSA) motions. If there are any segments not located, then **Segment Search** is executed to find the missing segments. **Segment-Image Array** then arranges the images into a pre-determined hexagonal image array on the commissioning NIRCam focal plane. **Global Alignment** generates individual segment wavefront maps that are used to more accurately position the secondary mirror and also provides course adjustment corrections for all PMSAs. During Global Alignment, one of the 18 unphased segment subimages of a separate guide star provide the signal for initial low-fidelity, closed-loop operation of the Fine Guidance Sensor. Finally, all segment images are then co-aligned to overlap at a desired position in the focal plane. These steps will result in a co-aligned image of the 18 single-segment images; at this point the full aperture wavefront will be dominated by the segment-to-segment piston errors of up to 100 microns.

MO-688 The next major step in the commissioning process is **Coarse Phasing.** This step includes correcting the PM segment piston mismatches. To start, the NIRCam pupil imaging lens is used to align the pupil image with the Dispersed Hartmann Sensor (DHS) devices in the commissioning NIRCam pupil wheel. Using a DHS, multiple simultaneous dispersed fringe spectra are generated. This is repeated for a second, rotated DHS device. Then, using a DHS reconstructor, the optimum piston adjustments for all 18 PM segments are determined. This results in a wavefront error for the coarse-phased telescope on the order of 1 micron rms.

MO-689 The final step in the formal WFS&C commissioning process is **Fine Phasing.** This step uses focus diverse phase retrieval, modified by incorporation of control and figure constraints that are inherent in the semi-rigid architecture for wavefront sensing. This step is initiated by taking a pupil image using the NIRCam pupil imaging lens for calibration. The next step is using different weak lens combinations located in the NIRCam filter and pupil wheels to collect a series of defocused images. Then, through ground processing, the wavefront error and corresponding actuator adjustments to bring the telescope into alignment are determined, Wavefront sensing is repeated at multiple field points to determine the corrections to align the OTE over the field. If no additional iterations are required, the telescope will now meet its final WFE performance requirement. During this last phase the NIRCam non-common path wavefront error is removed and the OTE performance is optimized over its entire FOV.

MO-690 The on-going, routine process for maintaining the telescope is through image-based **Wavefront Monitoring and Maintenance.** This process will be used during nominal on-orbit maintenance of the Observatory optics to measure and correct any detected degradation or alignment shift between OTE adjustments.

5.8.5 Operations Timelines

MO-691 The operations timeline, depicting the Commissioning Activities required to Commission JWST will be documented in OPS-01, the JWST Observatory Commissioning Plan. Activities following Solar Array Deployment will nominally be performed via real-time ground command, with on-board stored command sequences serving as a back-up where applicable.

6.0 NORMAL OPERATIONS

6.1 OPERATIONS UNDER THE OPERATIONS PLAN EXECUTIVE

MO-693 To clarify the event-driven nature of JWST operations, four scenarios involving the Observation Plan are presented:

- Nominal OPE execution,
- Modification of the on-board OP,
- Exception-handling by the OPE, and
- Wavefront sensing and control using the OPE.

MO-694 Each scenario is described in words and in a pictorial flow diagram.

6.1.1 Execution of the Observation Plan

6.1.1.1 Objective

MO-695 Most JWST in-flight operations will be accomplished through the execution of an on-board Observation Plan. Preplanned scientific and engineering requests are transferred to the Observatory in the form of visit files for on-board event-driven execution. This section describes the processing of a typical OP.

6.1.1.2 Assumptions/Preconditions

MO-696 The following assumptions and preconditions apply:

- The ground system has constructed an OP segment (that contains a time-ordered list of the visit file IDs sorted by earliest start time) and has uplinked it to the Observatory.
- The ground system has constructed the associated visit files and has uplinked them to the Observatory.
- The Observatory is operating under real-time command.
- The on-board Activity Description Library has been populated with the necessary tested and certified activity descriptions (ADs), also known as on-board scripts, to accomplish all the operational requests specified within the visit files.

6.1.1.3 Description

MO-697 During a communication contact, the FOT requests the OPE to start execution of the on-board OP. From this point, the processing of the on-board OP does not normally require ground contact.

MO-698 The OPE begins by examining the first visit file specified in the OP. If the visit’s start execution time window has passed, then the visit is skipped and the OPE examines the next visit file specified in the on-board OP. If start time for a visit has not been reached, then visit processing pauses until the earliest start time occurs. It is important that the ground system software optimally orders the visits in each OP segment so that minimal time is spent waiting for a visit's start execution time window to open. If the visit's start execution time window has opened as expected, then visit processing continues. In addition to the time window constraints, other visit level constraints may be specified, possibly such as SI availability or thermal stability. When other visit level constraints exist, they are all verified immediately after the start window check succeeds. If all constraints are not met, then the visit is skipped and the OPE examines the next visit file in the on-board OP. For successful visits, processing continues with the OPE ensuring that visit statement translation does not extend beyond the specified latest end time. If the visit lasts longer than the end time, the OPE will cause the visit to end in a graceful fashion.

MO-699 The OPE supports parallel operations such as science instrument dark calibrations during slews and guide star acquisitions, or parallel external calibrations with one science instrument while another science instrument is observing an external astronomical target. So, a visit file may specify one or more parallel paths (i.e., sequences) for the OPE to process simultaneously. A typical primary path in a science visit would consist of a slew and guide star acquisition followed by a set of MULTIACCUM exposures and dither pairs.

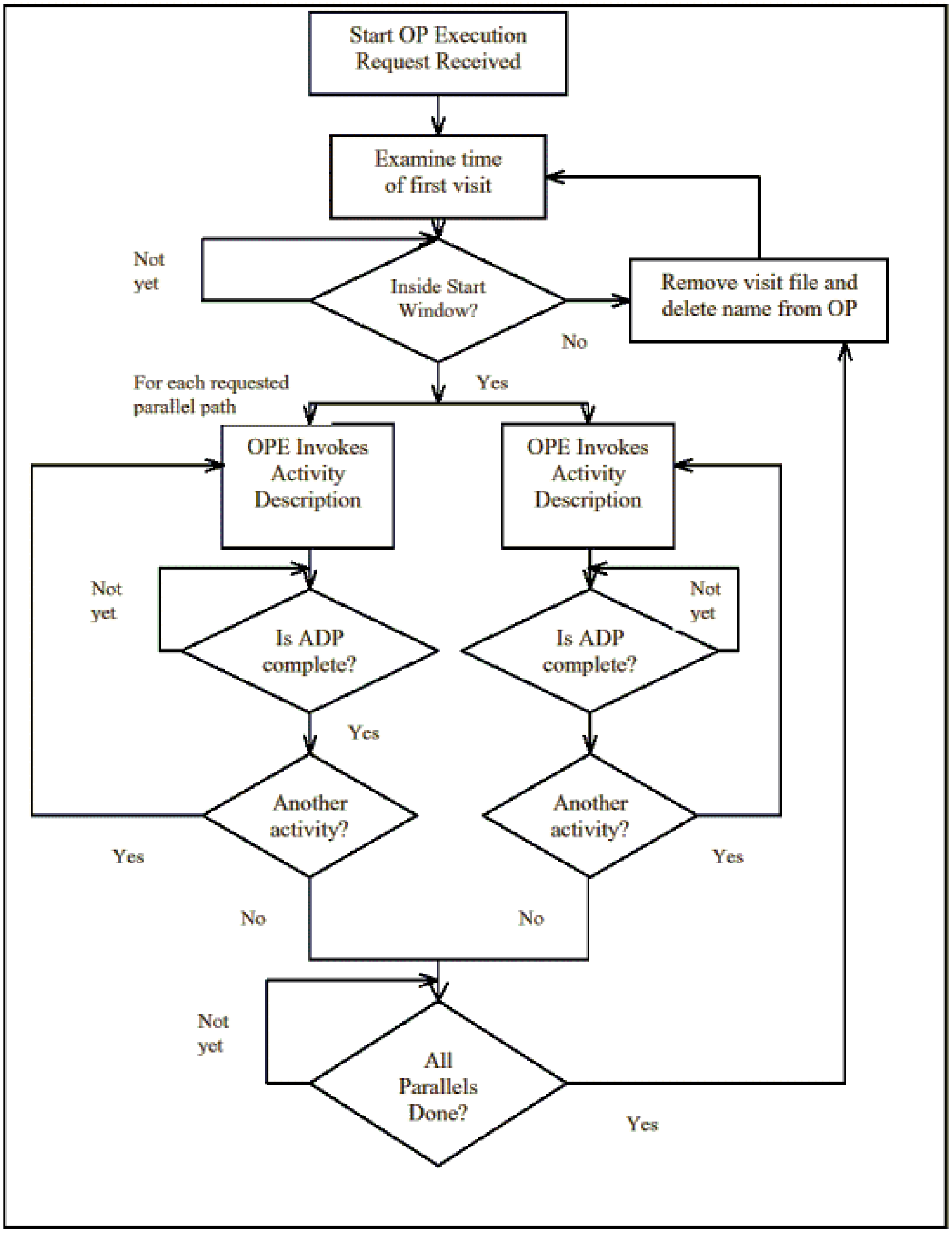
MO-700 Each parallel path includes a structured list of activity description invocations. Each invocation (i.e., visit file activity statement) consists of a script name accompanied by the appropriate parameter name/value pairs. The activity statement parameters are the input information required for script (this is, activity description) execution. When the OPE encounters an activity statement, it requests the services of the on-board Script Processor. The OPE waits for a completion message back from the SP before processing the next visit file statement within the parallel path.

MO-701 To implement the activity statements, the SP processes logical statements and passed parameters, interrogates on-board status information, performs timed waits, and requests flight software application support as directed by the invoked script. Thus, script execution to be influenced by the state of other on-board components. Status information from the flight software applications is provided to the script so that execution decisions can be made within a script. For example, once there is an indication that the previous flight software application request has been completed, the script processing continues. When a script completes, the script supplies status information to the OPE. The ability of the OPE and the SP to examine on-board status information is fundamental to event-driven operations on JWST. It will be possible to change the status information items accessible to the SP without requiring flight software code updates.

MO-702 While the OPE processes the visit and the SP processes a script, their actions are reported as events messages in the telemetry stream. For example, the actual start and end times of each visit file statement and the rationale for skipping a visit are reported. This activity log will be downlinked at the beginning of every communications contact and then periodically during long contacts. Upon receipt, ground system software automatically examines each activity log. Along with the available engineering telemetry, the ground will be able to reconstruct all on-board actions. Notification of non-nominal OPE processing will be sent to planning and scheduling staff resulting in the possible replanning of skipped visits.

MO-703 Once visit processing completes, the OPE deletes the visit file and reference in the OP.

MO-704 As the OPE executes the on-board OP, the ground constructs additional visit files and another OP segment. Before all of the observations in the on-board OP have been executed, the ground uplinks these visit files and appends the new OP segment to the current on-board OP.



Interaction between OPE and ADP

Figure 6-1. Interaction between the OPE and the SP

6.1.2 Modifying the on-board Observation Plan

6.1.2.1 Objective

MO-705 At times, the on-board OP will have to be modified in response to unanticipated events, such as an instrument safing or the activation of a target of opportunity observation. Example 1: A science instrument (SI) encounters a problem and goes "offline". All visit activities that require that SI will not be executed possibly resulting in many visits being skipped. If the problem is well understood, then it is prudent to insert the recovery visit as soon as possible to help minimize the effects on the Long-Range Plan. Example 2: A target of opportunity request for supernova observations is activated and they need to be executed during the period covered by the on-board OP. Example 3: An observer requests a last minute change to her/his visit definition and the modifications have been approved. The associated visit file is already on-board. This activity differs from adding to the OP since visits will be dropped in the OP that is on-board. This process is also referred to as a "replan".

6.1.2.2 Assumptions/Preconditions

MO-706 The following assumptions and preconditions apply:

- The OPE is operating using an existing OP and associated visit files. The OP has not been exhausted.
- A need for a modifying the existing OP has arisen.
- Observing programs are available that specify the required replan visits and a new schedule has been generated.

6.1.2.3 Description

MO-707 A single replan philosophy will be applied to process the various types of modification requests. It is based upon the method for normal OP segment uplink described in the previous scenario. Shortening the on-board OP and removing obsolete visit files are additional steps done prior to the uplink of a new OP segment.

MO-708 Visit files will be added and deleted on-board and then the on-board OP will be adjusted. Each of the three examples above will be addressed.

MO-709 Example 1-Recovery: The ground selects the appropriate visit files for this recovery from a prepared set of science instrument recovery visit files. After analysis and discussion, an intercept point in the on-board OP is chosen. An OP segment from the intercept point onward is created. At the next contact opportunity, the ground commands OP execution stop after a specific visit, loads the selected recovery visit files and deletes any obsolete visit files that are being displaced by the recovery tasks. The ground next truncates the on-board OP beyond the intercept point and requests for the new OP segment to be appended. When the OPE reaches the recovery visit specification in the on-board OP, it is executed just as any other visit file. When the recovery is completed, the OPE continues processing the rest of the on-board OP.

MO-710 Example 2: Target of Opportunity: Target of Opportunity requests are handled in a similar fashion. After the observer identifies the visits to be activated from her/his approved proposal and makes any last minute revisions, the ground prepares the associated visit files. After analysis and discussion, an intercept point in the on-board OP is chosen. An OP segment from the intercept point onward is created. At the next contact opportunity, the ground loads the selected target of opportunity visit files and deletes any obsolete visit files that are being displaced by the target of opportunity observations. The ground next truncates the on-board OP beyond the intercept point and requests for the new OP segment to be appended. When the OPE reaches the target of opportunity visits, they are executed just as any other visit file and the OPE continues processing the rest of the on-board OP.

MO-711 Example 3: Visit Change: After the observer/engineer identifies visit modifications and receives approval, the ground prepares the associated visit file. There may be an incorrectly specified filter or inaccurate target coordinates within the visit file, errors that can be correctly be modifying the visit file alone. At the next contact opportunity, the ground requests the deletion of the obsolete visit file that is being replaced and then loads the revised visit file. Note that the visit file names are not changed from the old to the new version, so no adjustment to the on-board OP is required. When the OPE reaches the revised visit, it is executed just as any other visit file and the OPE continues processing the rest of the on-board OP.

MO-712 It is possible that an appropriate on-board OP intercept cannot be found without disrupting the execution of a planned visit. For example, if there was a particularly long duration visit executing throughout the intercept window and it is decided to forfeit the executing visit, the new visit files and revised OP segment would be uplinked. The ground would request the OPE to stop processing the current visit at the completion of a specified task, then the OPE would begin processing the replanned OP.

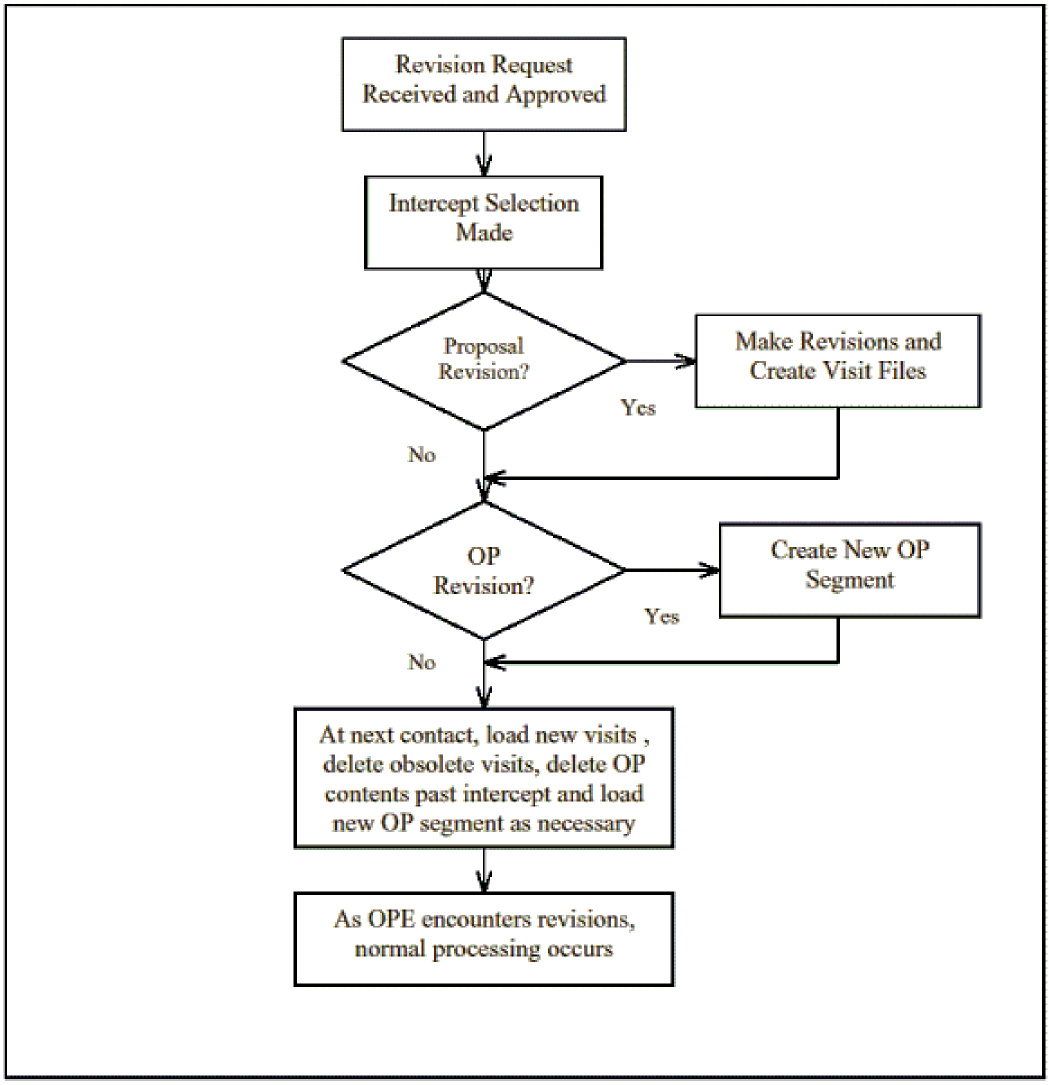


Figure 6-2. Modification of the on-board OP

6.1.3 Observation Plan Execution Exception Handling

6.1.3.1 Objective

MO-713 This section describes how the OPE handles problems in the execution of the OP that prevent the complete execution of the planned tasks. The OPE is capable of bypassing visits or parts of visits when certain failures occur. This section describes on-board OP exception handling. The representative situations of visit constraint violation, guide star acquisition failures, and target acquisition failures will be addressed.

6.1.3.2 Assumptions/Preconditions

MO-714 The following assumptions and preconditions apply:

- There is an on-board OP and the associated visit files have already been loaded that extends beyond the currently executing visit.
- During processing of the on-board OP, a situation arises that prevents the execution of a planned task. Example 1: The conditions/constraints specified within a visit file are not met. Example 2: The guide star acquisition flight software could not find or lock onto the specified guide star. Example 3: The target acquisition flight software could not find the specified target.
- No on-board hardware or software errors occur during the execution of this OP.

6.1.3.3 Description

MO-715 JWST observers will be able to specify conditions (i.e. constraints) for visits that must be met to carry out their observing program. The conditions will be transferred into the associated visit file created by the planning and scheduling subsystem. Additional visit constraints, such as execution window, will be created by the planning and scheduling subsystem and incorporated into the visit file. As the OPE[32] processes each visit file and encounters a constraint specification, it verifies that this required condition exists by examining on-board status information. Possible examples of visit file constraints are science instrument availability (i.e., that it is not off-line), acceptable temperature range of a particular Observatory element, or tracking on a specific guide star.

MO-716 The OPE will contain rules on how to proceed when visit file conditions are not met. The most common reaction will be to skip the visit, parallel path/sequence, or activity with which the constraint is associated. Note that the JWST event-driven concept does not include on-board re-ordering of the ground-specified operations. Tasks can be skipped but never re-scheduled by the on-board software. If, for example, a visit level constraint is specified but was not satisfied, then the visit would be skipped and the OPE would move on to the next visit. This functionality could also be used to define guide star dependent dither patterns within a visit. Each dither activity could have a specific guide star associated with it. Only the dither activities that were associated with the actual guide star chosen would be executed. The other dither activities would be skipped. The OPE reaction is always posted to an on-board activity log.

MO-717 Other generic constraints will also be implemented directly following established operational rules. An example might be the monitoring of science data recorder availability prior to every science exposure activity execution. Visit file processing would pause if the science data recorder were full. When space becomes available, the OPE could restart data taking.

MO-718 Guide star failures will occur occasionally during normal operations with JWST. They could be a result of 1) a bad coarse attitude, 2) a binary guide star, or 3) a catalog error that includes a nonexistent or extended object or one very different in magnitude. The FGS will be relatively robust against these types of problems; nevertheless, there will be times when guide star fine lock will not be achieved. When the guide star acquisition flight software fails to identify a usable guide star, it sends the guide star image data to the SSR, as is the case for a successful acquisition, and reports the failure. The guide star acquisition activity description (i.e., on-board script) recognizes the failure has occurred and takes appropriate action depending on the operational procedure implemented in the activity description. This could be to request the acquisition of another star or if no other stars are supplied, it could be to cease execution with a request to the OPE to skip the rest of the current visit as fine guiding was not achieved. A message is placed in the on-board activity log stating the visit was skipped due to guide star acquisition failure. After a visit is aborted, the OPE begins examining the next visit file as indicated on the on-board OP.

MO-719 The FOS will contain S/W tools that automatically review activity logs as they are received from the Observatory. As part of this system the FOS will notify the planning and scheduling system that a problem guide star was encountered. STScI staff will analyze the event data and the associated acquisition images to determine the nature of the failure. They will send an explanatory report to a visit failure review board. If the visit is still feasible with different guide stars, the visit will be rescheduled to appear on a future OP segment.

MO-720 JWST will have on-board target acquisition software for the spectrographs and the coronagraphs. In most cases, if this software does not properly find the requested target, then there is no point in continuing with the preplanned exposures of the visit on the same target. The OPE response for target acquisition failure would be very similar to that for a guide star acquisition failure as discussed above. The target acquisition flight software reports the failure and the target acquisition activity description recognizes the failure and ceases execution with a request to the OPE to skip the rest of the current visit as the science target was not located. A message is placed in the on-board activity log stating the visit was skipped due to target acquisition failure. After a visit is aborted, the OPE begins examining the next visit file as indicated on the on-board OP.

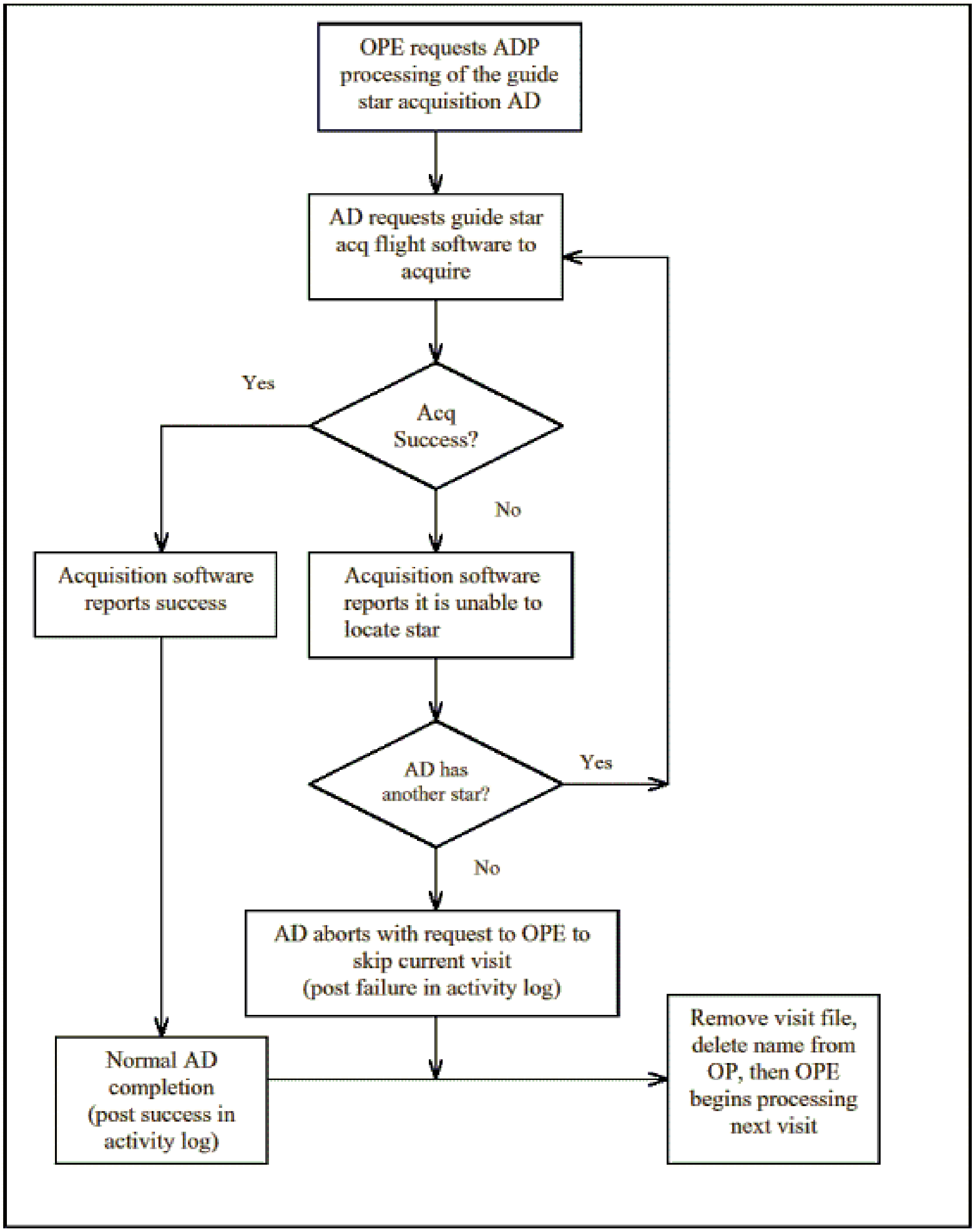


Figure 6-3. Response to guide star acquisition failure

6.1.4 Routine Wavefront Sensing and Control

6.1.4.1 Objective

MO-721 It will be necessary to periodically monitor and adjust the JWST OTE in order to maintain the optical quality of the PSF (Point Spread Function) within the scientific requirements (MR-285). This section describes the process of monitoring and adjusting the mirrors during normal operations. Standard proposal processing and normal OPE/SP functionality will be used. Note that monitoring the OTE figure is known as wavefront sensing, and OTE figure adjustment is known as wavefront control. OTE figure adjustment is achieved through actuator reconfiguration.

6.1.4.2 Assumptions/Preconditions

MO-722 The following assumptions and preconditions apply:

- WFS&C commissioning activities have been successfully completed and JWST has been executing science observations with good quality PSFs.
- A routine wavefront sensing and control (WFS&C) engineering proposal has been created with visit requests that consist of (1) a set of external NIRCam wavefront monitoring exposures and (2) a mirror adjustment request. The external exposures are of a WFS&C calibration star taken at multiple defocus settings using a NIRCam short-wavelength camera and the weak lenses in the pupil and filter wheels.
- The planning and scheduling subsystem has constructed a long range plan that contains periodic routine WFS&C visits on a timescale based on the PSF drift rate as specified in the proposal. Although an OTE adjustment opportunity is available in every routine WFS&C visit, adjustment will only be done when deemed necessary. That is, the WFS&C visits are scheduled based on the required PSF monitoring frequency and not on the required WFS&C control frequency. Using the inherent OPE functionality, if a mirror adjustment is not necessary at the time of a particular WFS&C visit, then the adjustment activity is skipped.
- The planning and scheduling subsystem has constructed the associated visit files from this proposal.
- An OP segment containing a routine WFS&C visit and the associated visit files have been uplinked to the Observatory.
- The on-board OP is currently being processed.

6.1.4.3 Description

MO-723 Figure 6-4 shows how mirror updates will be accomplished. After analyzing the WFS&C Executive output, it is decided to adjust the OTE figure. The set of mirror actuator reconfiguration update requests generated by the WFS&C Executive is delivered to Flight Operations for uplink. Without interrupting the on-board OP but prior to the next routine WFS&C visit, the segment update requests are uplinked to a wavefront control file in the ISIM for processing by the OPE.

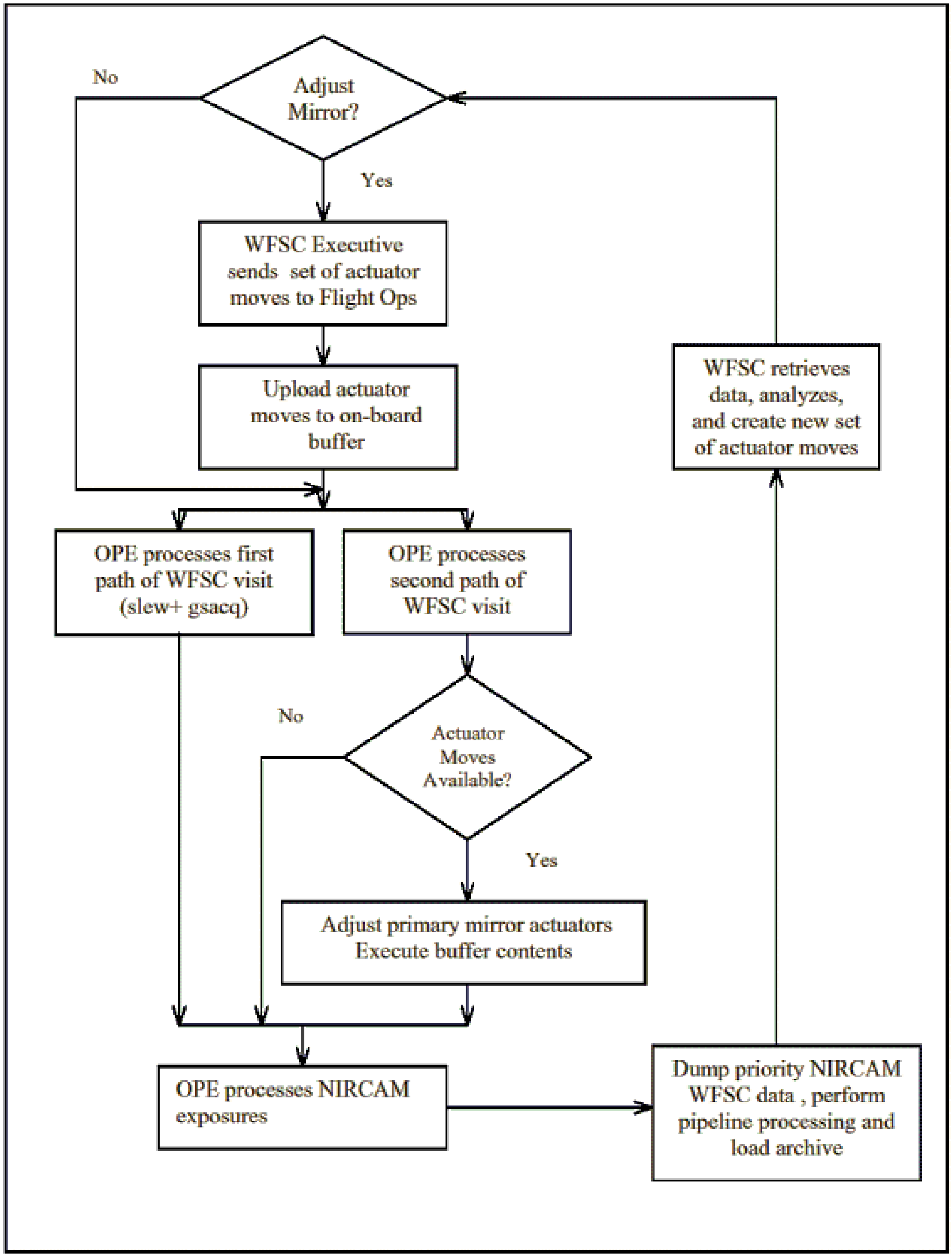


Figure 6-4. Flow Diagram showing how mirror updates would be accomplished

MO-724 The OPE begins processing the routine WFS&C visit when it is encountered within the on-board OP. All routine WFS&C visits will have the same structure: an initial Wavefront Sensing observation, an optional Wavefront Control activity that performs mirror adjustments, followed by a second Wavefront Sensing observation that provides verification of the mirror adjustment.

MO-725 WAVEFRONT SENSING: The Wavefront Sensing observation begins with a slew activity and a guide star acquisition activity to place a wavefront monitoring star at a specified location in the NIRCam short wavelength camera field of view. A set of NIRCam images are requested at various defocus settings using elements in the NIRCam filter wheels. Note that no on-board data analysis is done. These NIRCam images will be calibrated by the ground system and analyzed by the WFS&C Executive.

MO-726 WAVEFRONT CONTROL: The optional wavefront control activity begins with a query of on-board status to determine whether a wavefront control file intended for this visit has been uplinked. If the wavefront control file is not present, then the visit ends. If, as in this case, the wavefront control file has been uplinked, then the wavefront control activity stops fine guiding by the FGS, reads the actuator moves from the file, generates actuator move commands, and sends them to the OTE flight software. It is the presence or absence of an actuator update request that distinguishes pure sensing visits from sensing plus control visits.

MO-727 WAVEFRONT CONTROL VERIFICATION: When the wavefront control activity completes execution of the mirror adjustment, a second wavefront sensing observation is executed to verify the mirror adjustment. The guide star is acquired, the NIRCam wavefront monitoring star is placed at the same specified location as for pre-WFC, and another set of NIRCam images similar to the first set are executed. The visit then exits normally. These NIRCam images will be calibrated by the ground system and analyzed by the WFSC Executive.

MO-728 WAVEFRONT SENSING DATA PROCESSING: The wavefront sensing data are stored on the SSR for playback during the next contact. Flight operations will command playback of science data from the SSR after downlink of the recorded engineering telemetry data. The science data is forwarded to the Data Management Subsystem where it is processed into individual exposures and stored in the data archive. The WFS&C Executive is notified that the data is available, and the WFS&C Executive requests calibrated Wavefront Sensing data from the WFS&C visit be generated. The DMS retrieves and calibrates the NIRCam images generated by the WFS&C visit, and notifies the WFS&C Executive when the calibrated WFS&C data is available. The WFS&C Executive then retrieves the calibrated data, analyzes wavefront error, and if needed, generates another set of actuator moves that can be used to repeat the WFS&C process.

MO-729 Figure 6-5 shows a full cycle of routine JWST WFS&C operations. First WFS data are acquired, and then an optional WFC activiy is carried out to updae the OTE. After the WFC activity executes, WFS data are acquired again (or skipped if no actuator updates occurred). Routine WFS&C data are downlinked at a higher priority than routine science data.

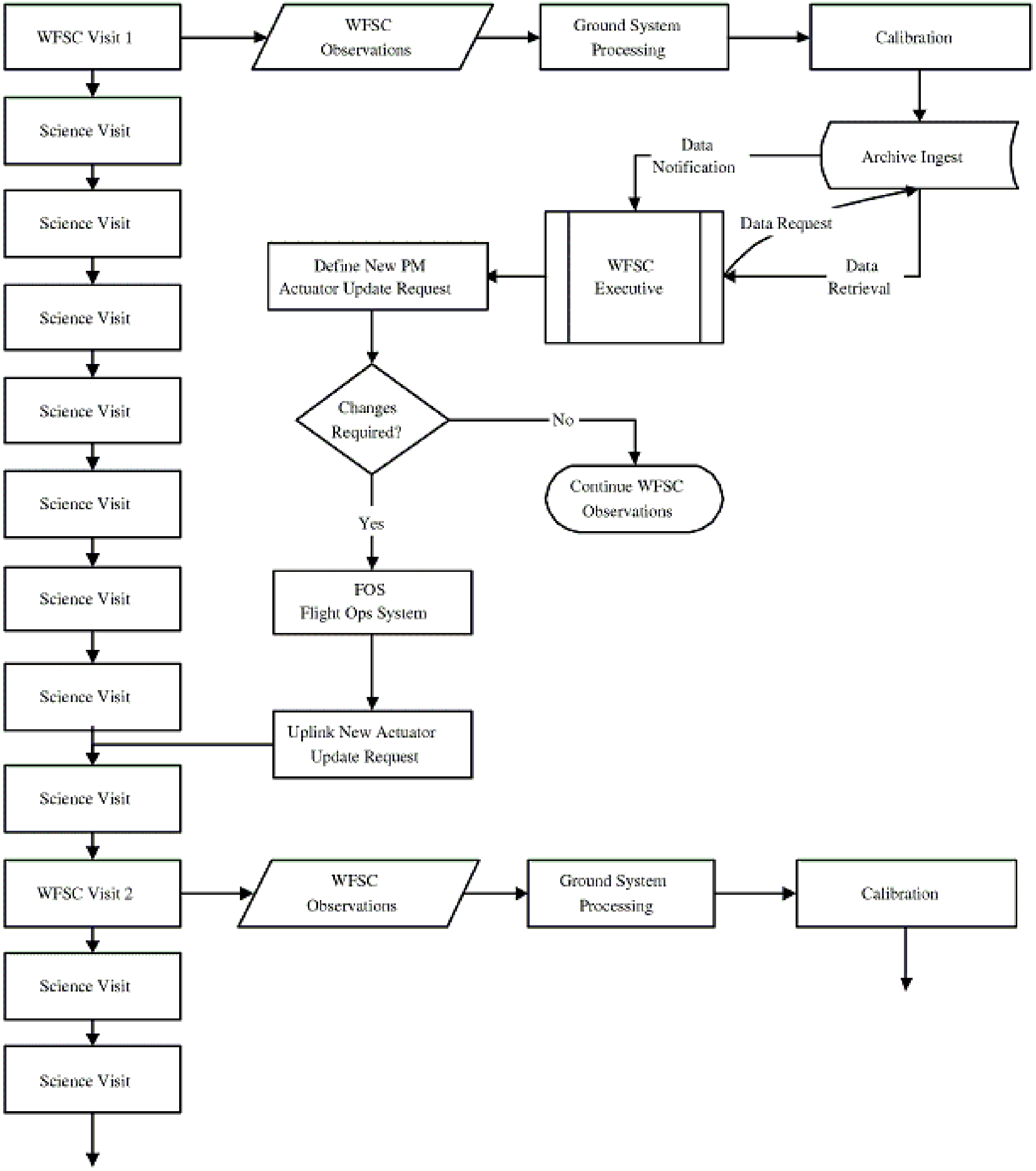


Figure 6-5. Schematic View of the Routine WFS&C Cycle

MO-730 Once the wavefront sensing data are on the ground, they are processed by the standard data pipeline and placed within the archive. Notification is sent to the WFS&C Executive that wavefront monitoring data are available and the WFS&C Executive initiates a data request. After the calibrated data arrive, the WFS&C Executive analyzes the data and generates a new set of segment update requests. This output will be used to decide when to execute the next adjustment.

6.2 REAL-TIME OPERATIONS

MO-731 "Real-Time Operations" are those that involve ground communication with the JWST Observatory.

MO-732 Table 6-1 provides a descriptive listing of operational events occurring daily, weekly, and quarterly. The table is based on NGST spacecraft operational experience and adapted for the JWST system.

MO-733 All activities that adversely affect science collection are typically scheduled at non-peak periods and coordinated in advance with the Observation Planning & Scheduling element.

Table 6-1. Real-time Operations Tasks

Task	Frequency	Duration	Description
Ground Station contact	Daily	Pre-pass: 45 minutes Pass: nominally 4 hours Post-pass: 15 minutes	Initiate high rate communications contact, establish real-time telemetry, downlink spacecraft logs, recorded engineering and science data, uplink Observation Plan and associated files, tables, etc.
Ranging and Doppler tracking.	Daily	30 minutes to 4 hours	Provide FDF tracking data for orbit analysis (30 minutes per day minimum)
Clock maintenance	Daily	5 minutes	Maintain spacecraft clock to 1-second accuracy.
Ephemeris management	Weekly	5 minutes	Update the onboard ephemeris
Orbit maintenance	~22 days	~2 hours	Conduct station-keeping maneuvers.
Flight Software (FSW) maintenance	As needed	Varies	Update flight software.

MO-734 The following sections detail how selected "Real-Time Operations" are performed.

6.2.1 Contact Scenario

6.2.1.1 Objective

MO-735 This scenario describes the nominal system functions performed for a normal communication contact between DSN and the Observatory. These are the functions that must be automated for the S&OC to perform autonomous communications contact.

6.2.1.2 Assumptions

- This is a nominal 4-hour ground contact with a DSN ground terminal. The last contact was ~ 20 hours earlier.
- The JWST S-Band transmitters are transmitting.
- Acquisition parameters were generated by FDF and provided to DSN
- Contact Schedule and ephemeris data were previously generated and uplinked.
- Uplink products (contact schedule, ephemeris update, Observation Plan files) have been generated and are awaiting uplink by the S&OC.
- The communications schedule indicates both the start and end times of the contact and the start time for DSN to begin set-up of the contact.

6.2.1.3 Description

MO-737 Prior to the contact, the S&OC will verify that all data planned for uplink during the contact are available and ready for uplink.

MO-968 DSN will begin set-up for the contact at the time indicated in the contact schedule. DSN will begin sending monitor blocks indicating the status of ground station equipment. S&OC will perform pre-pass checks with DSN (e.g. BERT [Bit Error Rate Test] check, NO-OP command check, etc.).

MO-969 At a time indicated in the contact schedule prior to the start of the contact, the Observatory will move the HGA to begin tracking the ground station identified in the contact schedule. The Observatory will use a Spacecraft to ISIM handshake to coordinate each motion of the HGA. The HGA will be moved when the pointing error exceeds a certain threshold (to avoid overly frequent maneuvers).

MO-970 At the contact start time, DSN will initiate a sweep pattern to acquire the S-band downlink. Upon acquisition of the S-band downlink signal, DSN will begin tracking the Observatory and passing real-time telemetry to the S&OC.

MO-971 The S&OC will monitor real-time telemetry to ensure the nominal condition of the Observatory. If contact is not established or if telemetry indicates problems with the

Observatory, an anomaly report is generated by the S&OC and appropriate personnel are notified.

MO-972 DSN will then activate command modulation and range modulation, and will notify the S&OC of S-band receiver lock.

MO-973 The S&OC will uplink commands to turn on the Ka-band transmitter, and notify DSN that the transmitter has been turned on when indicated in telemetry. DSN will acquire the Ka-band downlink and notify the S&OC of Ka-band transmitter lock.

MO-974 The S&OC will uplink a command to begin playback of the solid state recorder (SSR).

MO-975 The Observatory will begin playback of data on the SSR, beginning with downlink of the critical health and safety telemetry partition as a file using class 1 CFDP (unacknowledged), followed by files from the engineering data partition and the science data partition using class 2 CFDP (fully acknowledged with retransmission).

MO-976 The S&OC will receive the critical health and safety telemetry data from the DSN and will process it for indicators of anomalous conditions. Meanwhile, the DSN will begin sending transaction PDU data packets to the S&OC, which are formatted into CCSDS command packets and sent back to the DSN for uplink.

MO-977 When the Observatory condition is determined by the S&OC to be nominal, the S&OC will begin uplink of data planned for uplink. This data will include table and command sequence loads to the Spacecraft C&DH, and table and file loads to the ISIM C&DH.

MO-978 A short time prior to the scheduled end of the contact, the S&OC will uplink a command to stop playback of the solid state recorder. This will leave time for files that are currently playing back to complete downlink (less than one minute), for retransmission requests to be processed, and for successfully downlinked files to be acknowledged as finished.

MO-979 At the end of the contact, the S&OC will notify DSN that the Ka-band signal will be terminated, and then the S&OC will uplink a command to stop Ka-band transmission. The DSN will verify loss of Ka-band signal, and the S&OC will direct DSN to go passive, fade and terminate the support.

MO-980 In the meantime, DSN will continue to send completed files to the S&OC by FTP. These data will be transmitted to the S&OC within 8 hours of receipt by the DSN. The S&OC will process engineering telemetry files and construct an event activity log that indicates the execution of the Observation Plan. The S&OC will also process engineering telemetry and science data files for archive and data distribution.

MO-981 The DSN will store real-time and recorded telemetry data for up to 30 days, and make the data available to the S&OC in the event there is a problem that prevents the data from getting into the S&OC archive.

6.2.1.4 Flow Diagram

MO-743 The flow diagram in Figure 6-4 depicts the nominal contact flow as described in the previous paragraphs.

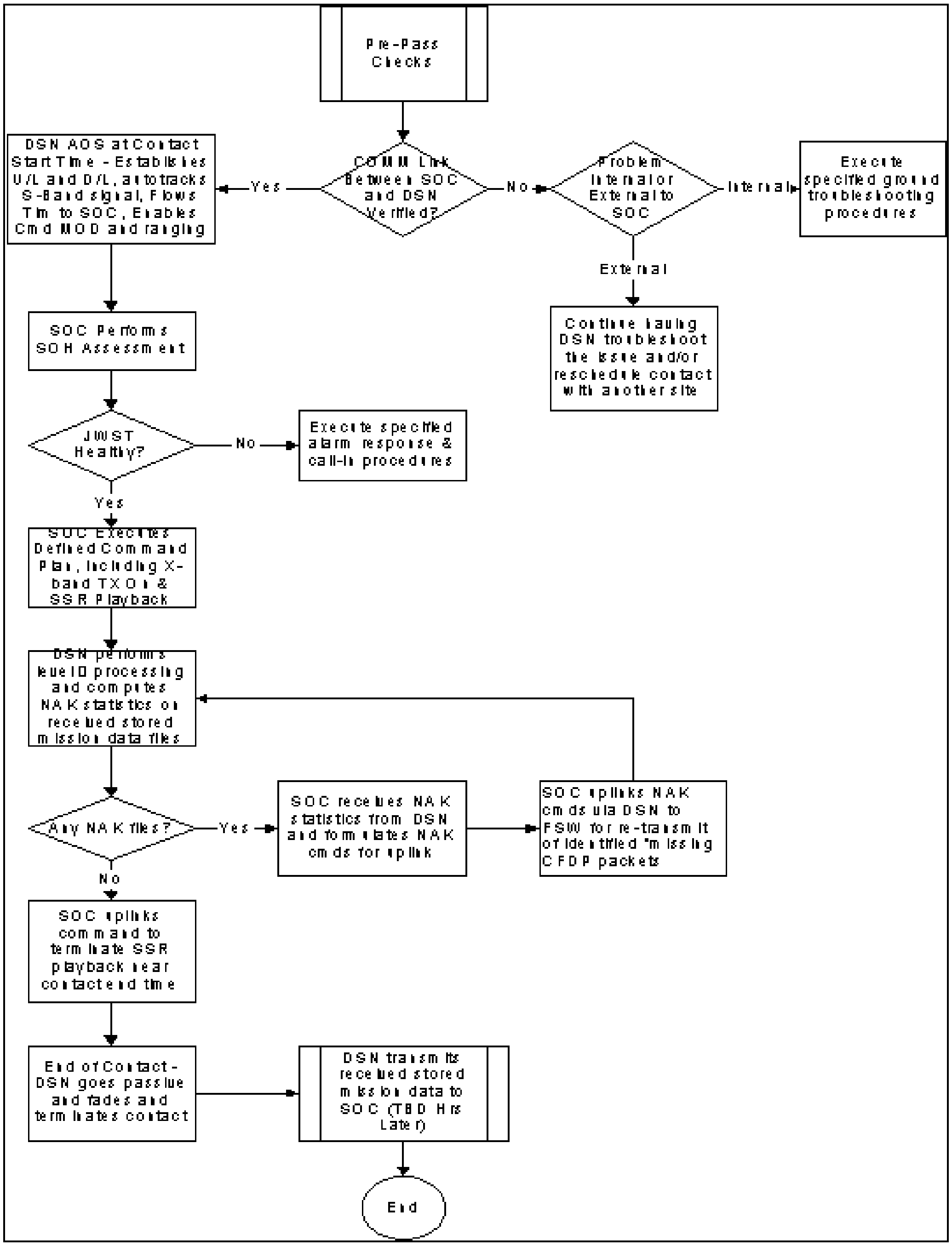


Figure 6-4. Nominal Space to Ground Contact Scenario

6.2.2 Orbit Maintenance Scenario

6.2.2.1 Objective

MO-744 This scenario describes the nominal system functions performed during the execution of a satellite station keeping maneuver.

6.2.2.2 Assumptions

- MO-745DSN is the T&C ground station
- The Station Keeping attitude is within the FOR.
- A Station Keeping engineering proposal exists.
- Pre-pass checks with DSN conducted successfully and nominally
- Station keeping Delta-Vs are performed during real time contact with ground. This activity assumes core team of FOT, Flight Dynamics & Support personnel are on-duty
- This contact assumed to be a 2 hour pass over a DSN Ground Terminal
- The JWST S-Band transmitters are assumed to always be transmitting
- The FOS coordinated and established the DSN contact schedule and resource use.
- The FDF previously generated the required products (e.g. post-burn ephemeris table load, ephemeredes for ground terminal locales, Burn Duration, Burn Start Time, Burn attitude quaternion, etc.) in a format ready for uplink
- Primary Catbed Heaters are ON (following initial turn-ON, catbed heaters require 60 minute warm-up period prior to burn)
- Thrusters have been calibrated, and control law integrator parameters for Delta-V burns have been verified
- A Visit was included in the OP that provides an opportunity to Stop OPE execution via ground command. The Visit was scheduled to allow the Stop OPE command at ~ 60 minutes prior to the planned Delta-V Burn time.
- The ACS FSW Fault Management trigger set points for excess attitude error and rates increase when in Delta-V mode. This expanded tolerance will maintain S/C protection in the event of an anomalous burn, but yet prevent an unnecessary safe mode entry due to expected attitude perturbations during the burn.

6.2.2.3 Description

MO-746 JWST must perform periodic station keeping Delta-V maneuvers to correct for orbit perturbations caused by the environmental dynamic forces of the orbit. A single 1lb DTM is located on a fixed boom, enabling station keeping Delta-V maneuvers in any direction relative to the Sun. However, the nominal approach employed for JWST uses Delta-V maneuvers at L2 without requiring any component along the Sun line.

MO-982 The FDF is responsible for determining the JWST orbit and generating the Maneuver Plan to maintain the orbit by using Tracking data obtained by the DSN during the daily communication contacts. DSN will utilize ground stations in both hemispheres to provide an adequate baseline for orbit determination. Tracking data collection must occur for at least 19 contacts (~ 19 days) after a station-keeping maneuver in order for FDF to converge on an orbit solution that will support the next station-keeping maneuver. The tracking data collected will be provided directly to the FDF by the DSN, without passing through the S&OC.

MO-983 Routine station keeping maneuvers will be planned and scheduled in the same manner as routine science and calibration visits using station keeping visits placed on the LRP and scheduled on an OP. The use of station keeping visits allows the planning and scheduling software the opportunity to synchronize the science and engineering activities, minimizing any gap time between the sets of activities, and allows the development, tracking, and reporting of the engineering activities using the same software tools as those used for the science and calibration activities.

MO-984 A station keeping maneuver is a mission critical activity and will be performed only during a Flight Operation Team supported contact with the Observatory. Thus each station-keeping visit will be restricted to execute in a time interval that is phased with a planned contact period that has been coordinated with DSN, FDF and the FOT.

MO-985 The station keeping maneuver attitude will not be known until after the orbit determination and could be anywhere in the FOR. This precludes having a slew activity in the station keeping visit. The station keeping visits will perform a placeholder function in the planning and scheduling process that reserves on the LRP and OP (about 2 hours) the time expected to perform the station keeping ground procedure.

MO-747 At contact start, both command and telemetry links are established with the vehicle via DSN. Once a valid communication link with the Observatory has been created, the S&OC performs an overall state of health assessment of the Observatory prior to proceeding with the defined station keeping pass plan.

6.2.2.3.1 Pre-Burn Preparation

MO-748 The station keeping pass plan is broken down into 3 phases. They are pre-burn preparation, burn execution, and post-burn reconfiguration. The following sections will describe the events that take place during each of these three phases.

MO-749 This phase of the station keeping sequence involves configuring and maneuvering the Observatory in preparation for burn execution. The FOT will begin by uplinking the post-burn ephemeris table memory load to the S/C FSW, however the ephemeris enable flag will not be enabled at this time. This protects against the S/C FSW accepting and using a post-burn ephemeris in the event that the burn is called off. Next, the FOT will uplink both the Delta-V burn absolute time SCS (Stored Command Sequence) and the Delta-V burn execution SCS, followed by memory dumps of the affected SCS memory locations for verification purposes. Once the burn SCSs have been verified to be successfully loaded, the FOT will then issue the commands to enable and activate the Delta-V burn absolute time SCS. This will in turn trigger the FSW to process the SCS commands, where the first command is absolute time tagged with the desired start time.

MO-750 The uploaded Delta-V burn absolute time SCS will perform the following S/C actions:

- Command Delta-V Thruster Catbed Heaters ON (60 - 90 minute warm-up period required prior to burn)
- Commands to stop OPE observation plan execution
- Command the FGS into standby mode
- Command the FSM to "zero" position
- Load the burn attitude quaternion (in ECI coordinates) into the correct FSW quaternion table location
- Command to widen auto momentum unloading thresholds in preparation for maneuver to burn attitude.
- Command to select the "new" burn attitude quaternion (i.e. slew maneuver to burn attitude start). This slew will be performed on wheels.
- Command ISIM to place SIs in safe state
- Command to transition to S/C Delta-V Mode ~ 5 minutes prior to burn start (this is a thruster based mode where the four 1 lb DTMs located on the bottom corners of the S/C provide reaction control during the burn)
- Absolute Time Command to Activate Burn Execution SCS
- The Burn Execution SCS executes the following:
- DTM Fire Command (i.e. Burn Start)
- Command to terminate burn
- Command to enable ephemeris upload flag. This alerts the S/C FSW that a new ephemeris is available.
- Command Delta-V Thruster Catbed Heaters OFF
- Commands to restart OPE observation plan execution

6.2.2.3.2 Burn Execution

MO-751 Before upload, the FDF verifies the burn attitude quaternion against the S/C simulator and constraint checker to ensure against a FSW detected sun constraint violation. So when the S/C FSW processes the uploaded burn attitude quaternion, it should not detect a sun constraint violation. It may however determine that the reaction wheel (RW) spin-up required to slew the vehicle to the desired attitude violates its accumulated momentum constraint, therefore resulting in a pre-maneuver momentum unload. But once the FSW determines the maneuver profile is acceptable, it will set the "slew in progress" flag and command the RWs to provide the required torque to slew the Observatory. During the maneuver to burn attitude, the STAs are still providing attitude update information and Earth pointing of the HGA is maintained.

At the completion of the maneuver, the ACS checks the accumulated momentum again to determine if an unload is necessary.

MO-752 Now that the S/C has achieved the burn attitude, and any attitude transients resulting from the maneuver have settled, the FSW executes the next set of commands in the burn SCS which request the ISIM to place the SIs in a safe state. Once completed, the FSW waits for the absolute timed event of commanding the vehicle into Delta-V mode to occur. This transition will put the vehicle in a thruster based mode that uses the four 1 lb DTMs for reaction control during the burn.

MO-753 Just prior to burn start, the FOT will assess the Observatory state of health and verify that the vehicle is ready for burn execution. Upon deciding that the Observatory is a “GO” for burn start, the FOT will uplink the command to ENABLE the burn execution SCS. If the burn execution SCS is not ENABLED by the ground prior to the Delta-V burn SCS issuing the activate SCS command, the burn will not take place. This two-step process utilizing two separate SCSs provides the ground will final authority on burn execution without reliance on a last-second command link to terminate the burn in the event of an emergency.

MO-754 At burn start the S/C FSW will execute the station keeping DTM fire command to initiate the burn. When the desired burn duration has elapsed, the S/C FSW will terminate the burn by issuing the thruster OFF command.

6.2.2.3.3 Post-Burn Reconfiguration

MO-755 Once it is determined that the burn was successful, the FOT will issue the command to transition the S/C from Delta-V mode back to wheel normal mode. At this point, the S/C is primarily back in its pre-burn configuration, with exception to the Delta-V thruster catbed heaters, which will be commanded OFF via the Delta-V burn SCS. As for the SIs, they will be reconfigured upon resumption of the operation plan. The remaining action to complete is FOT verification of S/C ephemeris acceptance at the specified epoch time, which will be planned to occur during the scheduled ground contact.

6.2.2.4 Flow Diagram

MO-756 The below flow diagram in Figure 6-5 depicts the nominal station keeping flow as described in the previous paragraphs.

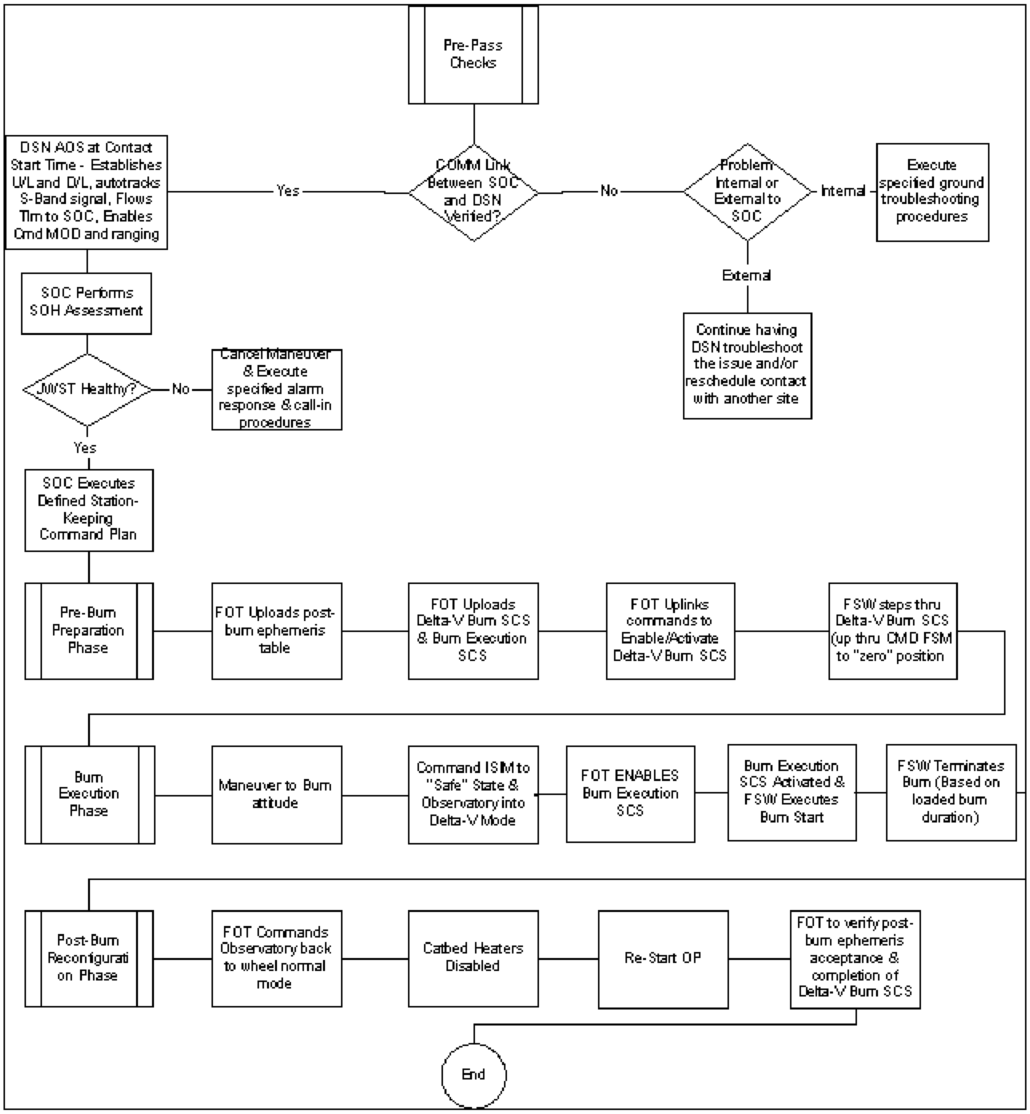


Figure 6-5. Nominal Station-keeping Scenario

6.2.3 Momentum Management Scenario

6.2.3.1 Objective

MO-986 This scenario describes the cyclic process that provides planned momentum management for the Observatory.

6.2.3.2 Assumptions

- Planned Momentum Unloads (MU) do not preclude the Observatory from performing an autonomous momentum unload if needed.
- The momentum can be managed with two (or less) MUs per ~22 day Station Keeping interval.

- On-board scripts exist that allow an OP initiated momentum unload.
- A Momentum Unload engineering proposal exists.
- A contact schedule has been established with DSN.
- The DSN contacts are roughly once a day.

6.2.3.3 Description

MO-987 Solar radiation pressure on the sunshield produces a torque on the Observatory, which is balanced by changing the spin rate of the reaction wheels. The reaction wheel speeds are kept within operational limits by momentum unloads using thruster firings and by minimizing the stored angular momentum accumulation by management of the observatory attitude via judicious observation scheduling (**TBD**).

MO-988 Momentum unloads perturb the Observatory's orbit which impacts the ability of FDF to obtain an orbital solution. This causes the momentum unloads and the Station Keeping orbit maintenance activities to be coupled:

- At most, two momentum unload activities can occur in the interval between two SK maneuvers.
- If needed, a momentum unload activity will be planned within one day before a planned Station Keeping maneuver.
- If needed, a second a momentum unload activity will be planned. The S&OC shall ensure that the second momentum unload activity is scheduled no closer than four days to the first momentum unload activity or previous SK maneuver.

MO-989 All planned momentum unloads will be planned and scheduled in the same manner as routine science and calibration visits using momentum unload visits placed on the LRP and scheduled on an OP. The use of momentum unload visits allows the planning and scheduling software the opportunity to synchronize the science and engineering activities, minimizing any gap time between the sets of activities, and allows the development, tracking, and reporting of the engineering activities using the same software tools as those used for the science and calibration activities.

MO-990 A momentum unload visit will slew to the momentum unload attitude, configure the observatory for the momentum unload, perform the momentum unload, and re-configure the Observatory for normal operations (Figure 6-6).

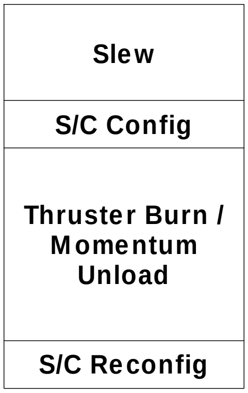


Figure 6-6: Routine Momentum Unload Visit

MO-991 For every momentum unload, the Observatory will use an optimized attitude, within the pointing constraints of the Observatory, such that the thruster firings for the momentum unload will produce the minimum perturbation on the JWST orbit. The momentum unload attitude may be calculated on the fly by on-board software, or may be determined by FDF and forwarded to the S&OC for uplink to the Observatory prior to the execution of the momentum unload.

6.2.3.4 Interaction between Momentum Management & Orbit Maintenance

MO-992 The requirement to provide FDF with a ~22-day attitude profile and the need to ensure the number of planned momentum unloads do not violate the constraints will nominally require the creation of a schedule that extends to the next SK maneuver or beyond. During the schedule construction, the S&OC will model the accumulation of the angular momentum in each reaction wheel and, as needed, will place a momentum unload visit in the schedule to maintain the reaction wheels within their limits.

MO-993 Figure 6-7 illustrates a momentum management timeline based on a nominal interval between station keeping maneuvers of 22 days, and two momentum unload activities in the 22-day period – the first occurring near the middle of the period and the second occurring within a day prior to the station keeping maneuver. The timing of the first momentum unload is not critical to the orbit determination process, subject to the constraints identified in the JWST Science & Operations Center Element Requirements Document (JWST-RQMT-002032). Additionally, the 22-day interval between station keeping maneuvers is not rigid, and may be extended by a few days.

MO-994 Not shown in Figure 6-7 is the weekly provision of telemetry to the FDF by the S&OC (definitive attitude profile, the reaction wheel load history, thruster firings, and mass estimates) or the daily DSN contacts. Finally, the FDF will provide ephemeris updates and other mission planning data to the S&OC on a weekly basis, as per the JWST DSMS Service Agreement (DSMS No. 870-421). This too is not shown in the diagram. The timeline description starts just after the first displayed station keeping burn in the diagram.

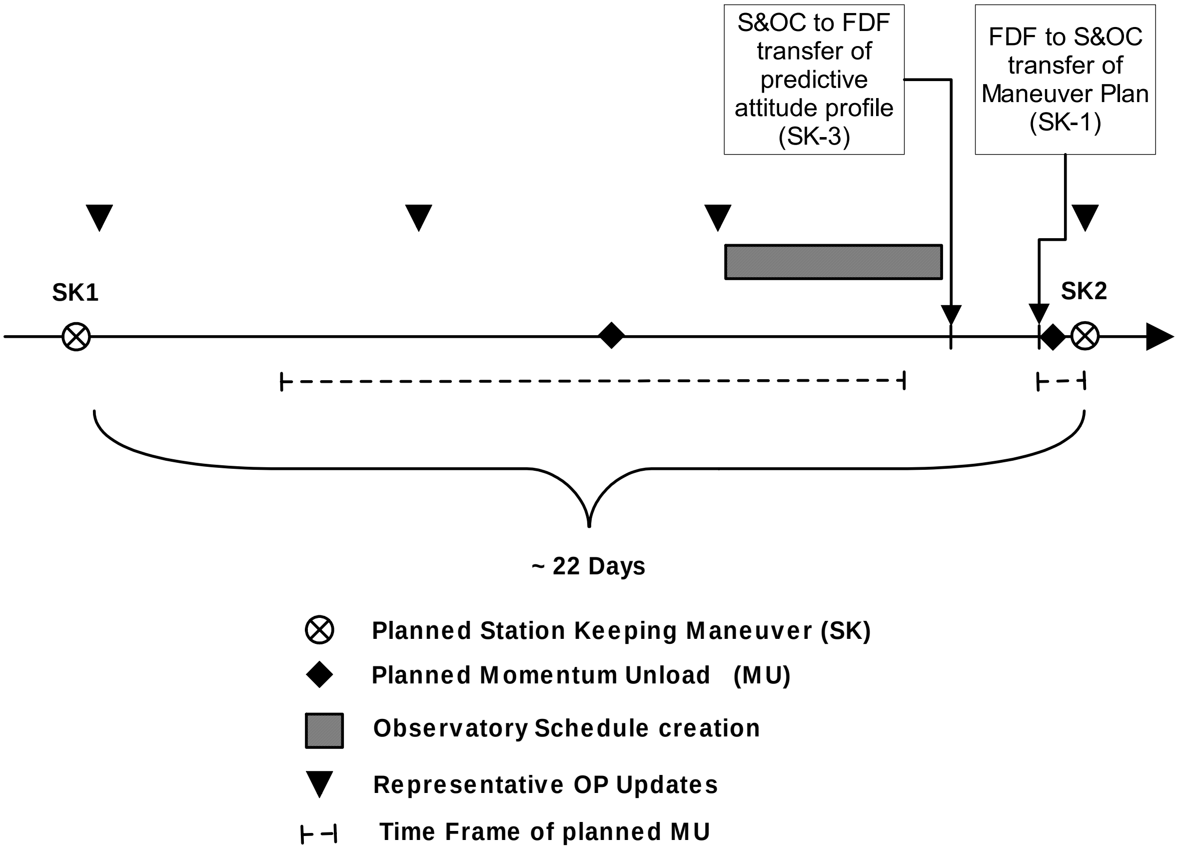


Figure 6-7: Momentum Management Timeline

MO-995 The OP execution is started by ground command after completing the SK burn and the reconfiguration of the Observatory for normal operations. During the interval between SK maneuvers, OP updates will occur as needed. In addition, the S&OC will monitor the execution of the OP and compare the current Observatory momentum state with that expected. Changes to the planned timeline, such as a visit failure will be examined to determine if modification of the unexecuted timeline is needed to prevent an undesired momentum unload.

MO-996 No planned thruster activity occurs until the planned momentum unload visits execute as part of normal OP processing.

MO-997 Starting about a week and a half prior to the next station keeping maneuver, and taking about a week, the S&OC will generate an observatory schedule covering the interval between the next two station keeping maneuvers.

MO-998 Three days prior to the station keeping maneuver, the S&OC will provide the FDF with a predicted attitude plan, generated from the observatory schedule, to be used by the FDF to bias the station keeping maneuver to allow for the anticipated effects of solar radiation pressure on the JWST orbit. At least one day prior to a station keeping maneuver, the FDF will deliver the maneuver plan to the S&OC, which specifies which thrusters will be fired for how long and the time at which the maneuver will be executed, as well as the attitude required for the maneuver. The S&OC will review the plan and convert it to actual spacecraft commands for uplinking to the Observatory. Following the execution of the station keeping maneuver, the cycle of activities repeats.

6.2.4 Memory Load Scenario

6.2.4.1 Objective

MO-757 The Observatory Flight Software (FSW) Memory Load scenario describes the process for commanding a software-assisted load of the flight software to RAM memory of an on-board processor. This process is used to update the flight software resident in the ISIM Flight Processor (FP) and the spacecraft bus FP and is applicable to “Table Loads” and “FSW patches” (also known as ”Raw Loads”); however, this scenario will focus on “FSW patches” since these require more rigorous attention. Memory loads can be performed in any operational Observatory mode. This scenario describes normal planned updates as part of normal operations and does not address contingency operational requirements.

MO-758 **Note:** A FSW “Table” is a high level construct that allows ground to access select onboard variables and constants independently of the physical address of that data. Each Table is defined with a static identifier. Some “table loads” (ephemeris updates, for example) will not follow the exact process as described within. Others (ACS K-Constants, for example) will receive the same level of attention as “FSW patches”.

6.2.4.2 Assumptions

MO-759 The following assumptions are made about the scenario:

- The FP being modified is the primary online and running processor (i.e., not a backup offline and running processor).
- The FP being modified is executing normally (i.e., the processor hardware and the command processing function in the processor software are executing normally and there are no additional contingency operations that need to be performed).

- The memory load is being made to RAM (i.e., this scenario does not describe how to update EEPROM).
- The appropriate CCB has approved the update, per established procedures.
- A FSW maintenance facility is in place and operational (i.e., the SVL or OTB).
- The Memory Load has been created and tested by software maintenance personnel.
- Flight software regression tests have been performed.
- The Memory Load has been scheduled.
- The Observatory is in ground contact.
- This scenario does not cover uploading of Observation Plans, Activity Descriptions (ADs) Visit files, or Translation Database Loads.
- This scenario does not describe how to perform CFDP uploads.
- The following data integrity protections are assumed to exist:

Table 6-2. Data Integrity Protections

Protection	Description	Fault Response
Error Detection And Correction (EDAC)	All JWST C&DH memories (FPs and SSR) use single error correction, double error detection (SECDED) EDAC. EDAC will automatically correct all memory single event upsets (SEUs) through detection on read cycles and continuous background scrubbing. This process is referred to as "scrubbing" memory. Memory scrubbing rate ensures error-free operation during the entire JWST mission lifetime. SECDED memory scrubbing will include existing FP “RAM disks.”	Double errors result in processor halts
FP Memory Checksum	FPs periodically perform algorithmic memory integrity checks that validate checksum regions of memory. Memory Scrubbing is an acceptable FSW test for “hardware” failed memory, but it doesn't protect against the ground overwriting critical memory in error. This is an additional memory integrity check that ensures a FP doesn’t continue operating if a memory load is mistakenly built for the wrong locations.	Checksum mismatch will result in FP halt.
File Checksum	Memory load processing provides an additional checksum calculation (“File Checksum”) that will be used in the file transfer process. “File Checksum” is ground computed checksum of all memory load file segment data. The memory load processing function will include this computed checksum with the memory load file when uplinked.	File checksum failure should result in message to ground and automatic deletion of memory load from FP memory

		load buffer
CCSDS Data Integrity	During reliable uplinks CCSDS transmits packets in segments called *Command Link Transmission Units* (CLTUs). CCSDS includes parity checksum checks at the CLTU level; and, Cyclic Redundancy Checks (CRC) at the CCSDS transfer frame level.	Bad CLTU is discarded, retransmit flag is set
Databus Integrity	All JWST C&DH processor address and data buses employ parity checks for internal data integrity.	

6.2.4.3 Description

6.2.4.3.1 Prep Phase

MO-760 The process of generating a FSW Patch begins with the identification of a need for a FSW change (or update). FSW maintenance personnel, an Observatory engineer, or the operations staff can make the change/update identification. A description of the problem is generated along with a proposed solution or corrective action. The affected FPs are also identified.

MO-761 The problem description and solution are presented to the appropriate CCB for approval. If the flight software update is approved, a software patch is prepared and tested by the FSW maintenance personnel using the FSW maintenance facility.

MO-762 The FSW maintenance personnel identify the source code areas that need to be patched and the algorithm required to fix the problem. Depending on the size, type, and complexity of the fix, the maintenance personnel may implement the algorithm using assembly instructions or by recompiling the code and determining the differences. If the fix is to a data base value, the fix may simply be a modification to that particular location in memory and can be created using automated tools.

MO-763 After a patch is prepared, it is tested using existing test procedures, as appropriate. New or modified test procedures may be required. Once the maintenance personnel are satisfied that the patch is correct, regression testing is performed with the FSW and Software Verification Lab (SVL) or Observatory Test Bed (OTB) to verify that the patch did not affect other algorithms executing in the FP. The originator of the update request also verifies that the patch has produced the expected result.

MO-764 After the patch is successfully tested, memory load commands need to be prepared to load the patch. These commands contain data such as the size of the patch, the address the patch is to be loaded to, the patch itself, and checksums. For large patches, multiple sets of memory load commands are created.

6.2.4.3.2 Build Load Phase

MO-765 To create memory loads, the FSW specialists and Observatory engineers have on-line support functions and off-line tools. The on-line support capabilities are provided by the Common C&T Ground System and include real-time *knowledge* of all FSW images on board the Observatory. That is to say that the common ground system will contain real-time images of FPs, and automatically update the ground images of FP memory as soon as telemetry indicates successful processing of memory loads. Included in this capability will be the common C&T ground system software function to provide a ground-computed checksum for all FPs of the Observatory. When a memory load uplink is requested, the common ground system will automatically insert the new expected computed checksum value into the memory load commands (per appropriate formats). This approach prevents pre-built memory loads (patches) from become stale (or unusable) because an unaccounted for memory load was uploaded which affected the checksum, making all subsequent loads with pre-built checksums stale. This is of greater concern in Observatory integration and test (I&T) where FSW patches, modifications, etc may require quick turn-around to complete testing in a timely manner.

MO-766 With the off-line tools, the FSW specialists and Observatory engineers will be able to produce a memory load which is compatible with the common ground system from an ASCII text file, or GUI, as input.

MO-767 The following requirement(s) based on the above are suggested.

6.2.4.3.2.1 Common Ground System Support Functions:

MO-768 The Common C&T System shall provide the capabilities for handling of Memory Loads:

MO-769 (A) Memory Load Formatting - The capability to format spacecraft flight software, spacecraft bus tables, and instrument calibration tables for the Observatory FPs.

MO-770 (B) Flight Processor Images - The Common C&T System shall contain images of on-board processors to support Memory Load Processing.

MO-771 (C) Image Checksum Calculation - Provide a ground-computed function that independently calculates memory checksum for all FPs on the Observatory. The Common C&T System will utilize its ground images of FPs to accomplish this function.

MO-772 **Note:** Memory load processing provides an additional checksum calculation (“File Checksum”) that will be used in the file transfer process. “File Checksum” is ground computed checksum of all memory load file segment data. The memory load processing function will include this computed checksum with the memory load file when uplinked.

MO-773 (D) Memory Load Uplink Processing - Accept memory load uplink files for the Observatory on-board processors, process them for upload, and perform upload including the appending of the new expected ground-computed memory checksum (see C above). This checksum is calculated when the user/operator requests a memory load uplink. Note that the new expected ground-computed memory checksum is calculated by mapping the changed data to the current image, determining the current values for each location and determining the new checksum to be placed in the load vector of the uplink load.

MO-774 (E) Checksum Compare Check - The ground capability to perform memory content verification of all reprogrammable Observatory FPs. This shall be a safety check type test that is performed by the Common C&T which compares the FPs computed checksums reported in telemetry to it's own ground-computed values for each FP image. This safety check is performed when manually invoked by the user/operator, before every memory load uplink, and/or (**TBD**) internal function. If the check fails, Memory Load Processing will be inhibited (this may be overridden by the FOT operator).

MO-775 (F) Memory Load Validation - Verify a FP is in a condition for memory load uplink by performing a Checksum Compare Check prior to each uplink. If the check fails, the load will be inhibited.

MO-776 (G) Checksum Calculation Update - The common C&T shall automatically update its ground image(s) of FP memory as soon as telemetry indicates successful processing of a memory load. The value and location for update as determined by the contents of the previously loaded memory load uplink file. "Successful processing" means successful ingest of the memory load file into its destination FP.

6.2.4.3.2.2 Offline Tools

MO-777 Memory Load Tools will be provided to support the creation of Memory Load files:

MO-778 (A) Table Load Input Tool - A GUI tool which builds an input file by filling in fixed fields which are controlled to only allow entries to match the FSW IPT defined field entries.

- The Table Load Input Tool shall be limited to Observatory Flight Processor (FP) variable names and engineering units and shall convert the variables to addresses and the appropriate hex value(s) using a memory map and a scale factor table.
- The output file will be a text file with an output extension: **.dat**.
- The ability to modify any given .dat via a text editor will be provided as an alternative solution to using the GUI tool
- The GUI tool will contain a "Finished button" which will automatically perform MLPP processing (see C, below) of the GUI inputs.

MO-779 (B) Stored Command Sequence Load Input Tool - A tool which builds an input file by filling in fixed fields which are controlled to only allow entries to match the defined SCS field entries.

- The SCS Load Input Tool shall be limited to Observatory FP SCS tables and shall convert the field entries to addresses and the appropriate hex value(s) using a memory map and a scale factor table.
- The output file will be a text file with an output extension: **.dat**.

- The ability to modify any given .dat via a text editor will be provided as an alternative solution to using the GUI tool
- The GUI tool will contain a “Finished button” which will automatically MLPP processing (see C, below) of the GUI inputs.

MO-780 (C) Memory Load Pre-Processor (MLPP) Tool - The tool that processes the input .dat files created by tools a-c above to create/build the Memory Load File in a form that would be recognized by the Common C&T System Memory Load Processing Function. When invoked to process a memory load (.dat) input file, the MLPP Tool will produce TWO output files:

- The uplink file containing the converted variables to addresses and the appropriate hex value(s). This output file will be a file with an output extension: **.ccf**. This is the final file that will be processed by the common C&T memory load processing function, when requested.
- A report version of the load to be used to review the work of the tools. This text file will contain the appropriate hex value for each address and indicate the load vector information to the user (starting address, how many consecutive words, anticipated file load checksum, etc). This output file will be a file with an output extension: **.lis**.

MO-781 **Note:** The benefit of these tools is that they provide the ground teams with a common interface for memory loads regardless of specific implementations of each FP (should differences occur). In other words differences could be handled automatically within these tools and functions based on targeted FPs such that the user doesn’t have to interact differently for the FP being patched.

6.2.4.3.3 Test Load Phase

MO-782 After the memory load commands are prepared to load the patch, they must be tested by FOT personnel on the OTB for accuracy prior to transmission to the Observatory. Then, a time is determined to upload the patch. This is coordinated with the operations staff.

6.2.4.3.4 Load Phase

MO-783 After approval for the load hast been attained and the uplink time established, the FOT Operator will make an entry at the command terminal/window requesting the common C&T memory load processing function to upload the file to the targeted FP of the Observatory. The common C&T memory load processing function would first respond by performing a check to see if it’s ground-computed checksum and the associated FP’s checksum as reported in telemetry are in sync. After successful verification o, memory load processing function would then prepare the memory load for uplink. Preparing the load for uplink involves retrieving the file from disk;

processing image checksum including the appending an expected memory checksum for the targeted FP; and uplink of the completed file per CCSDS protocols to the Observatory and stored in the memory load buffer of the targeted processor until the entire load is received. Once the load is received, the FP software verifies that the load was received correctly (e.g., correct size, correct buffer checksum, valid memory addresses). If the File Checksum Check fails, the FP software will issue a File Checksum Failure message to ground and automatically delete the failed memory file from the buffer. If the File Checksum Check passes, the FP software will complete memory load processing. The FP continues load processing by loading the memory load contents into FP memory, automatically deleting the memory file from the buffer at completion of the transfer, and issuing a Memory Load Processing Complete Message to the ground. Note that the FP software will also include a timeout function, that should the memory load fail to be completely uploaded within a specified time, the FP software will automatically delete the incomplete memory file from the buffer·

MO-784 **Note:** FPs periodically validate checksum regions of memory to detect and correct memory faults. To avoid false identification of memory loads as memory faults, the periodic on-board checksum processing is disabled during the memory load process and automatically re-enabled upon its completion.

MO-785 Upon telemetry reporting successful memory load, the common C&T memory load processing function would then automatically update the appropriate stored image file (in real time).

MO-786 Throughout memory load operations, the FOT crew monitors Observatory telemetry to verify that the memory load was correctly received and that the post load checksum is accurate. If desired, the modified portion of FP memory may be dumped for a comparison with the expected memory image maintained in the common C&T ground system. Memory load commands can be intermixed with other flight software commands to the same processor, but the flight software only processes one memory load at a time.

6.2.4.3.5 Post Load Phase

MO-787 After the successful loading of the patch, the FSW maintenance personnel update their baseline configured processor software image file maintained in the FSW maintenance facility to reflect the current on-board image, as required (for SDL, SVL, and OTB).

6.2.5 Ephemeris Management Scenario

6.2.5.1 Objective

MO-788 This scenario describes the nominal system functions performed during the upload of a new satellite ephemeris.

6.2.5.2 Assumptions

MO-789 DSN is the T&C ground station

- Pre-pass checks with DSN conducted successfully and nominally
- Ephemeris uploads are performed during real time contact with ground. Also, during the early months of nominal operations, each uploaded ephemeris will be time-tagged with an epoch time that occurs during the real-time scheduled contact. This will assure that the core team of FOT, Flight Dynamics & Support personnel are on-duty in the event of a major attitude excursion. This will be re-addressed once the team has gained confidence in their ephemeris generation processes, etc.
- This contact assumed to be a 1 hour pass over a DSN Ground Terminal
- The JWST S-Band transmitters are assumed to always be transmitting
- The FOS coordinated and established the DSN contact schedule and resource use.
- The FDF previously generated the required products (e.g. ephemeris table load, ephemeredes for ground terminal locales, etc.) in a format ready for uplink
- A time-tagged command was included in the OP that will issue a message log entry indicating the scheduled epoch time for ACS FSW acceptance of the new, uploaded ephemeris. This will alert the user community to the planned maintenance activity.
- A FOS memory load verification tool for real-time memory dump capture and verification has been developed.

6.2.5.3 Description

MO-790 JWST must perform weekly ephemeris uploads in order to meet and maintain the milliarcsec pointing requirements of the Observatory. Daily ranging contacts, distributed between DSN ground terminals located in the northern and southern hemispheres will be scheduled over a 21 day cycle to facilitate the orbit determination performed by the GSFC Flight Dynamics Facility. During the early phases of the mission, ephemeris uploads will be generated with an epoch time that occurs during the scheduled ground contact. However, once the team is confident in the orbit determination process and procedures, this requirement will be revisited.

MO-791 At contact start, both command and telemetry links are established with the vehicle via DSN. Once a valid communication link with the Observatory has been created, the S&OC performs an overall state of health assessment of the Observatory prior to proceeding with the defined ephemeris upload pass plan.

MO-792 The actual upload plan for ephemeris management is relatively quick and simple. The first step is to upload the FDF provided ephemeris table memory load to the S/C. Upon verification that the memory load was accepted by FSW, a verification dump of the affected memory region will be performed and captured in real-time with the FOS memory dump verification tool. This memory dump will allow a comparison to be made between the modified uploaded image against the expected image maintained by the FSW maintenance facility. Once the memory dump of the uploaded ephemeris has been completed and verified, the FOT will then uplink the command to ENABLE the ephemeris upload enable flag within the ACS FSW. This will trigger ACS FSW acceptance of the uploaded ephemeris table at the desired epoch time.

MO-793 The ACS FSW is designed with storage for 2 ephemeris tables. The first table contains the “in-use” ephemeris table that the ACS FSW uses for its attitude propagation and determination algorithms. The second table contains the “not-in-use” ephemeris table that is ignored by the ACS FSW unless the ground or OP commands the ephemeris upload “enable” flag to ENABLE. Once the ephemeris upload flag is enabled, the ACS FSW computes and converts the uploaded epoch time (i.e. the ephemeris “kick-off” time) into ACS mode time, therefore flagging the time for the ACS FSW to accept the new uploaded state vector.

MO-794 At the uploaded ephemeris epoch time, the ACS ephemeris enable flag will autonomously transition to DISABLE, indicating that the FSW has accepted, and is now using the newly uploaded ephemeris table. A slight attitude perturbation may be observed, but science should not be impacted.

6.2.5.4 Flow Diagram

MO-795 The flow diagram in Figure 6-8 depicts the nominal ephemeris table upload flow as described in the previous paragraphs.

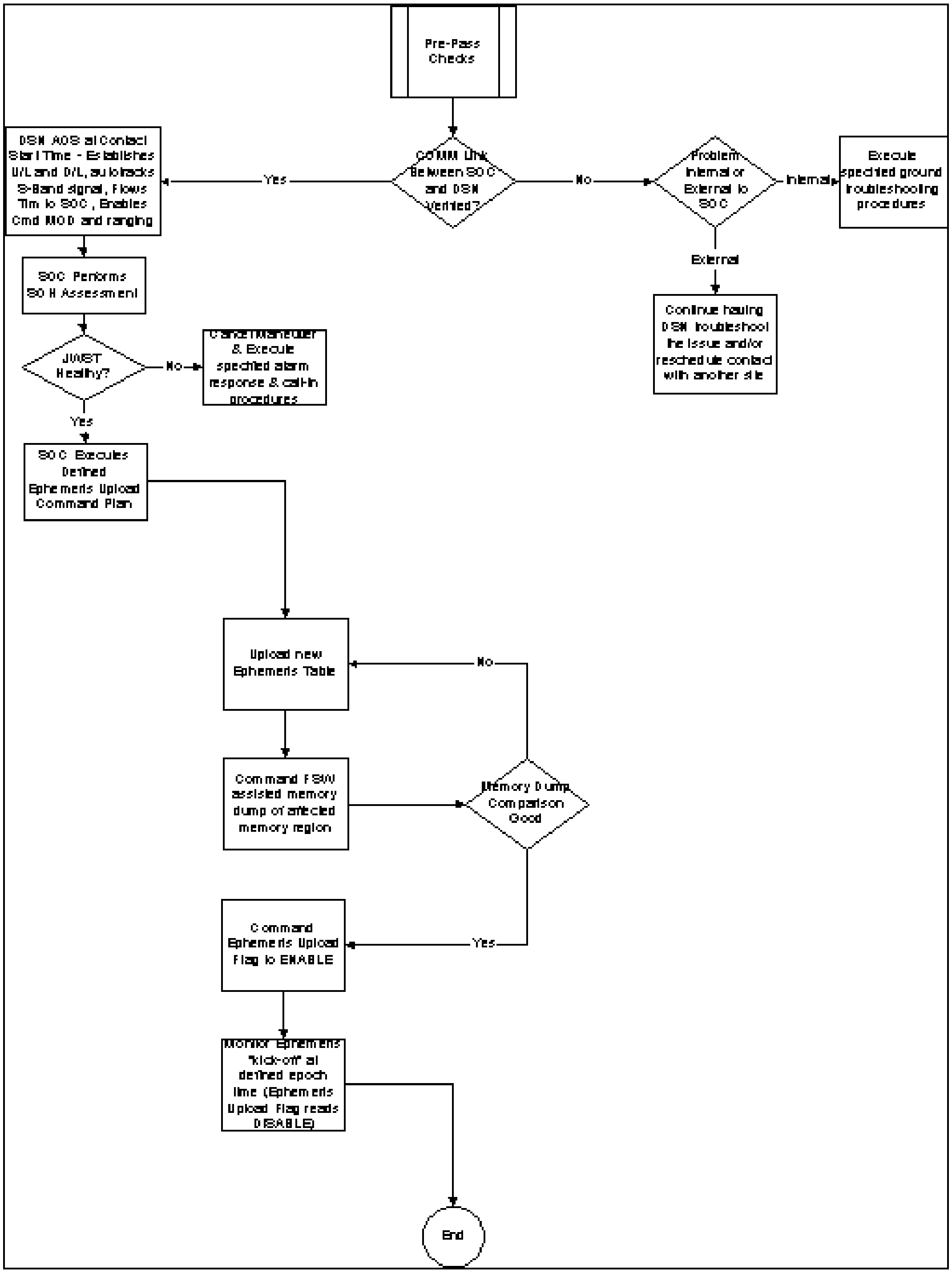


Figure 6-8. Ephemeris Upload Scenario

6.2.6 On-board Clock Synchronization Scenario

6.2.6.1 Objective

MO-796 This scenario describes the nominal system functions required to maintain S/C on-board time to within 1 sec of UTC (MR-142).

6.2.6.2 Assumptions

MO-797

- The requirement for the accuracy of the on-board clock is to be within +/- 1 s (UTC) (MR-142)
- The on-board clock is sufficiently stable that clock updates are needed no more than once a day (MR143). In fact, the EOL accuracy of the TCXO (temperature compensated crystal oscillator) that will be used on JWST is 4ppm. This implies in a worst-case drift of ~ +/- 346ms per 24 hour period, or a time of nearly 3 days (2.89 days to be precise) between clock corrections.
- The DSN is the T&C ground station
- Clock updates can be conducted at any time during a scheduled real-time contact.
- The JWST S-Band transmitters are assumed to always be transmitting
- The FOS coordinated and established the DSN contact schedule and resource use.
- Pre-pass checks with DSN conducted successfully and nominally
- Losses/delays attributed to internal S/C routing of data, and to DSN terminal equipment are known. Space to Ground delays computed in real-time using provided range data.
- A real-time tool that samples/reads the S/C telemetered hardware time stamp and the DSN ground stamped time tag (GRT - ground receipt time), and combines this data with user input data (e.g. DSN site and range data) and pre-defined “loss” data to compute a +/- delta between on-board S/C time and UTC (i.e. indicating a “fast” or “slow” on-board clock.) has been developed. This tool will also create a delta time data file that can/will be used for offline frequency drift trending.

6.2.6.3 Description

MO-798 Incorrect on-board time leads to pointing error. Therefore, JWST must perform periodic on-board clock updates to maintain its required Observatory pointing stability. In order to meet its stability requirements, the S&OC must maintain on-board time to within +/- 1 s of UTC.

MO-799 JWST will use the “Return Data Delay” (RDD) method for performing time correlation between on-board time and UTC. RDD requires knowledge of the internal S/C delays, the actual ground station in-use delays, and the range propagation delays at time of interest. On JWST, there is no ultra-stable oscillator used for time generation. Instead, a crystal oscillator (TCXO - temperature compensated crystal oscillator.) will be used to feed a hardware clock-time generator. Basically, a real-time telemetry VCDU on a specific virtual channel (e.g. channel 1) will cause an on-board hardware time stamp. The time stamp, VCID, & VCDU sequence counter are placed in a telemetry packet with a specific APID and sent to the ground. The RDD calculation will result in the delay from the time of this on-board hardware time stamp to the time of a ground UTC time stamp of this data.

MO-800 The S&OC will be provided with two ground command methods for on-board clock maintenance. The first is a straightforward time adjustment command. This method will utilize the aforementioned real-time time-delta tool, and will be the “routine” clock maintenance activity performed by the S&OC. The second method enables the S&OC to adjust the frequency of the crystal oscillator via uplink of a “drift correction factor. At present, the drift correction factor would be implemented via a memory load. The “drift correction factor” would cause the CTP to periodically adjust the hardware time-of-day clock to compensate for the drift, and subsequently minimize the frequency of ground commanded time adjusts. These two methods are described in the sections below.

6.2.6.3.1 Time Adjustment Command

MO-801 An on-board time delta check is performed during each scheduled real-time contact, or at least once a day. The FOS time-delta tool is used for real-time calculation of the desired command update parameters. At any time during the scheduled contact, the S&OC will commence execution of the time-delta tool. The tool will first compute the space-to-ground loss using the input DSN terminal and ranging data. Then, the tool will sample both the telemetered on-board hardware time stamp and the DSN time tagged UTC value. Adding the previously computed space-to-ground “loss” value to the sampled on-board hardware time stamp, and then subtracting that value from the sampled ground stamped UTC will result in a time-delta between the on-board clock and UTC that accounts for all of the losses in between. A positive result will be an indication of a “slow” on-board clock, whereas a negative result will be an indication of a “fast” on-board clock. If the computed time-delta falls outside of the +/- 1 s tolerance, then the time-delta tool will generate the on-board time adjustment command, which will adjust the time by “delta-time” steps, for uplink by the FOT.

Note: To avoid any resultant attitude disturbances during accurate pointing/science mode, the size of the time jumps will be limited by generating a sequence of time deltas for small scale corrections. For non-science/station-keeping periods, a single, large time delta will be performed.

MO-802 If an on-board clock update was commanded, then following acceptance of the commanded update, the FOT will re-run the time-delta tool to verify that on-board time is within the specified +/- 1 s tolerance of UTC.

6.2.6.3.2 TCXO Frequency Adjustment

MO-803 There is an inherent drift in the frequency of the TCXO that if unaccounted for will result in a daily divergence of on-board time from UTC. This divergence in time would violate the +/- 1 s tolerance requirement, and would necessitate frequent daily on-board time adjustments. Therefore, to minimize the effect of this drift rate on the hardware clock-time generator, a frequency adjustment memory load will be uploaded on an as-needed basis to “bias” on-board time and offset the daily “gain” or “loss” in time due to this frequency drift.

MO-804 Off-line trending analysis will be performed by the FOT to determine the daily frequency drift rate of the TCXO. Using the time-delta tool and the archived real-time telemetry, the FOT will playback the telemetry through the time-delta tool to generate a time-delta data file. This data file will then be used to generate a daily delta versus time plot that will assist the FOT in determining daily time “loss” or “gain.” Then based on the observed trend, and the current frequency of daily time adjustments, the FOT will make a decision as to whether a frequency adjustment is required.

MO-805 If the decision to perform a frequency adjustment is made, then the desired update is entered into the Memory Load Table Load Input Tool for input data file generation. The Memory Load Pre-Processor Tool in turn builds this data file into an executable memory load file for uplink by the FOT during the next scheduled ground contact.

6.2.6.4 Flow Diagram

MO-806 The below flow diagram in Figure 6-9 depicts the nominal on-board clock synchronization scenario as described in the previous paragraphs.

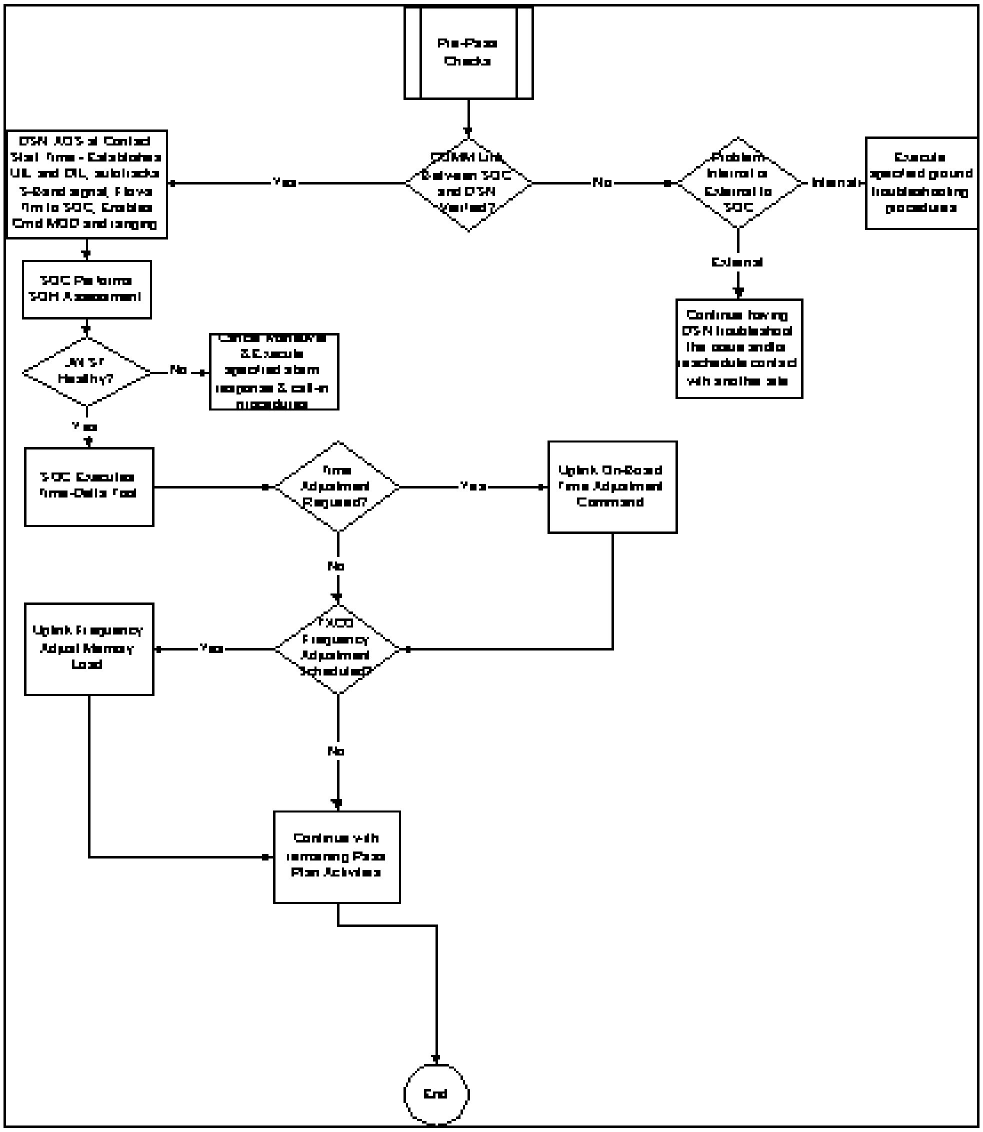


Figure 6-9. Scenario for On-board Clock Synchronization

7.0 CONTINGENCY OPERATIONS

7.1 SCIENCE INSTRUMENT CONTINGENCY OPERATIONS

7.1.1 Science Instrument Fault Detection and Recovery

7.1.1.1 Objective

MO-807 The Observatory flight software has the responsibility for monitoring the on-board hardware for anomalous conditions. In certain critical areas, an actual hardware monitor may exist. These software (and hardware) monitors must react appropriately to place the hardware in a "safe" off-line configuration. Ground investigation is required for most anomalous situations before the subject hardware can be used again. This section describes monitoring, analyzing and recovering from anomalous science instrument conditions during the normal operations.

7.1.1.2 Assumptions/Preconditions

MO-808 The following assumptions and preconditions apply:

- All the necessary science instrument health and safety protections are on-board the Observatory. This includes the sensors to do the measuring, and the flight software to enforce the legal operational ranges and to request the appropriate reaction.
- This scenario deals with the science instruments that are operated and monitored by the IC&DH computer (NIRCam, NIRSpec, and MIRI) or the FGS computer.
- An OP segment and the associated visit files have been uplinked to the Observatory.
- The on-board OP is currently being processed.
- No OPE processing errors occur during the execution of this plan.
- During OPE processing of this on-board OP, an anomaly arises that prevents the execution of a requested task. Example 1: The flight software NIRCam filter wheel voltage upper limit is exceeded. Example 2: A check of the IC&DH computer's integrity fails. Example 3: A detector electronics related error is detected for the MIRI imager.
- Flight software and hardware reactions to anomalies complete as planned and within sufficient time to prevent damage to the Observatory systems.
- Critical ground staff personnel are on-call to address anomalies as they are reported from the Observatory.

7.1.1.3 Description

MO-809 The IC&DH computer flight software monitors critical science instrument hardware and flight software status indicators and automatically responds to in-flight anomalies and exceptions. Each anomaly has a single flight software response. All the anomaly-response pairs will be defined and tested prior to launch. Based upon in-flight experience and science instrument degradation it may be necessary to update the response to a specific anomaly. The association of a response to an anomaly is ground modifiable and easily accessible (that is, a flight software code patch is not required to modify this association).

MO-810 So that management and tracking of flight software error paths can be simplified, each science instrument will have a limited set of responses. These can be thought of as different levels of science instrument safing. Examples of the possible response levels are: 1) report anomaly only, 2) take one field-of-view off-line, 3) take complete science instrument off-line, and 4) take IC&DH computer off-line.

MO-811 Anomaly notification is available for examination by the on-board ADs, and it is also placed within an on-board event data for future downlink that contains information on the type and time of each anomaly and the response taken by the flight system. The log is downlinked at the start of every communications contact and periodically during each contact. When reviewing the anomaly log, the ground monitoring software automatically and electronically notifies the appropriate on-call ground staff depending upon what anomaly was encountered. Analysis begins to identify the cause. Certain errors may require the formation of an anomaly review board, and it may take a considerable time to review the hardware/software failure, to identify the cause, and to devise a recovery plan. For every anomaly, an explanatory summary report is produced and posted in an electronically accessible archive. This archive is used to track each science instrument anomaly, its status (i.e., open, under investigation, closed), along with its final resolution. It is important for this anomaly archive to be searchable and properly designed so that similar and/or related anomalies can be categorized. For example, it should be possible to retrieve all anomalies pertaining to a certain hardware component or all anomalies relating to temperature violations, etc. The database will also include anomalies discovered by ground analysis of science and/or engineering data. Once the ground personnel and/or the anomaly review board have completed their analysis and an approved plan exists, then the engineering recovery visits are scheduled for placement on an OP segment.

MO-812 A visit failure review board (with its list of replanning policies) examines each skipped or compromised visit and determines a rescheduling recommendation. Lost visits due to hardware failures will likely be placed back into the planning visit pool.

7.1.1.4 Representative Response Examples

7.1.1.4.1 Take IC&DH computer off-line:

MO-813 If while processing the OP, an unexpected result within the IC&DH (or FGS) computer flight software is encountered, then the integrity of the IC&DH (or FGS) computer is in question. The IC&DH computer should be taken off-line because it can no longer be relied upon to protect the science hardware. Ground analysis is required before further JWST operations resumes.

7.1.1.4.2 Take complete science instrument off-line:

MO-814 The safing of a complete science instrument can occur when specific flight software applications detect a dangerous situation within its critical hardware components and instrument power must be removed. A dangerous situation could be an internal temperature/current exceeding health and safety limits, or the lack of critical mechanism motion verification.

MO-815 When the science instrument is taken off-line, that information is placed in the event data and is available for interrogation by on-board ADs. It is then possible for an AD to set a flag that causes the OPE to skip all tasks involving the subject science instrument while still processing the rest of the OP. The skipped tasks could include slews, guide star acquisitions and spacecraft dithers that support this science instrument's observations. As each task is skipped due to science instrument safing, notification is placed in the activity log. Ground analysis and a recovery plan will be created before operation of this science instrument resumes.

7.1.1.4.3 Take one field-of-view off-line:

MO-816 Note that not all science instrument anomalies require a full instrument shutdown. Depending upon how the science instruments are constructed, it could be possible just to shutdown the individual field-of-view at risk. This is the preferred method for handling an instrument anomaly - only remove power from or stop using those units affected. Just as it is not envisioned having to shutdown all OP processing for an isolated science instrument problem, it is not desirable to cause a total science instrument shutdown if only one of the field-of-views is having a problem. For example, if the health and safety monitoring in the IC&DH computer detects a problem with the MIRI imager, then it will notify the SP to discontinue use of the imager. MIRI spectroscopy, however, can still continue to be executed by the on-board scripts. The on-board OP continues to the highest extent possible while preserving the health and safety of the whole Observatory.

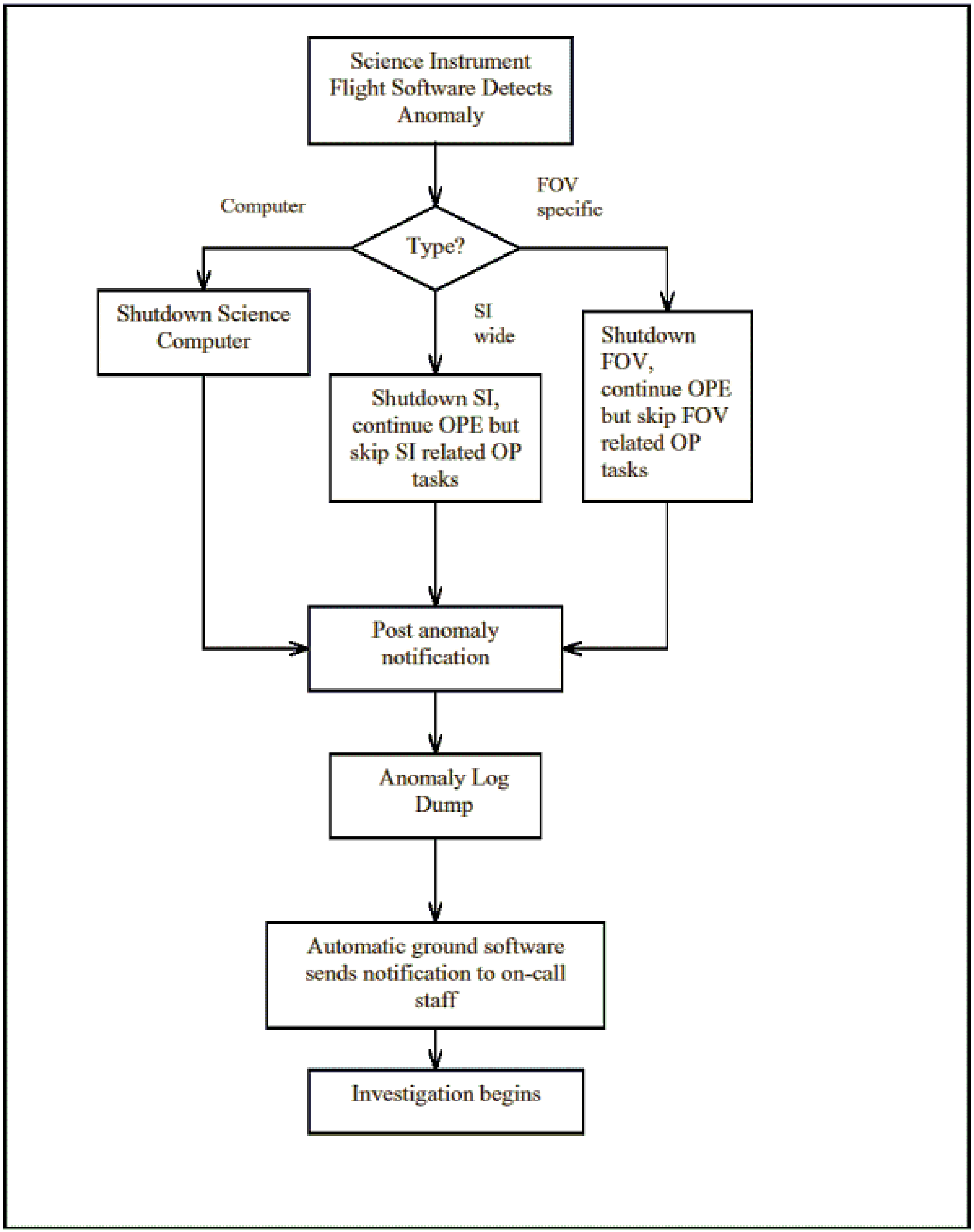


Figure 7-1. Scenario for anomaly identification

7.2 SPACECRAFT FAULT DETECTION AND RECOVERY

7.2.1 Spacecraft Safing

MO-817 Spacecraft bus safing occurs autonomously as described in section 5.6.7. Spacecraft bus design provides sufficient fault flags, event data, critical data sampling rates, and data storage to enable FOT anomaly investigations.

MO-818 The science and engineering data present in the SSR at the time of spacecraft safing will be available for dumping, once the FOT establishes it is safe to proceed with SSR playback (and following completion of autonomous safing sequences). The spacecraft bus does not provide automatic recoveries to primary configurations, as spacecraft anomaly recovery requires ground analysis and control.

MO-819 This section describes selected spacecraft bus failures to illustrate autonomous failure detection and response actions of the spacecraft bus, as well as FOT response actions to those failures for which there is no autonomous failure detection and response.

7.2.2 Loss of Telemetry Failure Scenario

7.2.2.1 Objective

MO-820 This scenario illustrates a Loss of Telemetry Failure by describing the activities involved with recovering from a failed on-board S-Band transmitter A that resulted in an acquisition of downlink signal failure.

MO-821 This is a spacecraft bus failure for which there exists no autonomous failure detection and response; i.e., the FOT must detect and respond to this failure

7.2.2.2 Assumptions

MO-822

- DSN is the T&C ground station
- This is a nominal 4-hour ground contact scheduled with a DSN ground terminal. The last S-band signal acquisition was nominal (~ 20 hours prior.)
- The JWST S-Band transmitters are assumed to always be transmitting
- The FOS coordinated and established the DSN contact schedule and resource use.
- FDF has previously verified that JWST will be in-view of the scheduled DSN ground terminal, and has provided S&OC with correct DSN antenna pointing angles.
- Pre-pass checks (e.g. NO-OP command check, etc.) and set-up (DSN antenna slewed to desired AZ and EL, data recorder configured, etc.) were successful and nominal (i.e. the comm. link between DSN and the S&OC is nominal.)
- All other satellite sensors and subsystems are performing nominally.

- Failure does not drive the Observatory into Safe Mode. It remains in wheel normal mode.
- The spacecraft bus provides a *dual* real-time telemetry downlink mode where real-time telemetry is routed via both the S-Band and Ka-Band downlinks.

7.2.2.3 Description

MO-823 Just prior to contact start, DSN will slew its ground antenna to the pre-defined pointing angles and await detection of JWST's S-band signal. Since the S/C S-band transmitter A is always ON, DSN is afforded the luxury of an active downlink beacon to acquire, lock, and track. The absence of this downlink beacon is an immediate indicator to DSN that there is a vehicle problem, or there is a ground terminal problem. In either case, the DSN will begin trouble-shooting activities and will query the JPL Operations Chief and the S&OC (if attended) of last known vehicle configuration. If this search is unsuccessful, then the S&OC and DSN will work together in exonerating the ground as a candidate cause of the failure to acquire the downlink.

MO-824 The following verifications will be performed prior to proceeding with any S/C contingency plan:

- Verify DSN is using correct antenna pointing angles
- Verify DSN is configured for receipt of an S-Band signal
- Verify that JWST is not emitting a "weaker" signal due to Safe Mode entry and transmitting through the omni antenna
- Verify that JWST is to be in-view of scheduled DSN site
- Verify (via a command log check) that the S-Band Transmitter A was not accidentally commanded OFF at the end of the last DSN contact
- Verify with FDF that the on-board HGA ephemeris is correct and up-to-date

MO-825 Once the ground has been exonerated, the S&OC will proceed with its "Failure to Acquire" procedure. The first step in this procedure will be to transmit commands in the blind, which activate the Ka-Band transmitter and configure real-time telemetry routing down the Ka-Band link. For purposes of this scenario, upon command acceptance by the spacecraft bus, DSN detects an Ka-Band downlink signal from JWST, and begins to auto-track that signal while passing real-time housekeeping telemetry to the S&OC for SOH analysis. Once it has been determined that JWST is "healthy" and is NOT in Safe Mode or Survival Mode, the S&OC will then begin configuring both the Observatory and the ground for an SSR playback. The decision to transfer to redundant S-Band transmitter operations will be deferred, pending an anomaly investigation. Subsequent review of the dumped data reveals an abnormal S-band transmitter thermal and power signature, characteristic of a failed transmitter. This finding is elevated to the JWST Flight Director and Anomaly Review Team, where the S&OC will be tasked to establish normal S-Band operations via the redundant S-Band transmitter. This task includes identification and update of all impacted Observatory operating procedures and products, in addition to any on-board safing algorithms that default to S-Band Transmitter A for contingency purposes.

7.2.2.4 Failure to Acquire Outline

MO-826 Since this scenario was "resolved" with the first step of the Failure to Acquire procedure, provided below is a brief outline of the Failure to Acquire philosophy.

MO-827 1. Re-apply commands to establish the expected command configuration. That is, command ON the primary S-Band Transmitter (assumed via the HGA)

- In Safe Haven, the on-board Fault Management will turn-ON the S-Band downlink via transmitter A and the low gain omni. So if the vehicle were in Safe Mode, we would expect to detect a "weak" downlink signal from JWST. Since DSN detects no signal, suspect a transmitter issue (although Observatory pointing is still a possibility.)

MO-828 2. Command ON the primary Ka-Band Transmitter (assumed via the HGA) and configure for real-time telemetry routing down the Ka-Band link.

- The spacecraft bus provides a dual real-time telemetry downlink mode where real-time telemetry is routed via both the S-Band and Ka-Band downlinks

MO-829 3. Lower uplink command rate, command S-Band RF switch to re-route downlink through omni, and re-apply commands to establish the primary S-Band Transmitter A ON

MO-830 4. Command ON the redundant S-Band Transmitter B via omni (S-Band Transmitter A remains ON)

- At this point, the vehicle is configured with two active downlinks through both the HGA and Omni RF paths. Should restore telemetry if bad JWST attitude; thus this action eliminates bad attitude as the cause should telemetry continue to be missing
- No downlink signal at this stage indicates double failures or flight processor issues.

MO-831 5. Alert JWST Flight Director of troubleshooting steps taken. Initiate Factory Support Call-In. Request DSN resources to search area of sky where JWST should be located. If DSN resources unavailable, declare spacecraft emergency to get additional resources.

MO-832 6. If no signal is detected, execute procedure to swap to "offline" Flight Processor and initiate Safe Mode Entry.

MO-833 7. If still no signal is detected, await Factory Support Team recommendation.

7.2.2.5 Flow Diagram

MO-834 The below flow diagram in Figure 7-2 depicts the S-Band Transmitter Failure response steps as described in the previous paragraphs.

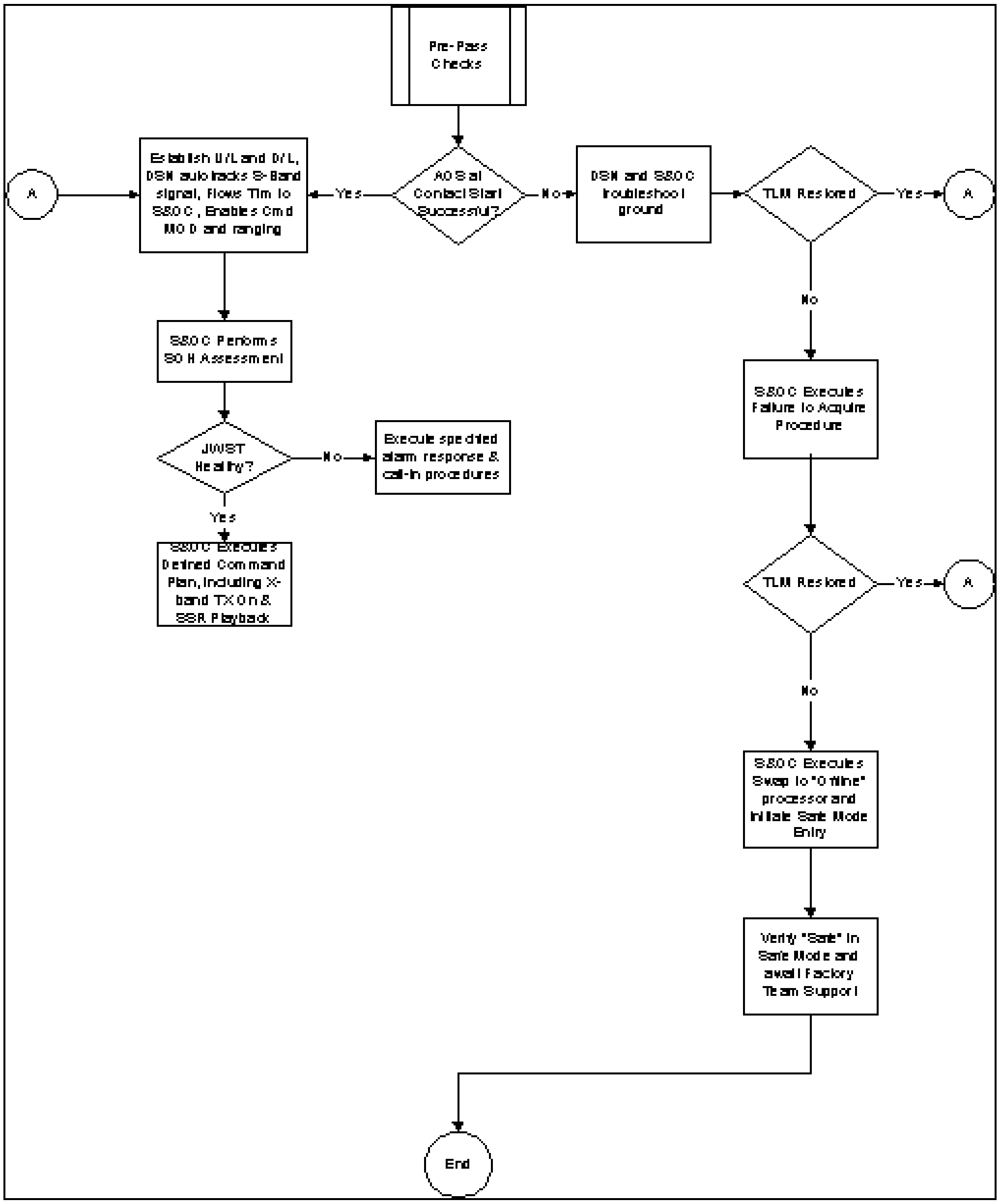


Figure 7-2. Loss of Telemetry Scenario

7.2.3 Loss of Uplink Commanding Failure Scenario

7.2.3.1 Objective

MO-835 This scenario illustrates a Loss of Uplink Commanding Failure by describing the activities involved with recovering from a failed on-board S-Band Diplexer, resulting in a loss of command through the HGA.

MO-836 This is a spacecraft bus failure for which there exists no autonomous failure detection and response; i.e., the FOT must detect and respond to this failure

7.2.3.2 Assumptions

MO-837

- DSN is the T&C ground station
- This is a nominal 4-hour ground station contact scheduled with a DSN ground terminal. The last contact was nominal (~20 hours prior.)
- The JWST S-Band transmitters are assumed to always be transmitting
- The FOS coordinated and established the DSN contact schedule and resource use.
- FDF has previously verified that JWST will be in-view of the scheduled DSN ground terminal, and has provided S&OC with correct DSN antenna pointing angles.
- Pre-pass checks (e.g. BERT [Bit Error Rate Test] check, NO-OP command check, etc.) and set-up (DSN antenna slewed to desired AZ and EL, data recorder configured, etc.) were successful and nominal (i.e. the comm. link between DSN and the S&OC is nominal.)
- All other satellite sensors and subsystems are performing nominally.
- Failure does not drive the Observatory into Safe Mode. It remains in wheel normal mode.
- S-band Telemetry Downlink has been established and is nominal via the HGA.

7.2.3.3 Description

MO-838 Just prior to contact start, DSN will slew its ground antenna to the pre-defined pointing angles and await detection of JWST's S-band signal. Since the S/C S-band transmitter A is always ON, DSN is afforded the luxury of an active downlink beacon to acquire, lock, and track. Upon acquisition of signal, DSN will pass the received S-band telemetry to the S&OC for initial assessment of the vehicle state of health. Once the S&OC determines the vehicle to be safe and nominal, the S&OC will begin execution of the approved pass plan, which usually begins with commanding ON the Ka-Band transmitter in preparation for the impending SSR dump.

MO-839 To initiate commanding, the S&OC will request DSN to go active with command modulation and range modulation enabled. Subsequent to going active on the vehicle, the vehicle's receiver lock status should read "LOCK" indicating the presence of a received uplink signal from the ground. For this scenario, upon DSN going active on the vehicle, the S&OC does not observe the expected receiver "LOCK" response in telemetry. Because of this, the S&OC and DSN operator begin troubleshooting the ground command path.

MO-840 The following items are verified prior to exonerating the ground and proceeding with any spacecraft contingency operations:

- Verify that the DSN ground terminal is in fact actively transmitting an S-band uplink
- Verify that the DSN ground terminal is configured for the correct S-band uplink command frequency
- Request use of other DSN antenna at scheduled site if available (if not available, proceed with Loss of Command procedure while noting that there still could potentially be a problem with the scheduled DSN antenna H/W.)

MO-841 Once the ground has been exonerated, the S&OC will proceed with its "Loss of Command" procedure. Inherent in the Loss of Command recovery philosophy is that the HGA is the primary path for S-Band commanding, and that the S-Band uplink RF switch (which selects command input from either the HGA or the Omnis) is in the "HGA" selected position. Therefore, the first step in this procedure will be to execute a NO-OP script that uplinks 5 NO-OP (Non-operational) commands to the vehicle to verify that the uplink path through the HGA has in fact failed, and that the HGA receiver LOCK status telemetry is not erroneous. If the command accept counter increments 1 to 5 times upon receipt of the NO-OP commands, then it is apparent that the receiver LOCK status telemetry is incorrect, and follow-up investigation into why that is will be initiated. However, for purposes of this scenario, no command accepts nor any command rejects (which also would be an indication of a good command path) were observed, so execution of step 2 of the recovery is warranted. Step 2 of the procedure directs the S&OC to uplink one of the "special" H/W commands that is not processed by the FSW and is issued directly to the subject piece of equipment by the CCM to command the S-band uplink RF switch from the HGA to the Omnis. Successful uplink of this command will result in a state change for the subject RF switch from "HGA" to "OMNI". The S&OC, upon verification of a successful RF switch change, will then re-execute the NO-OP script to verify the command link through the omni antennas. As stated previously, increment in the command accepts 1 to 5 times will indicate a valid command path.

MO-842 Now that the command link to JWST has been re-established, the S&OC will continue its configuration of both the ground and Observatory for an SSR playback. Subsequent review of the dumped data reveals that a failure occurred within the HGA S-Band diplexer in the command path, with no propagation or impact to the downlink path contained within the same diplexer.

7.2.3.4 Loss of Command Outline

MO-843 Below is a brief outline of the Loss of Command philosophy in relation to this specific failure.

MO-844 1. Uplink NO-OP command script to verify command path is faulty and receiver LOCK telemetry status is valid

- If the command accept counter increments, then exit procedure.
- If command accept counter does not increment, then continue to next step.

MO-845 2. Uplink "special" S-Band Uplink RF switch command to switch from "HGA" to "OMNI"

- Verify via telemetry RF switch status and Receiver LOCK status.
- If verified, continue to next step
- If Not verified, re-issue special command one more time (If Not verified for second time, proceed to step 4)

MO-846 3. Uplink NO-OP command script to verify command path via the Omnis

- If command accept counter increments, then exit procedure.
- If command accept counter does not increment, re-issue NO-OP script one more time. (If not verified for second time, execute S&OC/DSN ground command troubleshooting procedure. If unsuccessful at uplinking NO-OP script for a third time, then proceed to next step.)

MO-847 4. Request another DSN site

- If have already, and this is second scheduled DSN site, then notify Flight Director and initiate anomaly response team call-in prior to executing next step.
- If have not scheduled a second DSN site, then repeat procedure starting at step 1.

MO-848 5. Execute procedure to swap to "offline" Flight Processor and initiate Safe Mode Entry. This action will not only put the vehicle in a safe configuration, but it will also command the S-Band RF uplink switch to the "OMNI" position as part of the safing SCS.

MO-849 6. Await Factory Support Team recommendation before proceeding with further command link verification/checkout.

7.2.3.5 Flow Diagram

MO-850 The below flow diagram in Figure 7-3 depicts the loss of S-Band command response steps as described in the previous paragraphs.

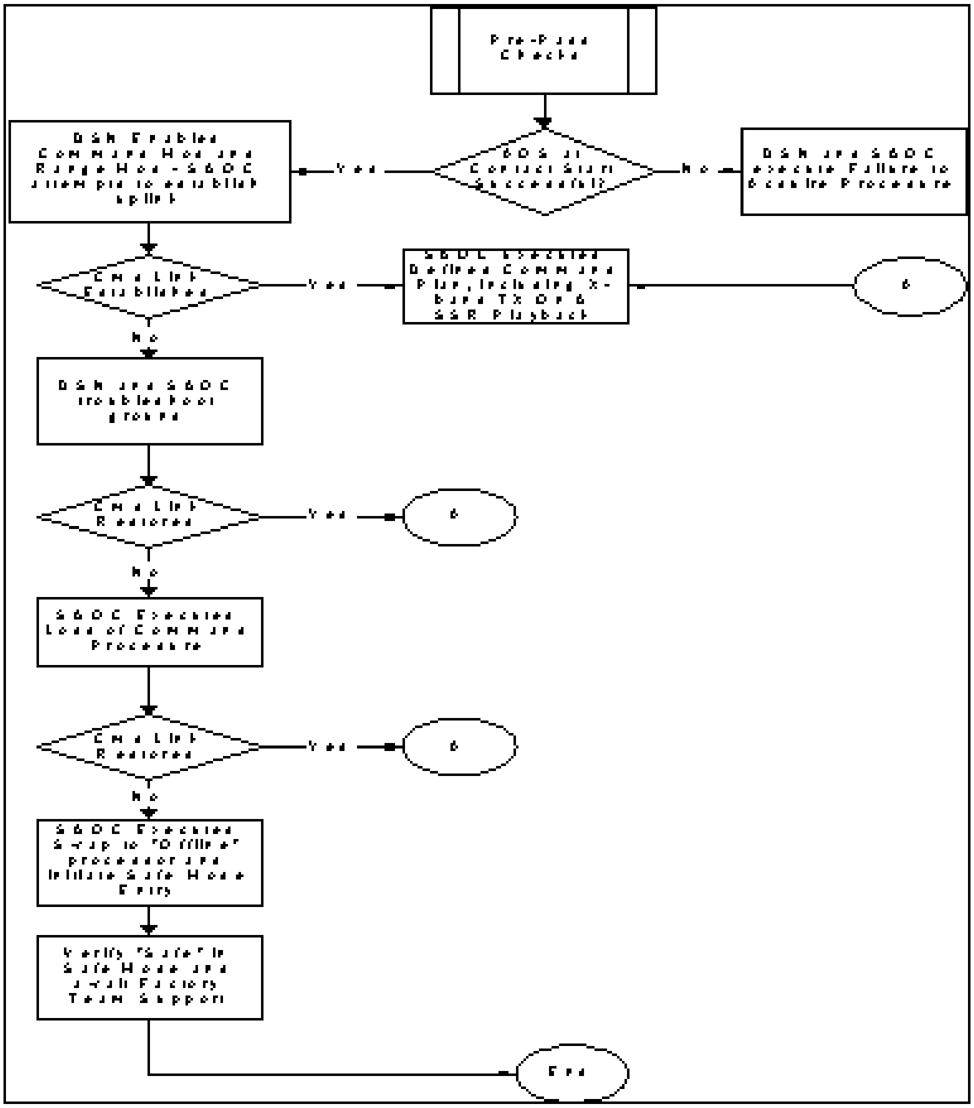


Figure 7-3. Scenario for Loss of Command

7.2.4 Flight Processor Failure Scenario

MO-851 This scenario illustrates the spacecraft bus autonomous failure detection and response for an on-board flight processor failure.

MO-852 Spacecraft is equipped with an independent on-board processing watchdog and reconfiguration control.

- The “offline” processor is healthy and available for contingency operations if called upon.

- "Swap" to redundant equipment is one way (i.e. A to B, not B to A) and A-side SBC is considered "online" for this scenario.

MO-853 The Configuration Control Module (CCM) monitors the IMOK signal from the JWST Payload Interface Module (JPIM) as an "aliveness" check of the SBC (Single Board Computer) / JPIM string of equipment. In this scenario, the A-side equipment is defined as the "online" string and the B-side equipment is defined as the redundant, "offline" string. In the nominal sequence of events, the online and offline strings of equipment perform the following actions:

MO-854 CCM - Monitors IMOK signal from JPIM-A

MO-855 JPIM-A (online) - 1553 Bus Controller, cPCI master, performs self-tests, monitors for SBC IMOK signal, issues IMOK signal to CCM, and sends CODA (Contingency Operations Database) to JPIM-B

MO-856 JPIM-B (offline) - performs self tests, provides health and status to JPIM-A side, and reads and stores CODA

MO-857 SBC-A (online) - performs self-tests, monitors subsystem health and status, and issues IMOK to JPIM.

MO-858 SBC-B (offline) - performs self tests, and provides health and status to SBC-A side

MO-859 CMM (Communications Management Modules) - provides syncs, command and telemetry interface, and critical command path to CCM

MO-860 In the event of a fault within the online processor (e.g. SBC power supply failure), the JPIM-A detects a loss of the IMOK signal from the SBC-A and withholds the IMOK signal to the CCM. The watchdog timer within the CCM then times out (due to no IMOK signal from the JPIM, which resets the watchdog timer function), initiating a CCM reconfiguration from the A-side string of equipment to the B-side string of equipment, as well as setting Safe Mode bi-levels to assist the offline SBC during its "wakeup" initialization logic. The reconfiguration sequence of events is as follows:

MO-861 1. IMOK withheld from CCM by JPIM-A

MO-862 2. CCM sets bi-levels to indicate Safe Mode Entry & initiates swap to offline string of equipment

- JPIM-A halted, operating out of SUROM with inactive 1553 bus driver configuration

- JPIM-B is reset, initializes, performs self tests, sends IMOK to CCM, serves as 1553 bus controller and cPCI master, checks CODA, determines S/C mode based on CCM set bi-levels or CODA, passes CODA to SBC-B (if available), and monitors for SBC IMOK
- SBC-A halted
- SBC-B is reset, initializes, transitions to Safe Mode based on CCM bi-levels or CODA, executes reconfiguration SCS, begins ACS & EPS control, configures command and telemetry for Omnis, and generates real-time and stored telemetry
- CMM A and B are reset

MO-863 Following a successful swap to the B-side equipment, the Observatory is in an SBC-B controlled sun-pointing mode (i.e. Safe Mode), with SBC-B maintaining both EPS and ACS control. In the event of a subsequent failure, depending on the severity of the failure, the Observatory will either "reset" the entire B-string of equipment or it will transition to survival mode where ACS and EPS control are independent of the SBC, and are executed by the JPIM-B.

MO-864 Recovery from Safe Haven is a ground-initiated activity. Once the anomaly response team has analyzed the downlinked SSR housekeeping data and determined a candidate cause for the failure, a recovery procedure will be developed by the FOT for execution upon Flight Director approval.

MO-865 The flow diagram in Figure 7-4 depicts the flight processor failure scenario of events as described in the previous paragraphs.

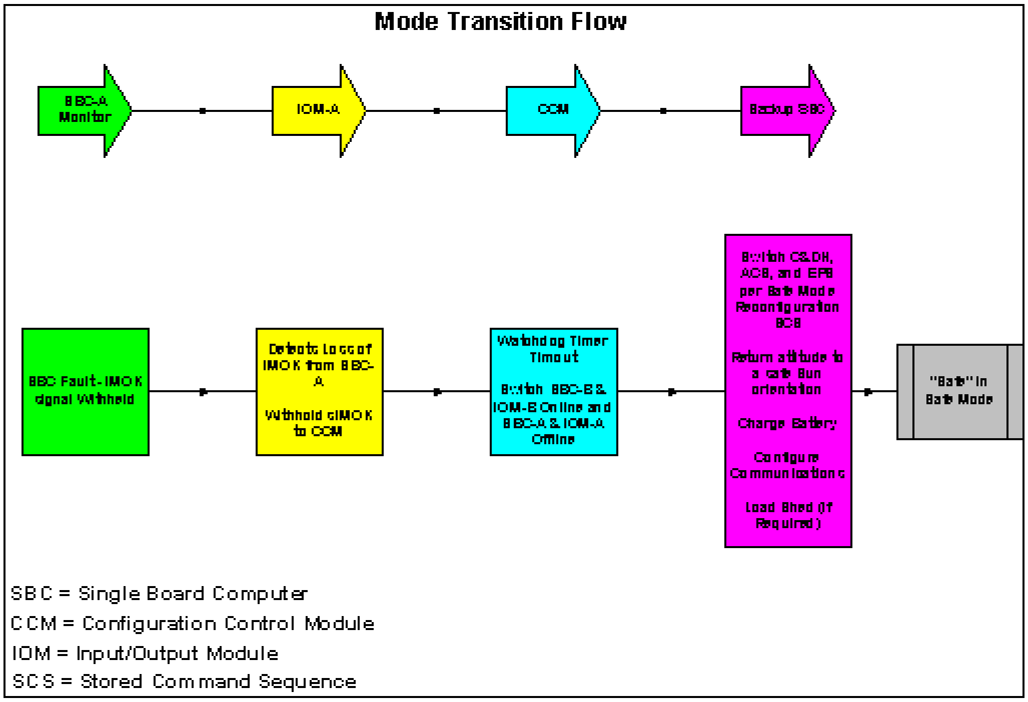


Figure 7-4. Flight Processor Failure Scenario

7.2.5 EPS Failure Scenario

MO-866 This scenario illustrates the spacecraft bus autonomous failure detection and response for an EPS low power contingency.

- MO-867A non-EPS failure contributed to the low power contingency (e.g. incorrect Observatory attitude slews array off of Sun, stuck ON thruster, etc.)
- The low power contingency is not the result of a design oversight.
- Solar Array is healthy (i.e. no failed cells or strings.)
- Actions discussed in this scenario take place on-board without ground intervention. However, the ground should be equipped with a battery state of charge (SOC) calculation tool that can compute SOC in real time if needed.

MO-868 For dangerously low power, the spacecraft will be configured so that the ground has the opportunity to recover safe operation in the event the spacecraft is unable to do so autonomously. For purposes of this scenario, we assume another fault has triggered Safe Mode entry, and that the battery continues to exhibit excessive discharge.

MO-869 The spacecraft is equipped with both FSW and H/W monitors that check battery state of charge and bus voltage respectively. Battery state of charge is computed via amp-hour integration using H/W sensor outputs from both the battery discharge current monitor and the battery charge monitor, in addition to the output from the load bus current monitor. Applying Kirchoffs Current Law to the read values results in the FSW computed battery state of charge. This computed state of charge is then checked against the fault management trigger for low battery state of charge violation. As for the load bus voltage, both the FSW and a H/W undervoltage sensor monitor for low bus voltage. The alarm trigger set in FSW is higher for bus voltage than that set within the H/W undervoltage monitor to allow for an initial corrective action to be taken prior to a H/W executed load shed.

MO-870 In this scenario, the original fault has diminished the array's ability to fully support the main bus loads, and the battery is forced to support the delta between the required load demand and the array output power. Because of this, the battery continuously discharges, thus reducing its state of charge. Concurrently, the FSW amp-hour integrator is computing the decreasing battery state of charge, and then passing the returned value to fault management for the low battery state of charge check. At a computed state of charge (~ < 30%), the fault management logic will set the Safe Power flag to "TRUE", command the solar array regulator bypass relay closed (i.e. enabling direct energy transfer from the array to the main load bus), and initiate the on-board emergency load shed algorithm. This emergency load shed will reduce on-board power loads by commanding OFF all instruments, the SSR, the 3 STAs, and the instrument survival heaters (specific fault management responses are in the Spacecraft Operations Requirements Document)).

MO-871 As aforementioned above, the FSW trigger limits are set higher than the H/W under-voltage monitor trip points. If the under-voltage monitor is tripped, then in all likelihood, the FSW initiated load shed has failed to resolve the problem, and the H/W conducted load shed will be a "last ditch effort" to reduce the power loads so that if Sun is on the array, the Observatory can remain "alive" until further ground action can be taken.

MO-872 When attitude control and battery state of charge is recovered, whether ground commanded or autonomously, the FSW will command the solar array regulator bypass relay to OPEN. It will be part of the ground initiated recovery procedure to power back ON and reconfigure equipment that was powered OFF as part of the emergency load shed.

MO-873 The below flow diagram in Figure 7-5 depicts the low power contingency sequence of events as described in the previous paragraphs.

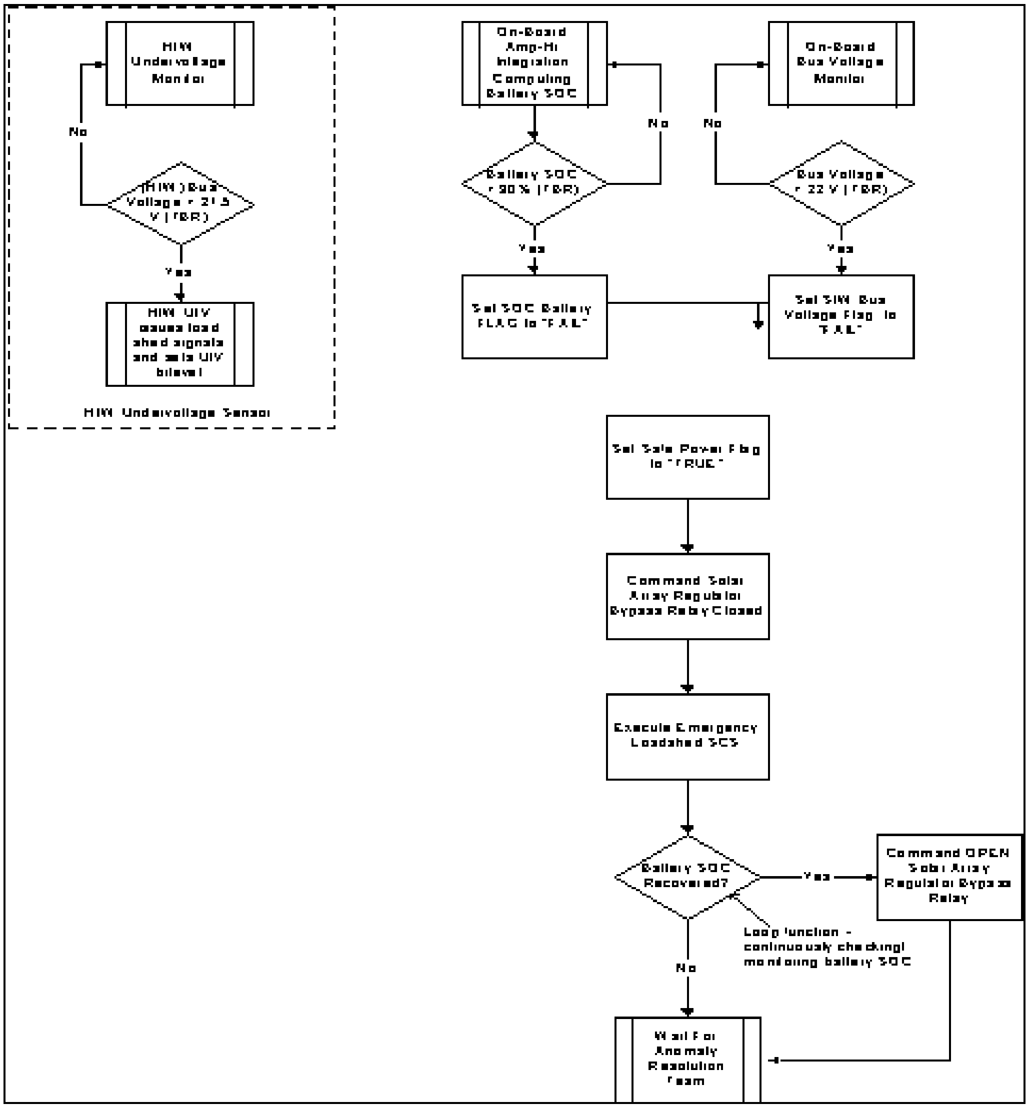


Figure 7-5. Low Power Scenario

7.2.6 ACS Failure Scenario

MO-874 This scenario illustrates the spacecraft bus autonomous failure detection and response for an ACS IRU (Inertial Rate Unit) fault.

MO-875

- All 4 rate sensing channels were nominal prior to failure occurrence
- Observatory in wheel normal mode at time of fault
- Loss of attitude knowledge by S/C does not occur as a result of this fault (i.e. No Safe Mode entry)

MO-876 The ACS (Attitude Control Subsystem) is equipped with one SIRU (Spacecraft Inertial Reference Unit) containing 4 gyros that provide 3-axis rate sensing data to the SBC. These are hemispherical resonator gyros that contain no moving parts. Three of the gyros are aligned along each of the spacecraft axes, while the fourth gyro is in a "skewed" orientation to provide redundant rate sensing information in each of the primary three axes, in the event of a failure.

MO-877 Nominal operation of the ACS is with all 4 gyros active. Using the outputs from each gyro, the ACS FSW computes 4 attitude solutions with 4 sets of 3 rate-sensing channels. It then computes 2 attitude solutions using the two FSW selected STAs (Star Trackers) and compares the STA derived attitude solutions, which is considered to be the "truth", to the computed SIRU attitude solutions to determine if an on-board update to the Kalman Filter used gyro biases is needed (to compensate for any gyro drift.) If both the STA and SIRU derived attitude solutions are in agreement within a particular tolerance, then the ACS exhibits "confidence" in its current attitude determination and continues propagating attitude using the same gyro configuration until its next attitude determination pass within the FSW.

MO-878 For this scenario, gyro B (oriented along the S/C Y-axis) starts outputting faulty rate data. When the ACS FSW computes the aforementioned 4 attitude solutions using 4 sets of 3 rate sensing channel information, the attitude solutions using the "faulty" channel data will deviate from the other computed attitude solutions. During a comparison of the computed attitude solutions, the healthy set of 3 channels will be determined. The ACS FSW will then "lock" out rate data from the faulty gyro, and continue computing and performing attitude updates using the remaining 3 healthy gyros. A status flag for the faulty gyro will be updated to read "FAIL" and subsequently reported to the ground during the next real-time contact for troubleshooting. If after analyzing the stored SOH data, the FOT determines that the "locked" out gyro is indeed still healthy, then the FOT will execute its SIRU reconfiguration procedure during the next available uplink opportunity. However, if the subject gyro is failed, then the FOT needs to do nothing, and the S/C will continue performing attitude updates with the remaining 3 gyros.

MO-879 The flow diagram in Figure 7-6 depicts the IRU fault isolation as described in the previous paragraphs

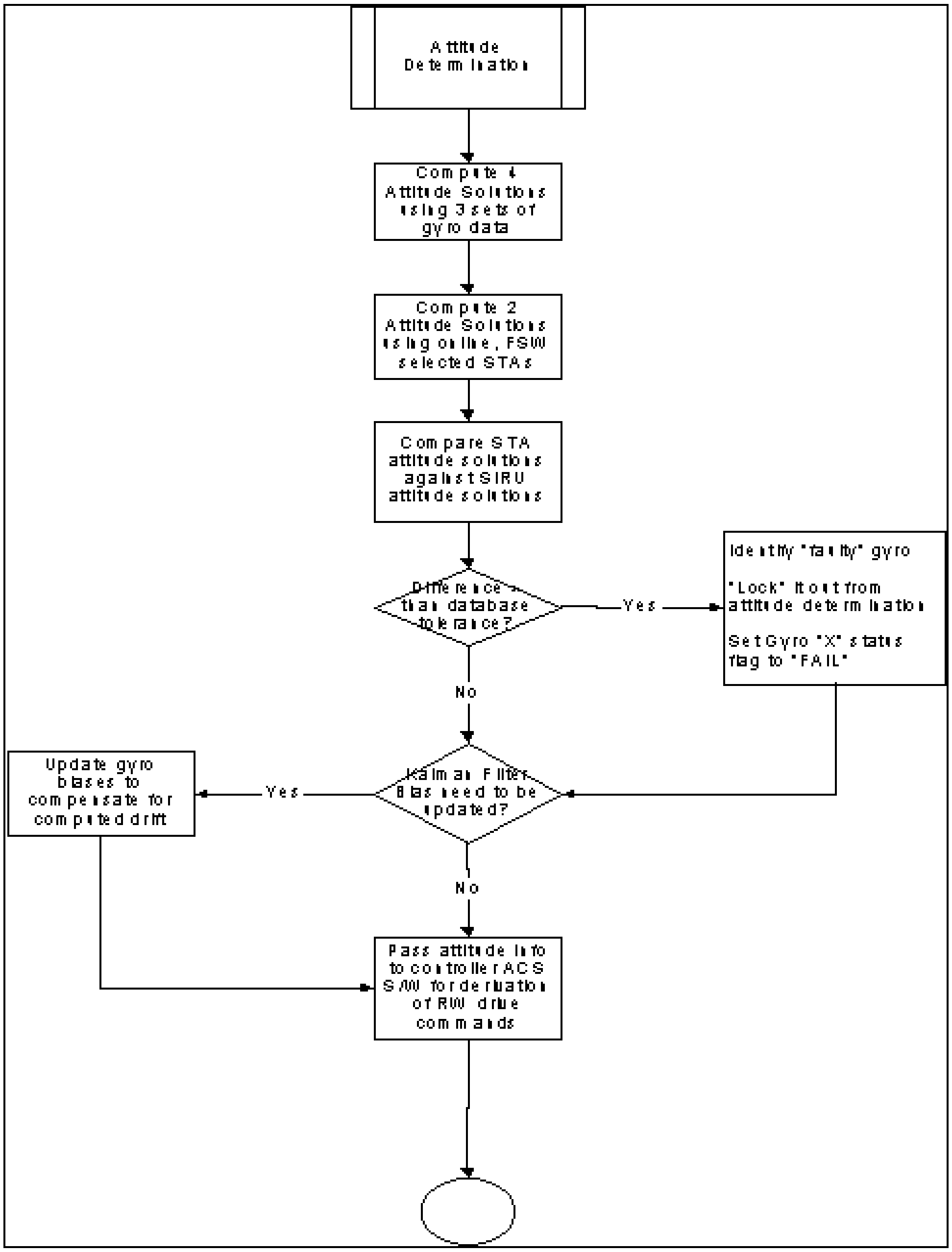


Figure 7-6. SIRU Failure Scenario

7.3 GROUND SYSTEM FAULT DETECTION AND RECOVERY

MO-880 To be supplied by STScI.

7.3.1 Missed Ground Site Contacts

MO-881 To be supplied in a future release.

8.0 INTEGRATION AND TEST

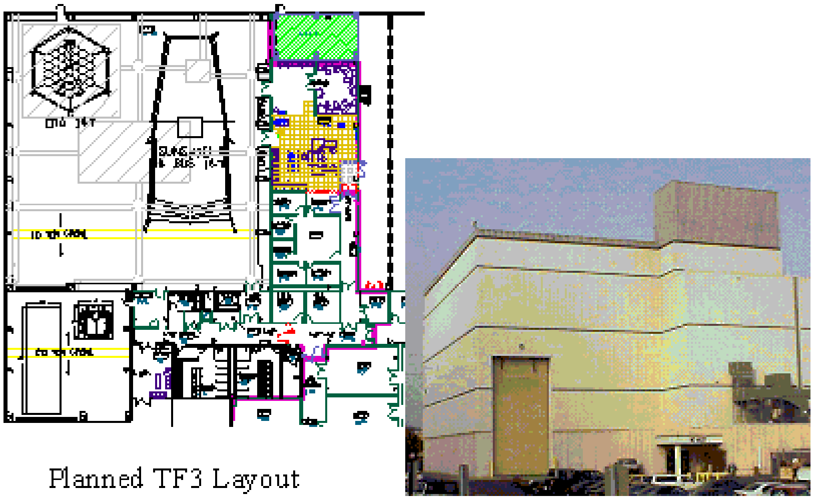
8.1 INTEGRATION & TEST FACILITY DESCRIPTION

MO-882 This section provides a description of NGST I&T Facilities that will be used to support Observatory-Level I&T

8.1.1 Integration and Test High-Bay (TF3)

MO-883 The primary NGST I&T facility for the JWST Observatory is located at the NGST Building TF3 Facility in Redondo Beach, California.

MO-884 The JWST Observatory Integration & Test Facility layout is illustrated in Figure 8-1. The facility includes a 220 by 69 ft high-bay and a 162 by 63 ft low-bay. A 75 by 150 ft annex/staging area adjoins the high bay. The low bay, high bay, and staging area provide approximately 25,000 ft2 of floor space.



Planned TF3 Layout

Building TF3 at NGST's Space Park Site

Figure 8-1. The I&T facility in NGST Building TF3

MO-885 Entrance to the I&T facility is through an airlock that contains an air shower, change-out locker room, gown room, and an equipment cleaning area.

MO-886 Other features of the I&T facility include the following:

- An isolated control room to house personnel and test equipment.

- Non-contaminating, non-ESD, level flooring
- High bay crane with 5-ton capacity, staging area crane with 30-ton capacity

MO-887 Standard utilities in all NGST integration and test facilities include electrical power (120, 220 and 440 Vac, 60 Hz), shop air, GN2 and LN2 feeder tanks or K-bottles, and a full range of consumables.

MO-888 The TF3 facility grounding system is the primary baseline for all electrical ground support equipment and test computers. Grounding systems at NGST are required to have a resistance to true ground of less than 1 ohm. Resistance from EGSE to true ground is specified to be less than 5 ohms.

MO-889 All I&T facilities will meet the JWST general requirement of Class 10,000. JWST hardware will be bagged and purged in any facility where the class 10,000-cleanliness environment is not present. Standard Practices and JWST specific operational procedures ensure and maintain those cleanliness requirements. More detailed descriptions of the contamination requirements and the procedures to be implemented for the JWST program are defined in the Contamination Control Plan.

MO-890 Temperature and humidity are maintained in all the NGST I&T facilities as noted:

- Temperature: 62 to 82ºF; 16.7 to 27.8ºC
- Humidity: 30% < RH <50%

Note: The relative humidity (RH) is maintained above 30% for ESD consideration.

MO-891 The first floor of the TF3 I&T facility houses a control room with raised flooring. This room contains test control stations, Electrical Ground Support Equipment (EGSE), and computers (servers) with their associated test conductor work stations (clients). The test control stations have direct under the floor access to the high bay cable trenches and can route associated EGSE cabling from the control room to the Observatory.

MO-892 The JWST I&T Test Control room is linked to all I&T facilities where JWST will be tested throughout the I&T Phase. Communication links provided are dedicated voice intercom and data hard lines to interface the satellite to the EGSE when it is located in environmental test areas (e.g., acoustic, vibration, thermal, etc test facilities).

MO-893 Standard communication services are provided in the TF3 high bay, as shown in the following:

- Intercommunication between the high bay and the control room
- Standard Ethernet interconnection between the high bay, control rooms, and the office complex

- Antenna interface panels in and out of the high bay for connectivity to a DSN compatibility test van.

8.1.2 Thermal Vacuum Chamber

MO-894 The JWST Spacecraft thermal vacuum test, including thermal balance test, will be performed in the NGST 30-ft spherical thermal vacuum test chamber located in building M1. This stainless steel test chamber is fitted with an aluminum and stainless steel shroud to provide background test temperatures from +150ºF to -320ºF. The chamber has a pumping capacity of 75,000 liters of gas per second. It is located in a class 10,000 high-bay with over 9000 ft2 of working area. The facility area has an electrostatic discharge (ESD) conductive epoxy floor, personnel airlocks, equipment entry airlocks, temperature/humidity control, and 10-ton overhead crane.

8.1.3 I&T Electrical Ground Support Equipment

MO-895 A Common Command & Telemetry System (CCTS) shall be used for spacecraft I&T, Observatory I&T, ISIM I&T, Science Instrument (SI) I&T, Spacecraft FSW verification and validation, and for commissioning and normal operations conducted at the Science & Operations Center (S&OC). JWST's concept for utilizing a common C&T for Phase C, D, and E operations will eliminate the effort to provide separate ground systems for each phase (which is typically the case), make the system more efficient and stable, save development dollars, and provide better-trained operations personnel.

MO-896 The CCTS together with the EGSE test set hardware & software elements comprise the I&T ground test system (see Figure 8-2). In the I&T environment, the EGSE is the stimulus and response interface between the CCTS and the Observatory, with standardized interfaces to the CCTS and special-purpose interfaces to the Observatory.

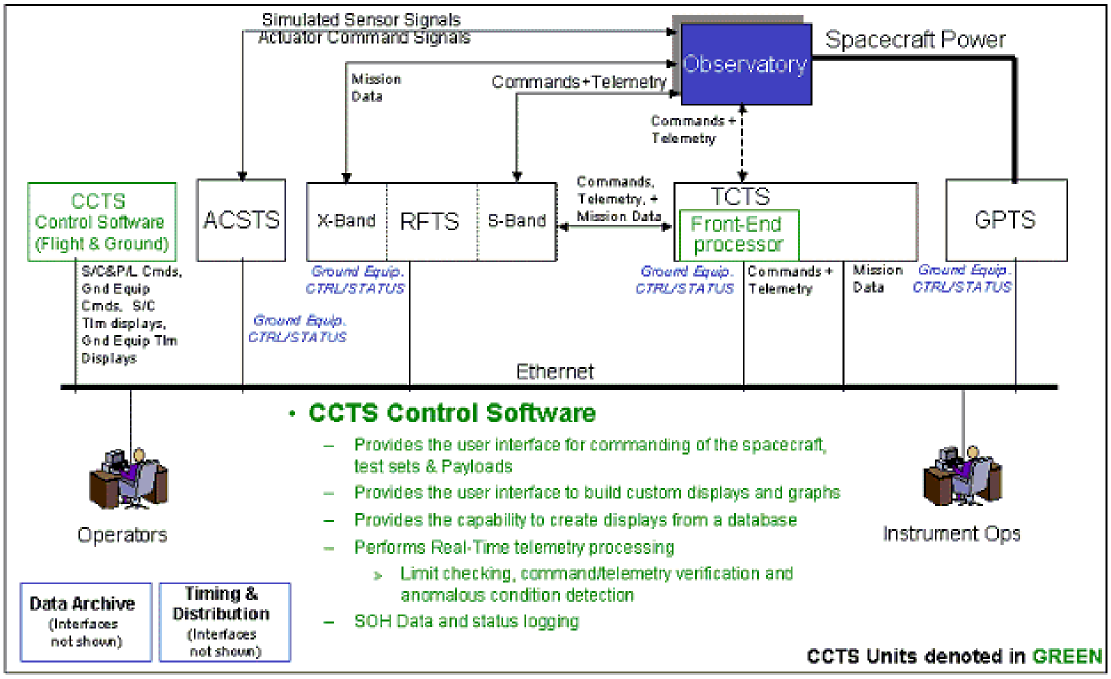


Figure 8-2. I&T Ground Test System

MO-897 Spacecraft/Observatory Integration & Test stresses the CCTS differently than Mission Operations, and thus the CCTS is required to provide the following I&T functionality:

- The ability to command at different levels (hard line vs. RF, with or without CCSDS encoding, as well as addressing different command layers such as Application Control Requests (ACRs) and Activity Descriptions (ADs), etc.) within the flight system as well as ground equipment used to support the test environment.
- The ability to handle non-operational oriented telemetry that has repetitive or non-existent spacecraft timing information and possibly missing telemetry data sources. This is to include "garbled" data resulting from Observatory and/or EGSE equipment reconfigurations. Test data needs to be recorded and cataloged for later analysis.
- The ability to script test scenarios used to control ground equipment setup, the test data sources, the commanding and recording of events and help produce test documentation.
- A much greater dependency on real-time telemetry for diagnosing problems and confirming spacecraft health requiring the ability to close history files and open new ones without losing data, and requiring the ability to trend real-time data while continuing with a test session.

MO-898 The I&T Ground Test System architecture (including EGSE) for JWST is shown in Figure 8-2. Descriptions of the major items shown are listed below.

MO-899 **CCTS.** The CCTS is a hardware & software test set which provides the following key functions:

- Remote control and monitoring of all other major EGSE components
- A base for automated test sequence (ATS) development
- Test conductor control of ATS execution
- Real time telemetry processing and verification
- Displays for user required information
- Control of spacecraft commanding
- Data archiving, retrieval, and logging
- Data analysis, trending and report capability
- Alarms and constraint checking

MO-900 **The Telemetry And Command Test Set (TCTS).** The TCTS is part of the NGST provided EGSE. The TCTS provides services either directly to the spacecraft through hard-line ports or through the RF equipment into the RF transponder.

MO-901 The TCTS, reused from IA, uses the VxWorks RTOS and is based on the Common Object Request Broker Architecture (CORBA).

MO-902 The TCTS contains a telemetry and command (T&C) processor. The T&C processor provides the following key functions:

- Decodes, decommutates, and preprocesses telemetry for the CCTS
- Handles compression and authentication as necessary
- Formats and transmits commands received from the CCTS
- Retrieves and distributes science data
- Provides science data processing

MO-903 **The Radio Frequency Equipment (also known as the RF Test Set, RFTS).** The RFTS is part of the NGST provided EGSE. The RFTS provides the following key functions:

- Downlink signal demodulation
- Uplink signal modulation and level setting
- RF signal analysis and testing

MO-904 **The ground power test set (GPTS).** The GPTS is part of the NGST provided EGSE. The GPTS provides the following key functions:

- Primary bus power or T-0 power
- Solar array simulator (SAS)
- Battery charging and monitor
- Ordnance load simulation and monitor
- Hard-line monitoring

MO-905 **The Attitude Control System (ACS) test set (ACSTS).** The ACSTS is part of the NGST provided EGSE. The ACSTS provides the following key functions:

- Sensor simulation and/or stimulation
- Actuator monitoring
- Reaction wheel over-speed protection

MO-906 In past space vehicle programs, commanding the space vehicle and processing its telemetry via a command and telemetry (C&T) system involved development efforts for two (minimum) separate C&T products: one for integration & test (I&T) and one for flight operations. Early JWST concept studies concluded a single development of a common C&T system (CCTS), incorporating the requirements of both I&T and flight operations, would be a more cost effective approach.

MO-907 The original JWST Statement of Work directed NGST to use this CCTS system for Observatory I&T; and, at the time it was to be provided as GFE. However, since that contract was let, JWST optimization efforts recommended a non-GFE approach in which NGST provides the common C&T to all JWST users. The most influencing factor in making this decision was the potential cost savings if JWST were to use the same CCTS as the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) program (another space vehicle system being developed by NGST). The suite of levied requirements between JWST & NPOESS are similar; therefore, JWST could obtain incorporation of I&T requirements into its CCTS. Therefore, the chosen C&T system for JWST became the Raytheon Eclipse™ product.

MO-908 The CCTS is a subset of the complete JWST ground system that includes all the functionality of the flight-operations ground system applicable to I&T. The CCTS will be deployed at the Observatory and instrument development/test facilities as well as at the launch facility (to support integration and testing of the Observatory with the launch vehicle and to support launch operations). The CCTS will also be deployed to support simpler activities e.g., software development laboratory, software verification laboratory, etc. The CCTS is used to operate the Observatory as well as operate I&T electrical ground support equipment.

MO-909 It's important to note that the CCTS is not solely comprised of the basic Raytheon ECLIPSE™ COTS product. The CCTS is a sum of products necessary to provide all the functionality of the flight-operations ground system applicable to I&T. For the purposes of managing the development of the CCTS, the CCTS was defined as the summation of 2 categories of products:

MO-910 **Category A** - Defined as the basic Raytheon Eclipse™ COTS product plus Eclipse™ functions added to support JWST.

MO-911 **Category B** - Defined as added tools and/or capabilities outside of Eclipse™ that are needed by all phases of the mission. Examples are database conversion tools and Flight Software (FSW) memory load and dump tools.

MO-912 There is an additional Category of Product related to the CCTS: **Category C**. Cat C is defined as all other tools and/or capabilities needed by any single user during the mission (but not necessarily needed by other users). It is important to note that these tools ARE NOT a part of the CCTS, but that they do exist.

MO-913 The Raytheon Eclipse™ software is a proven solution for both the satellite command and control and test environment. It is being used in other test environments and is being implemented for the testing of the NPOESS space vehicles.

MO-914 **Database Driven.** The Raytheon Eclipse™ software is database driven so that satellites and test equipment can be added without major modifications. Databases are provided by the sensor and satellite manufacturers and are incorporated into the Eclipse™ access database. The access database is used by Eclipse™ to generate the necessary files for initialization. This method means that there is minimal to no changes needed to incorporate a database.

MO-915 **Automation.** Extensive automated monitoring and control features allow for reliable management of satellite test and associated test stations.

MO-916 **Operator-Friendly User Interface/Ergonomic Command and Control System.** The operator's graphical interface is spread across multi-headed displays for optimal and ergonomic management of resources. The standard Windows user interface includes high-level graphical views of the satellite and the test stations used for system test.

MO-917 **Scalability.** The modular system architecture provides maximum flexibility in supporting satellite complexity, test station complexity, and system growth requirements.

MO-918 **The Raytheon Eclipse™ Software Functions.** The Raytheon Eclipse™ software provides the functions needed to control and monitor the satellite test stations and the satellite under test. These functions include:

MO-919 *Telemetry Processing.* Frame and CCSDS packet decommutation and engineering unit conversion are supported. Multiple level limit-checks and alarms and multiple telemetry format processing are supported.

MO-920 In addition, multiple, simultaneous telemetry stream, dwell telemetry, on-board processor support is provided. A user-friendly method for derived telemetry item generation gives the user the capability to generate user-defined equations.

MO-921 *Trending.* Analysis of processed telemetry data for trend detection is provided in real time. Generation of trend statistics, burn-in information and cycling statistics are performed as telemetry is being processed in real time. The statistics include minimum, maximum, mean, and standard deviation for the database defined telemetry values.

MO-922 *Commanding.* Commands can be sent to a satellite, ground equipment, or test sets. The user can send commands using a manual interface or using automated procedures. User authorization and authentication is supported for all commands. To ensure that the command is received and processed by the satellite, command validation and verification are supported for either clear or authenticated mode.

MO-923 *Intelligent Scripting Tools*: A user-friendly command procedure builder is included as part of the Eclipse™ software for easy development of spacecraft and ground command procedures.

MO-924 *User Interface.* A standard interface for all platforms is supported. This allows for the transparent integration of Microsoft Office and other COTS products. Because Eclipse™ is Windows compliant, it supports multifunctional and customizable windows. In addition, to support the user in understanding the use of Eclipse™, there is online help for fast access to key topics.

MO-925 *Data Logging and Retrieval.* Multiple logs are supported for quick online access and are archived to offline data storage. These logs include, operator actions, telemetry history, command history, alarm history, and a full real-time log and step-by-step instructions are accessible from the toolbar.

8.1.4 System Verification Laboratory

MO-926 A key NGST I&T facility is the System Verification Laboratory (SVL). The SVL is comprised of engineering model hardware and simulations that fully represent the Observatory (see Figure 8-3). The SVL is used for two purposes:

- Validate that the Observatory FSW functionally performs as intended.
- Demonstrate spacecraft I&T procedures before flight.

MO-927 The inclusion of selected engineering models, (e.g., the SSR) and a flight-like harness provide high quality checkout of interfaces during the SVL integration starting in October 2004. Common EGSE, in particular for electrical power, allow checkout of integration, power control, and spacecraft configuration procedures specific to I&T.

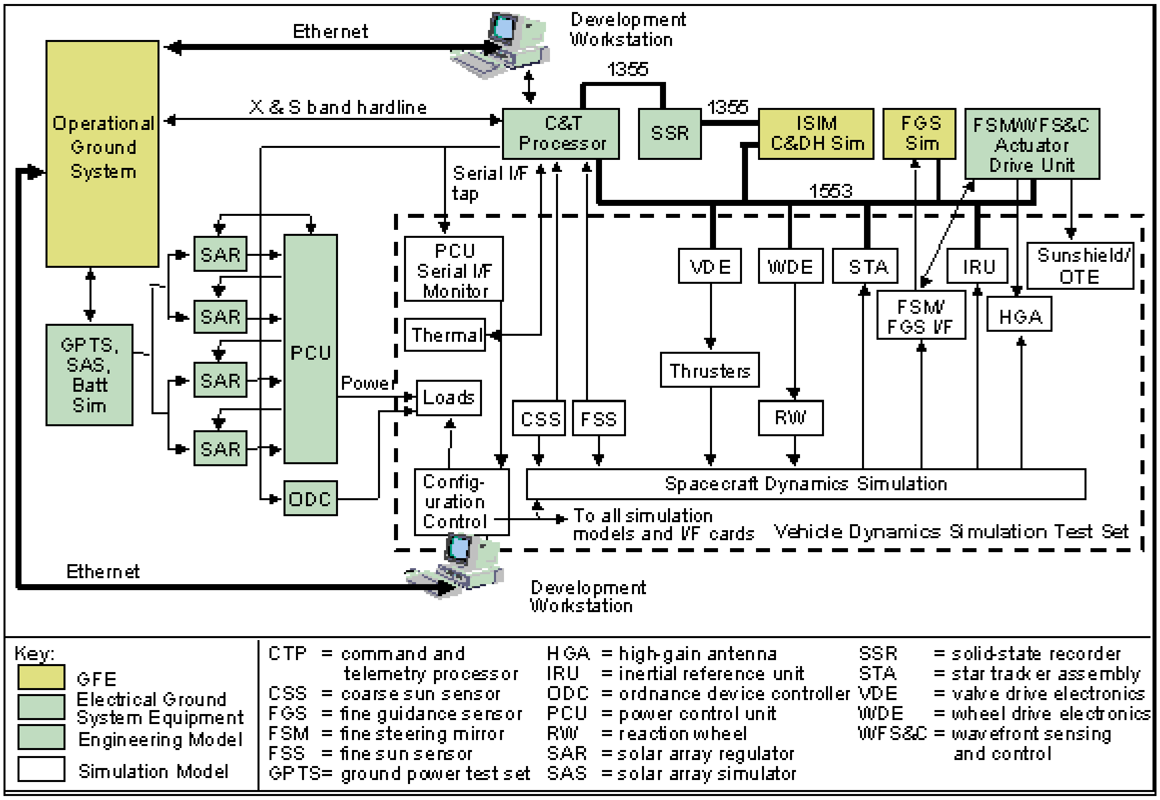


Figure 8-3. System Verification Laboratory Block Diagram

8.2 INTEGRATION AND TEST OPERATIONS

MO-928 This section describes the operations for Observatory-level integration and test.

8.2.1 Observatory-Level I&T

MO-929 Observatory-Level I&T begins with installation of the high-gain antenna and radiator shields to the spacecraft bus in preparation for the spacecraft bus thermal vacuum test. Complete details of JWST Integration & Test will be found in the NGST System Verification Plan (SE-05) delivered by SRR. However, for the purposes of communicating Integration & Test Operations Concepts, selected I&T activities shall be discussed in the following paragraphs.

MO-930 After cryogenic performance verification at Plum Brook, the OTE/ISIM is shipped to NGST Redondo Beach, CA for mating to the spacecraft and deployed sunshield.

MO-931 Once the OTE/ISIM is integrated into the Observatory and at various steps in the Observatory I&T, a visual inspection will be performed to verify that its integrity has been maintained throughout the integration process. An aliveness test will also be conducted to verify the functionality of the mechanisms. This will include a first motion test for all of the deployment mechanisms as well as a verification of the mirror actuator motions. Functional tests will also be performed on the ISIM to check the filter wheel mechanisms and the focal plane. A telemetry check will also be performed to verify the communication link to the spacecraft from both the OTE and ISIM. A final performance test at the Observatory level will include an optical throughput test to verify that the optical path is not obscured.

MO-932 After the mating of the OTE/ISIM to the Spacecraft-sunshield, the electrical interfaces will be verified using test ports and breakout boxes before power is applied to the Spacecraft.

MO-933 The solar arrays will be removed after Observatory level dynamics testing and remain off during remaining testing activities. They will be reinstalled on the Observatory as part of the pre-ship preparations, and a release and first motion test will be performed at that time. The objective of the first motion test will be to verify wing release energy and that the release motion has not been arrested by any physical interference after installation on the Observatory. These series of partial deployment tests will also verify that acoustic testing has not precipitated changes in the hinges, latches, harnesses, or MLI that would prevent release and deployment of the solar array.

MO-934 During this test series, many of the tests performed at the spacecraft level with the OTE/ISIM simulators will be duplicated. The onboard computer will be forced to terminate issuance of watchdog timer pulses and the resultant functions will be verified. The electrical interface assembly sequencer reconfigures the onboard computer, interface unit, and command and telemetry unit telemetry formatter from A string to B string operation.

8.2.2 Observatory Environmental Tests

MO-935 Environmental testing at the all-up systems Observatory level will consist of an acoustic test, a shock and separation test, and an EMI/EMC test. Thermal vacuum testing and sine vibration testing will be performed at the subsystem level (all-up Spacecraft less telescope and separately on the OTE/ISIM). There are no plans to conduct vibration, modal, or thermal cycle testing at the Observatory level.

MO-936 The purpose of this test will be to verify JWST Observatory self-compatibility, conducted emissions, and radiated emissions characteristics. During self-compatibility testing, one unit at a time will be run in the most sensitive mode while all other units are running in their most noisy states. This test will be repeated for all sensitive units. Conducted emissions testing will be performed on primary power lines to demonstrate compatibility between the JWST and the launch vehicle in the launch and in bay checkout modes. The radiated emissions test will also be conducted to demonstrate compatibility between the Observatory and the launch vehicle in the launch and in-bay checkout configurations. This series of tests will be conducted inside the TF3 integration high-bay area. It will be performed in accordance with the system level electromagnetic compatibility qualification test plan generated by the EMC/EMI test group.

MO-937 The mechanical verification tests at the Observatory level will be an acoustic test at acceptance level. A separation shock test will also be performed. Subsequent to the Observatory dynamic testing, a full deployment test of the Spacecraft, sunshield, and OTE will be performed after the Observatory dynamic testing is completed (with the likely exception of the solar arrays due to the lack of adequate access to them).

MO-938 To verify flight operations readiness, NGST will perform incremental end-to-end testing with the CCTS located at the S&OC throughout their I&T test activities; and, also perform end-to-end testing with the GFE DSN van. End-to-end testing is included in the element I&T, Observatory I&T, and launch operations testing.

MO-939 End-to-end Observatory Interface Tests and Mission Simulations will be performed with the Observatory commanded by the S&OC. A sensor stimulus will be used for photonic stimulation of the instruments, and the Observatory will be under the control of the S&OC for testing in a wide range of state configurations.

APPENDIX A. ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control Subsystem
AD	Activity Description
ADU	Actuator Drive Unit
AFP	Aperture Focal Plane
AGN	Active Galactic Nuclei
APT	Astronomers Planning Tool
AR	Archival Researcher
ASWG	Ad Hoc Science Working Group
CCSDS	Consultative Committee for Space Data Systems
CCTS	Common Command Telemetry System
CFDP	CCSDS File Data Protocol
C&DH	Command & Data Handling
CDS	Correlated Double-Sampled
CS	Common Systems
CSA	Canadian Space Agency
CSG	Guiana Space Center (Centre Spatial Guyanais)
CTP	Command & Telemetry Processor (the main spacecraft computer)
CXO	Chandra X-Ray Observatory
DDA	Deployment Drive Assembly
DFS	Dispersed Fringe Sensor
DHS	Dispersed Hartmann Sensor
DMS	Data Management Subsystem
DRM	Design Reference Mission
DSN	Deep Space Network
DTM	Dual Thruster Modules
EGSE	Electrical Ground System Equipment
EOS	Earth Observing System
EPS	Electrical Power Subsystem
ESA	European Space Agency
ETE	End-to-End
FDF	Flight Dynamics Facility
FFT	Fast Fourier Transform
FGS	Fine Guidance Sensor
FGS-TFI	Fine Guidance Sensor - Tunable Filter Imager
FITS	Flexible Image Transport System (a format standard for files that is widely used by the astronomical community)
FOR	Field of Regard
FOS	Flight Operations Subsystem

FOT	Flight Operations Team
FOV	Field of View
FPA	Focal Plane Array
FPE	Focal Plane Electronics
FSM	Fine Steering Mirror
GO	General Observer
GTO	Guaranteed Time Observer
HGA	High-Gain Antenna
HST	Hubble Space Telescope
ICE	Instrument Control Electronics
IFU	Integral Field Unit
IRU	Inertial Reference Unit
ISIM	Integrated Science Instrument Module
ISO	Infrared Space Observatory
I&T	Integration & Testing
JMS	JWST Mission Simulator
JNSS	JWST Network Support System
JPIM	JWST Payload Interface Module
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
LCC	Launch Commit Criteria
L&EO	Launch & Early Orbit
LGA	Low-Gain Antenna
LRD	Launch Readiness Demonstration
LRE	Launch Readiness Exercise
LRP	Long Range Plan
LRS	Low-Resolution Spectrograph
LS	Large-Scale
LV	Launch Vehicle
LVA	Launch Vehicle Adapter
MAST	Multi-Mission Archive at Space Telescope
MIRI	Mid-Infrared Instrument (JWST instrument)
MOT	Mission Operations Team
MRD	Mission Requirements Document
MSA	Micro-Shutter Array
NASA	National Aeronautics and Space Administration
NEA	Noise Equivalent Angle
NGST	Northrop Grumman Space Technologies
NGST	Next Generation Space Telescope - the name used for JWST during its planning stage. This acronym is not used here, except as it appears in titles of documents that were written prior to the name change.

NICMOS	Near-Infrared Imaging Camera and Multi-Object Spectrometer (HST instrument)
NIR	Near-Infrared
NIRCam	Near-Infrared Camera (JWST Instrument)
NIRSpec	Near-Infrared Spectrograph (JWST instrument)
NISN	NASA Integrated Services Network
ODC	Ordnance Device Controller
OP	Observation Plan
OPE	Observation Plan Executive
ORD	Operational Readiness Demonstration
ORE	Operational Readiness Exercise
OSS	Operational Scripts Subsystem
OTB	Observatory Testbed
OTE	Optical Telescope Element
PCU	Power Control Unit
PM	Primary Mirror
PMSA	Primary Mirror Segment Assemblies
POM	Pick-off Mirror
PPS	Proposal and Planning Subsystem
PSF	Point-Spread Function
PRD	Project Reference Database
PRDS	Project Reference Database Subsystem
RCS	Reaction Control System
RF	Radio Frequency
SA	Sub-Aperture
SAR	Solar Array Regulator
SBC	Single Board Computer
SCA	Sensor Chip Assembly
SEE	Space Exploration Engineering
SEU	Single Event Upset
SI	Science Instrument
SIRU	Spacecraft Inertial Reference Unit
SMA	Secondary Mirror Assembly
SMSS	Secondary Mirror Support Structure
S&OC	Science & Operations Center
SOH	State of Health
SP	Script Processor
SRD	Science Requirements Document
SSM	Spacecraft Support Module
SSR	Solid-State Recorder
SST	Spitzer Space Telescope
STA	Star Tracker Assemblies

STDN/DSN	Spacecraft Tracking and Data Network / Deep Space Network
STS	Software Telemetry Simulator
STScI	Space Telescope Science Institute
S/W	Software
SWG	Science Working Group
TA	Target Acquisition
TAC	Time Allocation Committee
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Resolved
TCM	Trajectory Correction Maneuver
TCS	Thermal Control Subsystem
TDRSS	Tracking & Data Relay Satellite System
TMA	Three-Mirror Anastigmat
TOADs	Training Observers and Directors
TST	Technical Support Team
TWTA	Traveling Wave Tube Assemblies
WFS&C	Wavefront Sensing & Control

APPENDIX B. REQUIREMENTS CROSS-REFERENCE

Requirement Number	Requirement Title	Reference Section Number
MR-041	Operational Orbit	2.5, 3.3.3.3, 3.3.3.4
MR-044	Science Mission Lifetime	3.3
MR-045	Commissioning Phase Duration	5.1.2
MR-047	Cryogen Lifetime	3.3
MR-048	Propellant Lifetime	3.3
MR-076	Compressed Science Data Volume	4.3.3, 5.3.10
MR-077	Normal Operations	5.6.1.1
MR-082	Deep Space Network	5.6.1.1
MR-102	Efficiency	5.0, 5.1.2, 5.3.9
MR-103	Annual Coverage	3.3
MR-104	Field of Regard	4.3.2
MR-105	Continuous Coverage	3.3
MR-106	Continuous Visibility Zone	4.3.2
MR-107	Wavelength Range	3.1
MR-124	Wavefront Error Correction Capability	4.3.1
MR-127	Observatory Event Logs	5.1.3, 5.6.2.6
MR-130	Storage Capacity	4.3.3
MR-131	Storage Data Priority	5.6.2.6
MR-135	Simultaneous Onboard Storage	1.0, 4.3.3.6, 5.1.2
MR-142	Coordinated Universal Time Correlation Accuracy	6.2.6.1, 6.2.6.2
MR-147	Command Safety	5.1.3
MR-148	Command Verification	5.1.3
MR-149	Report Verified Commands	5.1.3
MR-150	Command Validation	5.1.3
MR-153	Command Rejection	5.1.3
MR-156	Parallel Operations	5.1.2, 5.3.9
MR-157	Autonomous Operation	5.6.1.1
MR-161	Event-Driven Observatory Operations	5.1.2, 5.2.1
MR-166	In-Flight Changes	5.1.2
MR-174	Relative Offset Pointing Repeatability	1.0
MR-176	Field Orientation Knowledge	4.3.3.4
MR-177	Field of View Orientation	3.3
MR-187	Wavefront Sensing	4.3.1, 5.3.5.9
MR-190	Event Driven Execution	5.1.2, 5.2.1
MR-191	Science Instrument Operations	5.1.2
MR-195	Science Instrument System Monitoring	5.1.3
MR-196	Integrated Science Instrument Module Safe Mode	5.1.3
MR-232	Communication Operations	4.3.3.6

Requirement Number	Requirement Title	Reference Section Number
MR-236	Uncompressed Engineering Data Volume	4.3.3, 5.3.10
MR-239	Ranging	4.3.3.6
MR-242	Command Uplink Frequency	4.3.3.6
MR-245	High Rate Command Uplink	4.3.3.6
MR-250	Low Rate Downlink	4.3.3.6
MR-256	High Rate Downlink	4.3.3.6
MR-257	High Rate Downlink Data Rates	4.3.3.6
MR-262	Voltage	4.3.3.5
MR-272	Health and Safety Responsibility	5.1.3, 5.7.5.2
MR-273	Fault Tolerance	5.1.2
MR-276	Safe Modes	5.1.3
MR-277	Safe Mode Hierarchy	5.1.2, 5.6.7
MR-285	Wavefront Sensing and Control Executive	4.5.1, 5.4, 6.1.4.1
MR-289	Normal Operations	5.7.5.2
MR-290	Unattended Operations	5.1.3
MR-292	Execution of Mission Timeline	5.1.2, 5.2.1
MR-293	Timeline Recovery and Modification	5.1.2
MR-294	Transfer Orbit and Operational Orbit Determination	1.0, 5.6.4
MR-302	Validation Prior to Use	5.1.3
MR-307	Archive Catalog	5.7.3.2
MR-308	Other Contents	5.7.3.2
MR-310	Provision of Data to International Partners	5.7.3.2
MR-314	Product Format	5.7.3.2
MR-315	Use of Up-to-Date Calibrations	5.7.3.2
MR-316	Availability of New Data	5.7.3.2
MR-317	Timeliness of Delivery	5.7.3.2
MR-320	Health and Safety Protections	5.1.3, 5.7.5.2
MR-321	Deliberate Override	5.1.3
MR-323	Availability	5.1.2
MR-325	Prevention of Mutual Interference	5.1.3
MR-326	Primary and Backup Systems	5.1.2
MR-327	Mission Critical Operations	5.1.2
MR-328	Transfer of Non-Critical Operations	5.1.2
MR-330	Science and Operations Center Alternate Facility	5.1.2
MR-336	Observatory Monitoring	5.1.3
MR-337	Real-Time Telemetry Monitoring	5.1.3
MR-344	Science Proposal Support	5.0
MR-345	Observation Modifications	5.1.1
MR-346	User-Friendly Interface	3.1.5
MR-352	Communications Element	1.0, 4.3.3, 5.3.10

APPENDIX C.
OBSERVATORY, SPACECRAFT SUBSYSTEM, ISIM, AND OTE MODES

C.1 OBSERVATORY MODES

There are seven Observatory Modes for JWST. Each mode represents a different Observatory configuration that supports a different aspect of the mission. The associated configuration along with the purpose of each mode is described in this section. The use of the modes in support of nominal and contingency operations is described, as are the allowed transitions between modes.

C.1.1 OBSERVATORY MODE DESCRIPTIONS

Each observatory mode is used for specific functional capabilities. This section describes each Observatory mode and the functions that the mode is used for. Table C.1.1 shows a summary of the modes mapped to specific uses under nominal and contingency operations.

Observatory Mode	Nominal Use	Contingency Use
Launch	During pre-launch and launch	Failure prior to LV separation
Normal Pointing	OPE driven operations Science data collection Repositioning slews for new target, stationkeeping or momentum dumping Scheduled momentum dumping	None
Thruster	Damp rates following LV separation Solar Array Deployment Delta-V during transfer orbit Stationkeeping	None
Sun Pointing	Sun acquisition Sunshield OTE and HGA deployments	None
Inertial Pointing	Coarse phasing of mirrors	Some Fine Guidance Faults, some OTE faults
Safe Haven	None	CTP fault, ACS fault, safety net fault
Survival	None	Invalid RCB, fault in Safe Haven, CTP Reset

Table C.1.1. Observatory Mode Uses

C.1.1.1 LAUNCH MODE

The Observatory is in Launch Mode when attached to the launch vehicle. This covers the pre launch and launch phases of the mission, up to separation from the launch vehicle. All appendages are stowed. All thrusters and ordnance are disabled.

The Spacecraft will not perform any attitude control or active thermal control. All of ISIM except for the IRSU will be off in this mode. Spacecraft telemetry will be available for Ground monitoring of the Spacecraft health once the transmitters are turned on. In addition, spacecraft attitude control sensor data processing will be performed to allow for Ground monitoring of sensor data (SIRU, CSSA, FSSA).

The Spacecraft will monitor the status of payload fairing jettison and Observatory separation from the launch vehicle. After payload fairing jettison, the telemetry transmitters will be turned on. Once the Spacecraft detects launch vehicle separation, an autonomous transition to Thruster Mode will occur as necessary to damp launch vehicle induced separation rates in preparation for solar array deployment.

Launch mode is used during nominal and contingency operations. After the transition to Thruster mode following separation from the launch vehicle, this mode will never be entered again.

C.1.1.2 NORMAL POINTING MODE

Normal Pointing Mode is the mission mode in which science data collection occurs. Observatory activities are driven by the execution of the observation plan during this mode. The Operations Plan Executive (OPE) will be running, with the ISIM sending requests to the Spacecraft as needed to ensure the desired target pointing is achieved. During this mode, the Observatory can downlink science and engineering data and receive Ground commands. Observatory alignment and commissioning activities are also performed in this mode.

Maneuvers to change from one Observatory attitude to another using reaction wheels are performed in this mode to allow for pointing the Observatory to different science targets or to optimize the attitude for momentum unloading. Thrusters will be used in this mode only when unloading momentum. The Spacecraft will ensure that sun constraints are not violated during any maneuvers.

C.1.1.3 THRUSTER MODE

Thruster mode is used to null rates following detection of launch vehicle separation. Rates will be damped to levels sufficiently low to deploy the solar arrays. The Observatory will remain in Thruster mode during solar array deployment. This mode will also be used to perform delta velocity corrections as necessary to achieve an L2 orbit and for stationkeeping burns to maintain the L2 orbit. In addition, any Observatory attitude maneuvers prior to sunshield deployment will be performed in Thruster Mode.

The details of the thrusters used and their purpose (for example delta-V or attitude control) can vary within Observatory Thruster Mode. The thrusters used and their specific usage will depend upon the function being performed. Other than damping rates following launch vehicle separation, this mode will only be entered in response to Ground commands or a Ground initiated Stored Command Sequence. For correction or stationkeeping burns, the Ground will configure the Observatory to ensure the correct vehicle attitude and firing duration.

Spacecraft fault management will ensure that sun constraints are not violated.

C.1.1.4 SUN POINTING MODE

Sun Pointing Mode is used to support nominal operations prior to entering normal pointing mode for the first time. This mode is entered nominally after deployment of the solar array to ensure a power positive and thermally safe attitude. It is also used for sunshield, HGA and OTE deployments.

The Observatory attitude is fixed relative to the sun while in this mode. The attitude around the sun line is undefined. It is possible in this mode to induce a very slow rate around the sun-line.

C.1.1.5 INERTIAL POINTING MODE

Inertial Pointing Mode is a nominal and contingency mode where inertial pointing is performed. In this mode, the Observatory downlinks science and engineering data and the HGA is continually pointed towards the requested DSN ground station.

When this mode is entered, the Spacecraft will point the observatory in a defined attitude. A fixed inertial attitude can be maintained as well as a maneuver to change between inertial attitudes. The OPE operations will be suspended. Fine guiding is not supported in this mode.

Spacecraft fault management will ensure that sun constraints are not violated. Fault management will transition the Observatory to Safe Haven mode if necessary to avoid violating sun constraints.

C.1.1.6 SAFE HAVEN MODE

Safe Haven Mode is similar to Sun Pointing Mode, but the Observatory enters this mode in response to certain fault triggers. Redundant components can be used when entering Safe Haven Mode. Depending on the fault trigger(s) that cause the entry to Safe Haven Mode, the Spacecraft will either notify the ISIM to safe itself or notify the ISIM that it will be powered off. Note that ISIM will only be turned off if there is a Spacecraft power fault condition. This mode will never be entered under nominal operations.

Following a switch to the redundant Spacecraft processor, the Spacecraft design allows for retention of the data in the swapped-from processor for later access by the Ground for use in anomaly resolution. In addition, the swapped-to processor will have up to date information available to determine the Observatory configuration post swap.
Spacecraft fault management will ensure that sun constraints are not violated.

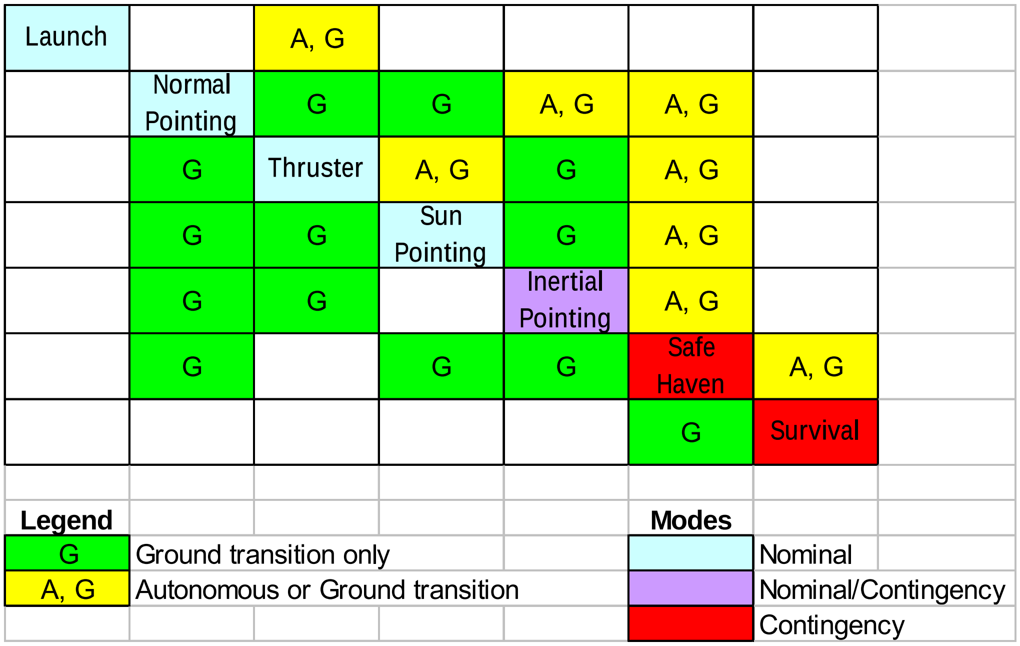
C.1.1.7 SURVIVAL MODE

Survival Mode is similar to Safe Haven mode with additional load shedding to ensure minimum power draw. Any components not needed to ensure the health and safety of the Observatory will be turned off. Survival mode will provide attitude control and communication links to the Ground.
This mode is entered by a reset or power cycle of the CTP. For this reason, Survival Mode determines the Observatory configuration based on information stored in non-volatile memory. The Ground updates EEPROM parameters as necessary to ensure Survival Mode will enter the appropriate configuration.

No change to IRSU/ITCE power configuration. Maintain survival temperatures. By definition, once in this mode sun constraints will be met.

C.1.2 OBSERVATORY MODE TRANSITIONS

Transitions between modes are limited to ensure the Observatory will remain in a safe configuration. Some transitions occur autonomously in support of nominal or contingency operations. While all autonomous transitions can be Ground commanded, some mode transitions will only occur in response to Ground commanding. Figure C.1.2 has the allowable mode transitions shown when followed clockwise between modes. Rows represent transitions from the mode in that row; columns represent transitions to the mode in that column.



Launch		A, G				
	Normal Pointing	G	G	A, G	A, G	
	G	Thruster	A, G	G	A, G	
	G	G	Sun Pointing	G	A, G	
	G	G		Inertial Pointing	A, G	
	G		G	G	Safe Haven	A, G
					G	Survival

Legend

G	Ground transition only
A, G	Autonomous or Ground transition

Modes

🟦	Nominal
🟪	Nominal/Contingency
🟥	Contingency

Figure C.1.2. Observatory Mode Transition (N^2) Diagram

C.2 SPACECRAFT SUBSYTEM MODES

Three spacecraft subsystems, ACS, EPS and TCS, have subsystem unique modes. A subsystem mode is defined by the functionality the subsystem is performing while in that mode, as defined in the sections below. For the ACS subsystem modes, there is a direct connection between an ACS subsystem mode and Observatory mode, although in limited cases there is more than one ACS mode for one Observatory mode and vice-versa. Power and thermal modes are not as closely matched with Observatory modes since in most cases thermal and power can be in any subsystem mode during any Observatory mode. The relationships between subsystem modes and Observatory modes are shown in Table C.2. For EPS and TCS, these are expected operating mode relationships, while ACS is linked directly to the Observatory modes as shown.

Observatory Mode	ACS Mode	EPS Mode	TCS Mode
Launch	Standby	Launch	Launch & Ascent
Normal Pointing	Normal	Trickle charge	Operational
		Main Charge	
		Battery Recondition	
		Data Gathering	
Thruster	Delta-V	Trickle charge	Operational
		Launch	Launch & Ascent
Sun Pointing	RCS Sun	Trickle charge	Operational
	Wheel Sun	Launch	
Inertial Pointing	Normal	Trickle charge	Operational
		Main Charge	
Safe Haven	RCS Sun	Trickle charge	Operational
	Wheel Sun	Main charge	Survival
Survival	RCS Sun	Launch	Survival
	Wheel Sun	Trickle charge	

Table C.2. Observatory to Subsystem Mode Mapping

C.3 ISIM MODES

An ISIM mode defines an ISIM configuration to the level needed to support specific observatory operations. Table C.3 shows the Observatory Modes to ISIM Modes mapping.

Observatory Mode	**ISIM Mode**
Launch	**Off/Survival (power applied to IRSU/ITCE)**
Normal Pointing	**Operating**
Thruster	**Off/Survival (early ops)** **Operating or Thruster (TBD)**
Sun Pointing	**Off/Survival (early ops)** **Initialize (initial turn on, fault recovery)** **Operating (initial start-up, fault recovery)**
Inertial Pointing	**ISIM Safe Mode**
Safe Haven	**ISIM Safe Mode or Off/Survival**
Survival	**Off/Survival**

Table C.3. Observatory to ISIM Mode Mapping

C.4 OTE MODES

An OTE mode defines an OTE configuration to the level needed to support specific observatory operations. Table C.4 shows the Observatory Modes to OTE Modes mapping.

Observatory Mode	**OTE Mode**
Launch	Off
Normal Pointing	Fine Steering Mirror CMU Enable (positioning mirrors)
Thruster	Off (early ops) Fine Steering Mirror (?)
Sun Pointing	Off (early ops) Standby (initial start up, fault recovery) CMU Enable (OTE tower and wing deployments)
Inertial Pointing	Standby CMU Enable (positioning mirrors)
Safe Haven	Standby Off
Survival	Off

Table C.4. Observatory to OTE Mode Mapping

APPENDIX D. DAY IN THE LIFE

This appendix contains step-by-step scenarios for various common activities on JWST. It is in the form of a separate Excel spreadsheet. It has not been updated for since the Delta-MDR release.

APPENDIX E. ENDNOTES

1. JWST-RQMT-000724
2. Ref: The Next Generation Space Telescope. Proceedings of a Workshop held at STScI Sept 13-15 1989, Edited by Pierre-Yves Bely, Chistopher J. Burrows and Garth Illingworth
3. Ref: A Vision for Ultraviolet-Optical-Infrared Space Astronomy, Report of the HST & Beyond Committee, edited by Alan Dressler - published 1996 by AURA Washington DC
4. Ref: (Visiting a Time when Galaxies were Young, Stockman 1996),
5. Ref: ‚JWST Project Science and Objectives (JWST-RQMTS-000804)
6. JWST Project Science Requirements Document (JWST-RQMT-002558)
7. Ref: NGST Monograph 1
8. Rauscher, Cosmic Ray Management on NGST (STScI_NGST-R-0003A)
9. Isaacs, Communications and Data Volume Study (STScI-NGST--R--0008c)
10. **Note**: -- As of November 2003, the dewar control electronics (CE→ DCE) had been moved to region 2. When new figures are available the MOCD will be updated.
11. **Note**: This drawing does correctly reflect the decision to refer to the cryostat as the dwar and the cryostat control electronics (CCE) as the dewar control electronics (CCE). When new figures are available the MOCD will be updated.
12. In October 2003, both Dispesed Hartmann Sensors and Dispersed Fringe Sensors were being considered as possible dispersing elements.
13. Rieke, M. 2003, U. Arizona, NIRCam-001
14. SWG, JWST Project Science Requirements Document (JWST-RQMT-002558)
15. Stockman, JWST Project Science Objectives and Requirements (JWST-RQMT-000804)
16. Stockman & Balzano STSci-JWST-TM-2003-0009
17. JWST-OPS-007
18. Fixsen, D. J., et al. 2000, PASP, 112, 1350
19. Regan & Stockman, Cosmic Ray Rejection with NGST Detectors (STScI-JWST-TM-2001-0005A)
20. Rauscher et al. 2003 <http://www-int.stsci.edu/~rauscher/miri/Supporting Documents/rauscher_et_al_2002_SPIE.pdf>
21. Target locates for NIRSpec are likely to involve the identification of several objects in the field because the orientation of the spacecraft must be measured and controlled

very accurately to assure proper registration of a large number of spectrographic apertures on the sky. Target locates involveing NIRCam and MIRI involve the location of a single object.

22. Ferguson et al. 2000, “Science Drivers for NGST Small Angle Maneuvers”, STScI-NGST-R-0002 A.
23. STScI-NGST-R-0014A, Casertano 2001
24. NIRCam Operations Concept Document, P. McCullough & M. Rieke 2003, JWST-43, U. Arizona.
25. NIRSpec Operations Concept Document, M. Regan et al. 2003, STScI-JWST-R-2003-0003 A, STScI, http://www.stsci.edu/jwst/docs/reports/R-2003-0003-A_3911.pdf.
26. MIRI Operations Concept Document, M. Meixner et al. 2003, JPL D-25632.
27. Nelan et al. 2003, “Observing Solar System Objects with JWST”, STScI Report R-2002-0006 A.
28. REVIEW OF HST TELESCOPE ALLOCATION COMMITTEE (TAC) ACTIONS AND PROCEDURES BEING COORDINATED BY STSCI, available online at <http://www.stsci.edu/institute/org/spd> under the report from the TAC Assessment link
29. Reference: Operational Work-Arounds for Meeting the 95% Guide Star Acquisition Rate with JWST, STScI-JWST-R-2003-0001A, 10 April 2003. Online at: http://www.stsci.edu/jwst/docs/reports/R-2003-0001-A_0856.pdf/docInfo
30. Isaacs 2001, NGST Data Volume Study (STScI-JWST-R-0008B)
31. Deleted
32. Actually, the OPE will probably invoke visit checking ADs to accomplish this.
33. The optimal mix of automated and human intgeraction for the ground activities described in this section have not been made for the activities in this section. Therefore, in this section, the S&OC will be the overall generic designee for all operation center functions outside of DSN.